Simulation for Speed Control of the Small Hydro Power Plant Using PID Controllers

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ABSTRACT: Power is a vital infrastructure input for the growth and development of any country. With change in environment, power generation method should be taken care. There various sources of energy renewable and non renewable. Though renewable source are easy source i.e. they are readily available everywhere, don't depends on the climatic condition, but major drawback is it can be replenished. So, country are now focused toward the renewable source like wind, water, solar etc. hydropower here play a important role as renewable and convectional resource. Hydro power is further divide into; large hydro, medium hydro, small hydro and micro hydro. From all the design small hydro are now in main concern. The small hydro power are easy to construct and built on run off river. Since the speed of water is variable, the speed of the system need to controlled to make the system supply frequency constant. This can ne done by a properly designed hydraulic governing system.

KEYWORDS: PID Governing system, PID servosystem, Turbine system, Small hydro power

I.INTRODUCTION

Hydro power are now playing a vital energy resource for the fulfillment of power required for the growth and development of the country. It a pollution free, renewable and environmental friendly source of energy. Hydropower represents use of water resources towards inflation free energy due to absence of fuel cost with mature technology characterized by highest prime moving efficiency and spectacular operational flexibility.
Constructing hydroelectric dam across a the water flow is the most common method of using energy from a water, where this water flows to turbine and cause its rotation and the energy is captured to drive a generator. There a different type of hydro power plant i.e. large hydro(>100MW),medium hydro(50-100MW) ,small hydro(10-50MW) and micro hydro plant(<10MW). Small hydro are preferable over the other because it is generally build on the run off river where construction of dam is not required. The plant can be connected to conventional electrical distribution networks as it a low cost renewable source of energy. Beside this these can be built on the isolated area or the area which distributed electrification are not reachable.

II. SMALL HYDRO POWER SYSTEM

The plant have the capacity from 10 to 50 MW and are built on the normal flowing river. This minimizes the civil works for construction a large dam or reservoir. Since the flow of river is variable, as water enter the turbine system varies. So to maintain the constant frequency of the power supply unit of a small hydro plant the speed needs to be control. Since the head is upto 2-100 meters, Kaplan turbine are preferred. The grid system f or small hydro is local which can feed 1-10,000 consumer capacity. The vertical turbine configuration keep the tail race value highest in the turbine house floor, thereby keeping the lower part of the turbine house water tight. In reaction turbine, Kaplan turbine, the speed is highest which also lower the cost of runner and alternator. To control the speed of a Kaplan turbine Proportionality-Integration-Derivative controller is used in the governing system. The basic block to control a speed of a hydraulic system are : governing system, servosystem, Hydraulic system and turbine dynamics.
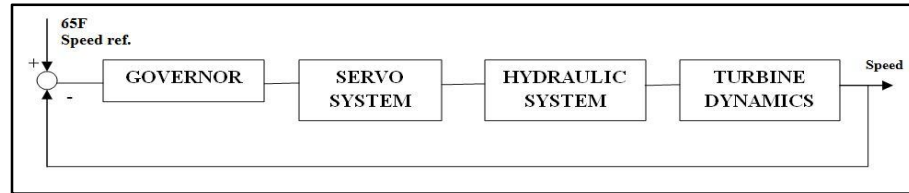
Fig1 : Speed control block diagram of a hydraulic system

III.PID GOVERNING SYSTEM

The main function a governing system is to control the network frequency on a isolates electrical network. This constant frequency can be brought into account if the speed is constant. The governor in a hydraulic system changes the rate of flow of water bringing the speed to a constant value. This main a balance between the input and output of the system. Since the flow of water in small hydro increase or decrease depending on the river condition, the chance of disturbance is more. So to make the error minimal Proportionality-Integration-Derivative controller is used in the governor control. This dynamic of PID controller is: the D mode reacts fast to the change in input to the controller, I mode leads the error to zero value by increasing the control signal and P mode takes suitable action to control the error. This modes help to determine the change in water speed from its rated value thereby a implementing a control mechanism to make the speed constant and eliminating the oscillation. Stability of the system is improved by the Derivative mode which enables in increase value of gain K and also decease integral time constant, thereby controller response speed increases.
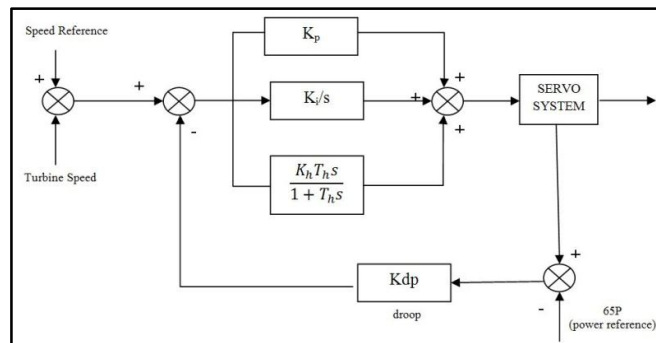

Fig 2: PID Governing system

IV.PID SERVOSYTEM AS AMPIFIER MODE

A servosystem consist of a controller, amplifier, motor and a position sensor. The servosystem receives signal from governing system. These signal are amplified and electric current is transmitted to the servo motor to produce motion which is proportional to input signal. The position sensor report the actual status of the motor. This position is compared with the input value. Any deviation in the system is identified by Proportionality-Integration-Derivative controller and give fast response to the change.
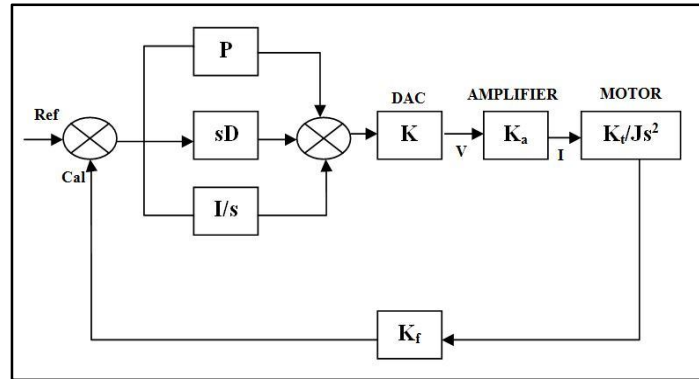
Fig 3: Simplified diagram of a servosystem

V.HYDRAULIC SYSTEM

A hydraulic system main constituent are turbine generator set. The turbine system is characterized by speed characteristic. Its main function is the production of electrical energy from the kinetic energy of water flow. The discharge of water depends on the gate position, head and turbine speed. When water flow to a turbine, the force of discharge water result in mechanical energy production. The torque developed by the force define the speed of the hydraulic turbine. The speed need to be control even though there is an increase and decease in load. The constant value of system supply frequency depend on the speed control. Thus, controlled speed avoid over-speed or under-speed thereby minimizes oscillation.

VI.MATHMATICAL MODELLING

1. Servosystem
In PID controller, the transfer function F(s), related to *x* number of output to *e* position error, is,

$$F(s) = \frac{x}{e} = P + sD + \frac{I}{s} \tag{1}$$

Where,
P is the proportionality gain of the controller
D is the derivative gain
I is the integral gain

In amplifier mode, the input voltage V is directly proportional to the output current i.e.,

$$I = K_a V \tag{2}$$

Then, Torque produced will be,

$$T_a = K_t I \tag{3}$$

Where, K_a is the proportionality constant
K_t is the torque constant
When the total moment of inertia of load and motor is J, and T_f is the opposing friction, then total torque produced in the system is,

$$J\alpha = T_a + T_f \tag{4}$$

The angular acceleration, α is

$$\alpha = \frac{d\omega}{dt} \tag{5}$$

Where ω is the velocity,

$$\omega = \frac{d\theta}{dt} \tag{6}$$

Taking Laplace transform of equation (5) and equation (6),

$$\omega = \frac{\alpha}{s} \ and \ \theta = \frac{\omega}{s} \tag{7}$$

If T_f is negligible, substituting equation (7) and (3) in equation (2), and solving for θ,

$$\theta = \frac{1}{s^2} \frac{K_t I}{J} \tag{8}$$

Solving Equation (8) in equation (2), the servosystem motor equation obtained is

$$\frac{\theta}{V} = \frac{K_a K_t}{J s^2} \tag{9}$$

The K_f is the encoder gain which is equal to the number of units of feedback per one radian of rotation. For *n* number of turns, the encoder gain will be,

$$K_f = \frac{2^n}{2\pi} \tag{10}$$

2. Hydraulic turbine model
Generally, hydraulic turbine equation for change in input torque is written as,

$$\Delta U = \frac{K_1 + K_2 T_w S}{1 + K_5 T_w S} \Delta Y + \frac{K_3 + K_4 T_w S}{1 + K_5 T_w S} \Delta N \tag{11}$$

The coefficients K_1 to K_5 are the constant which are defined in equation (12).

$$K_1 = \frac{\partial U}{\partial Y} \tag{12-a}$$

$$K_2 = \left(\frac{Q}{2H} - \frac{N}{2H} \frac{\partial Q}{\partial N}\right) \frac{\partial U}{\partial Y} + \left(\frac{N}{2H} \frac{\partial U}{\partial N} - \frac{U}{H}\right) \frac{\partial Q}{\partial Y} \tag{12-b}$$

$$K_3 = \frac{\partial U}{\partial N} \tag{12-c}$$

$$K_4 = \frac{Q}{2H} \frac{\partial U}{\partial N} - \frac{U}{H} \frac{\partial Q}{\partial N} \tag{12-d}$$

$$K_5 = \frac{Q}{2H} - \frac{N}{2H} \frac{\partial Q}{\partial N} \tag{12-e}$$

Where, Q is the discharge
  N is the turbine speed
  H is the turbine head
  Y is the gate position

U is the torque

Here, T_w is the water inertia time constant, which can be defines as,

$$T_w = \frac{Q_n}{gH_n}\frac{L}{A} \tag{13}$$

Where, Q_n is the rated discharge
H_n is the rated head at the entrance of turbine
L is the length of the penstock
A is the cross section area of the penstock
g is the acceleration due to gravity

The turbine model can be represented in terms of ΔT input torque and ΔN speed,

$$\Delta N = \frac{\Delta U}{T_m s} \tag{14}$$

T_m is called as mechanical starting constant time , which is defined as,

$$T_m = \frac{\pi G D^2 N^2}{120 g U_n} \tag{15}$$

Where, U_n is the rated torque at rated speed

GD^2 is the flywheel effect which is defined as,

$$GD^2 = \frac{1800\,PT}{\epsilon N^2}\; kNm^2 \tag{16}$$

Where, P is the rated power
T is the time closure of the wicket gate
ϵ is the coefficient for the incremental permissible speed which is,
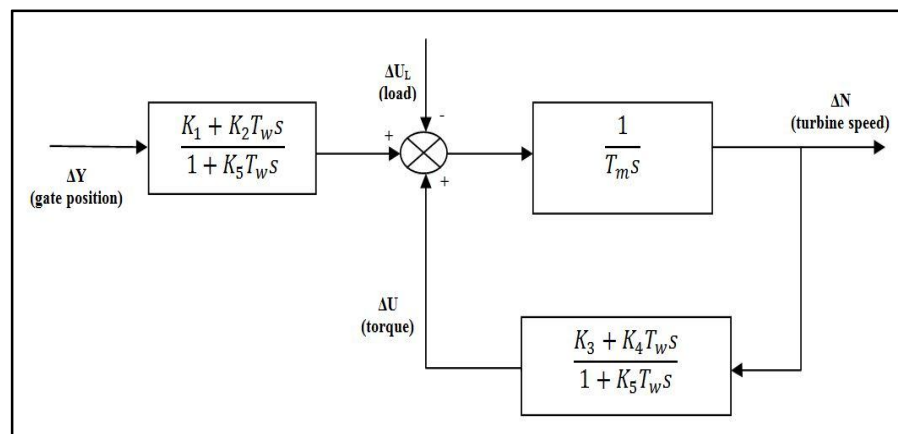
$$\epsilon = \frac{\Delta N}{N}$$

Fig 4: block diagram for the equation (11); hydraulic turbine system

VII.INPUT DATAS

The data taking for the simulation,

Table 1: Capacity of the system

MVA	MW
50	40

Table 2: Constant of the PID governor

Gov.	K_p	T_h	K_h	K_i	Kdp
PD	5.0	.01	0.1	10.0	0.04

Table 3: Value of constant of Servosystem

K_p	K_d	K_i	K	K_a	K_t	J	K_f
20	0.1	1	0.0488	0.5	0.1	0.004	656

Table 4: Turbine model constant

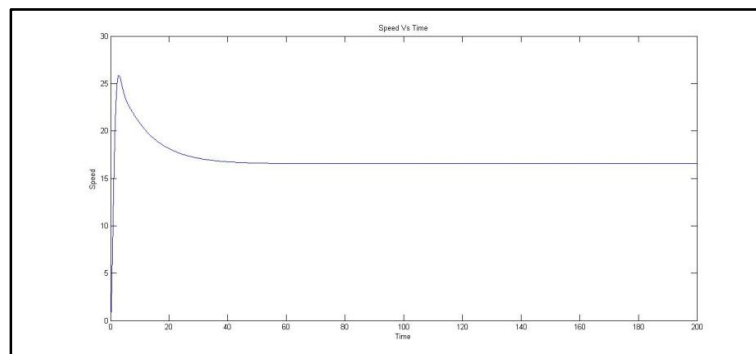| Controller	Y	K1	K2	K3	K4	K5
PID	0.72	0.72	-0.8	-1.4	-0.22	0.76

IX.SIMULATION AND RESULT

Fig 5: speed Vs time graph for the PID Servosystem

In the Fig 5, there is a sudden rise in speed when the system input is feed to the servosystem. The PID controller gives a fast reaction to the sudden rise in speed thereby responding to the change. The controller brings back the speed to a constant value and the amplifier amplifies the signal avoiding the oscillation in the speed characteristic.
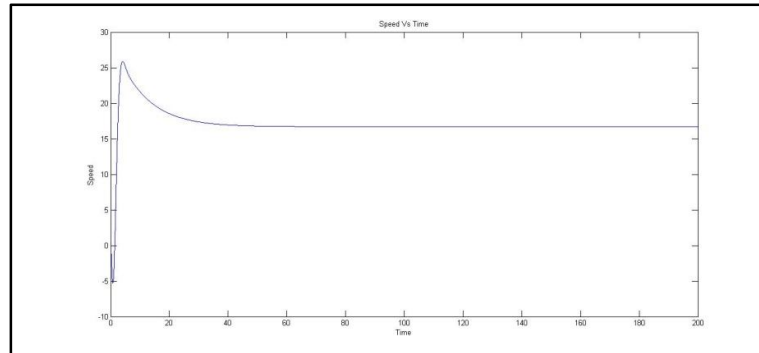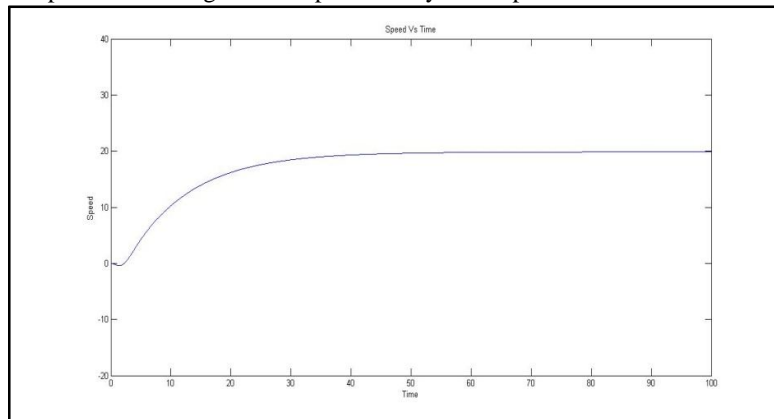
Fig 6: Speed Vs Time for PID Governing System

In fig 6, the speed is brought back to a constant value after a sudden rise in value. This rising value is due to sudden force of water to the hydraulic turbine. Presence of permanent droop compensator determines the amount of output change in response to a change in unit speed and try to compensate it.

7: Speed Vs Time controlled graph

From the graph Fig 7, it can be analysis that the settling time for the speed is less. The speed becomes constant within 30sec. the over speed and losses are minimizes due to the low settling time. Thus, system frequency is maintained by controlled speed. In place of the PID controller if it would have been replaced by a PD controller the settling time would have been greater which depicts the essence of usage of PID controller as it in short increases the efficiency of the plant.

X.CONCLUSION

In local grid supplied SHP are being implemented now a day because of its various advantages over other form of energy. It don't disturbs the local habitat, requires less civil construction, which indirectly result in minimum maintenance cost. The small hydro plants across a river also control flooding. But speed in a hydraulic power plant is a important factor which need to be control in anyway. Control speed avoid over heat of the system, minimizes losses and also keep the supply frequency constant.

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