Effect of tie line bias control in two area load frequency control system using polar fuzzy controller

Avdhesh Sharma, Pawan Kumar and Honey Singh

Abstract— When load on a single generator or a group of generators increases, the rotors gets slow down resulting reduction in system frequency. To overcome this problem automatic generation control (AGC) is necessary because governor control action is not sufficient. Conventional approaches to AGC controller design are based on the Proportional, Integral and Derivative (PID) controller structures, which do not provide always optimal and smooth controlling. To overcome these problems, a polar fuzzy logic controller (PFC) is proposed where only one gain is required to tune. PFC without biasing can restore the frequency and tie-line power in shorter possible time [15] but it can be further improved by using appropriate tie line bias control. PFC with bias factor provides quite improved frequency responses in both areas where as tie line power response is also smooth and affected insignificantly.

Keywords— Area control Error (ACE), Area frequency Response Characteristic (AFRC), Automatic generation Control (AGC), Integral Control, load frequency control (LFC), Polar fuzzy controller (PFC), fuzzy logic controller (FLC).

1 Introduction

WHEN system load increases; turbine speed drops before the governor adjusts the input. As the change in speed decreases, the error signal becomes smaller and the position of governor valves gets near to the required position to maintain constant speed. However the constant speed will not be the set point and there will be an offset. An integrator is generally added to overcome this problem, which will automatically adjust the generation and restore the frequency to its nominal value, this is known as automatic generation control (AGC). In interconnected system there are many control areas, which are connected with the tie lines and each of which performs its self automatic generation control with an objective of maintaining the area control error (ACE) close to zero using complete tie line bias control action. Each control area has responsibility for load frequency control effectively alonwith to set the tie line power at predecided schedule. Complete tie line bias control works effectively provided tie line bias control characteristic matches its own area governor drooping characteristic. Many number of control strategies had been suggested by reasercher to achieve better performance, however integral controller is generally used which can help to control the steady state deviation [16].

Fuzzy logic system has been proposed to control the deviation in in above systm [7]. Fuzzy logic system has the advantage of modeling complex, nonlinear rather than mathematically [10].

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The use of fuzzy logic requires the human knowledge to create an algorithm that mimics their expertise and thinking [8].

In this paper, an improved version of Fuzzy logic controller, as Polar fuzzy controller is proposed to obtain batter system performance. Polar fuzzy sets are used in quantitative description of linguistic variables known crisp values. Polar fuzzy sets are different from standard fuzzy sets in the sense of polar fuzzy sets are defined on a universe of angle, so it repeats shapes every 2π radian. Further effect of bias factor on system performance is also studied.

2. Load Frequency Control

Power system frequency regulation or load frequency control (LFC) is a major function of automatic generation control which has been one of the important control problems in power system design and operation. Normal frequency deviation beyond certain limits may directly impact on power system operation as well as system reliability. The large frequency deviation can damage equipments, affact load performance which cause the transmission lines to be overloaded and can interfere with system protection schemes and ultimately to an unstable condition. Two primary objectives of a power system load frequency control is to maintain frequency and tie line power interchanges with neighbouring control areas at the pre decided schedule.

3 Modeling Of Two Area System

3.1 Tie line model:

Power flow over the line is from system 1 to system 2 is given by

$$P_{12} = \frac{|V_1||V_2|}{X}\sin(\delta_1 - \delta_2)$$

Where, $|V_1|$ and $|V_2|$ are voltage magnitudes at ends 1 and 2, δ_1 and δ_2 are phase angles of voltages V_1 and V_2 respectively and X is reactance of tie line.

For small deviations in angles δ_1 and δ_2, the change in power transfer ΔP_{12} is given by

$$\Delta P_{12} = \left[\frac{|V_1||V_2|}{X}\cos(\delta_1 - \delta_2)\right](\Delta\delta_1 - \Delta\delta_2)$$

The synchronizing coefficient (T_{12}) of tie line is defined as

$$T_{12} = \frac{|V_1||V_2|}{X}\cos(\delta_1 - \delta_2)$$

Finally ΔP_{12} is represented as

$$\Delta P_{12} = \frac{2\pi.T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s))$$

Implementation of above tie line equestons in model is shown below in figure 1.

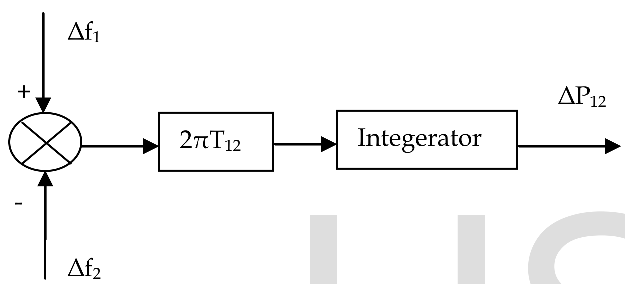

Figure 1: Representation of tie-line

3.2 Implementation Of Area Control Error:

The control signals are proportional to the change in frequency as well as change in tie line power. The area control errors for a two area system are given as

$$ACE_1 = \Delta P_{12} + B_1\ \Delta f_1$$
$$ACE_2 = \Delta P_{21} + B_2\ \Delta f_2$$

Where,
ACE_1 = Area control error of system 1
ACE_2 = Area control error of system 2
ΔP_{12} = Change in power transferred from 1 to 2
Also $\Delta P_{21} = -\Delta P_{12}$

B_1 and B_2 are constants which represent the frequency bias and can be determined from the size of the system. Generally it is standardized equal to area frequency response characteristic (B= D+1/R).

The outputs to the speed changers are given in the form of

$$\Delta P_{ref1} = -K_1 \int(\Delta P_{12} + B_1\ \Delta f_1)\ dt$$
$$\Delta P_{ref2} = -K_2 \int(\Delta P_{21} + B_2\ \Delta f_2)\ dt$$

The constants K_1 and K_2 are integrator gains and taken as best value calculatd from the methods like Ziegler-Nichols given in book "Power System Stability and Control by P. Kundur [2]. The minus sign in the above equations is essential because the generation in any area must increase when frequency error or tie line power increment is negative.

Mostly, one control area is interconnected to many other areas through several tie lines. If there are total m tie lines, then for the i^{th} control area, net interchange power is the sum of power transfer over all the m tie lines. The area control error ACE_i of the i^{th} area is proportional to total exchange of power and given as

$$ACE_i = \sum_{j=1}^{m} \Delta P_{ij} + B_i \Delta f_i$$

The tie line power data of all the lines are sampled continuously with intervals of about 0.1 second or so. These data are added in an energy control centre and compared with desired interchange [9]. The total line power transfer error (ΔP_{12}) is added to frequency bias error ($B_i\ \Delta f_i$) to give the area control error.

4 Fuzzy Logic System

An objective of fuzzy logic is to make computers think like human being. Fuzzy logic is deals with the vagueness intrinsic to human like thinking and natural language. Using fuzzy logic algorithms can enable machines to understand and respond to vague human concepts such as large, small, hot, cold etc. It is also provides a relatively simple approach to reach definite goal from imprecise information [10].

4.1 Fuzzy Logic Control

Fuzzy logic control is used polar fuzzy controller for automatic generation control (AGC) in a two area system is given below in form of block diagram.

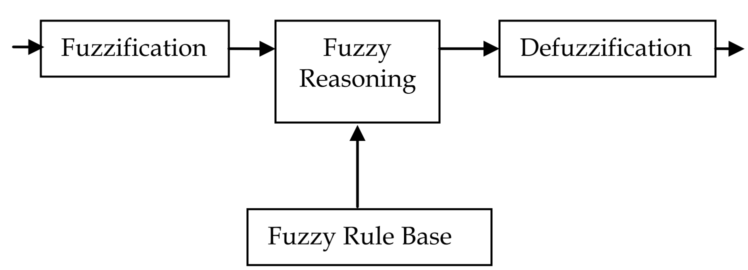

Figure 2: Structure of fuzzy logic controller [14]

Fuzzy Logic Controller consists of four main parts: Fuzzification, knowledge base, decision-making logic and defuzzification.

(i) The Fuzzification:

(a) It measures the values of input variables.
(b) Performs a scale mapping that transforms the values of input variables into universe of discourse.

(c) Convert input into suitable linguistic values.

(ii) The Knowledge Base:

The knowledg consists of data base and linguistic control rule base:

(a) The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in fuzzy logic controller.

(b) The rule base characterizes the control goals and control policy of the domain experts by means of set of linguistic control rules.

(iii) The Decision Making Logic:

The Decision Making Logic has the capability of simulating system like human decision making. It takes decision on as rules applied according to problem.

(iv) Defuzzification:

(a) Similar to fuzzification it converts the range of values of input variables into corresponding universe of discourse.

(b) Defuzzification yields a non-fuzzy and control action from an inferred fuzzy control action [8].

5 Polar Fuzzy Systems

To improve the performance of fuzzy logic controller, polar fuzzy controller (PFC) is proposed here. The polar fuzzy sets were first introduced in 1990. In PFC the linguistic values are formed to vary with angle θ, where the angle θ is defined on the unit circle. Polar fuzzy is basis in polar coordinates or the value of a variable is cyclic. Polar fuzzy sets differ from standard fuzzy sets only in their polar fuzzy sets, which are defined on a universe of angle and hence repeat shapes every 2π radian. Polar fuzzy sets are applied in quantitative description of linguistic variables known truth-values.

A polar fuzzy approach handles all the problems of fuzzy controller easily and efficiently. Angle used as an input in polar fuzzy controller and output of PFC is used as input for governer systrm. PFC needs only one gain to be tuned where in PID controller needs three gains (K_p, K_i and K_d) are to be tuned because the angle of PFC is calculated from the ratio of frequency deviation and the integration of frequency deviation. Also the polar fuzzy controller is a single input and single output system therefore, only two rules are sufficient in the rule base. The PFC is quite simple in construction and has great power to control complex non linear power systems.

The working of PFC is described here. The block diagram of polar fuzzy controller is shown in Fig.3. The frequency deviation (Δf) and integrated error or cumulative error used as complex plane and this complex quantity is then converted into polar co-ordinates i.e. angle-magnitude form [11, 15]. The input to the fuzzy logic controller is angle and its output is intermediate control action (U_{FLC}). The final output (U) is calculated by multiplying magnitude (R) of polar quantity and output of fuzzy logic controller (U_{FLC}).

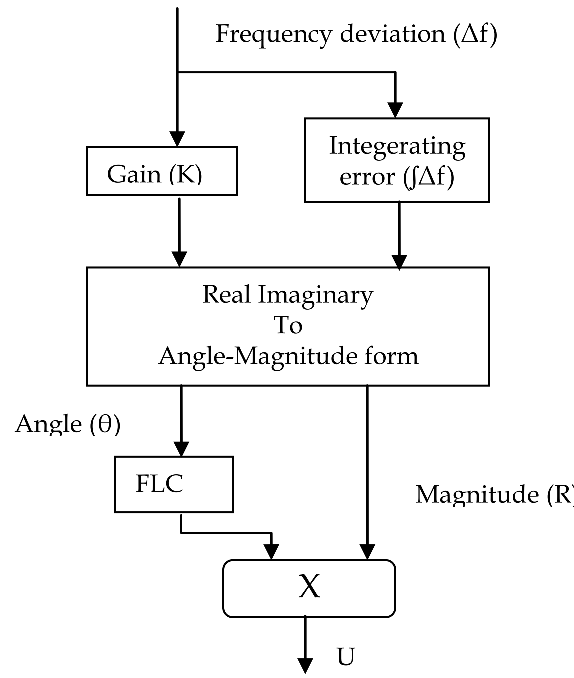

Figure 3: The block diagram of polar fuzzy controller

Two fuzzy sigmoid membership functions large positive (LP) and large negative (LN) in form of angle (θ) are used for input as shown in Figure 4. These membership functions are complimentary to each other. The range of input θ as input to fuzzy logic controller is taken from 0 to 5 because most of the time PFC operates in first quadrant. Two membership functions positive (P) and negative (N) used as output membership functions of the fuzzy logic controller (U_{FLC}), which are triangular in shape and taken in the range of -0.15 to +0.15 as shown in Figure 5.

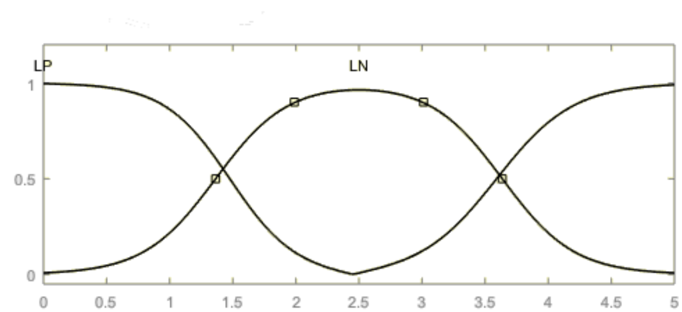

Figure 4: Polar fuzzy sets for input variable

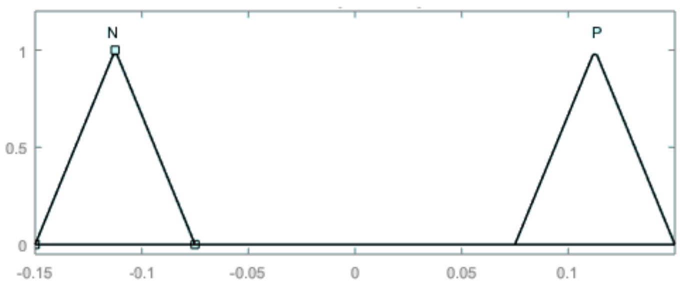

Figure 5: Fuzzy sets of output variable for PFC

There are only two simple rules are used:

Rule 1: If angle θ is LP then U_{FLC} is P.

Rule 2: If angle θ is LN then U_{FLC} is N.

Hence, the output of FLC is

$U = U_{FLC} * R$

Where,

θ: Angle in degree = $\tan^{-1}(ce/e)$

R: Magnitude = $\sqrt{(e^2+ce^2)}$

e: frequency error (Δf)

ce: cumulative frequency error (∫Δf)

Finally, thermal system is considered in both areas and the model is developed and implemented in MATLAB as shown in Figure 6 and Subsystem simulink model of Polar fuzzy controller (PFC) is shown in figure 7. Response of system is compared with PI controller with different value of biasing factor.

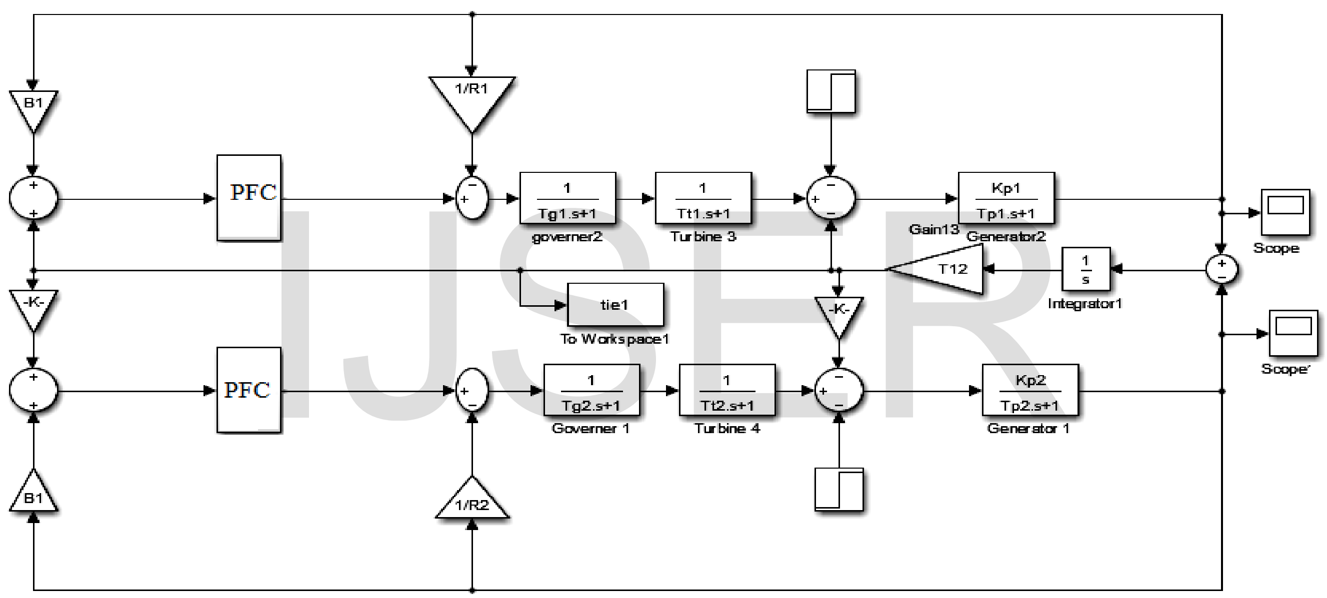

Figure 6: Simulation model of two area thermal System with PFC

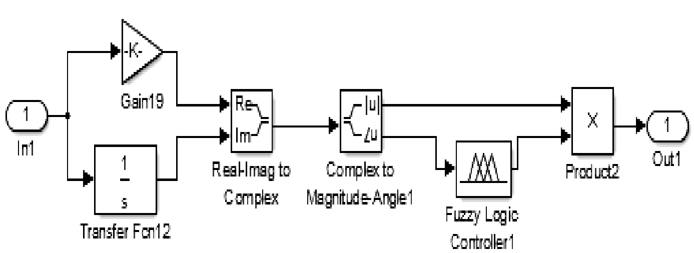

Figure 7: Model of polar fuzzy controller (PFC)

6 Analysis

The performance of Polar fuzzy controllers is tested in two area thermal system for 1% disturbance in first area and the result is compared for PFC without and with standard biasing (B=D + 1/R).

Here simulation study is carried out for two area system considering 1% disturbance area 1 and response is compared with response of PID controller based system as shown in fig. 8.

Response of PFC controller with and without bias factors (i.e. $B_1=B_2=0.425$ and $B_1=B_2=1$) are obtain relatively better than that of PID controller. Figure 8 shows, response can be further improved by increasing the value of biasing factors (B_1=B_2=2). Quantitative value of undershoot and settling time also corroborate the same facts as presented in table-1.

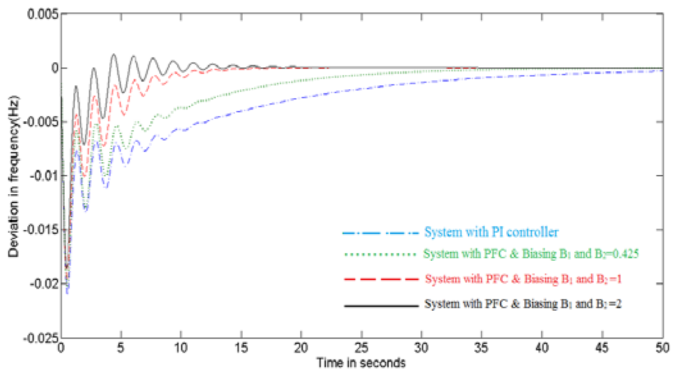

Figure 8: Comparison the deviation in frequency of area-1 of a two area Thermal System when 1% disturbance in area-1

Table 1: Time analysis parameters of simulations of area-1 for two area thermal system when 1% disturbance in area1:

Parameters	System With PI Controller	System With Standard biased PFC(B_1=B_2=0.425)	System Without biased PFC (i.e. B_1=B_2=1)	System With better biased PFC (B_1=B_2=2)
Under-shoot(Hz)	0.021	0.0203	0.0197	0.0186
Settling time(sec)	60	40	20	18

Now deviation in frequency in area-2 with different values of biasing, considering 1% disturbance in area-1 is also recorded and response are shown in Figure 9. The quantitative performance of controllers is given in table 2.

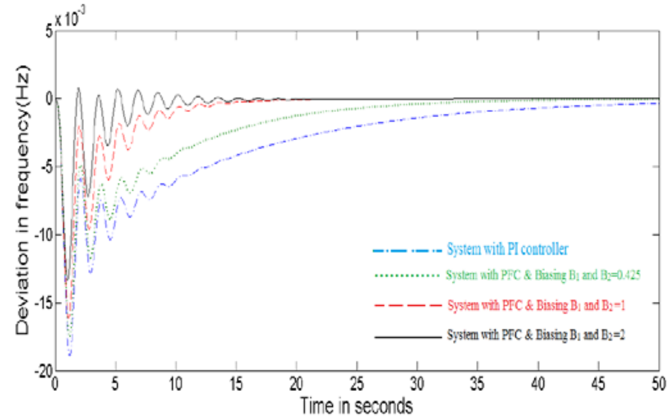

Figure 9: Comparison the deviation in frequency of area-2 of a two area Thermal System when 1% disturbance in area-1

Table 2: Time analysis parameters of simulations of area 2 for two area thermal system when 1% disturbance in area1:

Parameters	System With PI Controller	System With Standard biased PFC(B_1=B_2=0.425)	System Without biased PFC (i.e. B_1=B_2=1)	System With better biased PFC (B_1=B_2=2)
Under-shoot(Hz)	0.019	0.0175	0.0161	0.0135
Settling time(sec)	60	40	25	22

Hence, the performance of PFC controller is compared with PI controller and effect of biase factor has been analysed for frequency deviation. It is found that by increasing the value of biasing factor, settling time and undershoot value are decreasing.

Now deviation in tie line power of a two area Thermal System with 1% step load change in area-1 is compared and response is shown in Figure 10. The quantitative performance of controllers is given in table 3.

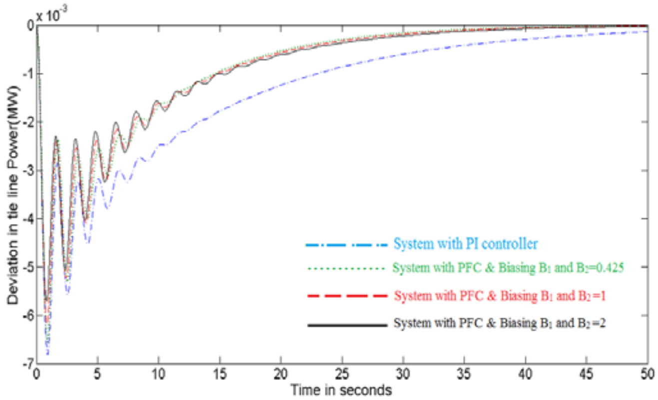

Figure 10: Comparison the deviation in tie line power of a two area Thermal System when 1% disturbance in area-1

Table 3: Time analysis parameters of simulations of tie line for two area thermal system when 1% disturbance in area1:

Parameters	System With PI Controller	System With Standard biased PFC(B_1=B_2=0.425)	System Without biased PFC (i.e. B_1=B_2=1)	System With better biased PFC (B_1=B_2=2)
Under-shoot(MW)	0.0068	0.0065	0.0062	0.0057
Settling time(sec)	70	40	40	40

The performance of PFC controller compared with PI controller and effect of bias factor has analysed for tie line power. It is found that by increasing the value of biasing factor, there is no significant changes observed in settling time and undershoot.

7 Conclusion

A simulation study of two area system with automatic generation control is carried out using SIMULINK model and results are analyzed for both in the traditional as well as knowledge based environment. The polar fuzzy controller can restore the frequency and tie line in smooth way to its nominal value in the shortest possible time.

As polar fuzzy controller approach is simple to use for adjusting the frequency and tie line power deviation because it needs only one gain to be tuned and it is a single input single output system therefore, only two rules are sufficient in the rule base. Performance of PFC without biasing, as given in reference [15], can be further improved by using appropriate biasing factors B_1 and B_2, it is found that by increasing the biasing factors, performance on frequency deviation is improved and affects the tie line power insignificantly.

Appendix - A

The nominal parameters for a two equal area thermal system:

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

$a_{12}=-P_{r1}/P_{r2}=-1.0$

$T_{g1}=T_{g2}=T_g=.08$ sec

$T_{c1}=T_{c2}=T_c=0.3$ sec

$T_{p1}=T_{p2}=T_p=20.00$ sec

$K_{p1}=K_{p2}=K_p=120$ Hz/pu MW

$H_1=H_2=H=5$ sec

$R_1=R_2=R=2.4$ Hz/pu MW

$D=1/K_p=0.00833$

$B_1=B_2=D+1/R=0.425$ pu MW/Hz

$P_{D1}=.01$ pu MW

$P_{D2}=0$

$\delta_1(0)=0^0$

$\delta_2(0)=30^0$

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