4th International Conference on
Energy, Environment and Sustainable Development 2016 (EESD 2016)

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 gird 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.

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 at el [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 el [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 1. Potential of conventional energy resources

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

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.

2.3. Renewable energy resources—Solar and Wind

Pakistan is one of the largest country in the world and the rate of electrification has not been in pace with ever expanding urbanization, population and industrialization and has resulted in the increasing gap between demand and supply of electrical power. This has not only caused under electrification but has also employed a heavy pressure over governments in order to maintain pace with electricity demand. As a result of this, the country is not only facing problem of unwanted shortages but also precious and heavy amount is expended on importing of furnace oil to operate the large thermal power plants in the country. Thus in such a case, use of renewable technologies can considerably help to overcome these problems.

Table 2. Potential of renewable energy resources

Energy Resource	Potential	Source
Wind Energy	346,000 MW	IEP 2009 and AEDB
Solar Energy	2.9 Million MW	IEP 2009 and AEDB
Bio Gas	2,000 Million MW	IEP 2009 and AEDB
Small Hydel	2,000 Million MW	IEP 2009 and AEDB

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)

$$E = A \times r \times H \times PR \text{ kWh} \quad (1)$$

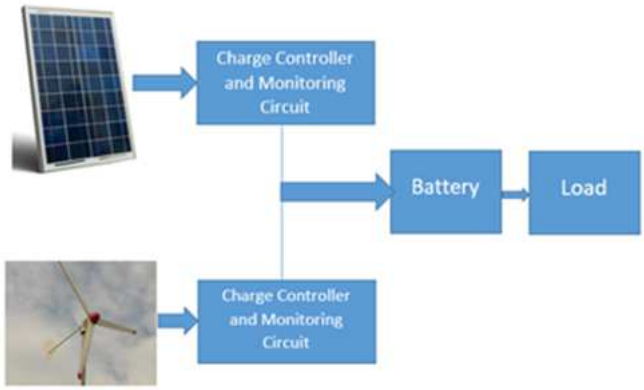

Fig. 1. Block diagram of proposed HPS

Table 4. Wind Power Generation Model Dimensions and Parameters

S.No.	Parameter	Type/Value
1	Type	HAWT
2	Material of blade	Fiber
3	Number of blades	3
4	Length of blade	3 ft
5	Twist angle of blades	10^0
6	Power rating of wind turbine generator	100 W (12V, 8.34A)
7	Shape of blade	As shown in Figure 3

Fig. 2. Types of solar cells

Table 3. Solar power generation model dimensions and parameters

S.No.	Parameter	Type/Value
1	Type	Polycrystalline
2	Inclination Angle	20º
3	Efficiency	21%
4	Power Rating	20W(12V, 1.7 A)

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):

$$P = 0.5\rho v^3 A \quad \text{Watts} \tag{2}$$

where A is effective disk area in m^2, v = wind velocity in m/s, ρ = Air density in Kg/m^2. 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 10^0 to 20^0 from root to tip. The parameters used for wind power generator model are given in Table 4.

Fig. 3. Shape of rotor blade used in wind generator model

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

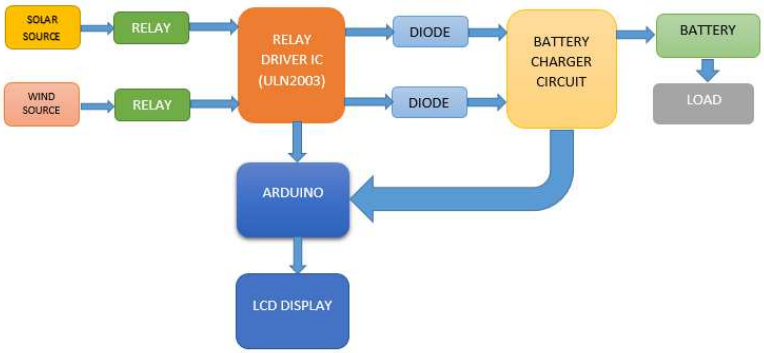

Fig. 4. Charge controller and status display system block diagram

at 10°. 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^{0}C to 30^{0}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.

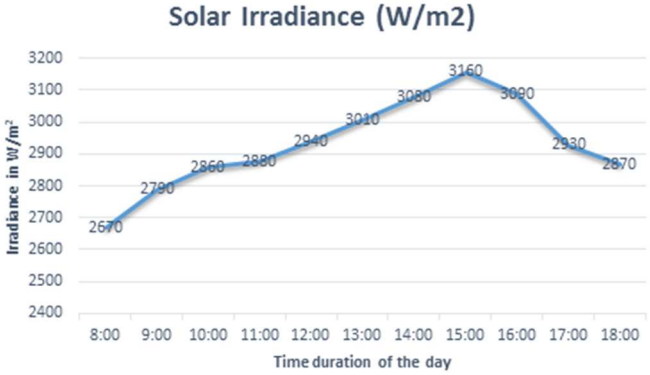

Fig. 5. Hourly variation in solar irradiance

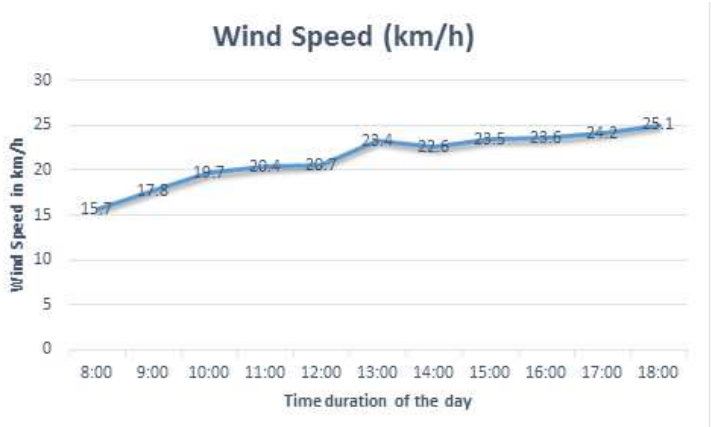

Fig. 6. Hourly variation in wind speed

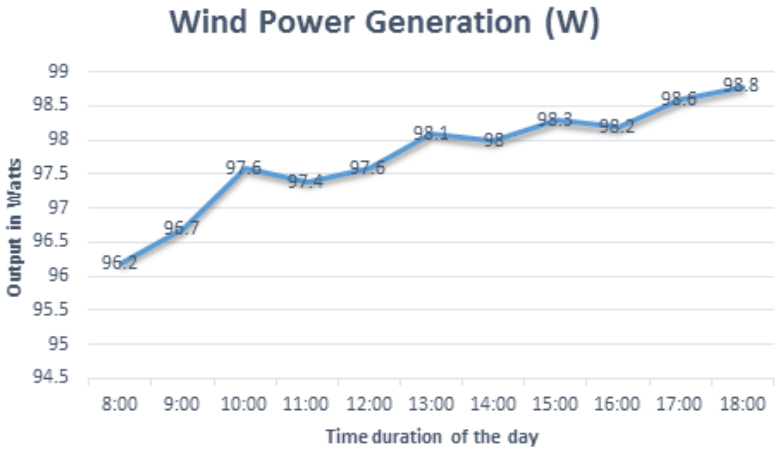

Fig. 9. Hourly variation in Wind Power Generation

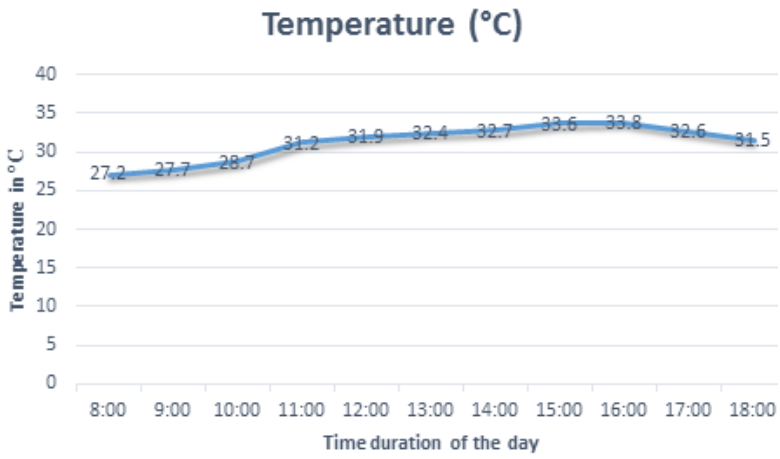

Fig. 7. Hourly variation in Temperature

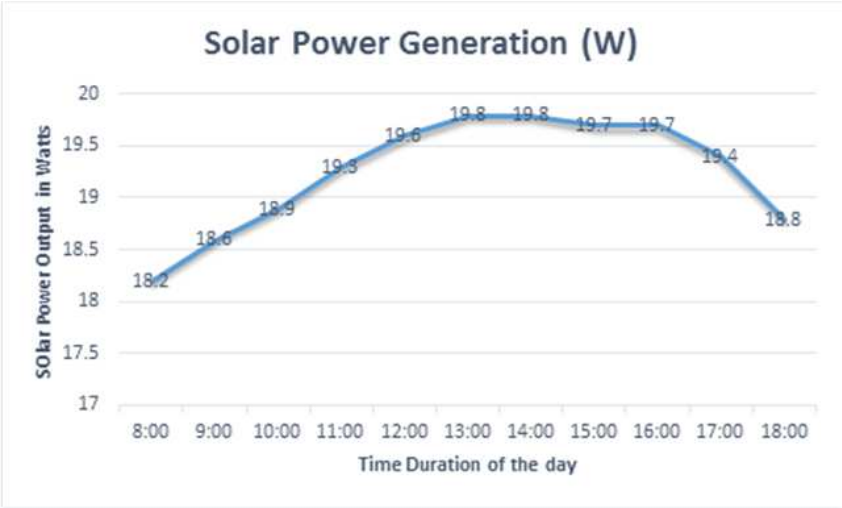

Fig. 8. Hourly variation in Solar Power Generation

Fig 8 shows the variation in solar 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 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

evening.

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:

$$P_{HYBRID} = P_{SOLAR} + P_{WIND} \tag{3}$$

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.

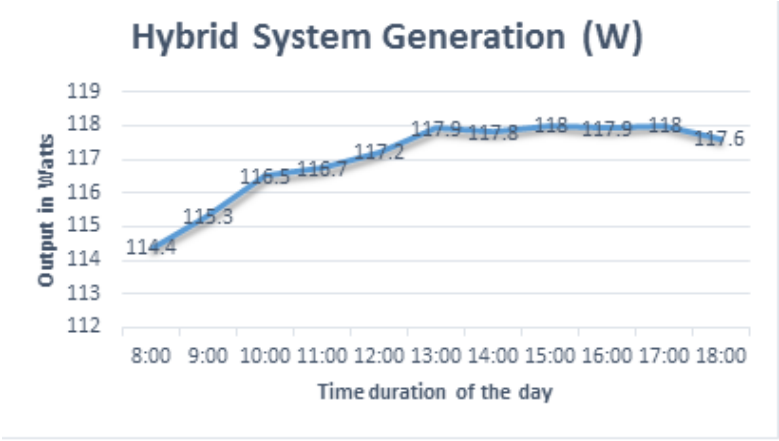

Fig. 10. Hourly variation in Hybrid System Generation

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.

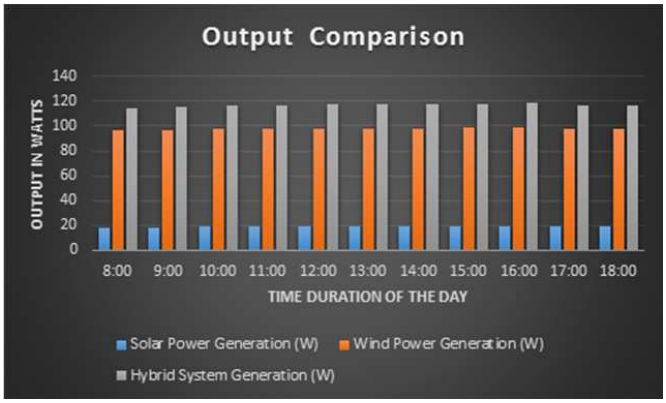

Fig. 11. Comparison of output of three power generation models

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 environmental 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

[1] D. Vitali, R. Ricci, “Design, testing and simulation of hybrid wind-solar energy systems” Curriculum: energy sciences, Doctoral School on Engineering Sciences. 2013.
[2] U.K. Mirza, N. Ahmad, T. Majeed, K. Harijan, "Wind energy development in Pakistan", Elsevier, Renewable and Sustainable Energy Reviews, vol. 11, No. 9, pp. 2179-2190, December 2007.
[3] K. Mousa, H. AlZu’bi, A. Diabat “Design of a hybrid solar-wind power plant using optimization”, 2nd International conference on Engineering Systems Management and its Applications (ICESMA), 2010.
[4] R. Maouedj, A. Mammeri, M.D. Draou and B. Benyoucef, “Performance evaluation of hybrid photovoltaic-wind power systems”, The International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, (TMREES’14), Energy Procedia, vol. 50, pp. 797 – 807, Beirut, December 2014.
[5] Subodh Paudel, J.N. Shrestha, Fernando J. Neto, Jorge A.F. Ferreira, Muna Adhikari “Optimization of hybrid PV/Wind power system for remote telecom station”, International conference on Power and Energy Systems (ICPS’11), December 2011.
[6] G. L. Terra, G. Salvina, T. G. Marco “Optimal sizing procedure for hybrid solar wind power systems by fuzzy logic”, IEEE MELECON, Benalmádena (Málaga), Spain, May 16-19, 2006.
[7] J. Chang, S-Y Jia, “Modeling and application of Wind-Solar energy hybrid power generation system based on multi-agent technology”, Proceedings of the 8th International Conference on Machine Learning and Cybernetics, Baoding, 12-15 July 2009.
[8] N. Pradhan, N. R. Kark, B. R. Pokhrel, “Reliability evaluation of small standalone hybrid solar PV-Wind power system”, IEEE ICSET 2012, Nepal.
[9] C. Marisarla, K. R. Kumar, “A hybrid wind and solar energy system with battery energy storage for an isolated system”, International Journal of Engineering and Innovative Technology (IJEIT) Vol. 3, Issue 3, September 2013.
[10] B. U. Musa, B. M. Kalli, M.G. Sadiq and B. U. Tijjani, “Modeling and Analysis of Hybrid Solar/Wind Power System for a Small Community”, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. I, pp 39-45, (Jan – Feb. 2015)
[11] W. Wang, C. Xiang, Y. Wang, L. Han, “Research on the battery power model for the power distribution of parallel-series hybrid power system”, 10th IEEE International Conference on Control and Automation (ICCA) Hangzhou, China, June 12-14, 2013.
[12] R. Luna-Rubio, M. Trejo-Perea, D. Vargas-Vazquez, G-J. Rios-Moreno, "Optimal sizing of renewable hybrids energy systems: A review of methodologies", Solar Energy, vol. 86, No. 4, pp. 1077-1088, April 2012.
[13] www.newspakistan.pk/2012/02/18/alternate-energy-sources