

Design of a Controller for Canal Based Small Hydro Power Plant

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Abstract: 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/Simulink 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 mechanical input to the generator and the gate operation during its steady state operation and also the transient behavior. The corresponding results for these are obtained for analysis. Later a PID controller will be designed in order to increase its performance both under steady state and transient state.

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. Modeling and simulation of small hydro power plant is valuable tool for planning power plant operations and judging the value of physical improvement by selecting proper system parameters. Earlier this was done for large or small hydro power plants. But for canal type small hydro power plants this study helps in verifying costs and safety conditions. It also helps in verifying the parameters of control equipment's like water level regulator, governor, exciter etc. and in determining the dynamic forces acting on the system which must be considered in structural analysis of the penstock and their support.

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.

1. 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:

$$\begin{aligned} i_q &= k_q (i_a \cos \theta + i_b \cos(\theta - 120^\circ) + i_c \cos(\theta + 120^\circ)) \\ i_d &= k_d (i_a \sin \theta + i_b \sin(\theta - 120^\circ) + i_c \sin(\theta + 120^\circ)) \end{aligned}$$

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:

$$i_0 = k_0 (i_a + i_b + i_c)$$

Recall our i_d and i_q equations:

$$i_q = k_d (i_a \cos \theta + i_b \cos(\theta - 120^\circ) + i_c \cos(\theta + 120^\circ))$$

$$i_d = k_q (i_a \sin \theta + i_b \sin(\theta - 120^\circ) + i_c \sin(\theta + 120^\circ))$$

We can write our transformation more compactly as

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

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 $k_0=1/\sqrt{3}$, $k_q=k_d=\sqrt{2/3}$ to get a power invariant expression).

2. Modeling of Hydraulic Turbine

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

1. The hydraulic resistance is negligible.
2. The penstock pipe is inelastic and the water is incompressible.
3. The velocity of the water varies directly with the gate opening and with square root of the net head.

The model of Hydraulic Turbine is given by

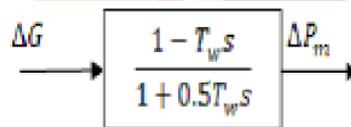


Fig.1

Here T_w is referred to as the water starting time.

II. 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
η	= 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

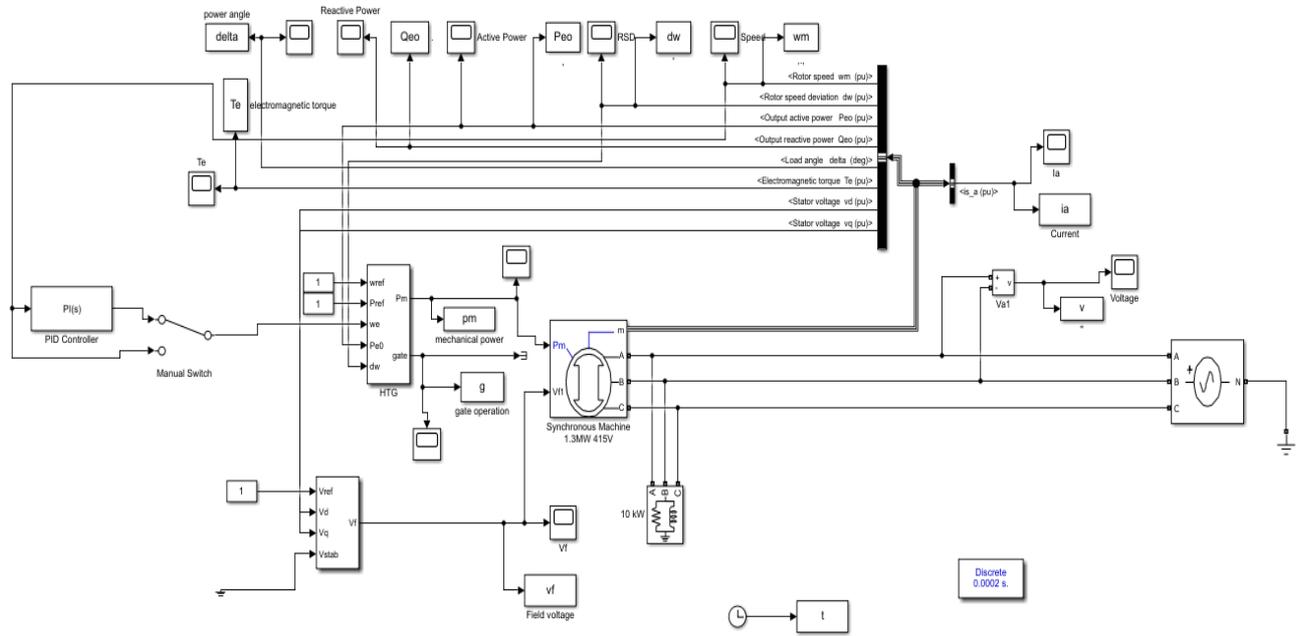


Fig.2: Simulation Model of Canal Based Small Hydro Electric Power Plant

IV. RESULTS

1. Response of Gate operation during steady state operation with and without PI Controller.

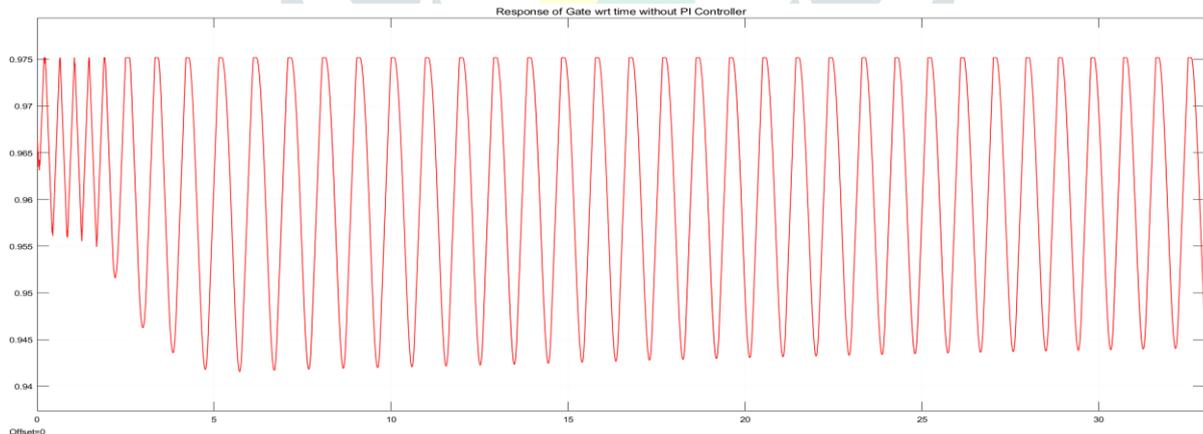


Fig. 3: Response of Gate Operation without PI Controller

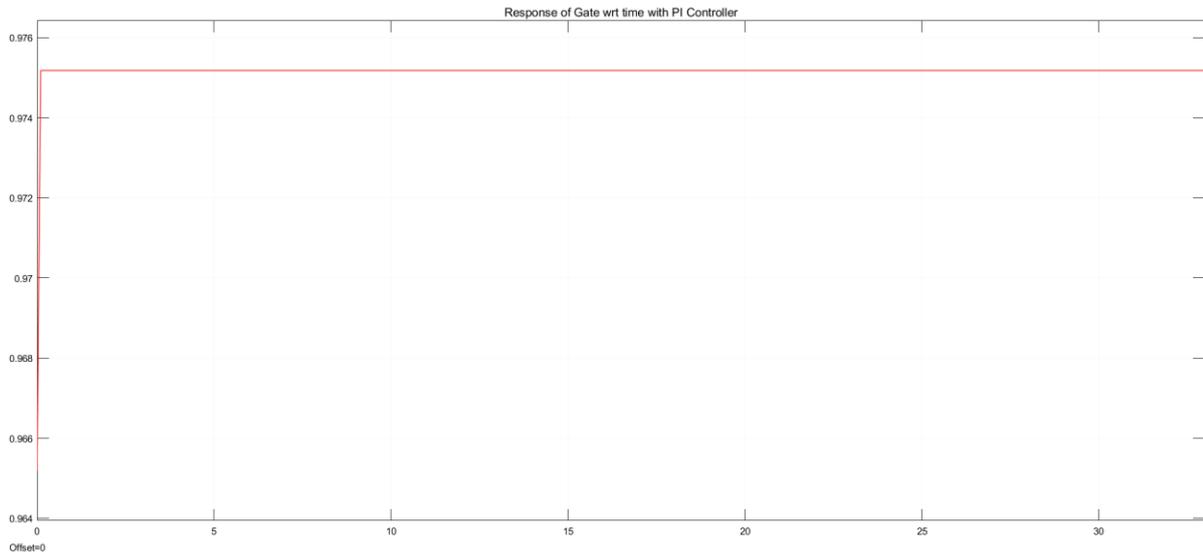


Fig. 4: Response of Gate Operation with PI Controller

2. Transient response of Gate with and without PI Controller.

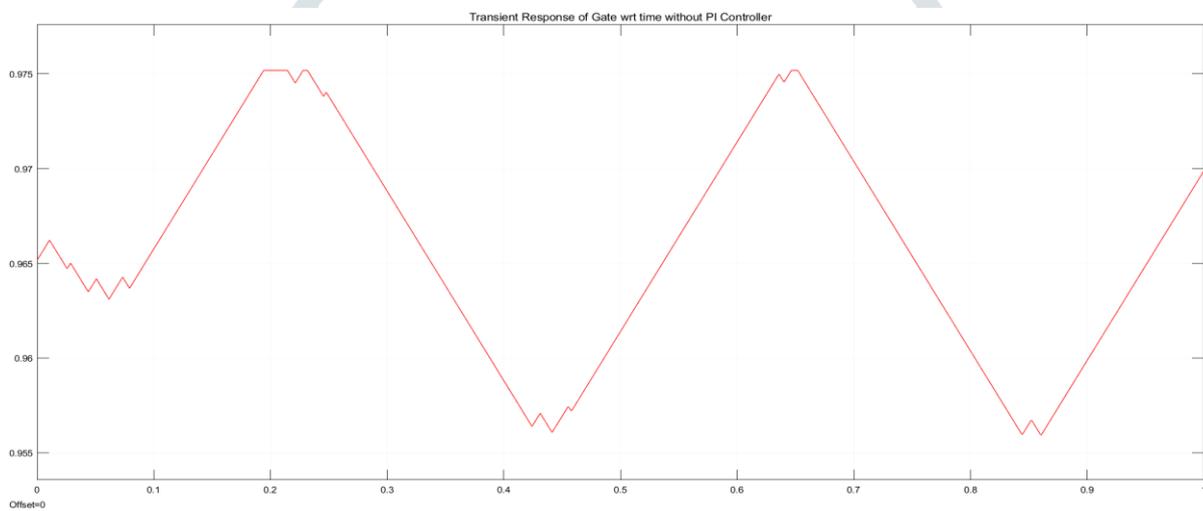


Fig. 5: Transient response without PI Controller

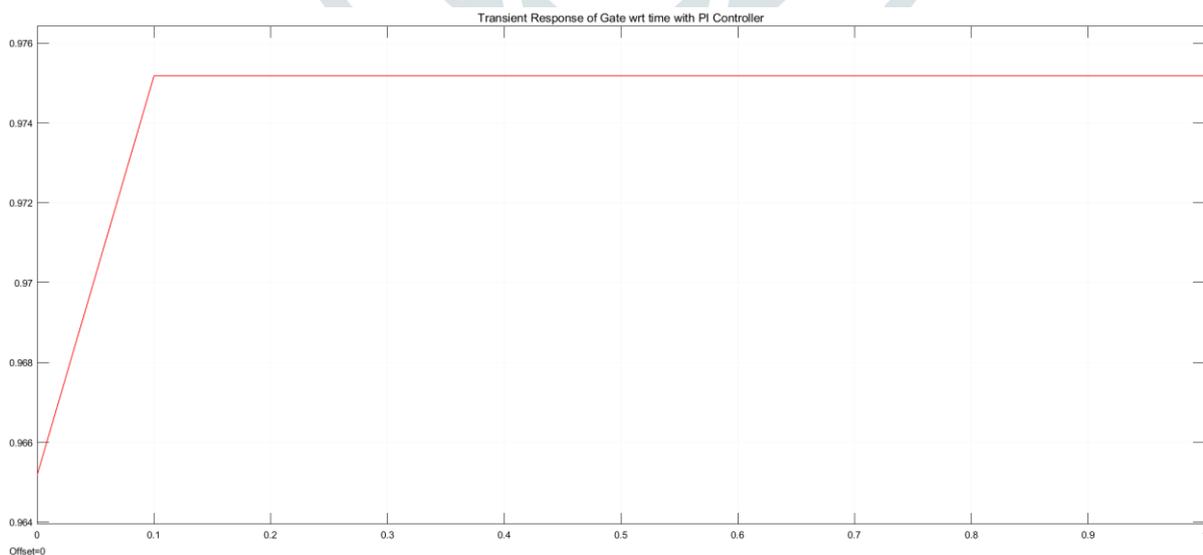


Fig. 6: Transient response with PI Controller

3. Response of Mechanical Input during steady state operation with and without PI Controller

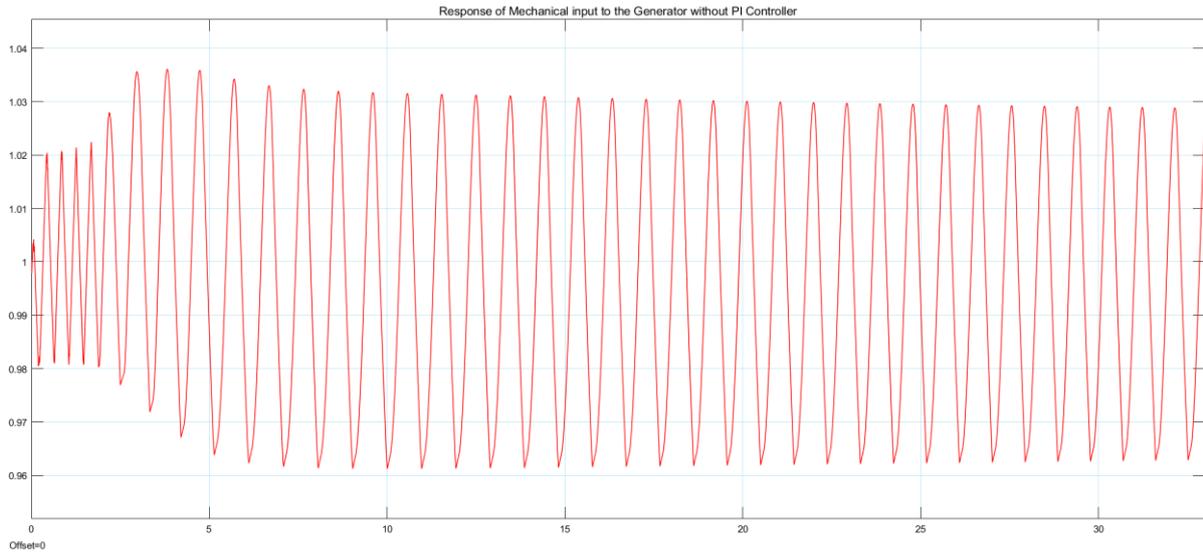


Fig. 7: Response of Mechanical Input during steady state operation without PI Controller

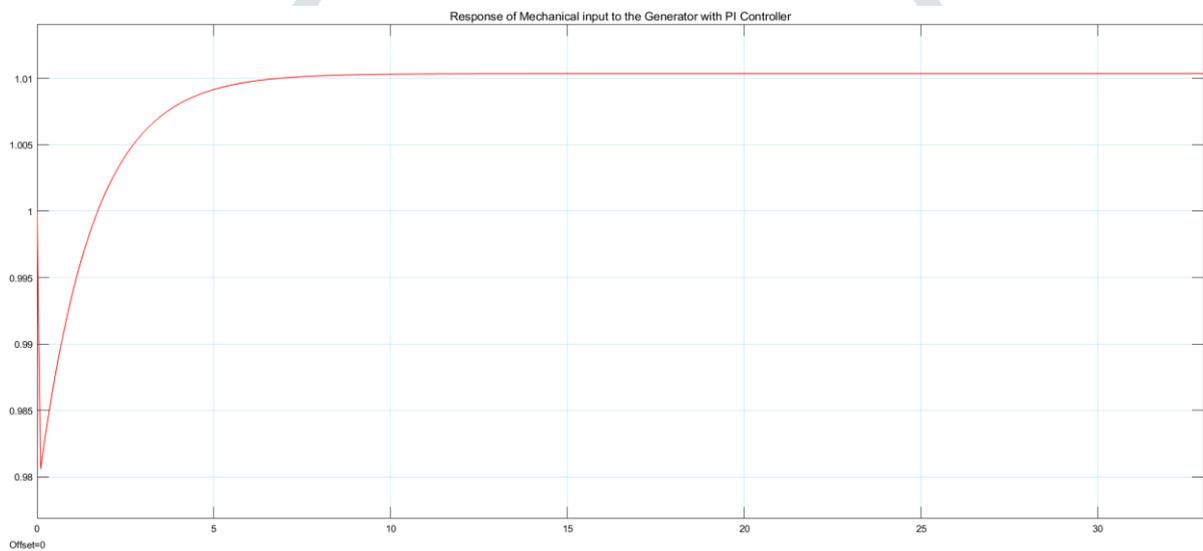


Fig. 8: Response of Mechanical Input during steady state operation with PI Controller

4. Response of Mechanical Input during transient state with and without PI Controller.

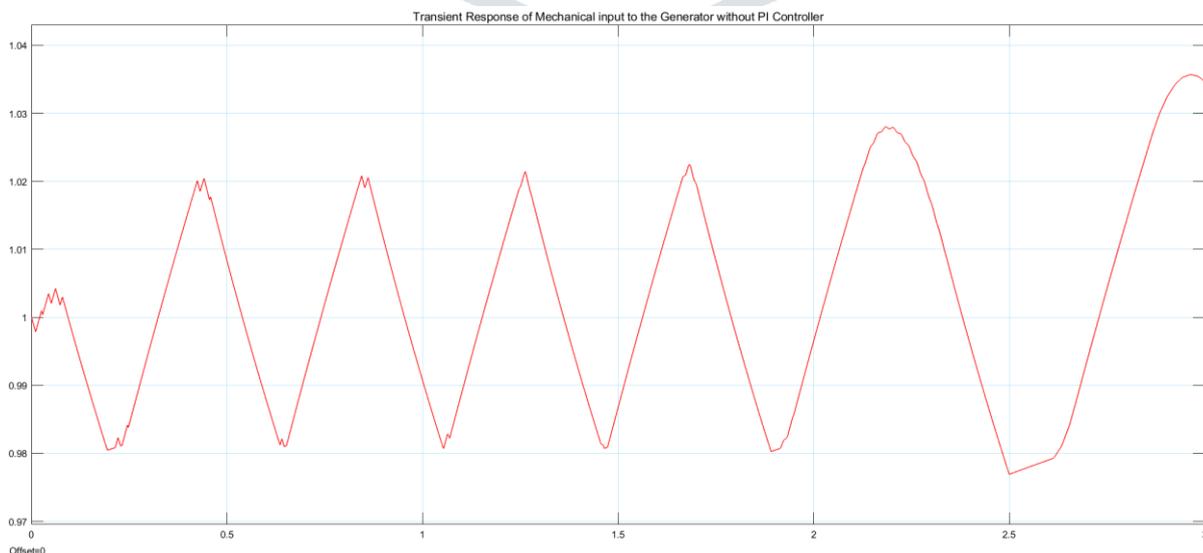


Fig. 9: Transient Response of Mechanical Input without PI Controller

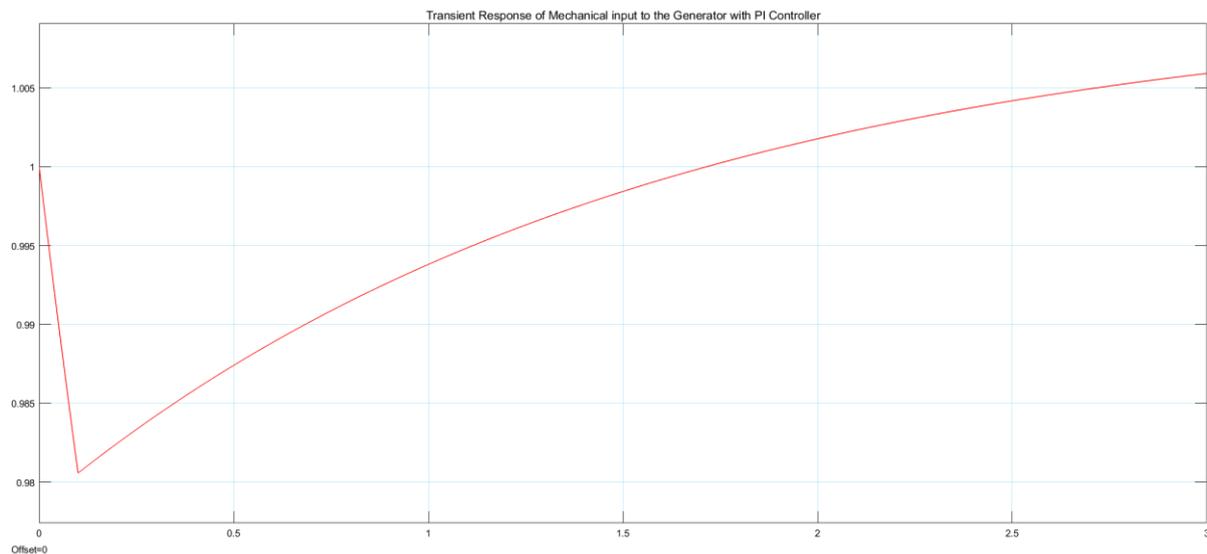


Fig. 10: Transient Response of Mechanical Input with PI Controller

V. ANALYSIS

S. No.	Name	Time in Seconds	Without PI Controller		With PI Controller	
			Min. Value	Max. Value	Min. Value	Max. Value
1.	Steady State Gate Operation	0-35	0.956- 0.943 pu	0.975 pu	0.967 pu	0.975 pu
2.	Gate Transient Response	0-1	0.958 pu	0.9751 pu	0.965 pu	0.9751 pu
3.	Steady State Mechanical Input	0-35	0.98-0.962 pu	1.035 pu	0.981 pu	1.01 pu
4.	Transient Response of Mechanical Input	0-3	0.9756 pu	1.036 pu	0.982 pu	1.0051 pu

VI. CONCLUSION

As soon the canal based power plant was connected to an infinite bus through a transmission line, both the mechanical input and the gate operation has been greatly affected during steady state and during transient period as well. In order to improve the behavior during both stated, a PI controller was designed. As it is clear from the obtained results that PI Controller has successfully controlled the oscillational behavior during steady state. It has also improved its transient behavior by keeping the values within limits.

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