Load Frequency Control of an Interconnected Three-Area Thermal Power System Using Conventional PID & Fuzzy-Logic Controller

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Abstract: **This paper deals with design of automatic generation control (AGC) of a three-area interconnected thermal power system using conventional PID, PID-N & Fuzzy-PID controller structures. A single input Fuzzy Proportional Integral Derivative (FPID) controller is used to study the transient response of the proposed system. Area-1 & 2 consists of two thermal generating units with reheat turbinesand area-3 has one thermal generating units of non-linear turbine model with GRC unit. The gains of the proposed three controllers are optimized using novelhybrid Differential Evolution-Particle Swarm Optimization (DEPSO) technique. Step load perturbation (SLP) of 1 % is applied in area1 to study the performance of the proposed algorithm upon three controllers on as the three-areas in terms of undershoot, overshoot & settling time. Finally it is observed that the FPID controller optimised DEPSO algorithm performs better than the other two.**

Keywords: Load Frequency Control (LFC), Fuzzy Proportional Integral Derivative (FPID) controller, Hybrid Differential Evolution Particle Swarm Optimization (DEPSO) algorithm.

1. Introduction

To look for competent & unswerving electric power flow with high quality, design of load frequency control (LFC) theatres a crucial role. Mismatches in frequency & unscheduled power deviation in areas are regular in LFC when it comes about load change & inconsistent circumstances. A change in the operating point of an electric power system occurs with respect to time. As the dimension of power structure getting superior, it is getting more and more intricate to poise load by some experience of dispatcher. To control the power grid frequency and area controlling error the implement of AGC synthetically has excellent progression probable. As the effect of real power is exclusively dependable upon the frequency, so it is to be ensured that the equilibrium of the system it is obligatory to sustain generation and load imbalances. To retain preferred power interchanges amid control areas and to endow with mutual assistance to shore up the power system frequency AGC allows individual control areas to respond appropriately to internal load changes. AGC plays key character in hydro, thermal in addition to diesel power plants.

i Minimizing unscheduled tie-line power flowsstuck betweenin the vicinity of controlling areas.

1. 2. Literature Survey

Author Pan & Liaw [1] have presented about an adaptive controller for LFC to satisfy the hyper stability condition. Carpentier **[**2**]** has presented an excellent critical review on the application of modern control theory to AGC.In reference no. [3] response time of generators, the regulation accurateness are resoluted for AGC using PSO algorithm. Khuntia & Panda [4] have recommended regarding the use of ANFIS on a three unequal area hydro-thermal system. Ghatuari et al. [5] acclaimed about the two-area thermal system by means of PID. In [6] Fuzzy-PID controller is optimised using DEPSO sequentially to get realistic approach. Ghosal [7] has used PSO optimization technique to optimize the PID controller gain for a fuzzy-based AGC. Authors in [8] have applied differential evolution (DE) algorithm to settle on the gainsof a PI controller for AGC of a two-area interconnected system. Ali and Abd-Elazim [9] have used bacteria foraging optimization technique to obtain the optimum gains of a PI controller. In [10] the gains of the PI controller are obtained by using craziness based PSO algorithm. Consideration of low head turbine in hydro area and also scrutinization of reheat category turbine in thermal area of an interconnected hydrothermal system have proposed by Parmar et al. in ref. [11]

2. Power system modelling

As the disturbance taken for the system is very small i.e. 0.01p.u. or 1%.the system beneath deliberation is a linearised model & is adequate for its dynamic demonstration. The system underneath study is a three-area thermal interconnected power system. Appendix in section 8 describes the purported parameters of the power system. Area-1 &2 consists of two thermal generating units with reheat turbines. Area-3 is also a thermal unit which comprises of GRC unit.

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GRC thermal turbine system is considered in area 3. T_t is the hydraulic time constant, T_G & T_{G1} governor time constant of area1,2 & 3 respectively. K_r & T_r are the reheat gain & time constant for all the 3 areas. Fig.4. is the transfer function model of the proposed system. B is the frequency bias constant. R_1, R_2 & R_3 are the regulatory droop constant for all the 3-areas. KP_1 & TP_1 are the control area gain & control area time constants for three areas.

A step load disturbance of 1% is applied to area-1 to study the dynamic behaviour of the proposed system. In order to improve the dynamic performance of AGC, PID, PID-N & FPID controllers one in each area is used. Triangular MFs have been used for FLC to explore the best of these from the view point of dynamic responses.

3. Hybrid DEPSO algorithm

It is a local search technique which is a linear combination of both PSO & DE. DE technique comprises of two mechanisms the differential mutation and crossover operation. So the primelead of the DE algorithm is its aptitude to keep the diversity in population to look at the local search. But inconvenience in it is the not havethe memory that may make the resolution to get stuck with local optima. PSO combines individual cognition p_{best} and social collaboration g_{best}. So, to take upon the advantages of both the algorithms i.e. to maintain the diversity and to add memory in population, hybrid DEPSO algorithm is anticipated in this work. 'c_1' & 'c_2' are the cognitive co-efficient= 0.5. 'w'=0.9. NP=No. of population & D is the Dimension.Here 'F' describes the scaling factor as 0.7. $X_{i,r1}$, $X_{i,r2}$ & $X_{i,r3}$ are three random vectors. Diverse steps involved in this hybrid DEPSO algorithm are:

a. Randomly engender an initial population of size [NP × D].

b. DE operation

  i. Generate the donor V_i vectorusing equation (1)

  $$V_i = X_{i,r1} + F.(X_{i,r2} - X_{i,r3}) \qquad (1)$$

  ii. Generate the offspring vector U_i performing the crossover operation using equation (2).

  $$U_i = V_i \text{ if } rand(0,1) \le CR \text{ or } U_i = X_i \qquad (2)$$

  iii. Select the target vector X_i in selection process using equation (3).

  $$X_i = U_i \text{ if } f(U_i) \le f(X_i) else, X_i = X_i \qquad (3)$$

  iv. Identify the local and the global best.

c. PSO operation

  i. Take X_i as the initial population & update the velocity of each swarm using equation (4).

  $$v_i^{k+1} = w.v_i^k + c_1.rand_1(p_{i,best}^k - x_i^k) + c_2.rand_2.(p_{i,gbest}^k - x_i^k) \qquad (4)$$

  ii. Update the swarm position using equation (5).

  $$X_{i,new} = X_i + V_i \qquad (5)$$

  iii. Compute the fitness of objective function& select the best particle for next iteration by comparing the fitness using equation (6)

  $$X_i^{G+1} = X_{i,new} \text{ If } f(X_{i,new}) \le f(X_i)$$
  $$X_i^{G+1} = X_i \text{ Otherwise} \qquad (6)$$

d. Revise the generation count.

e. Recur steps b – d until stopping criteria are met.

In the DEPSO part constraints definedas [2 0.01] works in 2 mechanisms. The values obtained through these progression compares the fitness assessment with apiece other that's the fitness obtained by DE & PSO. Whichever is the best it keeps that part.

Below mentioned figures are structures for FPID &PID-N. First figure is for fuzzy & the 2nd one is for PID-N. Fuzzy-Rules are explained below. K_1 & K_2 are the input scaling factors, K_3 & K_4 are the output scaling factors. Mamdani fuzzy interface engine is selected for this paper. The FLC output is determined by using centre of gravity method of defuzzification. The two-dimensional rule base for error, error derivative and FLC output is shown below. Linguistic variables such as negative big (NB), negative small (NS), zero (Z), positive small (PS) and positive big (PB) for both the input and the output.

If (input1 is NB) then (output1 is NB)
If (input1 is NS) then (output1 is NS)
If (input1 is Z) then (output1 is Z)
If (input1 is PS) then (output1 is PS)
If (input1 is PB) then (output1 is PB)

Control Rules for the above specified Fuzzy structure

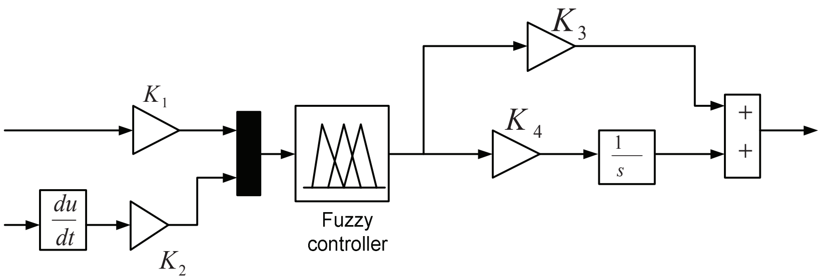

Fig.1. **Fuzzy-PI Controller structure**

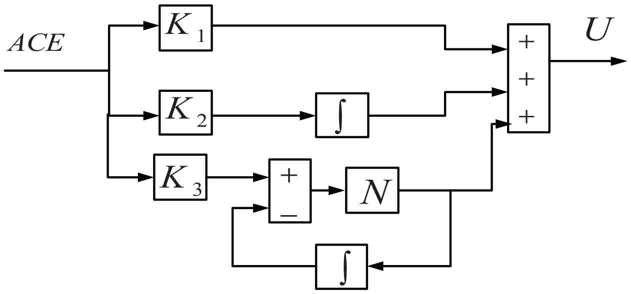

Fig.2. **PID-N structure**

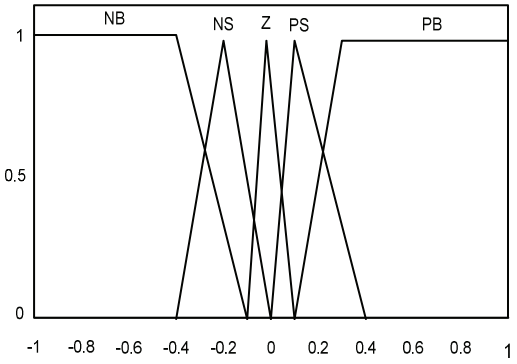

Fig.3. **Membership Function Structure**

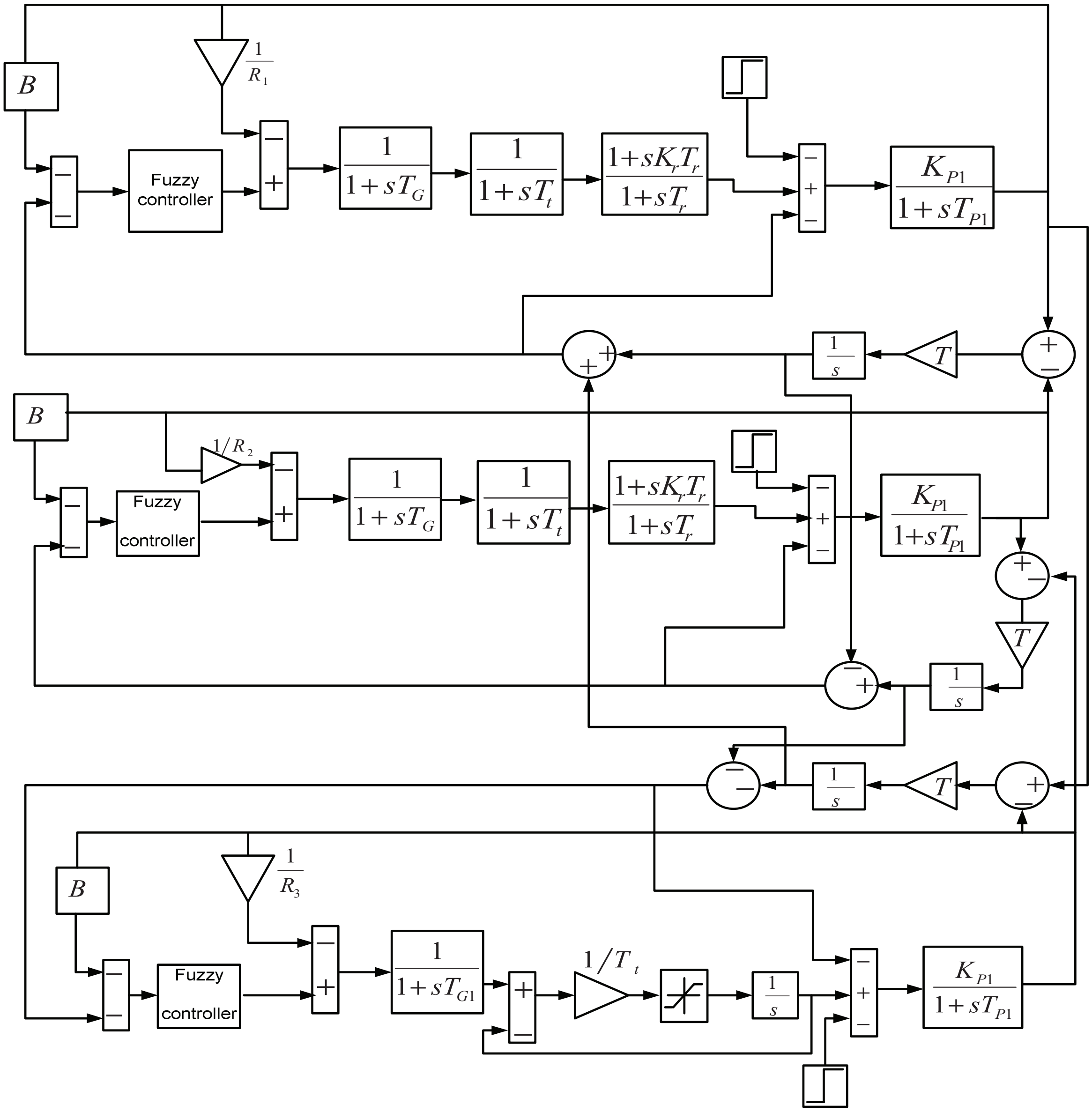

Fig.4 Transfer function model of the Three-Area Power System

6. Results and Discussion

A hybrid DEPSO algorithm is used in this work to optimally tune the gains of PID, PID-N &Fuzzy PID controllers. PID-N where 'N' is derivative filter co-efficient which lies between [300 500]. Number of population and maximum number of iterations are taken as 100. As the no. of population increases the efficiency of the system increases. Objective function for the proposed optimization techniques & for all the controllers is taken as ITAE. A step load perturbation of 1% or 0.01 p.u. is applied in area1 to study the dynamic behaviour of the proposed three-area system.

To obtain the control parameters of the proposed controllers in the power system model the range varies from [2 0.01]. The optimum values of the proposed algorithm are depicted in table1.

Though the aforementioned optimization algorithm is a hybrid form of DE & PSO algorithm as well as a global search technique it out forms well to the other two.

Table1 Optimum gains of proposed algorithms

Controller Structures	Gains	Optimum values of gains		
		Area1	Area2	Area3
PID	K_1	1.9989	1.3424	1.3323
	K_2	1.9898	1.6439	0.3476

	K_3	0.0101	1.7672	0.7607
PID-N	K_1	1.9999	0.6224	1.6464
	K_2	1.9989	1.5341	1.1160
	K_3	0.3219	1.3530	1.7288
	N_1	423.5279	375.6693	302.4970
FPID	**K_1**	**2.0000**	**1.1308**	**1.4209**
	K_2	**0.1728**	**1.6775**	**2.0000**
	K_3	**2.0000**	**1.4766**	**1.8508**
	K_4	**2.0000**	**1.9165**	**0.8575**

Frequency deviations in area1 and area2 and tie-line power deviation are respectively shown in fig.5, fig.6 and fig.7.

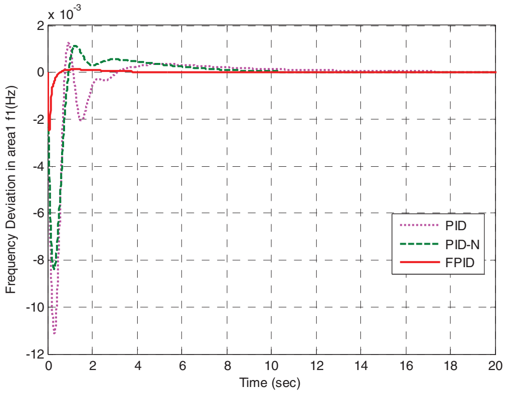

Fig.5 Frequency deviation in area1

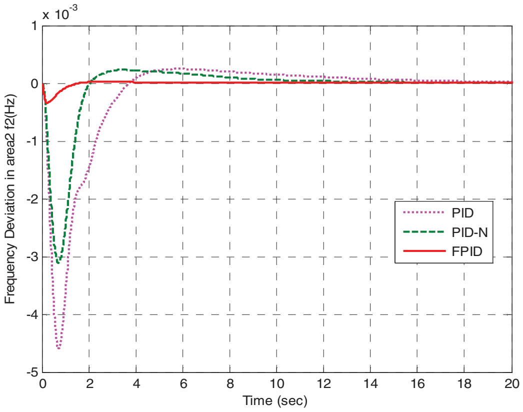

Fig.6 Frequency deviation in area2

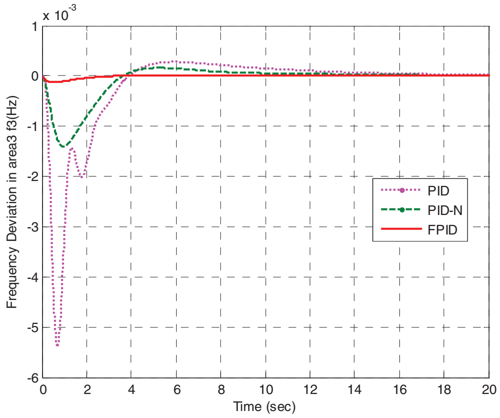

Fig.7 Frequency deviation in area-3

Table2 Peak undershoots (U_{sh}) ,peak overshoots (O_{sh}) settling time of Δf_1 , Δf_2 and Δf_3 for conventional PID, PID–N &FPID controller.

Controller structures		Δf_1 (Hz)	Δf_2(Hz)	Δf_3 (Hz)
PID	U_{sh} (x10^{-4})	-111.2907	-45.8842	-54.1105
	O_{sh} (x10^{-4})	12.6951	2.4716	2.8404
	Ts(x10^{-4})	13.1	20	17.21
PID-N	U_{sh} (x10^{-4})	-83.8230	-31.1494	-14.0756
	O_{sh} (x10^{-4})	11.2846	2.3125	1.6305
	Ts(x10^{-4})	10.38	18.22	12.97
FPID	**U_{sh} (x10^{-4})**	**-24.8154**	**-3.4515**	**-1.2391**
	O_{sh} (x10^{-4})	**1.2162**	**0.2502**	**0.0798**
	Ts(x10^{-4})	**4.76**	**5.7**	**2.11**

As, clearly specified in above three figures no:- 5,6 & 7 it is clearly observed that FPID controller proves better in comparison to the PID-N & conventional PID controller.

Table:-2 illustrate that in terms of undershoot, overshoot & settling time FPID proves more dynamic in nature.

7. Conclusion

In this work novel global search algorithm is used for the efficient tuning of three controllers PID, PID-N & FPID controllerstructure in each area for a three-area interconnected thermal power system. A step load perturbation of 1% is applied to analyze the transient response of the system in terms of peak overshoot, peak undershoot & settling time. Results obtained for FPID controller structure used for automatic generation control for the projected power system using DEPSO algorithm retains its supremacy over the conventional controller.

8. APPENDIX.

$R_1 = R_2 = R_3$=2.4MW/Hz; T =0.545; Kr =0.5; T_r =10s; KP_1=120; TP_1 =20s; TG=0.08s; T_t =0.3;

9. References

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