International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-2 Issue-2, January 2013

Electrical Characteristics of Micro-Hydro Power Plant Proposed in Valara Waterfall

Arun Varughese, Prawin Angel Michael

Abstract- ***The most important problem faced by a country like India is that of rural electrification. This paper proposes a permanent magnet synchronous generator (PMSG) based micro power plant, which is used for a standalone micro hydro power generation. The prime mover of the system is the hydraulic turbine, essentially a pelton wheel turbine in this proposed scheme. The power produced can be directly given to the load Centre, which is within 200 m radius of the generation site. In this paper we are considering a constant output power from the turbine system which drives the alternator. The detailed economic assessment of the power produced is also analyzed in this paper.***

Keywords- ***Hydro power, Permanent magnet synchronous generator, standalone power generation, water turbine.***

I. INTRODUCTION

The most serious problem faced by a country like India is the global warming and the serious power shortage faced by the country. Electricity is the most important commodity which is essential for any economy to survive. One of the most important and achievable method to produce electricity is to introduce a standalone electric power generation, using renewable resources [1]. The hydro power is an important resource which can be used to produce electricity, especially in the rural country side where there is no grid connectivity. In the proposed scheme a micro hydro power generation system is employed which produces 25kw power which can be used for rural electrificaton.This paper proposes a constant flow water stream whose energy is tapped by a hydraulic turbine which in turn act as the prime mover for the generator which produces the electricity.

A. System configuration

The outline of the system is shown in the figure-1.The hydraulic generator which converts the water power to mechanical power is fed with water from the 'forebay'.This special assembly not only protects the turbine assembly it also helps to have a constant water flow in the system[1].

There is also a valve system which can be used for the gate control of the hydraulic system. At hundred percentage of gate opening only we are able to produce the maximum power from the system. The provided machine energy by the hydraulic turbine is sent to the electrical system which is composed of a synchronous generator and power distribution assembly through a shaft. In the proposed paper we are using a natural waterfall in Valara, India which has a net head of over 100m and has a continuous water flow around the year. The Simulink model of the electric generation system of the micro hydro power generation system is shown in figure-3.

II. PENSTOCK DESIGN

The most important step in the design of system is the design of the penstock system. It is very important for optimally design the penstock so that the head losses occurring in the system due to the frictional losses and other losses are reduced to a considerable level [2]. In this paper we are using the Darcy's methodology to optimally design the penstock assembly. The method used in Darcy's methodology is trial and error. For the economic constrains of the penstock sizing is also considered in this paper. By the detailed analysis we found out that, as the penstock diameter is increased the losses are reduced.

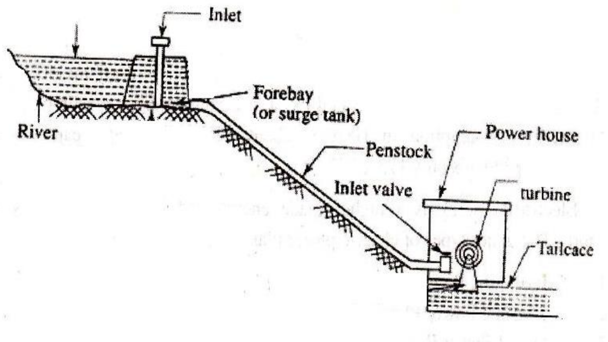

Figure-1. Outline of the system

The net effect of these losses is a reduction in the effective head of the system and so ultimately reduction of the water potential.

First consider the discharge of water in the site during last 10 years in Valara region.

Maximum discharge= 45.3 m^3 / sec

Average discharge=6.75 m^3 / sec

Minimum discharge= 0 m^3 / sec

For further design we are considering this average discharge rate

V= velocity in m/s

Reynolds No= $V*D*10^6$ (1)

D= diameter of penstock in m

Hf = (0.3164) / $Re^{0.25}$ (2)

Table-1. The head losses

Diameter of penstock (mm)	Head losses (m)
300	40.05

Manuscript published on 30 December 2012.
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325	27.51
350	19.31
400	10.26

It is to be noted that if the diameter of the penstock pipe is increased then the frictional loss are reduced drastically [3]. But the economy of the whole system is reduced, so we select the optimum diameter of 400mm. By keeping this important economical constrain in mind we are optimally selecting the diameter of the penstock system so that there is significant amount of water discharge without any high losses for power production , and also there is a good financial gain also due to optimal sizing of the penstock. The optimally designed penstock pipe carries enough water which is controlled using a control valve [3]. The gate opening characteristics of the turbine which is very important as far as the performance of machine is concerned is controlled using this penstock water control valve. In our proposed system we are selecting the optimal diameter of the penstock to be 400mm.

III. TURBINE SYSTEM

The hydraulic turbine is one of the most important aspects of the power system. Usually for high head systems we us the pelton turbine. In the proposed site a water head of around 100m is there. For these types of high head large discharge systems the pelton wheel turbine is the most suitable. The design of the turbine is as important as the selection of the turbine. For pelton turbines the diameter of the circle describing the buckets Centre line D (in m) is given by

D = (0.68*H*0.5)/n (3)

Where H is the net head (in m)

n is the speed of rotation (in rps)

The simulation model as shown in Figure-2 used to simulate the steady state output of the turbine for various gate positions. The output of turbine is 1.035 pu for 1.0 pu of gate opening. Besides the steady state simulation as stated above, the operation of turbine for other various operating condition is also simulated. It is assumed that machine is initially operating at 1.035 pu output corresponding 1.0 pu gate position. This is the mechanical power developed by the turbine system which is introduced to the generator system which ultimately produces the electricity [4].

The basic simulink model of the turbine can be formed by assuming a rigid conduit and incompressible fluid, the basic hydrodynamic equations are

$$U \propto GH^{\frac{1}{2}} \qquad (4)$$

$$Pm \propto HU \qquad (5)$$

Where,

U= velocity of water in penstock in m/sec

H = head.

Normalizing these above equations about the rated values

$$H = (U/G)^2 \qquad (6)$$

$$\frac{dU}{dt} = (1 - H + H_0) \times \frac{1}{Tw} \qquad (7)$$

Ideal gate opening (G) is related to real gate opening (g) as follows;

$$G = At \times g \qquad (8)$$

$$A_t = \frac{1}{gFL - gNL} \qquad (9)$$

Where,

A_t = turbine gain

g_{FL} = Gate Opening at full load

g_{NL} = Gate Opening at no load

H_0=loss of water in conduit length and Tw is the water starting time.

The gate opening in the turbine system must be controlled so to improve the safety and the S.O.R of the system [5].

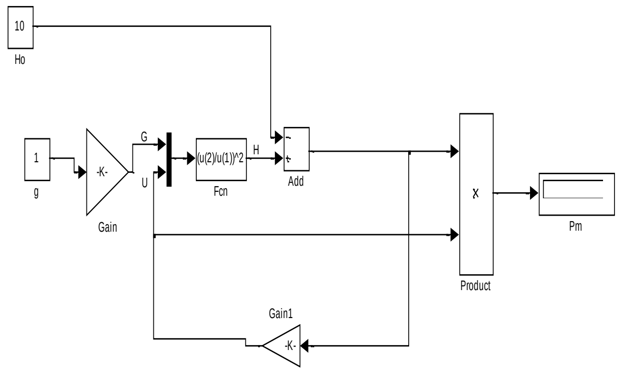

Figure-2.The Simulink model of turbine

IV. THE GENERATOR ASSEMBLY

The generator used in this paper to simulate the power production from a hydro power generator is a three phase synchoronous generator.The power produced by the generator can be used for two purposes,one is to store the excess power produced at off peak load time so that we can use in in peak load time otherwise we can directly give the supply to the load.

The electrical generator can be represented by two equations

$$\Delta\omega(t) = \frac{1}{2H} * \left(\int_0^t (Tm - Te)dt\right) - Kd\,\Delta\omega(t) \qquad (10)$$

$$\omega(t) = \Delta\omega(t) + \omega_0 \qquad (11)$$

Where Δω=speed variation with respect to speed of operation, H= Constant of inertia,

Tm= mechanical torque,

Te=Electromagnetic torque,

K_d= Damping factor representing the effect of damper winding.

ω(t)= Mechanical speed of rotor,

ω_0 = Speed of operation.

The optimal rating of the machine is selected by taking into account the water discharge and rated power rating of the turbine.

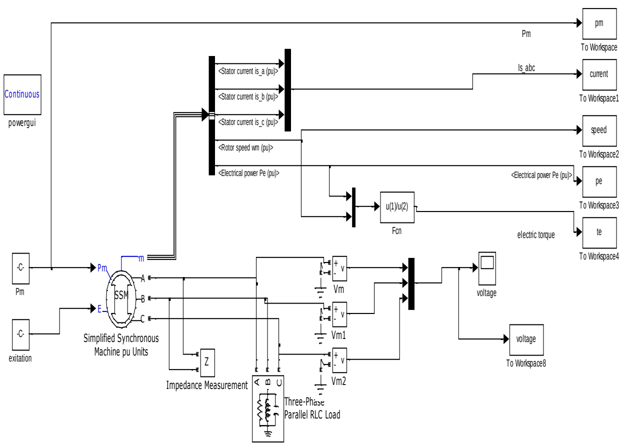

Figure-3. The simulink model of the generator

Published By:
Blue Eyes Intelligence Engineering
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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
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The machine used in the system is a standard 600rpm synchronous machine.We can also us an induction generator for the same purpose as it will be more stable in these type of variable soutrces.But the need of an reactive power source and the inferior performance of the induction generator makes the synchronous generator the automatic choise. An automatic voltage control device controls the field current to keep output voltage constant [6]. If the output voltage from the stationary armature coils drops due to an increase in demand, more current is fed into the rotating field coils through the voltage regulator (VR). This increases the magnetic field around the field coils which induces a greater voltage in the armature coils. Thus, the output voltage is brought back up to its original value [6].

V. THE SIMULATION RESULTS

The simulation result of the whole system is as shown in the figures.

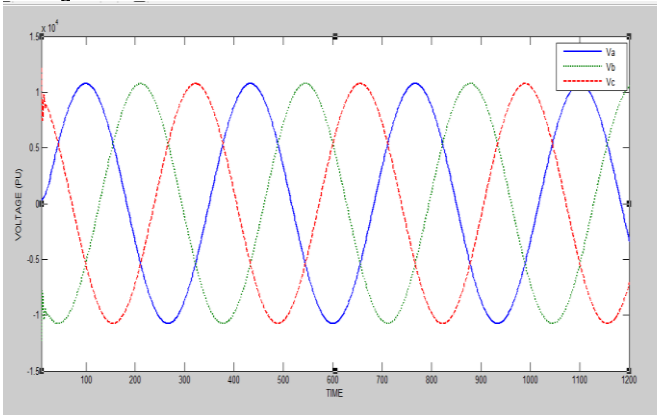

Figure-4. The output voltage

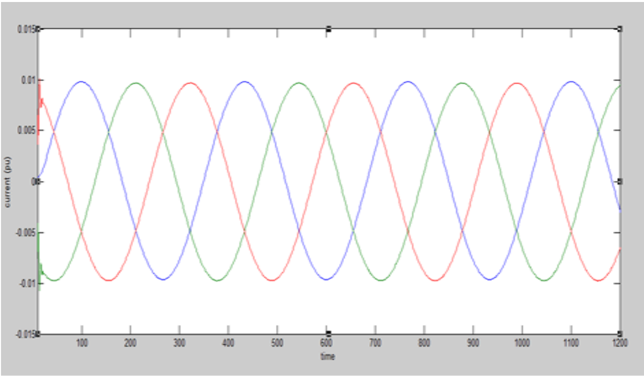

Figure-5. The output current of generator

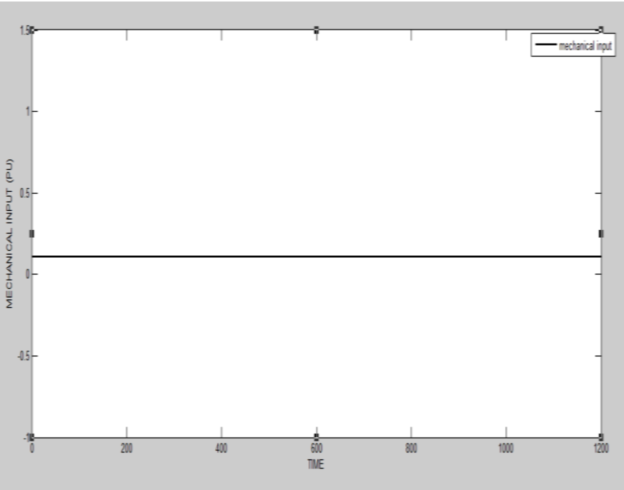

Figure-6. Mechanical output from turbine

From the Figure-4 and Figure-5 it is clear that the current and the voltage obtained from the generator is a perfect sinusoidal waveform. Due to that we are not conneccting any power conditioning circuits at the output side.Fig.6 shows the mechanical input to the generator.In this paper we are considering a constant output from the turbine.

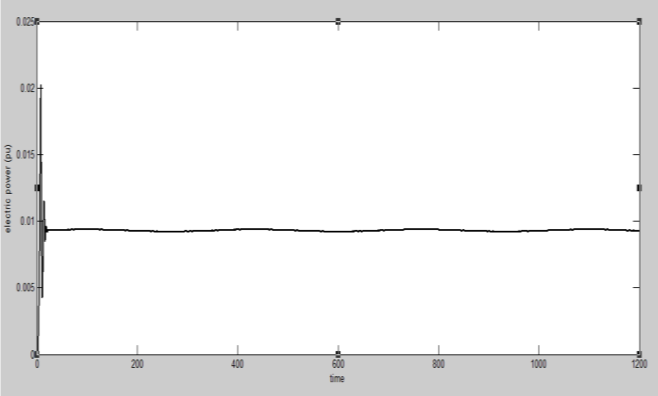

Figure-7. Electrical output power

Afer an initial transient condition the electrical power and torque generated will attain a constant stable value as shown in Figure-7 and Figure-8.For the easiness of simulation we considera constant load is connected across the system,in practical condition load will not be constant at any given time.

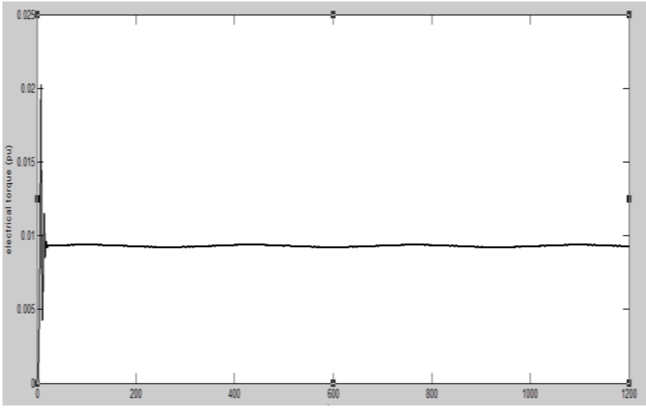

Figure-8. Electrical torque produced by generator

We have considered the water discharge and the velocity of the the stream and findout the optimal water potential of the water fall in the Valara waterfall.

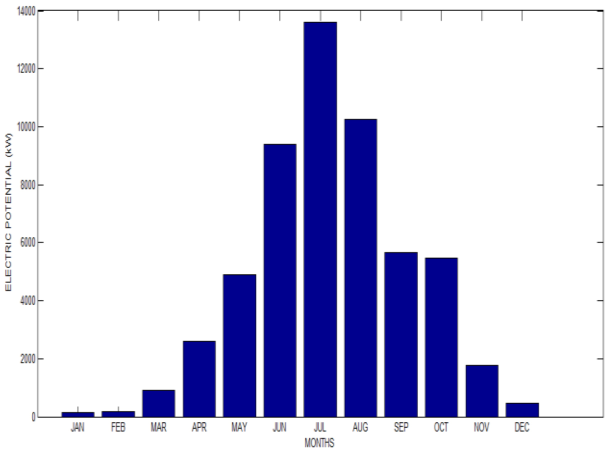

Figure-9. The average electric potential of the waterfall

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From the Figure-9 it is clear that, in the proposed site the water potential in any month of the year will be greater the the designed powe of 25kw.The power potential of the waterfall is directly depending upon the monsoon.During peak rainfall months the water potential is maximum and during off peak months it is significantly reduced.

VI. ENVIRONMENTAL AND ECONOMICAL IMPACT

This type of small hydro poweer plants are economically more sustainable and may cause less impact on environmment.Due to the simple construction and use of run-off water from the river directly the environmental imapcts are reduced considerably, also due to minimum construction works the ecconomy is also improved [7] .

Considering the full load condition the proposed generator produces around 600Kwh power daily which is aroud 0.05154 tonne of oil equallent daily.According to our estimation the system will save around 62 liters of diesel daily which means less pollution.The avoided cost of the fuel may constitute the fuel economy and this this avoided pollution is also considered as an economical advantage, it is also considered in the unit cost of power to be produced. Considering a modest plant load factor of 0.7 and effective plant life of 25 years we calaculated that we can produce and sell power at the rate of Rs1.10 per Kwh.This simple cost is very low considering other forms of power production.

When we consider any project the rate of return of the cost is very important.In the proposed scheme it is found that the rate of retun is around 4years and 10 months.Due to these staticitis we can infer that this proposed scheme is not only economically viable but also environmmentally friendly, which is the trade mark of a green project.The proposed scheme have not only environmental value, but also a socio-economical value also.The cheap poer produced from the generatorr can not only be cused for domestic lighting but also for other economical activites.

VII. CONCLUSTIONS

For a country like India, where is a deficit of electricity and grid connectivity the perfect answer for this power shortage is stand-alone power production. In most parts of India there is abundance of natural stream which can easily use to produce electricity. In relation to rural development, the simplicity and low relative cost of micro hydro systems open up new opportunities for some isolated communities in need of electricity. In this paper we are looking for a small hydro power plant which uses synchronous generator for power production. The power production was continuous and cheap and affordable power is generated. By considering all the technical aspects we can infer that the synchronous machine can be used effectively in these types of sources.

VIII. ACKNOWLEDGEMENT

First of all author like to thank the god almighty for showering his blessings which made us to complete this paper in time. Then author would like to thank the University chancellor Dr. Paul Dinakaran and all other University management for providing adequate infrastructure for completing this work. Then author would like to thank Dr E. J. James, the director of water institute, Karunya University for his timely help. Next author would like to thank The Institute of Water Technology and Management, Kozhikode which is a Government of Kerala research facility for providing us with the technical help and other logistical help for completing the field review and data acquisition. Then author would like to thank the local people of Valara village for helping us to conduct the field review and electrical load calculation. Last but not least, would like to thank all our collies and friends who helped us and motivated us to complete us to do this work.

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