Potential of Archimedes Screw Turbine in Rural India Electrification: A Review

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Abstract: ***With the growing population of India, the demand for energy consumption is increasing. For an overall development of a region, especially remote areas, electricity is of prime importance. Production of electricity in large scale can further lead to various effects like environmental pollution, climate change and it is also costly. Thus the need of a socio-economic energy conversion to electricity is of prime importance for a sustainable development. India have a huge potential in the Hydro to generate 2,50,000 MW. An Archimedes Screw Turbine that was earlier used as pump can give a very good solution in harnessing water potential. It rotates as water flows through it, rotating the generator's prime mover connected to it. Archimedes Screw turbines operate at low head of 0.8m to 10 m and relatively lower flow rate than the other turbines and more cost effective and are highly efficient. The AST is quite a new form of electricity generation practice which has been implemented in different countries along with India. Thus the electrification scenario in rural areas can be improved specially where there is a continuous flow of a river or canal by the installation of the low cost socio economic AST.***

Keywords: Archimedes Screw Turbine (AST), Archimedes Screw Generator (ASG), Sustainable Development, Small Hydro Power, Rural Electrification.

1. Introduction

Renewable energy is a beautiful gift from the nature. The proper harnessing of these renewable resources into a useful form of energy is of prime importance. But during this continuous conversion of energy, various natural hazards may occur. Thus a proper form of energy conversion should take place to meet the energy demands in an optimal way. Electricity the foremost important form of energy can be harnessed through hydro power where moving water is used to rotate the prime mover of the generator where electricity is produced through electromagnetic induction. India is blessed with massive amounts of hydro-electric potential and ranks 6th in terms of utilizable hydro potential with 2,50,000 MW.Currently India has a total potential of 15,000 MW in Small Hydro Plants out of which only 2000 MW is installed [20]. A major portion of the rural India is still under darkness with no electricity. For electrifying the rural and remote parts in India, various schemes formed by Govt. Of India, RGVVY (Rajiv Gandhi Vidyutikar Vikash Yojana), DDUGJY (Deendayal Upadhyaya Gram Jyoti Yojana (Launched in Dec, 2014) being some of them, led to the increase of the number of rural household electrified from 44% to 67%. For Ministry of New and Renewable Energy, Govt. of India, Small hydro power programme is one of the thrust area of generating power from renewable resource [1].

Basically, the power that is generated from a hydro power plant is given by,

$$P = \eta \rho g H Q \text{ (kW)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where η is the hydraulic efficiency of the turbine, P is the mechanical power of the shaft, g is the acceleration due to gravity, ρ is the density of water, H is the effective , Q is the mass flow rate. [2]. Hence, more the head or the more the flow rate, higher is the power generated. To get very high power energy, the head should be increased upto a substantial height by making a dam .but such a task is difficult to achieve takes longer time and a lot of money is to be invested. Thus, the Hydro Power plants should be reservoir-less or of very low head. This could be achieved by the proper selection of the turbine depending on the site located. The Archimedes Screw Turbine(AST) can be used in such low head sites.

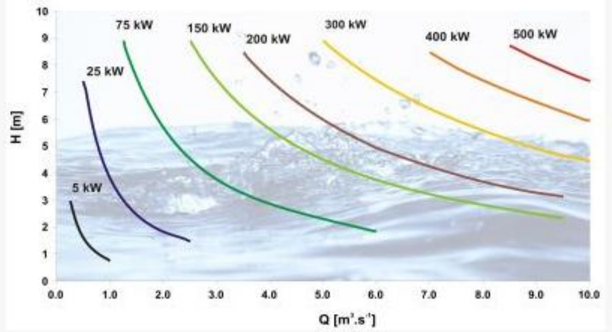

Figure 1: Power (kW) developed at different head and flow rate.

2. Rural India Electrification

The electricity situation in India, specially in the rural and remote areas is under groom with around 3,17,56,227 households unelectrified as on 10-Oct-2017 [7]. Electricity is either present or there are lot of interruptions in the power supply. Therefore, a proper way of conversion of energy into electrical energy that can be easily produced and distributed for that specific site, has to be chosen. For a developing country, these energy demands need to be satisfied. Electricity is one of the prime factors that can measure the development level of a country in terms of energy resource. It helps to increase productivity in agriculture and labour, gives access to communications (TV, RADIO), improved health conditions, improved lightning condition.For a rural and a remote a small hydro power plant is basically preferable as the installation cost and duration process is less. Small Hydro Power Plants can produce a net power of around 1-100 MW.

3. Archimedes Screw Turbine (AST)

Archimedes Screw generators have been started to be used widely specially at low head sites in Europe. In earlier days, the Archimedes Screws were used as a pump to lift water from a certain level to a higher level, specially in sewage treatment plants. These turbines are generally suitable in low head sites due to their high efficiency, low natural (environmental) impact, less cost and require less maintenance. These turbines can work under the head difference of as low as 1m upto 10m. An Archimedes screw consists of the cylindrical shaft along with some impinged helical surfaces called flights to form a screw like structure. The water enters the screw from the top and flows along the consecutive flights to rotate the shaft which in turn rotates the rotor of the generator. The maximum flow rate through the AST can be determined from the screw diameter. It can be installed in places with river or stream flowing in inclined way, an existing dam or weir, a dysfunctional hydropower plant, sites with variable flow.

3.1 Construction of AST

The main parts of a AST are the lower bearing, top bearing, gearbox, pump trough, floodgate, coarse screen and the Archimedes screw Turbine itself. The actual screw is below the upper bearing and the helical flights are formed from rolled flat steel plate, which is then welded to the central core. Majority of the screw turbines have three flights or helices welded around the cylindrical shaft [3].

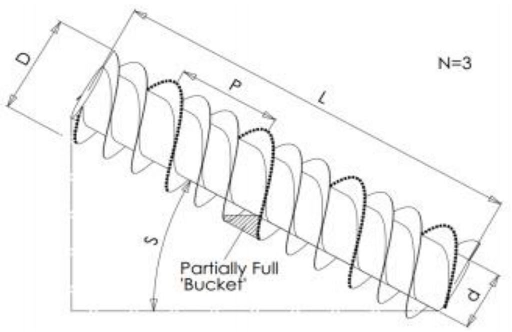

Figure 2: Example of ASG with 3 flights and geometric variables- Screw Turbine parameters [4]

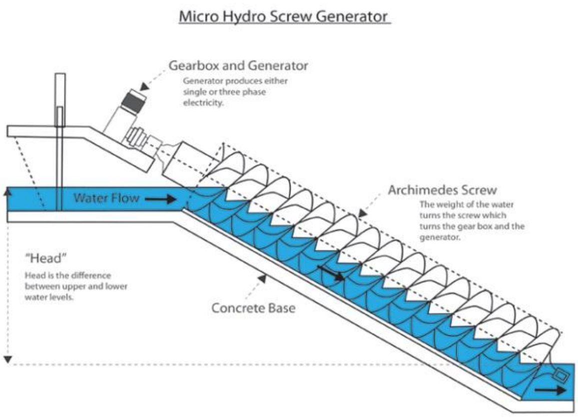

Figure 3: Basic model of Archimedes Screw Turbine [16]

Archimedes Screw is generally aligned 22 degrees from the horizontal, which is the most cost effective installation as per the experimental studies [10]. The mechanical power available at the turbine shaft is given by

$$P = \omega\, T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where ω is the speed of turbine m/s and T is the torque in Nm.

3.2 Efficiency

Efficiency of a turbine is its ability to transform the power and energy from the hydro power.

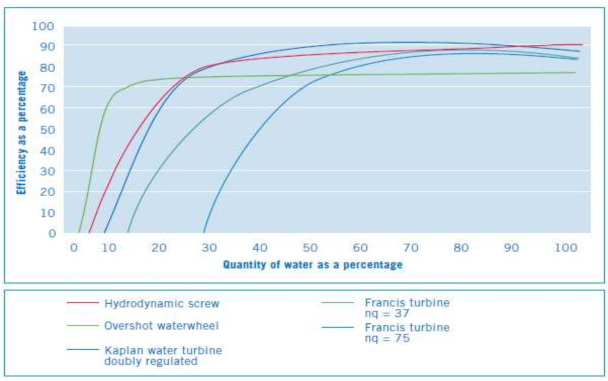

Figure 4: Efficiency comparison of different turbine types [15]

The efficiency is determined by the generator's efficiency and the various hydraulic losses. These losses include frictional loss due to fluid viscosity, leakage. So, these losses have to be minimum in order to obtain a higher efficiency.

Mathematically,

$$\eta = P_{mec} / P_{hyd} \quad \text{.......................... (3)}$$

$$P_{mec} = T\ \omega \quad \text{.......................... (4)}$$

Where, T is the torque provided by screw in Nm and ω = rotational speed of screw in rad/s.

$$P_{hyd} = \rho\ g\ Q\ H \text{ (in KW)} \quad \text{................ (5)}$$

Here P_{hyd} is hydro power, ρ is the density of water (kg/m^3), Q the flow rate in m^3/s, g = 9.81 m/s = the gravitational constant, H the head in meters [12].

C. Zafirah Rosly *et al.* in 2016 [13] conducted a study that identified various potential parameters of the turbine that can increase the power efficiency. They found that the combination of 3 blades with 3 helix enhances the overall efficiency. However a high efficiency of 81% was obtained when the turbine was designed with 2 blades and 3 helix turns. Through this study, it was found that the efficiency in AST is a function of the number of helix turns. Also in another research study by A. Nurul Suraya, N. M. M. Ammar and J. Ummu Kulthum in 2015 [14], it was found that lower inclination angle resulted in a higher efficiency.

4. Advantages of AST

(a) Environment Friendly: ASTs are one of the most environment friendly turbines. Being reservoir or damless there is no chance of flash floods near the site. Thus, the installation of an AST will not affect the surrounding. As a result, nearby people need not have to displace from the native part. Also as there is no chance of flash floods the natural vegetation nearby is not affected, so there will be no decomposition of this natural vegetation that might lead to the formation of the greenhouse gas methane which is primarily responsible for the climate changes hence reducing the CO_2 level.

(b) Fish friendliness of Archimedes Screw Generator (ASG): The safe passage of different aquatic animals specially fishes and debris makes the ASG even more versatile. An experimental test was conducted in the ASG present at the Dart River in Devon,UK and concluded that fish passes safely throughout the operation. Furthermore, it was found that the fishes less than 1 kg can safely pass through the blades if the blade tip velocity is upto 4.5 m/s without any protection on the leading edge of blade. A study by M. Lyons and W. D. Lubitz [4] showed that 98% of the fishes were able to pass through the turbine.

(c) Easy Set-up: It can be easily set up in small canals, ponds and rivers, etc. as the head requirement is not much (1m-10m). It also requires less maintenance and operational cost and it is easy to install as not much parts are there, thus reducing the civil work.

(d) Longer durability: The durability of an AST is more.A good quality AST has a design life of 30 years and further this can be extended with a major overhaul that includes re-tipping the screw flights. The wear and tear of the turbine is also less.

(e) Due to the low rotational speed of the turbine and more passage area, the debris can easily pass through the turbine and thus not affects the fertility of the soil towards the discharge basin.

(f) The maximum turbine efficiency of an ASG is upto 92% with a flow rate of 0.2-0.8 m^3/s with head from 0.8 m to 10 m.

The speed of the shaft is regulated with the help of the gearbox according to the current flow rate.

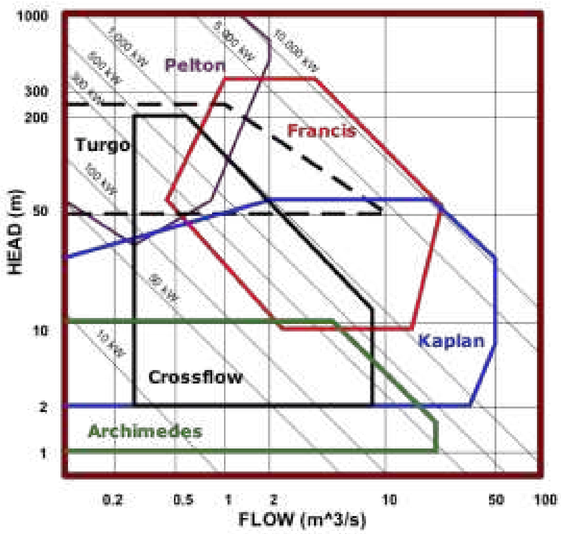

Figure 5: Classification of hydropower turbines for head V/s flow rate [14]

5. How can AST's solve rural electrification problem?

The unique, simple, environment friendly AST's being very cost effective and its specialty in low heads can be set up to electrify some of the rural and remote parts in the presence of a stream of river or continuous flowing water. If the requirement of power is high, then as per the requirement a different AST can be planned in a nearby place to meet the demands. ASTs if build as windmills in river, has the ability to generate upto few Megawatt's to electrify several households. As big dams are a major problem in various parts, ASTs can be planned in such regions to meet the energy demands.

6. Potential of AST in North East India

North East India, the Gateway to the South East Asia is gifted with vast bio-diversified energy resources and is considered as the future power house of India. Among the natural resources present, hydro energy has a huge potential in this region. According to the Ministry of New and Renewable Energy, these four states (Assam, Arunachal Pradesh and Meghalaya and Sikkim) together have utilized only 165 MW of capacity till date, though they are capable of generating 1,900 MW, a figure that is nowhere close to the real potential of these states. The Central Electricity Authority (CEA) has identified 63,238 MW in the Brahmaputra river basin. Also, the North Eastern region occupies around 34% of the country's total water wealth [11]. Archimedes Screws, since do not require much higher heads, can be properly planned in this region to electrify the darker regions.

Table 1: Hydro power scenario in North-East India as on 31.3.2017 [19]

State	Potential (MW)	Installed Capacity (MW)	Capacity Under Construction (MW)
Arunachal Pradesh	50328	405	2854
Assam	680	375	0
Manipur	1784	105	0
Meghalaya	2394	282	40
Mizoram	2196	0	60
Nagaland	1574	75	0
Sikkim	4286	1965	1326
Tripura	15	0	0
Total	**58971**	**3207**	**4380**

Note:- In addition, a total of 4785.60 MW of PSS are in operation and 1080 MW of PSS are under construction in all over India

7. Costs and economics

Investment and revenue streams are necessary for any financial analysis. The three main points that should be taken into account when doing the cost/benefit evaluation for the Archimedean Screw are -**(a)** the installation costs, **(b)** the annual operational costs and **(c)** the annual income from the electricity produced [3,4,17].

According to results of study conducted by Sachin Mishra, S. K. Singal and D. K. Khatod in 2012 [17], the total investment required for the Archimedean Screw can be divided into two main cost components – (i) The Electro-mechanical costs, and (ii) Civil Engineering Grid Connection and Installation/Commissioning Costs. The electro-mechanical costs consist of the main machine components of the scheme. Apart from the screw itself it should also include the trough, generator, gearbox, screen and inlet sluice gate. As for the civil engineering costs these should cover project management and site supervision through to materials (for screw supporting structure) and plant (shuttering, swing shovel etc.). The electricity generated will be sold to an energy company under a power purchase agreement.

The parameters on which the civil and electromechanical costs depend are the installed capacity, water head and year of commissioning [17].

$$C_{(a,b,c)} = a \times P^{b} \times H^{c} \ldots\ldots\ldots\ldots (6)$$

Above eqn. is the basic cost equation for a small hydro project, where a, b and c are coefficients, C= Cost in rupees (Rs.), P = Installed capacity in kilo Watt (kW), and H = Head in meter (m). With rigorous experimental observations [17], the coefficients have been found giving the final cost equation as:

$$C = 6.882 \times P^{0.6369} \times H^{-0.0782} \ldots\ldots\ldots\ldots (7)$$

where, C = Cost per kW in Indian Rupees, P = Capacity in kW, H = Head in m. A maximum deviation of ±10% has been observed and the cost prediction can be done in the initial stage. A lower head requirement for ASG thus lowers the cost of building a hydro power plant.

The AST with compared to the other types of turbine can be very cost effective. Use of AST requires less maintenance work and also less installation period (2-3 months), thus decreasing the overall cost. Since AST's work at low heads, not much has to be spent in building high reservoirs. Also, the setup of an AST does not require many parts [3].

8. Conclusion

ASGs are a proven hydropower technology appropriate for low head sites. Specifically, ASGs provide a unique opportunity for the private sector, small dam operators, and individual landowners to utilize existing hydropower renewable energy, adding a new source of renewable power into the region's energy mix. ASGs can be developed without many of the environmental impacts that accompany large-scale hydropower developments since many of the needed dams already exist. Furthermore, retrofitting already existing dams with ASG units would help improve dam safety, helping to safeguard property, individuals, and the environment from negative impacts of dam failure. ASTs are now widely used turbines especially in Europe and have been started to install in the U.S.A also. The rural India's electrical scenario can be thus improved by the installation of these turbines by locating the specific sites. Remote sensing and GIS can be used to determine the various parameters of a region like terrain surface, slope etc. [8]. AST is an eco-friendly, marine animals friendly, and the most important of all is that it is human friendly. It is 'Human Friendly' in a sense that since there is no need of construction of dam, therefore there will be no floods which will ultimately save people's life. Moreover, it is cost effective as it requires less labour, low maintenance and construction costs. It is more reliable compared to other turbines like Kaplan turbine, Pelton turbine, Francis turbine, etc. and also it requires less civil work. The uniqueness of AST is that at same discharge head condition, power output and speed vary as well as head efficiency. AST in relation with rural area development is that it can fulfil the need of electricity requirement and it can light up the darkest corners of India. Rural areas can easily have access to power with the help of a only a small stream and this generated electricity can be used for domestic purpose and they can also do small business using machineries that requires less power consumption. For larger demands the AST's can be setup as windmills in river.Thus AST's have the full potential to electrify and develop India sustainably.

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