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Automatic Generation Control of an Interconnected Hydro-Thermal System Using Fuzzy Logic and Conventional Controller

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Abstract— This paper deals with Automatic Generation Control (AGC) of interconnected two area Hydro-Thermal System using conventional integral and fuzzy logic controllers. The hydro area is considered with an electric governor and thermal area .is considered with reheat turbine. Effects of different number of triangular membership functions and inputs for fuzzy logic controller on dynamic responses have been explored. 1% step load perturbation has been considered occurring either in individual area or occurring simultaneously in all the areas. In this thesis, fuzzy sets and fuzzy logic are highly reflected by applying to the system. Consequently, improved results are also obtained. However, as fuzzy logic is human being dependent rule base, misinterpretation can corrupt the result. Hence by focusing on its proper methodology it is possible to acquire a low expenditure of time and effort as an optimal result.
Index Terms— ACE, Integral Control, Membership function, Step load Petrubation, Steady State, fuzzy logic controller, Tie-Line

1 Introduction

MODERN power system network consists of a number of utilities interconnected together & power is exchanged between utilities over tie-lines by which they are connected. Automatic generation control (AGC) plays a very important role in power system as its main role is to maintain the system frequency and tie line flow at their scheduled values during normal period and also when the system is subjected to small step load perturbations. In analyzing the problems associated with the controlled operation of power systems, there are many possible parameters of interest. In the classical AGC system the balance between generation and load was achieved by detecting frequency and tie-line flow deviations, which were used in generating an ACE signal. The ACE signal was used for an integral feedback control strategy. At steady state, the generation would be matched exactly with the load, causing tie-line power and frequency deviation to drop to zero. At transient state, there should be a flow of power from other areas to supply the excess load in the area where transient drop (during a sudden area load change, area frequency experiences a load, known as transient drop) occurs. Concordia and Kirchmayer [3] have studied the AGC of a hydro-thermal system considering non-reheat type thermal system neglecting generation rate constraints. Kothari, Kaul, Nanda [14] have investigated the AGC problem of a hydro-thermal system provided with integral type supplementary controllers.

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In modern hydro thermal system, reheat type turbine and electric governor [11] are used. Perhaps Nanda, Kothari and Satsangi [15] are the first to present comprehensive analysis of AGC of an interconnected hydrothermal system in continuous-discrete mode with classical controllers.

2 Operational Simulation Model

While two areas are operating in unison, the ultimate motive is to maintain the stability. To maintain stable operating condition frequency of the tie-lines should always be constant. If any unstable situation is raised in the system, load frequency relay should catch that and immediate action will be taken by the controller. Actually the relationship between speed and load can be adjusted by changing the input load reference set point. By changing the load reference the, the generator characteristics can be set to give the reference frequency at any desired output. The basic control input to a generating unit as far as generation control considered is the load reference set point.

It is seen that steady-state frequency can be brought back to the scheduled value by adjusting the speed changer set. This is achieved by integral control, which acts on the load reference setting of the governor of the unit. The integral control action ensures zero frequency error in steady-state. This supplementary control action is much slower than the primary speed control action. As such, it takes effect after the primary speed control has stabilized the system frequency.

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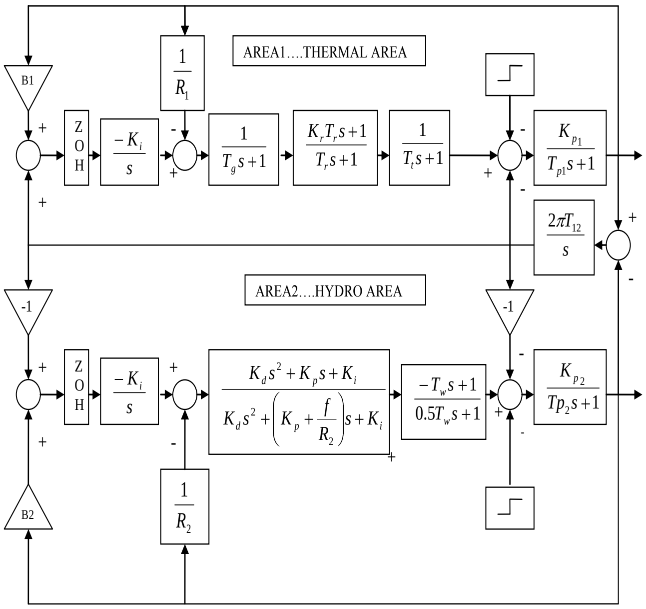

Fig.1. Transfer function Model of a Two-Area Interconnected Hydro-Thermal System.

3 Results

3.1 With Integral Controller

When fig.3.1 is considered where the integral controller is used to control the operation of the interconnected two-area hydro-thermal system, the response curves shows a lot of improvement and fast response. Dynamic responses (Δf1, Δf2, ΔPG1, ΔPG2 and ΔP_{Tie}) are obtained for 1% step load perturbation considered either in hydro area or thermal area. A sampling period of 2 second is considered in this system. The values of Integral gains considered are K_{11}=0.12 and K_{12}=0.09 for thermal area and hydro area respectively. The response curves become like under damped step response curve, which quite preferable in industrial arena. The frequency response curves for two area interconnected hydro-thermal system are given below.

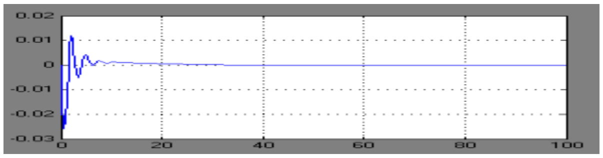

Fig. 2. Δf_1 (Hz) Vs Time (Sec)

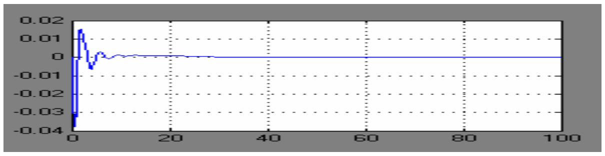

Fig. 3. Δf_2 (Hz) Vs Time (Sec)

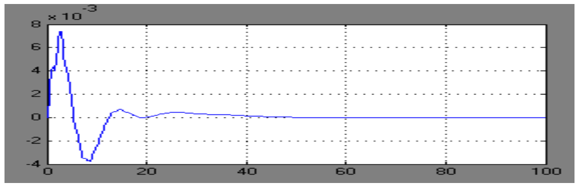

Fig. 4. ΔP_{Tie} (MW) Vs time (Sec)

3.2 With Fuzzy Logic Controller

3.2.1 Model (1) 3 MF with 9 Rules

In a fuzzy scale, each membership functions have three linguistic stages and those are Low (L), Normal (N) and High (H).

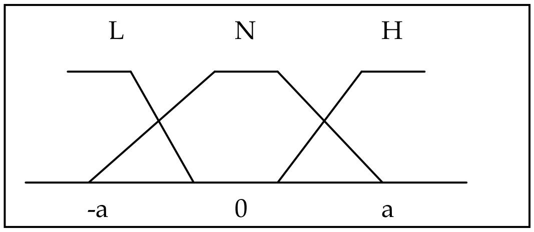

Fig. 5. Possible Fuzzy Quantization of the range [-a, a] by triangular shaped fuzzy numbers

With the 3MFs 9 rules are formed and applied to the system. Here from the curves of change in frequency (Δf_2) for the hydro area it can be concluded that 9 rules gives a very good result as compared to integral controller approach. The results show that the maximum peak overshoot is not reduced but the settling time is reduced as compared to integral controller approach. Similarly the other responses are observed.

Table 1
Fuzzy Rule for Three Membership Functions

Variable	L	N	H
L	L	L	N
N	L	N	H
H	N	H	H

But the curves of Δf_1, Δf_2 and ΔP_{Tie} show very good result as compared to that of integral controller approach. Because both the maximum peak overshoot and settling time are reduced. Here ΔP_{Tie} is considered by taking 1% step load perturbation in both the areas.

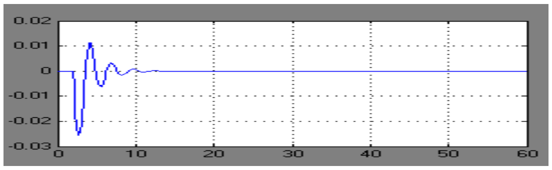

Fig. 6. Δf_1 (Hz) Vs Time (Sec)

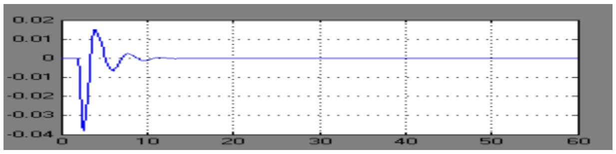

Fig. 7. Δf_2 (Hz) Vs Time (Sec)

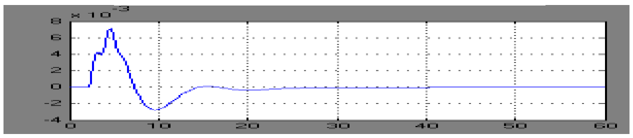

Fig. 8. ΔP_{Tie} (MW) Vs time (Sec)

3.2.2 Model (2) 5 MF with 25 Rules

In a fuzzy scale, each membership functions of five linguistic states of triangular type are mapped into the values of Negative Large (NL), Negative Small (NS), Zero Error (ZE), Positive Small (PS) and Positive Large (PL). With the 5MFs 25 rules are formed and are applied to the system. The response curves of Δf_1 and Δf_2 shows more stability. It shows typical hydro-thermal area like behavior with fast settling time.

TABLE 2
FUZZY RULE FOR 5 MEMBERSHIP FUNCTIONS

Variable	NL	NS	ZE	PS	PL
NL	NL	NL	NS	NS	ZE
NS	NL	NL	NS	ZE	ZE
ZE	NS	NS	ZE	PS	PS
PS	ZE	PS	PS	PL	PL
PL	ZE	ZE	PS	PL	PL

TABLE 3
OPTIMUM VALUES OF FEEDBACK GAINS FOR DIFFERENT MEMBERSHIP FUNCTIONS

Number of MFs	K_{t1}	K_{t2}
3	0.887	0.887
5	0.007	0.01
7	0.999	1.0
9	0.007	0.01

For different membership functions appropriate feedback gain K_t has been found that corresponds to zero steady state error in the dynamic responses. Here 1% step load perturbation is considered either in thermal and hydro area for $\Delta f_{1,}\Delta f_2$. But for ΔP_{Tie} 1% step load perturbation is considered in both the areas. The response curves show very good results as compared to 3MFs. Here both the settling time and maximum peak overshoot are reduced.

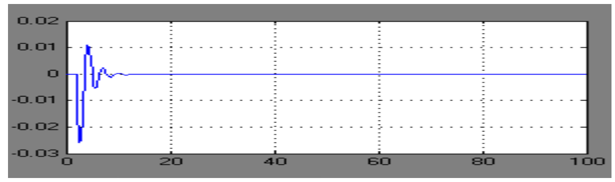

Fig. 9. Δf_1 (Hz) Vs Time (Sec)

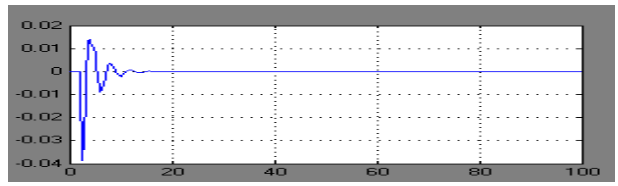

Fig. 10. Δf_2 (Hz) Vs Time (Sec)

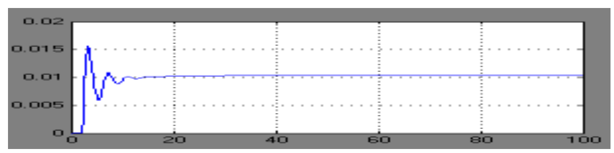

Fig. 11. ΔP_{Tie} (MW) Vs Time (Sec)

3.2.3 Model (3) 7 MF with 49 Rules

In a fuzzy scale, each membership functions are divided into seven linguistic stages of triangular type and are given as Negative Large (NL), Negative Medium (NM), Negative Small (NS), Approximately Zero (AZ), Positive Small (PS), Positive Medium (PM) and Positive Large (PL). By using these 7 MF's 49 governing rules are formed and applied to the system.

TABLE 4
FUZZY RULE FOR 7 MEMBERSHIP FUNCTIONS

Variable	NL	NM	NS	AZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	AZ
NM	NL	NL	NL	NM	NS	AZ	PS
NS	NL	NL	NM	NS	AZ	PS	PM
AZ	NL	NM	NS	AZ	PS	PM	PL
PS	NM	NS	AZ	PS	PM	PL	PL
PM	NS	AZ	PS	PM	PL	PL	PL
PL	AZ	PS	PM	PL	PL	PL	PL

The response curves produce not only the best results among all the controllers like integral controller and FLC with 3MFs even if its give the result almost like the ideal case. From the response curves, it can be concluded that the response curve became under damped system with the maximum peak over-

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shoot 0.015 unit. Here a step load perturbation of 1% is considered either in thermal or hydro area for Δf_1, Δf_2, but for ΔP_{Tie} 1% step load perturbation is considered in both the areas.

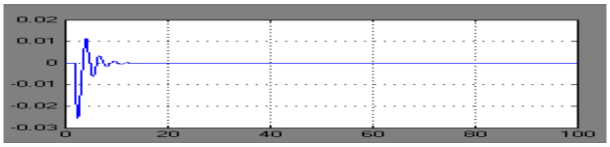

Fig. 12. Δf_1 (Hz) Vs Time (Sec)

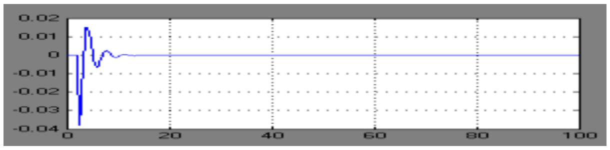

Fig. 13. Δf_2 (Hz) Vs Time (Sec)

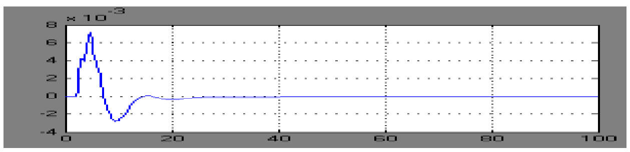

Fig. 14. ΔP_{Tie} (MW) Vs time (Sec)

3.2.4 Model (4) 9 MF with 49 Rules

In a fuzzy scale, each membership functions are divided into nine linguistic stages of triangular type and are given as Too Low (TL), Negative Large (NL), Negative Medium (NM), Negative Small (NS), Approximately Zero (AZ), Positive Small (PS), Positive Medium (PM), Positive Large (PL) and Too High (TH).

TABLE 5

FUZZY RULE FOR 9 MEMBERSHIP FUNCTIONS

Variable	TL	NL	NM	NS	AZ	PS	PM	PL	TH
TL	TL	TL	TL	TL	TL	NL	NM	NS	AZ
NL	TL	TL	TL	TL	NL	NM	NS	AZ	PS
NM	TL	TL	TL	NL	NM	NS	AZ	PS	PM
NS	TL	TL	NL	NM	NS	AZ	PS	PM	PL
AZ	TL	NL	NM	NS	AZ	PS	PM	PL	TH
PS	NL	NM	NS	AZ	PS	PM	PL	TH	TH
PM	NM	NS	AZ	PS	PM	PL	TH	TH	TH
PL	NS	AZ	PS	PM	PL	TH	TH	TH	TH
TH	AZ	PS	PM	PL	TH	TH	TH	TH	TH

Here a step load perturbation of 1% is considered either in thermal or hydro area for Δf_1, Δf_2, but for ΔP_{Tie} 1% step load perturbation is considered in both the areas. The response curves show very good results as compared to integral controller but comared with FLC 3MFs, 5MFs and 7MFs the show poor results.

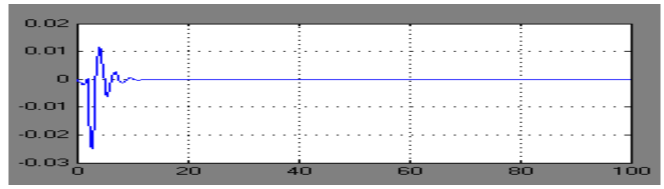

Fig. 15. Δf_1 (Hz) Vs Time (Sec)

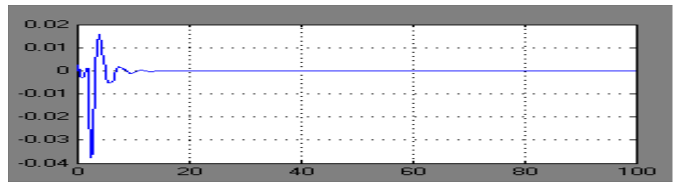

Fig. 16. Δf_2 (Hz) Vs Time (Sec)

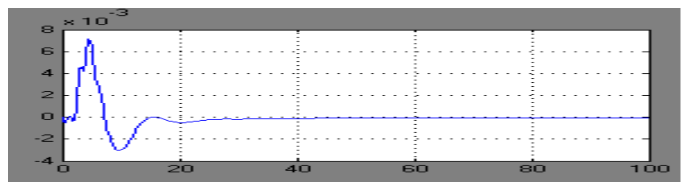

Fig. 17. ΔP_{Tie} (MW) Vs Time (Sec)

3.3 Stability Analysis

From the response curves maximum peak shoot and settling time can be calculated. From that damping ratio can be calculated by the formula-

$$\%M_P = e^{\frac{-\xi\cdot\pi}{\sqrt{1-\xi^2}}} \times 100$$

Where ξ= the damping ratio and M_P is the maximum peak overshoot.

By the following table, the stability of the system investigated by five controller approaches (four different FLC and Integral Controller) can be analyzed by comparing them.

TABLE 6

COMPARISION OF TS, MP AND Ξ

Controllers	Settling Time,Ts (Sec)	Max. Peak Overshoot Mp	Damping Ratio ξ
Integral	34.7	0.015	0.502
3 MF	17.56	0.015	0.502
5 MF	16.9	0.013	0.514
7 MF	17.33	0.015	0.502

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9 MF	**27.43**	**0.017**	**0.490**

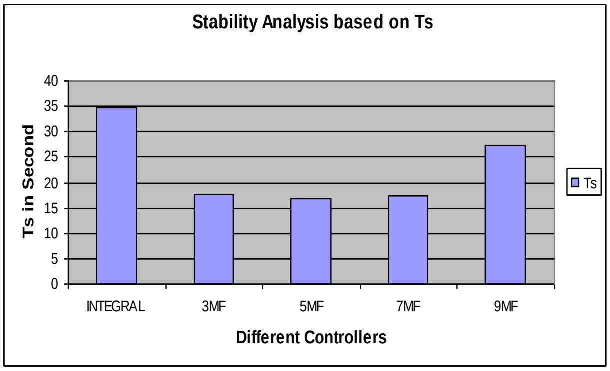

Fig. 18. Stability Analysis Based on Ts

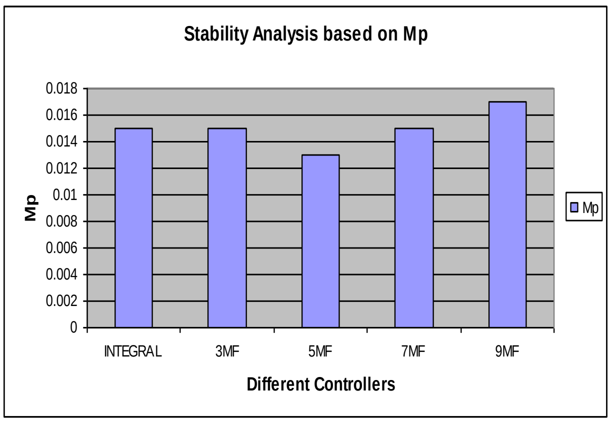

Fig. 19. Stability Analysis Based on Mp

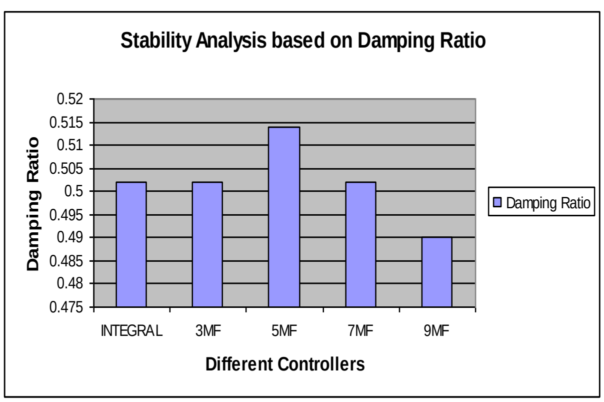

Fig. 20. Stability Analysis based on ξ

From the graphical representation it can be concluded that the FLC with 3MFs, 5MFs, 7MFs and Integral controllers help the system to be within very controllable margin as their $\%M_p$ is very small and the damping ratio is also small enough to control. According to settling time, FLC with 3MFs, 5MFs and 7MFs reached to the stable point very quickly than the other controllers. Finally from the above analysis and graphical representation it is clear that the FLC with 5MFs shows very good result as compared to other controllers with both the settling time and maximum peak overshoot reduced.

4 Conclusion

In this paper different controlling schemes are applied for the automatic generation control (AGC) of an interconnected hydro-thermal system. From the response curves and the stability analysis, the conclusion has come that

- Fuzzy logic controller shows very good dynamic response than conventional integral controller.
- The number of triangular membership functions (MFs) has an impact on dynamic responses and hence needs to be properly selected.
- FLC with 5MFs shows very good result as compared to all the other controllers
- The presence of fuzzy logic controller (FLC) in both the areas and a small step load perturbation in one area provides small steady state error.

5 Appendices

Appendix A: Symbols

f = Nominal System Frequency.
i = Subscript referred to area i (1, 2).
* = Subscript denotes optimum value.
P_{ri} = Area Rated Power.
H_i = Inertia Constant.
ΔP_{Tie} = Incremental change in tie line power
ΔP_{Di} = Incremental load change in area i.
ΔP_{gi} = Incremental generation change in area i.
$D_i = \Delta P_{Di}/\Delta f_i$.
T_{ij} = Synchronizing coefficient.
R_i = Governor speed regulation parameter.
T_{gi} = Steam governor time constant of i^{th} area.
K_{ri} = Steam turbine reheat constant of i^{th} area.
T_{ri} = Steam turbine reheat time constant for i^{th} area.
T_{ti} = Steam turbine time constant for i^{th} area.
B_i = frequency bias constant for i^{th} area.
$T_{pi} = 2H_i/f^*D_i$. (Power system time constant of i^{th} area).
$K_{pi} = 1/D_i$. (Power system gain for i^{th} area).
K_{Ii} = Integral gain for i^{th} area.
K_d, K_p, K_i = Electric governor derivative, proportional and integral gains respectively.
$\beta_i = (D_i + 1/R_i)$; Area frequency response characteristics.
T_w = Water starting time.
ACE_i = Area Control Error of area i.
$a_{12} = -P_{r1}/P_{r2}$.
J = Cost Index.
T = Sampling time period.

Appendix B: Nominal Parameters

$P_{r1}=P_{r2}$=2000 MW;

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H_1=H_2=5 Seconds

D_1=D_2= 8.33*10^{-3}P.U.MW/Hz;

K_{r1}=K_{r2}=0.5

R_1=R_2 =2.4 Hz/P.U.MW;

T_{r1}=T_{r2}=10 Seconds

K_p =1; K_d =4; K_i=5

T_{p1}=T_{p2}=T_{P3}=20 Seconds

T_{t1}=T_{t2}= 0.3 sec

f=60 Hz; $P_{tie, Max}$=200 MW; T_g =0.08 sec

Tw=1 sec.; a_{12}=-1;

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