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Modeling of Archimedes Turbine for Low Head Hydro Power Plant in Simulink MATLAB

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Abstract

Electrical power is necessity of human life. Now-a-days electricity is produced by number of ways like hydraulic energy coal, steam, wind stream and nuclear power. Electricity generated by hydraulic power is cheapest and environment friendly. A large dam is required to generate power in megawatt (MW), to build them need of large capital cost and large land reforms but now-a-days micro hydro power plant are common on simple run of river. A most suitable turbine for such a low head hydro power plant is Archimedes turbine. In this paper a model of Archimedes Turbine s designed in Simulink MATLAB while keeping all geometrical parameters. Archimedes screw is one of the oldest hydraulic machine and it has been used for long time in pumping water but now operating in reverse used in energy conversion. In this paper a theoretical model of Archimedes turbine is discussed with different flow rate of water and keeping drop head constant which will make easiness and robustness for design engineer.

1. Introduction

Archimedes screw is one of the oldest form of all known hydraulic machines and still is used. First, it was used to lift water from lower level to high level of water while in modern era its function is reverse as a generator. This machine was invented by Archimedes (287-212B.C). [1] Before its invention there was no such idea in history and its design required the geometric type in which Archimedes was master.

A roman engineer Vitruvius's write a detailed note on this machine in this book De architecture (X-chapter VI) to keep this device up-to-date Vitruvius's screw is shown in figure 01 made from tree. Its length is sixteen times its diameter and eight blades were made on it. Archimedes screw is monted in such a way that it can rotate about its length and tilted in front of hypotenuse of 3-4-5 triangle. But this technique is no more efficient. For more efficient screw a technique will be developed [2].

Archimedes screw is oldest device but till now all technical published data on it cannot describe its theory completely. Because of this reason a site equipped with Archimedes turbine is purely dependent on skills of design engineer. Published data about this old machine deals only with its empirical design and optimization of geometry with respect to volume, inflow water speed and its height. It is noted that efficiency of hydraulic screw depend upon only mechanical leakage losses as per Negal-1968 a handbook on Archimedean screw Pump [3] and efficiency of such screw is b/w 79% to 84% which change with change in flow water and radius of screw, make it a good replacement on other low head turbines for low head hydro power plant (Brada and Radik 1996, Brada 1999, Hellman 2003) [4][5[6][7][8]. A screw largest diameter screw is no more than 4 meter because of fatigue of weld, fabrication and operation of maintenance issues during performance on site. [5]

In developed countries, a fish friendly hydro power plant is a conduct of law which increases usage of Archimedes screw in low head hydro power plants. Archimedes turbine is fish friendly and even it can allow passing through small garbage like polythene shopping bags, forest grass etc. A research related to fish to fish friendly case was done by Mann Power in United Kingdom (UK) on river Dart with the name of "Fish monitoring and live fish trails Archimedes Screw Turbine, River Dart" which stated that a large number of fish passage has been observed by using camera's at inflow of water, inside of screw and at outlet of screw on various flow rate and speed of screw. No adverse effect found on brown trout while 1.4% (out of 1000 passages) of smolt fish suffer with recoverable scale loss and 160 passages of eel fish only 0.64 suffer with recoverable pinching to tail.[9]

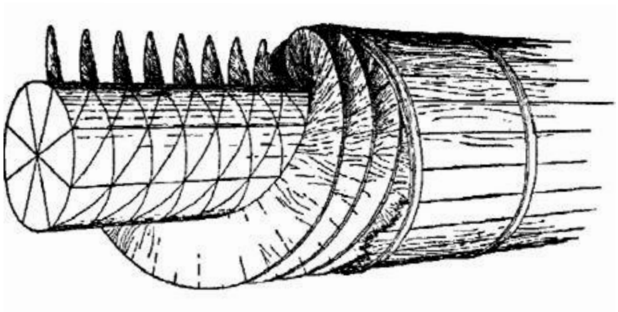

Fig 01: Vitruvius Screw Built from Trunk Tree having Eight Blades

2. Theory

Main difference b/w screws pump and screw generator direction of flow of water, out flow water condition and in flow water conditions [7]. It is assumed that inlet water has some weight which is caught b/w screw blades and drives the screw. Let assume that there is no loss of all potential energy (P.E) will be converted to the mechanical energy and efficiency is 100%. Power is product of velocity and force and as velocity is acting tangentially to surface of screw, only small part of water resting on outer section of blade will contribute to energy conversion. It has been notified that a large amount of water rests on trough of Archimedes turbine which does not move [8]

When going to put screw in hydraulic environment, first from site assessment and hydraulic environment Archimedean screw geometry information is drawn to make a theoretical model. Following predefined simplification can be used to to make idea about geometry

a. Screw with N blades is installed in inclined plane with angle β. less is β more is efficiency and vice versa.
b. Outer radius of screw should be significantly larger than inlet water flow h1.
c. Inner radius should be small.

A bucket form b/w blades and can trap water. When screw is rotating these buckets likes to rotate downward carrying water within it. Volume of each bucket is given by V_B and volume of all N buckets is $NV_B=V_U$, where V_U is water which screw put out in one revolution and chute is a region b/w two adjacent blades outer and inner radius of screw. If screw has N blades, screw has N chutes and volume given by (01) over one pitch length

$$\pi(R_a^2 - R_i^2)S / N \qquad (1)$$

Main purpose of this paper is to make Simulink model from scattered theory of Archimedes Turbine mainly following [7][10] and studying the behaviour of different geometric parameter's with flow rate and ultimate change in efficiency with constant head.

3. Designing Parameter of Low Head Hydro Screw Power Plant

3.1. Design of Flow, Head and Radius of Hydro Power Worm

Designing of water power worm starts from site assessment. From site, one can access the data about flow rate of water and idea to determine the geometry of screw like outer and inner radius. From these geometric parameters, output mechanical power can be determined. After assessment of site, one can get the dimensions of design flow rate (Q) drops height (H) and height of upper water level (UWL) at the inlet of screw, height of outlet lower water level (LWL) of screw with respect to sea level. Normally no such data is precisely predetermined by any authority, so before giving statement flow rate data in form of duration curves and geodetic height data should also precisely measured. Drop head will consult for given geodetic height of water and flow rate while upper and lower water level should be noted for different seasonal flow rate. However gross head for low drop height of water can be given [10]

$$Hgross = H + c_1^2 - c_4^2 / 2\square g \qquad (2)$$

But usually H is acceptable in most of cases. Water screw is installed in inclined plane with angle β and it will be slight (smaller) for large flow rate and drop height is low and in inverse case β will be high for low flow rate and high gradient of height. But most of case β is made b/w 22◦ to 26◦ for best efficiency β=26. Basic approximation for radius of screw is made from site and flow rate data curves with respect to time and outer radius and inner radius of screw related by

$$R_i = \rho\square R_a \qquad (3)$$

While building a screw one must ensure the wall thickness and support tube Ri is water proof as if in case of leakage the stability construction of screw can be limited.

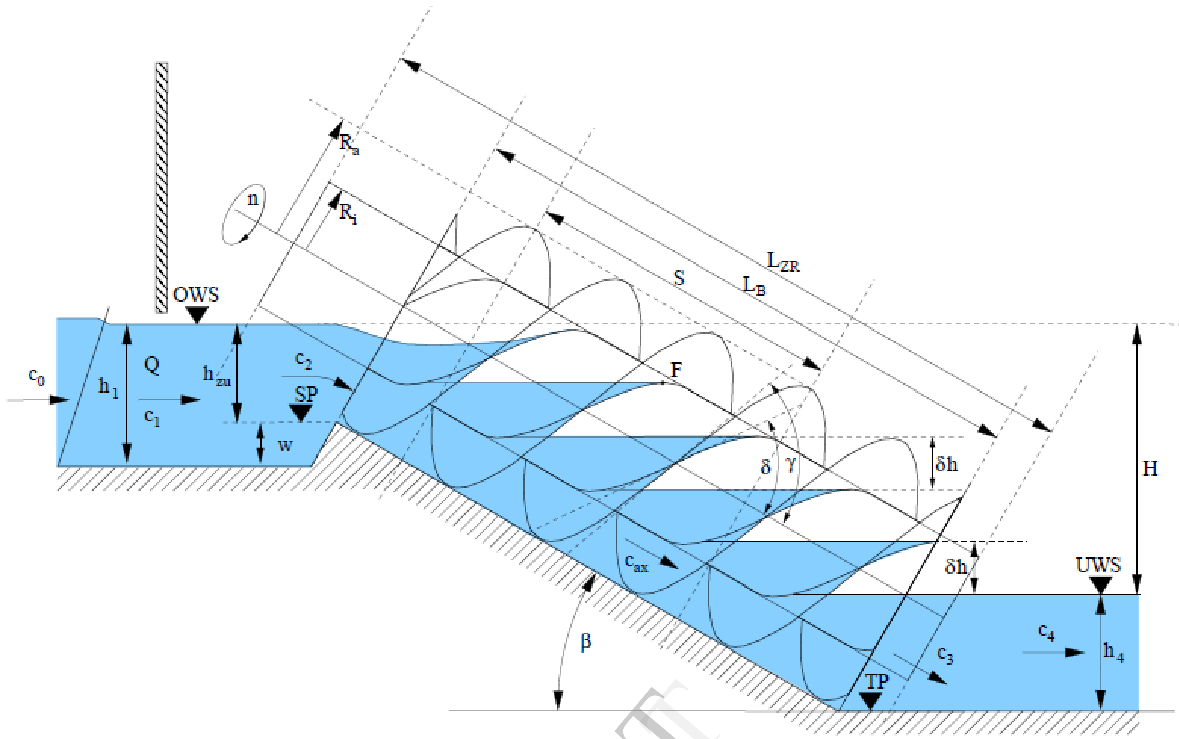

Fig 02 The parameters of the screw are defined as follows: β - Appointing angle of the worm , Ra – Outer Radius of the screw, the dimensions of the trough Ra + S_sp, wherein S_sp is the gap width between trough and screw, the radius Ri and length L_{ZR} the central tube, N is number of transitions of screw and S is the pitch, Lb is the length of blades, the employment angle on blades at outer and inner radius γ and δ, at the optimum head of water h1, the water depth in the inlet channel h1 is w, the optimum height underwater h4, the optimum filling point F where no water stays while just flows from central tube to the next cell. N is speed and the output torque M (transmission, stem, bearing design), the efficiency of the worm η, the nominal electric capacity at the terminals of the generator Pe and the drive and the system efficiency of the entire hydroelectric plant is ηA. [10]

3.2. Determination of Pitch and Speed of Screw

Pitch is defined as the period of spiral and it lies b/w zero and $2\pi R_a / \tan\beta$. It cannot negative or more than $2\pi R_a / \tan\beta$, while the distance b/w outer radius and trough (concrete and metal case in which water screw is filled) is given by **S_{SP}=0.0045√2.R_a** So the trough radius is $R_T = R_A + S_{SP}$ and Speed of screw is calculated by $n_{speed} = 60 \cdot Q / V_u$, where V_U is the volume lifted per revolution and this speed should follow the condition [5][6]

(4)

3.3. Hydraulic Power

Well known equation for hydraulic power also hold good for. Archimedes turbine

$$n_{speed} \le \frac{53}{(2 \cdot R_a)^{2/3}}$$

$$P_h = \rho \cdot g \cdot H \cdot Q \qquad (5)$$

And mechanical power output shaft's given by

$$P_{mech} = P_h \cdot \eta \qquad (6)$$

Where $\eta = \frac{2a+1}{2a+2}$ is efficiency of screw [8]

And $a = \frac{h_1}{\delta h}$ where $\delta h = \frac{H}{N}$

And total torque due to this mechanical power is obtained by dividing mechanical power to angular velocity is obtained.

3.3. Electrical Power Transfer

Transmitted electrical power from produced torque on mechanical power can be calculated by considering the multiplying factor in sense of efficiency of all installed auxiliaries to convert mechanical torque to electrical energy. For example if we use gear box, drive and generator to convert mechanical energy to electrical energy, so

$$P_e = \eta_{BD} \cdot \eta_{GB} \cdot \eta_{gen} \cdot P_{mech} \qquad (7)$$

4. Simulink Modelling of Archimedes Turbine

A Simulink model of Archimedes turbine for low head power plant is made which is ever not worked since its invention. All above mentioned designed equations and their reliability on taken [7] [8][10]. In this model, variable to flow rate is assumes with fix head of 1.5m and separate sub system is built for every designed parameter which ultimately depend upon flow rate and outer radius. It is found that the speed of worm which is Key output is mainly dependent on flow rate and volume of water powered to lower reservoir per revolution as shown in fig 4

Hydraulic power and ultimately electrical power directly relate with inflow water flow rate. More is flow rate; more is concerned power as shown in fig 5

Idea of geometry of screw starts from assessment of site and other radius of worm as discussed already but the outer diameter of screw is directly proportional to flow rate "Q" and slope "tan β " at which screw installed greater the slope…

As inner radius is product of radius ratio & outer radius so it will increase or decrease with radius ratio value as shown in fig.6 Mostly manufacturer take radius ratio value round to 0.3 to 0.5[7].

screw length Lsh plus shaft used for fixing and connection to gear box. It is found that directly relate to constant head difference and outer radius of screw while it is inversely proportional to sine of slope angle as shown in figure 07

Inflow of water height is directly proportional to flow rate Q as shown in figure09 while out flow of water is directly proportional to Ra as graph is depicting.

Efficiency of Archimedes turbine is independent of geometry of screw rather it depends upon only on inflow water depth, slope of screw and no. of turns/head drop on pitch of screw. Figure 10 (a) and (b) is showing the efficiency of screw changing with the inflow water depth and length of bladed screw. And finally mechanical power relation with electrical power is shown which is off course proportional or linear relation if one ignores the transmission losses as shown in figure 11.

5. How Hydro Power Screw Works

The river water flows downstream through the hydropower screw generator kick starts the initial rotation of screw pump water flow rotates the screw thus generating energy. A gear box increases the screw speed up to generator speed and generator convert mechanical energy into electrical energy. Operation of screw is possible by means of remote control. If required, the intake can be shut off by means of an automatic stop-log and its working can be online monitored by using the application of online monitoring mentioned in [11]. A coars screen will block large solid but allows fish to pass through unharmed and make sure there will be nothing at outlet of screw which can harm coming fishes. A fish pass enables fish to swim upstream which is available along the assembly of screw either side. Capacity of screw is 16 cubic meter per second until made with maximum diameter up to 05 meter with number of blades 5 which can give up to 800kW power. With change of flow rate, number of blade and installing angle of screw this power is vary. Minimum clearance between screw and trough is required for high efficiency. Plug and play construction for smaller and larger and units with optional adjustable inclination are available and can be installed. Hydro power plant with Archimedes screw require small civil work and shorter mounting time as its assembly (trough) can be made with concrete or metal which just put onside and passing water through it, will be in working condition. [12]

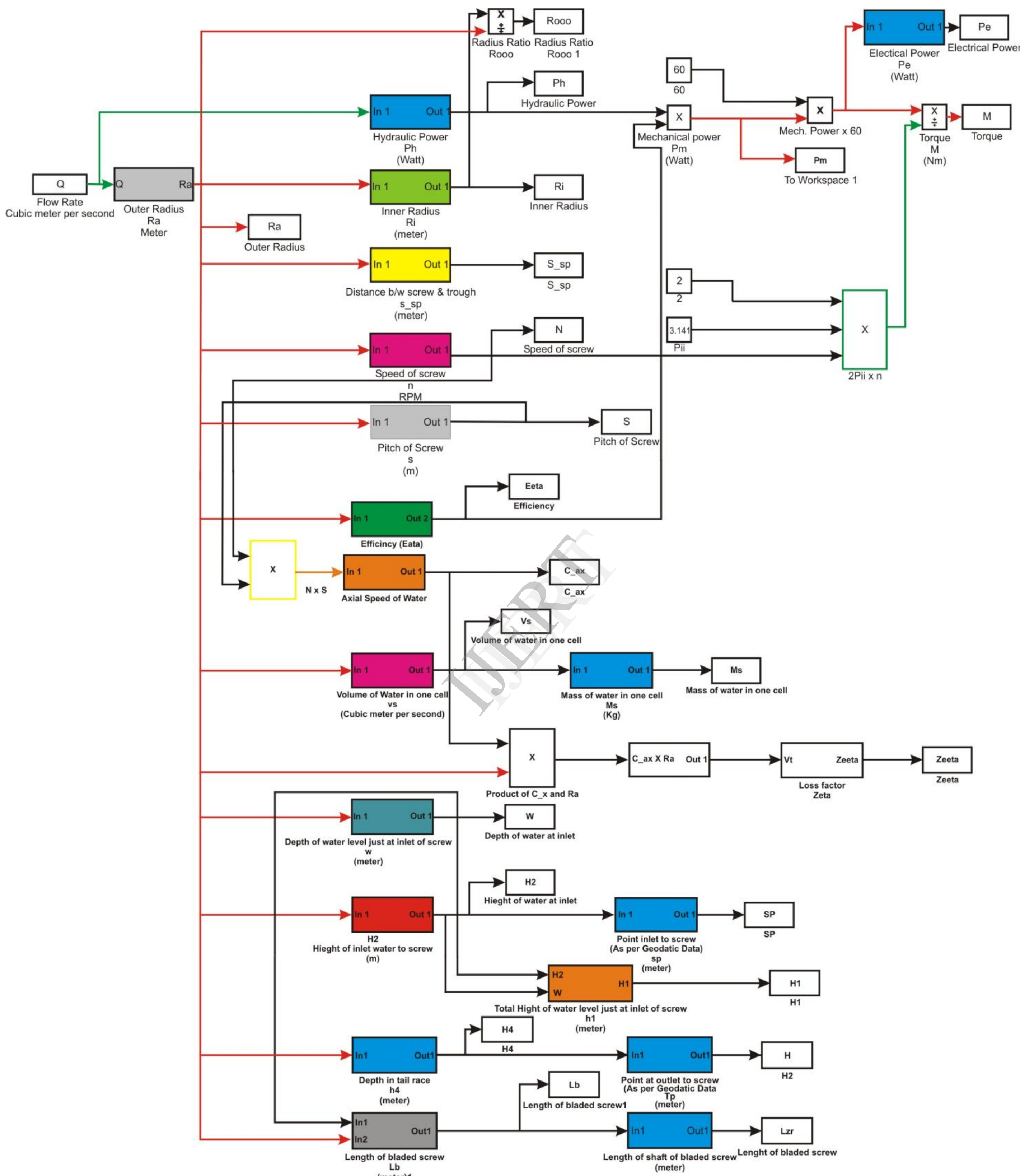

Fig.03. Simulink Model of Archimedes Turbine

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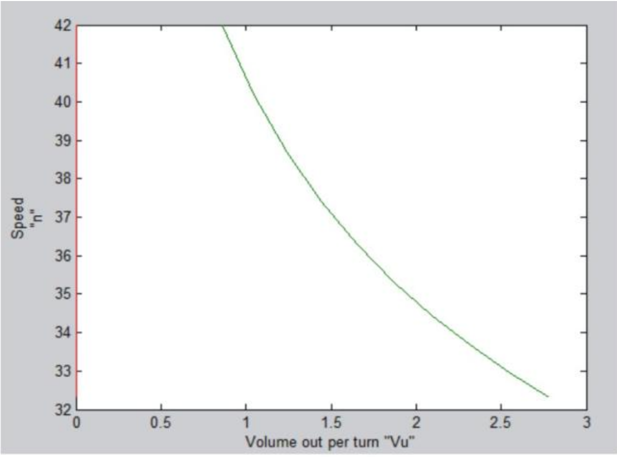

Fig. 4: Relation betweenVolume per turn and Speed of screw

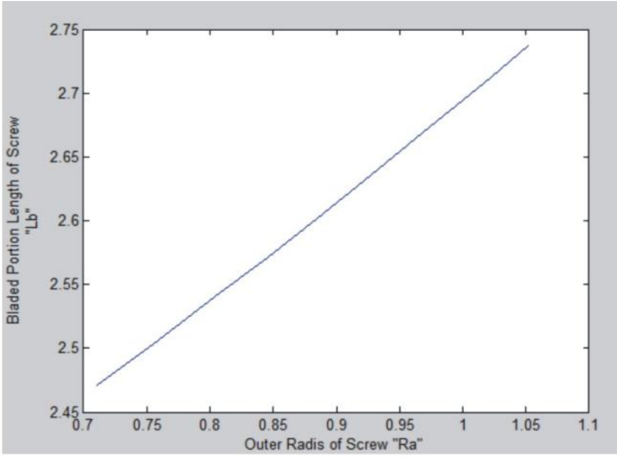

Fig. 7: Relation between Ra and Lb

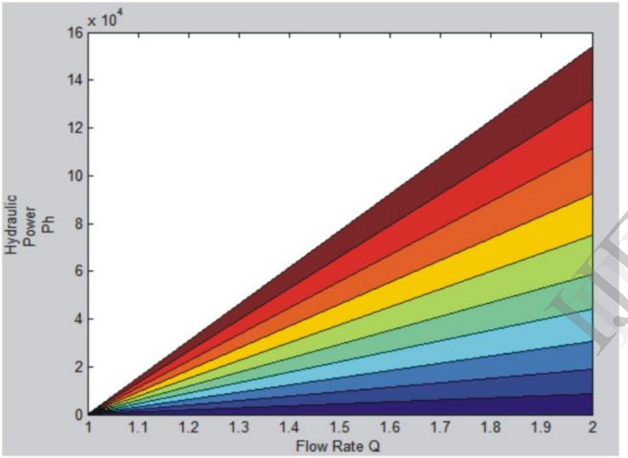

Fig. 5: Change of Power with flow rate

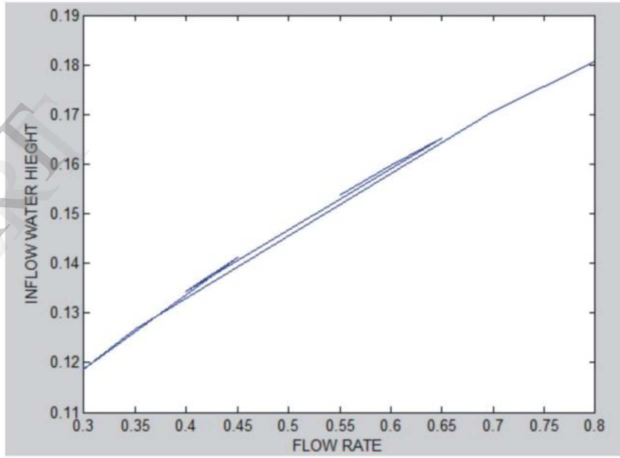

Fig. 8 : Relation Between Flow rate and Inflow water

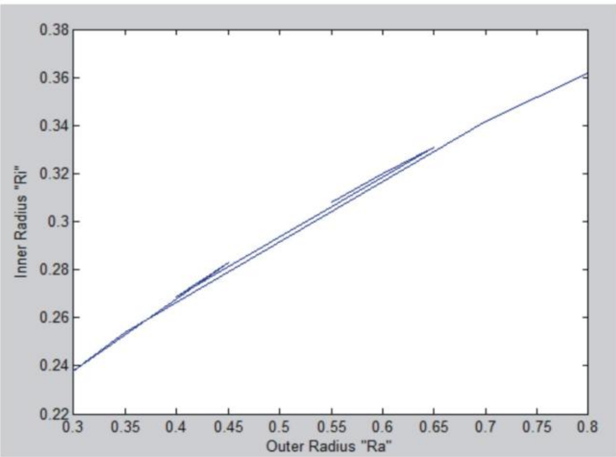

Fig. 6: Inner radius increase with increase of Outer radius

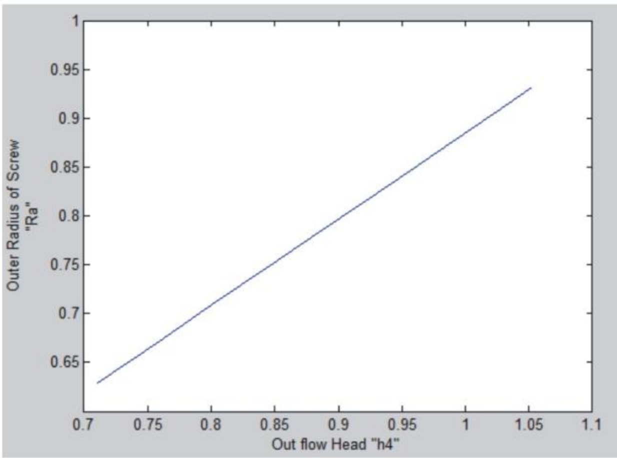

Fig. 9 : Relation Between out flow water and outer radius

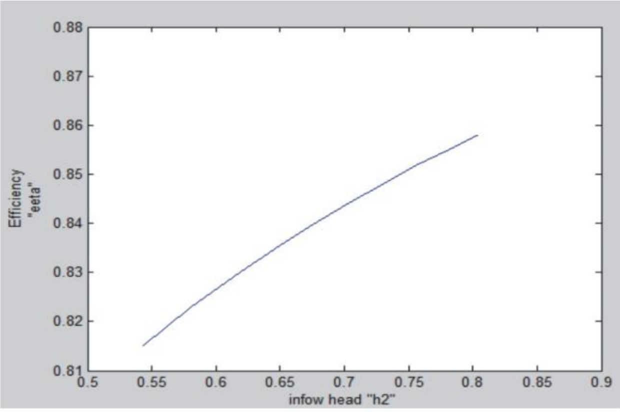

Fig. 10(b):Relation between Efficiency and inflow water depth

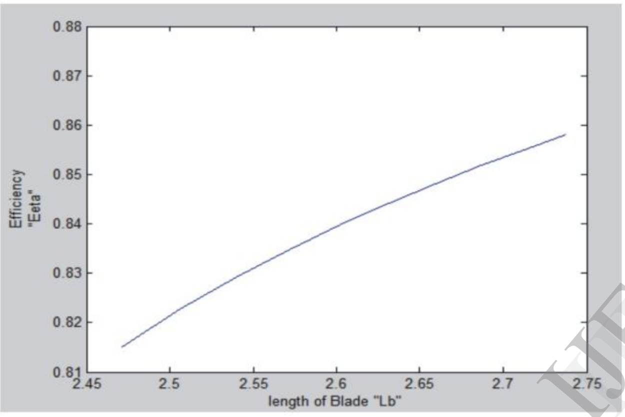

Fig. 10(b):Relation between Efficinecy and length of bladed screw

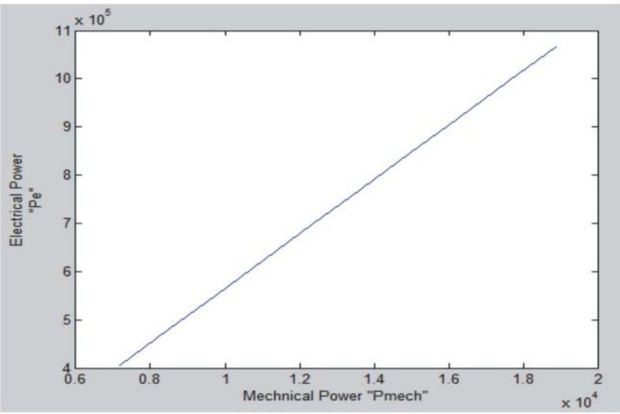

Fig. 11: Relation between Mechanical power and Electrical power

5. Conclusion

In this paper a Simulink model of analytical model of Archimedes screw is presented. By giving the site assessment parameters a designer of low hydro power plant can easily find the remaining parameters for that particular site.10 different values of flow rate at constant head considered and results found very close to the experimental work Brada [2][5]. It is observed from the work that efficiency of screw depends only on geometry, inflow water height, largely on flow rate and inclination angle. Slight Inclination angle gives high flow rate and less efficiency and opposite is that higher inclination angles gives low flow rate and high efficiency but still in designing a screw for a customer, designer need of parameter which gives maximum output efficiency by making assumptions.

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