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Tuning PID Controller Parameters for Load Frequency Control Considering System Uncertainties

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Abstract

In this paper, parameters of PID controller and bias coefficient for Load Frequency Control (LFC) are designed using a new approach. In the proposed method, the power system uncertainties and nonlinear limitations of governors and turbines ,i.e. Valve Speed Limit (VSL)and Generation Rate Constraint (GRC), are taken into account in designing. Variations of uncertain parameters are considered between -40% and +40% of nominal values with 5% step .In order to design the proposed PID controller ,a new objective function is defined. MATLAB codes are developed for GA based PID controller tuning, the results of which are used to study the system step response. All these are through in Simulink based background.

Keywords: Load frequency control; PID controller; ACE; Power system control; genetic algorithm

I. INTRODUCTION

The Load Frequency Control (LFC) system should maintain the system frequency and the inter-are a tie-line power flow close to the scheduled values[1,2].The conventional design method of LFC is based on the power system linear model with fixed parameters. The optimal control theory has been proposed in[2]andutilizedsinceearly1970s.ThePID controller is used here to nullify the effect of frequency and tie-line power deviations in both the areas. MATLAB code has been developed to achieve PID controller tuning based on genetic algorithm. PID controller tuning ensures the improvements in the system response in terms of settling time ,rise time, overshoot and steady state value. Studies are made for different contract conditions. The results are compared with step response of similar system having a PID controller tuned with PSO in conventional interconnected power system [14] without deregulation. The results obtained for the problem in hand provide interesting load control scenario in comparison to the conventional situation. The block diagram s of two area load frequency control under deregulation and conventional scenario are drawn in simulink and the overall system response is found for change of load in one area.

II. SYSTEM AND UNCERTAINTIES MODELING

There are various complicated non linear models for large power systems, but linearized model has been usually used [1,2].InFig.1,atwo-area power system is shown In this paper, this system is studied and the errors of the linearization are considered as

Parametric uncertainties and un-modeled dynamics. Each are a consists of three first-order transfer functions ,modeling the turbine ,governor and power system .In addition ,all generators in each area are assumed to form a coherent group.

The transfer function of PID controller in each area is considered as follow:

$$PID = k_P + \frac{k_I}{S} + k_D S \qquad (1)$$

The PID controllers are widely utilized in industries. In the industrial PID controllers, Low Pass Filter(LPF) is used in order to remove high frequency noise. Therefore, the transfer function of derivative of the PID controller has been replaced by $k_d s/(1+T_d s)$ (where $k_d<T_d$)[6].

In previous researches, different saturation limits have been considered for governor and turbine[9-11].In this paper, two saturation limits ,i.e. .VSL and GRCareconsidered.Fig.2showsthe governor and turbine linear model and their VSL and GRC ,respectively.

ΔP_V and ΔP_T are the deviations of governor position and deviations of turbine power respect to the nominal values, respectively.

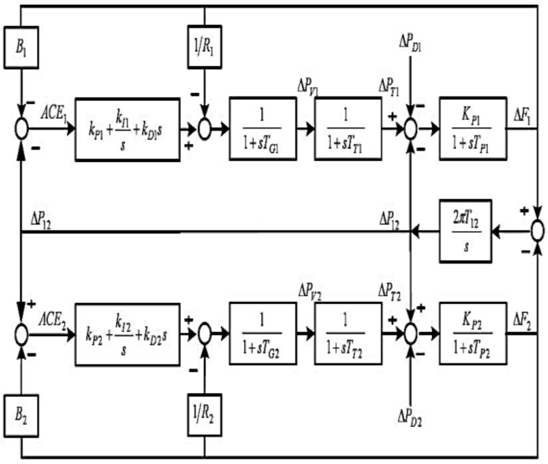

Figure 1. Block diagram of two-area power system using PID controller

III. OBJECTIVE FUNCTION CONSIDERING UNCERTAINTIES

In this section, the objective function of the proposed PID due to load changes (ΔP_L) is presented. The objective function is based on ITAE expressed by the following equation

In an *N*-area power system, the load disturbance (change) can affect the frequency of all areas. To design the load frequency controller, all inputs and outputs should be taken in to account .For PID controller; the objective function is defined as follows:

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} \\ cpf_{21} & cpf_{22} \end{bmatrix} \tag{1}$$

$$ACE_1 = B_1 \Delta F_1 + \Delta P_{tie12error} \tag{2}$$

$$ACE_2 = B_2 \Delta F_2 + \Delta P_{tie12error} \tag{3}$$

$$\Delta P_{tie12sch} = cpf_{12}\Delta P_{L2} - cpf_{21}\Delta P_{L1} \tag{4}$$

$$\Delta P_{tie12error} = \Delta P_{tie12actual} - \Delta P_{tie12sch} \tag{5}$$

the tie-line power deviation i.e .the difference between the scheduled power deviation (□$P_{tie12sch}$) and the actual power deviation (□$P_{tie12actual}$). The latter two are represented through(4)and(5).

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s \tag{6}$$

$$OB = \int_0^\infty \sum_{i=1}^{2} (ACE_i)^2 dt \tag{7}$$

The PID controller design is The most important part of the Automatic Generation Control (AGC).The choice of proportional-integral-derivative(PID) controller than proportional plus integral (PI)controller ensures better system response in terms overshoot and settling time[15]. The ACE signals are controlled using the PID controller to produce control vectors for the AGC. In this work, the PID controller tuning is done through Genetic Algorithm (GA). The proportional (k_p), integral (k_i) and derivative (k_d) gains are set using GA. The transfer function of the PID controller (6) used for both the areas are considered to be identical.

To get the optimized values of the PID gains, suitable objective function is developed here. However the maximum and minimum values of the gains are appropriately chosen. This objective function (*OB*) can be defined as the sum of the squares of the area control errors ($ACE_1$and ACE_2) in each area as shown in (8).

$$k_p^{\min} \le k_p \le k_p^{\max}, k_i^{\min} \le k_i \le k_i^{\max}, k_d^{\min} \le k_d \le k_d^{\max} \tag{8}$$

III. PID CONTROLLER PARAMETER TUNING USING GENETIC ALGORITHM

A combination of Darwinian Survival of the fittest principle and genetic operation is popularly known as Genetic Algorithm. This became an effective method of optimization. To accommodate the entire range of possible solutions, larger value of population size*(100)* is chosen. The implementation of GA starts with parameter encoding [16].This is done with great care so that the link between the objective function and the strings are maintained properly.

The decimal integers of binary strings are obtained following (9).

$$y_j = \sum_{i=1}^{l} 2^{i-1} b_{ij} \, (\text{j} = 1,2,\ldots.\text{L}) \tag{9}$$

Where

y_j is the decimal coded value of the binary string
b_{ij} is the ith binary digit of the *j*th string
l is the length of the string
L is the population size

Following a fixed mapping rule, the continuous variable x_j (10) is found in the search space where x_{min} and x_{max} are the minimum and the maximum values of the variable x_j.

Here, the minimum and maximum values of the PID gains are assigned as the minimum and maximum limits of the variables.

$$x_j = x_{\min} + \frac{x_{\max} - x_{\min}}{2^l - 1} y_j (j = 1,2,.....L) \qquad (10)$$

In the next step the most challenging task is done i.e. the evaluation of the best values of PID controller gains are obtained to minimize the objective function. This task ensures smallest overshoot, fastest rise time and quickest settling time.

Another important step in GA is to select the highly fit strings in population as the parents and a mating pool is formed. The probability [16] for selecting the i_{th} string is

$$p_i = \frac{f_i}{\sum_{j=1}^{L} f_j} \qquad (11)$$

Another important step is the crossover operation. In this operation new strings are generated by exchanging the information among the strings of the mating pool. The mutation operator is also introduced to bring variations. Here mutation rate is chosen to be 0.5.

This newly tuned PID gains are used to form the PID controller transfer function. The controller transfer function is then used to simulate the overall system response of two area Load Frequency Control in deregulated environment for a given step input. The main objective is to find the smallest overshoot, fastest rise time and the settling time for frequency deviation and tie-line power characteristics.

Particle Swarm Optimization, Bacterial For aging are currently being applied for the automatic generation control in multi-area system under de regulation. Such optimization techniques have also been used for automatic generation control of interconnected power system without deregulation. These techniques are used either to tune the different types of controllers or to set the parameters for power system stabilizers. These actions enable operators to improve the control oft he frequency deviation situation and restoration of he tie line power fluctuations quickly. In deregulated environment participation contract between two or more areas are regulated by an‘ independent system operator’. Contract violation and its effects are also important in these situations.

The algorithm used for tuning PID controller is written below:

1. Set the population size, mutation rate, string size, generation counter, population counter, minimum and maximum values of variables etc.
2. Code the problem variables *kp,ki* and *kd* into binary strings
3. Create the initial population of 100 members using random number generation
4. Initialize the generation counter.
5. Increase the generation counter and initialize population counter
6. Increase the population counter
7. Decode the binary string using (9) and(10).Use these values of variable sin PIDGA blocks of Simulink model to find out the objective function i.e. area control errors (*ACEs*). Send these values to MATLAB code.
8. Check the fitness.
9. If the population counter is less than population size, GOTOstep4 and repeat.
10. Select highly fit strings as parents and produce off springs according to their fitness.
11. Generate new strings by mating current off springs using crossover operation.
12. Introduce variations by using mutation operator and replace the existing strings by new strings.
13. Check if the generation counter is less the maximum iteration number. It true, GOTO step 5 and repeat. Otherwise,
14. Stop.

IV. RESULTS AND DISCUSSIONS

The code for PID controller tuning is written in MATLAB. The best values of PID controller parameters i.e. the gains k_p, k_d and k_i obtained using GA are used in PIDGA blocks of two area LFC block diagram (Fig.2) drawn in MATLAB/Simulink. The power system parameters used here are given in Table I.

TABLE .I
POWER SYSTEM DATA

Power SYSTEM DATA	Values
generator time constants T_{g1}, T_{g2}	0.2 s
turbine time constants T_{t1}, T_{t2}	0.3 s
power system gains K_{p1}, K_{p2}	120 Hz/pu MW
power system time constants	20 s
B_1, B_2	0.425pu MW/Hz
Speed regulation of governors R_1, R_2	2.4 Hz/pu MW

s = second, W = watt, M = mega.

TABLE II
VALUES OF PID GAINS

AREA	K_p	K_d	K_p
1	0.224	0.414	0.231
2	0.224	0.414	0.231

TABLE III
PERFORMANCE STUDY

Parameters	ΔF_1	ΔF_2	$\Delta P_{tie12actual}$
Settling time (s)	12.562	12.44	10.155
Rise time (s)	0.5086	0.466	4.4
% Peak Overshoot	13	17	9

The DISCOs of this problem take power from the GENCOs according to the DPM. Here it is assumed that the each element of DPM has a value of 0.5. At the same time each GENCO participates in automatic generation control according to the area participation factors apf_1 =0.5 and apf_2 = 0.5

Initially the system is run without the use of the controller due to the load change in area1 under deregulation. But it is found that the system is unstable. The tie line power deviation due to load change in area1 in two area load frequency control without controller is shown in Fig. 3. Hence with the application of PID controller the simulation is done again for the change of load in area1 by 0.1 pu in deregulated environment. The corresponding frequency deviations in area1 and area2 are shown in Fig. 4 and Fig. 5 respectively. The values of PID controller gains obtained through GA are shown in Table II. The tie line power deviation is depicted in Fig. 6.

The two area power system without PIDGA was simulated initially and it showed unstable response. With the application of GA tuned PID controller, the system became stable. The system performances based on the settling time, rise time and % peak overshoot are shown in Table III.

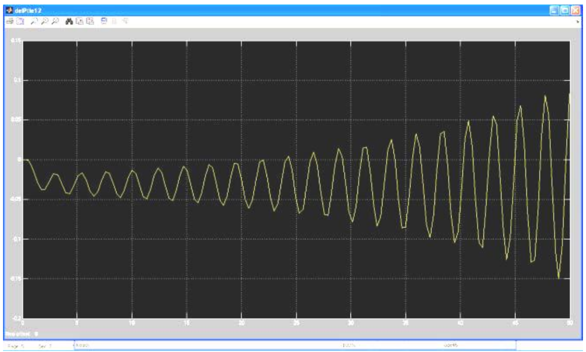

Fig. 3. Tie line power deviation (in pu) with respect to time (in sec) due to change in load of area1 without any PID controller.

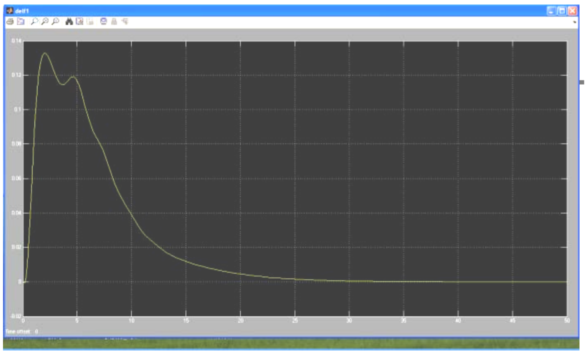

Fig. 4. Frequency deviation with respect to time (in sec) in area1 due to 0.1 pu load change in area1

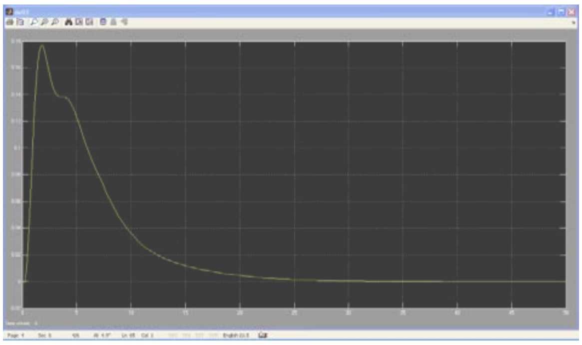

Fig. 5. Frequency deviation (in pu) with respect to time (in sec) in area 2 due to 0.1 pu load change in area1

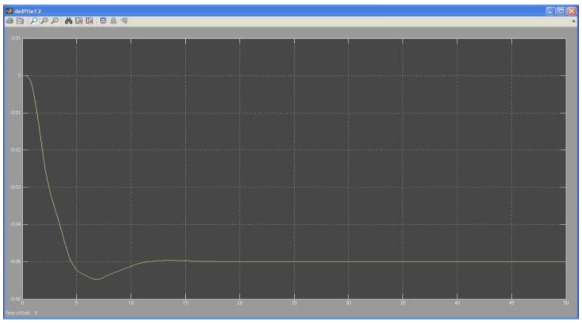

Fig. 6. Tie line power deviation (in pu) with respect to time (in sec)due to change in load of area1

It is observed from Table III that peak overshoot is well below 25%, settling time and rise time are also within limits i.e. the steady state frequency is restored within 12 sec (approximately) after the sudden change of load in area1. The tie line power characteristics show that the 0.1 pu change of load in area 1 is shared by both the GENCOs as per the DPM matrix. It means that the 0.05 p.u load will be supplied.

1. An interconnected power system having same parameters that of the power system chosen here was simulated using PSO based PID controller under deregulation in another work [14]. A comparison of the frequency deviation characteristics of these two works reveals that the numbers of oscillations have been

reduced in case of PIDGA (Fig.3 and 4) in deregulated environment.

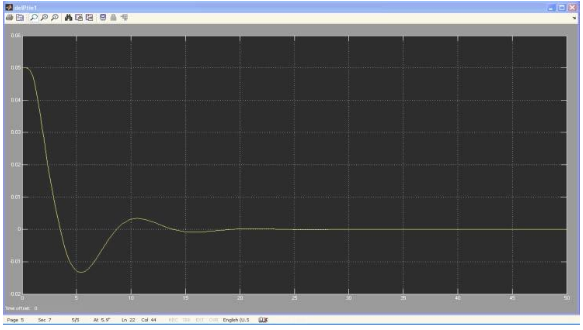

Fig. 7. Tie line power error i.e. □$P_{tie12error}$ (in pu) with respect to time (in s) due to 0.1 pu change in load of area1 without deregulation

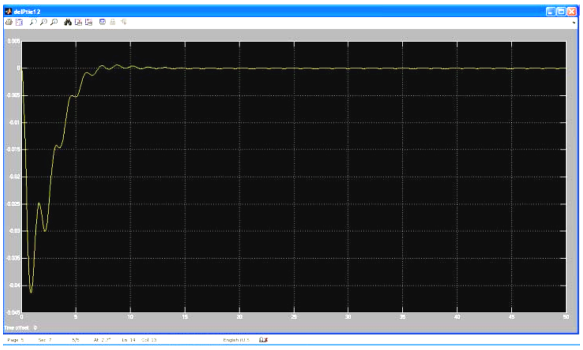

Fig. 8. Tie line power deviation (in pu) with respect to time (in sec) due to 0.1 pu change in load of area1 without deregulation

Fig. 7 shows the tie line power error i.e. $\Delta P_{tie12error}$ versus time. It is clear from the plot that the steady state value of tie line power error is zero and its settling time is less than 4 sec (2% basis). Fig. 8 depicts the tie line power deviation in two area load frequency control system without deregulation, the steady state value of which is zero. But the corresponding tie line power deviation plot with deregulation is smooth and has less oscillation than that without deregulation.

V. CONCLUSION

In this work, two area load frequency control is established under deregulation. The PID controller which is used to bring the system dynamics within comfortable limits is tuned with the help of genetic algorithm. With the variation of load in one area, the deregulated system response is better than the system without deregulation in terms of numbers of oscillations and at the same time the load change is accommodated of both the areas without overloading any one of them.

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