Design of PI Controller using MPRS Method for Automatic Generation Control of Hydropower System

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Abstract – In an interconnected power system with two or more independently controlled areas, any disturbance may cause a change in frequency of power system which results in instability. In addition the power interchange between the control areas is not constant. Automatic generation control regulates the frequency of the power system to the specified nominal value and maintains the power interchange between the control areas at the scheduled values by adjusting the output of selected generators. PI controller designed using Maximum peak resonance specification (MPRS) has been implemented to maintain frequency and the power interchange. The MPRS method uses the Nichols chart and it proves to be an effective and efficient method to control the overshoot, settling time and maintain the stability of the system. The results are then compared with other tuning methods of PI controller such as trial and error method and Ziegler –Nichols method.

Keywords – PI controller, Hydro turbine, Maximum Peak Resonance, Nichols chart.

I. INTRODUCTION

An interconnected power system consists of control areas that are connected to each other by tie lines. Each area feeds its control area and tie line allows electric power to flow between the area. Each control area should have to carry its own load except such scheduled portions of the other members. Each control area must agree upon adopting regulating and control strategies and equipment that are mutually beneficial under both normal and abnormal situation. The advantages of interconnection are effect of size and reduced need of reserve capacity. The main function of automatic generation control is to maintain the desired megawatt output and the nominal frequency in an interconnected power system. To maintain the net interchange of power between control areas at predetermined values.

Literature survey shows some of the earlier works involving AGC. Implementation of the layered ANN to study AGC problem in a four area interconnected power system[10] , in which three areas include steam turbines and the other area which is a hydro turbine. Each area of the steam turbine in the system contains the reheat effect non-linearity of the steam turbine and the area of hydro turbine contains upper and lower constraints for generation rate. Only one ANN controller is used. Back Propagation-through-time algorithm is used as ANN learning rule. By comparing the results with conventional ANN controller shows better performance. Two Decentralized control design methodologies for load Frequency control was then proposed [11], The first controllers,one is based on H_∞ control design using linear matrix inequalities (LMI) technique to obtain robustness against uncertainties. The second controller is more appealing from an implementation point of view. It is tuned by a proposed control design algorithm to achieve the same performance as the first one. The controller parameters are tuned by using the genetic algorithm optimization method in PI controller and it is subject to the H_∞constraints in terms of LMI. The second control design is called Genetic Algorithm Linear Matrix Inequalities (GALMI). Two proposed controllers are tested on a three-area power system with load disturbances to demonstrate their performances. A method based on fuzzy logic controllers (FLCs) for automatic generation control (AGC)of power systems including superconducting magnetic energy storage units [12], this technique can be applied to control systems including three areas having two steam turbines and the other one is hydro turbine which is tied together through power lines. During load variation, the frequency of the power system changes over time. Frequency transients can be minimized by using conventional integral controller and proportional controllers aiming of secondary control in AGC and zero steady-state error is obtained after sufficient delay time. Automatic generation control of a two-area interconnected thyristor controlled phase shifter based hydrothermal system using fuzzy logic controller (FLC) in the continuous mode[14], Open transmission access and the evolution of more companies for generation, transmission and distribution affects the formulation of AGC problem. The conventional AGC two-area system is modified to take into account the effect of bilateral contracts on the dynamics. By controlling the phase angle of TCPS we can stabilize the system frequency and tie-power oscillations. This control strategy using TCPS is proposed to provide active control of system frequency. Responses for small changes considering fuzzy logic controller and PI controller have been observed and is inferred that fuzzy logic controller shows better performance than conventional controller.

An interconnected power system having two or more areas connected by tie lines [5], each area supplies its own control area and tie lines allow the electric power to flow among the areas. But a load perturbation in any of the areas affects output frequencies of all the areas and also the power flow on tie lines. So the control system of each area needs information about transient situation in all the other areas to restore the nominal values of area frequencies and tie line powers. The information about each of the area is found in its output frequency and the information about other areas is in the deviation of tie line power .In literature survey, they have used various type of controllers.

The objective of the present work is to examine MPRS controller works in interconnected hydro turbine system, to test its robustness and to meet the performance criteria such as the steady state error must be zero, settling time should be less than 40 seconds

II. THE STRUCTURE OF POWER SYSTEMS

The function of an electric power system is to convert energy from one of the naturally available forms to the electrical form and to transport it to the points of consumption. An interconnected power system is a complex enterprise that may be subdivided into the following major subsystem they are Generation subsystem, transmission subsystem and distribution subsystem.

III. SYSTEM MODEL

The system consists of two generating areas, area 1 and area 2 comprising a hydro system .Hydro turbines are equipped with turbine speed governors. The function of the speed governor is to monitor continuously the turbine-generator speed and to control the gate position in hydro turbines. The generator converts mechanical energy produced in the hydro turbine into electrical energy. The linear model is shown in fig 1 for hydropower system [1]

Where, the transfer functions (T.F) of hydro area blocks are

T.F of Speed governor, $\frac{\Delta\omega_r}{\Delta Y} = -\frac{1}{Rp}\frac{1}{(1+T_t)}$ (1)

T.F of hydro turbine, $\frac{\overline{\Delta P_m}}{\overline{\Delta G}} = \frac{1-sT_W}{1+0.5sT_W}$ (2)

T.F of the generator, $\frac{\Delta P_m}{\Delta\omega_r} = \frac{1}{2Hs+D}$ (3)

where , P_m is Mechanical power , T_g is Main servo time constant, T_W is Water starting time, H is Hydraulic head at the gate ,D is Damping constant , G IS Gate position and $\Delta\omega_r$ Rotor speed deviation

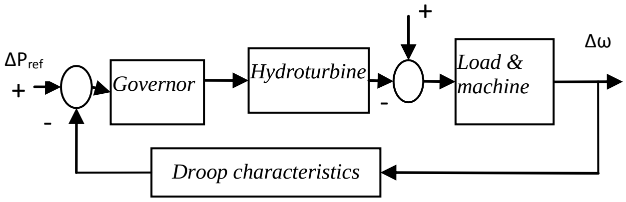


Fig. 1: Block diagram of hydro power system

For the hydro turbine system as the gain margin is negative, so any step change in load makes the system unstable. Therefore a compensator is necessary to make it stable

The compensator transfer function is

$$G_m(s)=\frac{1+sT_E}{1+(R_T/R_P)T_E s} \qquad (4)$$

Where, R_T and T_E are obtained using the equations given as follows:

$$R_T=[2.3-0.15(T_w-1.0)](T_w/T_m) \qquad (5)$$

$$T_E=[5.0-0.5(T_w--1.0)](T_w) \qquad (6)$$

Where, T_M is Mechanical starting time ,T_E is Reset time, R_P is Permanent droop and R_T is Temporary droop[1]

Two area system:

Two controlled areas are connected by a tie line is shown in fig 2 to form a two area system. The deviation between desired and actual system frequency is combined with the deviation from the scheduled net interchange from a composite measure $B_i\Delta f_i+\Delta P_{tiei}$ called the area control error, or ACE, where $B_i=1/K_{pi}+1/R_i$ where B_i is the frequency bias constant.

IV . TUNING METHOD USING MAXIMUM PEAK RESONANCE METHOD

The tuning method is based on the contours of the Nichols chart [4]. The specification is given in terms of the maximum peak resonance Mr of the closed loop system. The open loop transfer function G(jω) = Gc(jω) Gp(jω) follows the contour corresponding the desired Mr of the closed- loop system. Controller parameters are tuned so that the open loop transfer function$G(j\omega) = G_C(j\omega)G_P(j\omega)$, in which G_C is the controller transfer function which is $G_C(s) = K_P + \frac{K_I}{s}$ and and G_P process transfer functions which is $G_P(s) = \frac{1}{(1+T_t)}\frac{1-sT_w}{1+0.5sT_w}$ respectively follows the contour corresponding the desiredM_r of the closed- loop system

Overshoot to the set point change:

For a second order system ,the relation exists between M_p (in %) and M_r (in dB) the equation is given by %Mp = 100(exp $\left\{-\pi\left[\frac{1-\sqrt{1-10^{-0.1M_r}}}{1+\sqrt{1-10^{-0.1M_r}}}\right]\right\}^{1/2}$) (7)

Minimum phase and amplitude margin:

The minimum phase margin $\emptyset_m$ corresponds to the difference of the phase at which the contour crosses the 0dB axis and -180^0

Closed loop bandwidth:

The frequency region over which the G(jω) curve follow the specified contour influences the bandwidth of the closed loop system (ω$_b$). The selection of the region located at high frequency implies that the system will have a fast response.

The tuning method consists of direct minimization of the distance between G(jω) and the contour M_r over the frequency region . Let K be a particular contour and P(ω) and Q (ω) are the real and imaginary part of G(jω) and K is the equation of the contour given by,

$$K = \frac{|G(j\omega)|}{|1+G(j\omega)|} \tag{8}$$

Substituting ,real and imaginary part eqn.9 is obtained

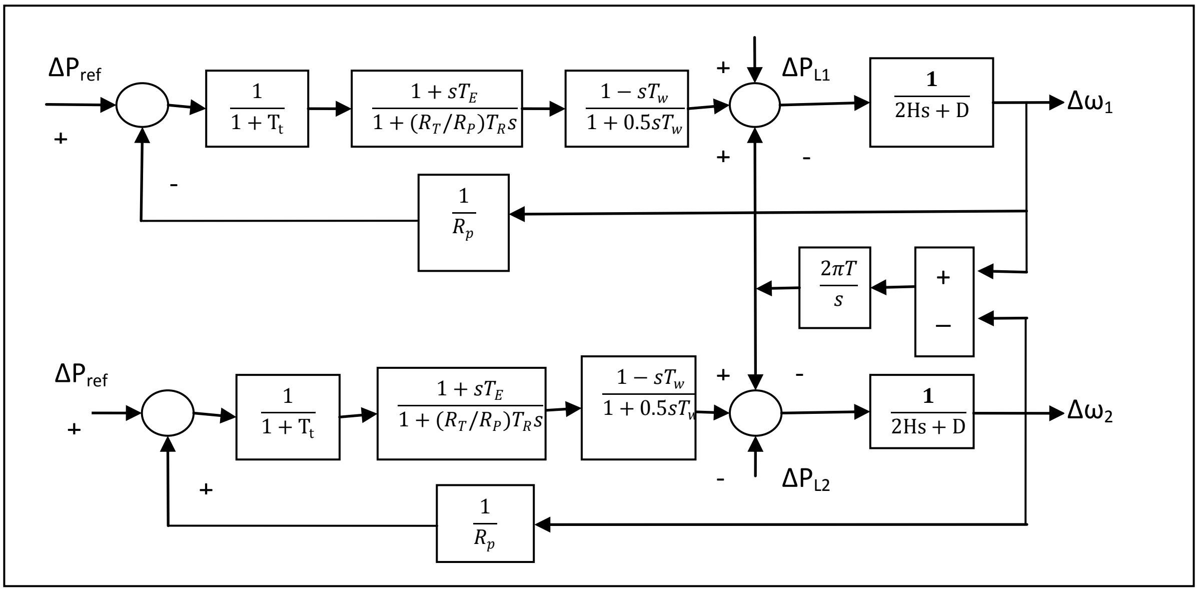


Fig. 2 : Block diagram of an interconnected hydropower system with transfer functions

$$K = \frac{\sqrt{P^2(\omega)+Q^2(\omega)}}{\sqrt{(P(\omega)+1)^2+Q^2(\omega)}} \tag{9}$$

When K=1, the equation of the contour in the Nyquist plane is a straight line parallel to the imaginary axis

$$1= \frac{\sqrt{P^2(\omega)+Q^2(\omega)}}{\sqrt{(P(\omega)+1)^2+Q^2(\omega)}} \tag{10}$$

$$P(\omega)= -1/2 \tag{11}$$

The distance, at a particular frequency ω_i , between G(jω) and the contour is given by

$$d_i = |P(\omega_i)| + {}^1/_2 \quad \text{, when} \quad h=1 \tag{12}$$

When K > 1 , the contours are circular

Distance at a particular frequency is

$$(P(\omega)-K^2/(1-K^2))^2 \; +Q^2(\omega) \; =(K^2/(1-K^2))^2 \quad (13)$$

Distance at a particular frequency is

$$d_i \; = \sqrt{\left(P(\omega_i)-\frac{K^2}{1-K^2}\right)^2+Q^2(\omega_i)}+\frac{K}{1-K^2} \qquad K>1 \quad (14)$$

Optimization problem formulation

The distance between G (Jω)and M_r is minimium over the frequency range formulated as a Constrained optimization problem in frequency domain to find controller parameters

$$J(\vartheta_c)=\begin{cases}\sum_{i=1}^{j}\left|\left(P(\omega_i)+1/2\right)\right| & M_r=0dB\\ \sum_{i=1}^{j}\left[\sqrt{\left(P(\omega_i)-\frac{K^2}{1-K^2}\right)^2+Q^2(\omega_i)}+\frac{K}{1-K^2}\right] & M_r>0dB\end{cases}$$

(15)

Where,ϑ_c represents the controller parameters. Constraints are introduced to preserve some properties of the system. The Constraints are

$$20\log|K(j\omega_r)| \; = \; M_r$$

$$|K(j\omega_r)| \geq 1 \quad \omega \leq \omega_r \qquad (16)$$

$$\langle G(j\omega_{co}) > \text{-}180^o$$

Where ω_r is the open-loop crossover frequency

The first constraint ensures that the specification is met and not exceeded The G(jω) curve follows but does not cross the contour . The second constraint ensures that the relation between M_p and M_r is preserved.

After designing the PI controller, this controller is placed in the feedback path, With the input as zero.

Design steps of PI controller using MPRS tuning method

The procedure is given below

Step 1: Draw the Nichols chart for the system 1 process transfer function with K_P(proportional gain), T_I (integral time) obtained from trial and error method

Step 2: Check whether the curve is tangent to the contour 0 db

Step 3: If not, Shift the traced locus over the Nichols chart vertically, so that it is tangent to required Mr contour. in this case, M_r =0dB

Step 4 : Take the value of K_P using the formula 20logK =difference between the curve starting points

Step 5 : find the value of T_I from K_P value

V. RESULTS

The interconnected hydropower system is shown in the fig.2 After simulation the valve position, mechanical power and change in frequency response of a two machine system are not settling as shown in fig (a) Since the valve position, mechanical power and change in frequency response of a two machine system are not settling design of PI controller using trial and error method has been done as shown in fig 3. The controller parameters are shown in table 1 . After simulation the valve position, mechanical power and change in frequency response of a two machine system are not settling, so design of PI controller using Ziegler-Nichols method is done. The controller parameters are shown in table 2. Here after the simulation the valve position, mechanical power and change in frequency response of a two machine system are not settled anywhere as shown in fig (b)

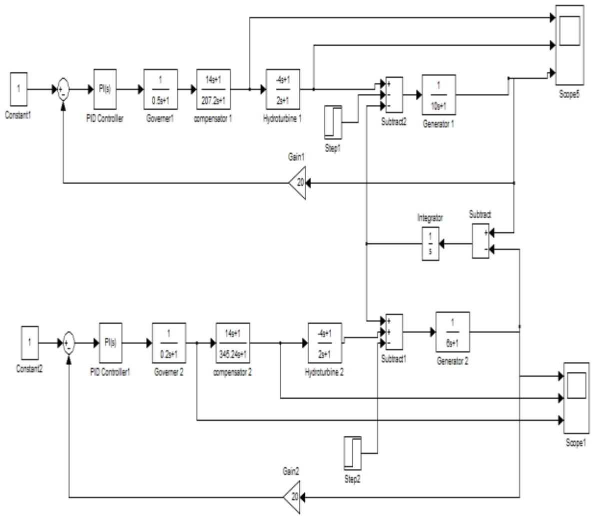


Fig 3: Simulation diagram of an interconnected hydropower system with PI controller (Using Trial and error method)

Table 1

	K_P	T_I
System 1	0.25	2
System 2	0.25	2

Table 2

	K_P	T_I

System 1	0.28	4.1091
System 2	0.22	5.367

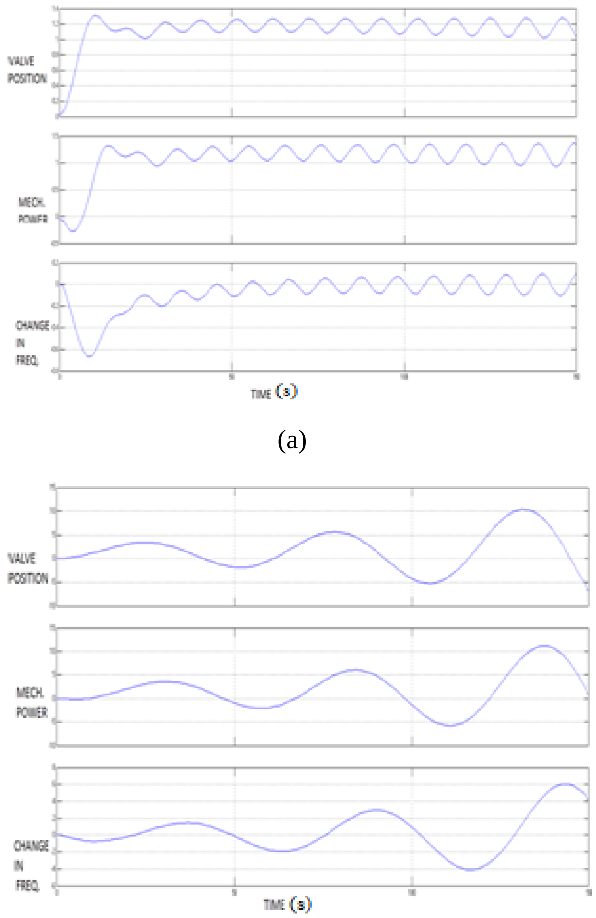
FOR SYSTEM 1

Draw Nichols chart for the transfer function

$$G(jw) = \frac{0.25(1+2s)(1-4s)}{2s(1+0.5s)(1+2s)}.$$

This open loop curve is tangential to 0.25db as shown in Fig (c) To make the curve to be tangent to 0db trace the curve in a tracing sheet. Shift the traced locus over the Nichols chart vertically, so that it is tangent to required M_r Contour. in this case, M_r =0dB (d) after shifting to Mr=0 dB 20logK=-1.75 which gives K=0.8175.

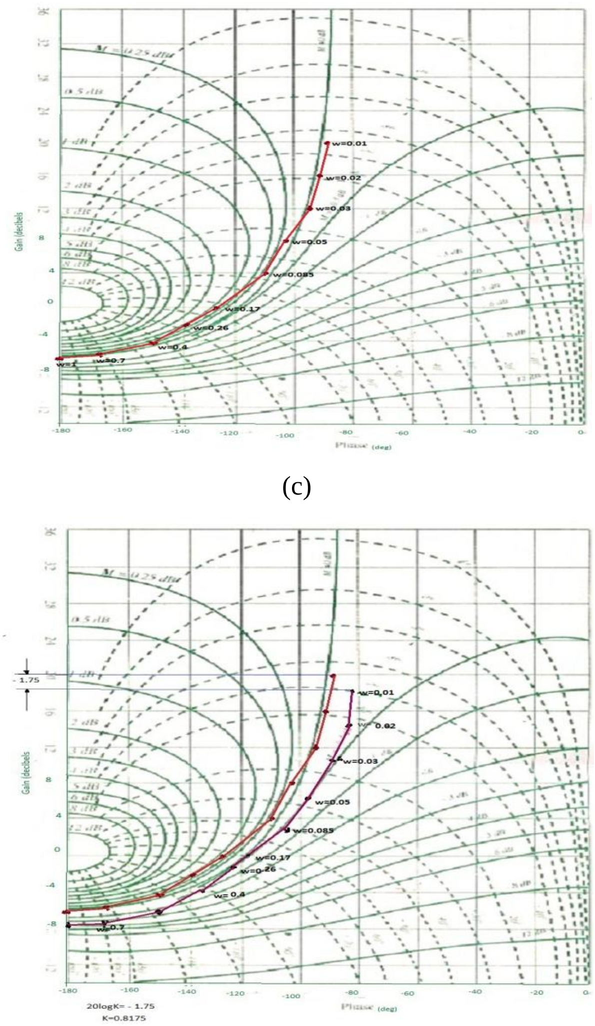
By similar way the system 2 controller parameters can be obtained and is tabulated in table 2



(a)

(b)

Fig. 4 : Valve position, mechanical power and change in frequency response of (a) interconnected hydropower system system (b) with PI controller (Z-N tuningmethod)



(c)

(d)

Fig. 5 : Nichols chart (c) for $G(jw) = \frac{0.25(1+2s)(1-4s)}{2s(1+0.5s)(1+2s)}$ with M_r=0.25

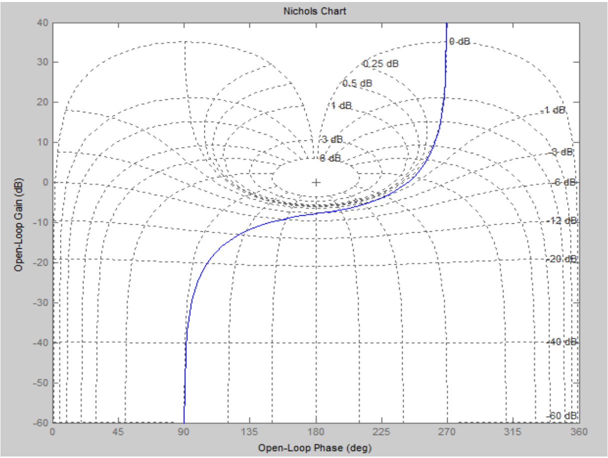


Fig. 6: Nichols chart (system 1)

Table 3

	K_P	K_I
System 1	0.204	0.102
System 2	0.1975	0.09

The MPRS controller has been designed and is simulated as shown in fig 7. In this method, valve position, mechanical power settle at 40 seconds but in the other two methods it had not settled. The tie line power is shown in fig 9.

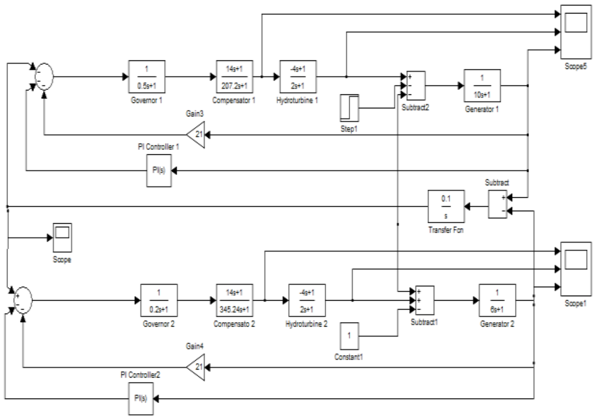
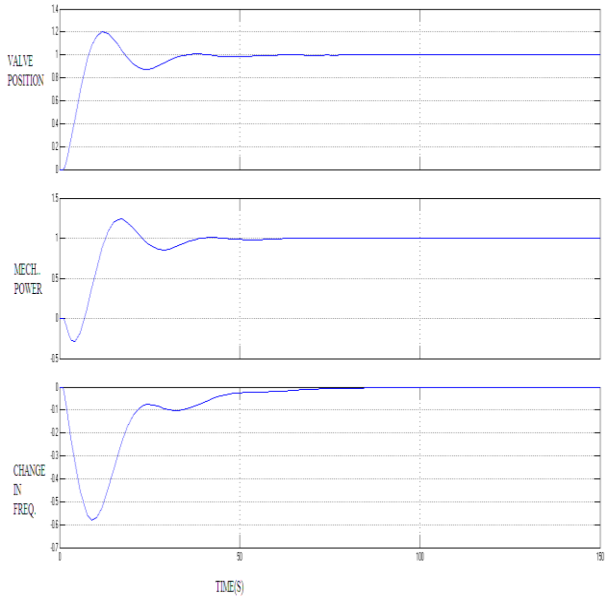


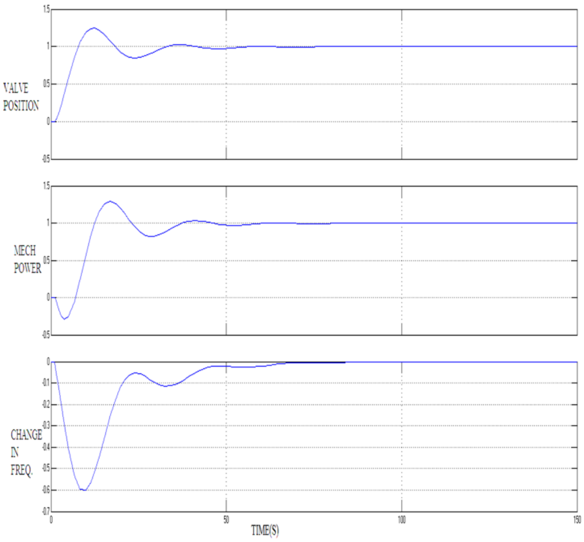
Fig. 7 : Simulation diagram of an interconnected hydropower system with PI controller (Using MPRS controller)



(e)

Fig. 8 : Valve position, mechanical power and change in frequency response of a interconnected hydropower system with MPRS controller (e)when step load is applied to both systems

After changing the load on both the hydropower systems, the valve position, mechanical power and change in frequency response of a interconnected hydropower system is not changes as shown in fig 9 (f).The tie line power is also get settled as shown in Fig 10.



(f)

Fig. 9 : Valve position, mechanical power and change in frequency response of a interconnected hydropower system with MPRS controller (f) when step load applied to one system and a constant load applied to other system

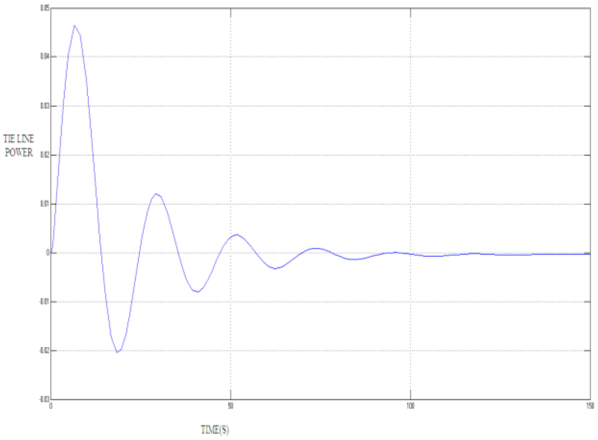


Fig. 10 : Tie line power of a interconnected hydropower system with MPRS controller

VI. CONCLUSION

In a two area hydro power system, change in load will result in the change in frequency as in the fig 1. So the two area hydro power system with PI Controller designed by Trial and error method, Ziegler-Nichols method and MPRS controller has been done and can be concluded as follows

The two area hydro power system with PI Controller designed by ziegler-nichols method shows that change in frequency is not settled at zero as shown in fig.(a) and fig. (b). Compared with trial and error method and ziegler-nichols method MPRS method of tuning gives good response as shown in fig (e) with rise time of 12.5 seconds , peak time of 10 seconds ,settling time of 40 seconds which can be applicable for almost all the process. The MPRS tuning method is robust so that any change in load in any of the system in an interconnected system does not alter the change in frequency.

Appendix

	2H	D	Tg	T_W	R_P	T_E	R_T
System 1	10	1	0.5	4	0.05	14	0.74
System 2	6	1	0.2	4	0.05	14	1.233

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