Power System Stability Analysis of Small Scale Hydro Plant and its Enhancement using PI Controller

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Abstract: The sensitivity of power system stability to generator parameters (including parameters of generator model, excitation model and exciter) is analyzed in depth by simulations. Here in this paper the simulated model was created by modeling the various components of a practically operating canal based small hydro power plant in a Matlab/Simulik based environment. The plant is located in Bathinda Punjab and is connected to the local grid. Using the model, the aim is to study the behavior of power angle and electromagnetic torque of the generator. The corresponding results for these are obtained for analysis. Later a PI controller will be designed in order to increase its performance.

***Index-Terms* - Mathematical models, Park Transformation, Small hydro-electric power plants, Controller, Proportional, Integral, Matlab/Simulink.**

I. INTRODUCTION

In Irrigation canal based Small Hydro plants, utilizing the heads available gives more or less constant power generation. But it is seen that the head available is almost constant whereas there are large variations in the discharge available. The power generation is completely dependent upon irrigation releases season wise through the canal which depends upon the crop pattern in the region. Power generation is for nine months as months of April, May and August are not considered since discharge is less than 1 cumecs. Fig. 1 shows a representation of our model and in the figure δ is Power Angle.

Fig.1 Machine connected to an infinite bus

Under normal operating conditions, the relative position of the rotor axis and the infinite bus axis is fixed. The angle between the rotor and the infinite bus axis is called the power angle or torque angle δ. Whenever the rotor speed decelerates or accelerates with respect to the synchronous rotating air gap mmf, the equation describing this relative motion is called the swing equation which is given by

$$M\frac{d^2\delta}{dt^2} = P_a - P_e$$

As shown in Fig.2, in an unstable system, δ increases indefinitely with time and machine looses synchronism. In a stable system, δ undergoes oscillations, which eventually die out due to damping.

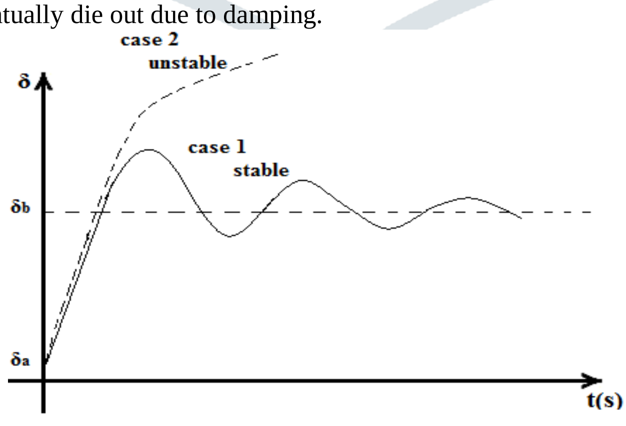

Fig.2 Power Angle

II. MATHEMATICAL MODELING

Generally differential equations are used to describe the various power system components. Study of the dynamic behavior of the system depends upon the nature of the differential equations.

Small System: If the system equations are linear, the techniques of linear system analysis are used to study dynamic behavior. Each component is simulated by transfer function and these transfer functions blocks are connected to represent the system under study.

Large System: Here state-space model will be used for system studies described by linear differential equations. However for transient stability study the nonlinear differential equations are used.

Mathematical Modeling of a Synchronous Machine:
The reason here to choose Park's transformation is because other approaches create us trouble because of inductances which are related to the stator-rotor mutual inductances that have time-varying inductances. In order to alleviate the trouble, we project the a-b-c currents into a pair of axes which we will call the d and q axes or d-q axes. In making these projections, we want to obtain expressions for the components of the stator currents in phase with the d and q axes, respectively. Although we may specify the speed of these axes to be any speed that is convenient for us, we will generally specify it to be synchronous speed, ω_s. Decomposing the b-phase currents and the c-phase currents in the same way, and then adding them up, provides us with:

$$i_q = k_q\left(i_a \cos\theta + i_b \cos(\theta - 120°) + i_c \cos(\theta + 120°)\right)$$
$$i_d = k_d\left(i_a \sin\theta + i_b \sin(\theta - 120°) + i_c \sin(\theta + 120°)\right)$$

Constants k_q and k_d are chosen so as to simplify the numerical coefficients

We have transformed 3 variables i_a, i_b, and i_c into two variables i_d and i_q. This yields an undetermined system, meaning

- We can uniquely transform i_a, i_b, and i_c to i_d and i_q
- We cannot uniquely transform i_d and i_q to i_a, i_b, and i_c.

We will use as a third current the zero-sequence current whose value is zero under balanced conditions. This is being done in order to have a balance:

$$i_0 = k_0\left(i_a + i_b + i_c\right)$$

Recall our i_d and i_q equations:

$$i_q = k_d\left(i_a \cos\theta + i_b \cos(\theta - 120°) + i_c \cos(\theta + 120°)\right)$$
$$i_d = k_q\left(i_a \sin\theta + i_b \sin(\theta - 120°) + i_c \sin(\theta + 120°)\right)$$

We can write our transformation more compactly as

$$\begin{bmatrix} i_q \\ i_d \\ i_0 \end{bmatrix} = \begin{bmatrix} k_q \cos\theta & k_q \cos(\theta - 120) & k_q \cos(\theta + 120) \\ k_d \sin\theta & k_d \sin(\theta - 120) & k_d \sin(\theta + 120) \\ k_0 & k_0 & k_0 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Here, the angle θ is given by

$$\theta = \int_0^t \omega(\gamma)d\gamma + \theta(0)$$

Where γ is a dummy variable of integration.

The angular velocity ω associated with the change of variables is unspecified. It characterizes the frame of reference and may rotate at any constant or varying angular velocity or it may remain stationary. We often hear of the "arbitrary reference frame." The phrase "arbitrary" stems from the fact that the angular velocity of the transformation is unspecified and can be selected arbitrarily to expedite the solution of the equations or to satisfy the system constraints.

The constants k_0, k_q, and k_d are chosen differently by different authors. One popular choice is 1/3, 2/3, and 2/3, respectively, which causes the magnitude of the d-q quantities to be equal to that of the three-phase quantities. However, it also causes a 3/2 multiplier in front of the power expression (Anderson & Fouad use $k_0=1/\sqrt{3}$, $k_d=k_q=\sqrt{(2/3)}$ to get a power invariant expression).

III. Simulation Model developed In a Matlab/Simulink Software Environment.

A typical canal based hydroelectric power plant with a Kaplan turbine, as shown in Fig. 2 reflects the Canal Type Small Hydro Power Plant in Bathinda Punjab run under Punjab Energy Development Agency (PEDA), and hence all the data of this plant is used for simulation. The simulation results are all in per unit system and the required data is given below:

Turbine and Governor Data

h	= 2.10
h_{char}	= 2.74
T_w	= 3
ω	= 93 rpm
ηt	= 91%
ω_{ref}	= 1p.u.
T_a	= 0.07
R_p	=0.05
K_p	= 3
K_i	= 0.10
K_d	= 3.26
T_d	=0.02
K_a	=10/3
g_{min}	=0.01
g_{max}	=0.97518
v_{gmin}	=-0.1
v_{gmax}	=0.1

Exciter

V_{ref}	= 1
V_{ter}	= 1
T_c and T_d	=0.00001, 0.00001
T_e	= 0.08
V_{rmax}	= -15
V_{rmin}	= 7.3
T_r	=0.87
K_a	=200
T_a	=0.02
K_e	=1
K_f	=0.03
T_f	=1
V_f	=1.2911

Synchronous Generator

P_n	=1.3 MW
V_n	=415V
f	=50
X_d	=0.911
X'_d	=0.408
X''_d	=0.329
X_q	=0.580
X''_q	=0.350
X_1	=0.3
T'_d	=0.7
T''_d	=0.035
T''_{q0}	=0.033
R_s	=0.03
H	=1
P	=4
V_f	=1

III. SIMULATION

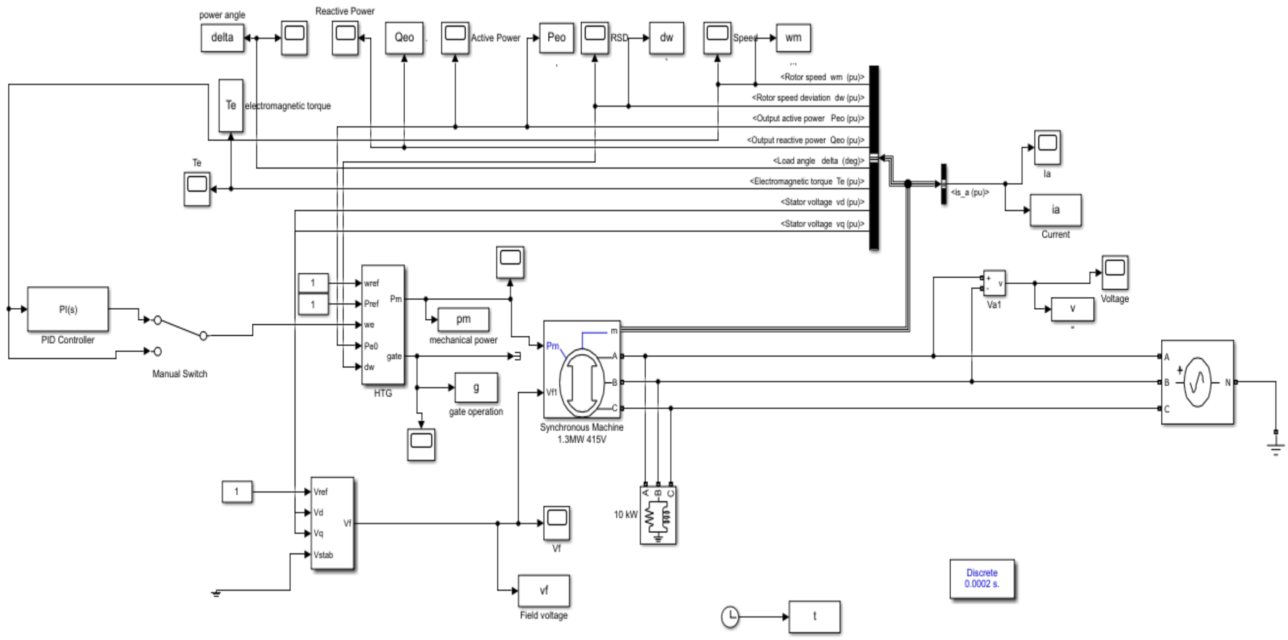

Fig.4: Simulation Model of Canal Based Small Hydro Electric Power Plant

IV. RESULTS

1. Response of Power Angle during steady state and transient state with and without PI Controller

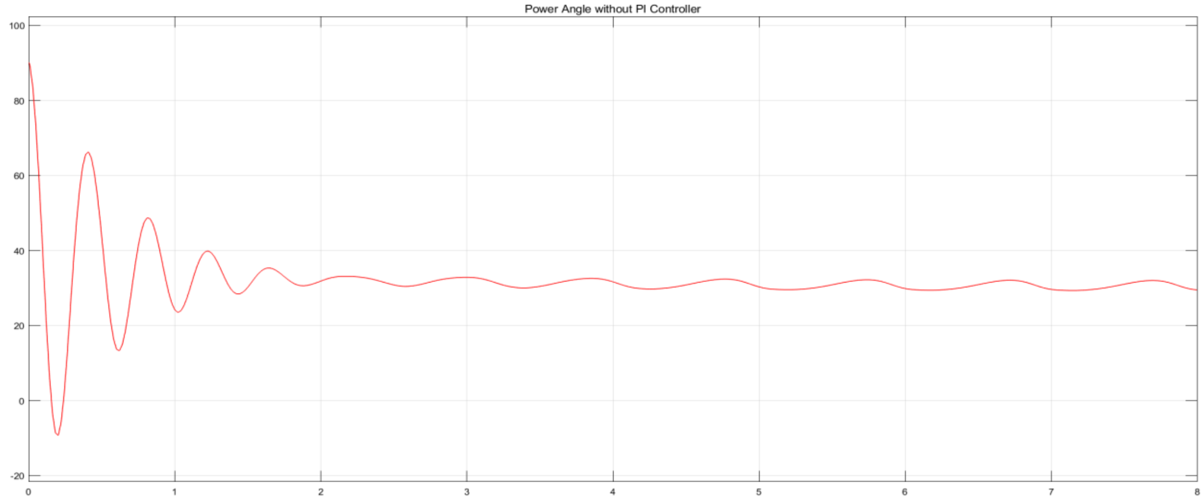

Fig. 5: Transient Response of Power Angle without PI Controller

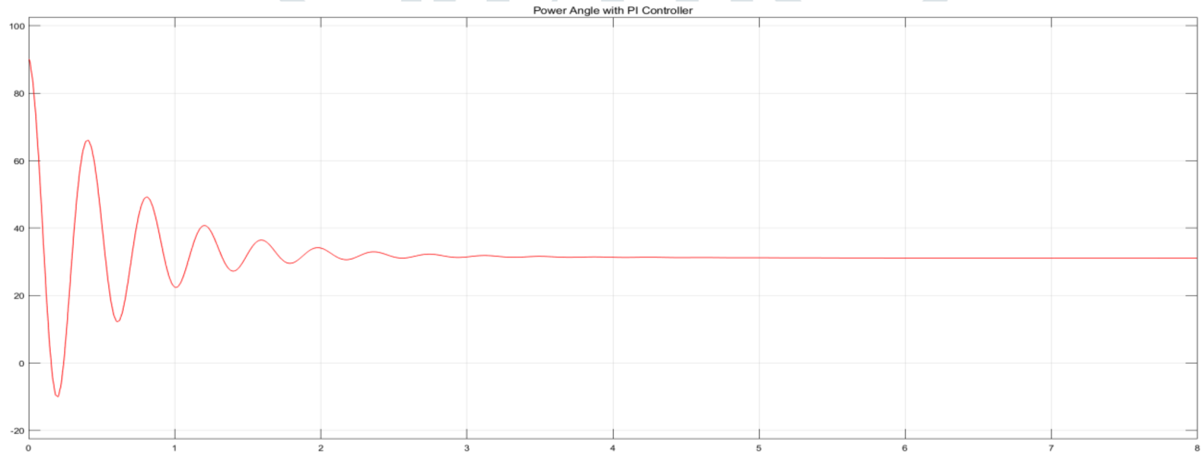

Fig. 6: Transient Response of Power Angle with PI Controller

1. Response of Electromagnetic Torque with and without PI Controller

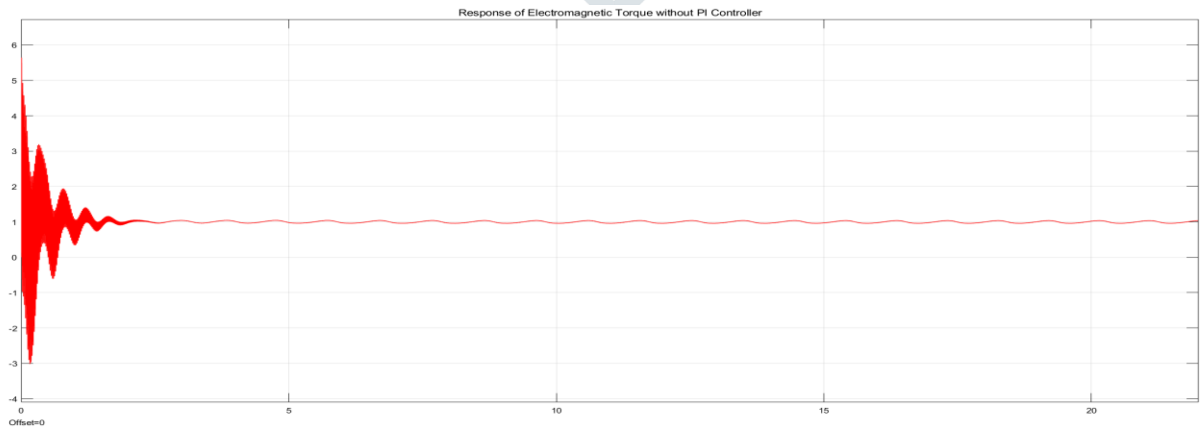

Fig. 7: Response of Electromagnetic Torque without PI Controller

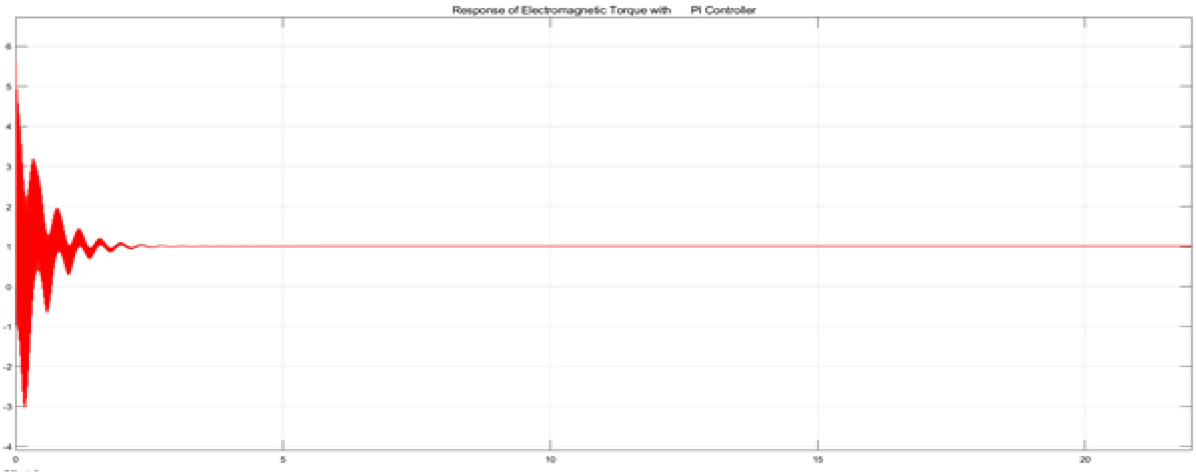

Fig. 8: Response of Electromagnetic Torque with PI Controller

V. CONCLUSION

As it is clear from the results that the average power angle in both the cases, with or without PI Controller is 36^0. It can be seen from Fig. 5, the oscillations are there in steady state as well. Whereas in Fig. 6 the oscillations has completely die-out during steady state because of PI Controller. Same is the case with Electromagnetic Torque. In Fig. 7 oscillations are still in steady state, but with the help of PI Controller they have been completely eliminated (Fig.8)

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