Modeling and Design of Smart Frequency Controller for Isolated Small HydroPower Plant

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Abstract

This paper describes the application of a stepper motor with PI controller in controlling the frequency of aisolated small hydropower plant. The frequencies of the existing small hydropower plants are controlled by mechanical governors. Unfortunately, these governors are expensive, complex and slow in response. Furthermore, the governors do not act fast enough during wide range load changes. In this paper, a stepper motor with PI controller which is cheap, fast, easy to control and less complexes used to control the frequency of a small hydropower plant. The stepper motor is used to rotate a spear valve which in turn controls the flow of water into the turbine of a small hydropower plant. The position of the stepper motor is controlled by a PI controller. Thus, a frequency control system forsmall hydropower plant using a stepper motor with PI controller is modeled, designed and simulated by MAT lab-Simulink software. Simulation results for small hydropower plant with Low Head capacity is demonstrate that transient and steady state performances are enhanced by replacing mechanical governors with stepper motors PI controller.

Keywords: *Frequency Controller, Small Hydro Power Plant, Stepper motor, PI Controller.*

I. INTRODUCTION

Internationally, “small” hydro power plant capacities typically range in size from 1 MW to 50 MW. Most of the rural part of world is not yet electrified. Unfortunately, it is not feasible both technically and cost wise to extend the national grid to isolated rural communities. As the current international trend in rural electrification is to utilize renewable energy resources, because of their matured technology and reasonable construction costs of small hydropower systems have become paramount. So many countries are naturally endowed with several small and medium sized rivers which can be exploited for the development of small hydropower systems. However, this vast renewable energy resource is not yet exploited sufficiently for electric generation.

One of the challenges in developing small hydropower plants is the control system. The control system should be cost effective, less complex, and more reliable, similar to that of large power plants, the voltages and frequency of small hydropower plants should be kept within permissible limits. To keep these parameters within permissible limits, the small hydropower plants should be controlled.

In a power system, usually, voltage and frequency are controlled separately. Voltage is maintained by control of reactive power of the synchronous generator. Most commercial synchronous generators have built-in automatic voltage regulators. Hence, there is no need for the design of the voltage control system in isolated small hydropower plants. Thus, designing the control systems of isolated small hydropower plants imply only the designs of the frequency control systems. The frequency of a small hydropower system exclusively depends on real power balance. The balance between generation and demand is achieved in two different ways by controlling either the mechanical input power or frequency.

Recently, because of their cost, complexity, slow response, heavy maintenance, and problems in accepting wide range load changes, traditional governors are not applicable to isolated small hydropower plants. DC servo motors with spear valves are being used in frequency control of isolated small hydropower plants.

Stepper motor with spear valve is used to achieve automatic generation control. Employing the stepper motor with PI controller has made the control system less complex, less expensive and more reliable. On the other hand, servo motor governors are not suited to the frequency control of isolated small hydropower plants. Generally, automatic load control is used in these systems. Electrical loads change randomly. It is possible to compensate the change in the electrical load, consequently the change in frequency, using system loads. If a load is increased (or decreased) in the small hydropower plants, the same amount of load will be removed (or accepted) from the system load so that the total load connected to the synchronous generator remains constant. This is known as automatic load control. Thus, in this paper, a frequency controller that avoids the problems associated with conventional speed governors is modeled and designed.

II. SMALL HYDRO POWER PLANT &NEED OF LOAD FREQUENCY CONTROL

A. *Small Hydro Power Plant*

Small hydropower systems are used to electrify residential homes, cottages, ranches, lodges, parks, factory, industries and small communities. They can also be connected to the grid system. Development of small hydropower plants requires the construction of diversion weirs, power canals, fore bays, penstocks and tail races. It also requires selection of the proper turbines and synchronous generators. Moreover, the control systems, the transmission lines, and the distribution systems should be designed. In general, there are some many key advantages that small hydro has over wind, wave and solar power plants.

The power available is proportional to the product of head and flow rate. The general formula for any hydro system's power output is

$$P = QHg\eta r \quad \text{KW}$$

B. *Need of Load Frequency Control*

Frequency stability can be defined as, the ability of power system to maintain steady frequency within an acceptable range (0.5%). It depends on the ability to keep the balance between a generated power and load demand, with minimum loss of load. A control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values. The frequency of a system is dependent on active power balance. As frequency is a common factor throughout the system, a change in active power demand at one point is reflected throughout the system.so that there is need of Modeling and design of Smart Frequency Controller for isolated Small Hydropower Plant.

C. *Stepper Motor*

A stepper motor is a motor with a rotating, armature magnetic field. The field is made to rotate through electronic switches. Stepping motors fill a unique niche in the motor control world. These motors are commonly used in measurement and control applications. Sample applications include ink jet printers, machines and volumetric pumps. A stepper motor transforms digital pulses into mechanical shaft rotation. It is less expensive, more reliable, and less complex. It operates in almost any environment and produces high torque at low speeds. These advantages are exploited to control a spear valve that controls the flow of water into the turbine of a small hydropower plant.

D. *Frequency controller scheme*

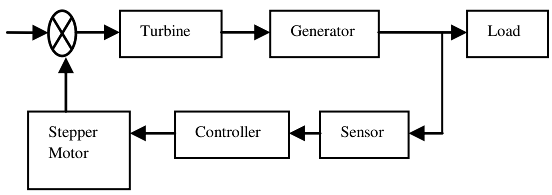

Figure1. Frequency control scheme of small HPs

III. Modeling of Small Hydro Power Plant

The first step in the analysis and design of the control system of small hydropower plants is mathematical modeling of the different components. The transfer function method is widely used in designing control systems.After proper assumptions and approximations are made to linear the mathematical equations describing the components, transfer functions are obtained. Thus, using these transfer functions, the small hydropower plants are modeled for load and flow control.

A. *Modeling the Synchronous Generator*

The model of the synchronous generator is derived from the swing equation. The swing equation states that the net torque, which causes acceleration or deceleration of the rotor of the synchronous generator, is the difference between the electromagnetic torque and mechanical torque applied to the generator. The net torque is the product of the moment of inertia of the rotor and its couples, and the angular acceleration of the rotor. And the swing equation dynamics of synchronous generator is under normal condition the relative position of rotor axis and resulting magnetic field axis is fixed. The angle between rotor axis and field axis is called power angle/torque angle. During any disturbance the rotor may accelerate/decelerate with respect to synchronously rotating machine. The equation describe this relative motion is known as Swing equation. Under steady state operation and neglecting loss

$$T_m = T_e$$

The difference of the two gives acceleration torque (Ta)

$$T_a = T_m = T_e$$

$$\text{Where} \quad T_{e=}\frac{Pe}{\omega e}$$

$$T_{m=}\frac{P_m}{\omega_m}, T_{a=}J\frac{d^2\theta m}{dt^2}$$

By substitution

$$J\frac{d^2\theta m}{dt^2} = \frac{P_m}{\omega_m} - \frac{P_e}{\omega_m}$$

Multiply aboveequation by ω_m

$$J\omega_m\frac{d^2\theta m}{dt^2} = \omega_m\frac{P_m}{\omega_m} - \omega_m\frac{P_e}{\omega_m}$$

$$J\frac{d^2\theta m}{dt^2} = T_m - T_e$$

Where J is the combined moment of inertia of the generator and the prime-mover [kg], θm is the angular displacement of the rotor in mechanical radian, Tm is the mechanical torque in N.m, Te is the electromagnetic torque in N.m, and t is time in seconds. The angular displacement of the rotor of the synchronous generator and prime-mover of the turbine is given by:

Thus,

$$\theta_m = \omega_{sm}t + \delta_m$$

Where, θm is rated angular velocity of the rotor in mechanical radians per sec, and δ_m is the angular displacement of the rotor with respect to the rotating magnetic field of the synchronous generator.

Double derivation the above equation yields:

$$\frac{d^2\theta_m}{dt^2} = 0 + \frac{d^2\delta_m}{dt^2}$$

$$\frac{d^2\theta_m}{dt^2} = \frac{d^2\delta_m}{dt^2}\ \frac{\delta_m}{d}$$

Where $\frac{\delta_m}{d}$ is change in speed $\Delta\omega$ and $\frac{\theta_m}{d}$ is the Angular acceleration of the rotor.

The equation above can be re written as

$$J\omega_m \frac{d^2\delta_m}{dt^2} = P_m - P_e$$

$$J\omega_m \frac{d^2\delta_m}{dt^2} = T_m - P_e$$

The angular momentum (M) = Jω

$$M \frac{d^2\delta_m}{dt^2} = P_m - P_e$$

It is convenient to write swing equation in terms of electrical power.

Electrical power angle δ is related to mechanical power angle δm by:

$$\delta_e = \frac{P}{2}\delta_m$$

Where p is number of pole

The swing equation can be

$$M \frac{2}{P}\frac{d^2\delta_e}{dt^2} = P_m - P_e$$

The per unit inertia (H) is defined as the kinetic energy in watt-seconds at rated speed divided by the rated volt-ampere, S base (G). Thus, using denote rated angular velocity in mechanical radians per second, the per unit inertia constant is mathematically,

$$H = \frac{K.E}{G} = \frac{K.E}{S_{base}}, K.E = \frac{1}{2}J\omega^2 = \frac{1}{2}J\omega * \omega$$

Where, J=momentum of inertia and angular momentum (M) =Jω therefore,

$$H = \frac{\frac{1}{2}M\omega}{G} = \frac{1}{2}\frac{J\omega^2{}_{m0}}{(S_{base})}\left[\frac{MJ}{MVA}\right] = \left[\frac{MWhr}{MVA}\right]$$

Equation is normalized in terms of the per unit inertia constant H and solving Equation together and rearranging, the expression in Equation is obtained

$$\frac{2H}{\omega_{m0}}\frac{d^2\delta_m}{dt^2} = \frac{Tm - Te}{\frac{Sbase}{\omega_{m0}}}.$$

Equation can be simplified to

$$\frac{2H}{\omega_{m0}}\frac{d^2\delta_m}{dt^2} = \frac{Tm - Te}{S_{base}}$$

Where *Pm* is the mechanical input power to the synchronous generator and *Pe* is the electrical power generated by the same generator.

Thus, the swing Equation in per unit is

$$\frac{2H}{\omega_{m0}}\frac{d^2\delta_m}{dt^2} = P_{m-P_e}$$

$$\frac{2H}{\pi f}\frac{d^2\delta}{dt^2} = P_{m-P_e}$$

From the network equation we have

$$P_e = P_{\max}\sin(\delta)$$

Where ωo = 0.5 pωm is the synchronous angular velocity of the rotor in electrical rad/s, p is number of poles and δ = 0.5 p δm is angular displacement in electrical radians.

When there is a load change in the small hydropower plants, it is reflected as a change in electrical torque output of the synchronous generator. This introduces a mismatch between the mechanical and electrical torques and thus accelerating or decelerating the rotor of the synchronous generator. This in turn results in the deviation of the frequency of the small hydropower system from its nominal value.

For small deviations (denoted by Δ) from initial values, the mechanical power, the electrical power, and the rotor angle are given by

$$P_m = P_{m0} + \Delta P_m$$

$$P_e = P_{e0} + \Delta Pe$$

$$\delta = \delta_0 + \Delta\delta$$

Where δ - is rotor angle after perturbation

δo -is initial rotor angle and

Δδ - is change in rotor angle due to perturbation

Substituting the expressions in Equation into the swing equation

$$\frac{2H}{\omega_0}\frac{d^2(\delta_0 + \Delta\delta)}{dt^2} = P_{m0} + \Delta P_m - P_{e0} - \Delta P_e$$

Applying the rules of calculus to Equation and simplifying results in

$$\frac{2H}{\omega_0}\frac{d^2(\Delta\delta)}{dt^2} = \Delta P_m - \Delta P_e$$

Or in terms of small perturbations in speed,

$$2H\frac{d\left(\frac{\Delta\omega}{\omega_0}\right)}{dt} = \Delta P_m - \Delta P_e$$

With the speed expressed in per unit and without explicit per unit notation, the swing equation is modified to Equation.

$$2H\frac{d\Delta\omega}{dt} = \Delta P_m - \Delta P_e$$

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}\left(\Delta P_m - \Delta P_e\right)$$

Taking the Laplace transform of Equation

$$\Delta\omega(s) = \frac{1}{2H_s}\left[\Delta P_m(s) - \Delta P_e(s)\right]$$

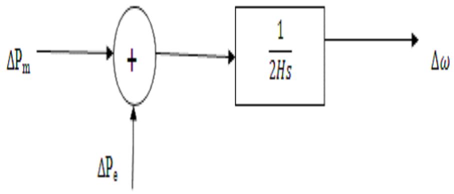

Figure2.Model diagram of a synchronous generator

B. *Modeling the Hydraulic Turbine*

In small hydropower plants, hydraulic turbines are used to drive synchronous generators. These hydraulic turbines convert the energy of flowing water into mechanical energy which in turn is converted into electrical energy.

The representation of the hydraulic turbine and water column in stability studies is usually based on the following assumptions:-

- The hydraulic resistance is negligible.
- The velocity of the water varies directly with the gate opening and with the square root of the net head.
- The turbine output power is proportional to the product of head and volume flow.

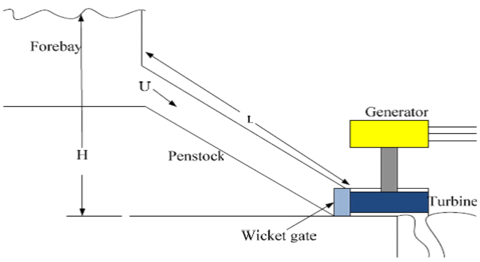

Figure 3.shows the essential parts of a typical small hydraulic plant.

The turbine and penstock characteristic are determined by three basic equations relating to the following:

a) Velocity of water in the penstock

b) Turbine mechanical power

c) Acceleration of water column

The velocity of water in the penstock is given by

$$U = K_u G\sqrt{H}$$

Where

U=water velocity

G=gate position

H=hydraulic head at gate

Ku=a constant of proportionality

For small displacements about an operating point,

$$\Delta U = \frac{\partial U}{\partial H}\Delta H + \frac{\partial U}{\partial H}\Delta G$$

Substituting the appropriate expressions for the partial derivatives and dividing through by

$$U_0 = K_u G_0\sqrt{H}$$

$$\Delta\overline{U} = \frac{1}{2}\Delta\overline{H} + \Delta\overline{G}$$

Where, the subscript 0 denotes initial steady-state values, the prefix Δ denotes small deviation.

The turbine mechanical power is proportional to the product of pressure and flow; hence,

$$P_m = K_p HU$$

Linear zing by considering small displacements, and normalizing by dividing both sides by

$$P_{m0} = K_p H_0 U_0$$

Substituting for $\Delta\bar{U}$ yields

$$\Delta P_m = 1.5\Delta\overline{H} + \Delta\overline{G}$$

Alternatively, by substituting for ΔH from equation we may write

$$\Delta P_m = 3\Delta\overline{H} + 2\Delta\overline{G}$$

The acceleration of water column due to change in head at the turbine, characterized by Newton's second law of motion, may be expressed as

$$\rho LA\frac{d\Delta U}{dt} = -A(\rho a_g)\Delta H$$

Where,

L=length of conduit

A=pipe area

ρ=mass density

ag=acceleration due to gravity

ρLA=mass of water in the conduit

ρagΔH=incremental change in pressure at turbine gate

t=time in second

By dividing both sides by $a_g H_o U_o$, the acceleration equation in normalized form becomes

$$\frac{LU_0}{a_g H_0}\frac{d}{dt}\left(\frac{\Delta U}{U_0}\right) = -\frac{\Delta H}{H_0}$$

$$T_W\frac{d\Delta\overline{U}}{dt} = \Delta\overline{H}$$

Where by definition,

$$T_W = \frac{LU_0}{a_g H_0}$$

Here Tw is referred to as the water starting time. It represents the time required for a head H_o to accelerate the water in the penstock from standstill to the velocity U_o. It should be noted that T_w varies with load. Typically Tw at full load lies between 0.5s and 4.0s.

Above Equation represents an important characteristic of the hydraulic plant. A descriptive explanation of the equation is that if back pressure is applied at the end of the penstock by closing the gate, then the water in the penstock will decelerate. That is, if there is a positive pressure change, there will be a negative acceleration change.

From above equations we can express the relationship between change in velocity and change in gate position as

$$T_W \frac{d\Delta\overline{U}}{dt} = 2\left(\Delta\overline{G} - \Delta\overline{U}\right)$$

Replacing d⁄dt with the Laplace operator s, we may write

$$T_W s\Delta\overline{U} = 2\left(\Delta\overline{G} - \Delta\overline{U}\right)$$

Or

$$\Delta\overline{U} = \frac{1}{1+\frac{1}{2}T_W s}\Delta\overline{G}$$

Substituting for $\Delta\bar{U}$ from equation and rearranging, we obtain

$$\frac{\Delta P_m}{\Delta G} = \frac{1 - T_W s}{1 + 0.5 T_W s}$$

From above Equation represents the classical transfer function of a hydraulic turbine. It shows how the turbine power output changes in response to a change in gate opening or an ideal lossless turbine.

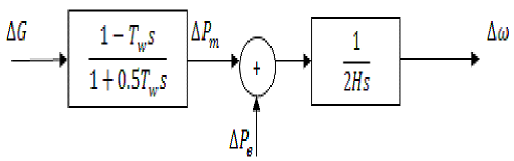

Figure 4. Block diagram of a hydraulic turbine and a generator

C. *Modeling the Load*

As depicted in Figure 1. the electrical load connected to the synchronous generator is of consumer load. The change in the total electrical load is due to changes in the consumer load.

$$\Delta P_e = \Delta P_{CL}$$

Where, ΔP_{CL} is change in consumer load.

The consumer load on a small hydropower pants consists of various types of electrical devices. Generally, the consumer load can be divided into two: non-frequency sensitive and frequency sensitive loads. Loads such as lighting and heating are independent of frequency whereas motor loads are sensitive to changes in frequency. How a load is sensitive to frequency depends on the composite of the speed-load characteristics of all the driven devices.

The speed load characteristic of a composite load is given

$$\Delta P_{CL} = \Delta P_L + D\Delta\omega$$

Where Δ and DΔare non-frequency-sensitive and frequency sensitive load changes in the consumer load respectively. D is the load damping constant and is expressed as percent change in load divided by percent change in frequency.

Substituting above Equation we have

$$\Delta\omega(S) = \frac{1}{2HS}\left[\Delta P_m(s) - \Delta P_L(S) - D\Delta\omega(S)\right]$$

The above equation is simplified as

$$\Delta\omega(S) = \frac{1}{2HS}\left[\Delta P_m(s) - \Delta P_L(S)\right]$$

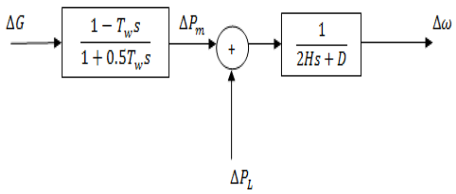

Figure 5.Modeldiagram ofTurbine, generator and load

D. *Modeling the load controller (PI controller)*

The load controller is modeled in the same way the governors of medium and large scale hydropower systems are modeled. Therefore, understanding the principle of operation of mechanical or electronic hydraulic governors is crucial. In medium or large scale hydropower systems, governors are designed to permit the speed to drop as the load is increased. The steady-state characteristic of such a governor is shown in figure6.below

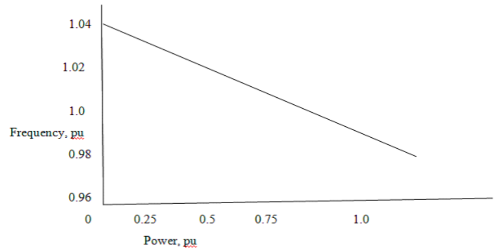

Figure 6.Governor steady-state speed characteristics

The slope of the curve represents the speed regulation R (usually 5 to 6%) and the input of the governor action is

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega$$

Where $\Delta P_{ref}$is the Load reference set point. In s-domain,

$$\Delta P_g(S) = \Delta P_{ref}(S) - \frac{1}{R}\Delta\omega(S)$$

To eliminate frequency error, a reset action is given to the load reference setting through an integral controller to change the speed set point.

Thus, Equation becomes

$$\Delta P_g(S) = \frac{-K_I}{S}\Delta\omega(S) - \frac{1}{R}\Delta\omega(S)$$

Where $K_I$is an integral constant.

The second term in Equation is similar to a proportional controller. Hence, Equation is obtained.

$$\Delta P_g(S) = \frac{-K_I}{S}\Delta\omega(S) - K_P\Delta\omega(S)$$

$$\Delta P_g(S) = \Delta\omega(S)\left(\frac{K_I}{S} + K_P\right)$$

Where = 1/R is speed regulation

The governor action is similar to the switching, in binary and phase delay load configuration, and the DC motor, in mechanical load configuration. Therefore, it is concluded that the load controller is approximated by a PI controller.

E. Modeling the stepper motor

A permanent magnet stepper motor is used in controlling the spear valve of a small hydropower system. The mechanical part of the permanent magnet stepper motor model can be expressed by

$$J\frac{d^2\theta}{dt^2} + D\frac{d\theta}{dt} + N_r n\phi_M i_A \sin(N_r\theta) +$$
$$N_r n\phi_M i_B \sin(N_r(\theta-\lambda)) + C\sin\left(\frac{d\theta}{dt}\right) + T_L = 0$$

This equation is the complete model of the permanent magnet stepping motor consists of the rotor dynamic equation.

where *J* is the moment of rotor inertia (*Kg.m2*), *D* is the viscous damping coefficient (*N.m.s.rad1*),*C*is the coulomb friction coefficient, *iB*, *iA*are the currents in windings *A* and *B*, *Nr* is the number of the rotor teeth, nΦM is the flux linkage, Θ is the rotational angle of the rotor and λ is the tooth pitch in radians and $T_L$is the load torque. On the other hand, the electrical part of a permanent magnet stepper motor model is described by voltage equations for the stator windings.

$$V - ri_A - L\frac{di_A}{dt} - M\frac{di_B}{dt} - \frac{d}{dt}\left(n\phi_M\cos(N_r\theta)\right) = 0$$

$$V - ri_A - L\frac{di_A}{dt} - M\frac{di_B}{dt} - \frac{d}{dt}\left(n\phi_M\cos(N_r(\theta-\lambda))\right) = 0$$

These two equations are differential equations for current equation. Where *V* is the DC terminal voltage supplied to the stator windings (volt), *L* denotes the self-inductance of each stator phase (*mH*), *M* represents the mutual inductance between phases (*mH*) and *r* is stator circuit resistance (*ohm).* Those equations are nonlinear differential equations. Since it is very difficult to deal with nonlinear differential equations analytically, linearization is needed.

The equilibrium position of the stator is Θ=λ/2. When both motor windings will differentiate by δΘ therefore, is Θ=λ/2+ δΘ. Then the nonlinearities expressed by sine and cosine functions in equations of the above will be approximated with knowledge of trigonometric identities and when NrδΘ is small angle:cos(NrδΘ)=1 and sin(NrδΘ)= NrδΘ. Then, the linearized model can be expressed by

$$J\frac{d^2\theta}{dt^2} + D\frac{d\theta}{dt} + 2N^2{}_r n\phi_M i_0\cos\left(\frac{N_{r\lambda}}{2}\right)\theta\delta +$$
$$N_r n\phi_M i_B\sin\left(\left(\frac{N_{r\lambda}}{2}\right)(\delta i_A - \delta i_B)\right) + C\sin\left(\frac{d\theta}{dt}\right) = 0$$

$$r\delta i_A + L\frac{d\delta i_A}{dt} + M\frac{d\delta i_B}{dt} - N_r n\phi_M\sin\left(\frac{N_{r\lambda}}{2}\right)\left(\frac{d\theta}{dt}\right) = 0$$

Where, cos(Nrλ\2) and sin(Nrλ\2) are constants.

The permanent magnet stepping motor transfer function is derived from equations of above are with the aid of Laplace transform. The coulomb friction coefficient *C* is considered to be zero.

The resulting form of the transfer function in two-phase excitation is:

$$\frac{\theta_0}{\theta_i} = \frac{\frac{r}{L}\omega^2 np}{S^3 + \left(\frac{r}{I_P} + \frac{D}{J}\right)S^2 + \left(\frac{rD}{L_{PJ}}\omega^2 np(1+K_P)\right)S + \left(\frac{r}{I_P}\right)\omega^2 np}$$
$$= G_P(S)$$

Where: $L_P = L - M, \omega^2 np = \dfrac{2N^2 rn\phi MI_0\cos\left(\frac{N_r\lambda}{2}\right)}{J}$

$$K_P = \frac{n\phi_M\sin^2\left(\frac{N_r\lambda}{2}\right)}{I_P I_0\cos\left(\frac{N_r\lambda}{2}\right)}$$

Neglecting the higher orders of the transfer function it can be simplified to the equation shown below. The transfer function model of the stepper motor is required. The transfer function between the desired and the output angle of a permanent magnet stepper motor is given by

$$\frac{\theta_0(S)}{\theta_i(S)} = T(S) = \frac{K_m I_P N_r}{Js^2 + \beta s + K_m I_P N_r}$$

where Θ_o is the output angle, Θ_i is the desired angle, J is the moment of inertia of the rotor, K_m is the torque constant of the permanent magnet stepper motor, I_p is the phase current,

N_r is the number of rotor teeth, and ʙ is viscous friction coefficient. The stepper motor is controlled by a controller. The controller calculates the deviation in the desired angle based on the frequency deviation in the small hydropower system. Here the controller is assumed to be proportional integral controller similar to the load controller.

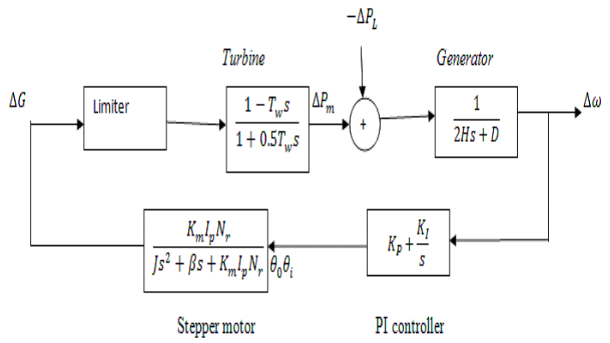

Figure 7.Complete model of a small hydropower plants

IV. Design and Analysis of the Control System

The frequency controller system is flow control mode. The flow control mode is applied to the frequency control of small hydropower systems

A. *Generator selection*

A synchronous generator with the specifications in Table1is selected, Based on the specifications, the inertia constant (H) of the rotor of the synchronous generator and turbine coupled together is calculated. Assuming the overall efficiency of the turbine and generator to be 80%, the moment of inertia of the rotor of the synchronous generator and its couples is calculated. Since the mechanical power of the prime mover is 196 kW, the moment of inertia becomes and S_{base}=225KVA, Ns=1500r.p.m, J=15.889Kg.m^2, H=0.87Sec.

Parameter	Value
Current rating	888A
The moment of inertia	3 kgm2
Power factor	0.8
Load damping coefficient	1.5%
Power rating	225kvA
Voltage rating	400 v
Speed	1500rpm
Number of pole	4

Table 1. Specifications of 1FC2-283-4 synchronous generator

B. *Stepper motor selection*

A stepper motor with the specifications in Table 2 is selected. The transfer function between the input and output angles of the stepper motor is given by From the table rated current 6.5A, steep angle 1.8 degree, number of rotor teeth=50

Parameter	Value
Model	43HS2A165-654
Number of teeth (Nr)	50
Rated phase current	6.5A
Phase resistance	0.65ohm
Phase inductance	14mH
Lead wire	4
Weight	11kg
Holding torque	26.0Nm
Step angle	1.8o
Inertia constant	0.0013kg-m2
Torque constant	4 N-m/A
Viscous friction constant(assume)	0.5N-m/rad/sec

Table 2. Stepper motor specifications

C. *Water starting time of turbine*

The water starting time is calculated by

$$T_W = \frac{LU_0}{gH_0}$$

Some assumptions should be taken to determine the water starting time. Table 3 Assumptions taken in calculating water starting time.

Parameter	Value
Penstock length	5m
Head height (Ho)	5m
Initial speed of water(Uo)	9.9m/sec
Acceleration due to gravity (g)	9.8m/sec

Table 3. Assumptions taken in calculating water starting time

The water starting times are Tw= 1.0sec, Tw =2.5 sec and Tw= 4.0sec for low, medium and high head small hydropower plants respectively.

D. *PI Controller*

There are different techniques of tuning PI controller are tested for determining the parameters of these controllers have been developed during past 60 years. Although most of these methods provide acceptable performances for some transfer functions of the systems, there is not a general method for tuning the parameters of these controllers, such as the refined Ziegler-Nichols method, pole-zero cancellation method, and MOCM performance criteria have been proposed to improve the performance of control systems which especially have a time delay. From these methods the

Ziegler-Nichols (ZN) method which is still widely used in industries for tuning because it gives a high overshoot and a long settling time.

Ziegler-Nichols tuning rule:

Ziegler-Nichols tuning rule was the first such effort to provide a practical approach to tune a PI controller. According to the rule, a PI controller is tuned by firstly setting it to the P-only mode but Adjusting the gain to make the control system in continuous oscillation. The corresponding gain is referred to as the ultimate gain (Ku) and the oscillation period is termed as the ultimate period (Pu). Then, the PI controller parameters are determined from Ku and Pu the Ziegler-Nichols tuning table.

Controller	K_p	T_i
P	1/a	--
PI	0.9/a	3L

Table 4. Tuning of PI controller Parameter according to Z-N Tuning

The most employed PI design technique used in the industry is the Ziegler–Nichols method, which avoids the need for a model of the plant to be controlled and relies solely on the step response of the plant. The main features of PI controllers are the capacity to eliminate steady-state error of the response to a step reference signal because of integral action and the ability to anticipate output changes when derivative action is employed and it provides the steady state error to zero. the approximate parameters are a = 0.9 and L = 0.042 so that the proportional 1 and integral gain constant is 0.125 each. After plugging the values of the proportional and integral gains, the block diagram is obtained:

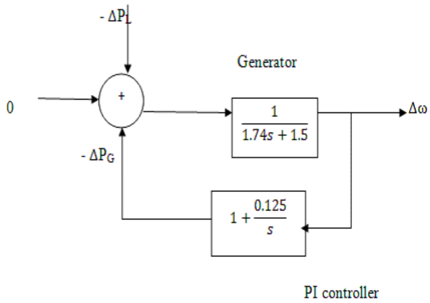

Figure 8. Model of a PI controller

V. SIMULATION RESULTS AND ANALYSIS

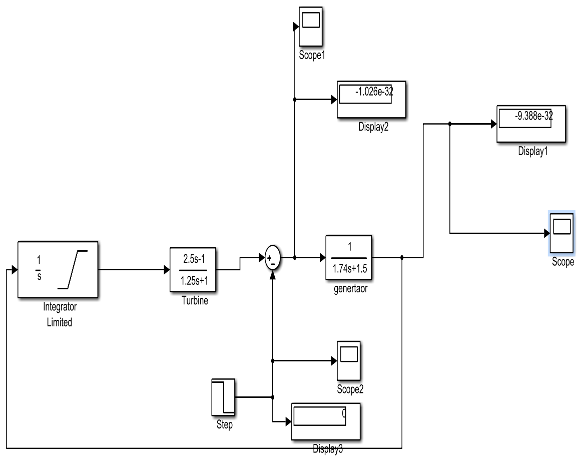

Figure9. Simulationmodel of a small hydropower plants without controllers

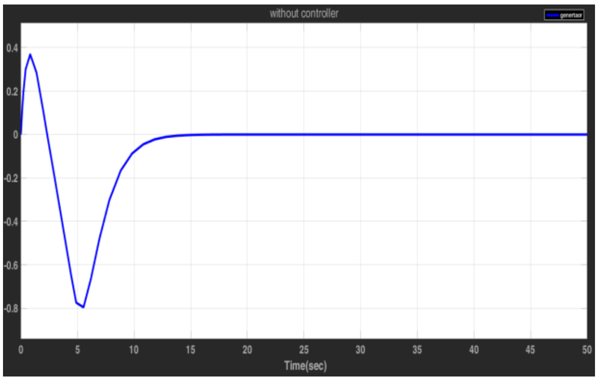

Figure 10.Simulation result without controller

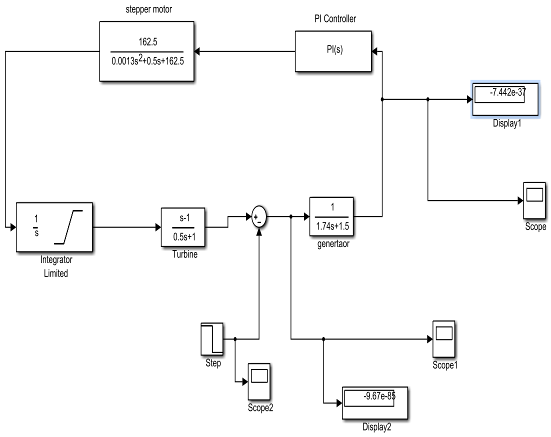

Figure11. Simulation model of a small hydropower plants with PI controllers

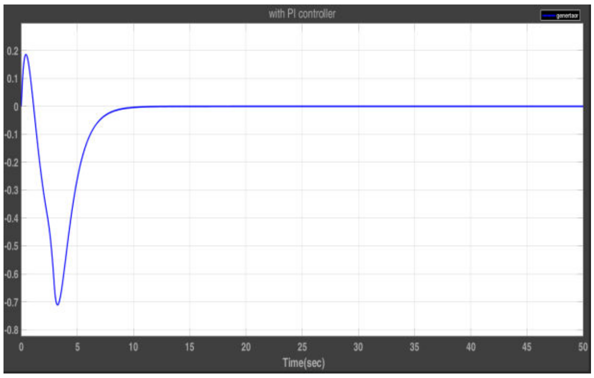

Figure12. Simulation result with PI controller of small hydro power

The step response of the frequency deviation of a 1492 kW, low head, and small hydropower plant for a 3% load change with and without controller is shown in Fig 10& 12. From the figure, it is seen that the small hydro power plant is stable and the steady-state frequency deviation is eliminated with the help of the PI controller.

VI. CONCLUSION

In this paper a novel alternative controller for load frequency control in an isolated Small Hydro Power Plant was proposed. Comparisonsbetween the stepresponses of frequencies changes for a 3% loadwere illustrated by with and without Controller.Small hydro power plantthat are one of the earliest known renewable energy sources have a significant role in the economic-social development of countries and they have found special importance due to their relatively low administrative and executive costs, and short constructiontime compared to other hydro power plant.

Themathematical model of a small hydro power plantis fundamental importance to understand physical system. In this paper, a control model on PI controller of a small hydro power plant has been proposed to overcome the disadvantages of the existing small hydropower plants which are controlled by mechanical governors, evaluate the performance, such as the rise time, overshoot, settling time, etc. Its effectiveness and practicability are tested and verified with simulations results in MAT lab-Simulink.

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