128. Efficiency Improvement of Mini Hydro Pump Storage Power Plant Using Archimedes Turbine

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Abstract

Electrical power is stipulation of human life. Electricity generated by hydraulic power is economical and environment friendly. One of the most suitable choices for storing the electrical energy is pump storage plant. The system absorbs energy throughout off-peak and produces energy at peak load. Apart from Pump storage hydropower being employed as a large battery, storing energy within the water of an upper reservoir until its release for instant power generation on demand. This approach is conventional for huge hydropower plants, except for this study; Pump Storage power plant is also used with a medium-scale hydropower unit to model a hybrid power plant employing a reversible turbine. Archimedes Turbine is an emerging renewable, low-carbon electricity generation technology. Archimedes Turbines are appropriate for low head hydro sites, such as existing small dams and rivers. Several hundred Archimedes Turbines have been installed in Europe. The purpose of combining the highly efficient Archimedes turbine and pump storage mechanism is to improve the overall efficiency of hydro power plants.

In this research paper we will compare the efficiency improvement of Mini hydro power plant by using pump storage and Archimedes turbine technology with the efficiency of conventional hydro power plants. Results obtained in this study established technically the idea of pumped storage and Archimedes turbine for small hydro power project could be used to meet peak demand of consumer more effectively.

Keywords: *Pump Stroage Power Plant; archimedes turbines; hydro power plant; renewable energy; peak demand.*

1. Introduction

Mini Hydro Pump Storage Power Plant (MHPSPP) is a vital sustainable energy asset and has great significance in progressive countries wherever government cannot afford the expenditures of grid station, transmission and distribution lines. MHPSPP will run as independent DG system. MHPSPP principally have medium rating that's why it's for small group of consumers or for medium scale consumers. These systems get significance wherever the rate of flow is quick and head is low or vice versa. During this analysis main focus is placed on first framework, turbine used is Archimedes turbine that was fabricated by Greek physicist Archimedes (circa 287-212 B.C.) [1]. Hydro power plants that have capability more than 30MW are known as large hydropower plants while less than 10MW are referred as mini power plant whereas power plants having capability less than 100KW are referred to as micro power plant [2][3].

In hydro power production system; the core parts of this section are turbine and generator. Choosing the appropriate turbine is one among the foremost necessary elements of designing a hydropower power plant and in our case Archimedes turbine will be most popular for low head.

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Mini Hydro Pump Storage Power plant (MHPSPP) main portions are turbine, slow moving coupling shaft, gear box, high speed coupling shaft and generator. From these chunks generator is that the utmost significant for medium scale generation of electricity wherever rate of flow of water change over the year output power of MHPSPP will change and therefore the grade of power may come to be dangerous which can harm the equipment. To avoid its correct control features are installed and main target is kept on voltage and system frequency that tells regarding the standard of power of any system. Each three phase and single phase induction/synchronous generator available however induction generators are usually more acceptable for MHPSPP [2]. Induction generators are more useful than synchronous generator just in case of mini hydro pump storage power plant as a supply of power. Induction generator reduced toughness, unit cost, brush-less in case of squirrel cage construction, reduced size, easy maintenance, self-protection against short circuit, severe over load and no need to provide the independent direct current (DC) supply whereas capacitor is use for excitation [1][4][5]. Induction Generator is employed for small or medium scale generation. A four pole induction machine to be used for small scale generation wherever small rate of flow of water is persisted as four pole machines has 1500 RPM instead of a two pole machine that has 3000 RPM. A turbine rotating at speed less than requisite revolution per minute (RPM) desires a speed boost mechanism named as gear box or correct pulley and belts. For MHPSPP exploitation of water a four pole induction generator machine is projected. It is a proposed idea to use induction generator for MHPSPP but for our prototype we use Dc generator for simplicity and ease. Second part deals with the integration of Pump Storage system in a Mini Hydro Pump Storage Power plant.

Among the alternative strategies for energy storage, exploitation the potential energy of water holds on in several heights has been considered by human for ages. Pumped up storage plants are fabricated for this purpose and are thought of collectively of the foremost reliable and effective strategies of storing the electrical energy [6-7]. In hydro pumped up storage power plants, induction machines are used as induction motor to pump the water from the lower reserve to the higher reserve and as induction generators to produce power by using the falling energy of the water that flows from the higher reservoir to the lower reservoir. It ends up in increase overall efficiency [8]. Despite the losses of the pumping method makes the plant a net user of overall energy, the system will increase revenue by selling a lot of electricity in periods of peak demand, once electricity costs are highest. Pump storage is the largest capability form of grid energy storage currently accessible. Additionally, with growing power networks and increasing vitality challenges, the storable energy systems with high speed response will be developing. Thus, some papers have targeting the application of systems that include alternative energy and pumped up storage [6-7]. This paper includes two main sections. In initial section the introduction of the Archimedes turbine for MHPSPP and within the next the interconnection of Pump storage power plant, the results of this sensible model are reported in this paper to demonstrates the efficiency improvement of MHPSPP.

2. Working of MHPSPP with Archimedes Turbine

When conduit water spate through the Archimedes turbine, generator begins its stimulation is the reason for initial rotation of reversible pump turbine and thus manufacturing mechanical energy. Gear box process is used to vary the low revolution speed to high matched speed of alternator to urge the electrical power from it. Operation of MHPSPP with Archimedes turbine may be done via wireless control. Intake to MHPSPP may be closed through PLC gate and its functioning may be examined by means that of on-line monitoring using wireless frequency [20]. A coarse screen is found in way of water to avoid MHPSPP screw from solids like branches, leaves and stones etc. but allowed to pass fish. Fish movement conjointly engineered besides the MHPSPP, allows the fish to swim upstream.

The aqueous volume sustaining capability of screw turbine is about $16m^3$/sec for the turbine screw having diameter of 5 m and variety of blades conjointly 5 giving electrical power output about 800 KW. Output power of the turbine changes with modification of any specification related to the blades variety, angle of inclination and the rate of flow of water.

To get best potency it's obligatory to stay minimal space between screw's outer boundary and trough. MHPSPP with Archimedes screw has plug and play composition with adjustable angle of inclination for various rate of flow and gradient of height. One among most vital advantage of MHPSPP is demand of a minimal construction work and small accession time as its package may be constructed from concrete or metal and simply ought to place it in path of water and MHPSPP will be operational [11] as shown in Fig 1:

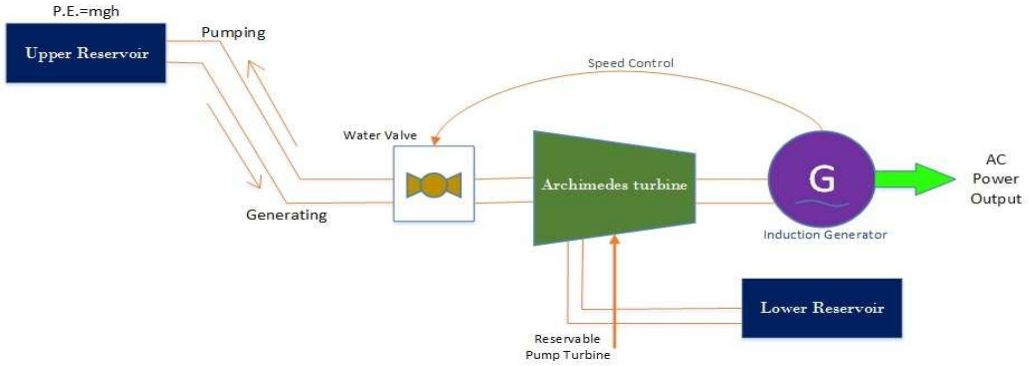

Fig. 1. Illustration of Principles of Archimedes Turbine with Pumped Storage Mechanism.

3. Operation of Pump Storage Mechanism

In general, a pumped up storage system employ by exploitation the surplus power production occasionally of low electrical requirement to pump water to a reserve at an elevated elevation. Once there is a peak demand of electricity, water is discharged back to the lower level reservoir through Archimedes turbine that generates electricity which will be run through the grid to fulfil the spikes during high load demand [9]. A typical pump storage system composes of an upper and lower reservoir that is shown in Fig 1: Facilities are often brought on-line within 90 sec and might be working at full power within 120 sec.

Moreover, a pump storage facility will switch from pumping to generation or from generation to pumping in 180-240 sec. The choice for an applicable pumped up storage system site is determined by topographical, geographical, and environmental concerns. Traditionally, pumped storage system requires enormous capital and nearly a decade to construct, but for this study we proposed that pump storage is also applicable for the MHPSPP so it will be considerably less expensive and need less time for construction. By using the Archimedes turbine, the pumping losses of the system will become minor because Archimedes turbine is a highly efficient turbine having the ability to pump water with maximum capacity without the huge losses for doing pumping [14]. During the period of low consumption of electricity or at night generator work as a motor to move the turbine in reverse direction to pump the water to the upper reservoir screw turbine is 83% efficient to pump water back [16].

4. MHPSPP Model Delineation

An extensive model of Archimedes Turbine is presented here in this paper. By using the AutoCAD software, its complete 3d modeling had been designed as shown in Fig.2 in order to fulfil the practical standards before fabrication of a sensible hardware model. Table 1 represents the design parameters of the hardware turbine model which is calculated to prove the efficiency improvement by using Archimedes turbine and Pump Storage mechanism.

Table 1. Designed Parameters for Archimedes Turbine

Description	Parameters
Inner Cylinder	4”
Outer Cylinder	12”
Blade 1	1’-4”,3 turns at 120°
Blade 2	1’-4”,3 turns at 120°
Blade 3	1’-4”,3 turns at 120°
Blade Internal Angle	71°
Inclined Angle	37°
Blades Thickness	0.008m
Mass of one blade	172kg
Mass of three blades	516kg
Torque	2020 Nm

Three blades of the turbine are displaced with each other at 120 degrees. So the cross sectional view of the turbine is shown in the Fig.2 (b) which clearly illustrates the all the information about the internal

structure of the turbine. Screw blades are designed in such a way that each blade supports the whole structure in the process of generation as well as pumping that's why is called as Reversible Turbine having the highest efficiency [13]. For increasing the rate of flow of water through the blades the outer cylinder plays the most important role so it depends on the construction of the turbine while mostly it is taken as semi-circled or full-circled.

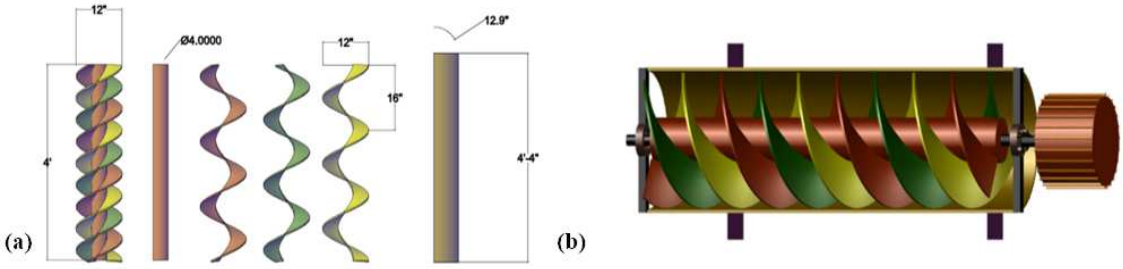

Fig. 2. 3d AutoCAD Design of Archimedes Turbine (a) Screw parameters (b) Cross sectional view.

Aluminium is selected for the construction of our prototype design because of some obstacles and due to high cost of aluminium, mild steel material is used which is also called as High carbon steel. All the parameters were taken under consideration according to the drawing of AutoCAD as shown in the Fig.2 (a). In hardware model Dc generator, a gearbox is used to accelerate revolution while minimizing the speed of a prime mover output shaft and a set of bearing is also used that constrains relative motion between movable parts to only the desired motion see Fig.3:

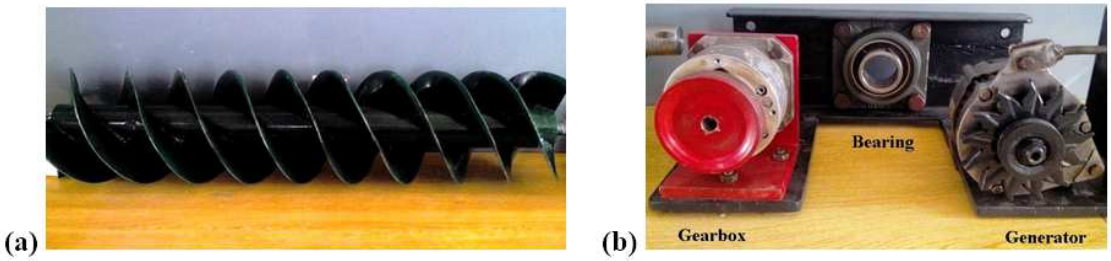

Fig. 3. Hardware Design of Archimedes Turbine (a) Screw (b) Other parts.

5. Model Exposition

Equation from "Entwurfsfluss für Wasserkraftschnecken*", (Design flow for hydropower screw)* [15] a Matlab Simulink case of Archimedes rotary engine is developed as shown in Fig.4: All the values were taken under consideration according to proposed model as shown in Fig.5: By inserting the output of the Archimedes Screw model to "Product of C_x and Ra" to observe its behaviour with the applied rate of flow of water but the result found by the prototype model are more authentic and useful for this hydropower system.

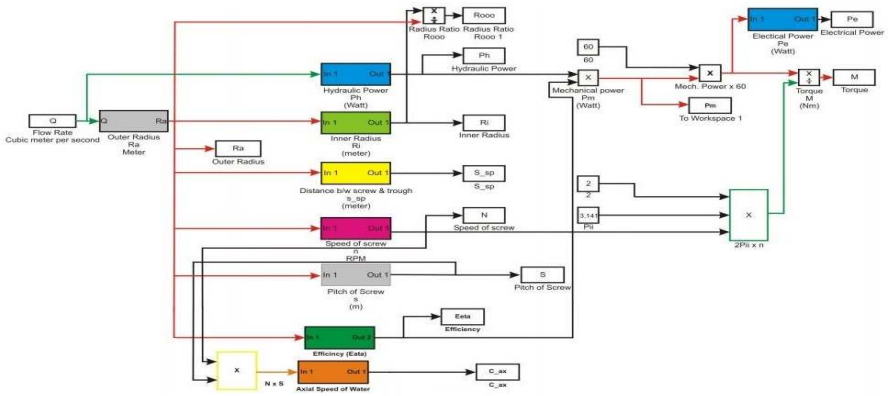

Fig. 4. Archimedes Screw Simulink Matlab Prototype

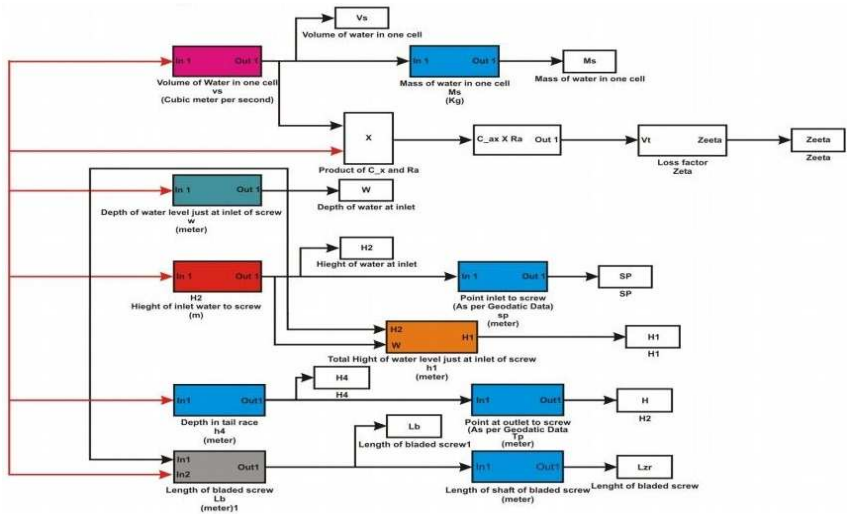

Fig. 5. Archimedes Screw Simulink MATLAB Prototype with Volume of water

6. Results and Analysis

Hydraulic rate of flow is sufficient for Archimedes Turbine to produce decent power to rush most of the loads. These results are found that output power of the system rely on the discharge rate and the angle of inclination of the turbine. By increasing the rate of flow of water through the turbine and angle of inclination of the turbine output generated power is also increased as shown in Fig.6: by using the "Eq. (1)".

$$P = Q \times g \times h \times \eta \qquad (1)$$

Product of all efficiencies connected of equipment like gear box, belt drive etc. ought to be reckon to calculate the overall power transfer from harvested mechanical power is given by "Eq. (2)".

$$P_e = \eta_{BD} \cdot \eta_{GB} \cdot \eta_{gen} \cdot P_{mech} \qquad (2)$$

As per the Archimedes turbine feature output power of the turbine varies with the variation of the other parameters such as the head, efficiency factor, rate of flow and its angle of inclination Fig.6 (a) shows that its output power keeps on increasing by changing its all other factors and in Fig.6 (b): it is clearly illustrated that power is gradually increasing by taking its angle of inclination constant and changing its other parameters.

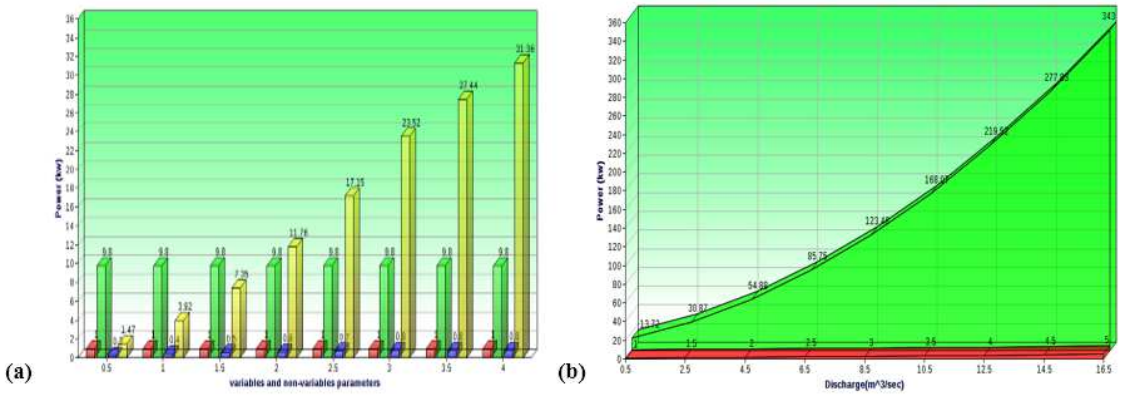

Fig. 6. Efficiency of Archimedes Turbine with (a) Different parameters (b) Fixed parameters

Experimental results reckon the dynamic behaviour of the Mini Hydro Pump Storage Power Plant in Fig.7:.It can be seen that in MHPSPP the pumping losses of the conventional pump storage power plant are reduced and the efficiency of the system increased because of minimized losses of the turbine and pumping. The results which are obtained by the practically running machine were of very low rating while from the experimental result are the induced results for MHPSPP. The results elucidate that in

traditional PSPP pump losses were more than 600 KW which is reduced to 400 KW and its top power is dramatically reached to almost 1200 KW from 1050KW.But still the system have some losses are present because it's not an ideal system.

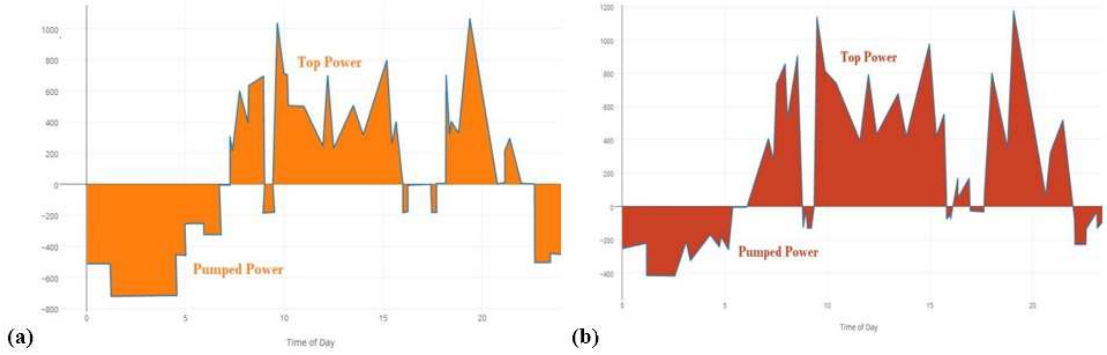

Fig. 7. Efficiency Comparison of (a) Conventional PSPP (b) MHPSPP

7. Conclusion

These results validate a hybrid efficient structure of a mini hydro pumped storage power plant with Archimedes turbine is appropriate and able to meet spike time requirement for electricity. In this paper MHPSPP prospective is described for rustic as well as metropolitan areas. MHPSPP is extremely reliable, cost effective and talented of producing stable energy at need due to its construction on small watercourse/runoff garbage plants that operate all over the year [12]. Model of Archimedes Screw Turbine is represented in Simulink Matlab software and its hardware model is tested on a canal located in Xi'an, China. Main objective of this research paper is to prove the efficiency improvement by using the combination of two efficient systems and it also proposed a solution to overcome the pumping and turbine losses of a power plant. In future this concept is also provable and implementable for the large scale hydro power generation and additionally from the waste product like the sewages [11].

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Appendix

3d	Three Dimensional
η	Efficiency
CAD	Computer Aided Design
DC	Direct Current
DG	Distribution Generation
g	Force of gravity
H	Height
kW	Kilowatt
MHPSPP	Mini Hydro Pump Storage Power Plant
MW	Megawatt
MATLAB	matrix laboratory
PLC	Programmable Logic Control
P	Power
PSPP	Pump Storage Power Plant
Pe	Power electrical
Pm	Power mechanical
Q	Flow rate
RPM	Revolution per minute
Sec	Second