100. Design and Development of Prototype Wind Concentrator Turbine

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Abstract

Non-renewable energy resources have fueled the world’s industrial compound for far too long. It has reached a point where the world is facing fast starvation in this sector. There are also other associated effects too which also need to be carefully looked at just to make sure things are running smoothly. With increased exploitation of these fossil fuels there are many environmental concerns like land pollution and air pollution which in turn affect whole ecosystem. Therefore a trend is observed that these non-renewable energy resources are replaced by renewable energy resources as Renewable energy is reliable, plentiful and will potentially be very cheap once technology and infrastructure is installed. Wind energy is a clean fuel source as it does not disturb the air quality like power plants that rely on combustion of fossil fuel. Therefore efforts are made to improve the efficiency of wind turbines. A wind concentrator is an enhancement made to wind turbine as it is a more efficient way to grasp wind energy. In the present study performance of saviniuous wind turbine with wind concentrator was studied experimentally. Lab scale test setup was developed and the experiments were performed by using forced air flow. It was observed that the application of concentrator is resulted in improvement of coefficient of performance of the system. The present system generated a power of 20 watt.

Keywords: wind turbine, wind concentrator, renewable energy, coefficient of performance

1. Introduction

Energy resources such as coal and oil are used to produce electric power since long time ago. But, this process produce tremendous amount of greenhouse gases that primarily have serious environmental impacts. These gases have terribly disturbed our ecosystem [1]. Due to these sever problems associated with health and environment these fossil fuel are being depleted, therefore scientists are showing their concerns towards alternative energy resources such as solar, wind, hydro, biomass etc. These, alternatives are intended to overcome the concerns related to fossil fuel. An important factor in global warming is carbon dioxide gas emissions which are a major component of fossil fuel burning. So, energy extracted from renewable energy resources (alternative energy resources) is produced without the undesirable out-turn innate in fossil fuel use. In the search of clean and safe renewable energy sources wind power is undoubted one of the most beneficial solutions [2]. But, the most irregular behaviour for the wind is its erratic nature. In addition, this variability exists over an extensive diversity of scales both in space and time. This is important because energy that is extracted from the wind varies with cube of wind velocity. Generally more wind is received on the top of mountains rather than low level areas. The power of the wind is proportional to the cube of wind velocity. The general formula for wind power is

\[ P = \frac{1}{2} \rho A V^3 \]  

As wind energy is a clean fuel therefore efforts are made to improve the efficiency of wind turbines [3]. So with relative and comparative studies of different research work done in past about the augmentation of wind turbines efficiency include wind turbine concentrators and diffusers as well which were able to increase wind velocity by 2 to 6 times [4]. The basic idea behind the concept is that wind concentrators are designed to overcome the problems associated with the turbulent wind flow and low velocity regions by providing structural and aerodynamic advantages. So it increase the velocity at outlet where turbine is placed.
2. Aims and Objective of Our Project

Objectives of the present projects are

- The objective of this project is to design and build a concentrator that will increase the wind velocity with factor of two. And is capable of producing power by using savonius wind turbine.
- To study performance of savonius wind turbine, installed in the concentrator framework
- To measure the power output, torque and rotational speed.
- Performance, testing, analysis of designed wind turbine in natural as well as in forced air.

3. Design and Fabrication of Test-Setup

The whole concept of concentrator is based on the duct and nozzle theory which helps to enhance the wind speed by two times of the inlet velocity. The inlet velocity strikes the wind turbine. Larger the mass of air it will increase its inlet velocity.

Through various studies of preceding concentrator designs it was intended to design a duct type structure that may be effective for either one-dimensional or multi-dimensional concentration of incoming air. The design consists of conical frustums and a symmetric quad arrangement of rhombus plates. Figure 1 represents the assembly of the whole test setup with labelled part. Figure 3 represents the structure of actual model.

3.1 Dimension & Calculation

The formula for calculating frustum is:

\[ V = \frac{1}{3} \times \pi \times h(R^2 + R \times r + r^2) \]  

As, the volume of frustum with thickness 2.5 mm,
Slope = 23 inch

\[ R_1 = 29.5 + 2(0.0984) = 29.6968 \text{ inch}, \quad R_2 = 11.5 + 2(0.0984) = 11.6968 \text{ inch}, \quad h = 15 \text{ inch} \]
\[ V = \frac{1}{3} \times \pi \times 15(11.6968^2 + (11.6968)(29.6968) + 29.6968^2) \]

\[ V = 21458.218 \text{ m}^3 \]

**Fig. 2. Graphical Representation of Frustum**

**3.2 Design of Rhombus Pillars**

The pillars are like rhombus shape welded with angle which is used to join the two frustums together one at the top and one at the bottom. Figure 3 represents

**Fig. 3. Front Views of rhombus pillars**

**3.3 Flange top and bottom base**

Sleeve length=0.0508 meter, Sleeve thickness = 0.0127 meter, Plate thickness =5x10^{-3} meter The pictorial view of flange top and bottom base is illustrated in figure 4.

**Fig. 4. Flange top and bottom base**

**3.4 Dimension of Shaft Used**

Height = 2.4384 meter, Diameter = 0.0254 meter

**3.5 Dimensions of pulley**

Small Pulley Diameter: 12 x 10^{-3} Meter

Large Pulley Diameter: 241.3 x 10^{-3} Meter

**Fig. 5. Pulleys**

**3.6 Specifications of Permanent Magnet Generator Used**

RPM = 2720 RPM, Power = 30 Watts, Voltage = 24 Volts, Current = 1.25 Ampere
3.7 Analysis of Concentrator

Larger Radius \((R_1) = 29.5\) inch, Circumference = \(2\pi R_1 = 2\pi (29.5) = 185.354\) inch

Smaller Radius \((R_2) = 11.5\) inch, Circumference = \(2\pi R_2 = 2\pi (11.5) = 72.256\) inch

3.8 Area at the inlet of air

Height = 69 inch, \(R_1 = 29.5\) inch, \(A_1 = h \times b = \frac{2\pi \times R_1}{4} + \frac{2\pi \times 29.5}{4} = 46.347\) inch

\[ A_1 = 69 \times 46.347 = \text{3197.943 inch}^2 \]

3.9 Area at the outlet

Height = 38 inch, \(R_2 = 11.5\) inch, \(A_2 = h \times b = 38 \times 18.064 = 686.432\) inch

Theoretical assumption is to be made for concentrator design. The wind speed is to be assumed 2m/s. Thus the concentrator will concentrate it by according to continuity equation;

\[ \rho A_1 V_1 = \rho A_2 V_2 \]

Hence the equation remains:

\[ A_1 V_1 = A_2 V_2, \]

Where,

\[ A_1 = \text{Area at the inlet of air} = \text{3197.943 inch}^2 \text{ (Calculated)}, \]

\[ A_2 = \text{Area at the outlet of air} = \text{686.432 inch}^2 \text{ (Calculated)} \]

\[ V_1 = \text{velocity at inlet} = 2 \text{ m/s (assumed)}, V_2 = \text{velocity at outlet} \]

\[ V_2 = \frac{A_1}{A_2} \times V_1 \]

\[ V_2 = \frac{3197.943 \times 2}{686.432} \]

\[ V_2 = 9.3176 \text{ m/s} \]

4. Material Selection

Factors that considered in selection of material are cost, strength, toughness, corrosion, reliable considering all these factors mild steel is selected.

5. Blades of Savonius Wind Turbine

Blades of savonius wind turbine are made up of aluminum sheets figure 6 represents the four blade geometry of designed savonius wind turbine. The length of each blade is 0.6858 meter.
6. Results and discussion

The aim of this project was to study the various factors on the performance of wind concentrator turbine in the local wind at Hamdard University and with forced wind as well. Test results prove that the concentrator is able to increase the wind velocity 2 times at the outlet of the duct where savonius turbine is placed on the shaft between flange top and bottom space. The concentrator is tested with local wind to attain the optimum concentration rate. As the wind fluctuates every single moment due to the power generation rate will not be achieved. Due to this reason axial blower was used to get best power output. The designed test setup is able to produce 20 watt of electricity. The concentrator is tested by using variable blades of savonius wind turbine to study the effect of concentrator by varying blades the results in the graph as well as in tabular forms are given below. The system developed for the present study was designed to provide flexibility for the change of no of blades for savonius wind turbine. With this provision three different configuration of savonius turbine were achieved i.e two blade, three blade and 4 blades. Experiments were conducted for all three setups by varying the wind speed from the cut in speed 0.5 m/s to be maximum of 6.2 m/s.

Average Wind Speed at Hamdard University

![Average wind speed available in Hamdard University for 12 months](image)

6.1 Concentration ratio in natural wind without connecting load on 3rd march 2016

The setup was placed in open air to find the concentration ratio of the concentrator. The wind velocity at the inlet of the concentrator and the outlet of the concentrator was recorded. The results are given in graphical form below.

![Concentration rates in natural wind on 3rd march 2016](image)

From the above results it was observed that for all the rated wind speed the concentration ratio is about twice the inlet air which is nearly 50% of the theoretical calculation. This could be fiction effect of material used.
6.2 Testing with two blades of turbine in forced air

Savonius wind turbine with two blades was placed in concentrator and the results obtained are represented in and graphical form.

![POWER Vs RPM Graph](image)

From the results it was found that the turbine can produce 9 watt at the 48.8 RPM with cut-in speed of 2.1 m/s which was observed by anemometer at the time of experiment and 20 watt at 90.4 RPM for the higher speed of 6.2 m/s (noted with anemometer).

6.3 Testing With 3 blades in forced air

Savonius wind turbine with three blades was placed in concentrator and the results obtained are represented in and graphical form.

![Graph of RPM Vs Power with 3 blades](image)

From the results it was found that the turbine can produce 5 watt at 42.7 RPM with the cut-in speed of 2.1 m/s and 18 watt for the higher speed of 6.2 m/s which was observed at the time of experiment with 82.7 RPM.

6.4 Testing with 4 Blades in Forced Air

Savonius wind turbine with four blades was placed in concentrator and the results obtained are represented in and graphical form.
From the result it was found that the turbine can produce 3 watt at 38.8 RPM with the cut-in speed of 2.1m/s and 15 watt for the higher speed of 6.2m/s at 68.2 RPM where cut-in speed is observed with anemometer at the time of experiment.

7. Conclusions

From the experimental results it was concluded that

- The concentrators have a beneficial effect on the performance of savonius wind turbine in terms of cut in speed.
- 2-blade configuration was found more efficient as compared to the other configurations.
- The performance of 3-blade configuration lies intermediate between 2 and 4-blade configurations.
- Cut-in speed= 0.5 m/s (for LED) at a distance of 4.2672 meter.
- Cut off speed=6.2 m/s (for 40 LED), at a distance of 0.9144 meter.

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References

113. Bioclimatic House Design Approaches in Rural Area of Mirpurkhas Sindh

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Abstract

Nowadays the world is utilizing renewable energy alternatives in different sectors and industries due to scarcity of natural resources. As residential houses consume a significant amount of energy, which otherwise can be utilized in different sectors for the development of any country. In addition to this, many regions all over the world are expected to become very hot due to rapid climatic changes. In this situation a house is a place where people feel more relaxation. So if building designs ignore the climatic conditions, than it can lead to serious human discomfort. Hence bioclimatic approaches in the design of a house can contribute to increase the level of human comfort and significantly reduce the energy consumption. This paper studies the various bioclimatic design considerations for an eco-friendly residential house to get benefits of weather conditions in order to conserve energy and also to have maximum human comfort. In this research, a rural area of Mirpurkhas, Sindh has been selected. The research proposed various site selection criteria, keeping in view all the design approaches for a bioclimatic house in the region. The result suggests different design criteria including passive design techniques (such as: orientation w.r.t sun and wind, placement and size of windows), energy efficient techniques (such as: wind catcher, vegetation, green roof, and shedding device etc.) and energy efficient system (such as: biogas by biomass process and solar system for electricity and water treatment) in design of a house. The results can also be utilize to design a bioclimatic house in other region of the country with comparatively same natural climate.


Keywords: Bioclimatic houses; Renewable Energy; Natural comfort; Mirpurkhas City; Rural Areas

1. Introduction

Bio-climatic house refers to the residential building that ensures efficient use of local, materials, vegetation, renewable energy without depletion of nature. The aim to build the Bio-climatic House is to introduce a safe living style in rural areas of Pakistan. Bioclimatic house uses less energy, water and natural resources than a conventional building [1]. The nature plays an important role to achieve bioclimatic design approach in a house building.

Recently, the global demand for energy is increased due to the industrial development and population growth and it has become a serious cause of energy crisis all around the world especially in Pakistan [2]. Pakistan being a developing country is facing serious energy crisis such as electricity load shedding, shortages of natural gas and petroleum etc. On the other side its geographic location and season throughout years affect the country in two different ways. As Pakistan is located near the equator in northern hemisphere with latitude of 30º00’ that’s why bit hot [3]. Secondly due to more sunny days and high wind pressure, a lot of energy can be produced in the country but production of energy from these resources on larger scale is bit costly. Huge amount of energy consumed by the use of artificial system (heating and cooling) to control the indoor thermal comfort of building and the health and productivity can be affected
by the room condition [4].
Hot climate is the cause of discomfort of house inhabitant. Rural areas face more problems (electricity and gas) than urban areas. High temperatures, undesirable climatic conditions and wind tunnel effects due to high rise buildings which are wrongly designed cause discomfort and unhealthy living conditions in the urban areas [5].

The security of indoor comfort and respect for environment leads to natural bondage between architecture and energy. Although conservation of energy is a vital issue nowadays but in case of buildings, human thermal comfort is the primary focus. Without compromising the thermal comfort, the energy conservation becomes a necessity rather than an option in both commercial and residential buildings [6]. Human’s physical and physiological health is vastly affected by the thermal comfort. The weather conditions or the climatic parameters in building design i.e. air temperature, rainfall (precipitation), relative humidity, wind velocity and direction and solar radiation etc. are very important [7].

In this research a rural area of Mirpurkhas Pakistan (Doulat Laghari) is studied. Mirpurkhas has a desert climate (hot and dry) with sun path east to west and wind direction is south-west to north-east [8]. Mainly houses are made up of brick masonry and roof are constructed with tier and girders. The concept of verandas, courtyard etc. is still famous there. Some houses are constructed with mud whereas some are constructed with brick masonry.

This research conducts a questionnaire and unstructured interview from the vicinity people and identifies few problems in that area such as: indoor and outdoor pollution, electricity deficiency, absence of gas etc. Considering these problems, this research results in various possible solutions such as passive design techniques (such as: orientation w.r.t sun and wind, placement and size of windows), energy efficient techniques (such as: wind catcher, vegetation, green roof, and shedding device etc.) and energy efficient system (such as: biogas by biomass process and solar system for electricity and water treatment).

2. Literature Review
A Bio-climatic House principles are based upon quality, natural comfort and energy efficiency. Bio-climatic Houses also require the concept of renewable energy to achieve inhabitants comfort. While delivering superior levels of comfort, the Bio-climatic house standard (such as building fabric to create a comfortable internal environment, air flow across ponds to create natural cooling, orienting rooms in different directions, optimizing use of the sun etc.) also protects the building structure [9].

2.1. Design Strategy
Design strategy is a policy for building which help to determine what the techniques can be used to make building more comfortable and how these techniques will be applied. This process involves the relationship between design and business strategies. Design strategies include form and placement of building, thermal control, even lighting, cross ventilation, vegetation, selection of building materials. A. C. Gallo (1994) researched that the underground wind catcher can be used in houses allowing the hot scorching days to remain cool and cool nights to remain warm [10]. D. L. Zr and S. Mochtara (2013) conducted the research in a tropical region of Jakarta and concluded that bioclimatic architecture like the passive design strategies include orientation, window openings, sun shades, landscaping, ventilation etc. is really beneficial for a sustainable design, to decrease energy consumption cost [11].

2.2. Climatic Factor
A host of interacting factors i.e. latitude, geography, elevation, nearby water, topography, ocean currents, landscaping, and prevailing winds influences the climate of any particular place. M. K. Singh et al (2007) studied North East region of India. The research is based on the bioclimatic classification of north east India. Its regions are classified into cool and humid, warm and humid and cold and cloudy zones. These classifications really help designers to design a good and sustainable building according to the need of climate. These classifications are not merely some simple job, they are achieved by 30 years of research and recordings, different bio charts and further studies. Many meteorological centres are spread all over the region to conduct the studies, surveys and other observations so that every climatic zone would be
designed according to its bio climatic features and according to proper solar and passive design mainly regarding residential houses [12]. N. Mazhar et al (2015) compared microclimatic characteristics (air, temperature and humidity) of two outdoor places of Lahore, Shalimar garden (green infrastructure) and Alhambra art centre (hard surface courtyard) and concluded that vegetation have great potential to cool outdoor spaces by shading and by evapotranspiration [13].

2.3. Energy Efficiency

The goal to reduce the amount of energy required to provide products and services is called energy efficiency. For example home insulation makes a building consume less heating and cooling energy for a comfortable temperature. The amount of energy required to attain the same level is reduced by natural skylights. By adopting a more efficient technology, improvements in energy efficiency are achieved. M. Medrano et al (2008) studied a new energy efficient institutional building (CREA). It is equipped with many energy systems and passive measures such as solar arrays, thermal collectors, combustion engine and chillers. Also the author concluded that natural CO₂ is used to save energy and all these facilities lead to a better energy saving building [14].

2.4. Thermal Insulation

By preventing heat gain/loss through the building envelope is an important technique to reduce energy consumption in buildings. N. Gaitani et al (2005) studied bioclimatic principles for increasing the thermal comfort for an outdoor space. For this purpose the author studied of two key points ‘comfa’ and ‘thermal sensation’ which was carried out to calculate the thermal conditions of Athens. The study stated that the bioclimatic design principles are for the better thermal comfort provision and the author figured out various means of architectural considerations too, such as constructional materials, water bodies and greenery infusion in the design [15].

F. M. Agugliaro et al (2015) focused on the strategies of bioclimatic architecture used in different climatic zones to achieve maximum reduction in energy consumption. The author concluded areas with similar climates could import certain bioclimatic architecture strategies that have been adopted in specific countries similar to them. The strategies were proven to be efficient and provided large energy saving measures related to solar protection, humidification or temperature increases [16].

3. Research Methodology

The research is started by identifying various problems (such as: thermal discomfort, unhealthy living conditions, weighing in energy bills etc.) in locality of Mirpurkhas, Sindh, Pakistan. Researcher discussed different problems of Pakistan related to energy crisis and thermal discomfort issues in residential buildings especially in rural areas. To reduce energy consumption for thermal comfort in residential building some techniques are addressed for varied seasons in this research. For this research a rural area of Mirpurkhas Pakistan is selected. The rural area is examined for more data such as their housing and living condition, energy crisis etc. A questionnaire survey is conducted within the vicinity people to examine the problems of rural area. The research suggests different passive design techniques which are used to orientate the building. Some energy efficient techniques are also suggested to gain more comfort and reduce pollution such as wind catcher (to achieve cool air in covered spaces), vegetation (for air filtration) and windows and their shading device with proper measurement (size, shape, placement and projections).

4. Result

After extensive research, studies and surveys, the author examined various problems in the rural area of Mirpurkhas such as; electricity scarcity, gas supply absence, environmental pollution and thermal discomfort. This research suggest the possible and efficient solutions which includes:

4.1. Passive Design Strategies

The passive design strategies which are used in research are:
4.1.1. Orientation

Orientation of building according to sun and wind i.e. drawing and dining room are placed in NE, veranda and courtyard placed in South side to reduce heat intensity. Kitchen and biogas plant are placed in North side opposite to wind direction so that the smoke of kitchen and smell of biogas plant may not be disturb other rooms. Study room and staircase are placed in North side for maximum north light as shown in fig. 1.

4.1.2. Wind Catchers

Another passive technique which are wind catchers, used to ensure the carriage of cool wind in hot day time (as shown in fig. 2) for the covered areas to provide thermal comfort.

4.2. Energy Efficient System

To reduce energy consumption author suggests an off grid solar system (100% run on sun light) is installed on the roof of house which generate electricity (as shown in fig. 3) on natural basis. This system fulfilled the electricity need of house without use of WAPDA electricity and a biogas plant which will produce gas through the utilization of dung (as shown in fig. 4). This gas is used for two purpose, one is for cooking and second one is electricity.

4.3. Vegetation

The environmental pollution could be tackled by the vegetation (greenery) which would cool and filter the polluted air (as shown in fig. 5) and make it healthy to breathe.
5. Conclusion

The rapid growth of today’s industrial world and increasing population demands for great amount of energy which infect can be a cause of energy crisis in any country. The consequences are faced but rural area suffers in majority put their living comfort in danger. For this purpose the author identifies various problems of vicinity such as gas, electricity, thermal discomfort in the houses. The author after examination suggested the best way to conquered these problems through the bioclimatic architecture which itself is the promoter of nature and nature friendly ways. The research suggest various passive design techniques (such as: orientation w.r.t sun and wind, placement and size of windows), energy efficient techniques (such as: wind catcher, vegetation, green roof, and shedding device etc.) and energy efficient system (such as: biogas by biomass process and solar system for electricity and water treatment). Nature has always been the best remedy to every problem and the concept of bioclimatic architecture prove to be the best and efficient solution to the problems faced by the rural area selected by the author.

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References

context of global climate change”, Landscape and Urban Planning [2015].


Design and Analysis of cross flow impulse turbine for water stream near Trapi village KPK Pakistan.

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Abstract

Pakistan is investing handsome amount in favor of setting up and evaluating the hydropower and hydro potential sites in Pakistan. This study is useful in calculating different selected turbine related parameters, their mutual relations and constraints effected by flow rate and head. The project can be beneficial and may be used as a reference for fabrication of a cross flow impulse turbine for energy generation on small scale.

Keywords: Head, Flow rate, Analyses, modeling.

1. Introduction

This article is about our work oriented to design and analysis of cross flow water turbine from the rural site of a seasonal spring at Trapi village situated about 160 km(s) from the capital Islamabad, Pakistan. Such turbine are applicable where there is very low head and flow rates are available. This turbine is also used for domestic purposes where there is no supply of electricity epically in mountain region i.e. remote areas. We have edge over fabrication of turbine due to simple geometry and it is performance is not too much dimensions sensitive. The article is based on designing an impulse water turbine and its feasibility. The core work of this project is based on design, model and analyses of cross flow Impulse water turbine. This article intends to explore and optimize energy generation the hydro potential sits of Pakistan to contribute countering the energy crises of the state

1.1 Cross flow Turbine: The Cross flow turbine comprises of a rotor like wise to a drum with a solid disk at each end and joining the two side disks [1]. A jet of water enters with a certain velocity the top of the rotor glides through the curved blades, flushes out on from far bottom end of the rotor by passing through the blades. The shape of the blades is fabricated in such a way that on each passage between the periphery of the rotor the Water transfers some of its momentum and force, before falling away with little residual energy [2].

1.1.1 Runner: Runner blades are manufactured from pipe sections and these are also fabricated or milled. Blades are connected by two discs called side discs on the shaft. If mass of turbine exceeds, bracing is sublimated to discs if required depending on the stress conditions and calculations. The shaft runs through the runner as one piece. The optimal running speed of the turbine is depends on the optimal running speed of the generator. If generator speed is estimated to be 1500 rpm the turbine is to be drags to have an optimal running speed up to at least 750 rpm [3]. The running speed may be increased by reducing the runner turbine diameter or increasing the head if available. Decreasing the diameter will increase the complexity of manufacture and cost so the running speed may be kept slightly less than 750 rpm [3].

1.1.2 Draft Tube: The draft tube is key module for manipulating the difference between runner and downstream
water level. During the turbine operation the air cavitation in the casing is injected in flushed out along with the water. Thus a vacuum is formed. With respect to exterior atmospheric pressure there is increment in suction column. And to counter this a provision is mounted which is a simple venting valve which is free of friction and the sole purpose of it controls the vacuum in the turbine casing to stabilize the energy potential.

1.1.3 **Nozzle:** The nozzle is the component with rectangular cross section area, discharges the water which impinges entire width of the turbine and usually enters the wheel at an angle of 16° w.r.t. tangential direction of the periphery of the rotating drum. The rectangular shaped jet is wide, and not too much deep. The water impinges on the blades mounted on the rim of the wheel, flows and glide over the turbine blade and leaves it, passing through the empty space between the middle parts of rim, enters the blade at lower side inner side of the rim, and discharges from the outer rim periphery. A variable area of nozzle is required for the alteration of jet thickness. That is the reason the optimal jet thickness could not be determined without experiment. This shall be done with a variable guide vane which has person to be locked into place with a basic ratchet system.

**Characteristics of Cross Flow Turbines [4]:**

- Cross flow runners have a definite operating ‘range’ transitionally between Propeller and Pelton of turbine types.
- Running at speeds calculated by the head they are operating (between 300 to 1500rpm).
- The head at which the cross flows is the best choice (with manageable operating speeds of between 500 to 1,000rpm)
- The turbine uses the head about 5-6 meters at minimum power (1-10kW) but up to 100 meters head can be suitable for higher powers up to 500 kW.
- This turbine have a speed as low as 300rpm for a runner operating at a low head and as high as 1,500rpm for medium range and small runner operating at high head.

2. **Technical Terminology:**

Some technical terminologies which are use are as follows [5]:

Pitch circle Diameter of runner = Dp

Outer Diameter of Runner = Do

Root Circle Diameter of Runner = Dr

Shaft diameter of Runner = d
**Pitch circle Diameter of runner [6]** The diameter of turbine runner from which the radius or curvature of blade is drawn.

**Outer Diameter of Runner [6]** It specifies that diameter of Runner at which turbine Blade intersects the side metal plates on the inner rim.

**Root Circle Diameter of Runner:** It is the Maximum Diameter of Turbine Runner, at which the Blade intersects the side Plate at the outermost edge [6].

**Shaft diameter of Runner:** The Shaft passes through the runner. The Diameter of Shaft depends upon the maximum or outer diameter of the turbine runner [6].

**The velocity triangle:** The blades of turbine undergo from the following forces and fluid shows the following velocity behavior. All paths are shown diagrammatically forming triangles known as velocity triangles.

![Figure 2 Velocity Diagram for Cross Flow Turbine [7]](image)

**Cross flow blade profile:**

The curve of the blade must be chosen from a circle whose center lies at the intersection of two perpendiculars, to the direction of relative velocity at and the other to the tangent to the inner periphery intersecting at.

![Cross flow blade profile](image)

**Formulas used:**

The calculation starts first by calculating net head. Other formulas used for carrying out various turbine parameters are following afterward:

A. **Calculation of the net head:**

This includes the calculations and measuring the net head of the hydro-power plant and its water flow rate [8].
Hn = Hg – Htl \ (m)

Where Hg = the gross head which was the vertical distance between water surface level at the intake and at the turbine. Htl = total head losses due to the open channel, trash rack, intake, penstock and gate or value. These considered losses equivalent to 6\% of gross head.

B. Calculation of the water flow rate (Q):
The water flow rate can be calculated by measuring river or stream flow velocity (Vr) and river cross-sectional area (Ar), then:

\[ Q = Vr \times Ar \ (m^3/s) \]

C. Relation of power produced by Turbine (Pt):
In terms of wattage the electrical can be calculated as:

\[ P_t = \rho \times g \times \eta_c \times H_n \times Q \]

D. Relation for turbine efficiency (\eta_t):
The maximum turbine efficiency can be calculated as:

\[ \eta_t = 12 \times C_2 \times (1 + \psi) \times \cos \alpha \]

E. Relation for the turbine speed (N):
The Turbine speed can be calculated with the formula below:

\[ N = \frac{513.25 \times \rho \times g \times H_n}{0.745 \times \sqrt{Q}} \ (r.p.m) \]

F. Calculation of runner outer diameter (Do):
The outer diameter of runner can be calculated using the following formula:

\[ D_o = 40 \times \frac{q}{4} \ (m) \]

G. Calculation of blade spacing (tb):
The tangential blade spacing can be calculated using the below formulae

\[ tb = 0.147 \times D_o \]

The tangential spacing (tb) is given as:

\[ tb = t \times \sin \beta_1 = K \times D_o \times \sin \beta_1 \]

Where \beta_1 = blade inlet angle = 30° when \alpha = 16°.

H. Calculation of the radial rim width (a):
It is the difference between the outer radius (ro) and inner radius (ri) of the turbine runner, so it is equal to the blade spacing and can be given as:

\[ a = 0.174 \times D_o \ (m) \]

I. Relation for the runner blade number calculation (n):
The number of the runner blades can be determined as

\[ n = \frac{\pi \times D_o}{v} \]

J. relation for calculating water jet thickness (tj):
It is also defined as nozzle width and can be calculated as

\[ tj = 0.233 \times q \times \sqrt{H_n} \]

K. Relation to determine Runner Length (L):
The runner length in meters can be calculated as:

\[ L = Q \times 50 \times \sqrt{H_n} \ (m) \]

Calculation of the distance between the water jet and the center of the runner (Y_1):
Y1 = 0.116 × Do

L. Calculation of the distance between water jet and the inner periphery of runner (Y2) [9]:

Y2 = 0.05 × Do

M. Calculation of inner diameter of runner (Di):

Di = Do - 2× a

N. Calculation of blade radius of curvature (r):

r = 0.163 × Do

O. Calculation of blade inlet angle (β1):

\[
\tan \beta_1 = 2 \times \tan \alpha
\]

P. Calculation of the blade exit angle (β2):

The blade exit angle should be of \( \beta_2 = 90^\circ \)

Q. Calculation of Diameter of shaft (d_{shaft}):

The shaft diameter can be calculated by the formula as under.

\[
d_{shaft} = 0.22 \times Do
\]

R. Calculation of Absolute Velocity of water (V1):

The absolute velocity can be calculated by the formula as follows.

\[
V_1 = c \sqrt{2\gamma H_n}
\]

Where “C” is the roughness coefficient of nozzle.

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Perimeter</th>
<th>Symbolic Representation</th>
<th>Quantity</th>
<th>Units (S.I.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Net Head</td>
<td>Hn</td>
<td>9</td>
<td>Meter(s)</td>
</tr>
<tr>
<td>2</td>
<td>Flow rate</td>
<td>Q</td>
<td>1.3</td>
<td>m³/sec</td>
</tr>
</tbody>
</table>

**Site perimeters and constants values:**

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Perimeter</th>
<th>Symbolic Representation</th>
<th>Constant quantity</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blade</td>
<td>ψ</td>
<td>0.98 (unitless quantity)</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>Nozzle</td>
<td>C</td>
<td>0.98 (unitless quantity)</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**Derived values of turbine from reference site values using formulae:**

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Perimeter</th>
<th>Symbolic Representation</th>
<th>Quantity</th>
<th>Units (S.I.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turbine power</td>
<td>Pt</td>
<td>100.47</td>
<td>watts</td>
</tr>
<tr>
<td>2</td>
<td>Efficiency</td>
<td>( \eta )</td>
<td>87.8</td>
<td>percentage</td>
</tr>
<tr>
<td>3</td>
<td>Turbine speed</td>
<td>N</td>
<td>263.15</td>
<td>R.P.M.</td>
</tr>
<tr>
<td>4</td>
<td>Specific turbine speed</td>
<td>Ns</td>
<td>32.92</td>
<td>R.P.M.</td>
</tr>
<tr>
<td>5</td>
<td>Runner outer diameter</td>
<td>Do</td>
<td>0.45</td>
<td>meters</td>
</tr>
<tr>
<td>6</td>
<td>Blade spacing</td>
<td>tb</td>
<td>0.0783</td>
<td>meters</td>
</tr>
<tr>
<td>7</td>
<td>Thickness of jet entrance</td>
<td>te</td>
<td>0.03915</td>
<td>meters</td>
</tr>
<tr>
<td>8</td>
<td>Radial rim width</td>
<td>a</td>
<td>0.783</td>
<td>meters</td>
</tr>
<tr>
<td>9</td>
<td>Number of blades</td>
<td>n</td>
<td>18</td>
<td>meters</td>
</tr>
<tr>
<td>10</td>
<td>Water jet thickness</td>
<td>tj</td>
<td>0.1305</td>
<td>meters</td>
</tr>
<tr>
<td>11</td>
<td>Runner length</td>
<td>L</td>
<td>0.76</td>
<td>meters</td>
</tr>
<tr>
<td>12</td>
<td>Distance h/w water jet and shaft center</td>
<td>Y1</td>
<td>0.0522</td>
<td>meters</td>
</tr>
<tr>
<td>13</td>
<td>Distance h/w water jet &amp; periphery of runner</td>
<td>Y2</td>
<td>0.0225</td>
<td>meters</td>
</tr>
<tr>
<td>14</td>
<td>Inner diameter of runner</td>
<td>Di</td>
<td>0.2934</td>
<td>meters</td>
</tr>
<tr>
<td>15</td>
<td>Radius of curvature of blade</td>
<td>ri</td>
<td>0.07335</td>
<td>meters</td>
</tr>
<tr>
<td>16</td>
<td>Water inlet angle</td>
<td>B1</td>
<td>30°</td>
<td>degrees</td>
</tr>
</tbody>
</table>
Modeling of Cross flow Turbine

The software used for modeling is Autodesk AutoCAD which is drafting and modeling computer application. The version used here is Autodesk AutoCAD 2012.

Starting from the scratch

The modeling is simple first I have created a 2d profile of turbine pictorially demonstrated below. Runner outer and inner periphery circles and middle circle equivalent to shaft diameter.

Blade Profiling:
Formation of Blade with the help of angles derived through previously mentioned formulas

Blade Profile insertion in runner profile:
The blade profile is inserted in the runner profile with the help of move command
Blade array generation on runner periphery:

Figure-6 Using array command.

Extruding and export:

Figure-7 Extruding the blades and sidediscs.

Extruded, trimmed, moved and thicken command are used and transformed the 2d image to 3d and finalize the modeling. The finished model is exported in IGES format to in order to import it to analyses software.

Casing Modeling:
Casing modeling is done in the same way as the runner.

Figure-8 A view of entire assembly.

Analyses of cross flow turbine

Import
The software package used here is ansys 16.1 version. The IGES generated by AutoCAD is imported in Ansys.
Casing Stress Analyses

Material Selection:

Steel is used as the material for casing and turbine

Meshing

The mesh is generated in the ANSYS workbench mesh module. Unstructured mesh with tetrahedral elements is created. Total number of elements created are 236255.

Boundary Conditions:

Pressure

\[ P = \rho gh \]
Where $p$ is the pressure, $\rho$ is the density, $g$ is the gravitational constant with value $= 9.81 \text{ m/sec}^2$. $h$ is the height of the water column above the turbine.

Using the following values for our calculations

$\rho = 1000 \text{ kg/m}^3$

$g = 9.81 \text{ m/s}^2$

$h = 9 \text{ m}$

The pressure comes out to be $= 8.86 \times 10^4 \text{ pa}$

**Constraint Boundary condition:**

The turbine casing is constrained by applying fixed supports at the top and bottom ends as shown below.

Results:

The stress analysis of the casing gave the results pressure in Figure above Von mises stress failure criteria is used which is presented below.

The deformation, stress, strain and factor of safety contours are presented below.

The maximum deformation is seen to be in the middle of upper part of casing and is equal to 0.82mm. Stress induced due to applied pressure in the casing is approx. = 98.9 Mpa and is present near the top fixed constrained condition. The corresponding strain induced due to applied pressure in the casing is approx. = 0.000585 Nm/m and is also present near the top fixed constrained condition.

Factor of safety $= n = \frac{\text{yield stress}}{\text{stress induced due to loading}}$

Yield stress = 250 Mpa

Stress induced in the casing due to loading = 98.9

$n = \frac{250}{98.9} = 2.527$

The factor of safety shows that our casing under the applied loading is safe and is below the failure limit. However, in order to further reduce the deformation, stress and strain we can reinforce our casing by applying ribs in the center of the upper part of casing as shown in the figure.
Figure -13 Casing total Deformation.

Figure -14 Casing equivalent Stress.

Figure -15 Casing equivalent elastic strain.
Runner Stress Analyses

Geometry Import:
Below is the view of imported geometry of runner from AutoCAD.

Results: The runner has eighteen blades equidistant mounted on the side discs. The assigned fixed supports are the interfacing areas between the shaft and side disc. The shaft is suppressed from analyses due to computing power issues.
Conclusion:

Pakistan is investing the hand some amount in favor of exploration and installation of hydropower plants. Our objective (proposal problem statement) was to design and analyses the turbine for the hydro potential sit and its feasibility study. We take a site (seasonal stream) at the location named Trappi which is about 155 kilometers from capital Islamabad in KPK province. The turbine can be designed as per the perimeters the head and flow rate available on site. The turbine can be operated at very low head and flow rate. It can also installed on domestic level also. The turbine is ideal for the home cottage industry especially in current power crises of the country. One of the novel idea is to build a small reservoir of water in which water is collected all day and during night by running the power plant we power up the street lamps of nearby highway in peak hours(for e.g. motorway interchange, road crossing traffic signals etc.)

We designed the turbine, analyzed it and we can also fabricate it locally. It seems a little mile stone but through implementation of further more number of these projects we cope with the energy crises. The most important fact is that the hydro power is the cheapest of all other resources and fossil fuels should kept secondary option because of huge cost and to reduce environmental hazards (Ozone depletion, greenhouse effect and pollution).

We have also fitted the casing with rib supports by which we counter deformation and drag the factor of safety further towards the safe side.

Cross flow turbine power plants are much feasible because Pakistan has countless sits especially in the Pohotwar platue region, Baluchistan and KPK areas due to the presence of glaciers in northern areas, which melts during the summer and at lower stream (Pohotwar platue, Baluchistan and KPK areas) if these plants are installed contributes a lot in power short falls of state.
References:

Abstract

As the concerns about rising fossil-fuel prices, energy security and climate-change increase, hydrokinetic power plays a vital role in producing local, clean and inexhaustible energy to supply world rising demand for electricity. But in order to obtain optimum power output from hydropower efficiency of system components is highly important. Therefore in this research parametric study of Vertical axis Micro Hydrokinetic Turbine (VAMHT) is carried out in FLUENT to analyze effect of pitch angle and blade profile on turbine performance. Different models were developed in gambit software at pitch angle of 0°, 5° and 10° for two different airfoils of NACA0015 and NACA0020. Simulation is done to solve Reynolds-Averaged Navies-Stokes (RANS) equations through finite volume method on unstructured mesh. Study uses $k-\omega$ SST turbulence model to predict the values of various performance parameters such as torque, lift, drag as well as pressure and velocity contours near turbine blades. Parametric study reveals that maximum torque is obtained at 0 degree pitch angle and increase in pitch angle results decrease in torque produced. Study also found that blade profile NACA0020 have better performance than NACA0015.

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Keywords: Pitch angle; Run-of-the-river (ROR)

1. Introduction

Rising energy demand increasing global warming and depleting fossil fuels have given great thrust for rapid development of renewable energy extraction. Out of the all renewable energy resources hydroelectric power is one intensive source to extract energy at the large quantity. In addition to that it was investigated that it provides power at very low cost in comparison of other energy resources like nuclear, thermal, wind as well as solar power [1-5]. From last few years most of the developing countries are putting their efforts to enhance hydro power extraction to lessen the threat to carbon emission. Specially for producing electrical energy hydropower is one of the favorable regulatory power sources that is easily control as well as adjust gates of dams. Hydropower regulation performances are comparable with plants burning coal and petroleum products. For the prosperity and development of any country it has become mandatory to produce clean, cost efficient and sufficient power.

Pakistan is a country having abundant hydropower resources with potential of about 41000 to 45000MW[6]. Whereas Pakistan is producing 6555MW power from hydropower resources which only accounts for 34% of their energy supply. As still there is lot of potential for hydropower which has to be harnessed. In generally there are three hydro-power producing techniques such as Conventional dams, Run-of-the-river (ROR) and Pumped-storage hydroelectricity (PSH). But, all the three hydropower techniques requires high capital cost, complex structure, more negative effects on environment and is highly whether dependent[7-9].Therefore in order to meet rising energy demand, lot of research is going on micro-hydro power technologies but still they are at developing stages. Since at present Pakistan is
under high energy crises due to various financial and technological issues. Hence this research is conducted to enhance efficiency of well-known Darrieus turbine which is relative simple, requires low maintenance cost, easily manufactured as well as can be installed in existing irrigation channels and canals. This type of power generation system does not require drive system and can be used to produce clean, local electricity for remote areas as well as rural electrification purpose up to few hundred kilowatts[10]. Since other micro hydro power techniques require some catchment for waters storage and to produce water head, if water level changes rate of flow would be affected. For those cases if water level can be estimated then power generation capacity can be estimated [11-13]. But VAMHT power producing characteristics are very different from those turbines which generate power by exploiting potential energy of water. These turbines produce power by utilizing kinetic energy of flowing water without creating any interruption in flow. These turbines don’t require so much civil structure and can be easily removed during or for maintenance purpose. Hydrokinetic power is generally believed to be zero-head power but still its share to share to world total energy demand is still very less. Few years ago hydrokinetic power have got importance to harness it. However from literature Vertical axis micro-hydro turbine uses basic structure of wind turbine to extract energy from water. Three straight blade H-Darrieus turbine has got extreme importance in wind power generation. Few years ago in 80s and 90s several turbine models was developed by using double and multiple stream tubes to predict performance of these turbines[14-19]. Sometime later number of wind tunnel experiments was carried out to analyze effect of Tip speed ratio (TSRs) on turbine performance at low wind speed. Their researches enhanced turbine efficiency [20-23]. During 1974 in response to energy crises American government decide to launch research on alternative energy resources including research on wind turbines. At the same time in a group of researchers at Sandia National Laboratory in Albuquerque at New Mexico conducted various experiments on wind tunnel as well as on full models scale. From their models one turbine reaches to 40% efficiency which is very near to horizontal axis wind turbines that is 45% [24].Recently research was conducted on high solidity and low TSR Darrieus turbines through various wind tunnel or water channel experiments but their experiments results showed to have a lower measured efficiency 25 to 30%[22, 23]. From extensive literature review it is concluded that lot of research is being conducted on Darrieus turbine by considering effect of solidity, tip speed ratio and number of blades etc. for considering it as wind turbine. However very less research were conducted on Darrieus turbine for using it as hydro turbines and still there is lot research needs to analyze as well as to optimize turbine performance by using water as working fluid. Therefore this research mainly focuses on parametric study of Darrieus turbine on the bases of hydropower production. This research seeks to explore

- Effect of blade pitch angle on its torque performance
- Blade profile effect on turbine efficiency
- Visualization of Flow behaviour in the vicinity of turbine at various pitch angles.

2. Micro-turbine concept

The turbine exploited in this research basically produce power in same way that of wind turbines. In these types of turbine at the first instant wind energy is converted into mechanical energy through that energy would be converted into electrical energy though generator. These turbines exploit kinetic energy of moving water rather than potential energy.

Simple construction and installation, which were the perceived benefits of using micro-hydro turbines in this study, allow micro-hydro turbines to be installed in any type of canal or irrigation channel without affecting the water flow. Micro-hydro turbines can exist individually in electrical power supplies. Available water power can be calculated by using an equation.

\[ P_w = \frac{1}{2} \rho A U_\infty^3 \]  

(1)

Where \( \rho \), \( A \) and \( U_\infty \) represents density of water (Kg/m³), swept area of turbine (m²) and free stream velocity of flowing fluid in (m/s). The equation (2) is used to determine output power at the end of generator after encountering the turbine performance, generator and bearing efficiency.

\[ P = K \frac{1}{2} \rho A U_\infty^3 \]  

(2)

\[ K = C_p \eta_b \eta_g \]  

(3)
Turbine power coefficient is the ratio of generated power to available water power and can be calculated by equation

\[ C_p = \frac{T \omega}{\frac{1}{2} \rho A U^3} \]  

As this research uses torque optimization for that torque coefficient corresponding to turbine radius can determined through following formula.

\[ C_m = \frac{T}{\frac{1}{2} \rho A U^3 R} \]  

Another important design parameter is the tip speed ratio of turbine that can be calculated if angular velocity, radius as well as free stream velocity of flowing stream fluid is known

\[ \lambda = \frac{\omega R}{U} = \frac{C_p}{C_m} \]

### 3. Numerical Simulation

#### 3.1. Turbine Modelling and Grid generation

In this research Darrieus turbine is selected because it is simple, easy to manufacture and requires less maintenance. The turbine size is kept in such a way that it can be installed in existing canals as well as in irrigation channels. Three bladed vertical axis turbines are designed with two different airfoils and at three different pitch angles. All the three blades are connected with central axis through arms in the turbines. Fig. 1 shows the turbine designed at 0° pitch angle and its specification is given in table#1. Three dimensional model of turbine is imported and fluid domain of appropriate size is generated in order to predict realist behaviour of flow around turbine as well as get accurate turbine performance. The grid generation is next most important step in Computational Fluid Dynamics (CFD) analysis of turbine. For that solid turbine model is subtracted from flow domain and processed for mesh generation. Mesh is generated in ANSYS ICEM where fine size tetrahedral mesh elements are used to generate large number of control volumes. Unstructured mesh is generated through patch conforming algorithm to get finer mesh in areas of interest.

<p>| Table 1. Geometric details of micro Hydrokinetic turbine |</p>
<table>
<thead>
<tr>
<th>Geometry of turbine</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade pitch angles</td>
<td>0</td>
</tr>
<tr>
<td>Blade length</td>
<td>1.5m</td>
</tr>
<tr>
<td>Turbine diameter</td>
<td>1.5m</td>
</tr>
<tr>
<td>Number of blades</td>
<td>3</td>
</tr>
<tr>
<td>Blade chord length</td>
<td>0.15m</td>
</tr>
</tbody>
</table>
3.2. Governing Equation & Turbulence Modeling

The fluid flow governing equations includes the conservation of mass, momentum as well as energy. Equations derived by using these principles are generally complex Partial Differential equations (PDE) which encounters small-scale fluctuation occurs in flow which make them even more difficult to solve analytically. In order to simplify those equations Reynolds averaging technique is applied. Here Reynolds average Navier-Stokes (RANS) equations along with turbulence models are numerically solved by using FLUENT. According to Reynolds averaging rule the solution variables in exact Navier-Stokes (NS) equations are decomposed in time averaged and fluctuating parts. By using averaging velocity of fluid in X-direction is

\[ u_i = \bar{u}_i + u'_i \]

Where \( \bar{u}_i \) and \( u'_i \) are average and fluctuating parts of velocity respectively. Following equations are obtaining by substituting all the flow variables by time averaged components in exact continuity and momentum equations resulting equations.

\[ \frac{\partial}{\partial x_i} (u_i) = 0 \]  

\[ \frac{\partial}{\partial x_j} (\rho u_i u_j) = \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + \frac{\partial}{\partial x_j} (-\rho \bar{u}_i \bar{u}_j') \]  

The equations 1 and two are known as Reynolds average Navier-Stokes equations. Additional terms in above equation are encountering the effect of turbulences. The last term \((-\rho \bar{u}_i \bar{u}_j')\) in equation 2 is called Reynolds stresses. Reynolds stress \((-\rho \bar{u}_i \bar{u}_j')\) terms should be modelled by selecting appropriate turbulence model to get accurate results [25]. To select best turbulence model various researches are conducted which come know that \(k-\omega\) model provides good results then \(k-\varepsilon\) model for near wall problems [26-28]. Though \(k-\omega\) model is better but its great sensitivity for the \(\omega\) values near rotational boundaries creates problem in case of shear flows. But this problem was solved by Menter’s \(k-\omega\) SST model which combines merits of \(k-\omega\) and \(k-\varepsilon\) model for near the wall and away from wall flows [29, 30]. The Shear Stress Transport (SST) model proved to be very helpful for encountering the effects in boundary layer and flow separation regions and also number of researches proved that \(k-\omega\) SST turbulence model highly suitable for vertical axis turbine simulation [31-35], transport equations of \(k-\omega\) SST model are [36].
\[
\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left( \Gamma k \frac{\partial k}{\partial x_j} \right) + \tilde{G}_k - Y_k + S_k
\]  
(9)

\[
\frac{\partial (\rho \omega)}{\partial t} + \frac{\partial (\rho \omega u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left( \Gamma \omega \frac{\partial \omega}{\partial x_j} \right) + \tilde{G}_\omega - Y_\omega + D_\omega + S_\omega
\]  
(10)

4. Computational Method/methodology

This study presents a novel numerical method of predicting turbine performance for unknown tip speed ratio. From the literature it was found that numbers of simulations are performed by assuming tip speed ratio. In this research numerical simulation of H- Darrieus hydrokinetic turbine is carried out in which turbine is assumed to stationary and torque due to force of flowing fluid is determined and optimized for three different pitch angle and different airfoils. CFD analysis is performed on FLUENT to solve Reynolds average Navier-Stokes (RANS) with turbulence models on unstructured mesh. This study solves partial differential equations governing fluid flow are generally linearized through implicit scheme because it converges more quickly than explicit scheme solver \[37\]. SIMPLE pressure-velocity coupling solution method is used to compute flow properties. Steady state simulation is performed by using pressure-based solver because flowing fluid is liquid water which incompressible.

5. Results and discussion

In this research CFD analysis of micro hydro turbine is carried out study effects of various design parameters on turbine performance. For that purpose several turbine models are simulated at three different pitch angles as well as at two different airfoils. Results are presented as follow.

5.1. Effect of pitch angle for air foil NACA0015

In order to determine effect of pitch on turbine performance the airfoil NACA0015 is tested for three different pitch angles such as 0°, 5° and 10°. Static pressure and velocity distributions on near the blades are shown in Fig 2, and 5 at different pitch angles. From pressure contour it is observed that pressure increase in front of blade whereas decreases on backside of turbine blade. This causes wake on the backside of turbine.

![Fig. 2. (a) Pressure variations near Turbine the blades at pitch angle 0 degree (b) Velocity Vector near Turbine blades at pitch angle 0 degree.](image)

5.2. Effect of pitch angle for air foil NACA0020

In this case air foil NACA0020 is selected to analyse effect of pitch angle for that purpose CFD simulation of three different pitch angle turbine model is conducted. Pitch angle of 0°, 5° and 10° are selected to analyse their effect. Static pressure and velocity distributions on near the blades are shown in Fig 2, and 5 at different pitch angles. From Fig. 6 it is observed that velocity of flowing water decreases when it comes closer to turbine because its pressure rises near the turbine blade. This decrease in velocity remains till to the point where fluid regain its kinetic energy.
CFD simulation of three blades micro-hydrokinetic turbine also predicted numerical values of different turbine performance parameters such as torque, lift and drag coefficient. But out of them this research is more interested in analysing the effect of airfoil thickness as well as pitch angle on torque production. Numerical simulation results reveals that increasing pitch angle from 0 to 10° results decrease in torque production for both of the airfoils. CFD simulation also reveals that blade profile NACA0020 have better performance than NACA0015. The comparison of variation in torque produce for two different airfoils at three different pitch angles given in table 3 and Figure 8.

<table>
<thead>
<tr>
<th>Turbine blade pitch angles</th>
<th>Torque generated on NACA 0015</th>
<th>Torque generated on NACA 0020</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree</td>
<td>220.1 Nm</td>
<td>265.12 Nm</td>
</tr>
<tr>
<td>5 degree</td>
<td>212.23 Nm</td>
<td>256.64 Nm</td>
</tr>
<tr>
<td>10 degree</td>
<td>190.3 Nm</td>
<td>235.57 Nm</td>
</tr>
</tbody>
</table>

5.3. Comparative Analysis of Torque with Varying Blade Angle

6. Conclusion

CFD simulation of Three bladed Vertical Axis Micro hydro Turbine (VAMHT) is carried out in order to find the analyse the effect of pitch angle and airfoil on torque production. In this study six different turbine models was developed in gambit and simulated in FLUENT 14.5. Numerical simulation of three bladed vertical axis micro hydrokinetic turbine simulation results reveals that increasing pitch angle from 0 to 10° results decrease in torque production for both of the airfoils. CFD simulation also reveals that blade profile NACA0020 have better performance than NACA0015. Through CFD simulation it was concluded that 0° pitch angle is capable of providing best results and airfoil NACA0020 has better performance, therefore study suggest that turbine should be designed by keeping 0° pitch angle.
References


Abstract

It is very significant to design pollution free energy generation system. Speed breaker Power Generator (SBPG) is the most emerging technique which produces electrical power with minimum input. An experimental study to generate the electricity by SBPG is described in this paper. In this system, a rack and pinions mechanism is used for the production of electricity. When a car reaches on the speed breaker, the rack moves downward to generate linear to rotary motion using pinions. The rotary motion is transferred to DC generator which generates DC power which is stored in batteries same as in solar technology. The generated power can be used for the domestic purpose or commercially, which are present near the speed breaker. This examined that SBPG is generating 273.24W on single push under the application of 400kg. In an hour, passing 100 cars of 400kg can generate 54.59 kWh. This mechanism utilizes both downward as well as the upward motion of the rack.

Keywords: Power generation, speed breaker, rack and sprocket pinion.

1. Introduction

During last few decades, electrical energy is the basic requirement of human beings. The ratio of electricity requirement is increasing day by day. But we know that the resources for power generation are limited, and this has caused the energy crisis. The increasing power demand results reduce in conventional resources for power generation and increase the pollutants emissions. It is a need of time to think about non-conventional energy resources or renewable energy resources which are eco-friendly to the environment. In order to minimise the emission of greenhouse gases, renewable energy technologies are widely used for electricity generation. Solar and wind technologies are frequently used for electricity generation. Fig. 1 is rearranged in MS Excel that shows power generation in Pakistan by each sector [1].

![Fig. 1. Power generation in Pakistan by sector in 2014](Sample output to test PDF Combine only)
vehicle growth in Pakistan is increasing day by day. The weight of vehicles in term of potential energy can be utilized for electricity generation purposes [5]. In this paper, we developed a method of generating electricity using speed breaker on the roads. To obtain maximum power, the flow of moving vehicles is very important. In this mechanism, a rack and pinions are used. This mechanism converts the kinetic energy of moving vehicles into electric energy with the help of speed breaker on the roads. This is generating many kilowatts of power by using downward as well as the upward motion of rack. Downward motion is caused by load and upward motion is due to restoring force utilizing store power in springs.

2. Methodology of working

When a car reaches on speed breaker, rack moves downward to generate linear motion [6]. Two pinions are attached to a rack which converts the linear motion of rack into rotary motion. Both pinions have unidirectional motion, like as bicycle sprocket. Two gears are mounted on pinion shaft’s to transfer mechanical power to the common shaft having one gear. At final shaft, a flywheel is used to provide uniform motion. A belt is used to transfer mechanical motion of the common shaft to DC generator. The complete gear box is dipped in lubrication oil sump to minimize frictional losses. There are no chances of slipping between rack and pinions due to guide slots. DC generator generates DC power which is stored in batteries same as in solar technology [7]. The generated power can be used for the domestic purpose or commercially, which are present near the speed breaker.

2.1. Rack and pinion mechanism

The rack and pinion mechanism in AutoCAD 2013 is illustrated in Fig 1. Fig 1(a) shows that when a car reaches on the speed breaker, it applies its weight on the speed breaker. The rack is connected with the speed breaker and two pinions mesh across the rack. Due to the weight on the speed breaker, rack moves downward and linear motion is obtained. It rotates the pinions which are attached on the both sides of the rack. At this point, linear motion of rack converts into angular motion. Only right sided pinion transfer power and pinion mashed on left side keep rotating without transfer of power. Fig 1(b) and Fig 3 represent that four springs help the speed breaker to move upward and thus only left sided pinion transfer power and pinion mashed on right side keep rotating without transfer of power a complete cycle of linear to rotary motion is obtained. The pinions were designed to work as sprocket of the bicycle. At load, one side of pinion engages and another side of pinion disengage. Similarly, restoring force engages another side of the pinion and first side of pinion disengage. They transfer power in forward as well as the reverse stroke of speed breaker respectively and provide continuous angular motion.

Fig 2 display working principle of rack and pinion mechanism and internal mechanism of SBPG in AutoCAD 2013. Gear of different teeth and diameter are mounted on both pinion’s shaft to maximize the number of revolutions. A gear mounted on the common shaft is placed between both pinion’s shafts. The flywheel is mounted on the common shaft. It keeps the rotation of the shaft in uniform angular motion. It stores the jerky rotations of pinion’s shaft. Mechanical rotation is used to rotate the shaft of the generator through a belt. The shaft of maximum RPM (common shaft) is coupled with DC generator. A DC
generator produces direct current [8]. According to Faraday's law of induction when coil moves inside the magnetic field, it generates electric current [9]. It rotates the rotor of the generator and in this way, the electricity is generated.

![Fig. 2. Rack and pinion mechanism (a) 3D internal mechanism of SBPG (b).](image)

Fig 3 represents the 3D model of SBPG mechanism is in AutoCAD 2013. Fig 3(a) identify 3D model by offing road and speed breaker. Four springs [10] are used to provide the upward motion. Utilizing energy (under the application of restoring force when the load is removed) rack moves upward and regain its original position. Two Support platforms for spring are welded to the frame to support the springs. Three supporting bars support whole mechanism. Guide slots lead speed breaker in the straight line and save it from trouble. Rubber beadings are used around the edges of SBPG to prevent water and dust from entering into it [11]. Fig 3(b) illustrate the complete 3D model of SBPG mechanism.
2.2. Prototype Model

Fig 4 represents a prototype model of SBPG system. This was developed by our team for the purpose of participation in DICE Automotive 2015. We presented this model in DICE Automotive 2015 SSME NUST Islamabad.

3. Experimental study and results

Consider 100 cars of mass 400kg pass over a speed breaker in an hour. The height of rack is 14cm, the diameter of the final pulley is 18mm and having revolution speed (N) is equal to 37 RPM. Down word
motion of speed breaker is due to the weight of moving the vehicle and upward motion of speed breaker is take place due to the utilization of energy from springs. Each car pushes speed breaker two times.

\[ \text{Force} = F = mg \]  \hspace{1cm} (1)
\[ r = 9\text{mm} \]
\[ T = r \times F \text{ (Nm)} \]  \hspace{1cm} (2)
\[ T = 9 \times 10^{-3} \times 3920 \]
\[ T = 35.28 \text{ (Nm)} \]
\[ P = T \omega \]  \hspace{1cm} (3)
\[ P = 35.28 \times 2\pi N/60 \]
\[ P = 35.28 \times (2 \times 3.14 \times 37)/60 \]
\[ P = 136.62 \text{ W} \]

Total generated in forward and reversed stroke.
\[ P = 2 \times 136.62 \text{ W} \]
\[ P = 273.24 \text{ W} \]

Revolution in one minute = \( \frac{200}{60} = 3.33 \text{rev/min} \)

Power generated per minute = \( 273.24 \times 3.33 \)
\[ = 909.89 \text{ W (minute)} \]

Power generated in one Hour = \( 909.89 \times 60 \)
\[ = 54.59 \text{ KW (hour).} \]

Different masses are applied on the speed-breaker and the measured the electrical power. Fig 5 shows the linear relationship between the load and produce power.

4. Conclusions

This is generating many kilowatts power by using downward as well as the upward motion of rack. With the help of speed breaker mechanism, linear motion of rack is converted into rotary motion of pinion and thus is used to rotate the shaft of DC generator. It generates 273.24 watts with 400kg of load and 14cm of the height of the rack. DC voltages charge the batteries during the passage of moving vehicles. Using inverter (DC to AC conversion), we will be able to use batteries power for other useful applications. It can be implemented on the toll plazas, highways. Guide slots and lubricating oil sump is required to minimise friction losses. The initial cost of this arrangement is high but after the first cost, it will be free energy system.

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References


155. Review on aerodynamic design optimization of small Horizontal Axis Wind Turbine
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Abstract
Wind is clean, non-exhaustible, low cost energy source, for its efficient utilization Horizontal Axis Wind Turbines (HAWT) are the best choice but large HAWT produce high noise, alter global climate conditions and requires the large area with optimum wind conditions. It thrusters for using high efficiency small wind turbines that can produce comparable power to large less efficient turbines. Small HAWTs are simple, portable with self-starting characteristics widely used for independent power production. Aerodynamic design improvement is one of best method of enhancing turbine efficiency by changing turbine design characteristics without significant increase in weight and cost. This work reviews the influence of various aerodynamic design parameters like airfoil geometry, winglets addition, chord wise pitch and twist distribution and effect of pitch angle on the starting as well as overall performance of small HAWTs.

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Keywords: “Airfoil; Starting Characteristics; Wind energy; Aerodynamics of turbine”

1. Introduction
Increasing global warming, rising level of greenhouse gases and increasing fossil fuel prices leads to invest on clean and low cost small wind turbines [1]. Small HAWT are simple, compact, portable and produce low noise [2]. These turbines do not rely on external power to start rotation and independent power production purposes[3]. Small HAWT can be installed on farms, remote areas, house roofs as well as on boats [4]. Due to all above advantages, Small HAWT are gaining much attention from researchers[5-9]. As it is a well-known fact that large HAWT are installed at areas with having optimum wind conditions but small HAWT can produce sufficient power output even at low wind speed they require less torque to start rotation[4, 10, 11]. Small HAWT solely rely on aerodynamic forces to start up rotation as well as uses tail vane for passive yawing. For the classification of small HAWT on basis of power generation refer to[1, 12, 13].

As the small HAWT operate at very low height and slow speed, because of topologies and obstacles to slow moving fluid laminar flow is rapidly changed to turbulent one that highly affects its efficiency and performance characteristics[4, 14]. For efficient working of turbine their starting characteristics are the key measurement parameters therefore considerable attention is given on starting characteristics [4, 15]. Due to small rotor size small HAWT is able to generate very low torque which may be insufficient to start turbine [12]. Therefore to achieve maximum power production lot of attention is given to minimize cut-in-speed of small HAWTs[13, 15, 16]. To improve starting characteristics aerodynamic design improvement is unique as well as bet way to solve this problem [17, 18]. The aerodynamic design optimization is method to get highly efficient turbine without any significant increase in weight as well as cost. Aerodynamic optimization is linked with the improvements and selection of optimum number of blades, airfoil profile, pitch angle, Angle of Attack (AoA), chord and twist distribution as well as any aerodynamic shape change in blade [19]. Number of researches were conducted to predict efficiency of HAWTs their research reveals that HAWTs mostly operate with efficiency from 20 to 45%[4, 20]. But it was also found that small HAWT operate with 30% or 35% efficiency in comparison with large HAWTs which operate at 45% this means that lot of research needs to improve efficiency of small HAWTs in order to operate it with optimum performance to achieve Betz limit of efficiency 59.2% [4].

2. Aerodynamics design of turbine
Aerodynamic design is the highly important step in design of turbine because performance of turbine is greatly influenced by its aerodynamic body profile. Aerodynamic design is based on airfoil (that is basically blade profile) shape as well as their twist and pitch angle of the blade. Airfoil is the complex two-dimensional body that causes
increase in pressure at lower surface and to produce lift is which in turns causes to generate torque. The primary goal of best aerodynamic design is to enhance torque production and to reduce noise generation. Increase in lift or torque productions results in to enhance power coefficient [10, 21]. In cases of small HAWT it is always desirable to increase (L/D) ratio in order to obtain best starting characteristics by producing high torque at low wind speeds, it also improves power coefficient [15, 21, 22].

\[
\eta_{\text{aero}} = \frac{1 - (C_D / C_L) \cot \phi}{1 + (C_D / C_L) \cot \phi}
\]

(1)

\[
\tan \phi = \frac{1 - \alpha}{\lambda_r (1 + \alpha)}
\]

(2)

Where \( \phi \) is the inflow angle and \( \lambda_r = \omega r / V_o \) is local speed ratio at any point on blade [23]. From equation (1) it is analyzed that L/D ratio and inflow angle are the controlling parameters of aerodynamic performance. From the literature related to small HAWT it was analyzed that turbine having less radius posses more difficulty in starting whereas increase in radius provides better stating characteristics. Starting characteristics mainly depend of aerodynamic torque generated and the resistive torque of drive system. Resistive torque is directly proportional to cube root of turbine radius \( R^3 \) [12]. Resistive torque is the cumulative torque offered by whole drive train mechanism. For rotor to rotate its aerodynamic torque should be more than resistive torque. Following expression is used to calculate the minimum cut in speed of turbine [24].

\[
U_c = \left[ \frac{2T_R}{N_b \rho R^3 I_{cp}} \right]^{\frac{1}{2}}
\]

(3)

where,

\[
I_{cp} = \int_r \left[ r \sin(2\theta_p) \left( 1 - \cos^2 \theta_p \right) \right] dr
\]

(4)

N_b is number of blades, \( \rho \) density of air (kg/m^3), \( T_R \) denotes resistive torque (Nm), \( R \) blade radius (m) and \( I_{cp} \) (chord pitch integral). The plan type blade geometry and pitch distribution \( I_{cp} \) of small wind turbine solely dependent on estimation of cut-in wind speed. In order to reduce the starting problem, variable pitch and high flow angle often fixed to expose are rarely terms of small wind turbines. When blade is rotating at 90° angle of attack then its performance has negligible dependence on thickness and camber. In that situation airfoils behaves like flat plate [24].

\[
C_L = 2 \cos \alpha \sin \alpha \quad \text{and} \quad C_D = 2 \sin^2 \alpha
\]

(5)

The parameters related with optimization of blade geometry are important, because when once optimized then similar power could produce by shorter rotor blades as compare to one that is larger in diameter and not optimize. Aerodynamic optimization of rotor is very important when it is coupled with optimization of twist distribution and chord, number of blades, selection of airfoil geometry, and the tip speed ratio (TSR) for more power extraction from low wind areas. Blade element momentum theory BEM depends on twist distribution, edgewise (blade thickness) distribution and flap wise (chord) distribution. Chord distribution along the blade span obtain from Eq. (6).

\[
C(r) = \frac{4\pi r F \sin \phi}{N_b C_L \left\{ \left[ (\lambda_r + \tan \phi) / (1 - \lambda_r \tan \phi) \right] - (C_D / C_L) \right\}}
\]

(6)

In above equation \( c_0/c_1 \) (minimum drag-to-lift ratio of the airfoil section), \( F \) (tip loss factor), \( \lambda = \omega R/V_o \) (design tip-speed ratio) and \( V_o \) (free stream wind velocity at hub height). The twist of the zero lift line is given by below equation which is from twist distribution [18].

\[
\theta_p = \left( \left( R \alpha_t / r \right) - \alpha_t \right) - k (1 - r / R)
\]

(7)

\( \theta_p, \alpha_t, r \) and \( \alpha_t \) denotes pitch angle, radial location and AOA at the tip of the blade respectively. whereas k is the acceleration factor and is greater than zero. In equation (6) \( \alpha_t, \phi, \) and \( \theta_t \) represent AOA at zero lift, in-flow angle and pitch angle at the tip respectively.

3. Airfoil design modification
3.1 Airfoil design for Small HAWT Applications

The central idea behind the design of small HAWT is to develop turbines which can operate at low wind speed, generate low noise so that it can be installed at urban areas. For turbine to operate at low wind speed requires special airfoil sections for their blades because the at low speed separated flow failed reattach in case usual airfoils and results in loss of aerodynamic performance [21, 25]. To operate turbine at optimum speed low Reynolds number ($Re$) airfoil are design which operate below $Re = 500,000$[22, 26, 27]. The number of researches were conducted to design efficient airfoil for low Re applications. Researches finally concluded that low Re number airfoils should be thinner as compared to high Re number airfoil [12, 22, 28] to reduce adverse pressure gradient at the upper surface of airfoil [21, 27]. In past lot of research was conducted for designing of low Re applications approximately 17 airfoils belong to family of thinner airfoils were tested at $Re = 10^5$ to $5 \times 10^5$. To optimize performance nose radius and cusping of trailing edge was increased this results significant improvement in its performance at low $Re$, increase in nose radius causes to decrease in adverse pressure gradient and increase in cusping results increase in aerodynamic loads in cusped region [22, 28, 29]. After some time [30] tested 6 different airfoils (E387, FX 63-137, S822, S834 and SH3055) at Reynolds number $10^5$ to $5 \times 10^5$ and found that airfoils (SH3055 and FX 63-137) achieve highest coefficient of lift equal to 1.8 in this range of Re. T. Urban 10/193 airfoil is designed and modelled on x-foil and their study found that maximum value of $C_L$ was obtained in the Re range of $6 \times 10^5$ to $10^6$ [15].

Recent research was conducted to optimize low Reynolds number airfoil for application of small HAWT which has to operate within wide range of Re number from $38,000$ to $205,000$. For that purpose S1210 and S1223 airfoils are selected to optimize their basic geometry by increasing trailing edge thickness. The series of test were conducted to compare number of low Re number airfoils for Reynolds number values $55,000$, $100,000$ and $148,000$ through x-foil results are shown in Fig. 1. Test results reveal that airfoil AF300 attained highest value of $C_L$ and L/D ratio. Experiments also reveals that for $Re=38000$ and angle of attack ranging from 0-18$^\circ$ coefficient of lift varies from 0.41 to 1.05, another test result was conducted on AOA 14$^\circ$ test results showed that $C_L$ increases with Re number and maximum value of $C_L$ found to be 1.86 for Re=$205,000$. It is also found that addition flat back trailing were proved to be beneficial to avoid flow separation, increase strength along with reduction in weight of blade. Reduction on weight in turns reduces inertia and improves starting characteristics that are highly important for small HAWT turbines which operate at low wind speed. It is also concluded that addition of flat back trailing edge results in increasing stall angle up to 14$^\circ$ means that turbine blade can operate at high angle of attack without stall this proved to be beneficial for improving aerodynamic performance[31].

![Fig. 1. Drag polar plots and (b) Variations of lift coefficients of s1223 and s1210 airfoils and their variants with different trailing edge thicknesses at Re =148,000][31]

3.2 Effect of Airfoil-camber line modification

For proper and efficient design of airfoil for small HAWTs various methods were developed but pressure inverse method was found to effective. This method is applied to design high lift airfoil with uniform pressure load along chord of turbine blade with inlet angle of 4$^\circ$ in Reynolds number range of $3 \times 10^5$ to $1 \times 10^6$. T. Urban 10/193 airfoil was design for that eight iteration are required to attain convergence. From the study it was analyzed that pressure load distribution increase slowly up to 20% of axial chord length starting from leading edge and decreases towards trailing edge, load remain constant in the remaining blade section. It is also analyzed that lift and drag production are affected by transition point. Near the trailing edge transition occurs at small angle of attack in the vicinity of suction side. It is also observed that transition point is shifted towards trailing edge along with increase in AOA for three different Reynolds numbers. T. urban 10/193 turbine blade section have unique characteristics that have high lift with moderate drag coefficient and soft stall uniqueness because of better design T.urban 10/193 blade section, as an isolated airfoil,
confirmed maximum lift and moderate drag with soft-stall uniqueness, due to a reduction of adverse pressure gradient on the upper side [15]. Study was conducted to design three bladed small wind turbine by using thin airfoil section and for tip speed ratio (TSR) of 3. The new thinner airfoil was generated from NACA4418 airfoil, the upper surface of newly designed airfoil is very closed to base airfoil but the wing profile of both airfoils is entirely different from one another [32]. The newly generated airfoil has 11% camber and 8.5% thickness at 0.35 and 0.10 of chords respectively. Whereas airfoil NACA4418 having 4% camber and 18% thickness at 0.40 and 0.30 chords respectively. Author conducted series of tests where it was found that thinner airfoil achieves higher value of Coefficient of lift ($C_L$) than that of NACA 4418 and 2.04 maximum value of $C_L$ was observed at 12° AOA. On the other hand, value of $C_D$ is near about same for both of the airfoils and for wide range of AOA, in some test was found that $C_D$ value of thin airfoil is higher than that of airfoil NACA 4418. Research results also showed that L/D ratio of thin airfoil is much higher than that of original NACA 4418 airfoil. Besides, for negative AOA L/D ratio is negative and near equal to zero for airfoil NACA 4418 and newly designed thin airfoil respectively shown in Figure 2.

![Fig. 2. Relationship between (a) lift–drag coefficients and (b) lift–drag ratios with angle of attack][32]

To improve airfoil performance, number of experiments as well as CFD simulations was conducted on seagull airfoil for the wide range of Re 100,000–200,000 [33]. Research results reveal that seagull airfoil showed better performance than airfoil NACA 4412 and it is capable of avoiding flow separation characteristics better than that of airfoil NACA 4412. As the Fig. 3 compare the performance of the number newly generated airfoils with original seagull airfoil where it was found that the original profile showed better performance than newly generated airfoil. Finally analysis showed that seagull airfoil can provide better aerodynamic performance during special circumstances and is better to use at turbine blade tip.

![Fig. 3(a,b) Comparison chart of aerodynamic characteristics of seagull and the transformation airfoils at Re=1x10^5][33]

Research was carried out to improve the performance of low Reynolds number airfoil, for that purpose number of low “Re” airfoils were combined and tested at three different Reynolds numbers for AoA from 0-22° [34]. Where xfoil results are validated with wind tunnel test results and it was found that airfoil SG6043_Eppler 422 has better aerodynamic performance than combination of other low Re airfoils. In order to analyze effect of various parameters numerical study was conducted and validated with experimental results. Validation study showed that numerical results and experimental results have better closeness for higher value of Re and stall angle for the airfoil was found to be 15° from numerical simulation it author concluded that combined airfoil SG6043_Eppler 422 have better aerodynamic characteristics than other airfoils and it is highly suitable for Small HAWTs. Moreover, maximum value of L/D ratio is obtained at 8° AoA hence this angle should considered as designed AOA in design of turbine blade.
4. Effect of chord and twist distribution on performance of SWT rotor

The small HAWT was designed and manufactured by using two different airfoils (FX66-S-196 and NACA63-621) to analyze aerodynamic characteristics on the outboard and inboard region[35]. By using Eq. (6) and (7), the twist distribution and chord were found out, thickness of blade at root and tip was kept 210 mm and 25 mm respectively and their thickness varies with linear distribution. The pitch angle of blade was determined by Eq. (7) pitch angle at tip was kept 0° and 2° and at root 22° as shown in Fig. 4. In case of pitch regulated turbine this designed blade produce power up to rated value. Beyond this range output characteristics of blade were controlled through a special type of controller that dumps excessive power. At starting speed of HAWT rotor produce more power as wind speed increases but it produce less power as compared to our expected. However rotor will produce more power as compared to our expected at operation in high wind speed. Moreover, highest power coefficient($C_p$) was found to be 0.412. Another researcher designed 500mm diameter and 18° pitch angle small HAWT by using airfoil NACA2404[2]. The designed turbine was tested for wide range of wind speeds from 8-12 m/s and it was found that $C_f500$ given high efficiency. Average $C_p$ was found near about 0.36 and 0.25 for 8 and 12 m/s free stream velocity respectively. Therefore it’s clear that UF500 shows good result with low (TSR) and the usage should be extend to use low wind resources and maximum $C_p=0.40$ were achieved at tip ratio of 2.7. Another study designed and manufactured turbine by using airfoils NACA23012, NACA4412, NACA0012 and NACA4415 and 310mm diameter[36]. Every blade model rotor have different properties such as blade angle, blade numbers, blade to hub angle and twisting angle. This study shows a strong correlation between blade angle, number of blades with $C_p$ and rotor rotation rate. Highest correlation of $C_p$ was found with blade profile, blade twist and wind speed. NACA 4412 profiles with 5° grade blade angle, 0° grade twisting angle are used to fabricate rotor models. Comparing double angle had high rotation rate with those fabricated by using NACA 4415 profile with 18 grade blade angle, 0 grade twisting angle and four blades which had high $C_p$, 3077rpm rotation rate with a $C_p$ ratio up to 0.425 are shown by rotor model. Blade performance was analyzed by using NREL’ slow speed airfoils S 822 and S 823 that are used on root and tip of the rotor respectively to improve the low speed HAWT blade [37]. Original blade root area is kept smaller to optimized radial variation of the chord length whereas radically decline curve achieved when twist angle is optimized inflexion line is contained by initial one. These changes are obtained by using modelling on the optimized blade and root area which contains of softer external curve. In optimized blade root area transferred from flat surface to circular surface due to which aerodynamic performance of blade is improved. Optimized blade have loosely outsized twist angle than initial blade at tip and middle as shown in Fig 5. For installing blade angle BEM theory is used and for maximizing chord length genetic algorithms is used. It has been optimized to improve the rotor $C_p$ of the original rotor in each case on the (TSR). When wind speed is less than 5 m/s at 50 rpm some remarkable changes occur, by optimizing blade aerodynamic performance was improved as shown in Fig 6. Optimized wind rotor blade have higher $C_p$ than the original blade [38].

Maximize the $C_p$ by using BEM method by operating at variable speed of designed two bladed rotors of 3.5 m which were use NACA 5317 airfoil. The design geometric parameters are good in range for fabrication. The pitch angle is almost linear and has a net variation of 13.3 linear in Fig 7. According to exiting wind turbine rotor performance is good and acceptable, the $C_p$ being 0.5 is used to lower the complexity of small HAWT rotor manufacturing. A double bladed rotor was design for working to work at low wind speed limit of 3 to 6 m/s which involves of AF 300 flat back airfoil. The 2-bladed rotor was especially design to eliminate laminar separation bubbles to achieve higher at very low Reynolds numbers which also helps in structure stability of bubbles and improve over competence of turbine[39]. The twist and taper were shared to the low Reynolds number for airfoilAF300 section which is based on BEM theory Eqs.(5 and 6), these Equations are used in low wind speed to increase the aerodynamic performance. The double bladed rotor attained the values of $C_p$ like 0.1, 0.217 and 0.255 at respective wind speed of 4, 5 and 6 m/s whereas for three bladed rotor achieve wind speed like 0.052, 0.112 and 0.15. The peak $C_p$ achieved by the double bladed rotor which was design at 6 m/s at 0.29 wind speed. In for controlling pitch angle the chord length distribution is used and with the help of decreasing weight and size while maintain the higher $C_p$ for blade [32]. With BEM theory blade shapes have improved and for thin airfoil chord length has become shorter as compared to optimum design. The thickness of chord length has been improved from 8.5 % of the chord and blade tip to 18.5 % although maintained the stiffness of blade the pervious chord length of thin tailored airfoil blade was 230mm from blade to blade tip to r =1.6 m and at the cut-off r = 0.4m and then altered linearly for modification up to 230 mm at r = 1.6m. At relative twist angle of 27° as shown in Fig 8, with optimum twist angle from 34° to 7° at the blade tip. The automatically controlled wind turbine with the parameters of such as average wind speed of 10m/s and a maximum wind speed of 19m/s shown a safely condition for running with a $C_p$ of 0.14 and average output of generator 1105W.
Fig. 4.(a) Blade thickness distribution and (b) graph of the zero lift line twist [35]

Fig. 5. Comparison of optimized chord distribution and twist of the blade with the original [37]

Fig. 6.(a) Comparison of performance of the optimized wind rotor with the original [37](b) Geometry parameters of the blades [38].

Fig. 7. Distribution of chord length and twist angle [32].
5. Effect of blade winglet on turbine performance

At present wing tip vortices is one of highly major issue that hinder to increase aerodynamic efficiency of turbine. Wing tip vortices causes increase in drag as well as enhance noise production. From literature it was concluded that winglets causes increase in aerodynamic performance but their effect is analyzed for particular flight conditions [40]. [41, 42] numerically analyzed effect blade winglets on turbine performance. Winglets were added on pressure side and suction side their research reveals that winglet addition on both sides causes 1.4% increase in power produced along with 1.6% increase in thrust at speed of 6m/s. [43] carried out research on small HAWT to analyze effect of winglets on turbine performance. Airfoil SG6051 is selected for turbine blade because it possesses high L/D ratio[44]. Their experimental work reveals that upwind winglet increased 27% in L/D ratio[43].

6. Effect of pitch angle on starting performance

Starting wind speed is key parameter at design stage of small HAWT because low starting speed made it attractive for use in low wind speed areas. For that purpose number of researches was conducted by considering various parameters but out all those parameters pitch angle effect is significant. [45] carried out research on 5kw wind turbine to analyze effect of pitch angle on its starting performance. Their research reveals that pitch angle greatly affect starting as well as operation performance and large pitch angle proven best starting characteristics for 8m/s wind speed. Small three bladed HAWT of diameter 1m was designed for power output of 600W by scaling down 2.5m diameter and 5kw turbine. This turbine shows 80% more power output in combination with new generator over the original and starting wind speed also reduced to 2.5 m/s. Performance of turbine was analyzed for the range of pitch angles from 0 to 35° with the increment of 5° [10]. Analysis results found that 0° pitch angle turbine with 5m diameter produced highest power of 5kw at wind speed of 10m/s. But at 0° pitch angle turbine shows poor starting characteristics. Results showed that increase in pitch angle improves starting characteristics and 20° pitch angle turbine was found to have best starting characteristics. The starting wind speed (cut-in speed) of two different power of turbines (600w[46] and 5kw) were investigated on the bases of chord pitch integral by field test[24]. Comparison of field test predicted starting wind speed with field test measurement in Eq. (4) and (3) result shows that the predicted cut-in speed is more than the actual cut-in speed. At starting high angle of attack occur, the drag and lift is predicated by using Eq. (5). The causes of over estimation is the short of information and insensitivity of pitch angle. The chord pitch integrand (Icp) are lower in tip region and higher in root, hence it shows that the power producing torque comes from near the blade tip. And the high solidity near the hub contributes to generate starting torque. The initial performance of HAWT turbine with three-bladed, 2m diameter, 600W was validated and investigated through the comparison with calculations employing a quasi-steady blade element analysis and measured field test[16].

The average wind speed for starting rotation is 4.6 m/s but its varied between 2.5 and 7 m/s and normally its coincide with increasing wind speed. Besides, most power extracted torque found near the tip zone and most starting torque near the hub side [16, 46], so it is possible to maintaining good power performance by optimize starting performance. By varying pitch of blade between the limits 15°, 18° and 20° the performance improvement is study and the starting wind speed (cut in speed) and the best result was found at 18° pitch angle [39]. The results of chord distribution to have higher solidity as compared to the baseline blade that have fast start up and low starting wind speed. The starting wind speed based on 10 s average data at the optimize pith angle that was 3.24 m/s whereas instantaneous starting wind speed was 2.34 m/s, related to the starting wind speed 3.58 m/s that measured of rotor with the baseline blade as shown in Fig. 9.
7. Conclusion

In order to improve turbine performance number of aerodynamic changes and their effect is discussed in paper. The number of design parameters which highly affects turbine is observed and following key points were concluded on the basis of available literature.

- Turbine blades with upwind winglet cause 27% increase in Lift-to-Drag (L/D) ratio[43].
- Thinner trailing edge airfoil for turbine blades have high L/D ratio, generate low noise along with improvement of starting characteristics [31,47].
- Low chord thinner airfoils improve ($C_p$) beside that they provide easy pitch control. The seagull airfoils provide best results against separation and it was found to be best choice for blade tip profile[32,48].
- It is observed that optimum pitch angle would be different for different airfoils and airfoil NACA5317 provides the best results as compared to the airfoils like NACA4412, NACA4415, AF300, and NACA63-621(root), F66-S-196(tip)[31,35]
- It was found from literature that blades with $20^\circ$ pitch angle have best starting characteristics but they are also affected by turbine blade radius as well as design of hub [10,16,46]
- The highest $C_p$ can be achieved (near about 0.5) for blade with airfoil NACA5317 and $13.3^\circ$ pitch angle[38].

Reference

164. Computational studies on the effects of employing water filled bags and glass as a chimney’s material on performance of solar chimney power plant

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Abstract

Energy plays a role of backbone for socio-economic development of a country. Pakistan is among underdeveloped countries and is facing worst energy crisis from previous few decades. Renewable and sustainable energy sources can play a vital role to minimize these crises. High solar energy potential and available deserted wastelands in Pakistan urge to develop novel technologies like solar chimney power plants, which have versatile applications in thermal and electrical energy sectors like electricity production, ventilation in buildings and crops cultivation etc. Solar chimney power plant (SCPP) or solar updraft tower is a renewable type power generation technology, having a promising potential for large scale usage of solar energy. It operates on the basis of three technologies namely, the greenhouse, chimney and wind turbine. Greenhouse effect and stack effect of chimney induces an air flow, driving wind turbine coupled with generator thereby generating electricity. In this study a comprehensive three dimensional CFD analysis of SCPP, utilizing the dimensions of first working Spanish prototype has been explicated in ANSYS FLUENT to examine heat transfer and fluid flow patterns. Numerical models were incorporated with solar load, DO (discrete ordinates) and RNG k-ε turbulence models. The numerical results were compared with the reported experimental results of Spanish prototype and were found to be in good agreement, testifying the numerical models adopted for predicting the performance of SCPP. On the basis of robustness of numerical models, several simulations were performed to study the effects of employing water bags beneath the collector and glass as a chimney material. Fluid flow, pressure, and temperature distribution were analysed and the results depicted that these two methods raise the overall velocity and temperature distribution inside SCPP. Computed results reveal that use of water filled bags and glass as a chimney’s material enhances the overall performance of SCPP approximately by 4% and 7% respectively.

Keywords: Pakistan; Solar chimney power plant; CFD; Numerical simulations

1. Introduction

Needless to say, energy plays a role of backbone for the socio-economic development of any country. Incessantly rising population and high living standards ask for endless energy resources to fulfil heightening energy demand. Pakistan is among underdeveloped countries and is facing worst energy crisis from previous few decades, seeing more than 12 hours of power outages especially during summer, with shortfall reaching up to 5000MW [1]. The shortfall is even more drastic in Southern Punjab and Sindh’s rural areas, therefore demands continuous progression in the energy sector to break through this crisis. A sustainable solution can be found in improving environmental friendly renewable power generation sector i.e. hydro, the wind and solar etc. In particular, solar energy is an entirely clean and green renewable energy source and the reason lies in the fact that it is free from greenhouse gas emissions and other waste materials. Amongst other renewable energy sources, solar energy is more attractive because of easy installation of solar panels and sunlight abundance, specifically in a country like Pakistan where the sun brightens up all year in most of the cities. Solar energy can be converted into electrical energy by two modes, by photovoltaic effect using solar cells and by solar thermal generators driven by steam produced from large-scale solar concentrators. In spite of being too much advantageous, these two technologies also have some drawbacks like high cost, complicated manufacturing of solar cells and abundant supply of water for steam generation in solar thermal technology are named only a few. In addition to these two, there is another technology which is free from such types of pitfalls, moreover, possessing the same capability of producing electrical energy from the sun with efficacy, namely as “Solar Chimney Power Plant” or
“Solar Updraft Tower”. In this technology, by using solar collector and updraft tower air flow is induced which is used to drive a wind turbine generating electricity. A schematic diagram of solar chimney power plant demonstrating its different parts including water filled bags and the generic procedure is shown in fig. 1.

Fig. 1. Schematic diagram of solar chimney

The basic idea of generating electricity from this technology was first suggested by J. Schlaich. Later on in 1983 J. Schlaich along with his team built first working prototype of SCPP in Manzanares Spain. This prototype had the capacity of producing 50 kW, with collector radius of 122m, chimney height of 200m and chimney radius of 5m. This prototype operated successfully for almost eight years. Afterwards the results obtained from Manzanares plant and working principle of solar chimney was described in detail by J. Schlaich [2-3]. This concept attracted many researchers and they utilized this technology in many other applications. Solar chimney concept was also applied in buildings to enhance the natural ventilation [4-5]. In 2000 Ganon and V. Backstorm presented a thermodynamic analysis of solar chimney including system loss and studied effects of variables on overall performance [6]. Y.J. Dai, H.B. Huang, and R.Z. Wang proposed a solar chimney power plant subjected to supply electric power to remote villages in Northwest China. They calculated the output electric power of a solar chimney power plant having 200m chimney height, 10m chimney diameter and 500m collector diameter by using a theoretical model. They concluded that this power plant can supply monthly 110-190kW all over the year to nearby villages [7]. During the last decade, due to the development of new computer software and hardware technology, computer aided engineering (CAE) tools like computational fluid dynamics (CFD) became much popular among designers and engineers to solve problems. Computational fluid dynamics (CFD) has become a vital component in design of a system due to its enormous advantages, like foreseeing performance before actual operation of system, time reduction, cost reduction, powerful visualizing capabilities, ability to analyze difficult and dangerous experimental setups etc. Roozbeh Sangi et al. [8] performed numerical simulations by iterative technique and through two dimensional axisymmetric modelling in CFD software FLUENT predicted the performance of solar chimney. The results of two approaches were compared ensuring good agreement. Greenhouse effect in the solar chimney was simulated using two band radiation models by Ehsan Gholalamizadeh and Man-Hoe Kim; they also concluded that considering greenhouse effect is critical for predicting the performance of solar chimney in an accurate manner [9]. The effects of geometric parameters on performance of solar chimney were studied by Sandeep K. Patel et al. in ANSYS CFX. Results at different collector’s inlet and outlet diameters, chimney diameters and divergence angles were examined and the best configuration for solar chimney was suggested [10]. Atit Koonsrisuk and Tawit Chitsomboon compared the results of CFD with five simple theoretical models and recommended the most accurate ones for predicting solar chimney performance [11]. Although worthful contributions were made to analyse different parameters of SCPP by CFD, but in most of them SCPP was simulated as two dimensional axisymmetric model. In general, two dimensional models don’t give a detailed picture of heat transfer and fluid flow patterns inside the whole system.
Geographical location of Pakistan shows that it has a huge potential of solar energy but with almost negligible utilization. The state of affairs demand for developing large scale affordable solar power plants, which must be built with our own skills and resources and need not be imported at unconscionable cost. Solar Chimney Power Plant is one of those technologies having versatile applications in energy sector. In this paper a three dimensional CFD analysis of solar chimney power plant is presented. Firstly, a solar chimney was modeled using the dimensions of Spanish prototype plant and the CFD results were compared with the experimental results, which were in good agreement with each other. Later the effects of employing water filled bags and glass as a chimney’s material were investigated.

2. Mathematical modeling

In order to analyze the thermodynamics and fluid dynamics involved in SCPP, ANSYS FLUENT 14 was used to perform the numerical simulations. The main governing equations used in modeling SCPP are based on the fundamental mass, momentum and energy conservation equations described below [12]:

\[
\frac{\partial}{\partial t} \rho \mathbf{v} + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) = \mathbf{S}_m
\]

Where \( S_m \) represents the user defined source term.

\[
\frac{\partial}{\partial t} \rho \mathbf{v} + \nabla \cdot (\rho \mathbf{v} \mathbf{v}) = -\nabla p + \nabla \cdot (\mathbf{t} \rho) + \rho \mathbf{g} + \mathbf{F}
\]

In the above equation \( p \) represents the static pressure, \( \mathbf{t} \) is stress tensor, \( \rho \mathbf{g} \) and \( \mathbf{F} \) are the gravitational body force and external body forces respectively.

2.1. Heat transfer modeling

In solar chimney power plant, we have to consider all three modes of heat transfer i.e. conduction, convection and radiation. FLUENT solves the energy equation in the following form [12]:

\[
\frac{\partial}{\partial t} \rho E + \nabla \cdot (\rho \mathbf{v} E) = \nabla \cdot \left( \left( k_{eff} \nabla T - \sum_j h_j \mathbf{I}_j \right) + \left( \mathbf{t}_{eff} \cdot \mathbf{v} \right) \right) + S_h
\]

The first three terms on right hand side in the above equation, represent energy transfer due to conduction, species diffusion and viscous dissipation. \( S_h \) indicates volumetric heat sources that user has defined. \( k_{eff} \) is the effective conductivity and \( \mathbf{I}_j \) is the diffusion flux of species j. Heat transfer through radiations was computed by using the discrete ordinates (DO) model, because DO model has the ability to solve radiations through semi-transparent walls and wide range of optical thicknesses. The radiative transfer equation for DO model is [12]:

\[
\nabla \cdot (I(\mathbf{r}, \mathbf{s}) \mathbf{s}) + (a + \sigma_s)I(\mathbf{r}, \mathbf{s}) = a n^2 \frac{\sigma T^4}{\pi} + \frac{\sigma}{4\pi} \int_0^{4\pi} I(\mathbf{r}, \mathbf{s}^\prime) \Phi(\mathbf{s}, \mathbf{s}^\prime) d\Omega'
\]

In the above equation \( I \) represent solar intensity, \( \mathbf{r} \) and \( \mathbf{s} \) represent position vector and direction vector respectively. \( T \) denotes the local temperature and \( \mathbf{s}^\prime \) is scattering direction vector. Where \( \Phi \) and \( \Omega' \) represent phase function and solid angle respectively.

2.2. Turbulence modeling

When heat is added to a fluid, density of fluid varies with temperature and a flow can be induced. Such flows are called Natural Convection or Buoyancy driven flows. The strength of natural convection flows is measured by Rayleigh (Ra) number, which determines about flow regime whether it will be laminar or turbulent. If \( Ra<10^4 \) then flow is laminar and flow is turbulent if \( 10^4< Ra<10^{10} \). Previous theories indicate that in solar chimney power plant flow is fully turbulent. Formula for Rayleigh number is given below:

\[
Ra = \frac{g\beta\Delta T L^3 \rho}{\mu a}
\]
Consequently, to model turbulence in flow, Renormalization group (RNG) k-\(\varepsilon\) model was used owing to its better reliability and accuracy to solve a wider class of flows. The transport equations of (RNG) k-\(\varepsilon\) model are given by [12]:

\[
\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_j} (\rho k u_j) = \frac{\partial}{\partial x_j} \left( \alpha_k \mu_{eff} \frac{\partial k}{\partial x_j} \right) + G_k + G_b - \rho\varepsilon - Y_m + S_k \tag{6}
\]

\[
\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_j} (\rho \varepsilon u_j) = \frac{\partial}{\partial x_j} \left( \alpha_\varepsilon \mu_{eff} \frac{\partial \varepsilon}{\partial x_j} \right) + C_1 \varepsilon \frac{\varepsilon}{k} (G_k + C_2 \varepsilon G_b) - C_2 \varepsilon \rho \frac{\varepsilon^2}{k} - R_\varepsilon + S_\varepsilon \tag{7}
\]

Where \(G_k\) and \(G_b\) represent the generation of turbulence kinetic energy due to mean velocity gradient and buoyancy respectively. \(S_k\) and \(S_\varepsilon\) are user defined source terms and \(\alpha_k, \alpha_\varepsilon\) stand for inverse effective Prandtl numbers for k and \(\varepsilon\) respectively. Collector efficiency can be expressed as the ratio of heat output of collector to the solar energy which enters via transparent collector[13,7].

\[
\eta_{coll} = \frac{\dot{m} C_p \Delta T}{G A_{coll}} \tag{8}
\]

Where \(\dot{m}\) is the mass flow rate, \(C_p\) is the specific heat of air and \(\Delta T\) is the temperature increase of air through collector. \(G\) represents the solar radiations in W/m\(^2\) and \(A_{coll}\) indicates the area of collector. Schlaich suggested that maximum power which can be taken by turbine is[2]:

\[
P_{\text{max}} = \frac{2}{3} \eta_{coll} \frac{g}{\rho C_p T_a} H G \tag{9}
\]

In above equation \(g\) stands for gravitational force, \(T_a\) for ambient temperature and \(H\) represents the height of chimney.

3. Solution methodology and boundary conditions

In order to understand heat transfer and fluid flow inside the whole plant, a solar chimney power plant with Manzanares Prototype plant’s dimensions was considered. This plant has a collector radius of 122 m, ground to collector distance of 1.85 m which increases up to 6m adjacent to collector at the base of chimney for directing air flow inside chimney. Chimney height and diameter is 195 m and 10 m respectively [2]. Model of SCPP was created in ANSYS Design Modeller and the entire domain was divided into half to reduce the computational efforts. ICEM CFD software was used for grid generation and grid independence test was conducted by judging maximum velocity on three different mesh sizes having 66619, 163496 and 346862 nodes. The maximum velocity obtained was 8.5, 9.15 and 9.12 m/s respectively. Maximum velocity achieved at nodes 163496 and 346862 shows very little difference, so further mesh refinement would only increase run time. Thus mesh size with 163496 nodes was chosen for all simulations. Steady state condition was assumed and SIMPLE algorithm was chosen for pressure velocity coupling. Solution was run for 2000 iterations to ensure that solution has converged and all residual values fall to convergence criteria. The main boundary conditions adopted at different zones are given in table 1.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chimney Surface</td>
<td>Wall (Opaque)</td>
<td></td>
</tr>
<tr>
<td>Collector</td>
<td>Wall (Semi Transparent)</td>
<td>Solar insolation</td>
</tr>
<tr>
<td>Ground</td>
<td>Wall (Opaque)</td>
<td>-</td>
</tr>
<tr>
<td>Collector Inlet</td>
<td>Pressure inlet</td>
<td>P=0 pa</td>
</tr>
<tr>
<td>Chimney Outlet</td>
<td>Pressure Outlet</td>
<td>P=0 pa</td>
</tr>
</tbody>
</table>

4. Results and discussion

CFD results were first verified by comparing them with the reported experimental results of Manzanares prototype. In Manzanares prototype, on a typical day in June, air velocity of around 9 m/s and temperature rise of 17-19K were reported [14]. In computed CFD results, maximum air velocity of 9.1 m/s at the base of chimney and temperature rise
of 16K in collector were predicted, which are in accord with the experimental results and thus testify the numerical models adopted for predicting the performance of SCPP.

4.1. Velocity and pressure distribution

The distribution of velocity and pressure in SCPP along symmetrical plane are illustrated in fig.2 (a) and (b) respectively. It is observed that velocity of air increases slowly through the collector, but escalates sharply while reaching at the base of chimney. At chimney inlet air achieves its maximum speed of 9.1m/s and then decreases gradually. Likewise, static pressure drops abruptly near the chimney base varying in accordance with the velocity. So it can be concluded that chimney base is the most suitable location for turbine installation, because air velocity is maximum at this point.

4.2. Temperature Distribution

Fig.3 illustrates the temperature distribution in SCPP. It clearly exhibits that temperature of air rises beneath the collector due to incident solar radiations and then almost remains constant along the chimney, because almost negligible heat transfer takes place through the chimney’s walls. Temperature of ground is much higher near the centre of collector, heating up more air and reaches up to 318K. This higher temperature of ground is due to the greenhouse effect and higher specific heat of ground.

![Fig.2. (a) Velocity, (b) pressure distribution along symmetry](image)

![Fig.3. Temperature contours along symmetry & ground](image)
4.3. Effects of employing water filled bags and glass as chimney’s material

The effects of using water filled bags and glass as a chimney’s material on the velocity distribution are illustrated below in fig.4 (a) and (b) respectively.

It can be observed in fig.5 that utilization of water filled bags beneath the collector causes an increase in velocity magnitude from 9.1 to 9.5 m/s. One reason is that water has higher specific heat than natural ground and thus can store greater amount of heat. This stored heat is radiated to the air flowing above, raising its temperature. Consequently, rise in temperature causes a greater up-thirst of air increasing its velocity. Likewise, employing glass as a chimney’s material enhances the air velocity up to 9.8 m/s as depicted in fig.6. Commonly, chimney is made up of metal or plastic material. So if chimney is made up of glass, solar radiations can pass through it heating inside air and as a result higher velocities are achieved.

A comparison of temperature along the centerline in horizontal plane for original Manzanares plant, employing water filled bags and chimney made up of glass is presented in fig.5. It shows that in case when glass is used as a chimney’s material, temperature rises sharply to a remarkable value of 67°C near the inlet of chimney. This is due to the fact that when glass is being used as a chimney’s material, chimney also participates in heat transfer and thus temperature of air is enhanced. On the other hand in case when water filled bags are utilized, temperature rise is 2-3°C higher as compared to original Manzanares prototype plant due to greater heat storage capacity of water.

![Velocity distribution](image1.png)

![Temperature comparison](image2.png)
Finally, the electric power output for three different cases is evaluated in fig.6. It illustrates that in case when water filled bags are placed beneath the collector, the power output increases from 44.6kW to 46.6kW showing a percentage increase of about 4%. In second case when chimney is made from glass the electric power increases up to 48kW with a percentage increase of around 7%.

Conclusion

In this study a numerical investigation on solar chimney power plant was conducted by considering the geometrical parameters of the Manzanares prototype in ANSYS FLUENT. Solar radiations were included by using solar load model and RNG k-ε model was used to simulate turbulence effects. The numerical results were first compared with the reported experimental results and were found to be in good agreement. On the basis of robustness of numerical models, simulations were performed to study the effects of employing water filled bags and glass as a chimney’s material. It was observed that usage of water filled bags and chimney made up of glass enhances the overall performance of SCPP by 4% and 7% respectively.

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References


170. Development of Standalone Hybrid Solar Wind Power Generation Model for Remote Areas of Pakistan

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Abstract

Hybridization of renewable power sources need to be the current policy objective of any of the country. The circumstances under which the hybrid power system have been trendy due to rapidly changing in prices, depletion of fossil resources, environmental concerns and significantly its production would add to the congestion of grid networks. This research has developed the hybrid solar and wind power system for both proximate and geographically dispersed locations that might progress towards electricity sustainability. The two renewable sources have been integrated to utilize each source potential intermittent power generation capability along with the storage battery. The storage battery has dual mode characteristics provided with charge control from the respective sources and supply source as well. The monitoring and controlling system has been the core of the entire hybrid power system to maintain the system healthy. The hybrid system posed satisfactory operation of integration of two renewable sources and feeding the load with connected storage battery source. The proposed system is cost-effective and can be utilized in remote locations where the load center is isolated from the grid network. In future the proposed system would be integrated with the grid network for utilizing the utility supply during unavailability of power generation from the renewable sources.


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Keywords: Hybrid Power System; Renewable; Energy; Solar; Wind; Integration

1. Introduction

The rapid depletion and scarcity of fossil fuels around the world has made it compulsory to look for alternative energy sources that would balance the required demand. In addition, a large ratio of world’s population lives in rural or remote areas, which are somehow populated but isolated geographically. They have very low demand, due to which such regions are not integrated to the grid. In order to develop such areas, efficient and financially feasible methods are required to provide electricity to these areas. Hence renewable energy sources are well-suited for this task.

Renewable energy sources (solar and wind energy) have been estimated as clean, unlimited, inexhaustible and environmental friendly. Such characteristics of these sources have diverted the energy sectors to use of renewable energy resources on a larger scale. Since, all renewable technologies are having drawbacks. One of the rare drawbacks is their dependence on variable factors such as weather and climatic conditions. However, due to both sources’ interdependent nature, some of the problems can be compensated by overcoming the weaknesses of one source with the strengths of the other source.

Pakistan is one of the prosperous countries in the world that is enriched with many renewable energy sources. The country is facing many problems nowadays such as energy crisis and also the problem of extension of grids to remote rural areas. Thus alternative energy sources have been proposed as a solution to overcome these problems. In such a case HPS can be a much preferable solution. HPS is the latest technology which has been designed to overcome the reliability issue of renewable energy sources. It basically integrates two or more renewable technologies to produce power. Nowadays research work is being done on HPS in order to improve its efficiency, power quality, making it cost effective, and designing an optimal HPS model.
Number of authors has reported different techniques regarding HPS. Daniele et al. [1] simulated a micro-generation solar-wind hybrid system for street lighting. Mirza et al. [2] studied the scope of wind energy and proposed ideas for development of wind energy in Pakistan. Karim et al. [3] deduced the parameters and values used for optimally designing the HPS. He also used the weather data of Middle Eastern countries and depicted the interdependent relationship between solar and wind plant in these weather conditions. Maouedj et al. [4] presented description of system components and technical specification of hybrid solar-wind power system. Subodh et al. [5] designed optimal mathematical model of hybrid solar-wind power system to supply energy to a remote telecom station. Giuseppe et al. [6] studied the design problem of HPS and provided the optimal design using Fuzzy logics. Jiang et al. [7] developed multi-agent technology based hybrid energy system to improve the control system and reliability of the system. Pradhan et al. [8] performed a case study to evaluate the reliability of HPS in Nepal. Chaitanya et al. [9] presented a multi-input hybrid solar-wind energy system and also proposed dynamic modelling and simulation of the system using SIMULINK. Musa et al. [10] used MATLAB SIMULINK for feasibility study for a stand-alone hybrid power system for three small communities at Maiduguri. Weida et al. [11] discussed the power distribution strategy for HPS to operate the engine in the zone of best fuel economy through power regulation of battery.

2. Scope of energy in Pakistan

2.1. Conventional energy resources

Pakistan is naturally rewarded with large reserves of various conventional sources of energy, including fossil fuels such as oil, gas, and coal sources. These conventional energy sources are able to produce power at large scale to meet the energy demand of the country [12]. Thus a major portion of electricity in Pakistan is produced by using these conventional sources of energy. The potential of these conventional energy resources is shown in Table 1.

<table>
<thead>
<tr>
<th>Energy Resource</th>
<th>Potential Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectricity</td>
<td>46,000 MW identified potential AEDB</td>
</tr>
<tr>
<td>Coal</td>
<td>185 billion tons Pakistan year book 2009</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>326 million barrels reserves Pakistan year book 2009</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>26 Trillion cubic feet proved reserves Pakistan year book 2009</td>
</tr>
<tr>
<td>Uranium</td>
<td>236 tons for nuclear power generation since 1980 Pakistan year book 2009</td>
</tr>
</tbody>
</table>

2.2. Alternate energy resources

It is the high time for Pakistan to switch to sustainable renewable energy systems. The renewable energy resources are abundantly available in nature and have almost infinite life and are also eco-friendly resources, thus will help to reduce the environmental hazards of that caused by the electricity generation through fossil fuels [13]. However, switching over alternative energy resources this much quick is very hard but yet these sources are proved to be very cost effective for power generation in the remote rural areas, where there is no extension of grid. In present times the ratio of alternative energy in total energy mix is negligible. But according to Vision 2030, after 14 years this ratio of alternative energy in overall energy mix seems to rise up to 5% [12]. Thus active efforts are required from stakeholders to achieve this ratio of 5%. The renewable energy resources’ potential in Pakistan is given in Table 2.

<table>
<thead>
<tr>
<th>Energy Resource</th>
<th>Potential Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Energy</td>
<td>346,000 MW IEP 2009 and AEDB</td>
</tr>
<tr>
<td>Solar Energy</td>
<td>2.9 Million MW IEP 2009 and AEDB</td>
</tr>
<tr>
<td>Bio Gas</td>
<td>2.000 Million MW IEP 2009 and AEDB</td>
</tr>
<tr>
<td>Small Hydel</td>
<td>2.000 Million MW IEP 2009 and AEDB</td>
</tr>
</tbody>
</table>
Renewable energy is considerably an under-developing sector in Pakistan. However, in recent time, some interest has been shown by some environmentalist authorities and groups to utilize renewable energy resources for producing electrical power, in order to overcome the energy supply and demand gap and undesired power outages which are influencing the economy of the country. Thus, there is lot of scope of using alternative energy resources such as wind and solar in Pakistan.

3. Methodology

HPS is a combination of different electric power generators to produce power. Hybrid systems, as their name suggests, integrate two or more electricity generation sources together. Mostly renewable technologies like photovoltaic (PV) panels and wind turbine generators are used for making a HPS. The block diagram of the proposed HPS is shown in Fig 1. Each step of developing HPS is further described in following sections:

3.1. Solar power generator

For solar power generation, solar cells have been used. A solar cell is a photo-voltaic cell which is photo sensitive. When sunlight falls upon the cell, the electrons in N side gain enough energy to breakdown and become free electrons and start flow from N to P. If an external circuit is connected the electron starts to flow through it thus generating electric power. Different types of solar cells are available in the market. For example, Monocrystalline (18% efficiency), Polycrystalline (15% efficiency) and Thin film or amorphous (10% efficiency) as shown in Fig 2. Different parameters are considered for selecting solar panel for generating the electric power. For example, (i) Power rating: This parameter usually varies from 0.1 to 1.5 kW, (ii) Inclination angle: This ideally is considered as 15 to 20 degrees to capture most of the solar irradiance, (iii) Efficiency: This is defined as how efficiently the solar panel converts solar irradiance into electricity, (iv) Solar output: This is the amount of electric power produced by solar panel depends on the amount of the sun light falling on the panel, size of panel and efficiency of the solar cells inside and is expressed by Eq. (1)

\[ E = A \times r \times H \times PR \text{ kWh} \]  

---

### Table 4. Wind Power Generation Model Dimensions and Parameters

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type</td>
<td>HAWT</td>
</tr>
<tr>
<td>2</td>
<td>Material of blade</td>
<td>Fiber</td>
</tr>
<tr>
<td>3</td>
<td>Number of blades</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Length of blade</td>
<td>3 ft</td>
</tr>
<tr>
<td>5</td>
<td>Twist angle of blades</td>
<td>10°</td>
</tr>
<tr>
<td>6</td>
<td>Power rating of wind turbine generator</td>
<td>100 W (12V, 8.34A)</td>
</tr>
<tr>
<td>7</td>
<td>Shape of blade</td>
<td>As shown in Figure 3</td>
</tr>
</tbody>
</table>
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Fig. 2. Types of solar cells

Table 3. Solar power generation model dimensions and parameters

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>Type/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type</td>
<td>Polycrystalline</td>
</tr>
<tr>
<td>2</td>
<td>Inclination Angle</td>
<td>20º</td>
</tr>
<tr>
<td>3</td>
<td>Efficiency</td>
<td>21%</td>
</tr>
<tr>
<td>4</td>
<td>Power Rating</td>
<td>20W(12V, 1.7 A)</td>
</tr>
</tbody>
</table>

where $A$ is the area of solar panel in m$^2$, $r$ is the solar panel yield expressed in percentage. $H$ is the average solar radiation annually on tilted panels, $PR$ is the performance ratio (value lies between 0.5 and 0.9, default value = 0.75). For the proposed system, following dimensions and parameters are selected and are shown in Table 3.

3.2. Wind power generator

For producing wind power generator, a wind turbine is used. It is basically a rotatory part that converts the mechanical pressure of wind energy into the electricity. There are two types of wind turbines: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). The wind power output theoretically is defined as 0.59 times the kinetic energy of the air passing through the effective disk area. Thus the maximum theoretical power output of the wind turbine generator is given in Equation (2):

$$P = 0.5 \rho v^3 A \text{ Watts}$$

where $A$ is effective disk area in m$^2$, $v =$ wind velocity in m/s, $\rho =$ Air density in Kg/m$^3$. In designing and fabricating the wind turbine usually following factors are considered: (i) Material of blade: In early times wood and canvas sail were used and now Aluminum metals are used due to their light weight, (ii) Number of blades: Number of blades greatly affects aerodynamics efficiency, component cost and system reliability. The optimum number of slides for wind turbine is 3, (iii) Shape of blade: Blade shape also plays an important role in voltage production. Both the surface area of the blade and shape are important. In the proposed system, the blade shape used as shown in Fig 3 for wind generator model in order to get the desired voltage output. (iv) Length of blade: Longer the length of blade, more the power can be extracted, (v) Twist angle of blade: Typically the twist angle of rotor blades of a wind turbine generator is kept from 10º to 20º from root to tip. The parameters used for wind power generator model are given in Table 4.
3.3. Charge controller and status display system

A charge controller circuit has been used to control the flow of charges from both the power sources to the battery. Furthermore, an LCD has been used to display the status of system. The block diagram of charge controller and display system is shown in Figure 4.

3.4. Hybrid solar wind power system

After completing the wind turbine and solar power generator setup, the output of each power source is checked. After successful power generations from both the power sources, these are combined. While doing this process, the voltage of each power source is considered, this is because, if there will be mismatch in any parameter stated before in Table 3 and Table 4 above, the system may not work or even a part of whole system may damage.

3.5. Energy storage battery

A battery is used to store the power generated by the system. The solar panel generates the power in day time only, while the output of wind turbine generator is dependent on the availability of wind. Thus the power generated by the hybrid solar-wind power system need to be stored as a supply backup. The power of system can only be stored only if the energy supplied by the system is greater than energy required by battery to store electrical power. In the proposed system a battery of rating 12V Ah is used. The battery stores the power, provided the both sources are supplying power or either any one of source is supplying power. This battery is also used to supply the DC electrical loads connected to it. The battery will supply loads only if energy stored in battery is greater than the energy required to drive the load.

3.6. DC Electrical load

In order to consume the DC output of the proposed hybrid system, a DC electrical load (LED light, DC fan) is used.

Results and discussions

In order to design a prototype of hybrid solar wind power plant for very small scale around 120 watts, 20 watts solar panel and a 100 watts wind turbine generator were used. The solar panel of a rating of 20 watts was directly purchased from market. Considering geographical location, the solar cell of polycrystalline has been used. In order to harness the maximum possible solar energy from the Sun, the plate was set at an angle of 20°. The typical cell operating temperature of solar cell was 45°C. For wind power generation, a wind turbine of 100 watts was designed. The fiber was used as the material of blades because it is very light in weight and can start rotating at very small amount of wind speed. The length of the blade was set to 3 feet in order to get the desired voltage and power. The twist angle of blade was set

Fig. 4. Charge controller and status display system block diagram
at $10^\circ$. To setup hybrid system, it was necessary that the DC voltage produced by both the sources should be equal. To synchronize both the sources their output voltage was checked first. When it was noticed that output voltage produced by both sources is equal then both sources were integrated together. In order to prevent the flow of current from one source to another or from battery to any source diodes were applied to prevent unwanted flow of current.

After setting up the hybrid system successfully, it was tested and results were evaluated. For this purpose, the model was operated over the old administration building of the Mehran University campus and its performance was evaluated in the Campus during working hours from 8:00 to 18:00. The solar irradiation, wind speed, solar generation model output and wind generation model output was evaluated as a function of time. The variation in solar irradiance throughout the working hours from 8:00 to 18:00 is shown in Fig 5. The horizontal axis show the time with the interval of one hour while vertical axis shows the irradiance in W/m$^2$. It can easily be observed from the graph that irradiance increases hour by hour reaching to peak hours of solar irradiance i.e up to 3-00 pm, after then it decreases slowly as sun sets down.

The variation in wind speed throughout the working hours from 8:00 to 18:00 is shown in Fig 6. The horizontal axis shows the time interval with the step of one hour while vertical axis shows the wind speed in Kilometers per hour. The graph shows that wind speed is low in early morning hours while it goes up in the end evening hours due to cloudy season in end of August.

The variation in temperature throughout the working hours from 8:00 to 18:00 is shown in Fig 7. The horizontal axis show the time interval with the step of one hour while vertical axis shows the temperature in scale of degree Celsius. The graph shows that in morning hours the temperature remains between $25^\circ$C to $30^\circ$C. However, as time increases, the temperature also increases and it remains high up to the evening i.e 4-00 pm. After that temperature start to decrease as the sun goes to set down.

![Fig. 5. Hourly variation in solar irradiance](image)

![Fig. 6. Hourly variation in wind speed](image)
Fig 8 shows the variation in solar generation model output throughout the working hours from 8:00 to 18:00. The horizontal axis shows the time while vertical axis shows the power in Watt. The graph reveals that solar model output is low in morning hours, since the solar irradiance is low in these hours. However, it produces high power of about 19.8 Watt in peak hours of heat, i.e from 1-00 pm to 3-00 pm. The power generation becomes low in the evening hours as solar irradiance starts to decrease in the
Fig 9 shows the variation in wind generation model output throughout the working hours from 8:00 to 18:00. The horizontal axis show the time while vertical axis shows the power in Watt. The graph shows the zigzag behaviour of the output of the wind power generation model. In morning hours the wind pressure is low, thus power generation is low, however, it increases with increase in time and gives highest output in the evening hours from 5-00 to 6-00 pm when there is good pressure of air in the atmosphere. It also can be noted from the graph that there is fluctuation in the output due to increasing and decreasing pressure of air throughout the day.

The variation in Hybrid generation model output throughout the working hours from 8:00 to 18:00 is shown in Fig 10. The hybrid power is the sum of power generated by the both sources wind and solar and mathematically is expressed as under:

\[ P_{HYBRID} = P_{SOLAR} + P_{WIND} \]  

The horizontal axis show the time while vertical axis shows the power in Watts. As the graph shows the power output is low in the morning hours as both solar and wind generation models produce low power output in the morning hours, while power output is high of about 118 Watts in the midday and in evening as solar model produce high power output in the mid of the day while wind model produce high power output in the evening.

Finally, we have compared the output of the three power generation models: Solar, Wind and Hybrid throughout the working hours from 8:00 to 18:00. The bar graph shown in Fig 11, depicts that the Hybrid system produce total power output of about 120 Watts, in which 100 Watts are contributed by Solar system while 20 watts are contributed by Wind power generation model.
4. Conclusions

Electricity demand is increasing day by day with increasing population, which cannot be fulfilled by non-renewable energy sources alone as they are depleting day by day. In order to cope with this demand, there is need of warmly welcoming renewable energy sources such as solar and wind, as these sources are unlimited, and environmentally friendly. These are exceptional options but unpredictable due to the stochastic nature of their occurrence. The proposed HPS integrates two renewable energy sources like wind turbine and solar system. Solar and wind energy system is one of the most prominent sources of energy. The field of solar–wind has experienced a remarkable growth for past two decades in its widespread use of standalone to utility interactive solar–wind systems. Solar and wind energy system works normally in standalone and equally operate on grid connected mode, but the efficiency of these sources is less due to the stochastic nature of solar and wind resources. The hybrid renewable energy sources with grid integration overcome this drawback of being unpredictable in nature. Thus it is more convenient to use hybrid-solar wind power system as it is more efficient and reliable and also ensures continuity of supply. The rural areas of Pakistan possess great potential of renewable energy resources (Sun and wind). Hence a stand-alone hybrid solar-wind power system can be a useful solution for producing electrical power in such regions. The proposed system can be used as stand-alone system at various off-shore-on-shore regions.

Acknowledgment

The authors are grateful to USPCAS – E Peshawar for project grant (USPCAS-E ARG-Dec15-042) to carry out the research. They would also like to acknowledge Mehran UET Jamshoro & UET Peshawar for joint carrying of the project.

References

[13] www.newspakistan.pk/2012/02/18/alternate-energy-sources
174. Study of Incremental Conductance Maximum Power Point Technique under Non-Uniform Solar Irradiations Conditions for Solar PV system


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E-mail address: zaibkamboh123@gmail.com

Abstract
To meet the increasing demand of power, there is rapid rise in the development and utilization of renewable energy resources, particularly energy scavenging from solar irradiations. In the recent years energy scavenging from sun has been receiving considerable attention due to versatile advantages. The advantages by the photovoltaic (PV) system when put to use for energy conversion include low maintenance cost, noiseless operation, no limitations, economical friendly and pollution free energy. PV is considered as one of the most important renewable energy sources, since solar energy is inexhaustible, free and clean. In this paper we will be focusing on the maximum output power utilization of PV array, by using incremental conductance (INC) MPPT method, which is commonly used methods to get the optimum efficiency from PV system under non-uniform solar irradiations. MPPT’s are used to maximize the output of PV arrays, by tracking MPP. MATLAB software is used for simulation and Microsoft Visio for diagramming and flow charts. In this paper we will investigate output voltage and power variations of INC MPPT technique at different duty cycles (ʎ) under non-uniform solar irradiations. Which will help in selecting the appropriate MPPT technique and its merits and demerits on solar PV array applications for future developments.

Keywords: “MPPT, Solar PV System Control”.

1. Introduction:
Power crisis are becoming extensive and more severe in today’s era. Because depletion of conventional fossil fuels, which unlimitedly used in power and transportation system. From the last few decades considerable efforts have been made to utilize renewable energy sources (REs) in to conventional power generation system to reduce the rapid diminution of fossil fuels and environmental pollution. Solar energy is one of the abundantly available sources of renewable energy which can be one of the main source of future power generation system in standalone and grid connected for domestic, commercial and industrial applications [1]. Due to its flexibility and adaptability in grid connected or standalone mode, photovoltaic has attracted extensive attention of PV system manufacturers and researcher for its maximum utilization and optimization. Technically there are two ways to improve the effectiveness and optimization of solar PV system, either it could be possible to develop low cost high efficiency solar conversion materials or to control the PV system at maximum power point (MPP) for getting best possible output power. Because of the high cost of solar cells, it is
necessary to operate the PV array at the maximum operating point. Therefore maximum power Point tracking (MPPT) is considered as an essential part of PV generation system and is one of the key issue for researchers to reduce the effects of nonlinear characteristics of PV array [2]. So far different maximum power point algorithms have been proposed for optimization of PV output power, such as Incremental Conductance (INC) [3, 4], Perturb & Observe (P&O) [5-7], Hill Climbing [8, 9], Fuzzy Logic Control (FLC), Neural Network (NN) and Genetic Algorithm (GA) [10-12].

Among all the aforementioned MPPT algorithms, incremental conductance (INC) and perturb & observe (P&O) are commonly used for small and large scale PV power plants because both the algorithms operates in accordance with power against voltage (P-V) curve of PV module and tune the duty cycle of converter to ensure the next MPP point accordingly. In this paper we will be investigating the INC MPPT method under non-uniform solar irradiance conditions with different duty cycles (6) to investigate its output voltage stability and power variations. PV array system configuration with MPPT and DC-DC boost converter is depicted in Fig.-1.

![Fig.1. PV System Configuration with MPPT](image)

2. **PV Module Modelling**

PV generation system are defined as voltage (V) or current (I) source. Practically solar cell is a hybrid behaviour device which can either be V or I source. Because of nonlinearity of environmental conditions PV module has non-linear characteristic. For PV system applications, it is important to model it according to the design requirements of MPPT. In this paper, 36W PV panel is taken as reference, and the required solar cell model is developed in MATLAB/SIMULINK by following the equation-1 to 4. Whereas, PV module electrical data sheet is given in table-1 [13].

\[
I_{ph} = I_{SC} + K_I(T - 298) \times \frac{1}{1000}
\]

\[
I_{rs} = \frac{I_{SC}}{\exp\left(\frac{qV_{OC}}{N_{p}kT}\right) - 1}
\]

\[
l_{oc} = l_{rs}\left(\frac{T}{T_{oc}}\right)^{3\exp}\left[q \times \frac{E_g}{k}\left(\frac{1}{T_{oc}} - \frac{1}{T}\right)\right]
\]

\[
l_{pv} = N_p \times l_{ph} - N_p \times l_{oc} \times \exp\left\{\frac{[q(V_{pv} + I_{pv}R_s)]}{N_{p}kT}\right\} - 1
\]

According to the data sheet specification of solar panel as given in table-1. 3 KW PV system is simulated where, in one PV panel number of parallel solar cell (Np=1), numbers of solar cell in series
(Ns=36) and PV output voltage V_{PV} are equal to open circuit voltage V_{OC} of PV panel.

### Table-1: Solar 36W PV Module Electrical Data Characteristic

<table>
<thead>
<tr>
<th>Description</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power (MP)</td>
<td>37.08 W</td>
</tr>
<tr>
<td>Voltage at (MP)</td>
<td>16.56 V</td>
</tr>
<tr>
<td>Current at (MP)</td>
<td>2.25 A</td>
</tr>
<tr>
<td>Open Circuit Voltage (V_{OC})</td>
<td>21.24 V</td>
</tr>
<tr>
<td>Short Circuit Current (I_{SC})</td>
<td>2.55 A</td>
</tr>
<tr>
<td>Total Number of Cell in Series (Ns)</td>
<td>36</td>
</tr>
<tr>
<td>Total Number of Cell in Parallel (Np)</td>
<td>1</td>
</tr>
</tbody>
</table>

3. **Incremental Conductance MPPT Method.**

The conventional incremental conductance method is driven by following the equation (6) to find the slope of P-V curve. In equation 6 it determines that the operating point of PV module is at its MPP level as can seen in Fig 2. Whereas, reference to equations (7) & (8) are operating at left and right side of P-V curve to achieve the MPP accordingly by increasing and decreasing duty cycle of INC controller algorithm methodology as shown in table-2 and in Fig. 3 its flow chart is given [14, 15].

\[
\frac{dl}{dv} = - \frac{l}{v} \quad \text{(6)}
\]

\[
\frac{dl}{dv} > - \frac{l}{v} \quad \text{(7)}
\]

\[
\frac{dl}{dv} < - \frac{l}{v} \quad \text{(8)}
\]

![Fig. 2. Incremental Conductance MPP Curve](image)

**Table-2. Incremental Conductance Algorithm Methodology[16]**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mode</th>
<th>MPP Level</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode-1</td>
<td>( \frac{dP}{dV} = 0 )</td>
<td>At MPP</td>
<td>Hold ( V_{PV} = V_{MPP} ).</td>
</tr>
<tr>
<td>Mode-2</td>
<td>( \frac{dP}{dV} &gt; 0 )</td>
<td>Left side of MPP</td>
<td>Increase Voltage till ( V_{OC} = V_{MPP} ).</td>
</tr>
<tr>
<td>Mode-2</td>
<td>( \frac{dP}{dV} &lt; 0 )</td>
<td>Right side of MPP</td>
<td>Decrease Voltage till ( V_{OC} = V_{MPP} ).</td>
</tr>
</tbody>
</table>
The scheme of (6), (7) & (8) is that the slope of P-V curve at MPP is equal to zero as described in (9).

$$\frac{dP}{dV} = 0 \quad (9)$$

Therefore, (9) can be rewritten as

$$\frac{dP}{dV} = \frac{d(i \cdot V)}{dV} = V \cdot \frac{dl}{dV} + I \cdot \frac{dV}{dV} \quad (10)$$

$$\frac{dP}{dV} = V \cdot \frac{dl}{dV} + I \quad (11)$$

Which implies that

$$\frac{dl}{dV} + \frac{I}{V} = 0 \quad (12)$$

However, in INC the slope of PV curve determines by varying the converter duty cycle in fixed or variable step size until the MPP is achieved. The larger step size helps to reduce the MPP tracking time but not get rid of the oscillation around MPP [17], the smaller step size reduces the oscillation under rapidly changing solar irradiance conditions with greater efficiency but due to smaller step size and complicated algorithm speed is slow [4, 18].

4. Simulation Results and Discussions.

To investigate the performance of incremental conductance MPPT method under non-uniform solar irradiance at different duty cycles. A MATLAB Simulink model was developed as shown in Fig. 4, which consist of the PV array, a DC-DC boost converter and incremental conductance MPPT controller technique.
Furthermore, to investigate the effectiveness of the incremental conductance MPPT method at different duty cycles at $\Delta d = 0.001$, $0.005$ and $0.01$. The output voltage results in Fig-5 (A, B and C) in magenta colour and output power in Fig -6 (A, B and C) in green colour clearly illustrates that performance of the INC MPPT.

It can be observe in Figs. 5 (A, B & C) as $\Delta d$ is increases from 0.001 to 0.01, INC's output voltage decreases from the range of (385-407) volts to (374-397) where the upper limit decreases to 10 volts and the lower limit went down to 11 volts.

In the same way, in Fig. 6 (A, B & C) output power of INC at $\Delta d = 0.001$, INC's output power is between (2775-3100) watts, and at $\Delta d=0.01$ INC's output power is (2625-2955).

Furthermore, table-3 surmises the measurement output voltage and power of INC at duty cycle $\Delta d=0.001$, $0.005$ and $0.01$ in order to verify the repeatability of the results. It can be seen that smaller $\Delta d$ reduces the steady-state losses caused by the oscillation of the PV operating point around the MPP, but it makes the algorithm slower and less efficient in the case of rapidly change in solar irradiations and larger step size contributes to faster dynamics but excessive steady state oscillations, resulting in a comparatively low efficiency as it can easily be seen in Figs. 5 & 6.
5. Conclusion

This paper presents a study analysis of incremental conductance method with different duty cycles (Δd) under non-uniform solar irradiations in MATLAB/Simulink. Simulation results reveals smaller Δd decreases the steady-state losses caused by the oscillation around the MPP and the larger the step size tends to faster dynamics but produces unnecessary steady state oscillations. Resulting in a comparatively low efficiency. Considering the best possible rapport of incremental conductance simulation at 0.001 step change response of Δd obtained maximum power from PV system.

References


182. Comparative Engine Performance Analysis using Diesel fuel and Biodiesel derived from Waste cooking Oil.

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Abstract

"Biofuels have been neglected by government policies and have not been given importance since long time. It ensures energy security through partially replacing by imported fuels. Biodiesel is mostly produced from oil-seed feed stock through transesterification process. Biodiesel can be effectively used in diesel engine without any engine modification. It has most of the properties very close to diesel fuel. Use of waste cooking oil in diesel engines is more sustainable if they can perform with similar properties as compared to petroleum diesel fuel. In this research paper, engine performance during endurance test has been analyzed using petroleum diesel (DF) as baseline and biodiesel blended fuel B20 (20\% waste cooking oil biodiesel and 80\% diesel fuel). However, an endurance test was carried out for 50 hours at constant speed of 1300 rpm and varied load conditions (0.1 Kg-m to 2.0 Kg-m) in a single cylinder four stroke compression ignition engine. During analysis, brake specific fuel consumption (BSFC) was increased by 8.16\% to 16.66\% with an average of 13.79\% for B20 as compared to DF, and brake thermal efficiency (BTE) was decreased by 5.17\% to 12.12\% with an average of 9.65\% for biodiesel blend B20 as compared to DF. Moreover, analysis of some fuel properties of DF and B20 has also been discussed in this research paper”


Keywords: Waste Cooking Oil Biodiesel; Engine Performance; Fuel Properties.

1. Introduction

Since industrial revolution many forms of energy have become part of life of human being. Secondly increase in population directly proportional to energy demand. Fossil fuels, petroleum based liquid fuels, natural gas have been got importance to fulfil our energy demand. However they are non-renewable, so these fossil fuels should be exhausted in the near future [1]. This situation has occurred adverse effect with rapid increase in energy demand with significant worldwide population growth. At present the uncertainties concerning adequate and stable supply of petroleum products have renewed interest in renewable energy source. Therefore the demand for clean, reliable and economically feasible renewable energy source was needed [2]. Edible and nonedible oils are renewable energy source can be used as diesel fuel. Vegetable oil, edible oil and nonedible oil have most of the properties very close to diesel fuel [3]. However direct use of vegetable oil in diesel engine leads to problems of gum formation and smoky exhaust due to incomplete combustion [4]. It is suggested to produce biodiesel from using waste edible oil due to its low cost, disposable problems and potential contamination [5]. Biodiesel is environment friendly, non-toxic and reduces atmospheric pollution level. Biodiesel blends can be used in compression ignition diesel engine without any modification in engine parts. However its 100\% use in diesel engine requires some modification [6]. Biodiesel has following advantages, carbon neutrality, potential for sustainable production, positive contribution to the energy self-sufficiency rate and prevention of air pollution [7].

Recent studies have been conducted on the physical, chemical properties and engine performance characteristics of biodiesel derived from waste cooking oil. Mofijur et al [8], studied the properties, performance of 5\% and 10\% palm and Moringa oleifera biodiesel blends (PB5, PB10, MB5,MB10) in a multi cylinder diesel engine at various engine speeds, PB5, MB5, PB10 and MB10 produced 1.38\%, 2.27\%,3.16\% and 4.22\% lower brake power and 0.69\%, 2.56\%,2.02\%, and 5.13\% higher BSFC, respectively than diesel fuel. Liaquat et al [9], investigated the effects of Palm oil biodiesel PB20 and
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diesel fuel during an endurance test, he found 3.88% higher BSFC, 11.7% lower BTE as compared to diesel fuel. Ndayishimiye and Tazerout [10], studied engine performance characteristics of palm oil biodiesel in a diesel engine and found that a high percentage of palm oil biodiesel blended with diesel fuel decreases the heating value, while increases brake thermal efficiency. In other study, Liaquat et al [11], worked on 5% and 15% blends of coconut biodiesel in a single cylinder diesel engine. A torque reduction was 0.69% and 2.58%, power reduction was 0.66% and 2.61% and higher BSFC were found 0.53% and 2.11% for 5% and 15% blended palm oil biodiesel respectively. How et al, [12] studied the effect of 10%, 30% and 50% blends of coconut biodiesel on performance in a multi cylinder diesel engine. They observed 0.4-20% higher BSFC than diesel fuel at different throttle settings. Sanjid et al, [13] evaluated the production, physiochemical properties, engine performance of jatropha, palm and combination of palm and jatropha biodiesel in a (PJB5 and PBJB10) in an unmodified diesel engine at engine speed from 1400 rpm to 2200rpm. PBJB5 and PJB10 biodiesel showed 7.55% and 19.82% higher BSFC, slightly lower Brake Power.

1.1 Economic features of Biodiesel

Pakistan is a country in acute shortage of energy. Pakistan can only progress by controlling energy shortage in swift and innovative fashion. One of the steps towards such solution is usage of Biodiesel. As discussed in earlier Biodiesel is an option which can not only be helpful in solution of the shortage of energy issue, but simultaneously can contribute heavily into the GDP of Pakistan. As the saying goes, every rupee saved is as good as rupee earned. In this section we are discussing in detail the amount of saving made in case use of biodiesel blend with Petroleum Diesel. B20 waste cooking oil biodiesel (20% waste cooking oil biodiesel and 80% Petroleum diesel) is used in single cylinder four stroke compression ignition diesel engine. The said research suggests that Biodiesel can be used in mixture with petroleum products up to 20% without any modification in the internal structure of engine. It may be noted that this use of biodiesel increasing in foreign countries. However, ratio of blend may be increased up to 40% without modification in engine parts. If the needful modification in the engine is made, the proportion of biodiesel blend in Petroleum Diesel fuel can be increased up to 100%, without compromising on engine efficiency. The cost of production of biodiesel is considerably lower than that of petroleum products; hence it will be a significant contribution to the national exchequer if its petroleum bill is reduced by a minimum of 20% (If we use 20% biodiesel with petroleum Diesel). Brief working of said calculation shows that total consumption of petroleum products was 18.68 MTOE out of 40.03 MTOE. (Pakistan Energy Yearbook 2012). However, the use of Petroleum Diesel in diesel engine is mainly in only two sectors i.e. Transport and Power sector, which consume about 90% of total petroleum products in combine, which accounts to almost 16.812 million tonnes. By using Biodiesel blend in diesel engine, if we reduce the consumption of the said energy by 20% in case of use of biodiesel up to 20% blend without modification in engine. Total consumption reduced by 20% which reduce our annual petroleum bills by 20%. Total petroleum consumption of 18.86 MTOE by 3.736 MTOE million tonnes could be saved. This lesser consumption of petroleum products will result in direct saving of Rs 315.638 Billion to GDP of Pakistan. As a matter of fact, if we can indulge in the exercise use of biodiesel which can be produced locally by planting non edible plants, like, Jatropha, moringa, etc, we can save our economy up to 20% of petroleum bills.

1.2 Biodiesel Properties

The ASTM D6751 and The European Union EN 14214 provide methods of biodiesel testing standards. The properties standards limitation of pure biodiesel B100 and biodiesel blend with diesel fuel are given in ASTM D6751. In this standard gives the quality level of biodiesel, whereas European Union EN 14214 gives the results of minimum fatty acid methyl ester. Limitation of ASTM D6751 and EN 14214 biodiesel properties are given in Table 4.1[14-16].
Table 1 Biodiesel Properties Standards ASTM D6751 and EN 12214

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>UNITS</th>
<th>TEST METHODS</th>
<th>ASTM D6751</th>
<th>EN 12214</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic Viscosity at 40°C</td>
<td>mm²/s</td>
<td>D445</td>
<td>EN ISO 3104</td>
<td>1.9-6.0</td>
</tr>
<tr>
<td>Density at 15°C</td>
<td>Kg/m³</td>
<td>D1298</td>
<td>EN ISO 3675</td>
<td>880</td>
</tr>
<tr>
<td>Calorific Value</td>
<td>MJ/Kg</td>
<td>EN 14214</td>
<td>45.54</td>
<td>35</td>
</tr>
<tr>
<td>Flash Point</td>
<td>°C</td>
<td>D93</td>
<td>ISO DIS 3679</td>
<td>Min 100-170</td>
</tr>
<tr>
<td>Pour Point</td>
<td>°C</td>
<td>D97</td>
<td>-</td>
<td>-15 to 16</td>
</tr>
<tr>
<td>Cloud Point</td>
<td>°C</td>
<td>D2500</td>
<td>-</td>
<td>-3 to 12</td>
</tr>
<tr>
<td>Oxidation Stability</td>
<td></td>
<td>D675</td>
<td>EN 14112</td>
<td>Min 3</td>
</tr>
<tr>
<td>Cetane Number</td>
<td></td>
<td>D613</td>
<td>EN ISO 5265</td>
<td>Min 47</td>
</tr>
<tr>
<td>Acid Value</td>
<td>Mg KOH/g</td>
<td>D664</td>
<td>EN 14104</td>
<td>Max 0.5</td>
</tr>
<tr>
<td>Water Content</td>
<td>%V</td>
<td>D2709</td>
<td>EN ISO 12937</td>
<td>Max 0.05</td>
</tr>
<tr>
<td>Canradsons Carbon</td>
<td>m/m</td>
<td>D4530</td>
<td>EN ISO 10370</td>
<td>Max 0.05</td>
</tr>
</tbody>
</table>

2. Materials and Method

In this section research methodology for achieving the objectives of the study has been discussed. Overall two fuels samples were tested in compression ignition diesel engine. In connection different parameters have been discussed like, fuel properties, engine performance, brake specific fuel consumption and brake thermal efficiency in compression ignition engine.

Engine performance tests have been carried out at Mechanical Engineering laboratories, Quaid-e-Awam University of Engineering, Science and Technology Nawabshah. For this purpose a single cylinder horizontal type water cooled four stroke diesel engine is used for calculating the performance parameters. The model type of the test bed is DWE-6/10-JS-DV. This is fully equipped with different instrumentations like fuel flow meter, tachometer, dynamometer, and thermocouples etc. which are helpful for collecting data from the engine. Details of engine specification are given in table 2.1

Two fuel tanks are attached to a diesel engine test bed. Both fuel tanks connected with common line; however flow can be controlled with two separate valves. One tank is filled with Petroleum diesel (D100) and other is filled with B20 Biodiesel (20% waste cooking oil Biodiesel and 80% Petroleum Diesel). An endurance test was carried out for 50 hours at constant speed and varying load conditions. As concerned with the Performance of the engine, engine Torque, Brake Power, Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE) were analysed. The varying load is changed from 0.1 Kg-m to 2.0 Kg-m at the constant speed of 1300 rpm. Waste cooking oil biodiesel was collected from Syntech Biofuels Private Limited, SITE Area Hyderabad. Engine performance can be calculating by using following basic internal combustion engine equations:

\[ BP = \frac{2\pi NT}{60} \]  

\[ BSFC = \frac{\dot{m}}{BP} \]

\[ BTE = \frac{3600}{BSFC} \times HHV \times 100\% \]

Where N is the engine speed in rpm, \( \dot{m} \) is the fuel flow in g/h, and HHV is the higher heating value of fuel in MJ/Kg.
3. Results and Discussion

In this research work an endurance test was carried out on two different fuel samples. One Petroleum Diesel D100 and secondly B20 Waste cooking oil biodiesel tested in single cylinder CI diesel engine. Endurance test was carried out for 50 hours on each fuel samples. In which engine performance parameters observed at various load condition and at various engine speeds. Engine Power, Engine Torque, Specific fuel consumption, Brake thermal efficiency was observed.

3.1 Fuel Properties

Fuel properties of waste cooking oil biodiesel are very close to Petroleum Diesel. For example kinematic viscosity of B20 Biodiesel is 3.61 mm$^2$/s, whereas kinematic viscosity of Petroleum Diesel is 2.91 mm$^2$/s. Density of Biodiesel is 880 Kg/m$^3$, whereas density of Petroleum diesel is 839 Kg/m$^3$. The biodiesel has higher density than diesel fuel, due to its affected property on compression [21]. The higher density
also effect fuel atomization. Higher density leads poor atomization and lean combustion which increase the engine temperature [22-23]. Further more detailed properties of B20 Biodiesel are given in Table 3.1.

Table 3.1 Properties of Prepared Biodiesel samples.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>Biodiesel B20</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic Viscosity @ 40°C( mm²/s or cSt)</td>
<td>2.5-5.7</td>
<td>3.61</td>
<td>(1.9-6.0) ASTM D445</td>
</tr>
<tr>
<td>Density Kg/m³</td>
<td>816-840</td>
<td>880</td>
<td>(860-900) ASTM D127</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>45-55</td>
<td>48</td>
<td>(45-55) ASTM D6890</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>50-98</td>
<td>110</td>
<td>(100-170) ASTM D93</td>
</tr>
<tr>
<td>Fire Point (°C)</td>
<td>112</td>
<td>121</td>
<td>(120-140) ASTM D93</td>
</tr>
<tr>
<td>Calorific Value MJ/Kg</td>
<td>45.9</td>
<td>43.78</td>
<td>(45.54) ASTM D240</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.835</td>
<td>0.846</td>
<td>ASTM D891</td>
</tr>
</tbody>
</table>

Fig.3.1 Properties of Diesel Fuel, Biodiesel B20 and Standards of Biodiesel

3.2 Engine Performance Analysis

The engine performance tests were carried on a single cylinder four stroke compression ignition diesel engine. The horizontal type water cooled diesel engine was mounted on the structure of the test bed. On the same structure dynamometer has also mounted which is also directly coupled with a diesel engine. It can control the brake load on the engine. The dynamometer controlled is attached to the panel of the test bed. In this work two different fuel samples were tested firstly Petroleum Diesel D100 and B20 Waste Cooking oil Biodiesel (include 20% Waste Cooking oil Biodiesel and 80% Petroleum Diesel blended). The engine performance parameters have been calculated on variable load and at constant speed 1300 RPM. The applied load on CI diesel engine is divided into 10 different point ranges from 0.1 Kg-m to 2.0 Kg-m. The performance parameters measured during the research work are, brake power, Torque, brake specific fuel consumption, brake thermal efficiency and mass flow rate. Two fuel tanks have been connected with a common single line separated with control valve attached with diesel engine. One tank is filled with diesel fuel, whereas other tank is filled with biodiesel blended fuel.
3.2.1 Brake Specific Fuel Consumption (BSFC)

The brake specific fuel consumption (BSFC) is a function of diesel engine at test bed. The variation in brake specific fuel consumption of a compression ignition engine is depends on engine speed, applied load and blending ratios of biodiesel blend. In this research work brake specific fuel consumption was analysed with three different cases. BSFC is firstly compared with engine torque, Brake Power and Engine Speed. It is observed that BSFC graph line firstly slightly decreased then goes in straight line in all three cases. BSFC is increased by 7.56% to 14.28% using biodiesel B20 as compared to Petroleum Diesel D100 with an average of 11.93% increase in BSFC using Biodiesel as compared to Petroleum Diesel.

The BSFC is an engine performance parameter that reflects how good engine is performing. The brake specific fuel consumption of an engine expressed in terms of Kg/Kwh. The BSFC values of Cooking oil Biodiesel is greater than Diesel fuel, it is just because of higher contents of oxygen in the fuel which results lower heating value. The lower density and lower heating value of the fuel requires higher mass flow rate for the same energy output from the engine.
3.2.2 Brake Thermal Efficiency (BTE)

Brake thermal efficiency is defined as brake power of CI engine as a part of heat supplied by the fuel. Brake thermal efficiency is used to determine the energy is extracted from fuel to convert into mechanical energy.

It has been observed that by using waste cooking oil biodiesel in CI diesel engine, the mass flow rate also increases which affect brake thermal efficiency. In this research work variation in BTE is observed in three different cases. Firstly BTE relationship with Engine Torque, Brake Power and Engine Speed. BTE is slightly increased up to 40% it is directly proportional with Torque and Brake Power, and then goes down with increase in Power and Torque. Brake thermal efficiency is decreased by 5.53% to 13.72% while using Biodiesel B20 as compared to Petroleum Diesel D100, with an average of 10.75% decreases BTE using biodiesel as compared to Petroleum Diesel. It is due to the reason of increment in percentage of oxygen contents which helps to improve the combustion process therefore due to a higher percentage of oxygen content it may produce faster combustion process.
4. Conclusion and Recommendations

In this study, the effects of Diesel fuel as a baseline and the B20 Waste cooking oil biodiesel blend on performance of single cylinder four stroke diesel engine was analysed during short term endurance test. Following conclusion were drawn from present investigation:

1. Waste cooking oil biodiesel blended fuel has very close physical and chemical properties to that of Diesel fuel.
2. During varying load from 0.1 to 2.0Kg-m and at constant speed 1300rpm, BSFC was increased by 8.16% to 16.66%, while using B20 biodiesel as compared to diesel fuel.
3. At same condition BTE were decreased by 5.17% to 12.12% as compared to diesel fuel.
4. During varying load from 0.1 to 1.9 Kg-m and with varying speed from 1300 to 2200 rpm, BSFC is increased by an average of 13.78%, while using B20 biodiesel as compared to Diesel fuel.
5. At varying load and varying speed BTE is decreased by an average of 9.8% as compared to diesel fuel.

For the future work it is recommended that unregulated exhaust emissions may be determined. As concerned about suggestion, Government should take steps to enhance for production of non-edible seeds for usage of biodiesel. Government should announce packages for growers and should purchase seeds from them. Chemical plants should be installed for tests of oils and for transesterification process. Also Government inform public through print media and social media for encouraging farmers to grow seeds for biodiesel purpose.
Acknowledgement:
The authors acknowledge the support extended by the Directorate of Post Graduate Studies, Mehran University of Engineering & Technology Jamshoro, and Mechanical Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah.

References:


183. Study to Investigate the Effect of Temperature on Performance of Thermotolerant Klueromyces Marxianus during the Production of Ethanol Using Numerical Simulation

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Abstract

Production of ethanol from renewable sources gives a new area of research for future fuel requirements. During fermentation reaction, heat generated can create problems and ultimately decrease microbial growth. In Pakistan, temperature ranges from 40-50°C in the summer season, during which production of ethanol is affected by temperature due to the use of yeast that grows in temperature ranges up to 29-36°C. Regarding this thermotolerant yeast, it is best for these environmental conditions. Temperature effects were investigated using numerical techniques with the help of C++ software. Experimental and model results also compared; the optimized experimental results were found at 45-50°C, with ethanol production reaching a maximum of 74 g/l. However, for numerical study, the best results at higher temperature ranges 45-50°C are about 76 g/l. Thermotolerant yeast has advantages that can be used in hot environmental conditions.

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Keywords: Thermotolerant Klueromyces Marxianus, ethanol, temperature, numerical simulation, RK order 4.

1. Introduction

Pakistan's level among other countries is 7th regarding sugarcane, ethanol production through fermentation is one of the well-identified techniques. Numerical techniques have been used to solve various differential equations that could affect ethanol production. During the process of fermentation, exothermic reactions occur that generate heat. Temperature effects on ethanol production were investigated using mathematical models. Fermentation processes done by different microorganisms but mostly used microorganisms are nothing but Saccharomyces cerevisiae. Molasses were used as feedstock, and Saccharomyces cerevisiae were used as biocatalyst to carry out fermentation [1]. During the process of bioethanol from native microorganisms, temperature effects had considered regarding growth of microorganisms. Models were prepared that express one factor which utilizes to sort out multiple growth of microorganisms [2]. Sanchez et al. discussed the temperature dependency that affects production of ethanol and xylitol kinetic parameter [3]. For explaining denaturation of ribosomes and enzymes explained through linear models. A were developed [4] an empirical linear model were developed for describing the temperature & nutritional effect on ethanol production through fermentation [5]. It had been well-known that microorganism activity could affect environmental conditions. Apart from this, fermentation processes are also victims of these environmental conditions that change the phenomena of process. Fermentation environmental conditions which couple with mass transfer and metabolic behavior of microorganisms that utilize to convert substrate into product. To gain insight into the morphology-associated time-variant process dynamics, various kinetic models associated with key parameters for ethanol fermentation have been proposed [6-16]. This work is related to the effect of temperature on ethanol production using numerical techniques.

2. Methodology

Experimental data were collected from Aziz 2009, different temperature ranges were used to see the effect on...
ethanol production by applying numerical method. Monod model equations were used to investigate the temperature effect on ethanol production. Figure 01 shows the successive steps for development procedure to carry out numerical simulation. Numerical simulation were done on the basis of numerical method (RK Ode4) using C++ programming as tool. Results were compared and analyzed by doing comparison between simulations with experimental results.

![Image of flow chart](image.png)

**Figure 1. Flow Chart for Numerical Simulation of Ethanol Production**

### 3. Model

Monod kinetic model were used to investigate the temperature effect on ethanol production. For cell growth, substrate utilization and ethanol production

\[
\frac{dx}{dt} = \mu_{max} \left( \frac{S}{k_{xx} + S} \right) x
\]

\[
\frac{dP}{dt} = q_{max} \left( \frac{S}{k_{xp} + S} \right) x
\]

\[
\frac{dS}{dt} = - \left( \frac{1}{Y_{x/s}} \frac{dx}{dt} \right) - \left( \frac{1}{Y_{P}} \frac{dP}{dt} \right)
\]

Where \( \mu_{max} \) = maximum cell growth, \( X \) = cell growth, \( S \) = substrate utilization, \( k_{xx} \) = half saturation constant, \( q_{max} \) = maximum specific growth, \( Y_{x/s} \) = yeild coefficient cell.

### 4. Results And Discussion

Experimental Results were analyzed with simulation tool C++ with to see the effects of temperature on ethanol production. Temperature ranges from 30-50 °C under study to observe effect on cell mass (g/l), Substrate (g/l) and Production of ethanol (g/l). Monod kinetic model were utilized to investigate the temperature effect on ethanol production.
4.1 Effect of temperature on Cell Mass (g/l)

During microbial growth in fermentation process effect by varying temperature because microorganism did not survive with unsatisfactory environment. Regarding this study was made to optimize the temperature ranges for cell growth, using simulation tool for solving model proposed by researcher for temperature effect. By keeping other process parameter under optimized conditions. The maximum cell growth occur at 40°C about 7.8g/l and minimum at 55°C during fermentation.

![Cell mass at different temperatures](image1)

Fig. 2. Cell mass at temperature ranges from 20-55°C

4.2 Effect of temperature on substrate utilization

Numerical simulation were using Monod model at different temp ranges to investigate the maximum utilization of substrate for alcohol production. Because when substrate utilize increase alcohol production increases. Temperature ranges from 25-55°C step size of 5°C were used to observe the maximum substrate utilization for alcohol production from molasses. Monod model give a best results at temperature 45°C for maximum utilization of substrate.

![Substrate utilization at different temperatures](image2)

Fig. 3. Substrate at temperature ranges from 20-55°C
4.3 Effect of temperature on ethanol production

Study was made on different temp ranges to investigate the temp at which maximum alcohol production occur, Monod model were used in this study using C++ programming for ethanol production from different temperature. The maximum ethanol production were occur at 33 °C. At this temp numerical simulation gave ethanol production about 76g/l, and for experimental results also gave 76g/l. the minimum ethanol production occur at 20-25 °C for numerical results.

![Ethanol production at different temperatures](image)

Fig. 4. Ethanol production at temperature ranges from 20-55 °C

5. Conclusion

Study was made for carryout temperature effect on ethanol production from molasses, it was found through experimental and numerical study that temperature had effect on ethanol production due to microbe use to carryout fermentation process. Cell growth, substrate utilization and ethanol production were made to study the effect of temp on it. It was found that by utilizing temperature 33–40°c give maximum cell growth 10g/l, maximum substrate utilize and maximum ethanol production about 76g/l for experimental and model results.

Acknowledgment

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References


186. Modular Multilevel Converters - An Emerging Trend in Advanced HVDC Systems

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Abstract

“Power Systems in today’s world has the same importance as the back bone in human body. With the advent of modern power electronics converters, it is now possible to transfer bulk quantity of conventional and non-conventional energies to the load centers. Presence of renewable energy in far flung areas like deserts, and offshore etc., requires efficient, stable and long distance transmission system. High Voltage Direct Current (HVDC) systems these days have come up with the solution of minimal losses and high grid stability during this energy transfer. In this paper significance of HVDC systems based on modern power electronics converters is discussed. Various topologies related to the modular multilevel converters (MMCs) are examined. Such topologies are certainly able to convert ac power into dc power and vice versa along with fulfilling the grid regulations. The exploration of renewable energy resources like offshore and onshore wind power plants can also be possible by employing such MMCs based multi terminal direct current (MTDC) systems. In the end of paper, some major worldwide HVDC projects are listed to show their fast growth, adoption and power handling capability.”

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Keywords: “HVDC Systems; Power Electronics Converters; Modular Multilevel Converters (MMC); MTDC”

1. Introduction

Electrical energy is accepted as universal energy. Due to its easy conversion from various types of energies like chemical, potential, kinetic, solar etc. and then its re-conversion into these types of energies, it holds the status of universal energy. It is transferred from far located generating stations via high voltage AC and DC transmission lines to the populated areas. The high voltage direct current (HVDC) transmission has several benefits over its counterpart-the high voltage alternating current (HVAC) transmission. HVDC transmission possesses the advantages of long distance efficient power transmission, less number of conductors thus resulting in material saving and low width transmission corridor, negligible reactance, lesser corona losses and lightning strikes, provision of asynchronous back to back connections, high grid stability and use of cables.

The HVDC transmission can be classified into three main configurations: the mono polar connection, the bi-polar connection, and the homo polar connection. These connections are used with various types of converters that are using power electronics switches and working as rectifiers/invertors. These power electronics systems are in continuous development phase and many advanced features are being incorporated in them by day to day research work [1-2].

Power electronics convertors are classified as line commutated convertors (LCC) and voltage source convertors (VSC). The VSC have gained great popularity in recent years because of their several advantages over LCC [3].

Various remote generating stations like wind farms and consumer loads can now be connected with the grid by using multi-terminal direct current (MTDC) transmission systems. This newly developed powerful aspect of HVDC systems
is making them more adaptable for future interconnection of renewable resources like on shore and off shore wind farms, and various loads.

This paper presents a detailed description of HVDC transmission systems along with associated worldwide projects.

2. Configurations of HVDC Transmission Systems

HVDC transmission systems have following configurations:

2.1 Mono-polar Configuration

In this configuration as shown in Fig. 1. (a), a single wire is placed to deliver dc power in between the convertors. The return path can be used via ground, sea or cable armoring. This method has advantage of great saving of conductor material but offers disadvantages of less reliability and corrosion of nearby metallic structures.

2.2 Bi-polar Configuration

As shown in Fig. 1. (b), this configuration involves two conductors having opposite polarities; use to transfer power between the convertor stations. Although it uses more conductor material, nevertheless, it will still provide half of the power via ground connection in case of breakage of any conductor [4].

2.3 Homo-polar Configuration

This configuration shown in Fig. 1. (c), uses two conductors for transferring power between convertor stations. It has same advantages as in bi-polar connection besides same polarity of the conductors, hence causing less corrosion in nearby metallic structures and less corona loss.

2.4 Back to Back Configuration

The great advantage of HVDC systems has been seen in connecting two different AC grids operating at different frequencies, as shown in Fig. 1. (d). No need of synchronization is necessary while power can be transferred from any side to other side with greater stability margin. Even a few meters connecting wires are sufficient to install this back to back intertie.

3. Types of HVDC Convertors

HVDC systems comprises of two major types viz., the Line commutates converter, also known as current source converter (CSC), and the more advanced voltage source converter (VSC) [3,5].

3.1 The Line Commutated Convertors (LCC)
The line commutated convertor (LCC), also known as current source convertor (CSC), uses thyristor as switching device operating at line frequency. This convertor requires natural commutation or line commutation therefore need of a strong synchronous power source is needed to operate this convertor satisfactorily. Although black start capability is not available with these types of convertors, nevertheless they are the most popular HVDC convertors used these days [6]. They can deal power as high as 10000 MW range with +- 1100 kV with a length of 2600 km as in the case of a Zhundong–Sichuan scheme located in China [7].

3.2 The Voltage Source Convertors (VSC)

The voltage source convertors (VSC) is based on IGBT technology, requires no separate synchronous power source and has the black start capability [8]. Instead of inverting the DC voltage polarity in both convertor stations as in LCC HVDC systems they have to change the direction of current flow. The famous high frequency based PWM is used as switching technique in these convertors making them comparatively less efficient and poor power quality producers. VSC has high degree of controllability of active and reactive power flow in both directions [9]. These powers can be given by Eq. (1) and Eq. (2).

\[
P = \frac{Vac \times V_{conv} \sin \delta}{X} \tag{1}
\]

\[
Q = \frac{V_{conv} \times (V_{conv} - Vac \sin \delta)}{X} \tag{2}
\]

Where \( V_{conv} \) is the converter voltage, \( Vac \) is the ac grid voltage, \( \delta \) is the angle between \( V_{conv} \) and \( Vac \), and \( X \) is the series reactance of the line inductor.

Various topologies have been developed to enhance the characteristics of these convertors. Some of them are listed below:

3.2.1 The 2- Level Convertor
The 2-level VSC converter produces a square wave output having lots of harmonics and power losses. The positive and negative terminals of the DC source are connected to the load by periodically switching on and off the switching devices so that the AC output voltage is obtained. Freewheeling diodes are also required to transfer the stored energy in the load inductances back to the DC source.

3.2.2 The Multi Level Converter (MLC)

To overcome the problems present in two-level converters, an improved topology called Multi-level converters (MLC) have been introduced. The MLC has the features of synthesizing an AC output waveform generated with the help of multiple input DC sources. In this manner both positive and negative levels are combined to construct a stepped AC waveform close to a sine wave having lesser harmonics. MLC can be operated at switching frequency either at power frequency (thus reducing switching losses to a great extent), or at high frequency (several kHz) to minimize harmonic content. Moreover, low dv/dt stress is also an added advantage of this type of converters. Therefore, commercial HVDC converters are based on multilevel technology. Following section gives an overview of multilevel topologies [10-14].

4. Multi-Level Convertors Topologies

MLC has many topologies including basic and derived topologies but three basic types are as below:

4.1 The Neutral Point Clamped Converter (NPC)

The neutral point clamped converter (NPC), also named as diode clamped converter, is the modification of the conventional VSC and was initially proposed as a three-level converter. This topology is shown in Fig. 6, the three-phase three-level NPC converter has three legs consisting of three upper and three lower arms. The midpoint of the armed switches is connected with a common neutral point through clamping diodes enabling the introduction of a zero
voltage level. By this configuration the switches have to withstand half of the dc linked voltage. The NPC convertor can be extended to more than three levels. This topology has the drawback of capacitor voltage unbalancing and distortion of output AC waveform. This scheme is not yet suitable for high number of voltage levels. \[15\]

### 4.2 The Flying Capacitor (FC) Converters

Fig. 7. Schematic of a 3-phase, 3 level FC converter

As illustrated in Fig. 7, each leg capacitor is charged up to various voltage levels and thus by switching on and off the devices, different voltage output levels can be achieved \[16\]. It has an inherent problem the initial charging of the capacitors but afterwards the capacitors store the energy and provide this energy in times of voltage outages and sags. Although this topology can be extended to a large number of cells, the addition of capacitors introduces increased complexity, need of control, and cost.

### 4.3 The Cascaded H-Bridge (CHB) Converters

Fig. 8. Schematic of two legs of a 3-phase CHB

The cascaded converter (either half bridge or full bridge) has inherently no problems such as voltage balancing and capacitor initialization like in NPC or FC convertors. Clamping diodes and flying capacitors are not needed in this type of convertors, rather series connected bridge switches known as cells, are required. The output phase voltage is the resultant of voltages generated by the series connected cells present in a particular leg of the converter \[16\].

### 4.4 Modular Multi Level Convertors (MMC)

Fig. 9. Schematic of a MMC

The MMC topology was proposed in 2002 by R. Marquardt and is one of the most emerging technologies in current
VSC HVDC systems. It is using a number of series connected cells also known as sub modules (SM). The SM is made up of a half bridge consisting of two Power switches with anti parallel diodes and a DC capacitor as shown in Fig. 10. By turning on specific SM switches, insertion or bypassing the SM into the converter arm can be possible while the uninterrupted current flow is achieved by the connection of the anti parallel diodes [17-18].

Table-1 and 2 below illustrate states of the switches along with status of sub module SM. The switches are to be operated in complimentary manner preventing short circuit of the SM source capacitor. Following a specific switching pattern, a staircase output voltage waveform can be achieved at the output.

![Figure 10. Schematic of (a) half bridge SM (b) full bridge SM](image)

**Table 1. Half bridge SM switching states**

<table>
<thead>
<tr>
<th>Upper switch state</th>
<th>Lower switch state</th>
<th>SM terminal voltage with current polarity</th>
<th>DC capacitor status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>+Vc (+) Charging</td>
<td>Charging</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0 (+) By passed</td>
<td>By passed</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>-Vc (-) Discharging</td>
<td>Discharging</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0 (-) By passed</td>
<td>By passed</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>- Short circuit</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>- Open circuit</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. Full bridge SM switching states**

<table>
<thead>
<tr>
<th>Upper left switch state</th>
<th>Upper right switch state</th>
<th>Lower left switch state</th>
<th>Lower right switch state</th>
<th>SM terminal voltage with current polarity</th>
<th>DC capacitor status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>+Vc (+) Charging</td>
<td>Charging</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0 (+) By passed</td>
<td>By passed</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-Vc (-) Discharging</td>
<td>Discharging</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0 (-) By passed</td>
<td>By passed</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>- Short circuit</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>- Open circuit</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 11, below is showing a schematic of HVDC MMC system. Here need for AC side filters and transformers are reduced. Other advantages of MMC based HVDC systems are their modularity, improved quality of output waveform, redundancy based reliability and increased efficiency [19-21].

![Figure 11. Schematic of a HVDC MMC system](image)

5. MTDC Systems and Integration of Renewable Power (like Wind, Solar)
In past years, HVDC systems had no provision for tapings in between the converter stations i.e. they are characterized with point to point configuration in contrast with HVAC systems which are offering tapings with respect to multiple source and multiple load connections. Due to tremendous research work in recent years a new concept of multi-terminal direct current (MTDC) systems is introduced, as shown in Fig.12, in which multiple generating sources as well as multiple loads can be connected via HVDC systems. Renewable resources like onshore and offshore wind farms and solar power parks can now be integrated into existing HVDC grid. Multiple bulk loads can also be connected via these MTDC systems. This powerful feature of multiple interconnections makes the HVDC systems more reliable for adoption in the near future [15].

6. Global HVDC Projects

Table 3. below is showing a short list of global HVDC projects with relevant details [7].

<table>
<thead>
<tr>
<th>Country</th>
<th>Project Name</th>
<th>Year</th>
<th>Type of Converter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Zhundong – Sichuan</td>
<td>2015 (Planned)</td>
<td>LCC</td>
<td>10000 MW, ±1100 kV, 2600 km</td>
</tr>
<tr>
<td>China</td>
<td>Gansu-Hunan</td>
<td>2015 (Planned)</td>
<td>LCC</td>
<td>8000 MW, ±800 kV, 2490 km</td>
</tr>
<tr>
<td>China</td>
<td>Northern Hami-Chongqing</td>
<td>2015 (Planned)</td>
<td>LCC</td>
<td>8000 MW, ±800 kV, 2223 km</td>
</tr>
<tr>
<td>China</td>
<td>Southern Hami-Zhengzhou</td>
<td>2015 (Ongoing)</td>
<td>LCC</td>
<td>8000 MW, ±800 kV, 2200 km</td>
</tr>
<tr>
<td>China</td>
<td>Zoushan multi-terminal</td>
<td>2014 (Ongoing)</td>
<td>VSC</td>
<td>1000 MW, ±200 kV, 141 km Subsea cable</td>
</tr>
<tr>
<td>China</td>
<td>Xiamen Island Infeed</td>
<td>2014 (Planned)</td>
<td>VSC</td>
<td>1000 MW, ±320 kV, 10 km Subsea cable</td>
</tr>
<tr>
<td>Norway</td>
<td>Skagerrak 4</td>
<td>2014</td>
<td>VSC</td>
<td>700 MW, ±500 kV, 244 km</td>
</tr>
<tr>
<td>France</td>
<td>Inelle</td>
<td>2013</td>
<td>VSC</td>
<td>1000 MW, ±320 kV, 65 km</td>
</tr>
<tr>
<td>Brazil</td>
<td>Rio – Madeira</td>
<td>2013</td>
<td>LCC</td>
<td>3300 MW, ±600 kV, 2375 km</td>
</tr>
<tr>
<td>Brazil</td>
<td>Rio – Madeira</td>
<td>2012</td>
<td>LCC</td>
<td>800 MW, 100 kV, back to back</td>
</tr>
<tr>
<td>UK</td>
<td>EWIC</td>
<td>2012</td>
<td>VSC</td>
<td>500 MW, ±200 kV, 261 km</td>
</tr>
<tr>
<td>China</td>
<td>Jingping-Sunan</td>
<td>2012 (Commissioned)</td>
<td>LCC</td>
<td>7200 MW, ±800 kV, 2090 km</td>
</tr>
<tr>
<td>China</td>
<td>Xiangjiaba-Shanghai</td>
<td>2010 (Commissioned)</td>
<td>LCC</td>
<td>6400 MW, ±800 kV, 1980 km</td>
</tr>
<tr>
<td>In between UK &amp; Netherlands</td>
<td>UK - Netherlands</td>
<td>2011</td>
<td>LCC</td>
<td>1000 MW, ±400 kV, 260 km</td>
</tr>
<tr>
<td>USA</td>
<td>Transbay</td>
<td>2010</td>
<td>VSC</td>
<td>400 MW, ±200 kV, 35 km</td>
</tr>
<tr>
<td>Namibia</td>
<td>Caprivi link</td>
<td>2010</td>
<td>VSC</td>
<td>350 MW, ±350 kV, 951 km</td>
</tr>
</tbody>
</table>

From the given table, it is evident that the advancement and adoption of HVDC systems all over the world are tremendously increasing day by day.

7. Conclusion

HVDC systems have gained great popularity in recent years due to their certain benefits in contrary with HVAC systems. Transfer of bulk power over longer distances is more feasible and economical when HVDC systems are under consideration. A great many research, improvement and development work is on going with respect to HVDC
converters connections and topologies. Two main converter topologies are LCC and VSC in which LCC is more confirmed for its well-established technology, efficiency and fault handling capability. Research is carried out in VSC based MMC systems which have the advantages of lesser harmonics, increased efficiency, reduced footprint because of reduction of AC side filters and bulky DC link capacitors, flexible control of active and reactive powers, use of multi-terminals, and integration of renewable power via cables with existing grid. Due to all these benefits, the MMC based HVDC systems have proven to be the most suitable topology for future HVDC applications.

8. References

[16.] Artjoms Timofejevs and Daniel Gamboa, “Control of MMC in HVDC Applications”, Master Thesis, Department of Energy Technology, Denmark, 2013
188. Regulation of Bus Voltage for Renewable Energy Based Direct Current Micro Grid

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Abstract

The rise in energy demand in the grid distribution network and grid isolated areas, the renewable energy sets with micro grid setup trendy to meet the challenge. The electricity generation from renewable sets specifically from photovoltaic cells and wind turbine is of stochastic nature. Hence, the demand is to regulate the output voltage in order to meet the standard load requirements. Therefore an integration of these renewable sets in a direct current micro grid (DCMG) setup has been proposed. This is considered due to practicability and economic viability to transform voltage output in DC and maintain the DC bus voltage at 12V. The simulation of two sources have been considered and maintained at a level of 12V under various conditions. The dc load of 500 Watts has been deployed for DCMG system performance measurements. The results show that the dc voltage level has been maintained satisfactorily at the dc-bus under various operating conditions of sources. Thus, the proposed model is significant for integrating multiple renewable energy sets for dc supply under isolated dc micro grid setup. Simulation of the proposed system is carried out in MULTISIM software.

1. Introduction

Unavailability of electricity in off grid areas, harness able issues of global warming, environmental pollution, price instability of non-renewable energy resources and electricity transportation made the current form of energy almost unsustainable. The development of renewable energy based Distributed Generation (DG) is moving fast to meet the worldwide urgent needs of utilizing clean energy sources and minimizing costs \cite{1, 2}. Researchers have discovered many renewable energy sources such as Hydro, Solar, Wind, Tidal, and Geothermal etc. Among these resources, solar and wind energy are considered as the most necessary resource because of their ubiquity, abundance, and sustainability \cite{3}. Micro-grid consists of distributed generation, energy storage systems and load capabilities. For distributed generation renewable energy sources such as Hydro, Solar, Wind, Tidal, and Geothermal etc, are used. For energy storage systems battery, super capacitor and fuel cell are used. Micro grid can work in both isolated and grid integrated modes of operation. This ability of micro grid will improve the reliability and power quality of users connected to them \cite{4}. Micro grids are classified as AC, DC and hybrid AC/DC micro grids. DC micro grid is preferred over AC micro grid because of the advantages, like; 1) higher reliability, 2) improved quality of power supply, 3) decreased losses due to absence of reactive power, 4) better utilization of the system 5) higher efficiency, 6) simple structure, 8) better performance and efficiency of dc converters \cite{5-10}.

In proposed system, solar and wind renewable energy resources are used for distributed generation and battery is used as a storage system. Both solar and wind power are variable in nature, as their output power dependable of seasonal and weather conditions. Power produced by photo voltaic system is depend upon sun shine hours i.e., irradiance and temperature of sun. While power generated by wind is dependable of wind speed and air density. Hence, the power outputs of both resources are instable in nature. This instability problem can be overcome by integrating both sources of power generation. This integration not only improves the system stability but also make the system more efficient and reliable.
The technology of integrating renewable power source is a the future of the power industry at all power level such as high, medium and low [11].

This paper focuses on the design of a DC micro grid system, consists of hybrid wind solar power generation systems, to maintain the system voltages constant which is 12 volts in the proposed case. By regulating the system voltages, reliability and improved quality of generated power can be achieved.

2. Proposed DC micro-grid system

Block diagram of the proposed system; consists of photo voltaic and wind power generation sets, battery for energy storage, hybrid wind solar charge controller and various dc loads; is shown in Fig. 1.

2.1. System description

For the countries like Pakistan where sun shines invariably under clear weather conditions for the major part of the day, power output from the photo voltaic system almost remains constant during sun shine hours. That’s why for the proposed system, PV panels output is feed directly to the dc loads and is also stored in the battery via hybrid charge controller system. Hybrid battery charge controller is used to charge the battery from two available sources, solar and wind energies, and also protects the battery from over charge and over discharge. By nature, the wind energy has stochastic behaviour in the major portions of the world. Keeping this in view, the power produced by the wind turbine generator set is not feed directly to the load but is used solely to charge the battery via hybrid charge controller system. Battery used here will provide the energy supply and demand gap, hence make the system reliable and helps to maintain the system voltage.

3. System components and their configurations

3.1. Solar panel

Solar photovoltaic system is used to convert sun light directly into electricity. PV cells are usually connected in series and parallel to increase system voltage and current respectively. Solar power is variable in nature and this is dependable of sun shine hours, temperature and irradiance of sun. The equivalent figure of a solar cell system is show in Fig. 2.

The relationship among sun shine hours, temperature and irradiance of sun are given in Eq. 1;
The output of solar PV system can be obtained from Eq. 2 and Eq. 3
\[ P = V \times I \]  
\[ P = N_P I_p h \left[ \frac{q}{k_B T} \cdot \frac{V}{N_S} - 1 \right] \]  

Though the study of the proposed system is carried out via simulation but keeping in view the practical specifications of the solar panels available in the market, the suggested configuration of the solar panels for proposed system is;

Number of solar panels = 4
Open circuit voltage, \( V_O \) (per panel) = 18 Volts
Short circuit current, \( I_{SC} \) (per panel) = 7 Amperes
Total power obtained from 4 panels = 450–500 Watts

The output of the PV system is variable in nature which varies from 0 to 18 volts. Solar produces maximum 18 volts during high rate of sun shine hours, temperature and irradiance of sun is available. As sun shine hours, temperature and irradiance of sun is decrease with time, output voltage decrease proportionally and approaches to zero in late hours of the day.

\[ P = V \times I \]
[Eq. 2]
\[ P = N_P I_p h \left[ \frac{q}{k_B T} \cdot \frac{V}{N_S} - 1 \right] \]
[Eq. 3]

### 3.2. Wind generator set

Wind generator uses the kinetic energy of air in motion and converts this wind energy into other useful forms, such as, using wind turbines and generator to make electrical power, windmills for mechanical power, wind pumps for water pumping or drainage, or sails to propel ships. Wind speed directly affects the generated amount of wind energy and is illustrated in Eq. 4;

\[ E = \frac{1}{2} m v^2 = \frac{1}{2} (A v t) \rho v^2 = \frac{1}{2} A t \rho v^3 \]  
[Eq. 4]

Where
- \( \rho \) = density of air;
- \( v \) = wind speed;
- \( A v t \) = volume of air passing through \( A \) (which is considered perpendicular to the direction of the wind);
- \( A v t \rho \) = mass \( m \) passing per unit time.
- \( \frac{1}{2} \rho v^2 \) = kinetic energy of the moving air per unit volume.

Power is energy per unit time, so the wind power incident on \( A \) (e.g. equal to the rotor area of a wind turbine) is, Eq. 5;

\[ P = \frac{E}{t} = \frac{1}{2} A t \rho v^3 \]  
[Eq. 5]

Configuration of the wind turbine generator set for the proposed system is;

Maximum voltage, \( V_{max} \) = 12 Volts
Maximum current, \( I_{max} \) = 8.33 Amperes
Maximum power output of the unit = 100 Watts
Output of the wind generator (as it is variable in nature) varies from 0 to 12V, depends upon the wind speed. Wind produces maximum 12 volts when high rate of wind speed is available. The output voltage decreases gradually and approach to zero when very low rate of wind speed is available.

3.3. Hybrid charge controller

Hybrid battery charger circuit is consists of two similar stages, one for the wind turbine of 12 volts rating and other for the solar PV of 18 volts rating. Wind turbine side is responsible for charging of the battery only whereas while solar stage is responsible to directly supply its energy to the load and also for charging of the battery.

The hybrid battery charger circuit consists of basis components like; resistors, capacitors, diodes, zener diodes, transistors and operational amplifiers. The operational amplifiers are configured as comparator, where non inverting pin used for sensing input and inverting pin used as reference input. The resister R3/R4 selected such that at the required battery charging voltage sense pin just become higher than reference pin. When wind voltage is applied to op-amp stage, the op-amp tracks the voltage and as soon as op-amp tries to exceed the set threshold voltage. At this time pin 6 of IC goes high which is turn switch ON transistor $T_1$ and $T_2$ instantly short circuit the excess energy restricting the voltage to the battery at desire voltage limit. Solar PV also implements same function but in solar $T_2$ transistor is used whenever the solar energy is higher than the set threshold. $T_2$ keeps on cutting it OFF resulting supply to battery at specified rate which is safe for battery. The circuit diagram of hybrid battery charger is show in figure (3).

3.4. Energy storage system (Battery)

Distributed Generator (solar and wind) used in this system are dependable of environmental conditions. Power produces by these energy resources are non dispatchable in nature. Therefore integration of system will face the problem of balancing the supply and demand in case of one source is not available. To overcome this problem an energy storage system comprises of a battery or group of batteries connected in parallel can be used. This energy storage system is directly connected to DC bus. Battery will charge through two energy sources i-e solar and wind energies with help of hybrid battery charger. This hybrid charge will increase battery life by protecting the overcharge and over discharge rate. Hence, battery is used to provide the supply and demand gap in the system.

3.5. DC bus and DC load

DC bus is the common conductor which carries the current from source to the load. In proposed system, 12 volts with ±5%, voltage is maintained at the dc bus under various loading conditions in between 0 to 500 Watts. 20 number of 25W bulbs are simulated for the designed load of 500 Watts.

4. Simulation and Results

Simulation of the proposed system is carried out in Multisim software and is shown in figure (4). To illustrate
the performance of the system, results under various operating conditions of solar and wind are obtained.

Table 1 presents the dc bus voltages of the designed system at various operating conditions.

<table>
<thead>
<tr>
<th>PV systems output voltage</th>
<th>Wind Systems output voltage</th>
<th>Voltage at the dc bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>18V</td>
<td>12V</td>
<td>12V</td>
</tr>
<tr>
<td>18V</td>
<td>10V</td>
<td>12V</td>
</tr>
<tr>
<td>18V</td>
<td>8V</td>
<td>12V</td>
</tr>
<tr>
<td>14V</td>
<td>12V</td>
<td>11.9V</td>
</tr>
<tr>
<td>10V</td>
<td>12V</td>
<td>11.9V</td>
</tr>
<tr>
<td>10V</td>
<td>10V</td>
<td>11.9V</td>
</tr>
<tr>
<td>10V</td>
<td>8V</td>
<td>11.9V</td>
</tr>
</tbody>
</table>

**Case 1**: Both solar and wind systems supply sufficient energy (i.e. Solar = high, Wind = high)
Under this condition, both solar and wind systems operate closer to their rated limits and batteries do not have to supply any additional amount of energy. Performance of the system under this system can be best observed from the graph presented in figure (5).
**Case 2: Solar energy is sufficient and wind energy is insufficient (i.e. Solar = high, Wind = low)**
Under this condition, only PV system will supply its energy whereas wind energy is insufficient to contribute any of its part into the hybrid system. Graph of the proposed systems performance under this condition is given in figure (6).

![Fig. 6. When wind energy is insufficient to supply power to DC bus](image)

**Case 3: Solar energy is insufficient and wind energy is sufficient (i.e. Solar = low, Wind = high)**
As expected in night times when solar energy is not available, the only possible source of energy be the wind generator system if sufficient wind speeds are available. Graph of the proposed system under this condition is given in figure (7).

![Fig. 7. When wind energy is sufficient to supply power to DC bus](image)

**Case 4: Both solar and wind energies are insufficient (i.e. Solar = low, Wind = low)**
Under this condition, the energy storage system will be the only means to fully or partially meet the load demand, depend on the capacity of the storage system. Hence batteries will supply their energies up to the time when get fully discharged. Figure (8) shows the graph of the system under this condition.

![Fig. 8. When both solar and wind energies are insufficient to supply power to DC bus](image)
4 Applications of the project

The proposed system has vast applications such as, standalone power generation sets employed to villages that do not have access to electricity. This is also feasible for various purpose buildings such as residential, commercial, office and industry as well as the management of distribution system independently. Moreover, these technicalities of the project will help the policy makers for the penetration of renewable energy technologies within the power system.

5 Conclusion

The proposed system comprises of the basic electronic components and will maintain dc voltages at 12 volts under various operating conditions.

Acknowledgements

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References

Abstract

This research paper provides consolidated argument for renewable energy resources being more significant as compare to conventional energy resources (oil & natural gas) in Pakistan’s power sector for following important reasons: First is that, from statistical data regarding vast utilization of oil and natural gas resources of Pakistan for various purposes (industries, power plants, transport, domestic applications..) it is estimated that country’s natural gas and oil reserves will become extinct in about 15-16 years, thus this estimated evidence compels to find such energy resources in the country that would be able to fill the gap of oil and natural gas resources in power sector of the country once they (oil and natural gas resources) are extinct. Second is that, Use of oil and natural gas resources in power plants is a source for generation of flue gases that are exhausted into atmosphere, these flue gases in the atmosphere significantly contribute to global warming which as of present has reached its peak value in Pakistan. The effects of global warming are devastating as it contributes in warming the planet significantly that is making life on earth unbearable. Thus to avoid any further increase in global warming of the country (Pakistan) use of oil and natural gas resources in power sector must be curtailed and adequate replacement in terms renewable energy sources (solar, wind, biomass and hydro) must be utilized in power sector of the country, because the use of renewable energy resources in power sector do not generate any harmful gases that can damage the planet. So basically this research paper shall provide a solid reason for utilizing the renewable energy resources in Pakistan’s power sector as compare to near extinction conventional energy resources.

Keywords: “Green energy, Solution to power crisis”

1 Introduction

In this research paper statistical data for projected power demand on Pakistan’s power system for years 2015-16 to 2029-30 along with statistical data for projected installed capacity of Pakistan’s power system for years 2015-16 to 2029-30 are analyzed for determining the power demand and installed capacity gap for years 2015-16 to 2029-30.

Based on the analysis process projected power demand/installed capacity gaps for years 2015-16 to 2029-30 are focused and further analyzed in terms of constraints likes financial restrictions, conventional fuel resource shortage and no rehabilitation of existing power houses for determining projected power demand/supply gaps, and then based on the projected power demand/supply gaps for years 2015-16 to 2029-30 role of renewable energy resource power projects is defined for bridging the projected power demand/supply gaps in order to eliminate power crisis to some significant extent.

1.1 Analyzing future power crisis of Pakistan

As per national power system expansion plan the projected future power demand of Pakistan (KESC+PEPCO) for years 2015-16 to 2029-30 is evaluated by first determining the energy sales/energy demand (including the energy shed) for future years using regression analysis formula in which the important parameters used are historic energy sales/energy demand (including the energy shed for 2004-
15) for years 1970-2015 with 2015 taken as base year and projected growth of GDP, Population and category wise tariff rates ETC for years 2015-16 to 2029-30 and then projected Transmission/Distribution losses, projected auxiliary consumption and projected load factor are used to finally project the peak power demand on Pakistan’s power system for years 2015-16 to 2029-30. The data for projected peak power demand of Pakistan for years 2016-2030 under normal load forecast scenario is shown in Fig 1 and is detailed in appendix A.

Similarly the projected installed generation capacity of Pakistan (PEPCO+KESC) for years 2015-16 to 2029-30 as per NTDC’s future power project list is shown in the fig 1.1 and is detailed in appendix B.

Then by comparing the projected peak demand and installed capacity of years 2015-16 to 2029-30 power demand/installed capacity gaps for years 2015-16 to 2029-30 are determined this is shown in fig 1.2 and is detailed in appendix C.
As indicated in Fig. 1.2 from years 2015-16 to 2022-23 and year 2026-27 projected peak power demand on Pakistan’s power system shall be less than installed generation capacity by significant margin thus if it is assumed that actual generation capacity of country’s power system is equal to its installed capacity provided all the power houses are operating up to their rated capacity then Pakistan surprisingly shall not face any power crisis for those years from 2015-16 to 2022-23 and 2026-27 but unfortunately due to presence of constraints like shortage of fuel resources (import oil/gas) for thermal power stations (as per financial restrictions and natural gas allocation and management policy 2005) and hydro resources in winter for hydro power stations and no rehabilitation of existing power houses it is expected that actual generation capacity shall not be equal to installed capacity rather it is expected to be less than the power demand therefore by considering these factors it is expected that Pakistan shall face power crisis for years 2015-16 to 2022-23 and 2026-27. For the years 2023-24 to 2029-30 except 2026-27 projected peak demand on system is expected to be greater than installed generation capacity, thus even if actual generation capacity is assumed to be equal to installed capacity for years 2023-24 to 2029-30 except 2026-27 Pakistan is still expected to face power crisis and if factors like shortage of fuel resources for thermal/hydro power projects and no rehabilitation of existing power houses are considered then actual generation capacity is expected to be way below the power demand thus further consolidating the power crisis for years 2023-24 to 2029-30.

1.2 Conclusion (Role of renewable energy resources for eliminating future power crisis)

As discussed earlier in section 1.1 even though the projected installed capacity of Pakistan’s power system succeeds the power demand for years 2015-16 to 2022-23 and 2026-27 the country shall still be facing power crisis because of constraints already mentioned due to which conventional resource power stations shall be operating below their rated capacity and therefore actual generation capacity shall be lower than projected installed capacity and peak power demand thus widening the power demand/supply gap.

But in case of years 2023-24 to 2029-30 except 2026-27 power demand exceeds installed capacity thus country shall be facing severe power crisis even with actual generation capacity being equal to installed capacity and if factors like shortage of fuel resources for thermal/hydro power projects and no rehabilitation of existing power houses are considered then actual generation capacity is expected to be way below the power demand thus further increasing the severity of power crisis for years 2023-24 to 2029-30.

In order to reduce power demand/supply gap upto a significant margin for downgrading projected power demand/supply gap it is essential to focus on renewable energy resources as they are inexhaustible and carbon-free sources of energy which can significantly reduce the power demand/supply gap and help in mitigating the power crisis.
crisis of years 2015-16 to 2029-30 GOP must consider following steps:

- While considering shortage of conventional fuel resources and with renewable energy resources (wind+solar) available in abundant quantity within Pakistan, GOP shall put forward a mandate for construction of renewable energy resource (wind+solar) power projects on small scale along with rehabilitation of existing power houses for years 2015-16 to 2022-23 and 2026-27 for bridging demand/supply gap in order to reduce the power crisis upto some significant/tolerable extent.
- The above is true for years 2023-24 to 2029-30 except 2026-27 with one exception that is the renewable energy power projects must be constructed on massive scale because of power demand being greater than installed capacity for these years.

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1. Engr. Shakir Ali Soomro (Acting Chairman Elec. DPT)
2. Engr. Dr. Mohsin Tunio

References

[1] EDF (Energy Demand Forecast) 2011-2035 NTDC.

Appendix A Load forecast (PEPCO/KESC/SELF Generation) Normal

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20. Simplified and Accurate Photovoltaic Module Parameter Estimation Method Based on Single Diode Model

Mohammad Affan*

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Abstract

The aim of this paper is to introduce a simplified and accurate method for the estimation of five electrical model parameters of Photovoltaic (PV) module namely diode ideality factor (a), series resistance (R_s), shunt resistance (R_sh), dark saturation current (I_o) and photo-generated current (I_pv) under standard test conditions (STC) and to compare the different analytical and iterative methods already popular in technical literature with the proposed method. The parameters extraction approach proposed in this paper exploits a new equation dP/dI=0 at maximum power point for iterative solution rather than dV/dI=-1/R_p or dV/dI=-1/R_s. Thus, avoiding the complexity and dependency over series and shunt resistance for five parameters extractions.

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Keywords: parameter estimation method; photovoltaic module; MPP; single diode model.

1. Introduction

Over the last few years, the exponential increase in energy demand have caused the rapid depletion of fossil fuels like coal, oil, natural gas etc. and also due to emission of greenhouse gases, the world is shifting towards renewable energy sources. Although, renewable energy is relatively expensive [1] but due to inexhaustibility, free availability and environmental friendly nature, renewable energy is becoming more and more popular [2]. Among many renewable energy types solar photovoltaic system is one of the most popularly used one. Photovoltaic system directly converts light into electricity by using phenomenon called photoelectric effect. Photovoltaic module is an arrays or modules formed by either grouping the solar cells in series, parallel or in both. PV systems are never connected directly to the load due to highly non-linear IV-characteristics which results in poor overall efficiency of the system. Therefore, to operate PV system at maximum possible efficiency, many state of the art techniques have been developed worldwide in recent years and are in practice, including MPP tracking, power loss reduction and optimization of algorithms and electronic converters. In order to study and optimize electronic circuits and MPP algorithms, an accurate model of PV module has to be established. Furthermore, mathematical models are developed by researchers to study the effect of temperature, irradiance and other factors on performance of PV modules.

2. Mathematical Modeling

An accurate knowledge of the parameters of solar cell model is necessary for the design, control and process optimization of a solar cell. The selection of mathematical model for the representation of PV module is mainly based on the compromise between the simplicity and accuracy [3]. However, in practice mostly two types of mathematical models are used namely single diode and double diode model. The single-diode model [3] shown in fig 1 requires an extraction of five parameters. The advantages of single diode model include simplicity, accuracy [1] and the possibility of the extraction of all five required parameters from the information provided by the manufacturer’s datasheet [4], [5], [6].
Applying Kirchhoff’s current law, Shockley diode equation and current divider rule on circuit in fig. 1.

\[ I = I_{ph} - I_o \left( e^{\frac{V+IR_s}{nV_t}} - 1 \right) - \frac{V+IR_s}{R_{sh}} \]  

(1)

Where \( I_{ph} \) is the photon generated current, \( I_o \) is reverse saturation current, \( R_s \) is series resistance, \( R_{sh} \) is shunt resistance, \( a \) is diode ideality factor, \( V \) and \( I \) are module output voltage and current respectively, \( V_t \) is the junction thermal voltage given by the equation

\[ V_t = \frac{N_sKT}{q} \]  

(2)

In above equation \( q \) is charge of electron, \( K \) is Boltzmann’s constant, \( T \) is temperature at STC in Kelvin and \( N_s \) is number of cells connected in series in photovoltaic module.

In order to model a photovoltaic module it is necessary for design engineer to have value of all unknown parameters [2]. Unfortunately, the manufacturer datasheet provides only the following specifications \( V_{oc} \) (open circuit voltage), \( I_{sc} \) (short circuit voltage), \( I_{mp} \) and \( V_{mp} \) i.e. current and voltage at maximum power point, open circuit voltage coefficient(\( K_v \)) and short circuit current coefficient(\( K_i \)) and Power at maximum power point (\( P_{mp} \)) with reference to STC and NOCT. Therefore, unknown parameters must be evaluated. Unlike, electrical sources that either works as current source or voltage source the PV cell has the ability to behave as current source as well as the voltage source based on the operating point region [1]. Furthermore, parameters like \( I_{ph} \), \( I_o \), \( R_s \) and \( R_{sh} \) not only depend on IV-characteristics of a photovoltaic module but also on the external factors such as temperature and irradiance [7]. More sophisticated calculations involves consideration of external parameters like air density, wind speed, different illuminated levels etc. The following equations are present in literature to calculate values of \( I_{ph} \), \( I_o \) and \( V_{oc} \) at varying temperature and irradiance.

\[ I_{ph} = (I_{ph}, n + K\Delta T) \frac{G}{G_n} \]  

(3)

\[ I_o = \frac{I_{sc} + K\Delta T}{e^{\frac{V_{oc} + K\Delta T}{nV_t}} - 1} \]  

(4)

\[ V_{oc} = Voc, n + Kv\Delta T \]  

(5)

Where \( V_{oc,n} \), \( I_{sc,n} \) are nominal open circuit voltage and short circuit current, \( \Delta T \) is \( T - T_n \) where \( T \) and \( T_n \) are the actual and nominal temperatures in Kelvin(K) respectively, \( G \) and \( G_n \) are the real and nominal irradiations in watts per meter\(^2\).

3. Literature overview

This section aims to give an overview of the most widely used single diode based PV module parameter estimation methods found in technical literature:

3.1. Villalva Method

3.1.1. Description

Villalva iterative algorithm extracts two parameters \( R_s \) and \( R_{sh} \) simultaneously keeping diode ideality factor \( a \) constant relying on the fact that there is only one pair of \( (R_s, R_{sh}) \) which satisfies...
$P_{mp, model} = P_{mp, curve}$ at MPP of IV-curve i.e. to say the maximum power obtained from IV model Eq. (1) should be equal to the maximum power point provided by the manufacturer data sheet IV-curve at MPP. The given method’s extracted values greatly depends upon the increment value of $R_s$ and tolerance band [2].

In this method, the author initially assumes the diode ideality factor ($a$) as constant which later on can be modified to better fit the IV-curve, $R_s=0$ which must be slowly incremented during the iterative process and $I_{ph}=I_{sc}$, but when $R_s$ and $R_{sh}$ converge towards the best model solution the Eq. (5) is used to find $I_{ph}$ value

$$I_{ph} = \frac{R_s + R_{sh}}{R_{sh}} I_{sc}$$

The initial value of $R_{sh}$ is:

$$R_{sh, min} = \frac{V_{mp}}{I_{sc}} - \frac{V_{ac}}{I_{mp}}$$

The relation between $R_{sh}$ and $R_s$ is obtained by using relation $P_{mp, model} = P_{mp, curve}$ at MPP which leads to the Eq. (8)

$$R_{sh} = \frac{V_{mp} (V_{mp} + R_s I_{mp})}{V_{mp} I_{ph} - I_{ph}}$$

The above equation suggests that for any value of $R_s$ there will be only one value of $R_{sh}$ which makes the given electrical model traverse the $(I_{mp}, V_{mp})$ i.e. MPP provided by the manufacturer datasheet.

![Fig. 2. Flowchart of Villalva’s Method](image)

### 3.1.2. Limitations

Villalva method is accurate near MPP but it can be inaccurate in other regions [3] because all values are evaluated at MPP and $a$ is treated constant.

### 3.1.3. Algorithm

The flow chart of Villalva method is given in fig 2.

### 3.2. Non-linear Least Square Method

#### 3.2.1. Description

The least square method is the most widely used curve fitting method which extracts the required parameters by minimizing the squared error between the estimated target variables and experimental data [2].
To estimate the five parameters \(a, R_s, R_{sh}, I_{ph}, I_o\) of PV module, the non-linear least square method uses five objective functions

\[
f_1(x) = 0 = I_{ph} - I_o \left[ e^{\left(\frac{V_{mp}+R_s I_{mp}}{V_{oc}}\right)} - 1 \right] - \frac{I_{oc} R_s}{R_{sh}} - I_{sc}
\]

\[
f_2(x) = 0 = I_o \left[ e^{\left(\frac{V_{mp}+R_s I_{mp}}{V_{oc}}\right)} - 1 \right] + \frac{V_{oc} - I_{ph}}{R_{sh}}
\]

\[
f_3(x) = 0 = I_{ph} - I_o \left[ e^{\left(\frac{V_{mp}+R_s I_{mp}}{V_{oc}}\right)} - 1 \right] - \frac{V_{mp}+R_s I_{mp}}{R_{sh}} - I_{mp}
\]

\[
f_4(x) = 0 = V_{mp} \left[ \frac{\frac{I_o}{R_{sh}}}{\frac{V_{mp}+R_s I_{mp}}{V_{oc}} + R_{sh}} + \frac{1}{R_{sh}} \right] - I_{mp}
\]

\[
f_5(x) = 0 = \left[ \frac{\frac{I_o}{R_{sh}}}{\frac{V_{mp}+R_s I_{mp}}{V_{oc}} + R_{sh}} + \frac{1}{R_{sh}} \right] - \frac{1}{R_{sh}}
\]
The above five objective functions are based on the system of non-linear equations corresponding to the short circuit, open circuit and MPP condition of photovoltaic module and other two equations. The minimization of objective function is obtained by fsolve command in MATLAB [3]. Trust region dogleg algorithm is used for the minimization. Lower and upper bound constrains are used to avoid anomalous results.

3.2.2. Limitations

NLS method may confine to local minima during minimization iterations and does not represent the actual parameters [3]. Furthermore, the appropriate choice of initial values is inevitable because rate of convergence and accuracy of algorithm depends on initialization [2].

3.2.3. Algorithm

Flowchart of Trust region dogleg algorithm based NLS’s method is given in fig 3.

3.3. Lambert W-function based explicit solution

3.3.1. Description

The method presented in [7], [8] utilizes the symbolic expressions for solving $R_s$ and $R_{sh}$ of electrical model. Unlike iterative method, which uses mutually dependent non-linear equations for parameter extraction this method uses the two separate independent equations to approximate $R_s$ and $R_{sh}$. Starting values of $I_{ph}$, $a$ and $I_o$ are given in Eq. (9-11)

$$I_{ph} = I_{sc}$$

$$a = \frac{k_e - V_{oc}}{V_{oc} - (\frac{k_i}{I_{ph} - \frac{V_{oc}}{I_{ph}}} - \frac{k_{gap}}{k_{oc}})}$$

$$I_o = I_{ph} \cdot e^{-\frac{V_{oc}}{aT}}$$

Based on the change of variable

$$x = \frac{V_{mp} + R_s \cdot I_{mp}}{aV_f}$$

The above equation allows to write series and shunt resistance as

$$R_s = \frac{x a V_f - V_{mp}}{I_{mp}}$$

$$R_{sh} = \frac{V_{mp} + I_{mp} R_s}{I_{ph} - I_{mp} - I_o (e^{-\frac{V_{mp}}{aV_f}} - 1)}$$

After few substitutions and approximations

$$x = W \left[ \frac{V_{mp} (2 I_{mp} - I_{ph}) e^{\frac{V_{mp} (V_{mp} - 2 V_{oc})}{a^2 V_f^2}}}{aV_f I_o} + 2 \frac{V_{mp}}{aV_f} - \frac{V_{mp}^2}{a^2 V_f^2} \right]$$

Where $W$ is the Lambert W-function whose value is computed by the algorithm proposed in the [9] which uses Halley’s method and series approximations as initializations.

The value of $x$ obtained from Eq. (15) is substituted in Eq. (12) and Eq. (13) to get values of series and shunt resistance.

3.3.2. Limitations

According to comparison presented in [7] it can be in inferred that the explicit solution based on lambert W-function is not accurate. Although the transcendental nature of Eq. 1 can be converted into explicit
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analytical expression by the use of lambert W-function but it increases the complexity e.g.: the use of CC function by Ortiz-Conde et al make the curve fitting multi-dimensional[10]

4. Proposed Method

The proposed method uses the same initialization procedure as adopted by Villalva. However, unlike Villalva’s method which adjusts Rs and Rsh to match the Pmp,model=Pmp,curve at MPP keeping diode ideality factor(a) constant [1], the proposed method adjusts Rsh, Rs, and n simultaneously at MPP using two different differential Eq. (19) and Eq. (20) thus, providing more accurate results.

\[ \frac{dP}{dv}_{MPP} = I_{mp} + V_{mp} \frac{dl}{dv} = 0 \]  
\[ \frac{dP}{dl}_{MPP} = V_{mp} + I_{mp} \frac{dv}{dl} = 0 \]

The Eq. (21) represents derivative of power with respect to voltage at MPP which is equal to zero. Similarly, another Eq. (22) is obtained by taking derivative of power with respect to current at MPP. It should be noted that according to the best knowledge of author, Eq. (22) does not occur in previous literature for any kind of iterative solution. The Eq. (22) replaces the equation usually used by researchers that is \[ \frac{dI}{dv} = -1/(R_{sh}) \]. The Eq. (20) not only eliminates the dependency over shunt resistance for an iterative solution but also ease the technical complexity, excessive model parameters adjustment[11] which in turn increases the computational time and accuracy. Since the proposed method tends to adjust Rsh, Rs, and n efficiently and simultaneously, it minimizes the error previously present in iterative and numerical methods. The flow chart of proposed method is given in Fig. 4.

5. Case Study

For case study KC200GT Panel is selected [12]. The manufacturer provided parameters are provided in table I. A case study is conducted to compute five parameters of PV panel KC200GT from Kyocera solar
using datasheet values at STC (parameters can also be evaluated under varying conditions by using open circuit and short circuit current coefficients listed in datasheet). The five parameters are extracted by each discussed method separately and are given in table 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Villalva Method</th>
<th>NLS Method</th>
<th>Lambert-W method</th>
<th>Proposed Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{mp}$</td>
<td>7.61A</td>
<td>8.21A</td>
<td>8.21A</td>
<td>8.21A</td>
</tr>
<tr>
<td>$V_{mp}$</td>
<td>26.3V</td>
<td>32.9V</td>
<td>32.9V</td>
<td>32.9V</td>
</tr>
<tr>
<td>$P_{mp,curve}$</td>
<td>200.143W</td>
<td>200.143W</td>
<td>200.143W</td>
<td>200.143W</td>
</tr>
<tr>
<td>$I_{sc}$</td>
<td>8.21A</td>
<td>8.21A</td>
<td>8.21A</td>
<td>8.21A</td>
</tr>
<tr>
<td>$V_{oc}$</td>
<td>-0.1230V/K</td>
<td>-0.1230V/K</td>
<td>-0.1230V/K</td>
<td>-0.1230V/K</td>
</tr>
<tr>
<td>$K_v$</td>
<td>0.0032V/K</td>
<td>0.0032V/K</td>
<td>0.0032V/K</td>
<td>0.0032V/K</td>
</tr>
<tr>
<td>$N_s$</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td>54</td>
</tr>
</tbody>
</table>

6. Conclusion

This paper have discussed the different popular methods present in literature and then compare the proposed methods with them. Unlike, other methods the proposed method does not require any guess value (such as $n$ [1]). The proposed method is found more accurate than discussed method as comparison shown in table II. In addition to being accurate the proposed method is very simple and does not require any complex calculations. Furthermore, the proposed method uses a new differential equations based approach for numerically determining five parameters of a PV cell.

References


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Abstract

“Most of the high grade geothermal resources of the world are found within seismic belts of weak crustal plate margins and centres or volcanic activity. Similarly, geotectonic framework of Pakistan directs towards a region which poses a commercially exploitable sources of geothermal prospects of energy. Presence of alteration zones and fumaroles, hot springs as well as Quaternary volcanism are all indication of good prospects.

The Southern most Indus basin of Pakistan are lie in the Geo-Pressurized Thermal zone system. Geothermal activities are thermal spring, geysers such as in Karachi and Dadu area, as well as abnormal high temperature in drilling oil/gas wells, is due to the great thickness and geo-pressured water of sedimentary basins. The presence of two thermal springs at Mangho Pir and Karsaz, Karachi specify a Cl - HCO³ and Cl-SO⁴ types of water chemistry. Reservoir temperature also reported comparatively low by the Silica geothermometers due to mixing of sea water and rock water interaction in subsurface. However, geochemistry of thermal water indicates further to conduct a detailed survey of the area for exploring future prospects of geothermal resources.”

Keywords: “Geothermal water; Reservoir temperature; Geothermometers; Lower Indus basin.”

1. Introduction

Geothermal energy is considered as the energy which is derived from the heat of earth internal core. It is clean abundant and reliable source of energy as compared to other source of conventional and unconventional means. If geothermal source is properly developed, it can offer a renewable and sustainable energy source.

People have used geothermal energy resources in many ways including healing and physical therapies, cooking, space heating and other applications. It is also used for electricity generation, direct use of heat and geothermal heating pumps

Geothermal systems commonly can be classified as:

- Volcanic systems with the heat source being hot intrusions or magma chambers in the crust,
- Convective systems with deep water circulation in tectonically active areas of high geothermal gradient,
- Conductive sedimentary systems with permeable layers at great depth (2-5 km),
- Geopressed systems often in conjunction with oil resources,
- Hot dry rock or EGS systems where abnormally hot masses of low permeability rocks are found at drillable depths, and
- Shallow resources in normal geothermal gradient areas utilized with ground-source heat pump applications.

A classification for geothermal systems was proposed in Iceland which is divided into low and high-temperature geothermal systems where temperature is below 150°C in the uppermost layers (km) and a
temperature of 200°C is reached at 1 km depth respectively. The high-temperature geothermal fields are all related to volcanism whereas the low-temperature geothermal fields draw heat from the general heat flow of the crust. Low-temperature geothermal system is directly related to the sedimentary basin which has thin conductive permeable sedimentary layers.

A global seismic belt passes through Pakistan and the country has a long geological history of geotectonic events. Permo-carboniferous volcanism (Panjal traps in Kashmir) as a result of rifting of Iran-Afghanistan microplates, Late Jurassic to Early Cretaceous rifting of the Indo-Pakistan Plate, widespread volcanism during Late Cretaceous (Deccan traps) attributed to the appearance of a "hot spot" in the region, emergence of a chain of volcanic islands along the margins of the Indo-Pakistan Plate, collision of India and Asia (Cretaceous-Paleocene) and the consequent Himalayan upheaval, and Neogene-Quaternary volcanism in the Chagai District (Kazmi & Jan, 1999; Raza & Bander, 1995).

2. Location & Method

The study area comprise of Southern Indus basin marginal zone where the existence of a large number of thermal springs indicates the presence of widespread geothermal systems. The clusters of thermal springs in the Dadu district, Mangho Pir and Karsaz area at Karachi represent interesting areas for geothermal exploration. Correlation between the hot springs and tectonics is not easy in the flat basin, prior to geological and geophysical investigation. (Mughal, 1998). However, a large number of thermal spring along the Indus basin marginal zone and its marginal extension at Karachi can be a good prospect for further study. Apart from this, numerous exploration wells has been drilled in Indus basin and offshore trough region for oil and gas exploration, many of which showed higher than normal subsurface temperature. This paper also encountered all those factor to give a precise review of geothermal prospects.

3. Tectonic Framework

Tectonically, Pakistan is situated on the western-rifted margin of the Indo-Pakistan subcontinental plate. In the existing plate tectonic setting, Pakistan lies partly on (i) the northwestern corner of the Indian lithospheric plate, (ii) the southern part of the Afghan craton, and (iii) the northern part of the Arabian oceanic subducting plate. The eastern part of Pakistan represents (a) the Tertiary convergence with intense collision between the Indian and Eurasian plates in the north creating Karakorum Thrust Zone and (b) the translation between Indian continental plate and the Afghan craton in the north-west developing Chaman Transcurrent Fault System that connects the Makran convergence zone (where oceanic lithosphere is being subducted beneath the Lut and Afghan micro-plates) with the Himalayan convergence zone (where the Indo-Pakistan lithosphere is under thrusting the Eurasian continental plate).

4. Potential Geothermal Sources In Pakistan

Most of the high ranking geothermal resources of the world are found within seismic belts associated with zones of crustal weakness such as plate margins and centres or volcanic activity.

The geotectonic framework of Pakistan suggested that the region poses a commercially exploitable sources of geothermal prospects of energy. It is further reinforced by the equitably extensive development of alteration zones and fumaroles in many regions of Pakistan, presence of a fairly large number of hot springs in different parts of the country, and indications of Quaternary volcanism.
In general, the geothermal exploration addresses at least nine phases of integrated study, i.e., i) identification of geothermal phenomena, ii) classification of the geothermal field production field exists, iii) location of productive zones, iv) ascertaining that a useful geothermal, v) estimation of the size of the resource, vi) determination of heat content of fluids that will be discharged by wells in the geothermal field, vii) compilation of a body of data against which the results of future monitoring can be viewed, viii) assessment of pre-exploitation values of environmentally sensitive parameters, ix) determination of any characteristics that might cause problems during field development. First three phases have so far been undertaken in Pakistan on limited scale to study the geological characteristics of the geothermal energy sources.

Thus in our country Pakistan, these manifestations of geothermal energy are found within three geotectonic or geothermal environments.

- Geo-pressurized systems related to basin subsidence which is mainly encountered in the Indus river basin in Southern part of Pakistan.
- Seismo-tectonic or suture-related systems: is found in northern part of Pakistan, manifested by many thermal spring. This regime is comprised of Karakorum, Hindu Kush and Himalayan thrust mountainous belts, exhibits strong seismicity activities.
- Neogene-Quaternary volcanism. Lies in the western belt of Pakistan and associated with Chaghi magmatic arc and Koh-e-Sultan volcanoes manifested by mineralized thermal spring. This regime apparently exhibits the highest potential of geothermal source in Pakistan (Zaigham, 2005).

5. Geothermal System Of Southern Indus Basin And Trough

This paper aims to provide a general characteristic of Thermal system of Southern lower part of Indus basin. Pakistan. This zone along with the western margin of the Indus Plain are lie in the Geo Pressurized Thermal zone system. The Lower Indus Basin is filled with 5,000 to 10,000 m thick sedimentary rocks of Mesozoic to Recent Ages. It is generally considered that geothermal systems in sedimentary grabens usually derive their origin from the difference in thermal conduction, i.e. the “isolating effect” due to low thermal conductivity of sediments. The hot sedimentary aquifers are associated with hydrocarbons and also developed as a result of development of secondary faults in the Indus Basin where dozens of geothermal springs have been identified.

The geothermal activities which is found in the Indus basin are thermal spring, geysers such as in Karachi and Dadu area, as well as abnormal high temperature (>110 °C) due to geo-pressured hot water associated with hydrocarbon, are encountered in drilling different oil/gas wells.
5.1. Lower Indus Trough

The lower Indus trough and offshore are also characterized by more than normal geothermal gradient for instance a well Damiri-1 had a geothermal gradient of 4°C/100m (Khan and Raza, 1986), whereas the wells at Talhar and Khaskheli have encountered geothermal gradients in the range of 30 to 3.5°C/100m. The offshore well at Dabbo Creek revealed a geothermal gradient of 3.7°C/100m. Generally, in this system the normal heat flow is trapped by insulating impermeable beds in a rapidly subsiding sedimentary basin. It is due to its great depth (as much as 6,000 m) that temperatures ranging from less than 93°C to more than 150°C encountered. They commonly contain pressurized hot connate water at pressures ranging from 40% to 90% in excess of the hydrostatic pressure corresponding to the depth. Gradual subsidence has led to the ultimate isolation of trapped pockets of water contained in alternating pervious and impervious sequences.

5.2. Karachi Area

Karachi area geologically fall in Kirthar province of Indus basin. It may broadly divide into two parts, the hilly terrain on the North and West part and underlying plain and coastal area, are in South-East. The hilly part in Karachi are the southward extension of the Kirthar ranges which merges into alluvial plain of Karachi. The rocks exposed in Karachi are of sedimentary origin and range from Paleocene to Recent in age.

There has been two hot spring are found in Karachi shown in Fig 2.

i. Mangho Pir thermal spring (K1) is located in Karachi West (Lat. 24°59’N; Long 67°03’E). It is situated on the eastern flank of the anticline, at an altitude of about 20m above sea level whereas,

ii. Karsaz hot spring (K2) is located in Karachi East (Lat. 24°53’N; Long 67°06’E) approximately 11 km North of Arabian sea.

The exposed rock of these area consist of shale, sandstone and limestone of Nari and Gaj formation of Oligocene and Miocene age (Fig.3). There is no volcanic activity found in this area. The system of fracture and fissure developed in shale formation of Mangho Pir area are commonly closed and the permeability is also very less. However aquifer of the mineral water found in the Orangi Town nearby
area of Mangho Pir, are primarily exist in sandstone of Nari formation (Muslim & Das 1988). In this way, shales of Nari and Gaj formation play a role of cap rock. Fractured Limestone and sandstone is considered to act as a shallow geothermal reservoir in Mangho Pir area (Todaka, Shuja).

![Generalized geological map of Karachi](image)

**Fig. 3. Generalized geological map of Karachi**

**5.2.1. Characteristic of Thermal Waters and Its Classification**

Geochemistry of thermal water mainly used to provide estimates of the surface reservoir temperature and the general chemical characteristics. This information helps further in the selection of geothermal areas for more detailed surface explorations and exploratory drilling. Various chemical geothermometers have been proposed for this purpose, based on different relationships and reactions between the fluid and the host rock.

According to Todaka, hot spring thermal water at Mangho Pir and Karsaz zone are classified as Cl-HCO$_3$ and Cl-SO$_4$ type (Fig 4). The physical features of these hot spring in Karachi are shown in table 1. It is believed that the presence of high contents of HCO$_3$, Hg and H$_2$S or SO$_4$ in near-surface waters are indicators of high temperatures at depth. Similarly, high Cl/F ratio and Cl/SO$_4$ ratio may indicate the existence of a high temperature system as well. Generally, geothermal water contains a variety of elements with different solubility resulting from the water rock interaction when the water flows through the rocks at the ambient temperature. The source of the hot waters in both areas assumed to be the fracture and fissures in subsurface host rock. It also contain high value of Na and Cl which is due to the precipitation and mixing with sea water, especially in Karsaz hot spring, because of its close proximity to Arabian Sea coast. Classification of thermal water has shown in Fig 5. (Todaka)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sample (K1)</th>
<th>Sample (K2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.45</td>
<td>7.87</td>
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<tr>
<td>EC (us/cm)</td>
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<td>7910</td>
</tr>
<tr>
<td>TSM (mg/l)</td>
<td>1560</td>
<td>5780</td>
</tr>
<tr>
<td>Na (mg/l)</td>
<td>355</td>
<td>1400</td>
</tr>
<tr>
<td>K (mg/l)</td>
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<td>81</td>
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<tr>
<td>Ca (mg/l)</td>
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<td>Mg (mg/l)</td>
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<tr>
<td>Cl (mg/l)</td>
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<td>1971</td>
</tr>
<tr>
<td>SO$_4$ (mg/l)</td>
<td>221</td>
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</tr>
<tr>
<td>HCO$_3$ (mg/l)</td>
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<td>243</td>
</tr>
<tr>
<td>CO$_3$ (mg/l)</td>
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<td>0</td>
</tr>
<tr>
<td>SiO$_2$ (mg/l)</td>
<td>24</td>
<td>46</td>
</tr>
<tr>
<td>Water Temp at field</td>
<td>50.3</td>
<td>39.0</td>
</tr>
</tbody>
</table>

**Table 1. Chemical composition of water from Mangho Pir & Karsaz (Todaka 1998)**

To a large extent, chemical content of the water controls, its properties with regard to utilization and therefore it is very important to have a good database of it at an early stage. Low-temperature geothermal waters in crystalline rocks are usually dilute, i.e. have low values of total dissolved solids (<500 mg/l), and no harmful trace elements. Such waters can often be used directly, e.g. for heating of houses or swimming pools and even for direct agricultural use or drinking. However, if the...
chemical content is high, such as with low-temperature fields in sedimentary rocks, high temperature fields and brine fields in general, indirect usage may be necessary in order to utilize the energy and avoid scaling or corrosion in pipes and systems.

![Hexadiagram showing chemical composition of water from Karachi hot springs (K1, K2)](image)

Often, heat-exchangers of various types can be used so that hot geothermal water heats up dilute cold water which is then used for the heating systems or agricultural purposes. Sometimes mixing chemicals can solve these problems. Of special importance is keeping the systems closed, so the water does not absorb oxygen, as this increases the corrosive properties of the hot water. For electrical production, geothermal steam can usually be used directly, though in some cases mixing chemicals may be necessary to avoid scaling or corrosion.

![Classification of water from Karachi thermal spring (Mangho Pir, Karsaz)](image)

### 5.2.2. Reservoir Temperature

Reservoir temperature are usually estimated by chemical geothermometers, which can be used in both high- and low-temperature geothermal systems. Many chemical geothermometers have been developed during the past two decades, the most commonly used ones being the silica geothermometers (e.g. Fournier and Potter, 1982; Arnórsson et. al. 1983) and Na-K I Na-K-Ca (Mughal 242 Report 9). These geothermometers often give different reservoir temperatures for the same fluid. This may be due to
lack of equilibrium between minerals and thermal fluids or mixing of cold water during the upflow. It is also suggested that the thermometers are not suitable for some area due to specific geological conditions. (Fig. 6) Different rates of response may show temperatures from different depths and/or ages. The most commonly used geothermometers is the silica geothermometers. The quartz geothermometers is used for prediction of high temperatures (> 180°C), while the chalcedony geothermometers is used for low reservoir temperatures. The solubility of silica is affected by the pH values of the fluid, thus, pH has to be accounted for when it is greater than 9.5. In order to deal with high pH and hard waters that do not yield reliable temperatures when using the silica geothermometers, the Na-K and the Na-K-Ca geothermometers were proposed and have been used successfully in such systems.

According to Todaka and Shuja the reservoir temperature of Mangho Pir and Karsaz is estimated in range from 71° to 89° by the Silica geothermometers and from 138° to 170° C by the Na-K-Ca geothermometers showing in table 2.

![Fig. 6. Conceptual model of a geothermal system at Mangho Pir (K1) and Karsaz (K2) area, Karachi, showing the probable transfer of heat from the subsurface (Source: GSP / JICA, 1988)](image)

Usually, geothermometers (Fournier and Trusedell, 1973; Ambrsson et al., 1983) and it’s relatively show high temperature than Silica Geothermometers. However, in this case it is apparent that the reservoir temperature is comparatively not much higher. This may be due to chemical composition of the hot water, which is subjected to the influence of mixing of sea water and the quantity of silica content is also very low. Hence, silica geothermometers may indicate low reservoir temperature less than 100° C. (Todaka, Shuja)

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Sample K1</th>
<th>Sample K2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
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</tr>
<tr>
<td>Thermometer</td>
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<td></td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>Adia. 76</td>
<td>Conc. 71</td>
</tr>
<tr>
<td>Na-K-Ca</td>
<td>138</td>
<td>170</td>
</tr>
<tr>
<td>Mg</td>
<td>170</td>
<td>18</td>
</tr>
</tbody>
</table>

### 6. Discussion

Nearly half of the developing countries have rich geothermal resources, which could prove to be an important source of power and revenue. Geothermal projects can reduce the economic pressure of developing country fuel imports and can offer local infrastructure development and employment. The advantage of geothermal power in a country like Pakistan, where coal and oil resources are limited, is evident. The geothermal resources can provide a clean source of energy. Direct utilization for bathing and heating and possibly electrical production may satisfy local needs in villages and small towns. The area belongs to the sedimentary basin and along the whole margin zone, the presence of thermal springs and abnormal high temperature in oil/gas well contribute a positive indication of geothermal
energy potential in Indus basin marginal zone. Besides geochemistry, deep reaching methods can be preferred, such as resistivity sounding and gravity. However, high salinity of the sedimentary rocks may, in some places, pose a difficulty for the usefulness of the resistivity method. Gradient wells could be used with advantage to map local near-vertical structures.

Due to the subtropical climate in the southern part of the area, such as near Karachi and Dadu district, and with a resource of relatively low temperatures, a study of utilization prospects needs to be done before any expensive exploration programme. Hot water or steam springs, geysers or fumaroles are type of hydrothermal energy resources which are continuously flowing in many areas of Pakistan. Many of abandoned deep dry oil & gas wells with high temperature having more than 105°C show deep geothermal energy resources could produce geothermal energy for power generation in Pakistan. However detailed investigations are required to evaluate the potential of each well for power generation.

References

Abstract

Developing countries like Pakistan are composed of numerous small villages and deserts, making it economically unviable to extend the electrical national grid to every location where it is needed. These countries still struggle with the lack of water in many villages and farms. These factors, along with the increase in the price of conventional energy sources and concerns regarding sustainable growth, have led to utilization of solar energy to generate the off-grid electric power is a prominent technology, which is utilized in photovoltaic based water pumping system for agriculture and community water supply in this study. Pakistan has good sun exposure almost all year and many of its villages still have lack of water.

The target area in this research is Tharparkar desert of Pakistan. This work presents techno-economic analysis of photovoltaic based water pumping system by using mathematical model and RETScreen software.

Fuel saving per annum for selected six villages in Tharparkar has estimated as 1567 L to 5622 L. The simple and equity payback periods has estimated as 1.6 to 2.5 and 1.5 to 2.4 respectively. Annual reduction in GHG emission calculated as 3.8 to 14.9 tCO2. Therefore, enthusiastic results have been obtained because of the occurrence and estimation of solar energy for water pumping. The results reveals that indigenous solar potential capability can be used to produce the required amounts of electrical power to meet the water drinking, non-drinking and cultivation water needs of the desert communities in environmentally sustainable manner.

Keywords: Solar Water Pumping; Photovoltaic; mathematical model; RETScreen; Off-grid.

1. Introduction

Humans cannot survive without energy and a certain amount of daily intake is essentially required to avoid a condition leading to starvation. To survive, a human requires at least the level of energy amounting to 5443 Joules a day, and if fewer calories are consumed, it could cause death due to starvation (Edlin and Golanty 2000). These amounts of energy are produced from food and water. The question arises as to whether the necessary amount of energy can be provided to all the areas equally, especially in the isolated places such as desert. Water is the primary source of life for humanity and one of the most basic necessities for rural development.

In developing countries, like Pakistan water pumping energy requirement is meeting out through electric and diesel power and the electric power is supplied for a limited period of the day. This duration is not sufficient for domestic, irrigation and livestock purpose, on the other hand diesel water pumping system would be used but its operation is costly because of high diesel fuel cost. Many researchers worked on the sustainable energy consumption, renewable energy sources, energy efficiency in developing countries (Akella et al 2007, Brunicki et al 2002, Elliot 2004 et al, Panwar et. al, 2011, 2013).

Solar photovoltaic (PV) water pumping has been recognized as suitable for grid-isolated rural locations in developing countries such as Pakistan where there are high levels of solar radiation. Solar photovoltaic water
pumping systems can provide water for irrigation without the need for any kind of fuel or the extensive maintenance required by diesel pumps.

The climate data on solar radiation per unit area and per unit time at Tharparkar, Pakistan on horizontal and tilted surface reveal higher values of radiation during summer months and lower in the winter months. An average solar radiation on horizontal surface is 5-7 kwh/m2/day whereas cleanliness index 0.6 to 1 (Shah, 2012).

However, in many areas of Tharparkar, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive. Furthermore, diesel fuel is often expensive and not readily available in rural areas of many developing countries (Oi, 2005). The consumption of fossil fuels also has a negative environmental impact, in particular the release of carbon dioxide (CO2) into the atmosphere.


Fig. 1. Schematic diagram of solar photovoltaic water pumping
2. Analysis

The analysis has been performed by using the RETScreen Clean Energy Project Analysis (CEPA) software, which is able to perform energy production analysis, financial analysis, and GHG emission analysis.

![Fig. 2.1. RET Screen Model Flow diagram](image)

### 2.1. Calculation of Hydraulic energy

For calculation of hydraulic energy for all selected villages in Tharparkar are carried out using mathematical equation. The basic parameter for calculation of hydraulic energy is required daily volume of water $Q$ in (m3/d) that has to be lifted to a height $h$ in (m) the daily hydraulic energy demand $E_{hydr}$ (in J).

$$E_{hydr} = 86400 \rho g Q h (1 + \eta_f)$$  \hspace{1cm} (2.1)

Where
- $g$ = acceleration of gravity (9.81 m s\(^{-2}\)),
- $\rho$ = density of water (1000 kg m\(^{-3}\)), and
- $\eta_f$ = factor accounting for friction losses in the piping.

Given the pump system efficiency pump $\eta$ this hydraulic energy translates into an electrical energy requirement $E_{pump}$:

$$E_{pump} = \frac{E_{hydr}}{\eta_{pump}}$$  \hspace{1cm} (2.2)

Energy delivered is simply:

$$E_{d\text{daily}} = \eta_{pump} \min(E_{pump}, E_A)$$  \hspace{1cm} (2.3)

Where
- $E_A$ = energy available from the array.

Daily water delivered is obtained from...
\[ Q_{dvd} = \frac{E_{dvd}}{86400 \rho g h (1 + \eta_f)} \]  \hspace{1cm} (2.4)

Suggested array size is calculated simply by inverting the above equations and is therefore equal to

\[ \frac{E_{pump}}{\eta_A} \]  \hspace{1cm} (2.5)

Where: \( \eta_A \) = overall array efficiency
Table 2. Basic Parameters for Economic Evaluation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual O/M cost</td>
<td>SPV pump</td>
<td>Fraction</td>
</tr>
<tr>
<td></td>
<td>Diesel pump</td>
<td>0.10</td>
</tr>
<tr>
<td>Capital cost of the system</td>
<td>SPV pump (2.4 kWp)</td>
<td>Millions</td>
</tr>
<tr>
<td></td>
<td>SPV pump (4.6 kWp)</td>
<td>Millions</td>
</tr>
<tr>
<td></td>
<td>SPV pump (1.2 kWp)</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Diesel pump (2 kW)</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>Diesel pump (4kW)</td>
<td>0.075</td>
</tr>
<tr>
<td>Market price of diesel</td>
<td>Litter</td>
<td>1.10</td>
</tr>
<tr>
<td>Overall efficiency of the diesel engine pump</td>
<td>Fraction</td>
<td>0.40</td>
</tr>
<tr>
<td>Overall efficiency of the SPV pumps</td>
<td>Fraction</td>
<td>0.40</td>
</tr>
<tr>
<td>Specific fuel consumption in diesel engine pump set</td>
<td>MJ/l</td>
<td>43.5</td>
</tr>
<tr>
<td>Useful lifetime of the SPV pump</td>
<td>Years</td>
<td>25.0</td>
</tr>
<tr>
<td>Useful lifetime of diesel engine pump</td>
<td>Hours</td>
<td>20,000</td>
</tr>
<tr>
<td>Miscellaneous losses of SPV pump</td>
<td>Fraction</td>
<td>5.0</td>
</tr>
<tr>
<td>Inflation rate</td>
<td>Fraction</td>
<td>10.8</td>
</tr>
</tbody>
</table>


2.2. Economic analysis

Figure representing the cumulative cash flowchart for domestic and irrigation in chosen villages of Tharparkar by means of RETScreen software. In this chart simple payback period and equality payback period are illustrate. Length of the total time taken by the project is equity payback period, in situation when net cash flow results zero. Also, in the chart, the specified length of time to earn its initial cost is simple payback period. As earlier the project cost would be recovered, the investment will result more cost effective. Parallel axis is shown in years, which indicates life of project, while perpendicular axis is represented in PKR, in cumulative cash flowchart.

Fig. 2.3. Cumulative Cash flow Graph of Village Nabisar

Fig. 2.4. Cumulative Cash flow Graph of Village Singharo
Fig. 2.5. Cumulative Cash flow Graph of Village Malo Bheel

Fig. 2.6. Cumulative Cash flow Graph of Village Kasbo

Fig. 2.7. Cumulative Cash flow Graph of Village Sarh

Fig. 2.8. Cumulative Cash flow Graph of Village Rarkou
3. Result and Discussions

The PV based water pumping system seems a promising option for energy conservation and it is helpful for reducing the CO2 emission. PV panels ranging from 2400Wp to 46800Wp are sufficient for domestic, irrigation and livestock’s purposes for filling the water requirement in selected village of Tharparkar. Fuel saving per annum for selected six villages in Tharparkar has estimated as 1567 L to 5622 L. The simple and equity payback periods has estimated as 1.6 to 2.5 and 1.5 to 2.4 respectively. Annual reduction in GHG emission calculated as 3.8 to 14.9 tCO2. As per the environment, off Grid, fuel price and fuel import concerned with the analysis there is only PV based water pumping system can be used to produce the required amounts of electrical power to meet the water drinking, non-drinking and cultivation water needs of the desert communities in environmentally sustainable manner.

![Simple & Equity Payback Period of PV pumps](image1)

![Annual Fuel Saving (PKR, Millions)](image2)
4. Conclusions

The technology is not only reduces the GHG emissions but also help in fuel conservation. The PV based water pumping system is off-grid technology means it can be utilized where grid energy is not accessible. It is economically viable option. This technology is also increasing the sustainability index. It can save money, time and environment of the world.

References


Shah, S.A; (2012), Analysis of solar energy production, utilization and management for facilitating sustainable development in and around the deserts of Pakistan. PhD Thesis. The School of Mechanical, Aerospace and Civil Engineering (MACE), at the University of Manchester, United Kingdom (UK)
Comparison of thin film versus crystalline PV modules for utility-scale electric power production in Pakistan

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Abstract

Today energy has become an important global concern. The development and economic growth of a country is directly connected with the progress in the energy sector and energy availability. Combustion of fossil fuels is not only leading towards the depletion of their resources, but also causing hazardous environmental impacts. That’s why the world is searching for cleaner and sustainable resources which can replace fossils. Recent surveys show that renewables have maximum consumption growth by source in the past few years. Among the renewable resources, Solar PV offers huge potential as well as is relatively easy to deploy.

In this study, we first assess the feasibility of different sites in Pakistan for installation of solar photovoltaic (PV) technology to produce utility-scale electric power. Energy performance of solar PV in ten different cities of Pakistan is extensively studied. Furthermore, nowadays consumers are attracted towards deployment of thin film solar PV modules instead of crystalline silicon solar cells due to low manufacturing costs. Here, we also determine the economic viability of thin film PV and crystalline Si (c-Si) PV modules, for a 20MW power plant in Bahawalpur, Pakistan uses NREL system advisor model (SAM). The weather data for this model is obtained from National Solar Radiation Data Base (NSRDB). Upon detailed investigations and analyses, it is revealed that thin film PV is more suitable than crystalline Si due to availability of the large barren area in Pakistan. Capacity Factor (CF) for thin film and c-Si PV is 18.86\% and 18.54\% respectively. Performance Ratio (PR) is calculated to be 0.76 and 0.75 respectively. Also, simulation results show that total annual energy produced by thin film versus c-Si is 33,041 MWh and 32,469 MWh respectively. Finally, analysis of the CF and PR for different cities of Pakistan demonstrates significant annual energy production for utility-scale electric power production as compared to other European countries.

Keywords: Solar energy; Photovoltaic system; Utility scale; System advisor model; performance ratio;

1. INTRODUCTION

The increment in consuming energy on our planet is threatening. The world energy consumption was about 1.17\times10^{15} in 2005. [1] This trend estimates the energy consumption will increase 53\% from 2008 to 2035 [2]. Energy consumption for the OECD (organization for economic co-operation) countries i.e. U.S.A, Canada, Germany etc. increase only 0.6\% per year while for non-OECD countries like Pakistan, China, India increase up to averagely 2.3\% per year. This immense amount of increment in energy demand in non-OECD countries invoke to produce low cost and environment
friendly production of electricity.

On average the Sun irradiance on Earth surface is \( \sim 5 \text{ kWh/m}^2\text{day}^{-1} \). With this solar irradiance it’s easy to fulfil the increasing energy demands. The natural resources of energy on earth rapidly depleting and also the fossil fuels had bad impact on environment make the renewable as a perfect alternative. While wind and hydro energies have been used for many years, the solar market has been expanding rapidly as more efficient and cost effective solar devices begin to be developed.

Among solar devices, silicon cells first come to mind. Efficiencies upwards of 15-20% have been achieved for crystalline silicon devices [3]. However, the cost of purifying crystalline silicon is very high and energy intensive. Due to this high cost, focus has shifted to thin film solar cells, which have greatly reduced cost of production. Currently the most popular thin film device uses CdTe and CuIn\(_{x}\)Ga\(_{1-x}\)Se\(_2\) (CIGS) as the light-absorbing layer and thus far cell efficiencies of up to 20.4% have been recorded [4].

Pakistan is struggling since last decade to fulfil its energy demand. Pakistan is huge potential of solar PV. For the last decade or so, Pakistan has been facing a severe energy crisis. With installed generation capacity of about 23,600 MW,
4th International Conference on Energy, Environment and Sustainable Development 2016 (EESD 2016)

a. Crystalline Si

Crystalline silicon is promising technology and well established in world. More than 80% of PV market share by crystalline Si. The first generation solar cells are made of crystalline silicon, which is also known as traditional or conventional solar cell were developed in 1950s which is still used widely across the world. Crystalline solar cells are made of silicon wafers about 160 to 200 µm, which is also called wafer-based solar cell.

b. Thin film (CdTe)

A second generation solar cell is thin film solar cell which is made of depositing one or more thin layers of photovoltaic material on substrate, substrate is made-up by metal, plastic or glass. There are several solar cell such as copper indium gallium diselenide (CIGS), cadmium telluride (CdTe) and amorphous silicon (a-Si) where thin film technology is used. [5]. Among the thin film solar cells, CdTe mostly used as commercial solar cell. It’s a lower cost as compared to conventional crystalline silicon for megawatt system. Its energy payback is less than a year as compared to silicon which is 2.3 year [6-8]In the world the largest photovoltaic power plant CdTe solar cells are used in Topaz Solar Farm (550 MW) and Desert Sunlight Solar Form (550 MW) in California. It contributes 5.1% of the worldwide, more than half of the thin film market is all about in 2013[9]. The company, First Solar which is situated at Tempe, Arizona is the prominent manufacturer for the CdTe.

<table>
<thead>
<tr>
<th>Table 1. Comparison of Mono-Si Vs CdTe module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Cell efficiency</td>
</tr>
<tr>
<td>Derate cell to module efficiency</td>
</tr>
<tr>
<td>Module efficiency</td>
</tr>
<tr>
<td>Wafer thickness / layer thickness</td>
</tr>
<tr>
<td>Kerf loss</td>
</tr>
<tr>
<td>Silver per cell</td>
</tr>
<tr>
<td>Glass thickness</td>
</tr>
<tr>
<td>Operational lifetime</td>
</tr>
</tbody>
</table>

Source: IEA-PVPS, Life Cycle Assessment, March 2015 [10]

2. MODELLING & METHODOLOGY

The computational software used in this project was SAM (System Advisor Model) which facilitates the researcher involved in renewable energy industry to enhance the performance and assist with financial problems. System advisor model use to predict the energy performance, grid connectivity installation and operating cost for specific designed parameters and inputs. Weather data file used of national solar radiation data base. The most recent version of NSRDB was established by physical solar model. Data available in this version is from 1998 to 2014.meteorological data for NRSDB is comprised of 30-minutes solar. Data available along the area by latitude 60° N on north and -20° S on south, and longitude 175° W on the west and 25° E on the east.

In our work modeling is based on location, type of module used and assess the energy performance of utility scale PV solar plant at ten different locations in Pakistan.

a. Capacity factor calculation

The capacity factor is defined as the ratio between the system's predicted electrical output in the first year of operation to the nameplate output, which is equally defined as the amount of energy generated in a year operated at nameplate capacity.

\[
CF = \frac{\text{Net Annual Energy (kWhc/yr)}}{\text{System Capacity (kWdc or kWac)}} \times \frac{1}{8760 \text{ (h/yr)}}
\]

The Nameplate capacity of the system depends on the modelled technology. One of the feature using same is it to convert the units to an appropriated value such as (MW, kW, or W) before using in their calculations. A DC power rating is used for photovoltaic model and for other AC power rating is used.

Capacity is to be defined as the optimal power generation of the power plant usually measured in kW, MW or GW rating. Which is also rated the efficiency of that plant is actually the capacity factor.
b. Performance ratio calculation

Industrialist uses a different method for the calculation of performance ratio. SAM method proposed by NREL of USA [5]. Performance ratio calculated by SAM as follows

\[
P.R = \frac{\text{Annual Energy (kWh)}}{(\text{Input Radiation (kWh)} \times \text{Module Efficiency} \%)}
\]

Annual energy is the system total net AC electrical o/p per year, whereas the i/p radiation is the total solar energy incident on the array after seeding and soiling for the year. Module Efficiency is the module nameplate conversion efficiency.

3. DATA COLLECTION

3.1 Viability of 20 MW solar PV plants in Pakistan

Pakistan country has huge potential of solar PV. As the cost of solar PV decreasing worldwide. Now there is chance for thirds world countries to take benefit from it and enhance the quality of life. Here below is energy assessment of PV of different cities of Pakistan Using system advisor model.

Table 2. 20MW solar PV system in different cities of Pakistan

<table>
<thead>
<tr>
<th>City</th>
<th>Solar Radiation (kWh/m2/Day)</th>
<th>Annual Energy (GWh)</th>
<th>Capacity factor (%)</th>
<th>Performance Ratio</th>
<th>E yield (kWh/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swat</td>
<td>5.18</td>
<td>33</td>
<td>18.8</td>
<td>0.79</td>
<td>1651</td>
</tr>
<tr>
<td>Peshawar</td>
<td>5.16</td>
<td>31</td>
<td>17.7</td>
<td>0.75</td>
<td>1547</td>
</tr>
<tr>
<td>Islamabad</td>
<td>4.02</td>
<td>30.7</td>
<td>17.5</td>
<td>0.76</td>
<td>1534</td>
</tr>
<tr>
<td>Lahore</td>
<td>4.68</td>
<td>29.5</td>
<td>16.8</td>
<td>0.74</td>
<td>1475</td>
</tr>
<tr>
<td>Faisalabad</td>
<td>5.03</td>
<td>30</td>
<td>17.1</td>
<td>0.74</td>
<td>1501</td>
</tr>
<tr>
<td>Bahawalpur</td>
<td>5.13</td>
<td>32.3</td>
<td>18.4</td>
<td>0.75</td>
<td>1614</td>
</tr>
<tr>
<td>Jacobabad</td>
<td>5.17</td>
<td>32.9</td>
<td>18.8</td>
<td>0.74</td>
<td>1648</td>
</tr>
<tr>
<td>Gilgit</td>
<td>4.57</td>
<td>33.8</td>
<td>19.3</td>
<td>0.84</td>
<td>1694</td>
</tr>
<tr>
<td>Karachi</td>
<td>5.34</td>
<td>35.5</td>
<td>20.3</td>
<td>0.76</td>
<td>1777</td>
</tr>
<tr>
<td>Quetta</td>
<td>5.46</td>
<td>38.2</td>
<td>21.8</td>
<td>0.78</td>
<td>1912</td>
</tr>
<tr>
<td>Sibi</td>
<td>5.23</td>
<td>34.6</td>
<td>19.8</td>
<td>0.75</td>
<td>1731</td>
</tr>
</tbody>
</table>

3.2 20 MW PV plant at Bahawalpur

20 megawatt AC solar PV system analysed by system advisor model located at Bahawalpur, Punjab Pakistan. System is analysed for crystalline Si and CdTe thin film solar cells. Parameter of analysis are annual energy production, capacity factor and performance ratio.

3.2.1 Energy production by c-Si

For analysis mono-c-Si (Sun Power SPR-E1910-COM) module is used. Capacity of each module is 310.1 DC Watts. Total energy produced by c-Si in year is 32,459,000 kWh.

3.2.2 Energy production by thin film

For thin film CdTe solar cell were used. Capacity of each module is 117 dcW. Total energy produced per year is 33,041,000 kWh.
4. DISCUSSION

System advisor model to used analysed the performance of utility scale PV system for the different location in Pakistan. Assessment is on the base of solar radiation data used for different location. In Table.2 performance of solar power in different cities of Pakistan. In most cities, energy yield is greater than 1500 kWh per kW of nameplate capacity. Performance ratio is greater than 0.75 and capacity factor is also good above 18%. At the base of above two parameters, solar PV is suitable in most cities. But the problem of land for utility-scale production. So in Table.2 on the base of C.F. P.R, and cheap & vast land availability south-west area of Pakistan like Quetta, Sibi, Jacobabad and Bahawalpur are much suitable for the utility-scale production of electricity.
In the comparison of mono-crystalline silicon solar cell and Cadmium telluride, the thin film is based on their energy out. It already is proven that efficiency of the thin film is less than crystalline technology but the cost of production make thin film competitive with crystalline technology. Due to different properties of material both technologies have different output power. Fig.2 and Fig.3 show that total energy produced by Mono-c-Si system which fed to the grid is 32,469,000 kWhac and the CdTe system is 33,041,000 kWhac. A CdTe system producing more energy as they both have same input radiation and nameplate capacity is due CdTe is more resistant against high temperature. It produces 10% more power as the temperature of module rising up to 60oC or above.

Loss diagrams Fig.4 and Fig.5 tells the story of losses in both solar PV technologies. In both PV systems are same except the module loss in mono-c-Si is 15% and 13.4% for CdTe base PV system. This module loss makes difference in the final energy output of the both system Losses
5. CONCLUSION

Utility-scale Solar PV system analyzed for ten different cities of Pakistan with various locations and different climate using the NREL System Advisor Model (SAM) software. Performance comparison of crystalline silicon with the thin film solar cell for utility scale power production in Bahawalpur area also done by using the SAM. Results show that Quetta is the most suitable city for utility-scale PV power production with capacity factor 21.8% and performance ratio 0.78. Simulation result also suggests another city like Bahawalpur, Jacobabad, and Sibi also the good and exploitable potential for utility-scale PV system.

In the comparison of crystalline silicon with Cadmium telluride (CdTe), thin film result shows that annual energy produced by the thin film is greater than energy produced by crystalline silicon (Mo-c-Si). Annual energy produced by CdTe thin film is 33,04,000 kWh and by Mo-c-Si is 32,469,000 kWh. Capacity factor and performance ratio of CdTe and Mo-c-Si are 18.86% & 18.54% and .76 &.75 respectively.

The result also reveals that Pakistan is a tremendous amount of solar PV potential for Megawatt installation. Thin film solar PV is more feasible as compared to costly crystalline silicon technology.

References

263. In-Pipe Hydropower, an Unexplored Green Energy

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Abstract

The development of urban areas has rapidly increased the global energy demand. Of which renewable energy system can provide clean, reliable, secure, competitive energy to meet this demand. Despite of various renewable resources available, the in-pipe hydropower is one of the unexplored green forms of energy. These in-pipe water-to-wire power systems are considered to be more interesting and innovative for the generation of power from excess head pressure of water pipelines that can be the solution for the growing energy demand. The in-pipe power systems already proved to be successful. The in-pipe water-to-wire power system would be helpful to recover the energy that is used to treat or supply water. The energy is obtained from the pipe water; where the turbine will rotate due to flow and pressure of water, and the rotating turbine is connected to a generator to generate electricity. This paper illuminates one of the important pragmatic aspects of production of green energy and its integration to grid and other green energy sources.

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Keywords: In-pipe; Hydropower; Green energy; water to wire

1. Introduction

Energy and water are strongly linked. A lot of energy is consumed to deliver water and a lot of water is needed to produce energy. The cost of Energy is a big issue for municipal water utilities—waste and drinking water facilities consume a lot of energy to treat water. To recover the consumed energy a new technology known as in-pipe or in-conduit hydropower has been introduced. The in-pipe hydropower system is water to wire energy recovery based solution. This renewable power system enables agricultural industrial and municipal facilities to produce low cost, clean and reliable electricity from gravity fed water pipes. The system includes in-pipe hydrodynamic turbine and generator to capture clean energy from fast flowing water of large gravity fed pipes, converting the in-pipe water into continuous source of electricity. The recovery of untapped energy is done by the excess head pressure in gravity fed pipelines without affecting the operations. The hydrodynamic turbines are designed and tested in order to maximize the power production without disturbing the flowing water. A company named Lucid energy is testing and designing this in-pipe system since 2007. The company developed and installed lucid pipe (in-pipe) power system in Portland. They have installed 200kW power system in water pipelines of Portland. Which is able to produce an average of 1100Mwh of clean energy per year, enough energy to light up to 150 houses? [1][2]

1.1 Advantages

- It produces neat and clean energy (it does not affect environment).
- It does not depend upon weather (like solar system depends upon sun and wind system depends upon air).
• It does not affect the quality of drinking water.
• It is the one of the cheapest way to produce power (where as in case of solar and wind they will cost 3 or 4 times more to produce same amount of energy)
• It can also be installed in Agricultural, industrial, wastewater pipeline.
• Electricity can be produced all the time with the flow of water.
• Quick installation
• Recovers process-based energy

1.2 Applications

The system can be installed in:
• Water pipelines
• Waste water pipelines
• Tap pipes
• Agricultural
• Industrial

2. The system

The system depends upon two main components [4]

• In-pipe hydrodynamic turbines
• generators

The idea of the system is that one can fix hydrodynamic turbines in gravity fed water pipes that would start rotating as the water flow through the pipe. More the velocity of water more will be the speed of rotation of the turbine, which will result more extraction of energy. The turbine shaft is connected to generator set. Voltage is generated at the terminals of generator. The design of system is main concern. It consists of a hydro-electric generator which is connected externally and a hydrodynamic turbine that is placed inside the flowing water of pipe. The turbine rotates with the flow of water and the shaft of rotating turbine rotates the rotor of generator, in result the electricity is generated. Then the generated electricity is transferred to the grid. The design of turbine is key point to obtain more clean energy from the flow of water. A number of blades and a shaft at the central part are combined to form a hollow turbine. The blades are specially designed to reduce the resistance to the flow of water. The blades are sized according to the need of project (the thinner, the better).

3. Methodology

To give a recovery based and green energy solution to the crisis of energy in Pakistan, we had done this research. Research was done from the reports and findings of lucid energy’s Portland project and Toronto’s sewerage pipeline project. The project is water to wire hydropower system, consisted of turbine and generator. Lucid energy had installed this system in Portland’s water pipelines and Toronto in sewerage pipelines, turning the pipelines into continuous source of generating electricity. Lucid energy is testing this system since 2007. They had tested 9 turbines in 2011, measuring their vibrations with piezoelectric accelerometer, changes in pressure with piezoelectric pressure sensor and working speed with tachometer. The tests had been conducted to make the design of system less noisy and more sufficient for the production of electricity without disturbing the flow of water. All the 9 turbines had different swept area; their resulted concluded that swept area is one of the major factors for the increase in output power. The swept area of turbine should be smaller than area of remaining pipe. The smaller swept area will cause the increase in velocity of water, which will result in more production of power (higher the velocity, higher will be the power generated). The analysis and calculation for the extractable power were made on data provided by lucid energy reports and their present work, the data includes formula for the extractable power and parameters like head, flow rate and hydropower system efficiency. We had also done a case study for Jamshoro, based on data provided by lucid energy. The case study of Jamshoro is just to give idea that this system can be installed in Pakistan for producing clean energy with low cost. We had calculated the power extractable from this system, if it is installed in Jamshoro. The parameters included in calculations are flow rate, efficiency of system and head of Jamshoro which is 13m. [5] [6] [7].
3.1 Results

The case study has been considered for Jamshoro.

(Case study - Jamshoro)

Table 1. Values for parameters [1]

<table>
<thead>
<tr>
<th>S#:</th>
<th>Parameters</th>
<th>Formula</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow rate</td>
<td>Velocity x pipe area</td>
<td>1.78 m^2/s</td>
</tr>
<tr>
<td>2</td>
<td>Head Elevation</td>
<td></td>
<td>13 m</td>
</tr>
<tr>
<td>3</td>
<td>Efficiency</td>
<td>Output/Input x 100%</td>
<td>90%</td>
</tr>
</tbody>
</table>

3.1.1 Formula for extracted power from system. [5]

Total energy available (kW) = \( \frac{H \times F \times \text{Efficiency}}{11.8} \)

Where:
- \( H \) = available head in feet
- \( F \) = flow rate in cubic feet per second
- Efficiency = efficiency of turbines
- 11.8 is a constant for converting the equation to kW

Total energy available (kW) = \( \frac{13 \times (2.20 \text{ m})}{(1.78 \text{ m}^3) \times (3.20 \text{ m}^3)} \times 0.9 \)

Total energy available (kW) = 204.27 kW (it is energy extracted per pipe)
Fig. 3. Transferring the power to grid

Fig. 4. In-power system model of Toronto waste water pipeline
3.1.2 Graph showing relation between Powers generated and Head drops:

4. Conclusion

In-pipe power system is one of the cheapest way to produce clean energy. Once the system is installed it will produce energy with even lower cost. The system can be installed in water pipes and sewerage pipes, making it the reason of recovery of energy that is wasted to treat and supply water through the pipe. The process of recovery of clean energy can be done all the time with the flow of water as it is independent of weather. The other advantage of system is its efficiency, which is 90 percent as it is a hydropower system. The installation of system will also help us in management of all water networks without affecting the quality of water. This system can be the solution for crisis of energy in Pakistan, as it will produce clean energy from the already following water in pipes so there will be no need of any other source. This idea will be helpful in retrieving the energy, previously consumed on the supply of water in industrial and agricultural work, which will reduce the cost of farming and industrial work. [3] [6]

References

269. Municipal Solid Waste to Energy in Pakistan: A case study of Haripur District (Pakistan)

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Abstract

This study attempts to estimate the energy recovery potential from Municipal Solid Waste (MSW) in Haripur district. The data gathered in this study revealed that Municipal Authorities (MAs) are failing to treat the collected waste and it is disposed without reuse, recycling or recovery. It is estimated that approximately 3600 metric tons of highly combustible waste is disposed by the MAs in Haripur district, which could be used to produce up to 3,222,960 kWh of energy every year. If recovered recyclable only, the amount of waste going to landfill can be reduced by 59%. However, with the help of energy recovery, the total volume of waste can be reduced by 90% while contributing to meet the ever-rising energy demand of the country. Based on the quantity and composition of waste available in the district, this study recommends the use of gasification technology for energy recovery although the gasification plant requires comparatively frequent cleaning and maintenance than other thermo-chemical waste to energy conversion techniques. In terms of cost and benefit of waste to energy, the Levelized Cost of Electricity (LCOE) was identified to be 10.87 Pakistani Rupees (PKR) per kWh. The current selling price of residential electricity is between 12-13.33 PKR per kWh. Though the overall economic profit from the sale of electricity is low, the environmental public health benefits and the potential rise in energy consumption prices in future makes the adoption of waste to energy technology promising.

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Keywords: Municipal Solid Waste, Waste to Energy, Environmental Public Health

1. Introduction

The state of Municipal Solid Waste Management (MSWM) in most developing countries is dismal. MSW produced in developing countries is either not collected, or it is inadequately disposed after the collection. Poorly managed MSW releases pathogens and toxic compounds into the environment affecting the environmental quality. In turn, poor environmental quality threatens public health [23].

In the context of Pakistan, JICA and PK-EPA [14] estimates that 55000 tonnes of MSW is produced in urban areas of Pakistan every day. A large quantity of this waste is dumped in unscientific way without treatment. According to Batool and Chaudhry [5], relevant MSWM authorities collect 60% of total waste generated in the cities of Pakistan. A large quantity of this waste (up to 90%) is dumped openly. Such waste management practices are causing serious environmental public health damage. Environmental Protection Department of Pakistan highlights that poor MSWM is causing skin diseases, eye infections, and dust related breathing problems in children and adults [8].

In contrast, MSW in developed world is not only collected efficiently but also used as a resource preserving the public health and the environment. Hoornweg and Perinaz highlights that the average MSW collection rates in developed world are nearly 98% [13]. The waste collected by waste management authorities is mostly reused, recycled and recovered. A good example of MSWM can be seen in Germany. It produced 47.7 million tonnes of MSW in 2010. Approximately, 62% of total waste produced was recycled, 37% was incinerated to produce energy and the land filling was almost 0% [7].

Pakistan is facing serious energy crisis. According to Kugelman [15], the energy deficits of Pakistan are around 5,000 MW that sometime soared up to 8,500 MW. Power shortage not only affected the lives of ordinary citizens but business also suffered, causing serious economic damage. Deterioration in the
power sector was identified to be a major cause of GDP decline and it shaved off 2 percent of annual GDP growth [19]. The existing literature suggests that a major cause of energy crisis is the cost of electricity production that exceeds the revenue generated from the sale of electricity [4]. For example, the cost of electricity production from Residual Fuel Oil (RFO) is estimated to be 17 Pakistani Rupees (PKR) per unit. In case of High Speed Diesel (HSD), it is 23 PKR per unit [18]. Lahore Electric Supply Company estimates that, an average household consuming 200-700 unit of electricity per month pays between PKR 11-13.33/unit [16]. It suggests due to expensive fuels to produce energy, the cost of production is higher than its sale price. A stabilized, economically feasible, and environmental friendly energy production system may help to fulfil energy demand, grow national economy and improve the quality of life of people. In this context, MSW is an alternative source of energy that can contribute to fulfil the energy demand of country while helping to protect the environment and public health.

The following section presents the current waste management practices in Haripur district, the quantity of waste collected and Energy Recovery Potential (ERP) of collected waste.

2. Methodology

2.1 Introduction of study area

Haripur district is situated in the Khyber Pakhtunkhwa province of Pakistan. The area of the district is 1725 Sq. km [20]. It has 3 Municipal Authorities names Khalabat, Haripur and Ghazi managing MSW in their allocated areas. Fig. 1 shows the geographic location of the district.

2.2 Surveying Questionnaire

A survey questionnaire was developed to assess the current MSW management practices by local MAs in the district and to estimate the quantity and composition of waste. It included open and close-ended questions. All MAs in the district participated in this survey. The data about the composition of waste was gathered in collaboration with Khalabat Township Municipal Authority (MA).

2.3 Energy potential modelling

To estimate ERP of mixed MSW; firstly, total quantity and composition of waste was determined and the weight of inert contents was subtracted from total weight to facilitate the estimation of ERP. Inert contents are inappropriate to be used in WtE system due to lack of energy content. ERP of waste was calculated on the basis of dry mass that is, Total Moisture Content (TMC) of waste was determined and subtracted.

In order to calculate TMC of various components in a sample of mixed waste, the total quantity of each waste component in 1kg of sample was determined in g/kg. The information about the average moisture content of each waste component was taken from the literature [1]. By using the equation (1), specific moisture contents of each component in 1kg of sample was calculated and subtracted from normal weight (as collected by MAs) to identify dry weight.

\[
TMC = \frac{NW}{100} MC
\]
Where TMC is Total Moisture Contents, NW means Normal Weight of each component in g/kg and MC is Moisture Contents in percent.

In a sample of dried mixed waste, each component possesses specific energy contents. Han [11] estimated the Lower Calorific Value (LCV) of various waste components based on dry weight. By using the information about LCV of each waste component, the Total Energy Contents (TEC) of each component was calculated by using equation (2);

\[
TEC = (LCV)DW
\]  

Where TEC is Total Energy Content in MJ/kg, LCV is Lower Calorific Value in MJ/kg and DW is Dry Weight in kg.

Based on TEC of mixed waste, ERP of MSW was calculated by using equation (3);

\[
ERP = (LCV)W
\]

Where ERP means Energy Recovery Potential in MJ, LCV is the Lower Calorific Value of waste and W is total waste quantity in kg.

To facilitate the estimation of total ERP and the selection of appropriate waste to energy conversion technology, characteristics of various technologies were consulted.

2.4 Waste to energy: Cost benefit analysis

Lastly, based on the total ERP, financial cost benefit analysis was performed to assess the economic feasibility of waste to energy in the district. To identify the Levelised Cost of Energy (LCOE), firstly, Fixed Charge Rate (FCR) was determined by the using equation 4.

\[
FCR = \frac{k_d \cdot (1 + k_d)^n}{(1 + k_d)^n - 1}
\]

Where \(k_d\) is real debt interest and \(n\) is number of years in terms of plant’s operating life.

The LCOE was calculated by using equation 5.

\[
Simple\ LCOE = \frac{CAPEX \cdot FCR + OPEX}{Annual\ Output}
\]

In this formula, CAPEX is Capital Expenditure of plant, FCR is Fixed Charge Rate, OPEX is Operating Expenditure and annual output is electricity output in kWh.

3. Results

3.1 MA Survey

MAs were collecting the waste 6 days a week and up to 80% waste was reported to be collected from allocated urban areas. Inadequate bins, deficiency of waste collection staff and vehicles were identified as major causes preventing efficient waste collection.

To dispose the collected waste, MAs leased land where waste was simply spread on the ground. Occasionally, it was set on fire to reduce its volume. No waste segregation was performed for material recovery and no risk assessment was made in terms of potential environmental damage due to open waste disposal.
3.2 Quantity and Composition of Waste

The quantity and composition of MSW in Haripur is shown in table 1 and 2.

<table>
<thead>
<tr>
<th>Municipal Authority</th>
<th>Quantity of waste collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khalabat Township</td>
<td>10 metric tons per day</td>
</tr>
<tr>
<td>Haripur</td>
<td>12-14 metric tons per day</td>
</tr>
<tr>
<td>Ghazi</td>
<td>10 metric tons per day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>% of total waste</th>
<th>Waste type</th>
<th>% of total waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food/kitchen waste</td>
<td>5</td>
<td>Metals</td>
<td>2</td>
</tr>
<tr>
<td>Paper</td>
<td>10</td>
<td>Glass</td>
<td>2</td>
</tr>
<tr>
<td>Textile</td>
<td>5</td>
<td>Garden waste</td>
<td>2</td>
</tr>
<tr>
<td>Wood</td>
<td>10</td>
<td>Carrier Bags</td>
<td>10</td>
</tr>
<tr>
<td>Plastics/Rubber</td>
<td>8</td>
<td>Inert waste</td>
<td>46</td>
</tr>
</tbody>
</table>

3.3 Estimation of reuse and recycling potential from MSW in the Haripur district

The following calculation is based on approximately 30 metric tons of waste collected in the district per day. Inert contents of 13.8 metric tons are excluded with 16.2 metric tons of waste available for recyclables extraction.

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Percent of total waste (by weight)</th>
<th>Price per kg (Rs)</th>
<th>Quantity of each component kg/metric ton</th>
<th>Estimated income potential (PKR/metric ton/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food/kitchen waste</td>
<td>9</td>
<td>---</td>
<td>90</td>
<td>---</td>
</tr>
<tr>
<td>Paper/card board</td>
<td>18</td>
<td>8-12</td>
<td>180</td>
<td>1440-2160</td>
</tr>
<tr>
<td>Textile</td>
<td>9</td>
<td>---</td>
<td>90</td>
<td>---</td>
</tr>
<tr>
<td>Wood</td>
<td>18</td>
<td>8-14</td>
<td>180</td>
<td>1440-2520</td>
</tr>
<tr>
<td>Plastics/Rubber</td>
<td>15</td>
<td>7-22</td>
<td>150</td>
<td>1050-3300</td>
</tr>
<tr>
<td>Metals</td>
<td>4</td>
<td>20-35</td>
<td>40</td>
<td>800-1400</td>
</tr>
<tr>
<td>Glass</td>
<td>4</td>
<td>2</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Garden waste</td>
<td>4</td>
<td>---</td>
<td>40</td>
<td>---</td>
</tr>
<tr>
<td>Carrier Bags</td>
<td>19</td>
<td>---</td>
<td>190</td>
<td>4810-9460</td>
</tr>
</tbody>
</table>

Based on the quantity and composition of waste collected and current market price of various recyclables (as suggested by respondents); material recovery for recycling can help to generate 4810 to 9460 PKR/day/metric ton of waste collected. As 16.2 metric tons of mixed waste collected per day in the district (approximately 9.6 tons of recyclables), the income potential from recyclables may range from Rs 46,176 to 90,816 per day depending on quality of recyclables. Segregation of recyclables can help to reduce the quantity of waste going to landfill by 59%.

3.4 Waste to Energy: ERP of MSW collected by MAs in Haripur District

In order to determine ERP, dry weight of each component was determined by identifying and subtracting TMC using equation (1) as shown in table 4.

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Percent of total waste (by weight)</th>
<th>Normal weight (g/kg)</th>
<th>TMC (%)</th>
<th>Moisture loss (g/kg)</th>
<th>Dry mass weight (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food/kitchen waste</td>
<td>9</td>
<td>90</td>
<td>58.6</td>
<td>52.74</td>
<td>37.26</td>
</tr>
<tr>
<td>Paper/card board</td>
<td>18</td>
<td>180</td>
<td>3.27</td>
<td>5.886</td>
<td>174.11</td>
</tr>
<tr>
<td>Textile</td>
<td>9</td>
<td>90</td>
<td>5.3</td>
<td>4.77</td>
<td>85.23</td>
</tr>
<tr>
<td>Wood</td>
<td>18</td>
<td>180</td>
<td>5</td>
<td>9</td>
<td>171</td>
</tr>
<tr>
<td>Plastics/Rubber</td>
<td>15</td>
<td>150</td>
<td>2.3</td>
<td>3.45</td>
<td>146.55</td>
</tr>
<tr>
<td>Metals</td>
<td>4</td>
<td>40</td>
<td>0.9</td>
<td>.36</td>
<td>39.64</td>
</tr>
<tr>
<td>Glass</td>
<td>4</td>
<td>40</td>
<td>1.2</td>
<td>.48</td>
<td>39.52</td>
</tr>
<tr>
<td>Garden waste</td>
<td>4</td>
<td>40</td>
<td>16.2</td>
<td>6.48</td>
<td>33.52</td>
</tr>
<tr>
<td>Carrier Bags</td>
<td>19</td>
<td>190</td>
<td>1.9</td>
<td>3.61</td>
<td>186.39</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>1000</td>
<td>86.78</td>
<td>913.22</td>
<td></td>
</tr>
</tbody>
</table>
It is estimated that the mixed waste collected by MAs in Haripur district possesses approximately 8.6% of moisture content by weight. By removing moisture from 16.2 metric tons of normal MSW, 14.81 metric tons per day of dry waste becomes available for energy recovery.

TEC of various waste components in 1kg of dry waste sample was determined using equation (2). These values are shown in Table 5.

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Energy content for dry mass MJ/kg</th>
<th>Dry Weight in sample (kg)</th>
<th>Total Energy Content MJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food/kitchen waste</td>
<td>13.9</td>
<td>0.0407</td>
<td>0.5657</td>
</tr>
<tr>
<td>Paper/card board</td>
<td>17.6</td>
<td>0.1906</td>
<td>3.354</td>
</tr>
<tr>
<td>Textile</td>
<td>20.5</td>
<td>0.0952</td>
<td>1.910</td>
</tr>
<tr>
<td>Wood</td>
<td>19.3</td>
<td>0.1872</td>
<td>3.612</td>
</tr>
<tr>
<td>Plastics/Rubber</td>
<td>25.6</td>
<td>0.1604</td>
<td>4.106</td>
</tr>
<tr>
<td>Metals</td>
<td>0.7</td>
<td>0.0433</td>
<td>0.030</td>
</tr>
<tr>
<td>Glass</td>
<td>0.2</td>
<td>0.0432</td>
<td>0.008</td>
</tr>
<tr>
<td>Garden waste</td>
<td>15.1</td>
<td>0.0366</td>
<td>0.543</td>
</tr>
<tr>
<td>Carrier Bags</td>
<td>33.4</td>
<td>0.2040</td>
<td>6.813</td>
</tr>
</tbody>
</table>

The TEC of waste (LCV) in Khalabat Township was estimated as 20.94MJ/kg based on 1kg of dried mixed MSW sample. By using LCV of waste and an assumed Weight unit of 1 metric ton in equation (3), ERP is equal to 20,940 MJ/metric ton.

Theoretically, 1 metric ton of mixed dried MSW can produce 5800 kWh of gross energy.

This ERP value is based on 100% energy extraction from the waste. By using RDF, total ERP can be improved as RDF is normally composed of highly combustible material such as paper, plastic, wood and textile. The table (6) shows the ERP of waste using RDF.

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Total Energy Content MJ/kg</th>
<th>Quantity of each component (kg/metric tons)</th>
<th>Total Energy Content MJ/metric tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper/card board</td>
<td>17.6</td>
<td>227.8</td>
<td>4009.28</td>
</tr>
<tr>
<td>Textile</td>
<td>20.5</td>
<td>113.9</td>
<td>2334.95</td>
</tr>
<tr>
<td>Wood</td>
<td>19.3</td>
<td>227.8</td>
<td>4396.54</td>
</tr>
<tr>
<td>Plastics/Rubber</td>
<td>25.6</td>
<td>189.8</td>
<td>4858.88</td>
</tr>
<tr>
<td>Carrier bags</td>
<td>33.4</td>
<td>240.5</td>
<td>8032.7</td>
</tr>
</tbody>
</table>

From total MSW collected by the MAs in Haripur district, a total of 11.69 metric tons of material can be obtained as RDF per day. Each metric tons of dried RDF on average possesses 23,632 MJ of energy (6546 kWh/metric tons). As gasification system can extract up to 90% of total available energy [6], a steam turbine can covert at least 15% of this energy into electricity [2&3]. As a result, RDF can help to produce 10,330 kWh of electricity per day. If waste is collected over 6 days a week, the total annual electricity output will be approximately 3,222,960 kWh.

3.5 Cost benefit analysis: Estimating LCOE and revenue potential of waste to energy

To estimate LCOE, FCR was initially calculated by using equation 4. The K_d for this study was identified as 6.5% [22] whereas; n was assumed as 20 years. As a result, FCR was calculated as 0.09.

LCOE was calculated by using the CAPEX as addition of RDF processing plant and a gasification plant. The cost of RDF processing plant is taken from an operational RDF plant in Pakistan that is 320,000,000 PKR [9]. The cost of a 1MW capacity Gasification plant is suggested by Saini et al [21] as 10,000,000 Indian Rupees (15,000,000 PKR). Likewise, the O&M is estimated as 5.5% of total investment cost of gasification plant which totals as 825,000 PKR/year. The O&M cost for RDF plant is estimated at 435 PKR/metric tons [10]. As collected waste in the district is 9300 metric tons/year, the total O&M cost of RDF processing is calculated as 4,071,600 PKR/year. The total annual electricity output using RDF as feedstock in gasification plant is estimated to be 3,222,960 kWh. By using equation 5, the LCOE is 10.87 PKR/kWh.
4. Discussion

Although waste collection efficiency in Haripur district is significantly higher (80%) than many other places in Pakistan, the collected waste is inadequately disposed by local MAs. Such waste disposal practices in Pakistan are highlighted by researchers in the existing literature [5]. The composition of waste suggests that the percentage of inert contents is significantly higher. The food contents of waste were surprisingly low in contrast to a number of other studies [5&12]. High amount of inert contents in waste are likely due to dry weather resulting into formation of dust. Likewise, as MA Khalabat particularly serves residential area, low commercial activities such as few food markets appeared to be contributing to the production of low food waste. A number of contents in the waste were highly combustible, suitable for waste to energy. The presence of high combustible components is also observed by a number of other studies conducted on MSW in Pakistan [12&17]. The results of survey revealed that a significant amount of recyclables can be recovered and sold in the market from the waste disposed by MAs previously overlooked by many researchers.

The existing literature suggests that bio-chemical processes requires high organic components. Since organic components are identified to be low in the collected waste, only thermo-chemical waste to energy technologies are considered for energy recovery. Incineration and gasification are among most prominent technologies used to recover energy from the waste. However, World Bank highlights that mass burn incineration requires at least 50,000 metric tons of waste to sustainably operate an incineration plant [24]. As the amount of waste collected in the district is approximately 9300 tons/year (3600 metric tons as RDF), a small-scale 1MW gasification plant appeared to be most suitable option to recover energy from the waste in the district. A gasification plant require frequent cleaning than an incineration plant that adds to the cost of maintenance. However, the existing literature suggests that the capital cost of gasification plant is 3 times lower than incineration plant [21]. It favours the installation of a gasification plant for waste to energy recovery.

5. Conclusion

This study revealed a greater potential of energy recovery from the waste collected in Haripur district by MAs. MSW can offer a renewable source of energy reducing the dependency on non-renewable sources such as fossil fuels which helps to protect the environment.

The results of survey revealed that the waste collected by MAs in Haripur district possesses a high calorific value. Energy content of RDF was identified to be 6546 kWh/metric ton, enough to produce 3,222,960 kWh of energy every year. As the aim of MSWM is to reduce the amount of waste going to landfill, the results of this study revealed that waste to energy is most appropriate option to significantly reduce the amount of waste going to landfill that is up to 90%. Recycling only can reduce the amount of waste going to landfill by 59%. Waste to energy process also allows the segregation and collection of recyclables during RDF production facilitating additional revenue generation. The waste characteristics revealed that gasification was most suitable technology to use in the district. Unlike the utilization of fossil fuels, the revenue generated from the sale of electricity can compensate the cost of production. However, further research is required to assess the quantity and composition of waste involving other districts to effectively manage MSW on national level in Pakistan.

References


290. An Intelligent MPPT Design of DC-DC Converter for PV in a PV/SC Hybrid Power System

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Abstract

The current literature is greatly populated with various conventional control schemes for Photovoltaic (PV) system to acquire maximum power from it. This piece of work presents an intelligent fuzzy logic Maximum Power Point Tracking (MPPT) controller for a boost converter to control PV under variable real weather conditions in a PV/Super-capacitor (SC) hybrid power system. The proposed intelligent fuzzy logic controller makes the control of nonlinear characteristic of PV array more feasible. Additionally, a SC module is used to regulate the DC bus voltage and store energy during surplus power and/or backup device during load demand. The proposed hybrid power system operates under classical-based supervisory switching algorithm. The performance of proposed controller is compared with/without Proportional Integral Derivative (PID) perturb and observe MPPT controllers for the real weather patterns and load conditions at Sibi, Pakistan. MATLAB results indicate the effectiveness of proposed controller in terms of feasibility and dynamic response.

Keywords: Fuzzy logic MPPT controller; PV system; Super-capacitor; Hybrid power system; Load tracking

1. Introduction

The researchers are keen to develop technologies which are inexpensive, efficient, and environmentally friendly. The demand for the renewable energy is increasing due to the increasing demand of electrical energy. In Pakistan, the total energy supply is above 24,000 MW in the year 2014-2015 as reported in [1]. The report also concludes that only 106 MW (0.43% of total generation) is generated from Renewable Energy Sources (RES) while the remaining power is produced from fossil fuels. In recent years the Pakistan government initiated various RES mini projects to reduces the use of fossil fuels and protect the environment from excessive pollutions [2], [3], [4]. Therefore, PV industry annual growth rate is significantly raised to 40% in the recent years [5]. PV based power generation is becoming progressively important as RES since they present many advantages such as pollution free, emitting no noise, non-depleted, incurring no fuel costs, and requiring less maintenance among others. However, PV needs a favorable condition as the power and cost of electricity are greatly dependent on the local climatological variables. The output power of PV systems is heavily dependent on the weather patterns and thus the instantaneous power available from PV often does not meet the instantaneous load demand. Energy storage systems support transient stability during the rapid solar radiation change and load.
variations while electronic interface is used to extract maximum power from PV and also convert into AC appropriate voltage level [6]. Maximum Power Point (MPP) of PV has a non-linear relationship with cell temperature and solar irradiance. Hence, in order to operates PV at MPP, the system must have MPP tracker [7]. Several intelligent and conventional control schemes are established by different experts and researchers to capture maximum power and achieve optimum efficiency [8]. Conventional schemes contain perturbation and observation (P&O), voltage-feedback methods, Hill Climbing (HC) and Incremental Conductance (IC) etc., while intelligent method includes Fuzzy Logic Control (FLC), Genetic Algorithm (GA), Ant Colony Optimization (ACO) and Neural Network (NN), etc. [9]–[12].

Several studies have been performed on conventional and intelligent control MPPT based schemes. In [13]–[16], the authors track the MPP with P&O, IC and HC schemes due to its simple operation. Nevertheless, the authors are unable to eliminate the power oscillation created on MPP and divergence caused due to weather changes. For example, the P&O algorithm, which moves the operating point near to the MPP through increasing or decreasing the array voltage periodically, is often applied in many PV power applications. This method is beneficial in a situation where the irradiation does not fluctuate quickly with time; however, the P&O method is slow and get confused due to quick variations of atmospheric conditions. The IC algorithm is also often used in the PV based power systems. This method tracks the MPP by matching the incremental and instantaneous conductance of the PV array. The IC method provides good performance during rapidly changing weather conditions. Nevertheless, the IC technique has two parts, and the structure is analogous to the P&O method due to the condition \(\frac{dP}{dV} = 0\) that rarely occurs. Moreover, in the IC technique, four sensors are essential to accomplish the measurements for computations and decision making. Therefore, it is required to have an appropriate MPPT which can reduce oscillation and coverage quickly. Hence, intelligent control methods are used to overcome the drawbacks of conventional control techniques [17].

In literature different researcher established intelligent control based MPPT schemes in different studies [18], [19]. GA is used to increase the accuracy of an ANN-based MPPT algorithm and reported in [20]. Population size, mutation rate and number of generations are the common expected problems with GA. In [21], the authors used PSO with the capability of direct duty cycle to track MPP of a PV system but PSO still has the dependency problem on initial values of the particles. In [22], a novel ACO is implemented to get the PI-MPPT controller gains. ACO is used to enhance both the design efficiency of PI control systems and its performance to get optimal PI parameters. In ACO, the optimal selection of number of ants, solution archive and locality of search space etc., are some thoughtful issues.

In this manuscript, an Artificial Intelligent (AI) based MPPT PID controller is designed. The proposed controller extracts maximum power from PV system and operates on two primary inputs i.e., PV voltage and power and generates an appropriate duty cycle. This study mainly targets on investigating MPPT performance, which was created by studying P-I graph of PV array and determining rule base of fuzzy logic controller with different weather conditions. Diffident linguistic variables are used to develop fuzzy model.

This work is distributed in six different sections. Introduction is covered in Section 1. Section 2 defines the proposed test-bed. PV array modelling is covered in Section 3. Section 4 describes the proposed methodology for designing intelligent fuzzy logic MPPT controller. Section 5 explains the detailed simulation results followed by conclusion in Section 6.

2. Proposed Test-bed

The test-bed comprises a PV system along with storage device (i.e., SC) which is connected to Utility Grid (UG) via three phase inverter. The PV is connected to inverter via DC-DC boost converter, which is controlled by an intelligent fuzzy logic MPPT controller. SC is added to regulate the DC bus voltage and also provide backup to the grid during demand. UG receives power from PV and SC during peak hours while delivering power to SC for charging during off peak hours. Power sharing between different sources is performed by Power Management System (PMS). The complete architecture of test-bed is shown in figure 1.
3. PV Modeling

The structural unit of PV array is the solar cell (SC), which is fundamentally a p–n semiconductor junction. The current–voltage (I-V) characteristic of a solar PV is a non-linear nature and is given by [23], [24].

\[
V_{PV} = N_s \left( \frac{AKT}{Q} \right) \ln \left( \frac{(N_p I_{SC} - I_{PV}) + N_p I'}{N_p I'} \right) - \frac{N_s}{N_p} I_{pv} R_S
\]  

(1)

where, \(I_{sc}\) is the short circuit current, \(N_s\) is number of cells in series of a PV module, \(N_p\) is number of cells in parallel of a PV module, \(I_o\) is diode saturation current, \(T\) is PV cell temperature, \(A\) is temperature coefficient for short-circuit current, \(q\) is charge of an electron and \(k\) is Boltzman’s constant. The output power delivered by the PV system into the DC bus could be written as

\[
P_{PV} = V_{PV} I_{PV}
\]  

(2)

Eqs. (1) and (2) are implemented during the simulations to get the output characteristics of PV system at weather patterns. The output power of PV system varies according to atmospheric condition or load current as shown in figure 2.

The parameters used in the modelling of PV are given in table 1. At 1000 W/m², the maximum output power is 260 kW.
4. Proposed Methodology

Modelling a non-linear system with a conventional controller in terms of regulation, damping, etc is difficult. The intelligent fuzzy logic MPPT controller is based on the set of fuzzy rules developed using expert knowledge. An intelligent fuzzy logic MPPT controller contains a fuzzifier, fuzzy inference engine, fuzzy rule base and defuzzifier as shown in figure 3.

\[
\Delta V = [V(n) - V(n-1)] \times Z_1 \\
\Delta P = [P(n) - P(n-1)] \times Z_2 \\
k(n+1) = [k \pm \Delta k] \times Z_3
\]

where \( n \) represents the time index, \( Z_1, Z_2 \) and \( Z_3 \) are input and output scaling gains, \( V(n) \) and \( P(n) \) represent the instantaneous voltage and power of PV array.

Five fuzzy sets are established using seven linguistic variables. These linguistic variables are associated on two input variables. The linguistic terms used in establishing a fuzzy model are Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS) and Positive Big (PB). The Membership Functions (MFs) are defined in interval of [-1,1] with \( Z_1 \) and \( Z_2 \) as input scalar and \( Z_3 \) as output. Initially, different types of MFs are selected i.e., Trapezium, Cauchy, Gaussian, Triangle, etc. Using expert knowledge [25], trial and error method, Triangle and Trapezium methods are used together. MFs for \( \Delta V \), \( \Delta P \) and \( \Delta D \) are shown in figures 4, 5 and 6, respectively.
The input-output control surface for fuzzy controller is shown in figure 7. After understanding system parameters and error manipulations, the rules are developed for intelligent fuzzy logic MPPT controller. The rule based developed for system is shown in table 2. The fuzzy inferences system is designed using Mamdani model.

During designing of intelligent fuzzy logic MPPT controller, a base of 9 rules was used due to its low computational cost, but it does perform so well. Therefore, in this research a base of 25 rules is used for
better performance. To find an optimal MPP, P-V characteristics of PV panel are taken. Based on input parameters (ΔP and ΔV), appropriate output signal (Δk) is generated. The output is a Pulse Width Modulator (PWM) signal. The PWM signal (known as k) is fed to DC/DC boost converter to operate inverter. The crisp output is obtained by center of gravity defuzzification process [26].

\[
k = \frac{\sum_{j=i}^{n} k_{j} \mu_{A}(k_{j})}{\sum_{j=1}^{n} \mu_{A}(k_{j})}
\]  

(6)

5. Simulation Results and Discussion

In this research, the real time weather data (solar irradiance and temperature) of Sibi, Pakistan is used. The weather statistics is recovered by Pakistan Meteorological Department (PMD) for 1st July, 2016 [27], [28]. The weather data for Sibi, Pakistan is shown in figure 8. However, for simplicity, only minutes when sun rises and sets are shown in figure which are nearly 6 AM and 8PM.

![Weather data of Sibi, Pakistan (1st July 2016)](image)

Fig. 8. Weather data of Sibi, Pakistan (1st July 2016)

Initially, to test the proposed system, all the energy sources are modeled ideally in MATLAB/Simulink via simpower system toolbox. The PV boost converter is simulated without any control applied to the boost converter attached to it. Hereafter, the conventional PID based MPPT controller is installed. The PID is tuned with automatic build-in tuner in Simulink. The PID based system is simulated and the results are stored. Finally, based on corresponding inputs (ΔP and ΔV), rules based fuzzy control is developed through Fuzzy toolbox.

The simulation results of PV MPPT controller in terms of PV output power are shown in figure 9. The black dotted line, blue solid line, brown dashed line and pink dot-dashed line represents the PV power reference (P_{PV}^*) (theoretically calculated with formula), actual power using FLC (P_{FLC}), PV actual power via PID technique (P_{PID}) and without any controller (P_{WC}), respectively. From figure 9, due to continuous change in irradiance level, the output powers using FLC and PID controllers are likely to be nearly same. However, in zoom figure, the power difference is clearly visible at 676.5 minute.

The performance of any controller is evaluated by plotting absolute difference of reference and actual powers obtained from each controller. Using the same idea, absolute error is calculated at each sample and plotted with respect to time is shown in figure 10. From figure 10, without any controller, the average absolute error is 12 kW with a peak error of 20 kW. Similarly, the average absolute error using PID controller is 1 kW while with fuzzy controller it’s 0.5 kW.
The average absolute error for each controller is calculated as:

$$\overline{e}_{i} = \frac{1}{T} \int_{0}^{T} (P_{PV}^i (t) - P_i(t)) dt \quad i = FLC, PID, WC$$  \hspace{1cm} (7)$$

Using above equation, the efficiency of proposed FLC is calculated as:

$$\eta = \frac{\overline{P}_{PV} - \overline{e}_{FLC}}{\overline{P}_{PV}} \%$$  \hspace{1cm} (8)$$

where $\overline{P}_{PV}$ is the average reference power and calculated as:

$$\overline{P}_{PV} = \frac{1}{T} \int_{0}^{T} P_{PV}^* (t) dt$$  \hspace{1cm} (9)$$

After evaluating the above equations, the $\overline{P}_{PV}$ is calculated as 23.4 kW for complete day. Similarly, using equation (7), the average error for proposed FLC, PLD and without controller are obtained as 0.208 kW, 0.519 kW and 4.582 kW, respectively. Putting the values of average errors of each controller into equation (8), the efficiency for proposed FLC, PID and without controller are calculated as 99.11%, 97.7% and 80.41 %, respectively. So, it is concluded that, after applying proposed FLC based MPPT algorithm to boost converter, its efficiency is significantly improved.
Before finally concluding the performance of proposed FLC, let go through the impact of proposed FLC on power system voltage, frequency and Total Harmonic Distortion (THD). In light of IEEE 1547 Standards [29], the maximum alteration in system voltage RMS, frequency and THD level are 0.8%, 6% and 5%, respectively. The test-bed simulated in this research have a fundamental system frequency of 50 Hz with line-line RMS voltage of 440V. Keeping these facts, the allowable alteration in system frequency/voltage RMS are ±0.2Hz/±26V. Now, the figure 11 represents that, the alteration in system parameters are in allowable range.

![Graph showing system RMS voltage, frequency and THD level.](image)

### Fig. 11. System RMS voltage, frequency and THD level.

### 6. Conclusion

The intelligent fuzzy logic MPPT control of boost converter for PV is established to provide power to the grid in PV/SC hybrid power system. Evidently, the proposed controller outperformed in transitional states than with and without P&O PID based MPPT schemes. The feasibility of the proposed controller is supported by the simulations done in MATLAB under real-world record of weather patterns. The proposed method concludes that that MPP of any PV systems find with intelligent controller in shorter time runs compared to classical control methods.

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### References


292. Sustainable Energy Measures in Saudi Arabia Based on Renewable Energy Sources: Present Actions and Future Plans

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Abstract

Conventional power generation sources are a major cause of environmental pollution and have had a grave impact on public health and safety through greenhouse gas emissions, acid rains, etc. A global transition towards sustainable energy options is underway in order to meet present day demands without jeopardizing the environment and future generations. Even though Saudi Arabia is the top oil producer of the world, it has a strong interest in participating in the development and utilization of new environment-friendly technologies that exploit renewable energy sources. It is projected that about US $117 billion will be invested in the country’s power sector according to its 25 year strategic energy plan. This plan ensures that the future energy sources should be practically accessible, sustainable, affordable, and costs-optimal to adopt. Despite the current economic constraints, the Kingdom has established a scientific city, ‘King Abdullah City for Atomic & Renewable Energy’ (KACARE) which is working on the potential of utilizing renewable energy sources in the Kingdom. This paper addresses the current status and future potential of renewable energy applications in the Kingdom. A technical and economic assessment, of major renewable energy sources in this heavily subsidized, oil-rich country, is also discussed.

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Keywords: Sustainable energy, Environmental pollution, Major oil producing country, renewable energy, KACARE

1. Introduction

Global increase in energy demand and environmental awareness has brought great concern to supply sustainable energy in an environment-friendly manner. Conventionally, oil, coal and natural gas are the chief energy sources being utilized in the major part of world [1]. Mainly the conventional energy sources are responsible in contributing in environmental degradation via greenhouse gases emission and other ways. The renewable clean energy sources appear to be viable substitutes to protect the environment and public health [2].

A large portion of the oil and natural gas reserves is located in the Gulf Cooperative Council (GCC) countries. The GCC countries are rated as in the top 25 countries with the highest CO$_2$ emissions per capita [3]. The GCC has recently adopted a progressive approach towards environmental reformation, however, to have consistent developments in this direction, lots of work has to be done [4]. The Kyoto protocol in 2005 stressed that the European Union (EU) and GCC broaden their cooperation and that they should take a collaborative approach in the direction of CO$_2$ reduction. EU and GCC increased their interactions and set realistic goals. They took various innovative measures to accomplish these objectives however; there is still a great need to speed up the resolution of major issues, such as CO$_2$ emissions and controlled use of energy [5].

The Kingdom of Saudi Arabia (KSA), with an area of about 2.25 million km$^2$ is the largest country in the Middle East. Oil reserves of the KSA were discovered during the year 1938 and the country started exporting oil from next year. Within a few years the country became the chief oil producer and exporter in the world [6]. Saudi Arabia, with a population of more than 31 million and a rapidly growing...
industrial sector, is facing high growth rate in energy demand, with an average of 5% per annum [7]. The domestic electricity use and, ultimately, oil consumption in the KSA is increasing at a very alarming rate compared to the other countries in the world. Therefore, it is important to work out energy conservation measures for the various sectors in the Kingdom as early as possible [8]. It is estimated that the electricity demand in KSA is going to reach more than 60 GW by the year 2020. It is also estimated that by year 2020 a reduction of 1% in the annual electricity consumption could provide saving in electricity bills about $35 billion [9]. Even though Saudi Arabia is the main producer of oil, it has taken a profound interest in participating in the development and utilization of new technologies for exploiting renewable energy sources. The central grid system is supplying the power to roughly 80% users within cities but, it is not practicable to further extend the power supply grid system to sparsely populated remote areas. Therefore, there is still requirement for power source in these areas. Hence, these locations represent a substantial potential for renewable energy applications. It is to be noted that these energy sources may also be connected to the central grid in order to utilize during high demand periods [10]. It is projected that more than US $117 billion will be capitalized in the power production according to the country’s 25 year strategic energy plan. The plan ensures that the future energy sources should be practically accessible, sustainable, affordable, and costs-optimal to adopt. Furthermore, despite the current economical constrains the Kingdom has established a scientific city ‘King Abdullah City for Atomic & Renewable Energy’ (KACARE) which is working on the potential of utilizing renewable energy sources in the Kingdom.

The utilization of renewable energy resources which includes solar, wind, hydro, waste material and geothermal energy seems to be one of the most efficient and effective ways of achieving this goal. Saudi Arabia has plans to develop self-reliance on various power sources including renewable energy. Country aims to invest in its solar and wind power sources utilization programs to fulfill its energy requirement in the future. Various studies in the KSA indicate that, among various renewable resources, the most sustainable and appropriate energy sources for the country are solar and wind energy.

This paper addresses the current status and future potential of renewable energy source applications in the Kingdom. A technical and economical assessment of major renewable energy sources such as solar, wind, hydro, waste-to-energy and other clean energy technologies is discussed. In addition to the present status, environmental and technical evaluation of the sources and their potential in the future is also discussed.

2. Solar Energy Option

The geographic location of Saudi Arabia on the solar belt has endorsed it as one of the most suitable producer of electricity using solar energy. Saudi Arabia has an abundant of solar radiation, which is estimated at about 2200 kilowatt hours per unit area (kW h/m²). Availability of solar radiation and enormous areas of vacant desert which can be used for installation of solar equipment makes Saudi Arabia an excellent site for solar power generation [10]. This shows that solar energy is one of the valuable renewable energy sources for Saudi Arabia and need further exploration to materialize the plans.

According to Aljarboua [11] the available solar energy is sufficient to produce 12,425 TW-h of electricity that can power the kingdom for more than 70 years. The proximity with the equator and a huge desert area qualifies Saudi Arabia as a well suitable country to utilize solar energy for power production. As reported by Aljarboua it can be seen from figure 1 that the annual average monthly incident radiation for Saudi Arabia is quite promising [11]. Three cities; Jeddah, Riyadh and Dammam are receiving high levels of solar radiation due to their geographic location on the equatorial region. On the local scale (5.78 kW h m² per day average), all three cities ranked about average. However, on the international scale (1.36 kW h m² per day average), they are ranked significantly higher [12]. In addition to altitude, Aljarboua pointed out factors such as surface air temperature and the zenith angle are responsible for the small variations between cities [11].
2.1. Progress in solar energy utilization

Although practical implementation of solar energy in the country materialized during 1960, work in this field had started quite earlier [13]. Organized research work on solar energy technology was started after 15 years by ‘King Abdul-Aziz City for Science and Technology’ (KACST). Several researchers studied the viability of solar radiation in the KSA. For example Baras and co-workers discussed the opportunities and challenges of solar energy in Saudi Arabia which detailed the heating mechanisms as well as solar-thermal processes and desalination prospects [14]. Similarly Pazheri has given an update of the solar energy projects in KSA including the current status and future prospects [15].

The Energy Research Institute at KACST led numerous joint programs at international level in the area of solar energy which includes SOLERAS with the USA. Research activities throughout Saudi Arabia showed that solar radiation has feasibility to produce electrical power in the country [13]. Ibrahim Babelli, the country’s deputy minister for economy and planning during a press conference in Dubai emphasized on the use of solar energy as a major energy option for the country [16]. In addition to power generation, options such as Water and Ventilation-Air Preheating systems where solar energy is used to heat water or air are also studied and found promising areas of solar energy utilization.

2.2. Future plans

The cost of installation of solar power plants is tremendously decreasing globally due to increase in manufacturing capability, modified design and reduction in component costs. Saudi Arabia is planning to increase renewable energy production to 9.5 G-Watts, according to new energy plan. Saudi Aramco installed a 10-MW solar powered plant in Dhahran city. Country has planned to spend about $100 billion in producing 41 G-Watts of power by 2030. Chadbourne a US based company involved in installing 4-G-Watts independent power projects (IPP) in Qurayyah said to be the biggest IPP in the world [17]. In order to implement the plans still some hindrances such as dust in the desert area, intermittent availability in addition to availability of subsidized oil need to be further evaluated. However, the available information and obtained experience declaring solar energy option a feasible one.

3. Wind Energy Option

Numerous studies in the past indicated that wind energy is one of the most efficient and promising option of the renewable energy [18]. During 1980’s concern for harnessing wind energy augmented enormously in most of the developed countries due to increase in energy demand and persistent issues of environmental degradation [19]. By the end of 1998 the global installed capacity of modern wind
turbines connected to grid was around 10 G-Watts and the annual global progression rates of installation were around 40%. In addition to that during last decade the cost of wind energy decreased by 35%.

Studies in the Kingdom at various locations revealed that country has viable wind energy potential, which is estimated to 5-hour of full-load wind per day on average. In Saudi Arabia the coastal areas along Arabian Gulf and the Red Sea having great potential for wind energy development.

### 3.1. Progress in wind energy utilization

A Prof of Anderson’s College, Glasgow has installed first windmill which was used as a source of electricity production in Scotland in 1987 [20]. Early 5000 B.C, Egyptians have used wind energy to sail their ships in Nile river [21]. During 1940, Vermont hilltop has the largest wind turbine of their time which has the maximum capacity of 1.25 MW which supply electrical power to the local area network [22]. Recent studies have shown that the global projected wind energy potential is 72 TW for the next 10 years [23]. Every 3 years capacity of wind energy is steadily increasing at the average rate of 25.7%. During these days among renewable energy sources, wind energy is the rapidly growing energy source in the world whose installed capacity reached to 14 GW. USA, Spain, Germany and India are considered as the leading countries which has total about 80% of worldwide installation energy power [10].

In Kingdom of Saudi Arabia, various studies of potential of wing energy have been conducted. Martin and Bakhsh during 1985 have studied twenty different locations which are suitable of wind energy potential and having feasibility for wind energy harnessing in Saudi Arabia. It was suggested that the North and coastal region of country has the maximum potential for generation of wind energy [24]. Good potential between 16° to 26° latitudes of Red Sea coast has been found by Khogali and coworkers when they evaluated the wind energy potential in Makkah. However the inland area has the low potential for generation of wind energy [25]. The good potential has been found for coastal and Northern areas of Kingdom of Saudi Arabia by Radhwan when he analyzed the wind pattern in 1994 using weather stations data for 10 years [26]. Different technical details, equipment installation and detailed specifications of sites was provided by Alawaji in various region of Kingdom of Saudi Arabia in 1996.

Economically, for installation of wind parks, Yanbu and Dhahran have been considered as most feasible locations for potential wind energy based on feasibility report by Rehman in 2005 [27]. Haql has been considered as the most potential location for production of maximum wind energy by Khrishna and Thalhi during last year study as it has the wind speed maximum throughout the year [29]. Average wind speed of 5.04 m/sec have been recorded for Al Wajh. Umluj and Duba can be selected for the wind power but Tina and Tabuk do not have wind speed sufficient for wind energy harnessing. Economic and potential viability of wind has been indicated by these studies for conversion of wind energy into electrical energy.

### 3.2. Future plans

Studies have suggested that Kingdom of Saudi Arabia has promising potential of wind energy utilization. In Yanbu, annual wind speed reported at fifty meters above the ground level is 6.7 meter per second which ranges 7.1 to 8.1 meter per second during summer months. In the nearest future, grid connected wind farms and wind-diesel hybrid systems will be introduce by the authority [30]. The major challenge being faced for utilizing wind energy by KSA is that the wind energy is irregular and without batteries it cannot be stored. Additionally, the location feasible for these grid farms is far from the demand centers. It has been reported that despite of hurdles, KSA will be expected to issue procurements for 13 Giga Watts of geothermal, wind and waste-to-energy plants by year 2032. The release of a white paper by the KACARE, to the renewable energy procurement agency is considered to be the first step for this process [17]. It was found that the possibility of utilizing wind energy in the Kingdom of Saudi Arabia is not fully explored and most of them are funded student projects.

Studies indicated the need of probing more in this area from economic feasibility point of view. Study also revealed that Kingdom of Saudi Arabia has two major regions along the Red sea and Arabian Gulf coasts where wind speed and duration is economically feasible to produce energy from wind power.
Application of previous experience shows a good potential for exploring wind power as one of the renewable energy source in the KSA.

4. Hydro Power

Kingdom of Saudi Arabia is the country which does not have any natural river system but holds few perennial streams [31]. The precipitation value of the world as an average is 1123 mm while Kingdom of Saudi Arabia receives an annual rainfall of 100 mm per year which is considered to be far behind the world [32]. Due to this reason the water bodies like major ponds and lakes are not present. Rain recharge does not replenish available ground water and is depleted rapidly. Water table significant drawdown can be seen in most of the aquifers [33]. There is a massive desalination network which at present is covering up to 70% potable water demand. Some dual-purpose desalination facilities in the country are contributing to fulfill more than 20% of total electricity demand of the country.

There are several dams constructed in the country despite of less rainfall in order to control flood and providing recharge to groundwater aquifers. It has been estimated that there are more than two hundreds of dams which have cumulative reservoir capacity of about 770 Million m$^3$ [35]. The largest dam in Kingdom of Saudi Arabia is King Fahad Dam (storage capacity of 325 Million m$^3$) in Bishah which is considered as the 2nd largest dam in the Middle East. It has hypothetical potential energy of about 91.2 Megawatt hour [36]. Kingdom of Saudi Arabia is not been feasible to construct any hydrological structure for generation of electricity because of significant evaporation and excessive sedimentation of dams to achieve the targeted purpose of storage.

5. Geothermal

Saudi Arabia has significant tectonic activity due to its geographical location. Many volcanic ridges are existing along the Red Sea shore. With respect to geothermal resources, there are 10 hot-springs with varying temperatures ranges from 50 to 120°C and different flow rates. In addition to this, there are three major harrats namely Khaybar, Kishb, and Rahat of geothermal concern. The crust thickness in these areas varies between 20 and 40 km and its lower part consists of mafic meta-igneous granulite [37].

In order to promote renewable energy sources during 2008 Ministry of higher education provided huge funds for establishing a centre of research excellence in renewable energy at King Fahd University of Petroleum and Minerals. The research activities in the centre include wind, solar and geothermal power resources to evaluate and utilize [38]. Lashin in early 2014 conducted various research studies in two potential areas Al-lith and Jizan investigating potential of utilizing geothermal energy in those areas. They reported Al-Khouba geothermal resources as an important site for exploiting geothermal energy for power production [39]. In their studies they evaluated thermal parameters heat flow, discharge enthalpy and subsurface temperature and estimated as 144 mW m$^{-2}$, 318 kJ kg$^{-1}$ and 135°C, respectively. A good geothermal potential of 17.9 MW is estimated for Al-Khouba hot spring having estimated volume of 1.125 cubic kilometers. They recommend the site for future technical investigation to explore geothermal energy as a source to obtain electrical energy. [39].

In another study Lashin characterize the reservoir surface area of the volcanic flows, flow rates, heat flow and geothermal grades. They reported that the wet geothermal systems can produce energy up to $23 \times 10^9$ kWh. Lashin also reported that in the western region a large number of pre and post orogenic highly radioactive granites with very high generating capacity (from 15 to 134 µW m$^{-3}$) is existing. They reported that this granite can produce about 160 TWh of electricity [40]. Therefore, it seems that geothermal energy is one of the potential sources of renewable energy in the kingdom.

6. Waste To Energy

Rapid increase in global population and living standards promote the generation of more solid waste as well as energy requirement. The trend is with increasing order which is forecasted to reach about 2.2 billion tons per annum in 2025 [41]. The final disposal place for of municipal solid waste (MSW) is landfills or dump sites. In Saudi Arabia few steps have been taken to manage the MSW. Option of
producing energy from waste material has dual benefit controlling the environmental pollution and utilizing waste material to produce valuable energy [42].

In the year 2010 KACARE was established and after 3 years the new regulations stressed the implementation of an integrated MSW management program in the country. KACARE proposed a framework to utilize the MSW for renewable energy production. Plan covers twenty years schedule including production of about 54 GW from nuclear and renewable energy sources. KACARE reported the potential of generating about 2073 MW of electricity by the year 2032. The results show that energy production from waste has great potential in the Kingdom. MSW can be a good source to produce electricity and contribute to electricity supply in the Kingdom [43].

7. Hybrid Energy System

Renewable energy technologies have their inherent limitations and use of a single source is practically not feasible. For example intermittent availability of wind energy and diurnal variation in solar energy limits the use these options for sustainable supply to grid. The use of storage source such as battery bank is required to utilize these technologies. Therefore, use of two or more renewable sources, called as hybrid system is appropriate. Generally, to overcome economy two systems are preferred [44], the feasibility of combinations such as wind or solar with diesel generator or power bank is essential. Selection should be made based on ease of availability of technology and performance of conversion. One of the criteria is the capital and operational cost of the hybrid system. Study reported that the hybrid system is the best means of providing decentralized power with higher reliability. Typically the selection of one or more of these options mainly depends on the reachable energy, the efficiency of conversion system and the characteristics of the electrical load [45].

In Saudi Arabia related information and data is inadequate and there is a need to further evaluate the hybrid system in detail. The feasibility studies for practical implementation are imperative to decide future plans in the kingdom.

8. Summary and Conclusions

The gradual shift from fossil fuel to renewable sustainable energy sources is imperative for global environmental protection. Among other countries, Saudi Arabia has tremendous potential for renewable energy sources, mainly solar and wind, for electricity production. During the last fifty years, extensive research has been done in the area of solar and wind energy and valuable data and information has been obtained which has acted as the basis for the establishment of renewable energy programs in the KSA. The most promising energy source in the KSA is solar energy, having a wide range of applications, including electricity generation. It has been demonstrated that solar water and ventilation-air preheating have great economic benefits. Wind energy is the second most potential renewable source available in sufficient amounts in various coastal regions of the Kingdom. However, feasibility of wind energy has not been fully explored and experience gained in the field is mainly based on various research projects and installation experience obtained through governmental establishments such as KACST. Other energy sources such as geothermal and waste-to-energy have some potential. However, available data and information on these sources is up to pilot-scale level only. Operation of hydro power has insignificant potential in the region due to the unavailability of it’s main components such as rivers or significant water bodies. However, studies show that the use of hybrid systems, such as solar and wind with diesel generators, has great potential to be implemented as they minimize the limitations of these technologies. Therefore, uninterrupted power supply is possible if considering hybrid systems. There is a need for future applications to explore more in this area, in order to make them economical and practical. A generous subsidy from the government is also required, at least for the initial period, to bring these ambitious plans to realization. There is a need to develop a framework, to encourage private sector investments in the renewable energy sector, including financial support incentives to potential developers.

At present, in a country which has huge oil reserves, and where the oil supply is profoundly subsidized, it is very difficult to utilize renewable energy sources as a prime energy source. Today’s conventional energy costs, when compared to solar and wind energy, leave no chance for competition in the Saudi
market. Even if the country is eager to shift from conventional to renewable energy sources, a great deal of change in the country’s policies is required. The key factors which may bring about this transformation could be the environmental concern and longer sustainability.

It is confirmed that the long-term future of renewable energy is looking quite bright, as a great reduction in greenhouse gas emissions will be achieved when using renewable energy sources instead of conventional fossil fuel. This will result in a reduction in environmental pollution and reduced expenditures on public health care. As the trend shows, the cost of reusable energy is declining steadily, and in the future, its cost will be less than that of conventional energy sources and will make this option even more attractive.

Acknowledgements

Authors are grateful to the Jubail University College, Saudi Arabia for providing help and support in the research and preparation of the paper.

References

302. Voltage Stability Improvement by Using FACTS Device Static VAR Compensator (SVC)

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Abstract

"Power system engineering forms an immense and foremost part of electrical engineering studies. It is mainly concerned with generation of electrical power and its transfer from Launching end to acceptance end as per client need, meet with least quantity of losses. The power at acceptance end is regularly subjected to changes because of burden distinction and due to turbulences tempted inside length of transmission line. Therefore the expression "Power System Stability" is of most extreme significance in this field, and used to characterize the inclination of framework to convey back its operation to relentless state condition inside least likely time subsequent to having experienced some kind of transition or aggravation in the line. Power System Stability depends upon various factors one of them is “voltage stability”. If we don’t take measure to preserve the voltage stability in our power system, ultimately we have to face worst conditions under such circumstances that is voltage collapse & how we can mitigate it. In order to improve voltage stability and diminish the losses of power system we are using one promising FACTS device called “Static VAR Compensator”. Static VAR Compensator using the modern technology of power electronic switching device in the arena of power transmission system economically enhancing the voltage regulation. The Static VAR Compensator is increasingly applied in electrical power transmission system economically to improve the post disruption retrieval voltages that can lead to system instability. We will study few models using MATLAB for scrutinizing the above defined parameters of power system. How they act and what impact of SVC on power system."

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Keywords: “FACTS (Flexible AC Transmission System); SVC (Static VAR Compensator)”

1. Introduction

Day by Day, demand on transmission network are increasing due to escalating number of non-utility generators and utility among your contenders. The increase in demand on transmission system, the lack of long term planning and the need to provide open access to energy production firms and consumers; all together they have created trend toward a reduction in safety and reduction in quality of supply. The alternating current transmission system has several limitations, classified as static and dynamic limits [1-3]. These inherent limitations restrict the feeding operation, which lead to under-utilization of existing transmission resources. Conventionally, motionless or mechanically switched capacitor series and shunt reactors and synchronous generators have been used to solve many of these problems. However, there are some constraints on the use of these conventional strategies. It was able to attain desired performance successfully. The wear of mechanical components and sluggish response were the biggest glitches. As a result, it has been necessary for alternative technology power electronic devices with fast response characteristics. The requirement has been further fueled by the restructuring of worldwide utilities, environmental regulations, and increasing efficiency and difficulty in obtaining permits and right of way for the construction of electricity transmission, materials mounting [4]. This, along with the invention of the thyristor semiconductor switch, opened the door for the development of FACTS controllers. The route drivers based historical facts to modern thyristor converters technically advanced voltage source based FACTS controllers, made possible by rapid progress in high-power semiconductor switching devices [1-3]. A compensator Static VAR (SVC) is an electrical device to provide reactive power...
compensation fast action in networks of high voltage transmission and can help improve the voltage profile in the transient state and, therefore, improving the performances of quality electrical services. An SVC is one of the FACTS controllers, which can control one or more variables in a power system [5]. The dynamic nature of the superior vena cava is the use of thyristor devices (e.g. GTO, IGCT) [4]. The thyristor, which is usually located inside a “house of the valve” can change the capacitors or inductors input and output circuit on a per-cycle, allowing rapid superior control system voltage.

The compensator studied in this paper consists of a fixed reactor connected in series to a thyristor-controlled (TRC) reactor, based on bi-directional valves- and a fixed capacitor bank in parallel with the combination reactor-TRC. The thyristors are activated by suitable control which regulates the magnitude of the current.

2. Static VAR Compensator

2.1 Configuration of SVC

SVC provides an outstanding source of shunt reactive compensation quickly controllable for dynamic voltage control through use of thyristors high-speed switching / controlled devices [6]. A SVC is generally composed of coupling transformer, thyristor regulators, reactors, capacitance (often tuned for harmonic filtering).

2.2 Advantages of SVC

The main advantage of SVC on simple, mechanically switched compensation schemes is their almost instantaneous response to variant the system voltage. For this cause, they are often used close to their zero point, to maximize the correction of reactive power [7] - [10]. They are larger overall capacity cheaper, faster and more reliable than dynamic compensation systems as synchronous compensators (condensers). In a word:

1) Improved system stability at steady state.
2) Improved stability in the transitional system.
3) Better division burden on parallel circuits.
4) Reduced voltage drops in load areas for serious disorders.
5) Reduction of transmission losses.
6) Better adaptation expense line.

2.3 Control Concept of SVC

SVC is a controlled shunt susceptibility (B), as defined by the control settings injecting reactive power (Q) for the system based on a square of the terminal voltage. Fig. 1 illustrates an SVC TCR, containing the operational concept. The control objective is SVC to maintain a desired voltage on the high voltage bus. At steady state, the SVC will provide a steady state control voltage to keep the high voltage bus to a predefined level.

If the high voltage bus begins to fall lower than its range of set point, the SVC will inject reactive power (Qnet). In increasing the voltage of the bus back to your network desired level of tension. If the bus voltage increases, the SVC will inject less (or TCR will absorb more) phantom power, and the result will achieve the desired bus voltage. From Fig. 1, + QCAP is a fixed capacitance value, so the magnitude of the reactive power injected into the system Qnet is controlled by the magnitude of reactive power absorbed by the TCR-Qind. The foundation operation of the valve which controls the thyristor TCR is described here. The thyristor switch is self each zero current, therefore the current through the reactor is obtained by gating or triggering the thyristor into a conducting or desired firing angle in relation to the voltage waveform [11].
3. Static VAR Compensator

The base of the thyristor-controlled reactor (TCR) shown in Fig. 2. The control element is the thyristor controller, shown here as two oppositely propelled thyristors conducting alternate half cycles in the power frequency. If the thyristors are closed in driving precisely the peaks of the supply voltage, the results of driving full in the reactor, and the current is the same as if the driver were shorted thyristors.

3.1 Principle of Operation

The reactive current is primarily going voltage at about 90°. It has a small in-phase components due to power losses in the reactor, which can be of the order of 0.5-2% reactive power. Total drive current shown by the waveform in Fig. 3 (a). If the gating is stuck by equal amounts on both thyristors, a series of current waveform is obtained, such as in Fig. 3 (a) to 3 (d). Each of these corresponds to a particular value of a propagation angle which is measured from a zero crossing of the voltage. Total drive is attained with an angle part 90°. Drive selection is obtained from propagation angles between 90° and 180°. The effect of increasing the propagation angle is to reduce the fundamental harmonic component of the current. This is equivalent to an increase in the inductance of the reactor, reducing its reactive power, as well as its current. So far as the major component of current is concerned, the reactor is controlled by a controllable thyristor susceptance, and can therefore be applied as a static compensator.

4. Performance Analysis of SVC Controller

4.1 Modeling for Dynamic Performance Analysis with SVC Applications

By studying the performance of the system and dynamic voltage control, system modeling is an important aspect, especially in and around the specific area of study. It is typical of many power companies to share large system models consisting of thousands of buses representing the interconnected system. The details of the modeling are discussed elements "system" such as transformers, generators,
transmission lines and shunt reactive devices (ie, capacitors, reactors), etc., for short term stability analysis. A significant aspect and continually debated modeling is the model "load". For the short-term stability analysis, the loads are modeled with both (eg real power, reactive power) static and dynamic characteristics [12]. The block control voltage automatic regulator (AVR) is an important part of SVC models that operate in a voltage error signal. The AVR basic control block is defined by the transfer function as shown in Fig. 3.

![Fig. 3. Transfer Function of AVR Control Block](image)

Where $K_r$ and $T_r$ indicates the gain and time constant, respectively. The tilt adjustment, maximum and minimum Susceptance, thyristor firing lag transport, lag measuring voltage, etc. are the functions of the additional control block commonly used dynamic models SVC.

4.2 Controller Design Analysis

SVC is operated as a bypass device for supplying power to support voltage or inductance to reduce the bus voltage. The fixed capacitors are tuned to absorb the harmonics generated by the TCR operation. Although the SVC is able to provide support for the short-term stability and power oscillation damping, its main function is to support dynamic voltage and reactive power. The SVC in principle is a controlled shunt susceptance (+/- B) as defined by the SVC control settings injecting reactive power (+ Q) or remove reactive power (Q) based on the square of its terminal voltage. The block diagram shown in Fig. 4.

In this application, $Q = V^2 \times B$, and L and C are the components that are dimensioned such that $Q \geq 0$ is the single margin of operation. The AVR in the form of proportional and integral control, operates in a voltage error signal there are also measuring delay (DT) and thyristor transport lag burning (T1). The B output of this control block diagram of the pulse generator feeding controller that generates the thyristor trigger signal required for the light triggered TCR.

![Fig. 4: Detailed SVC Block Diagram](image)

4.3 Performance Criteria of SVC Operation

The control objective is to uphold the system voltage in 275 kV bus at 0.038+j0.32 p.u. Voltage. If the bus starts to drop below 0.038+j0.32 p.u., SVC will inject reactive power (Q) in the system (controlled within their limits), thereby growing the bus voltage back to its desired 0.038+j0.32 p.u. voltage according to its tilt configuration, XSL. On the contrary, if the bus voltage increases, the SVC will inoculate less (or TCR will absorb more) reactive power (within their controlled limits), and the result will be the voltage required bus in [9]-[10]. Simulink block diagram of SVC controller is given in Fig. 5. The steady state response in SVC will follow the current-voltage (IV) characteristic curve shown in Fig. 6. The feature VI is used to illustrate the VCS classification and steady state performance in the typical
region of operation steady state is mainly based setting Vref, XSL, and system impedance.

![Simulink Block Diagram of SVC Controller](image1)

Fig. 5. Simulink Block Diagram of SVC Controller

![Steady State V-I Characteristics of SVC](image2)

Fig. 6. Steady State V-I Characteristics of SVC

### 4.4 Typical Parameter of SVC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_d$</td>
<td>Time Constant</td>
<td>0.001-0.005</td>
</tr>
<tr>
<td>$T_1$</td>
<td>Time Delay</td>
<td>0.003-0.006</td>
</tr>
<tr>
<td>$X_{sl}$</td>
<td>Slope Reactance</td>
<td>0.01-0.05 pu</td>
</tr>
</tbody>
</table>

![Scope 1: The Required Pulse](image3)
5. Performance Testing

HUB – JSO is a 500kV single circuit line of 181 kM. This line consists of 4 wire bundle conductor arrangement. The conductor used in this circuit is code named GREELEY. Greeley is an AASC (Aluminum Alloy Stranded conductor) type conductor. When wind velocity is zero m/s, a current fellow of 566 A will rise the conductor temperature to 40 degree Celsius, and current fellow of 681A will rise conductor temperature to 50 degrees Celsius. When wind velocity is 0.61m/s (2.2km/h), a current fellow of 791 A will rise the conductor temperature to 40 degree Celsius, a current fellow of 901A will rise conductor temperature to 50 degrees Celsius. An extensive series of tests was made during and after commissioning to check the performance of the compensator. These tests included measurements of regular transfer function.

Case-1: Voltage and current waveforms as shown in Fig. 7(a).

Sample output to test PDF Combine only
Case-2: Energizing the capacitor bank producing a sudden change of MVAR as shown in Fig. 7(b).

References

Abstract

One of the major causes for the environmental degradation is the use of fossil fuels to produce electric energy. Thus, people of developing countries such as Pakistan still depend upon the use of grid system and uninterruptible power supply (UPS) system for the supplying of electrical energy. These systems are not only harmful to their surroundings but very expensive too. Solar photovoltaic system (SPV) can be best substitute to conventional energy generation and supply methods. SPV system is a renewable energy system that generates and supply electricity simultaneously from solar radiation, as solar energy is not only cheap but it is also environmental friendly. The prime object of this research is to generate electric energy from solar radiations. This study is carried out by developing the mathematical model of solar photovoltaic (SPV) system for Hyderabad. Due to recent advance in technology and falling price of SPV system, these systems are more reasonable for use to generate and supply electricity, especially in rural areas where other power sources are unreachable. From this research it was found that electricity supply from SPV system is more significant and cost saving than grid and UPS systems.

1. Introduction

Pakistan is facing energy crisis as a consequence of tremendous growth in population and heavy reliance on imported fuel. Our national economy has been under a tremendous pressure due to the change in international oil markets and because of these changes unit cost of electricity keeps on fluctuating and inflation rate has become difficult to manage. The addiction to conventional sources for electricity generation has hit Pakistan’s economy badly. Currently, Pakistan relies on completely on conventional energy resources to fulfill its energy demand; the share of renewable energy is even less than 1% as shown in Table 1.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Existing Energy Mix</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Public Hydro</td>
<td>7013</td>
</tr>
<tr>
<td>2</td>
<td>Public thermal</td>
<td>5861</td>
</tr>
<tr>
<td>3</td>
<td>Nuclear</td>
<td>665</td>
</tr>
<tr>
<td>4</td>
<td>IPP's Hydro</td>
<td>84</td>
</tr>
<tr>
<td>5</td>
<td>IPP's Thermal</td>
<td>8678</td>
</tr>
<tr>
<td>6</td>
<td>K-Electric</td>
<td>2422</td>
</tr>
</tbody>
</table>

Electric-machines have become essential part of human life. Many rural areas in developing countries will not have access to cheap electricity for several years to come. Urban and rural areas of Pakistan are becoming automated and require continuous supply of energy for the better development. There is a direct relation between the energy consumption and development of a country. The 80% of primary energy supply are met by fossil fuels and remaining 20% by other sources [1] & [2]. The rise in demand for energy is necessary for the safe world for future generation. The fossil fuel resources are decreasing continuously and the cost of production of electricity using fossil fuels is higher. Another disadvantage of...
the utilization of fossil fuel resources is increase in greenhouse gases. The increase in greenhouse gases is causing increase in global warming and environmental pollution. The utilization of renewable energy is increasing due to the environmental damage caused by greenhouse gases. The solar energy being a renewable energy source has received worldwide attention as it is a sustainable solution to meet energy needs. The solar light reaches the surface of earth in the form of electromagnetic waves. The solar radiation is a carbon-free and environmental friendly source of energy. It has been observed that the amount of solar energy reaches the earth is about (4.3x1020 J) and that is greater than 5% of the total annual energy consumption of the world. Solar photovoltaic (PV) cells convert the solar radiation in the form of electric energy. Solar PV cells are easily available solar technology. Despite huge potential, solar photovoltaics do not yet have significant contribution in the energy mix of developing countries and emerging economies. The use of solar PV cells is increasing due to the advancement in solar panel manufacturing and efficiency. Electric current is produced when electrons are released from the atomic bonds of the semiconductor material of the PV cells when the solar radiation strikes on it. The solar PV cell has a life period of about 20 years. Hyderabad is the second largest city of Pakistan and is situated at 25.3792 Latitude and 68.3683 Longitude. Hyderabad receives a handsome amount of solar radiation annually and receives annual radiation between 4.0-4.5 kWh/m²/day. The solar PV cell has negligible maintenance and no moving parts. The power output from solar PV cell is maximum when the sun is directly above the solar PV cell. If a mechanical device is fitted with the solar PV cell that allows it change the orientation by tracking the sun’s position, efficiency of solar PV cell is increased since the power output from solar PV cell is maximum when the sun light is directly above the surface at 90° angle.

2. Methodology

A solar PV technology converts the solar radiation in the form of electrical energy, it has no moving parts and no or less maintenance as compared to conventional fossil fuels.

2.1. Solar Photovoltaic System

During the last decade, there has been some promising progress in photovoltaic systems in Pakistan. Appreciable advancement is achieved in the solar cells, modules and systems fabrication expertise of the institutes of the country. Photovoltaic systems are more suitable for remote areas and small power requirements. First large scale solar power generation project is in operation in Pakistan, having 100MW capacity in first phase and additional 900MW in next two phases. It is named as Quaid-e-Azam Solar Power (QASP) park and is located in Bahawalpur, Punjab [6]. Three thousand solar power systems are set up in villages of district Tharparkar, Sindh. During the last fifteen years private companies have imported almost 54.77 MW Solar panels. AEDB has approved and received many project feasibility studies conducted by different companies [7].

The main components of solar photovoltaic system are battery, solar panel, inverter and solar charge controller as shown in Fig 1. A solar panel is the most important component of a solar photovoltaic system.

The input of a solar panel is heat energy from the sun and output is the electrical energy [3]. The generation of electrical energy from solar panel is dependent on the amount solar radiation being strike on the solar panel surface. The electrical energy from solar panel is in the form of DC current. The DC
electrical energy from the solar panel can be utilized by home appliances only if they are working on DC current. Since most of the home appliances in our country are working on AC current therefore an inventor is used to convert DC current from solar panel in to AC current so that home appliances can utilize it. DC current from solar panel is stored in battery, and then DC current from battery is converted to AC current by inventor. Charge controller is used to regulate current and voltage.

2.2. Solar photovoltaic system's mathematical formulation

The following steps are taken in to consideration while designing of solar photovoltaic.

2.2.1 Determination of power consumption demands

This is the basic step in order to design a solar photovoltaic system for any home, office or any building. The load of each appliance is measured in Watts and the running (operating) time on daily basis of that appliance is measured in hours [2]. Load and the running time vary from appliance to appliance.

For calculating the total energy consumption demand,

The load of each appliance and its corresponding running time both are multiplied to give individual load for the appliance.

Load for appliance (Watt-hours) =Power (Watts) x Running time (Hours)

Total Load (Watt-hours)=Summation of Individual loads for appliances

$$E_t = P_a \times t$$  (1)

2.2.2 Determining the size of PV Module

A PV module is rated in peak-watts. Peak-watts produced by the PV panels depend upon the size of the panel and the climate conditions of the location selected.

Knowing the fact that PV panel can’t be used to run directly the AC appliances, the battery, solar charge controller and inverter must be used along with PV panel. Hence, in order to determine the peak-watts for a solar panel, the efficiency of battery, solar charge controller and inverter must be counted. The efficiency of most of the batteries ranges from 80% to 90% while the efficiency of solar charge controllers is about 90% [3]. When this efficiency is counted, A solar panel must produce an additional thirty percent (30%) energy. Secondly, amount of energy produced by the PV panel depends upon the location where it is going to operate. Number of hours of day sunlight varies from one location to the other.

The mathematical formula for determining the size of PV panel can be given as

$$E_{pv,t} = E_{t} \times 1.3$$  (2)

2.2.3 Determining the size of Battery

When determining the size of battery, it is essential to remember that Battery is the alone energy source for running the appliances for some duration. Size of battery depends upon total load of appliances, the efficiency of the inverter, the days of autonomy, depth of discharge and the nominal voltage of the battery. The load of appliances can be calculated as discussed in section (2.2.1). Efficiency of an inverter plays a vital role because battery needs an inverter to run any AC appliance. Inverters are not 100% efficient because of the losses. Efficiency of most of the inverters is from 85% to 90% (10 to 15 percent power wasted). The days of autonomy are the days without sun or cloudy days in which there will be no power generation from the PV panel. Battery will be the only source of power. The days of autonomy depends upon the location selected. As a standard, there are 1.5 to 3 days of autonomy. Hence, the size of battery should be increased by a factor of 1.5 to 3. Depth of discharge ranges from 40 % to 80 %[4].
battery capacity is highly affected by the time at which it is discharged. The discharging time should be as high as possible within the limits. Finally, nominal voltage of battery also needs to be counted while selecting a proper battery capacity.

Considering all above variables a mathematical formula can be formulated for determining the battery size

\[
E_{bc} = \frac{E_t}{(0.85 \times 0.6 \times V_n)} \times t_{au}
\]  

(3)

2.2.4 Determining the size of solar charge controller

Overcharging and discharging are two main problems associated with the batteries. These two problems can be overcome by utilizing a solar charge controller between a solar panel and a battery [5]. It controls the current and voltage coming from the panel to a battery and avoids chances of back current to the solar panel. The size of a solar charge controller is measured in units of amperage and voltage [6]. Amperage is obtained from the PV panel or array while the voltage is the same as the nominal voltage of a battery.

Mathematically, the size of a solar charge controller can be expressed by the formula

\[
I_{sc} = I_{s,t} \times 1.3
\]  

(4)

2.2.5 Determining the size of Inverter

All the household appliances take AC power as an input. A solar panel generates DC power which is stored in a battery. This stored DC power is converted into AC power by a device named inverter. For ensuring safety, the inverter size should be designed 25% - 30% greater as compared to the power to be utilized by the appliances. If a motor or a compressor is to in any appliance, the size of inverter is considered as 5 times the energy demanded by the appliance [7].

\[
P_i = P_x \times 5
\]  

(5)

3. Result and discussion

A huge variation of Direct and Diffuse radiation intensities is because of cloudy conditions. These varying intensities results are plotted and presented in Fig 2. The figure clearly defines the trend of direct and diffuse solar radiations. The direct radiation values are highest in the month of April and November. The effect of diffuse radiation to global radiation is small during winter season because during these months sky is sunny and clear and does not surpass 40% even in the cloudy condition.

Pakistan Council of Scientific and Industrial Research provided the data for daily radiation and temperature conditions as presented in Fig. 3 (a) and (b). This data is average for the year of 2011 in winter and summer seasons of Hyderabad.
Average radiation for a week was about 728.1953 WATT/m² in the month of June for Hyderabad.

Design and analysis of solar system of current study is done by considering a small house having two washrooms, two dining rooms and a kitchen as given in Table 2. However, electrical appliance power consumption and solar panel’s produced power for an identified number of hours is given in Table 3. Table 2 shows physical features of solar panel for finding electricity requirements.

<table>
<thead>
<tr>
<th>Utilizations</th>
<th>Number</th>
<th>Power (W)</th>
<th>Hours (Average)</th>
<th>Watt Hours (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling fan</td>
<td>2</td>
<td>1.80×10²</td>
<td>8</td>
<td>1.44×10³</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>1</td>
<td>5.0×10²</td>
<td>12</td>
<td>6.0×10³</td>
</tr>
<tr>
<td>Electric iron</td>
<td>1</td>
<td>1×10³</td>
<td>1</td>
<td>1.0×10³</td>
</tr>
<tr>
<td>Television</td>
<td>1</td>
<td>2.0×10²</td>
<td>6</td>
<td>1.2×10³</td>
</tr>
<tr>
<td>Energy savers</td>
<td>8</td>
<td>1.92×10²</td>
<td>8</td>
<td>1.536×10³</td>
</tr>
<tr>
<td>Computer</td>
<td>1</td>
<td>1.2×10²</td>
<td>5</td>
<td>6×10²</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>2.192×10³</td>
<td>40</td>
<td>11.776×10³</td>
</tr>
</tbody>
</table>

Whereas price description for solar panel is presented in Table 4

<table>
<thead>
<tr>
<th>S. No</th>
<th>Components of Solar Panel</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2900 Ah battery cost</td>
<td>0.46 Million Rupees</td>
</tr>
<tr>
<td>2</td>
<td>2kW solar panel array</td>
<td>0.20 Million Rupees</td>
</tr>
<tr>
<td>3</td>
<td>12V 50A solar charge controller</td>
<td>0.42 Million Rupees</td>
</tr>
<tr>
<td>4</td>
<td>7kW inverter cost</td>
<td>0.98 Million Rupees</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>0.80 Million Rupees</td>
</tr>
</tbody>
</table>
The Table 5 shows electrical appliance power requirements via grid system and bill paid for each unit.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Grid System Characteristics</th>
<th>Value &amp; unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Daily consumption of power = 11776Wh</td>
<td>1.2×10^4 Wh</td>
</tr>
<tr>
<td>2</td>
<td>Monthly consumption</td>
<td>3.5×10^2 kWh</td>
</tr>
<tr>
<td>3</td>
<td>Monthly bill paid</td>
<td>0.045 Million Rupees</td>
</tr>
<tr>
<td>4</td>
<td>Annually bill</td>
<td>0.54 Million Rupees</td>
</tr>
</tbody>
</table>

Characteristics of solar panel are presented in Table 6

<table>
<thead>
<tr>
<th>S. No</th>
<th>Solar Panel System Characteristics</th>
<th>Value &amp; unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Energy generated (on daily basis)</td>
<td>1.8×10^4 Wh</td>
</tr>
<tr>
<td>2</td>
<td>Energy generated (on monthly basis)</td>
<td>0.54×10^3 kWh</td>
</tr>
<tr>
<td>3</td>
<td>Cost saved per month</td>
<td>Rs. 2,240</td>
</tr>
<tr>
<td>4</td>
<td>Cost saved annually</td>
<td>0.027 Million Rupees</td>
</tr>
</tbody>
</table>

Total Cost Saved by Solar Panel System WAS 0.027 Million Rupees.

The cost for solar panel system and the parts of UPS system for 25 years is presented in following tables.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Element</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48V 400 Ah liquid battery</td>
<td>0.035 Million Rupees</td>
</tr>
<tr>
<td>2</td>
<td>for 25 years</td>
<td>1.75 Million Rupees</td>
</tr>
<tr>
<td>3</td>
<td>7000W inverter</td>
<td>0.098 Million Rupees</td>
</tr>
<tr>
<td>4</td>
<td>for 25 years</td>
<td>2.45 Million Rupees</td>
</tr>
<tr>
<td></td>
<td>Total UPS system cost for 25 years</td>
<td>4.2 Million Rupees</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S.No</th>
<th>Component</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 kW panel array</td>
<td>0.20 Million Rupees</td>
</tr>
<tr>
<td>2</td>
<td>12V 2900 Ah battery</td>
<td>0.46 Million Rupees</td>
</tr>
<tr>
<td>3</td>
<td>for 25 years</td>
<td>2.3 Million Rupees</td>
</tr>
<tr>
<td>4</td>
<td>12 V 50 A solar charge controller</td>
<td>0.042 Million Rupees</td>
</tr>
<tr>
<td>5</td>
<td>for 25 years</td>
<td>0.21 Million Rupees</td>
</tr>
<tr>
<td>6</td>
<td>7 kW power inverter</td>
<td>0.098 Million Rupees</td>
</tr>
<tr>
<td>7</td>
<td>for 25 years</td>
<td>0.49 Million Rupees</td>
</tr>
<tr>
<td></td>
<td>Total solar power system cost for 25 years</td>
<td>3.2 Million Rupees</td>
</tr>
</tbody>
</table>

The comparison of cost saving show that the solar power system will save RS 980,000 in 25 years as compared to UPS system.

As UPS requires electric power from external source which is water and power development authority (WAPDA) therefore for the comparison electric bills were not considered. If yearly bills are also considered then amount of capital cost saved by solar system will also be huge cost of UPS system depends upon these bills. As UPS requires electric power from external source which is water and power development authority (WAPDA) therefore for the comparison electric bills were not considered.

4. Conclusion

It is observed from the obtained results that the operating cost of grid power and UPS system is higher than solar based power system, while the initial cost of solar power based system is higher than grid power and UPS system. The UPS system is less appropriate than the solar power based system because the life of battery and inverter in solar power based system is higher than the UPS system. In solar system the dry batteries are used which require no water filling while in the UPS system batteries require
change of water regularly. Solar system does not depend upon grid power hence it work continuously whereas UPS system function depends upon grid power hence due to load shedding its operation will also be affected.

References


Abstract

When a Photovoltaic (PV) panel is exposed to sunlight an I-V characteristic curve of that panel is observed. The I-V characteristics of the PV panel continuously changes with the change in irradiance and temperature of the surroundings which also changes maximum power point MPP of the PV panels. This affects the charging process of the batteries connected with the PV panels. This paper presents an efficiently designed Solar PV system for charging the batteries. The system uses Perturb & Observe (P&O) algorithm to track the MPP. The MPP tracking algorithm works in conjunction with a DC-DC Buck (step-down) converter. The power from the PV panels is fed into a charge controller, which equals the PV voltages to the battery voltages with maximum power being delivered from PV panels to the batteries. A dsPIC microcontroller is used which continuously tracks the MPP even with the changing conditions and handles the charging battery voltages. A MATLAB based modelling and simulation is also designed and is first used to test the algorithm along with the charge controller under the changing conditions and then it is implemented on the hardware. The simulation results shows that the algorithm tracks the MPP point of the PV panels, including the hardware results which verifies the efficient working of the proposed design.

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Keywords: Maximum Power Point Tracking (MPPT); Perturb and Observe (P&O); MATLAB; DC-DC Converter.

1. Introduction

With the increasing crisis in the availability of energy and its resources; like fossil fuels, solar energy has become one of the most demanding resources for the production of electrical energy. Solar panels need to be operated at maximum power point (MPP) in order to extract maximum power out of it. This is done with the help of a power dc-dc converter allowing the panels to thoroughly operate at maximum power point. PV Panels when being operated at the maximum power point gives the highest efficiency. There are numerous algorithms for MPP tracking, the one used here is hill-climbing algorithm commonly known as Perturb and Observe (P&O), which is one of the most extensively used algorithm due to its simplicity and ease of implementation [1] [2]. It operates by perturbing the operating voltages of the PV array. The P&O works well under slight variations in irradiance [3].

The solar panel used is JC120S-12/Zb and the characteristics are enlisted below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power at STC</td>
<td>120 Wp</td>
</tr>
<tr>
<td>Open Circuit Voltage</td>
<td>19.8 V</td>
</tr>
<tr>
<td>Optimum Operating voltage</td>
<td>16.0 V</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>8.03 A</td>
</tr>
<tr>
<td>Optimum operating current</td>
<td>7.50 A</td>
</tr>
</tbody>
</table>

For a battery with lower voltages the power rate of charging losses increases when directly connected to the solar panels, which is catered by this MPPT charger. These losses occur because of the current-voltage (I-V) characteristics curve of the solar panels. Every PV module has its own I-V curve which gives information about the characteristics of the module. The proposed power converter for this project is a step-down DC-DC converter known as Buck Converter, which steps down the input DC voltages. This paper focuses throughout on efficient battery charging through solar panels with minimal losses.
2. MPPT Battery Charging System Model

PV panels provide dc output voltages with a certain I-V curve characteristics, each panels has its own curve characteristics depending upon the design. This dc voltage is not stable enough to directly charge the batteries therefore they need to be converted up to a voltage level to stably charge the batteries. This is done with the help of a dc-dc converter which is a buck converter in this case. A MPP tracking algorithm is implemented using a dsPIC microcontroller. This controller keeps tracking the MPP and operates the panels at this point. A simple block diagram of this model is shown in Fig. 1.

![Fig. 1. MPPT Battery Charging system model](image)

3. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking as the name suggests is an algorithm used for the tracking of maximum power of the solar panels being used. MPP can easily be understood referring to a non-MPPT based system; in which if we talk about a non-MPPT based battery charger means that the solar panels are directly connected to the battery terminals without any kind of circuitry in between them. In this case the panels operate only on the battery voltages thereby not delivering their maximum power. Contrary to it a MPPT charger ensures solar panel to function on voltages at which it is able to supply maximum power to the batteries for charging. A solar panels comes with the specs including Voc and Isc and each panels have different I-V Curve under constant irradiance as discussed. The real-time I-V curve of two JC120S-12/Zb solar panels in series is shown in Fig. 2.

![Fig. 2. Real-Time P-V & I-V curve of 2 series connected solar panels](image)

The I-V curve in Fig. 2 is a real time graph plotted on MATLAB. The V_{oc} and I_{sc} are 35 volts and 6.5 Amperes respectively. The maximum power point MPP lies on the knee of this curve which is around the point where I_{pv}=5.8A & V_{pv} = 25V. The basic objective of MPP algorithm is to track this knee. The maximum power can be seen from the PV curve which is at 145 Watt.

3.1 Maximum Power Point Tracking (MPPT)

A number of researches have took place in this field for efficiently tracking the MPP of a panel. There are a number of ways to track the MPP, out which few are listed below:
The method used here is Perturb and Observe MPPT algorithm.

4. Perturb & Observe (P&O)

Perturb and Observe, an MPPT algorithm commonly known as P&O algorithm; in this method the voltages in small amount from the PV panel are set by the controller, the controller calculates the power and if there is an increase in power the controller makes further adjustments in that direction until the power no longer changes [4].

The P&O algorithm measures the voltage, current and calculates the power of the PV panels and then perturbs the voltage to estimate the changing direction. Fig. 3 shows a PV curve of a PV panel.

![Fig. 3. P-V Curve of a Solar Panel](image)

It can be witnessed from the left side the PV panel power increases with the increase in panel voltages and after the maximum power point (MPP) at the right hand side the power starts decreasing. This concludes that if the power is increasing in a certain direction the perturbation must also be performed in the same direction either from left to right or right to left. Contrary to it if there is a decrement in power reverse perturbation must be performed [5].

The MPP is achieved when the ratio of change in power and change in voltage is equal to zero i.e. \( \frac{dP}{dV} = 0 \). The functional operation of P&O algorithm can be summarized with the help of the table below:

<table>
<thead>
<tr>
<th>( \Delta P_{PV} )</th>
<th>( \Delta V_{PV} )</th>
<th>Perturbation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0</td>
<td>&gt;0</td>
<td>Increase V</td>
</tr>
<tr>
<td>&gt;0</td>
<td>&lt;0</td>
<td>Decrease V</td>
</tr>
<tr>
<td>&lt;0</td>
<td>&gt;0</td>
<td>Decrease V</td>
</tr>
<tr>
<td>&lt;0</td>
<td>&lt;0</td>
<td>Increase V</td>
</tr>
</tbody>
</table>

Table 2 with reference to Fig. 3; when the change in power and voltage of the panels is greater than 0 the perturbation must be done so as to increase the panel voltages. If the change in power is greater than 0 and the change in voltage is less than 0, the perturbation must be done in a manner to decrease the voltage of the panels. A flow chart representing the flow of P&O algorithm is shown in Fig. 4.
The solar panel voltage and current is initially measured and the power is then calculated. The change in power $\Delta P_{PV}$ and change in panel voltages $\Delta V_{PV}$ are then calculated after this the panel voltages are perturbed by a constant value. If this perturbation causes the power to increase the perturbation must be done in the same direction else if the case is opposite then reverse perturbation must be applied. This P&O algorithm is also known as hill climbing algorithm [6].

5. DC-DC Converter

It is a power electronic circuitry that converts DC voltages from one level to another. It can be either a step-up (boost) or a step-down (buck) converter and is a class of power converters. Depending upon the applications there are a wide range of DC-DC converters. There are a variety of DC-DC converters depending on the method of voltage level conversion two of them are:

i- Linear DC-DC Converters
ii- Switched mode DC-DC Converter

The dc-dc converter is the main circuitry responsible for the tracking of MPP [7] [8]. There are some drawbacks of linear DC-DC regulator in terms of power losses; like they can only output lower voltages than the input supplied to them. Considering the efficiency of the switched mode converters (75-98%) we will be using these for MPPT purpose to charge the battery. The dc-dc converter used here for the MPP tracking is a Buck Converter.

5.1 DC-DC Buck Converter

A buck converter is a step-down DC to DC converter which reduces the voltages applied to its input by a certain factor. A general circuit diagram of buck converter is shown in Fig. 5.

Where $V_i$ is input voltage, $V_o$ is the output voltage, $S$ is an active switching device, $D$ is a diode, $L$ is an
5.2 Working Of Buck Converter

A switch mode converter; buck converter in this case contains a switch which is usually a mosfet an active device. When a switching device is introduced there exist a dual state of operation; namely ON state and OFF state. These states are named with reference to the switching device in the converter, a mosfet.

During the ON state, when the mosfet is on the circuit in Fig. 5 becomes as shown below:

![Fig. 6. Buck Converter in ON state.](image)

In this state the switch S is on, the current from the input voltage source passes through the switch, the inductor and capacitor finally it flows through the load. Initially the current does not pass to the load directly when the switch is on because the inductor stores the charge in itself. And as the diode is in parallel with the Vi source therefore a positive voltage occurs on it reverse biasing the diode, hence it acts as if it is not present in the circuit.

During the OFF state the Buck converter looks as shown in Fig. 15.

![Fig. 7. Buck Converter in OFF state](image)

In this state the switching device (mosfet) is switched off, now the energy stored in the inductor L comes into play this energy is released in the circuit. The voltages developed across the inductor known as electromagnetic force (emf) causes the current to flow in the circuit through the diode D and the load R. The diode in this case is forward biased. When all the energy stored in the inductor is supplied then the capacitor becomes the source for current. Now the current flows till the next ON state occurs.

The major portion here is the switching part for the converter, without which the converter is of no use to us. The switching is done through an external source through a controller or a function generator which supplies a square wave generated at 20 KHz or above. Below 20 KHz is an audible range and the inductor starts producing noise as it gets saturated [9].

5.3 Equation Analysis Of Buck Converter

The transfer function of the buck converter elaborates the functioning of the buck converter. In order to derive a T.F for this converter we will have to consider both the cases i.e. the ON state and the OFF state. Referring to Fig. 6; the ON state, we can observe the inductor voltages are:

\[ v_L(t) = V_i - v_C(t) \]
\[ v_L(t) = V_i - v(t) \]
\[ v(t) = V - v_{ripple} \]

Where:
\[ |v_{ripple}| \ll V \]
\[ v_L(t) = V_i - V \]

Now referring to Fig. 7; the OFF state, we can observe that the inductor voltages are:

\[ v_L(t) = -v_C(t) \]
\[ v_L(t) = -v(t) \]
\[ v_L(t) = -V \]

The ON time is represented by \[ DT \] and OFF time is represented by \[ D'T \] where D is the duty cycle,
T_s is the switching time which is the inverse of switching frequency and D’+D = 1 which is the complete duty cycle. Using the area formula we get the equation below:

\[(V_i - V) D T_s + (-V) D'T_s = 0\]
\[V_i D - V D - V D' = 0\]
\[V_i D - V = 0\]
\[V_i D = V\]

\[V = D \times V_i \]  \(\text{(Equation A)}\)

Equation \(A\) above is the final transfer function of an ideal buck converter.

6. Equation Analysis Of Buck Converter

The MATLAB model for 12V battery charger is shown in Fig. 8 is simulated at different values of irradiance at standard temperature conditions STC of 25ºC. The PV simulator simulates the PV characteristics which gives us the P-V curve of the panels. The MPPT controller when comes into play the PV curve shows the red dots on the \(P_{max}\) points which indicates that the P&O algorithm is being processed and it tracks the MPP. The P&O algorithm works in combination with the buck converter. The result of processed P&O algorithm is shown in Fig. 9.

![Fig. 8. MATLAB Model for MPPT Battery Charger](image)

![Fig. 9 Processing and output of P&O algorithm](image)

The red dots in Fig. 9 shows that the hill top or in other words the maximum power has been tracked, and that too not only for a single irradiance but for all changes in irradiance.

7. Hardware Results And Discussions

The complete hardware setup designed for this project is shown in Fig. 10.
The real time result of P-V and I-V curve is shown in Fig. 2. The maximum power point MPP lies on the knee of this curve which is around the point where $I_{pv}=5.8\text{A}$ & $V_{pv}=25\text{V}$, the P-V curve also shows that the maximum power is 145 Watts, the MPP tracking algorithm is implemented in a dsPIC30F4013 microcontroller which is responsible for the tracking of MPP throughout the entire function of the designed battery charger. The MPP tracking graph for this system is shown in Fig. 11.

The MPP algorithm tracks the MPP of the solar panel in real time which can be observed by the dense blue dots at the top left corner of the P-V & I-V curves of the hardware results plotted on MATLAB. The result is more evident in the left graph of Fig. 11 which shows the P-V curve of tracked MPP at 145 Watts.

8. Conclusion

In this paper, P&O algorithm is used for the application of battery charging with MPP tracking for efficient charging of batteries while maximum power is being delivered for the charging process, which increases the efficiency of the system reducing the losses which occurs in the case of direct connectivity of the batteries for charging purpose. The paper shows the results of MATLAB simulations and its implementation on actual hardware.

Acknowledgements

The authors would like to thank PAF-KIET and especially Dr. Kashif Ishaque for his untiring efforts throughout this research with his worthy knowledge.

References


52. Thermodynamic Assessment of Solar Chimney Based Air-Conditioning System for Agricultural and Livestock Applications

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Abstract

The present study addresses the applicability of solar-chimney based passive-air-conditioning (SCAC) system for agricultural and livestock applications. As the system is free from any kind of refrigerant, therefore enables zero ozone depletion (ODP) and global warming (GWP) potential. The SCAC utilizes well-known Maisotsenko cycle (M-Cycle) in order to achieve the sensible load of air-conditioning (AC) efficiently. Recent studies have proven the advancement of M-Cycle in the field of AC. Therefore, in the present work SCAC system’s applicability together with M-Cycle conception has been thermodynamically investigated. Ideal AC zones are established on psychrometric charts for storage of various agricultural products (including: green tomatoes, sweet potatoes, sapodilla, banana, bitter melon, breadfruit, papayas, sweet pepper, pineapples, ugli fruit, sugar apples, cabbage, onion, mushroom, dew/blue/black berries, grapes, and dates etc.), and for animals’ thermal comfort (including: sheeps and lambs at growing stage, dairy cattle and cows, pig farrowing houses, pig nursery barns, beef cattle and cows, poultry breeders and laying houses etc.).

A simplified correlation has been established in order to predict the M-Cycle performance for SCAC system on the basis of experimental data available in literature. The correlation shows good agreement with the experimental data, and therefore is analyzed for four big cities of Pakistan namely (1) Karachi, (2) Lahore, (3) Multan, and (4) Peshawar. The thermodynamic analysis shows that the SCAC can efficiently achieve the sensible AC load for various agricultural and livestock applications, however, the performance index may vary according to the nature of application. Results showed that the SCAC system’s applicability is limited in humid areas because of the nature of M-Cycle operation, therefore, may not be sustainable standalone AC system for various applications. However, it can be handy solution in order to minimize the AC load as well as to develop low-cost chilled ceiling for various agricultural and livestock applications. It is worth mentioning that it can be efficiently utilized in most of the dry and moderate areas.

Keywords: air-conditioning; solar chimney; M-Cycle; agricultural products; livestock

1. Introduction

Modern life style requires huge amount of primary energy due to extensive & precise thermal comfort in terms of heating, cooling, humidification, dehumidification and ventilation. In this regard, air-conditioning (AC) becomes basic need for offices, buildings, schools, shopping malls, and transport busses/trains etc. Therefore, lots of research and systems have been studied and are in practice in order to achieve humans’ thermal comfort. However, animals’ thermal comfort is hardly studied and implement
specially in developing countries. Similarly in agricultural sector of developing countries, proper storage structures as well as conditions are rarely accomplished for the storage of post-harvest agricultural products due to the high pricing of conventional AC technologies.

From the above prospective, authors investigate the M-Cycle based renewable energy (i.e. solar-chimney) driven passive air-conditioning (SCAC) system for various agricultural and livestock applications. The concept of M-Cycle driven SCAC system was first time introduced by Miyazaki et al. [2] which presents the numerical simulation model for the SCAC system. One of the key component of SCAC system is M-Cycle unit for indirect evaporative cooling. In the present work, authors tried to utilize the experimental findings of M-Cycle (available in literature) in order to investigate the SCAC system’s applicability in agricultural and livestock applications. Consequently, a simplified correlation has been established in order to find out the performance by M-Cycle unit on the basis of Anisimov et al. [3] and Pandelidis et al. [4].

Fig. 1. Psychrometric representation of ideal AC zones for: (a) animals’ air-conditioning; and (b) agricultural products’ storage
1.1. Development of ideal AC zones

Temperature and humidity requirements for ideal air conditioning vary according to nature of an individual application. As far as storage of post-harvest agricultural products is concern, it may vary according to respiration, transpiration, and fermentation etc. of the agricultural product [5]. On the other hand the AC requirements for animals are completely different as compared to conventional AC for humans’ thermal comfort which is due to the variability in metabolism rate, respiration rate, nature of food and genetic factor etc. In the present study ideal AC zones are developed on psychrometric charts for various agricultural and livestock applications on the recommendation given by ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers) [6] and FAO (Food and Agriculture Organization) [7]. Fig. 1(a) shows the ideal AC zones for animal’s thermal comfort for: (i) sheeps and lambs (growing stage), (ii) dairy cattle and cows, (iii) pig farrowing houses, (iv) pig nursery barns, (v) beef cattle and cows, and (vi) poultry breeders and laying houses. Fig. 1(b) shows ideal storage zones for various agricultural products which include: green tomatoes, sweet potatoes, sapodilla, banana, bitter melon, breadfruit, papayas, sweet pepper, pineapples, ugli fruit, sugar apples, cabbage, onion, mushroom, dew/ blue/ black- berries, grapes, and dates etc.

2. Solar chimney based air-conditioning (SCAC) system

A typical renewable energy operated M-Cycle based SCAC system was first time introduced by Miyazaki et al. [2] in 2011. The system captures the psychrometric renewable energy from the ambient air (from roof-side) and produces cooling effect via chilled ceiling (in room side). The driving force for the system air flow comes from thermal head of the solar-chimney. A typical schematic diagram of the SCAC system is shown in Fig. 2. Referring to the system schematics, it can be seen that ambient air from roof side is passed from the wet and dry channels of M-Cycle and exhausted into the ambient air. However, water evaporated into the wet channel of M-Cycle unit produced cooling effect due to the heat of water vaporization. Therefore, cooling effect has be induced in the room side by means of convective and radiative heat transfer from the additional dry channel of M-Cycle unit. This is a kind of indirect evaporative cooling, however, the in this case air has the potential to be cooled to the ambient air dew-point temperature by means of innovative conception of M-Cycle. M-Cycle attains energy from air by utilizing psychrometric renewable energy available from the latent heat of ambient air water evaporation [1]. It can be seen that M-Cycle unit has three channels in which two are dry but intermediate channel possesses water for evaporation. Firstly, air from roof side enters in dry channel and then moved to wet channel where it is cooled due to water vapor evaporation similar to IEC. On the other hand, heat is transfer from the room air (lower dry channel in Fig. 2) via radiative and convective heat transfer while keeping the humidity ratio constant. The details of M-Cycle can be found from the authors’ previous work [1]. It is worthy to mention that the conventional IEC system limits the cooling effect up to the ambient air wet bulb temperature.

![Fig. 2. Schematic diagram of SCAC system for agricultural and livestock applications, reproduced from [2].](image-url)
3. Research methodology and development of simplified correlation

In the present study SCAC system has been proposed for various agricultural and livestock applications. As the efficiency of SCAC system is based on performance by the M-Cycle unit, therefore, experimental data of M-Cycle unit is explored from the literature carefully. Upon review of available literature on M-Cycle [1], it has been realized that the studies published by Anisimov et al. [3] and Pandelidis et al. [4] can give the real insights of M-Cycle performance. In the studies [3-4] authors also developed a precise model for the estimation of M-Cycle performance based on experimental data of M-Cycle for various ambient air conditions. However, the model is relatively complicated, therefore, in the present study a simplified correlation has been established in order to find out the M-Cycle performance for various ambient air conditions. In this regard, experimental result points of M-Cycle unit at different ambient air conditions were taken from the studies [3-4], and optimizations has been made for: $T_i \approx 20^\circ C$ to $45^\circ C$ and $H_i^{spc} \approx 10$ g/kgDA to 25 g/kgDA, using the following fundamental conceptions:

$$T_o = f \left( T_i, H_{spc} \right)$$  \hspace{1cm} (1)

$$H_o^{spc} = H_i^{spc} = H_{spc}$$  \hspace{1cm} (2)

$$RH_o, h_o, T_{dp}, T_{web} = f \left( T_o, H_o^{spc} \right)$$  \hspace{1cm} (3)

$$Q = f \left( T_i, H_{spc} \right)$$  \hspace{1cm} (4)

Where $T_o$ and $T_i$ represent the outlet and inlet air temperature [$^\circ C$], respectively, in the product channel (lower dry channel in Fig. 2) of M-Cycle. $H_o^{spc}$ and $H_i^{spc}$ represent the specific humidity (humidity ratio) of corresponding outlet and inlet air [g/kgDA]. Q represent the cooling capacity of M-Cycle unit [kJ/kg/s] whereas subscript $i$ & $o$ represent inlet and outlet to the product channel of M-Cycle. Rest of the parameters are explained in nomenclature in detail. Optimization has been made for the statistical error minimization and consequently the $R^2$ values were kept more than 0.95 in each formulation.

Using the above mentioned correlation, the performance of M-Cycle as well as SCAC system has been investigated for four big cities of Pakistan namely: (1) Karachi, (2) Lahore, (3) Multan, and (4) Peshawar. As the scope of the M-Cycle is limited in humid areas, therefore, different ambient air conditions were selected. Similarly, the scope may be limited depending upon the nature of application as well as air flow rates. It is worthy to mention that, the metrological data of the cities was obtained from the Meteonorm 7 (licensed version) from Swiss Meteotest Company. Consequently, Fig. 3(a) shows the outdoor air profile (monthly basis) of ambient air temperature and relative humidity whereas Fig. 3(b) represents the outdoor air profile (monthly basis) for ambient air enthalpy and ambient air dew point.

![Fig. 3. Outdoor air profile on monthly basis for four big cities of Pakistan: (a) ambient air temperature and relative humidity; and (b) ambient air enthalpy and ambient air dew point.](image)
4. Results and discussion

In the present study M-Cycle based solar-chimney driven passive air-conditioning (SCAC) system has been proposed for the storage of various agricultural products and for animals’ thermal comfort. Schematic diagram of SCAC system is shown in Fig. 2 whereas the various agricultural and livestock AC applications are represented on psychrometric charts on Fig. 1. It is obvious that the output consistency of SCAC system is based on the net performance of integrated M-Cycle unit and the net effect of solar-chimney. The M-Cycle [1] is well known in AC field due to its potential of dew-point evaporative cooling. The M-Cycle conception was first time integrated in SCAC system by Miyazaki et al. [2] and the authors developed a simulation model for the system. However, in the present study, experimental results of M-Cycle available in the literature by Anisimov et al. [3] and Pandelidis et al. [4] are utilized for the formulation of simplified correlation for the approximation of thermodynamic properties of M-Cycle product air. Although model of Anisimov & Pandelidis et al. [3-4] is precise but relatively complicated, therefore, a simplified correlation is established using the fundamental conceptions (Eqs. 1-4) as explained in methodology (heading 3). The developed simplified correlation is represented by Eq. 5 and Eq. 6 for product air temperature ($T_o$) and for cooling capacity ($Q$), respectively. The validity range of simplified correction is: $T_i \approx 20^\circ$C to $45^\circ$C and $H_{spc}^{5Pe} \approx 10$ g/kgDA to 25 g/kgDA.

$$T_o = A_1 + B_1(T_i) + C_1(H_{spc})$$

(5)

$$Q = A_2 + B_2(T_i) + C_2(H_{spc})$$

(6)

where $T_o$ and $T_i$ represent the outlet and inlet air temperature [°C], respectively, in the product channel of M-Cycle (see Fig. 2). The parameter A, B, and C are the constants of simplified correlation, and their optimized values given in Table 1. A comparison has been made between the developed simplified correlation (Eq. 5-6) with the experimental data [3-4]. Fig. 4(a) and (b) shows comparison outcomes for outlet air temperature ($T_o$) and cooling capacity ($Q$), respectively. It can be seen that the simplified correlation can represent the experimental data reasonably for both of the cases with $R^2$ values more than 0.95.

It is obvious that SCAC system’s functionality is based M-Cycle unit whose performance indices are based on ambient air humidity [1]. Therefore, the performance of M-Cycle unit is investigated for four big cities of Pakistan (namely: 1. Karachi, 2. Lahore, 3. Multan, and 4. Peshawar) which enable different nature of atmospheric conditions of temperature and humidity. In this regard, thermodynamic properties of M-Cycle product air are estimated from simplified correlation (Eqs. 1-6) for four big cities of Pakistan for summer and winter seasons. Fig. 5(a)-(f) shows the resulted profile for: (a) outlet air temperature (dry-bulb) profile; (b) relative humidity profile; (c) dew point temperature profile; (d) wet-bulb temperature profile; (e) enthalpy profile; and (f) cooling capacity of M-Cycle unit, respectively. It can be seen that the Karachi possesses the worst scenario in all the profiles due to excessive ambient air humidity (as depicted in Fig. 3) which is the outcome of sea water evaporation. It is because the M-Cycle performance is based on net amount of water vapor evaporation, and the humid air is unable to support the phenomena which results in low cooling effect. Similarly, in moon-soon season all the cities don’t have much different results due to the higher humidity.

From the above mentioned results, it can be concluded that the SCAC system should only be adopted where the ambient air humidity is relatively lower with higher solar radiations. Moreover, system can be utilized in the hours of a particular day when there are drier conditions as well as sunny hours (or in optimised situations). Same as, SCAC systems’ applicability will be limited for the agricultural and livestock applications which has to carry out in humid climates. Therefore, the SCAC conception may not be feasible as a standalone AC device in various climates.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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</tr>
<tr>
<td>$A_2$ [-]</td>
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</tr>
<tr>
<td>$B_1$ [-]</td>
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</tr>
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<td>$B_2$ [-]</td>
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</tr>
<tr>
<td>$C_1$ [-]</td>
<td>0.5298</td>
</tr>
<tr>
<td>$C_2$ [-]</td>
<td>-0.5946</td>
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</tbody>
</table>
Fig. 4. Validation of developed simplified correlation (Eqs. 1-6) with the experimental data of Anisimov et al. [3] and Pandelidis et al. [4] for: (a) outlet air temperature; and (b) cooling capacity. The correlation is valid for the range of $T_i \approx 20^\circ$C to $45^\circ$C and $H_i^{pre} \approx 10$ g/kgDA to $25$ g/kgDA.
Fig. 5. Thermodynamic properties of M-Cycle product air estimated from simplified correlation (Eqs. 1-6) for four big cities of Pakistan for summer and winter seasons: (a) outlet air temperature (dry-bulb) profile; (b) relative humidity profile; (c) dew point temperature profile; (d) wet-bulb temperature profile; (e) enthalpy profile; and (f) cooling capacity of M-Cycle unit.
however, it will be a handy and low-cost solution for the reduction of AC loads in various applications. Moreover, a hybrid systems can also be developed for sustainable operation. Also, innovative ceiling structures can be developed using this conception for many applications shown in Fig. 2.

5. Conclusions

The present study addressed renewable energy (i.e. solar-chimney) operated passive air-conditioning (SCAC) system for the storage of various agricultural products and for animals’ thermal comfort. In this regard, ideal air-conditioning zones are established on psychrometric charts for the storage of various agricultural products and for animals’ thermal comfort. The SCAC system can produce cooling effect by means of water vapor evaporative similar to indirect evaporative cooling using the concept of chilled ceiling. However, M-Cycle evaporative cooling technique is integrated intelligently in SCAC system by which air can be cooled to the dew point of the ambient air. In this regard, experimental data of M-Cycle unit available in the literature has been investigated, and a simplified correlation has been established which can predict the M-Cycle performance accurately. The simplified correlation has been verified against the published data of M-Cycle experiments and a reasonable agreement has been found (with $R^2$ values more than 0.95 for all cases).

The correlation is further utilized for the analysis of SCAC system for four big cities of Pakistan namely: (1) Karachi, (2) Lahore, (3) Multan, and (4) Peshawar. Results showed that the system’s applicability is limited in humid areas and worst situation (among the studied) are resulted for the climate of Karachi. Similarly, it has been found that the system may not be valid for the highly humid period and/or climates e.g. moon soon season of Pakistan and climate of Malaysia etc. Therefore, it is recommended that the system may not be a sustainable as standalone system for optimum AC, however, it can be a handy solution in order to reduce the AC load as well as in order to develop the chilled ceiling for various application in agriculture and livestock.

Acknowledgements

The authors acknowledge the financial support from Bahauddin Zakariya University, Multan for this study through the research project entitled “Evaluation of solar chimney driven passive air-conditioning system for agricultural and livestock applications in Pakistan”.

References


Nomenclature

- $A$, $B$, $C$: constants of correlation [-]
- $AC$: air conditioning
- $GWP$: global warming potential
- $H$: humidity [g/kgDA]
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<th>Symbol</th>
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<tr>
<td>$h$</td>
<td>enthalpy [kJ/kg]</td>
</tr>
<tr>
<td>IEC</td>
<td>indirect evaporative cooling</td>
</tr>
<tr>
<td>M-Cycle</td>
<td>Maisotsenko Cycle</td>
</tr>
<tr>
<td>ODP</td>
<td>ozone depletion potential</td>
</tr>
<tr>
<td>$Q$</td>
<td>specific cooling capacity [kJ/kg/s]</td>
</tr>
<tr>
<td>RH</td>
<td>relative humidity [%]</td>
</tr>
<tr>
<td>SCAC</td>
<td>solar chimney based air conditioning</td>
</tr>
<tr>
<td>$T$</td>
<td>outlet air temperature [ºC]</td>
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<tr>
<td>$\eta$</td>
<td>M-Cycle effectiveness [-]</td>
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**Sub/super-scripts**

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<tr>
<td>spc</td>
<td>specific</td>
</tr>
<tr>
<td>wb</td>
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Optimization of Dye Sensitized Solar Module for High Hydrogen Production from Photoelectrochemical Water Splitting

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Abstract

The working capability of the dye sensitized solar module (DSM) in low light conditions and transparency make them suitable to assist water split in a photoelectrochemical cell (PEC) for clean and low cost hydrogen production. In this study, a transparent and double sided (bifacial) W-type dye sensitized solar module (DSM) of active area ~100cm$^2$ was designed to assist water split in an optimized photoelectrochemical cell (PEC) for efficient and commercialization of hydrogen production. The optimal width and thickness of the TiO$_2$ film obtained for high hydrogen production were 12nm and 18µm respectively. To optimize the efficient hydrogen production we have connected five optimized cells of width 12mm of area 20cm$^2$ in series on a single substrate to obtain the optimized voltage. We have measured ~ 9mLh$^{-1}$ and ~ 2.31mLh$^{-1}$ of hydrogen gas at light intensities of 100 and 33mWcm$^{-2}$ respectively, from an optimized W-type DSM with an optimal voltage of 3.34V in series with an optimized PEC cell in a water electrolysis system. The optimized tandem cell with high stability produced maximum hydrogen of 443.4 mL (9.24 mL/cm$^2$.h) for 48 h.

Keywords: Dye solar module, Photoelectrochemical cell, hydrogen production, water electrolysis system

1. Introduction

To reduce our dependence on fossil fuels and control the exhaust of CO$_2$, we need to make a large-scale transition toward new, sustainable source of energy [1]. Solar energy is one of sustainable sources of energy that has the potential to meet all our energy needs. As the contribution of solar energy to the total energy mix increases, the energy storage solutions need to be implemented [2]. One of the best possibilities to store solar energy is in the form of chemical fuel that has advantage of high energy storage densities and ease of transportation. The hydrogen, methane, methanol, gasoline, diesel, etc., are the examples of the chemical fuel. The hydrogen is one of the best chemical fuels that require no source of carbon to store energy among all. Also it can be readily converted into electricity—an back again—with fuel cells and electrolyzers. This offers the prospect of a future energy infrastructure based on sunlight, hydrogen, and electricity [3-4].

The conversion of solar energy into hydrogen appears to be a much more attractive route. Water is a convenient and abundant source of hydrogen, and there is more than enough water available. A back-of-the-envelope calculation shows that ~3.5 x 10$^{13}$ L of water is needed to store the energy the world uses in 1 year (4.7 x 10$^{20}$ J) in the form of hydrogen. Many techniques have been used to produce hydrogen from the conversion of water and sunlight. Photoelectrochemical water splitting with semiconductor photoelectrode is one of the most promising techniques due to production of hydrogen and oxygen on separate electrode at room temperature [3-6]. The key component for PEC systems is the semiconductor photoelectrode. The light absorption, charge separation, charge transport, and H$_2$ or O$_2$ evolution at its surface are the task performed by photoelectrode [7-8]. No semiconducting material has yet been found that can simultaneously and efficiently oxidize and reduce water without external assistance.

A photoelectrochemical cell combines visible light harvesting by a nanocrystalline semiconductor thin film with the electrolysis of water. Photons with energies higher than the band gap of the semiconductor generates electron–hole pairs in the conduction and valence bands. At the semiconductor surface, holes oxidize water to oxygen, whereas the photo-excited conduction band electrons are transferred to the counter-electrode of the PEC cell, and reduce water to form hydrogen gas [9-13]. The PEC cell give very low efficiency because the device mostly used the large bandgap semiconductors. Moreover, the band edge potentials of many semiconductors are unsuitable for oxygen and hydrogen evolution. For efficient water cleavage PEC cell should have negative conduction band to provide enough potential (~ 1.9 – 2V) [14].

\[
\text{H}_2\text{O} + \text{Solar energy} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2
\]

The generated holes oxidized water to oxygen at the semiconductor’s surface.
While the generated electrons, transferred to the counter-electrode of the PEC cell, reduce water to form hydrogen,

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2$$

The most appropriate configuration to date for water splitting using two devices with semiconductor of different band gaps coupled in a cell arrangement is known as tandem cell. The tandem cell configuration of two photovoltaic cells is a practical approach to unassisted water photosplitting. Dye sensitized solar cell, due to its low cost fabrication and long-time operation has attracted significant attention for use in solar water splitting tandem cell with a stable photoanode. In a tandem arrangement, a PEC cell generates electron-hole pairs. An oxygen gas has been produced at the surface of the semiconductor when holes react with water. A DSM increased the electrochemical potential of collected electrons injected in the conduction band of semiconductor and feeds them back through the counter electrode (CE) of PEC cell where hydrogen has been produced by reducing the water [14]. In current study for the production of hydrogen, a parallel DSM connected in series with PEC cell produced low amount of hydrogen because the system did not exceed the maximum voltage of 0.8V. Therefore, to produce an efficient hydrogen a serial DSM is required that give ~2.0 V or more. Thus, the study has been focused on using next-generation photovoltaic that can also be fabricated with inexpensive, solution processing method for an efficient hydrogen production technology in comparison with Si solar cell which are too expensive and required direct sunlight. Mishra et al. [15] reported a hydrogen production rate of 2.5 mL/cm².h over the TiO₂ thin film which was immersed in the 1 M NaOH electrolyte and connected to 5 V silicon-based solar panel. Deng et al. [16] produced hydrogen connected to a triple-junction amorphous silicon that exhibit 2.3 V. Grätzel used a dye-sensitized solar cell to provide a bias voltage to WO₃ or Fe₃O₃ photoanode [17-18]. M. Kang et al. reported [19] about dye sensitized solar module with open circuit voltage of 3.51V produce hydrogen of 2.1 ml h⁻¹. N.M. Mohamed et al. [20] reported the hydrogen production of 2.12 mLh⁻¹ achieved under the optimum conditions using the parallel DSM in series with PEC in the aqueous KOH and glycerol solution under visible light irradiation. Mendes et al. [21] connected two dye sensitized solar cell in series in a tandem arrangement for hydrogen production by water splitting method. Though, the voltage of the solar cell increased by connecting the cell in series but the hydrogen production efficiencies still low. Therefore, a more efficient and optimized design is needed for commercialization of PEC cell connected in series with DSM.

In the present work, we have fabricated a transparent and double side W-typed DSM of active area 100 cm² with optimized width of 12nm at constant film thickness of 18 μm in series with optimized PEC cell for the hydrogen production from water electrolysis. The photoelectrode and counter electrode are printed on the same substrate in turn, delivering identical output when illuminated from either sides in a fabricated W-typed DSM. The optimal width and voltage for the high hydrogen production were determined. The hydrogen production was measured under the different light intensities. The area of the cells were enlarged by varying the width of TiO₂ film fabricated separately. The performance parameters are extracted from standard current-voltage characteristic and electrochemical impedance spectroscopy.

2. Experimental

2.1. Dye Solar Module and PEC fabrication.

The W-typed DSM fabrication process initiated on Fluorine doped tin oxide (FTO) glass by marking, engraving, drilling to make hole for the injection of electrolyte on one side of the substrate, washing, and sintering at 510 °C. The working photoelectrode and counter electrode are printed on the same FTO substrate. First, on the FTO substrate Pt paste (Dyesol) was printed and dried. Second, the Dyesol 18NRT TiO₂ paste printed three times to achieve the optimized thickness on the odd number of cell dried and sintered to get the high efficiency. The same method is applied to the second substrate to make the module. First the Pt was printed on the odd number of cell and dried. The TiO₂ paste was screen printed three times dried and sintered at 510 °C. The silver paste printed to collect the electron from the electrodes. The sintered electrodes were immersed in N719 dye at room temperature overnight. A 50 μm Surlyn thermoplastic sealant was placed between substrates, heated and pressed at 175 °C for 10s. The electrolyte iodide/triiodide couple solution was injected through a hole drilled on one side of substrate. The hole was then covered using a transparent epoxy (Dyesol). The fabricated five columned W-type DSM had an open circuit voltage of 3.34 V.

The fabrication of optimized photoanode of area 2cm² used in PEC cell of the tandem system reported in [20]. A standard three electrode configuration consider for the purpose of characterization, Ag/AgCl/sat electrode (Autolab, Metrohm) as a reference electrode; a pure platinum wire as a counter electrode where the hydrogen production collected using an inverted burette [22], and the optimized photoanode as working electrode.

A tandem system was designed based on PEC cell and optimized W-typed DSM to produce hydrogen from water splitting presented in Fig.1. A PEC cell generates electron-hole pairs. First, the oxygen has been produced when generated holes are migrated to the surface of semiconductor and react with water. Second, generated electron injected...
into the conduction band of semiconductor collected by DSM that increase the electrochemical potential of the photo excited electron of the PEC cell and feed them back through the PEC cell’s counter electrode to split the water for hydrogen production. Optical hydrogen efficiency calculated based on the assumption that all the current generated from the optimized W-typed DSM transfer completely for hydrogen production using water splitting system.

Figure.1 schematic diagram of experimental setup

2.2. Characterization

To study the photoelectrochemical behavior, a computer controlled potentiostat (Autolab PGSTAT302N, Metrohm) was used with a frequency response analyzer (FRA) module supported by NOVA software. The frequency range of 0.1 Hz-100 KHz with the magnitude of the modulation signal was 10 mV considered for electrochemical impedance spectroscopy (EIS) measurements. The photocurrent- voltage curve was tested using universal photovoltaic test system at 100 mW/cm² intensity of illuminate Xenon lamp at AM 1.5 radiation angle connected to a voltmeter and ampere meter (Keithley, model 2420) with variable load.

2.3. Result and Discussion

To optimize the W-typed DSM for efficient hydrogen production, the dye sensitized solar cells of different area were fabricated by varying the width of the TiO₂ film and their impedance were measured. Fig.2a shows the impedance according to the change in the width of the TiO₂ film (6mm, 8mm and 12mm). The lengths of the TiO₂ films were at constant 168 mm. An optimized 18 µm thickness of TiO₂ film were considered reported in [23-25]. The impedance spectrum of the dye sensitized solar cells of different area showed two semicircles over the frequency range 0.1-100 kHz. The first semicircle, Rpt, is related to charge transfer at the counter electrode, and was measured in the kHz range. The second semicircle, Rbr, is related to electron recombination at the TiO2/dye/electrolyte interface in the range, 1-100 Hz [26-29]. Here, the ohmic serial resistance (Rs) is associated with the series resistance of the electrolytes and electric contacts in the DSC cell. Nyquist plot shows typical EIS spectra of DSCs as a function of device area, in which both real (Z') and imaginary (Z'') parts of the total impedance marked a surprising decrease in magnitude with increase in area. In addition, the frequencies corresponding to the recombination shifted to higher values with increase in device area showing its crucial dependence on charge transport. The 45° behavior in the EIS curve, from where the Rt is calculated using the transmission line model (juan bisquert, et al., 2000) [30] shifted to slightly lower Z' showing that the Rt decreased with increase in device area. Fig.2b shows the AC resistance calculated directly from the Nyquist plots. The high frequency region of the AC resistance that corresponds to the first semicircle in the Nyquist plots, showed a weak dependence on frequency thereby confirming the electron transport process. The transport resistance decreased as area of the electrode increased. The lower Rt is preferred for fabricating high efficiency DSCs, shifting of frequencies corresponding to Rbr have adverse effects as discussed below. The radius of the second semicircle corresponding to the charge transfer process continuously decreased with increasing electrode area thereby shifting the characteristic frequency corresponding to the Rbr to higher values. It is important to note that the area of the cells varied but sheet resistance of DSC cell is approximately constant due to the close relationship of surface resistance, Rs with FTO glass. In general, the surface resistance of FTO glass was approximately 15Ω per unit area. The constant value of the Rs shows lower dependency on increase of FTO area with increase in the width of TiO₂ films.
Figure 2 (a) Nyquist plot, and (b) AC impedance of the devices as a function of frequency for representative areas, 10, 13.4 and 20 cm$^2$ area respectively.

Fig. 3 shows the Bode plots calculated from the Nyquist curves, which mark the variation in phase angle of the complex impedance as a function of frequency. The phase angle peak corresponding to the electron diffusion time constant in the TiO$_2$ film usually appears in the 100 – 1 Hz frequency range, from which the electron lifetime can be calculated using the equation $\tau_n = 1/2\Pi f_c$. The peak frequency ($f_c$) for 10 cm$^2$ DSC is 6.33 Hz and the $f_c$ shifted to ~ 10.0 Hz for area > 10 cm$^2$. The characteristic charge transfer frequency, $\omega_{rbr}$ for 10 cm$^2$ DSC is 39.75 Hz and for area > 10 cm$^2$ is ~ 62.8 Hz. The electron lifetime for the area 10 cm$^2$ was 25.15 ms and the lifetime for area > 10 cm$^2$ were ~ 15.92 ms. i.e., electrons are short lived as a result of enhanced diffusion path as the electrode area increases. The ~ similar efficiency of area 10 cm$^2$ and > confirm that all electrons are collected though the area increases due to proper interfacing of the working electrode this is what we expected.

Figure 3 Bode plots of the fabricated DSCs as a function of device area

3. Optimized W-type DSM and hydrogen production

Fig. 4 shows the optimized W-type DSM was connected to the multiple layers of the thin film printed on FTO substrate as WE and the Platinum (Pt) rod as a CE in the PEC cell. All electrodes were immersed in the fabricated glass reactor vessel with an aqueous solution of 1 M KOH and 10 vol% glycerol (sacrificial agent). Glycerol as an industrial by-product was mixed with the KOH solution to capture irreversibly the photogenerated holes and reduce the recombination rate. The production of hydrogen was calculated when a fabricated PEC cell was connected to the DSM in series and irradiated with a 500 W halogen lamp with an adjusted intensity of 100 mWcm$^{-2}$ and 33 mWcm$^{-2}$ at room temperature respectively. We have obtained the 9.24 ml h$^{-1}$ hydrogen evolution at the optimum voltage of 3.4 V under light intensity of 100 mWcm$^{-2}$ and ~ 3.21 ml h$^{-1}$ at light intensity of 33 mW cm$^{-2}$. To check the stability of the system, tandem cell illuminated under light intensity of 100 mw cm$^{-2}$ and produced maximum hydrogen production of 443.4 ml (9.25 mL/cm$^2$ h) for 48h.
Figure 4 experimental setup using PEC + DSM for high hydrogen production

Fig. 5a shows the $I$-$V$ curves, photoelectric efficiency and the Nyquist plot of the optimized W-typed DSM of area 100 cm$^2$ illuminated under different light intensities used for hydrogen production. The electrochemical study of the DSM verifies the results obtained from the $I$-$V$ characterization. The low internal resistance of the 100 cm$^2$ DSM shows the proper interface between TiO$_2$/dye and electrolyte, so that the current remain same in five cells connected in series to make an efficient W-typed DSM.

<table>
<thead>
<tr>
<th>W-typed DSM</th>
<th>Voc</th>
<th>Isc</th>
<th>FF</th>
<th>$\eta$</th>
<th>$H_2$ evolution (ml h$^{-1}$)</th>
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<td>DSM@1Sun</td>
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<td>0.506</td>
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<td>31.25</td>
<td>0.612</td>
<td>1.885</td>
<td>2.31</td>
</tr>
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Figure 5. $I$-$V$ curve, photoelectric efficiency and Nyquist Plot of optimized W-typed DSM.
Fig. 6 shows the hydrogen evolution for first eight hours when an optimized five columned W-type DSM connected to optimized PEC cell for water splitting under 100 mW cm\(^{-2}\) and 33 mW cm\(^{-2}\) light intensities. The hydrogen evolution is four times higher than the M. Kang et al. reported [19] about dye sensitized solar module with open circuit voltage of 3.51 V produce hydrogen of 2.1 ml h\(^{-1}\) at 100 mW cm\(^{-2}\) and ~ same amount of hydrogen has been produced at the light intensity of 33 mW cm\(^{-2}\). In current study we have observed the high hydrogen production replacing the parallel DSM module with optimize W-type DSM connected to optimized Cu-Ni/TiO\(_2\) photoanode [20].

Figure 6. Hydrogen evolution when optimized five columned W-type DSM connected to PEC cell measure under light intensity of 100 and 33 mW cm\(^{-2}\) respectively.

4. Conclusion

An efficient DSM was prepared with optimized TiO\(_2\) film width and with optimum voltage to assist the optimized PEC cell for the enhancement of hydrogen production in a water electrolysis system. To obtained an optimized DSM of area 100 cm\(^2\) we have fabricate separately the cell of different area (10 cm\(^2\), 13.4 cm\(^2\), and 20 cm\(^2\)) by varying the width of the TiO\(_2\) film (6 mm, 8 mm, and 12 mm) and keeping the thickness of TiO\(_2\) film 18 µm constant. The length of the cell was 168 cm for all the cells. An optimized width of 12 mm was considered for the fabrication of the W-type DSM of area 100 cm\(^2\). We have measured the hydrogen production by connecting the optimized PEC cell in series with DSM. The optimized tandem arrangement give high hydrogen production i.e., 9.25 ml h\(^{-1}\) at light intensity of 100 mW cm\(^{-2}\) and 2.31 ml h\(^{-1}\) at light intensity of 33 mW cm\(^{-2}\) with an optimum voltage of 3.4 V. This study introduces a practical approach to improve the solar hydrogen production and photo conversion efficiency of the system for large scale application. The optimized tandem cell with high stability produced maximum hydrogen of 443.4 mL (9.24 mL/cm\(^2\) h) for 48 h.

5. References

99. Modeling and Simulation of Diffuser Augmented Wind Turbine

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Abstract

In this work the diffuser augmented wind turbines have been studied to increase the mass flow rate through the rotor which results in improved energy extraction from the wind. The pressure drop is caused by a flange at the exit of diffuser. For analyzing the flow behaviour of bare and flange type diffuser ANSYS Fluent 12.0 is used. The study showed that power can be augmented using flange type diffuser on simple horizontal axis wind turbine. Power coefficient increases due to addition of flange type diffuser and wind velocity also increases at rotor of the turbine. Further this study also confirms the experimental work of Yuji Ohya a Professor at Kyushu University Japan.

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Keywords: diffuser augmented wind turbine, flow behaviour, flange type diffuser, CFD, Power coefficient

1. Introduction

With the growing requirement of sustainable energy sources and growing crisis of climate change and clean environments in the whole world therefore the development of clean and sustainable energy gradually become more and more important research subjects. Wind energy is one of important sustainable energy source. Researchers around the world have been making many efforts to develop advanced wind power systems. Wind turbine is one way to extract the power from the wind. The power output is directly proportional to cube of velocity so that small changes in velocity can significantly increase.

Therefore the development of an effective wind acceleration system by placing the turbine rotor inside a shroud has attracted much attention of researchers. This kind of wind turbine is often referred to as diffuser augmented wind turbine (DAWT) [1]. The research on Diffuser augmented wind turbines has been shown by many studies can significantly increase the power output. The present study on the development of a wind power system with high output aims at determining how to collect the wind energy efficiently and what kind of wind turbine can generate energy efficiently from wind. For this purpose we have modelled a diffuser type shroud in Gambit software that is capable of collecting and accelerating the approaching wind. Furthermore we placed a wind turbine inside the diffuser shroud equipped with a flange and evaluated the power output generated. As a result the shrouded wind turbine equipped with a flanged diffuser demonstrated power augmentation for a given turbine diameter and wind speed by a factor of about 4-5 compared to a standard micro wind turbine [2]. Simple diffuser consists of three sections (Fig. 1a): inlet section, turbine section or throat and diffusing outlet section. Despite the importance of diffuser geometrical parameters there is limited experimental study comparing the performance of bare turbine with shrouded turbine under controlled flow condition and rotor speed [3]. Diffuser causes the flow to accelerate because the flange on diffuser causes the drop in the pressure at the exit of Diffuser. Vacuum causes flow to accelerate and increase in mass flow and velocity which eventually lead to increase in power co-efficient. The ANSYS Fluent 12.0 and Gambit Softwares have been used for simulation and modelling purpose respectively. The diffuser design parameter play very important role in increasing the mass flow and wind velocity. There are four parameters which can effect the power output which is length, angle of diffuser, and flange height. ANSYS Fluent have been for simulation purpose in this study and k-w and k-ԑ model have been used for obtaining the results the k-ԑ and k-w model are best methods to apply from design analysis.
2. Modeling and Simulation

To create the geometry of the DAWT we have used the GAMBIT 2.4.6 software. Our model design starts with the designing of hub, designing of blades, designing of diffuser and meshing of geometry.

2.1 Designing of Hub

The diameter of hub we have taken is 62mm and length is 95mm.

2.2 Designing of blades

The span of blades is 64mm, chord is 25mm, the thickness of blades is 2.5mm and number of blades are 3.
2.3 Designing of Diffuser

The rotor diameter ($D$) is 190mm, Outlet diameter is 240.73mm, Length ($L$) is 120mm and the Expansion angle ($\alpha$) is $5^\circ$.

![Fig. 4. Shaded view of diffuser around domain](image)

2.4 Meshing of Geometry

The last step in designing has been performed and now we will try to mesh our geometry. For that we will go into meshing option and fac mesh option. We will quad+tri type mesh. After completing the meshing we will apply boundary conditions to our geometry.

![Fig. 5. Shows creation of volume](image)

![Fig. 6. Shows complete mesh](image)
For simulation purpose we shall use the computational Fluid dynamics program “FLUENT” which is part of ANSYS 12.0 software program. We have used the 3D Simulations.

3. Results and Discussion

From our simulations we now summarize our findings. We determined that power output can be increased to bare wind turbine by addition of diffuser. In this attempt the k-omega model was used and simplec 2nd order equations were applied. In solution control we reduced parameter of pressure from 0.3 to 0.2. The 500 iterations were given and solution was converged at 256 iterations.

![Convergence of Solution using k-ω model](image)

We have also defined the MRF and value was given 20mrf. The initial velocity was given as 6 m/s to model. The velocity increased from 6 m/s to 13.54 m/s by means of 5 degree diffuser shroud with turbine inside.

![velocity vector on turbine](image)

The Fig. 8 shows clearly that velocity has increased from 6 m/s to maximum 13.54 m/s around wind turbine. With increase in mass flow rate and increase in velocity the power output will also increase. In next attempt we changed some parameters such as we used k-epsilon model instead of k-omega model and 3rd order equations were applied. The initial value of velocity was given as 6 m/s. The value of MRF was 20 mrf and diffuser angle was 5°. The augmentation in wind was from 6 to maximum 9.96 m/s and solution was converged at 801 iterations. In this case we created the plane near diffuser inlet and we observed the augmentation in the wind velocity.
Using function calculator we found that default area of interior was $0.00566 \text{ m}^2$ and volume was about near to $0.0039 \text{ m}^3$. The mesh report showed that number of nodes on MRF and static were 5780 and 162548 respectively. The number of elements on MRF and static were found to be 28098 and 899927 respectively. The total number of node were 168328 and total number of elements were 928025. The force on turbine was $0.188 \text{ N}$ and area of turbine was $0.0226 \text{ m}^2$. Mass flow rate at Vin position was $23 \text{ kg/s}$ and volume at Vin position was $0.0059 \text{ m}^3$. The maximum value of velocity on turbine was $13.54 \text{ m/s}$ and maximum value of velocity near diffuser inlet was $11.54 \text{ m/s}$.

For comparison between two methods $k-\omega$ and $k-\varepsilon$ we run the solution again and we find that $k-\varepsilon$ with 2nd order equations and with Vin $6 \text{ m/s}$ was converged at just 150 iterations. The maximum value of velocity on turbine was found to be $9.95 \text{ m/s}$ which shows there was augmentation of almost $4 \text{ m/s}$ in wind velocity. However at the inlet of diffuser the maximum velocity was found to be $9.0003 \text{ m/s}$. While $k-\omega$ with simple 2nd order equations and with Vin $6 \text{ m/s}$ was converged at 256 iterations. The maximum value of velocity was $13.56 \text{ m/s}$ which shows that there was augmentation of almost $7.56 \text{ m/s}$ in wind velocity and inlet velocity near diffuser was $11.54 \text{ m/s}$. Hence it was concluded that $k-\omega$ model was giving us more promising results than $k-\varepsilon$ model.
Power curves between Diffuser augmented wind turbine and bare wind turbine clearly shows the power output of diffuser augmented wind turbine is higher than bare wind turbine.

![Comparison of power between Bare and Diffuser augmented Wind turbine](image)

**Fig.11. Shows the power comparison between Bare and Diffuser augmented wind turbine**

The values of power obtained using diffuser augmented wind turbine and bare wind turbine are given below in the following table as a power $10^6$.

<table>
<thead>
<tr>
<th>No Diffuser</th>
<th>0.45</th>
<th>0.71</th>
<th>1.52</th>
<th>1.7</th>
<th>2.09</th>
<th>2.78</th>
<th>3.61</th>
<th>4.59</th>
<th>5.73</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuser</td>
<td>0.89</td>
<td>1.3</td>
<td>2.4</td>
<td>2.89</td>
<td>3.21</td>
<td>4.12</td>
<td>5.18</td>
<td>6.2</td>
<td>7.8</td>
</tr>
</tbody>
</table>

The above given table shows that power obtained through diffuser augmented wind turbine is much higher than bare wind turbine. Hence, we can say that diffuser augmented wind turbine with flange can produce more power than the base wind turbine and also diffuser augmented wind turbine is best to install where wind speed is low. The power curve given above shows that power can be increased with diffuser augmented wind turbine almost 1.6-1.7 times according to our study, which is close to the values of Yuji Ohyo results of experimental work. Hence this study confirms results of experimental work performed by Yuji Ohyo a Professor in a Kyushu University Japan.

### 4. Conclusions

We simulated the wind accelerating device (diffuser with no turbine inside) that makes it possible to concentrate the wind energy. It was confirmed that hollow structure such as flange type diffuser is an effective for accelerating the wind. Based on iterations performed on ANSYS Fluent 12.0 at various conditions following conclusions are obtained:

- A properly designed diffuser with optimized dimension can be used to increase mass flow of wind.
- A diffuser having diameter of 0.4m, diffuser angle 5°, and flange height of 0.2m is most effective design at reduced flow separation and improving wind speed from 6m/s to 13.5m/s.
- If we reduce the diameter further upto 3m or 2m that causes the turbulence and flow separation inside the diffuser.
- Flange type diffuser was more effective than without flange.
- K-ω model was giving better results than K-ε, because model constants of k-ω are less than the k-ε.

### 5. Future Work

Further research could lead to integrated diffuser and rotor design. A way to do this could be equating the thrust of diffuser to the rotor of blades. So if first the velocity distribution for an existing design is calculated and based on that an improved rotor design can be made. These calculations should be iterated till the convergence is obtained.
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- Re-optimize the diffuser design and location of wind turbine inside the diffuser.
- Re-optimize the diameter, flange angle and flange height of diffuser to make the effective use of low density wind.
- To validate the present model an experimental setup of model dimension can be built and analyzed for different flow conditions.

Acknowledgement:

Thanks to almighty Allah for giving us strength and ability to understand, learn and complete this research. We express our gratitude to Prof. Dr. Ahmad hussain whose profound concern and guidance made us able to complete this work. I am also thankful to Mr. Atteque Ahmed who helped me.

References:


178. Computational Analysis and Protein Structure Modeling of Zinc & Iron dependent Alcohol Dehydrogenases for maximum Bioethanol yield in Thermophiles

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Abstract

Climate change, dramatic fluctuations in the cost of oil and price increases for basic food items, Pakistan is undergoing serious energy crisis. Fortunately this degrading situation is countered with the help of biomass energy (bio ethanol) invention. However the selection of best strains with efficient enzymes for the production of bio ethanol is in continuous process of improvement. The objective of this work is to compare and analyze the structure of extremophilic strains with currently used organisms. Major goal behind targeting thermophiles is to isolate the cost effective and environment friendly strain. Gene and protein sequences of thirteen different strains both zinc and iron dependent alcohol dehydrogenases were retrieved from National Centre of Biotechnology and Information. Sequence analysis using gene sequence was conducted separately for both Zn and Fe strains with S. Cervisae and Z. Mobilis respectively with the help of CLUSTAL W software. Protein Data Bank assisted in retrieving structure based information & metal binding interactions with their residues for organisms. Upon acquiring complete genetic and structural information of target strains, mutations were carried out in one Fe and two Zn based organism to check best conformation of the enzyme for maximum bioethanol yield. The study demonstrated that having the ability to withstand high temperature ADH of thermophilic bacteria is considered key enzyme for bioethanol production. Metal binding residue site GHE in Zn strains and co-factor binding site GGGSXXD in Fe strains was conserved. Ligand interaction with residues in Fe strains was found similar in all target strains. In all three mutations conducted, disturbance in catalytic pocket and bonds was observed hence subordinating the overall enzyme-substrate complex and decreased efficiency in binding lignocellulosic biomass as a substrate.

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Keywords: “thermophiles ; ADH ; metal binding site ; co-factor binding site ; mutations ; enzyme-substrate complex”

1. INTRODUCTION

The world has an energy disaster due to growing concern related to “fossil fuel sources”, such as environmental impact, climate change, finite availability and security of supply Atomi et al., (2011). Renewable energy can be an attractive option at this point as they offer number of advantages over non-renewable fossil fuels. One of the best examples that we have for it is bio ethanol. It presents an attractive option for fulfilling energy demands (Demirbas, 2016). “The most commonly used ethanologic organisms being intensively studied or already in use for industrial-scale production are “Zymomonas mobilis”, “Saccharomyces cervisiae”, “ Escherichia coli and Klebsiella oxytoca”. However, lack of appropriate microorganisms that can efficiently alter the raw biomaterials to bio-ethanol has been one of the main obstacles to widespread use of bio-fuels”. Production of bio-ethanol using “thermophilic” and “hyperthermophilic” organisms is the focus of many research groups. Several distinct advantages are associated with using thermophiles over “mesophiles”, including high temperatures and the mostly anaerobic nature of “thermophilic organisms”, the high temperature of the process leads to lowering the viscosity of reaction mixtures, causing improved production yields. One of the key enzymes in both ethanol production pathways
is “alcohol dehydrogenase”.

“ADHs isolated and characterized from thermophilic and hyperthermophilic archaea and bacteria, with the physiological roles of several proposed to be in the reduction of aldehydes to alcohols, other enzymes involved in the ethanol production pathways are not well characterized, especially the enzyme(s) that catalyse the production of acetaldehyde from pyruvate”.

(1) “A two-step pathway that is used by yeast and a few bacteria like Zymomonas mobilis and Sarcina ventriculi. In this pathway pyruvate is non-oxidatively decarboxylated to acetaldehyde and carbon dioxide, which is catalysed by pyruvate decarboxylase (PDC). Acetaldehyde is then converted to ethanol that is catalysed by ADH”;

(2) “A three-step pathway that is more widespread in bacteria. Pyruvate is oxidatively decarboxylated to acetyl-coenzyme A (acetyl-CoA) by the metalloenzyme pyruvate ferredoxin oxidoreductase (POR) and/or pyruvate formatelyase (PFL). Acetyl-CoA is then converted to acetaldehyde by a CoA-dependent-acetylating acetaldehyde dehydrogenase (AcDH). Finally, acetaldehyde is reduced to ethanol by ADH. Erum et al., (2013)”

The current research is aimed at investigating zinc and iron dependent alcohol dehydrogenases of extremophiles (thermophiles & halophiles). Major motives set through the processing of computational study were comparisons of zinc based alcohol dehydrogenases with reference to S.cervisiae strain and iron based alcohol dehydrogenase with reference to zymomonas mobilis. Moreover, certain comparisons were also conducted to analyse the capability of these strains to produce bio ethanol. In later stages, to authenticate there functional properties, mutations in various strains were carried out.
2. METHODOLOGY

2.1. Key enzyme in bio ethanol production

In bacteria ADH is vital for fermentation; an anaerobic cellular process in which organic food is converted into simpler compounds accompanied by the production of ATP. The reaction shown below is catalysed by ADH.

\[
\text{Glucose} + 2\text{Pi} + 2\text{ADP} + 2\text{H}^+ \rightarrow 2 \text{ethanol} + 2\text{CO}_2 + 2 \text{ATP} + 2\text{H}_2\text{O}
\]

They can be divided into three major groups based on their molecular size and metal contents:

1) “Zinc-dependent long chain alcohol dehydrogenase; sizes of 300–900 amino acids”.
2) “The short chain alcohol dehydrogenase: which contain no metal ions and have approximate lengths of 250 amino acids”.
3) “The long-chain iron dependent ADHs; with a length of 385–900 residues”.

2.2. Insilico study of zinc dependent ADH

Nine basic strains containing zinc metal were selected for the analysis. The gene sequences, protein sequences, secondary protein structures were extracted from NCBI and PDB for each one of them. For those strains whose secondary structures were not available on PDB, they were first modeled through SWISS MODEL and then predicted. The sequences were then aligned with most widely and commercially in use reference sequence of \textit{S.cervisiae} through CLUSTAL W software for comparison.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Gene sequence</th>
<th>Protein sequence</th>
<th>Secondary structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeropyrum pernix</td>
<td>gi 1118430835</td>
<td>NC_14480.2</td>
<td>I2B</td>
</tr>
<tr>
<td>Agrobacterium Fabrum</td>
<td>gi 1159184118</td>
<td>NP_355113.2</td>
<td>IF8F (modeled)</td>
</tr>
<tr>
<td>Burkholderia Pseudomallei</td>
<td>gi 153717639</td>
<td>YP_106820.1</td>
<td>IUUF (modeled)</td>
</tr>
<tr>
<td>Geobacillus Kaustophalus</td>
<td>gi 156418535</td>
<td>WP_011232248.1</td>
<td>4CPD</td>
</tr>
<tr>
<td>Haloferax Mediterranei</td>
<td>gi 1389848445</td>
<td>YP_006350704.1</td>
<td>JRJW (modeled)</td>
</tr>
<tr>
<td>Streptomyces Coelicolor</td>
<td>gi 132141095</td>
<td>NP_625979.1</td>
<td>3COS (modeled)</td>
</tr>
<tr>
<td>Sulfolobus Acidocaldarius</td>
<td>gi 170605853</td>
<td>NP_253245.1</td>
<td>IH2B (modeled)</td>
</tr>
<tr>
<td>Sulfolobus Solfataricus</td>
<td>gi 155896971</td>
<td>NP_343875.1</td>
<td>1JVB</td>
</tr>
<tr>
<td>Thermotoga Maritima</td>
<td>gi 15643202</td>
<td>NP_228246.1</td>
<td>1VJ0</td>
</tr>
</tbody>
</table>

2.3. Insilico study of iron dependent ADH

Four basic strains containing iron metal were selected for the analysis using the same method previously illustrated for iron based strains. The sequences were aligned with another widely in use reference sequence of \textit{Z.mobilis} through CLUSTAL W software for comparison.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Gene sequence</th>
<th>Protein sequence</th>
<th>Secondary structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archaeoglobus Fulgidus</td>
<td>gi 11497621</td>
<td>NP_070843.1</td>
<td>Modeled</td>
</tr>
<tr>
<td>Thermococcus Gammatolerans</td>
<td>gi 1240102057</td>
<td>YP_002959938.1</td>
<td>IO2D (modeled)</td>
</tr>
<tr>
<td>Thermococcus Onnurineus</td>
<td>gi 212223144</td>
<td>YP_002307321.1</td>
<td>Modeled</td>
</tr>
<tr>
<td>Thermoplasma Volcanum</td>
<td>gi 13540831</td>
<td>NP_110915.1</td>
<td>Modeled</td>
</tr>
</tbody>
</table>

3. RESULTS

3.1. Zinc based strain analysis

Sequence alignment of target strains with reference \textit{Saccharomyces Cervisiae} indicated that amino acids GHE were conserved in all the strains and appears to be in similar pattern. This depiction was confirmed further when multiple alignment of all strains is done with yeast.
Secondary structure analysis indicated that the site which appeared conserved (GHE) in these strains is responsible for binding zinc residues. Although the amino acid out of GHE on which these residues bind is not constant and varied considerably according to strains but one or two of the residues do bind on any three of them for sure.

3.2. Iron based strain analysis

3.2.1. Structural representation of residue interaction with iron ion:

Since four out of five strains have to be modelled in order to identify their structures, on the basis of their similarities the closest structures identified were of *Z.mobilis* and *T.maritima*.

Sequence alignment of target strains with reference to *Zymomonas Mobilis* indicated that amino acids GGGG were conserved in all the strains and appears to be in similar pattern.

Analysis of secondary structure indicated that the site which appeared conserved (GGGS) in these strains is responsible for binding NAD co-factor residues. Although the amino acid out of GGGS on which these residues bind is not constant and varied considerably whereas the structural bonding of residues with metal indicated the same alignment and amino acids (three histidine and one aspartic acid) interacting with the metal.

3.3. Mutations
3.3.1. *Themotoga Maritima* (1O2D)

Fig 3.2a: Dimer Structure

Fig 3.2b: Close view of Iron interaction

Mutated Structure:

Fig 3.2c: Chain A with His 193 mutated to Arg

Fig 3.2d: Chain A with His 256 mutated to Arg

Fig 3.2e: Chain A with His 256 and 270 mutated to Arg

Fig 3.2f: Chain A with His 193, 256 and 270 mutated to Arg
3.3.2. *Saccharomyces Cerviseae*

![Zn interaction](image1)

Fig 3.3a: Close view of Zn interaction

Fig 3.3b: Change of residues abolishes the site

3.3.3. *Thermoanaerobacter Brockii*

![Zn interaction](image2)

Fig 3.4a: Close view of Zn interaction

Fig 3.4b: Disturbance of catalytic pocket

4. Discussion

The course of this research imperatively included the identification of conserved GHE region in all zinc containing alcohol dehydrogenases which happens to be the zinc binding residue site as well. While in iron dependent alcohol dehydrogenases region GGGSXXD was concluded conserved with declared status of co-factor binding site. The preserved region indicated the same symmetry of zinc binding and co-factor binding site making these enzymes’s catalytic region similar to that of reference. Elleuche *et al.*, (2013), Xiangxian *et al.*, (2008) authenticates the presence of this result by confirming the site GGGSXXD site as co-factor binding site. The typical coenzyme binding site, GGGSXXD, of iron-containing ADHs is located in the amino-terminal region

Furthermore the structural modelling done with certain mutations indicated the most stabilized form of mutations as when the changes were computed the results were not positive. First mutation that constitutes an iron based ADH of *Thermotoga Maritima* also showed a negative change. Three histidine residues interacting with metal at catalytic site were at first replaced with arginine (arg) individually followed by dual replacement and lastly all three together changed with arginine. The results for mutations were the disruption of the interactions residing in between the metal and residues. The changes completely disturbed the pocket rendering failure of enzyme-substrate complex formation. Steven *et al.*, (2011) already conducted this study suggesting His-Arg mutation was conversely close to the
active site iron and co-factor binding sites. It likely involves the net charge that might alter the relative co-factor binding capacity. Mutation in *Saccharomyces Cervisiae* too resulted in a negative change. The change was targeted at the zinc binding residue glutamic acid (glu-67) that was substituted with glutamine (gln). Although both are acidic in nature but due to variable properties of glutamine the conformation of the active site changed, bonds in between metal and residue were disturbed to an extent, decreasing the overall efficiency of ethanol production the structural interpretation confirmed the results that were previously being studied literature. Savarimuthu *et al.*, (2015) demonstrated same results indicating that substitution of Glu-67 with Gln-67 decreases the catalytic efficiency by 100-fold. Third zinc based ADH *Thermoanaerobacter Brockii* mutation in which zinc binding residue site histidine 59 was replaced with alanine. The change not only disrupts the catalytic site but also broke all the potential bonds responsible for holding the active site functional. As the result the mutation brought about negative change. Oren *et al.*, (1996) stated this mutation, which illustrated Site directed mutagenesis to replace any one of the three putative zinc ligands of ADH, Cys 37, His 59, or Asp 150, with the non-chelating residue, alanine, abolished not only the metal-binding capacity of the enzyme but also its catalytic activity, without affecting the overall secondary structure of the enzyme.

5. Conclusion

Hence in nutshell, the homology in between the strains shows that there is a great potential for the production of biofuels within them. In addition with the kind of hostile and resilient environment that they can bear makes them favourable for practical experiments. Theoretical work conducted on their mutations makes a viable collection for precise practical demonstration as well.

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References