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Load Frequency Control of Hybrid Hydro Systems using tuned PID Controller and Fuzzy Logic Controller

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Abstract **- In this paper isolated hybrid Hydro Systems, namely Hydro-Thermal, Hydro-Solar, Hydro-wind and Hydro Diesel Systems are modeled. The tracking and handling the deviation in frequency known as Load Frequency Control (LFC) is done using tuned Proportional Integral and Differential (PID) controller and Fuzzy Logic Controller (FLC). Though the PID controller for LFC is ubiquitous, it is proved that the tuned PID controller in MATLAB gives closed loop stability and performance in the hybrid hydro system. The stability and the step response of the system is determined using MATLAB. Both the graphical and quantitative results of LFC with FLC for hybrid hydro systems are presented.**

Keywords: Load Frequency Control, PID Controller, Fuzzy Logic Controller, Hydro-Thermal, Hydro-Solar, Hydro-Wind, Hydro-Diesel

1. INTRODUCTION:

In recent trends the hydro system plays a major role in the generation of electrical power in rural areas as the cost of generation in relatively low. But it is seasonable, that is during dry seasons the availability of water reduces due to which the demand of the area could not be met. So in order to meet the demands during off seasons hybrid hydro systems are preferred. During dry seasons the area has sufficient sunlight, so a consistent exploitation of the complementarities of these two sources of energy is able to meet the demand. Similarly wind power is very consistent in areas, so wind power is used in conjunction with hydro electric power sources to give a reliable supply during off seasons. If the source of solar and wind are less, the hydro plants can be operated with Diesel plants if the demand is relatively less. In case of higher demands it is preferred to meet the demand with thermal plants called as hybrid hydro-thermal power systems. So the situations lead to hybrid hydro systems namely: Hybrid Hydro-solar, hydro-wind, hydro-diesel and hydro-thermal systems

In power system the change in load causes the frequency to deviate, so in order to minimize the deviation, Load Frequency Controllers (LFC) is synthesized in the power system[1-2]. The incorporation of LFC has a long history and the preliminary LFC schemes have evolved over the past decades. Conventional LFC are suitable for working at specific operating points and are not efficient in modern power systems with renewable energy resources. Many new approaches in LFC with an improved ability to maintain tie-line power flow and system frequency close to specified values has been proposed. Several intelligent control techniques like Fuzzy Logic, neural network, Tabu Search, Genetic Algorithm, Ant Colony Optimization and hybrid intelligent techniques has also been proposed for LFC. The intelligent methods have become an appealing approach as they are more adoptive and flexible.

Now a days because of the simplicity, reliability and robustness Fuzzy Logic Controller (FLC) is preferred in LFC. FLC becomes non-linear and adaptive in nature when the parameter varies. It has the ability to perform desired control actions for complex, uncertain and non-linear systems without the requirement of their mathematical models and parameter estimation. Several Fuzzy logic based LFC schemes have been reported [3-6].

In this paper, hybrid hydro systems namely: Hydro-solar, hydro-wind, hydro-diesel and hydro-thermal systems are modeled and the step response with and without controller is presented. The tuned PID controller and FLC are used as controllers.

2. MODELLINE OF HYBRID HYDRO SYSTEMS:

2.1 Modelling of Hydro Power Plant:

The hydro model consists of a Hydraulic Governor, Turbine and Generator Load model [7-8]. The transfer function of the hydraulic Governor is given by,

$$G_{HG} = \left(\frac{K_{HG}}{1-ST_{HG2}}\right)\left(\frac{1+ST_{HG1}}{1+ST_{HG3}}\right) \quad \text{--- (1)}$$

The transfer function of the turbine is

$$G_{HT} = \frac{1-ST_{HG2}}{1+0.5ST_{HG4}} \quad \text{--- (2)}$$

where K_{HG} is the gain of the Hydraulic Governor and $T_{HG1}, T_{HG2}, T_{HG3}\, and\ T_{HG4}$ are the time constants of the hydro model.

The generator dynamics is modeled using the swing equation.

The hydro model is shown in Fig. 1.

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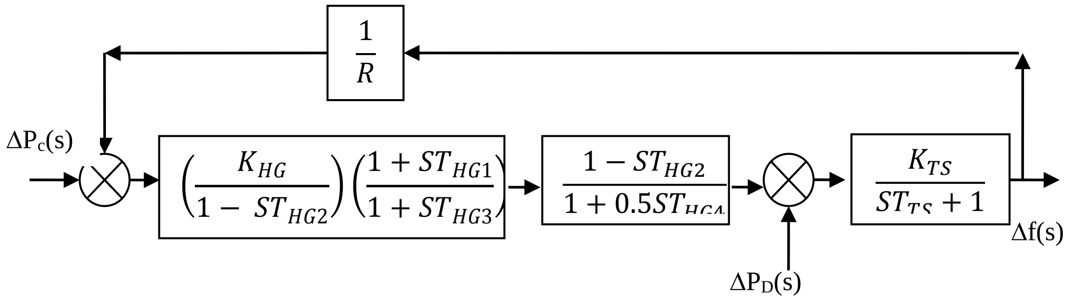

Fig. 1 Model of Hydro Powe Plant

2.2 Modelling of Thermal Power Plant:

The thermal plant is one of the bulk power generator which consists of a speed governor, turbine and a generator. The speed governor gives a command ΔP_c which initiates a sequence of events which leads to the opening and closing of the pilot valve [9-11]. The speed of the turbine depends on the opening and closing of the pilot valve. The transfer function of the speed governor is given by

$$G_{TG} = \frac{K_{TG}}{ST_{TG}+1} \quad \text{--- (3)}$$

Where K_{TG} is the gain of the thermal speed governor and T_{TG} is the time constant of the thermal governor.

The dynamic response of the steam turbine depends on the change in the steam valve opening which in turn changes the power generation. The turbine model is given by a first order system,

$$G_{TT} = \frac{K_{TT}}{ST_{TT}+1} \quad \text{--- (4)}$$

Where K_{TT} is the gain of the turbine

T_{TT} is the time constant of the thermal turbine.

The generator-load model of the thermal is given as

$$G_{TS} = \frac{K_{TS}}{ST_{TS}+1} \quad \text{--- (5)}$$

Where K_{TS} and T_{TS} are the gain constant and time constant of the generator load model of the thermal system.

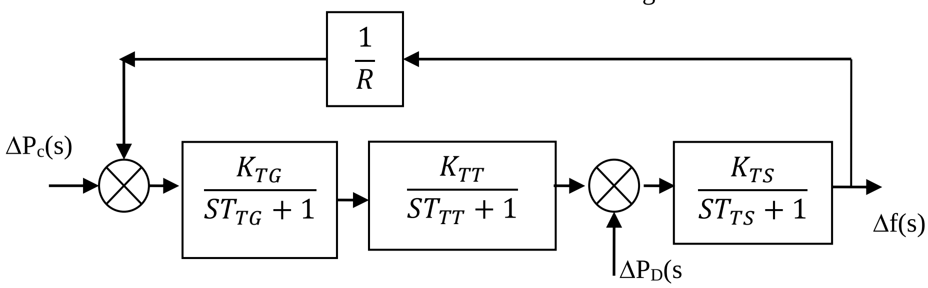

Fig. 2 Model of Thermal Power Plant

2.3 Modelling of Diesel Generator System:

Diesel generator is a small scale power source which has high durability, starting speed and eeficiency. The fuel is regulated accordingly to the variation in load. The DG consists of a generator and a governor, which are normaly denoted by first order inertia plants [13-14]. The continous time transfer function model is given in Fig. 3.

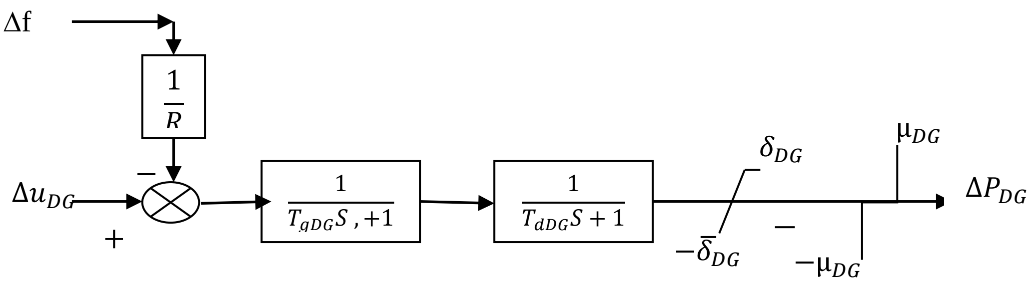

Fig. 3 Model of Diesel Generator system

In the model,

Δf is the Change in Frequency

Δu_{DG} is the controller signal to the DG

T_{gDG} and T_{dDG} are the time constants of the governor and DG respectively

$\pm\delta_{DG}$ and $\pm\mu_{DG}$ are the power ramp rate limit and power incremental limit respectively

2.4 Modelling of Wind system:

The transfer function of the Wind model is of very high order and has large number of non linearities. But the wind model can be described by a second order transfer function. The wind turbine model has two major parts namely, the wind turbine and the electric generator[12-16]. The objective of the control of the wind model is to maintain a constant angular speed and a constant power. The angular speed is fedback to accomodate the fluctuations in the wind speed.When the angular is controlled the aerodynamic torque is controlled, inturn the mechanical power is extracted. When the aerodynamic torque and the angular speed is controlled the output power P_m remains constant. The wind turbine and the electric generator are simplified into a first order system.

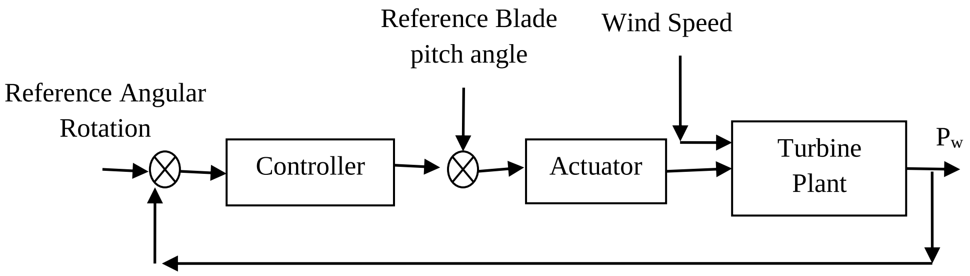

Fig. 4 Model of Wind System

Transfer function of the wind turbine ,

$$G_{WT} = \frac{K_{WT}}{sT_{WT}+1} \quad \text{--- (6)}$$

Transfer function of the Generator of the wind model,

$$G_{WG} = \frac{K_{WG}}{sT_{WG}+1} \quad \text{--- (7)}$$

Where K_{WT} and T_{WT} are the gainconstant and time constant of the wind turbine,

K_{WG} and T_{WG} are the time constants of the generator.

2.5 Modeling of Solar Panel:

The PV model is considered with PV panel, Maximum Power Point Tracking (MPPT) inverter and filter.The transfer function of the PV panel is determined from the equation of solar cell output current and photo current equations. The MPPT is a method to harness the maximum power from the solar panel. The MPPT model is found by considering the ON and OFF state of the boost converter. By combining the transfer functions of all the components the transfer function of the PV model is obtained.

3. LOAD FREQUENCY CONTROLLERS OF HYBRID HYDRO MODELS

3.1 PID Controller for Load frequency control of Hybrid Hydro Models:

The PID Controller is one of the conventional and commercial controller. For a mathematical model of a plant it is possible to apply different design techniques and the paramters of the controllers which meet the transient and steady statespecification of the closed loop can be determined. The process of adjusting the controller parameters to the optimum for the desired control response is called as controller tuning [17].

In this paper the PID controller is tuned using the mathwork algorithm for tuning PID controllers which meets the objectives of PID tuning namely, closed loop stability, adequate performance and robustness. The PID gains are tuned such that there is a good balance between performance and robustness.The mathwork algorithm chooses a crossover frequency based on the plant dynamics in default. Then it designs for a target phase margin of 60^0. When the response time, bandwidth, transient response or phase margin are changed the PID gains are computed. The Integral gain, Rise Time, Settling Time, Overshoot, Peak, Gain Margin and Phase Margin of the controller are determined. The Closed loop stability is also determined.

The PID tuning is done by initially selecting P which results in a highly oscillatory stable response with D and I as zero. Then the parameter D is selected by having P selected earlier, to take care of transient performance. Then the value of I is acquired with the P and D values which were selected in the previous steps to take care of steady state performance. Then a complete tuned PID controller with P, I and D values is designed.

The compensator formula is given by

$$P + I\frac{1}{s} + D\frac{N}{1+N\frac{1}{s}} \quad \text{--- (8)}$$

where P is proportional,

I is integral,

D is Derrivative and

N is the filter co-efficient.

3.2 Fuzzy Logic controller for LFC of Hybrid Hydro models:

Inorder to adequately deal the system complexity, non-linearity and uncertainity Fuzzy Logic Controllers are used. FLCs are the intelligent controllers which are smart in handling non-linear systems. In FLCs the control parameters are adjusted by fuzzy rule based expert systems. The FLC is designed to improve the performance of the governor. The FLC uses the system frequency deviation as the feedback input, so that it can offset the mismatch between the system generation and the load demand.The

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FLC consists of a Fuzzifier, Rule base fuzzy interference and De-fuzzifier.

The steps involved in the FLC are:

i. The inputs and the outputs are decided. The input are the error E (Δf(s)) and the change in error ΔE. The output is ΔPc.

ii. The inputs are fuzzified using the membership functions into linguistic labels or fuzzy sets. Fuzzification is done using seven fuzzy linguistic sets.

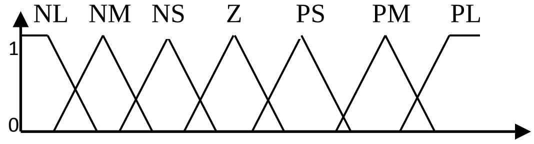

Fig. 5 Membership function

iii. The fuzzy interference process is done in which the conclusions or generating hypothesis from the given input state are determined. The fuzzy logic rules which defines the dependancies between linguistically classified input and output values.The fuzzy rule base is given in Table 1.

Table 1. Fuzzy Rule Base

E/ΔE	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PM	PM	PS	Z
NM	PL	PM	PM	PM	PS	Z	PS
NS	PM	PM	PS	PS	Z	NS	NM
Z	PL	PM	PS	Z	NS	NM	NL
PS	PM	PS	Z	NS	NS	NM	NL
PM	PS	Z	NS	NM	NM	NM	NL
PL	Z	NS	NM	NM	NL	NL	NL

iv. Defuzzification of the ouput is done.Defuzzication is done using the centre-Of-Area (COA) method

4. RESULTS AND DISCUSSIONS:

The load frequency control of various hybrid hydro models, namely Hydro-Thermal, Hydro-Wind, Hydro-Diesel and Hydro-Solar system with the tuned PID controller and FLC is discussed. The deviation in frequency of the system has been obtained with controller, with tuned PID controller and with FL controller. The step response of the PID controller with tuned valued, rise time, settling time, overshoot percentage, peak, gain margin and phase margin is also presented.

The deviation in frequency of the hydro model is shown in Fig. 6 which clearly shows a high deviation in frequency. The chosen value of K_{HG} is 1 and the time constants $T_{HG1}, T_{HG2}, T_{HG3} and\ T_{HG4}$ are 48.7s, 5s ,0.513s and 1s respectively. The deviation in frequency is about 0.045. Fig. 7 shows the deviation in frequency with the tuned PID controller in which the deviation in frequency is zero. Fig. 8 shows the step response of the tuned PID controlled whose I value is 6.332. The rise time, settling time, overshoot percentage, peak, gain margin and phase margin of the response is 24.7, 47.3, 0, 0.999, 13.1 and 83 respectively. The response of the system with FLC is shown in Fig 9.

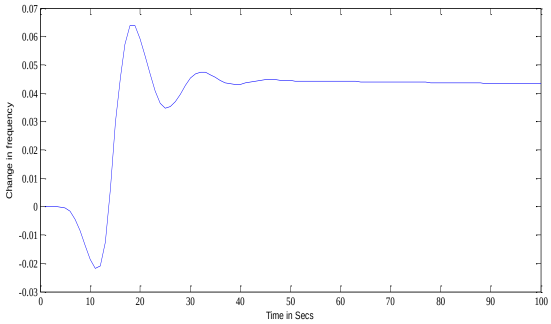

Fig. 6 Deviation in Frequency of hydro model

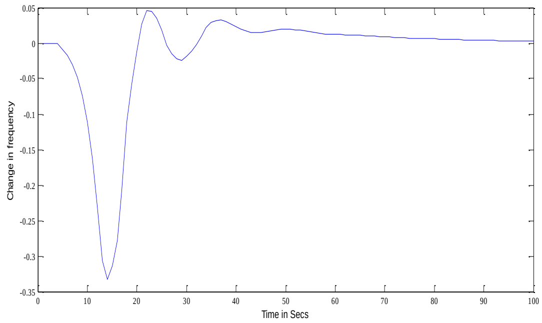

Fig. 7 Deviation in Frequency of hydro model with tuned PID controller

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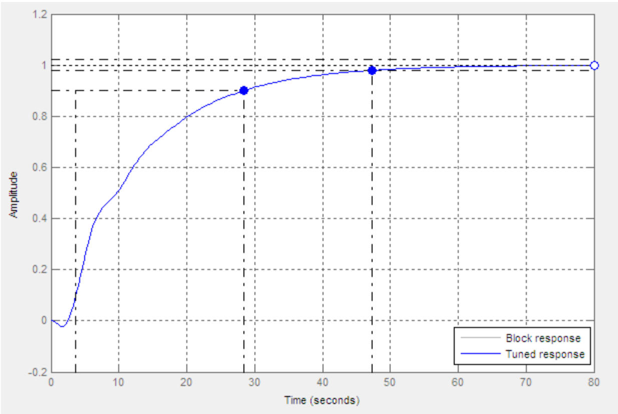

Fig. 8 Step response of the tuned PID controller of Hydro model

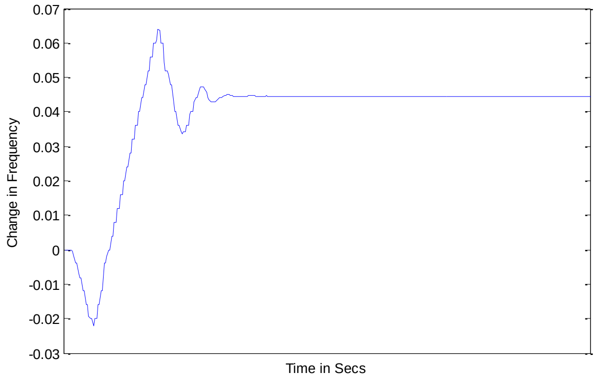

Fig. 9 Deviation in Frequency of hydro model with FLC

Fig. 10 shows the deviation in frequency of the hybrid Hydro-Diesel system by choosing the values of T_{gDG} and T_{dDG} as 0.025s and 1s. The deviation is frequency is zero with the tuned PID controller which is depicted in Fig. 11. The step response of the tuned PID controller with rise Time - 24.4 s ,settling time 46s, overshoot- 0%, peak -0.999, gain margin-13.1 rad/s, phase margin- 82.2 is shown in Fig 12 . The value of I is tuned as 6.4008. The Closed loop stability of the system is Stable and the response time is 26.5 s. The deviation in frequency of the hybrid Hydro-Diesel system with FLC is shown in Fig.13.

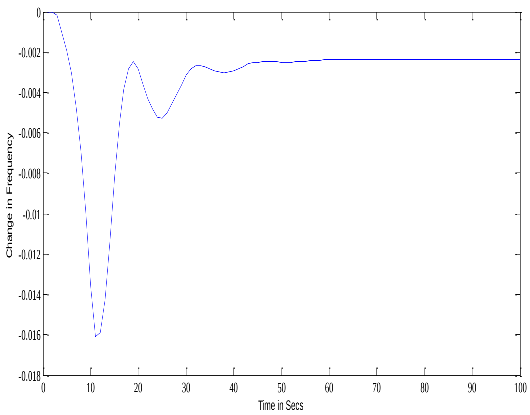

Fig. 10 Deviation in Frequency of Hydro-Diesel model

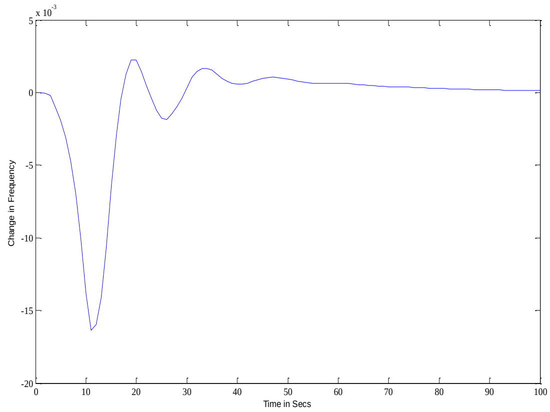

Fig. 11 Deviation in Frequency of Hydro-Diesel with tuned PID controller

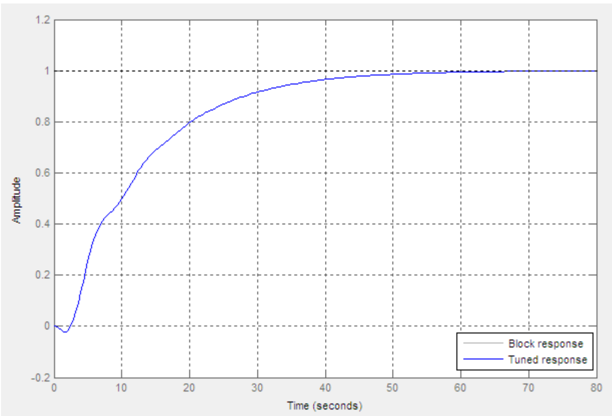

Fig. 12 Step response of the tuned PID controller of Hydro-Diesel
model

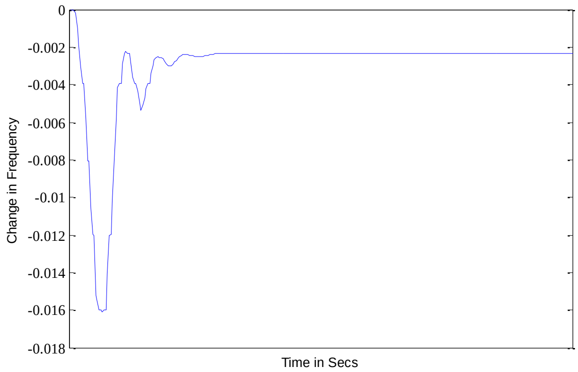

Fig. 13 Deviation in Frequency of Hydro-Diesel with FLC

The gains of the wind turbine and the generator are set as 1.The time constants of the wind turbine and the generator of the wind model are 1.5 and 0.5. The deviation in frequency of the hybri Hydro-Wind model without controller is given in Fig.14.

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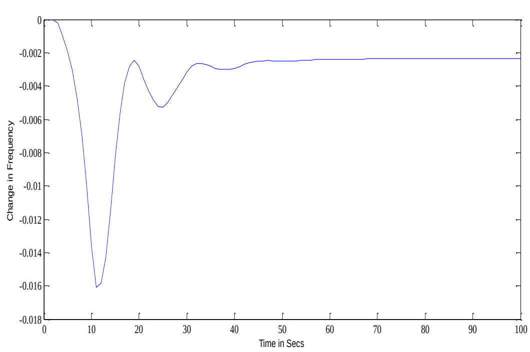

Fig. 14 Deviation in Frequency of Hydro-Wind model

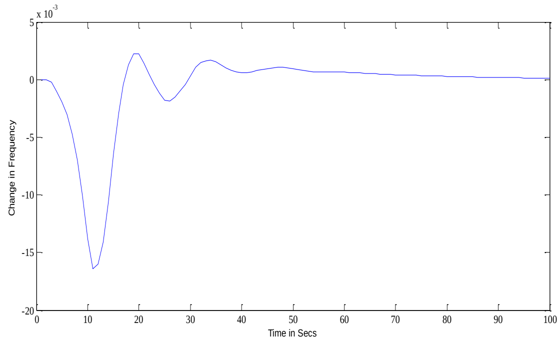

Fig. 15 Deviation in Frequency of Hydro-Wind with tuned PID controller

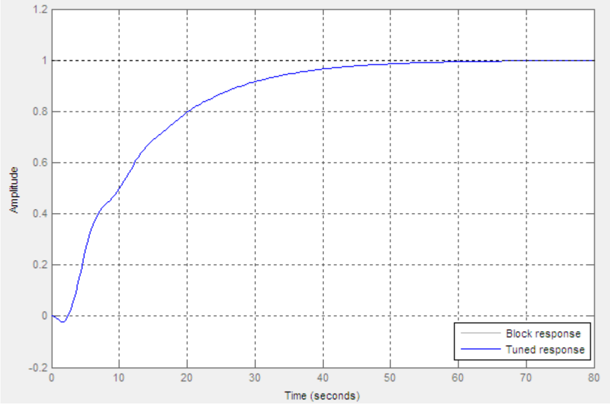

Fig. 16 Step response of the tuned PID controller of Hydro- Wind model

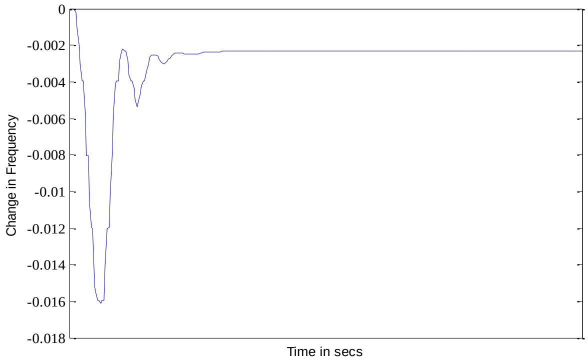

Fig. 17 Deviation in Frequency of Hydro- Wind with FLC

The response of the hybrid Hrdro-Wind model with tuned PID controller and the step response of the controller is shown in Fig 15 and Fig. 16 respectively. The value of I is obtained as 6.4008 and rise Time, settling time, Overshoot %, peak, gain margin, phase margin of the tuned PID controller is 24.4s, 46 s, 0% , 0.999, 13.1 rad/s and 82.2 respectively.The Closed loop system is stable. Fig. 13 shows the deviation in frequency of the hybrid Hydro-Wind system with FLC.

The deviation in frequency of the hybrid Hydro-Thermal system without controller by choosing K_{TG} and T_{TG} as 1 and 0.08s, K_{TT} and T_{TT} as 1 and 0.3s and K_{TS} and T_{TS} as 120 and 20s is shown in Fig. 18. The frequency of the hybrid Hydro-Thermal system settles to zero with tuned PID controller whose Integral gain is 0.05204. The step response of the tuned PID controller with is shown in Fig. 20. The parameters of the response are rise Time- 41.2, settling time - 69.7 s, overshoot - 0%, peak- 1, gain margin - 14 rad/s, phase margin -79.1 rad/s. The Closed loop stability of the Hydro-Thermal system is stable. The frequency deviation of the hybrid Hydro-Thermal system is shown in Fig. 21.

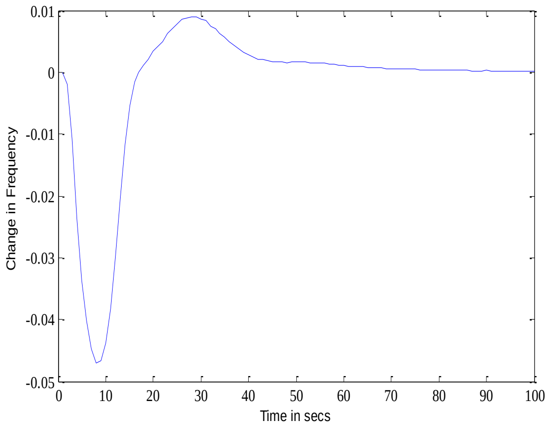

Fig. 18 Deviation in Frequency of Hydro-Thermal model

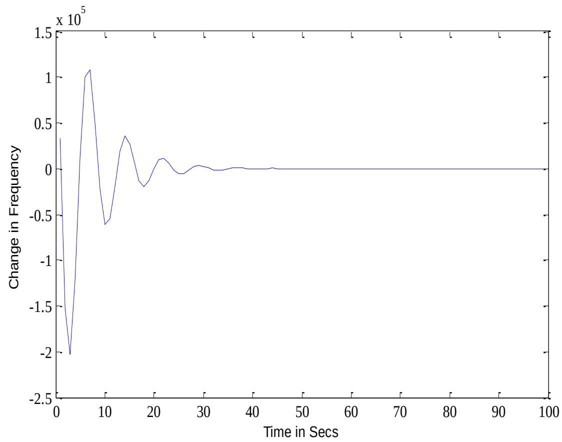

Fig. 19 Deviation in Frequency of Hydro- Thermal with tuned PID controller

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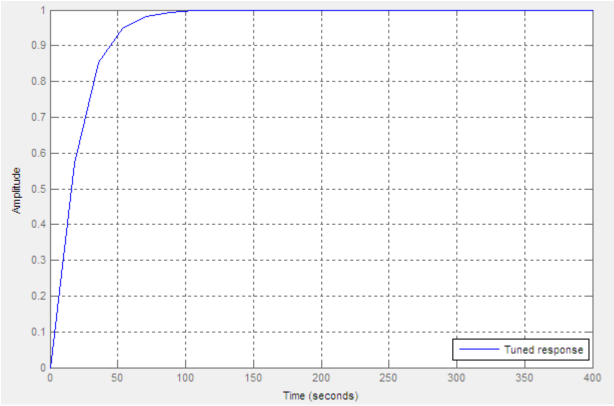

Fig. 20 Step response of the tuned PID controller of Hydro- Thermal model

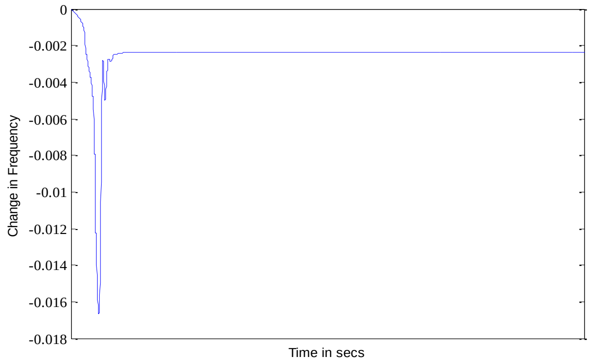

Fig. 21 Deviation in Frequency of Hydro- Thermal with FLC

Fig. 22 shows the deviation in frequency of the hybrid Hydro-Solar system without controller. Fig. 23 and Fig. 24 depicts the response of the tuned PID controller of the Hydro-Solar system. The values of I and P are obtained as 0.2833 and 0.0345. The rise time, settling time, overshoot, peak, gain margin and phase margin of the controller is 5.31s, 55.6s, 0%, 0.997, 40.8 rad/s and 60 rad/s respectively.The closed loop Hydro-Solar system is stable. The deviation in frequency of the the Hydro-Solar system with FLC is shown in Fig. 25.

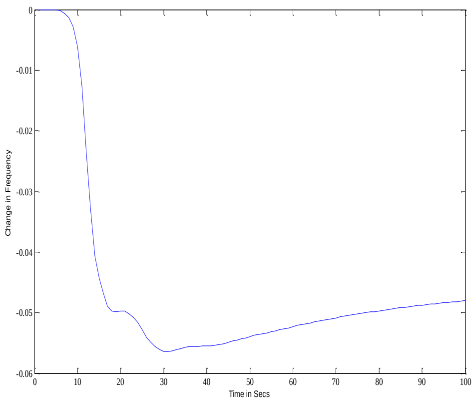

Fig. 22 Deviation in Frequency of Hydro-PV model

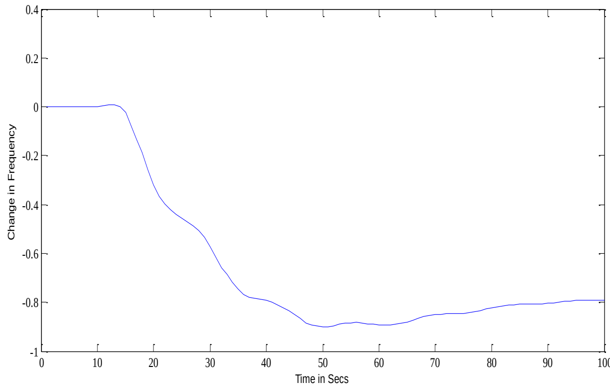

Fig. 23 Deviation in Frequency of Hydro-PV with tuned PID cor

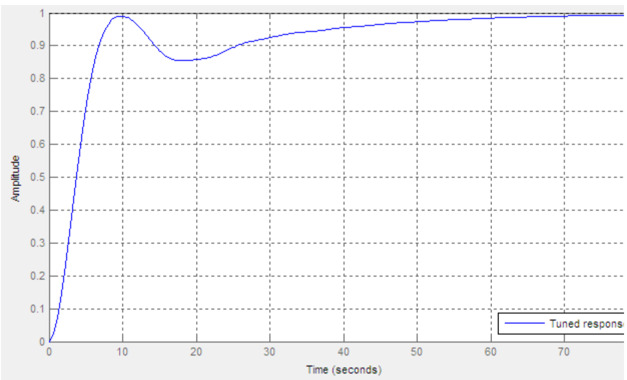

Fig. 24 Step response of the tuned PID controller of Hydro- PV model

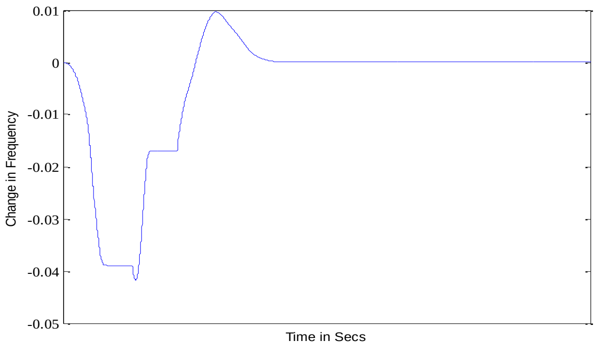

Fig. 25 Deviation in Frequency of Hydro- PV with FLC

5. CONCLUSION:

Hybrid hydro systems were modelled with the synthesis of Thermal, Wind, Diesel and Solar Plants. The PID controller and FLC were designed for the hybrid systems and the step response were determined. The stability and the response of the system were analyzed. The results obtained reveals that the PID and the FLC controllers for LFC have adequate performance and robustness.

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