A Genetic Algorithm Based AGC of a Restructured Power System

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Abstract: *In this paper, the parameters of PID controller for Automatic Generation Control (AGC) is tuned according to Generic Algorithms (GAs) based performance indices in the restructured power systems. The key idea of the proposed method is to use the fitness function based on figure of demerit. The simulation results are shown to illustrate effectiveness of the proposed method to solution of AGC problem under different operation condition for a wide range of parameter uncertainties and system nonlinearity.*

Keywords: AGC, Restructured Power System, Genetic Algorithms, Fitness Function.

1.0 Introduction

The dynamic behavior of many industrial plants is heavily influenced by disturbances and, in particular, by changes in the operating point. This is typically the case for deregulated power systems. Automatic Generation Control (AGC) in power systems is very important in order to supply reliable electric power with good quality. The main goal of the AGC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area deregulated power system. In addition, the power system should fulfill the requested dispatch conditions. One of the important problems in AGC is, designing suitable controller. The conventional control strategy based on numerical analysis for the AGC problem is to take the integral of the control error as the control signal. An integral controller provides zero steady state deviation but it exhibits poor dynamic performance [1-2]. It is well known that the conventional method to tune gains of PID controller with numerical analyses may be tedious and time consuming. Some papers offer proportional Integral Derivative (PID) controller to improve the transient response. The transient performance of the restructured power system with respect to the control of the frequency and tie line powers obviously depends on the value of the PID controller gains. The optimum parameter values of the controller have been obtained in some paper by minimizing the popular Integral of the Squared Error criterion (ISE) [3-5]. This criterion has been used because of the easy computation of the integral both analytically and experimentally. In this paper, we investigate the optimum adjustment of the PID controller gains using Genetic Algorithms, which is very simple, robust, and global search techniques. It has excellent properties for optimization [6-7]. The performance indices, ISE, Integral Time multiplied Absolute Error (ITAE) based on Area Control Error (ACE) and Figure of Demerit (FD) based on system responses characteristic are chosen as a fitness function. A two area restructured power system is considered as a test system to demonstrate the effectiveness technique. In addition, a new fitness function based on mean square error has been developed for optimization of PID parameters. The results of the optimal controller based on proposed fitness function for different performance indices are compared with each other. Optimization of PID parameters based on new fitness function using the FD index not only achieves good robust performance for a wide range of load changes and parametric uncertainties even in the presence of Generation Rate Constraints (GRC), but also system performance indices are extremely improved using this method.

2.0 Plant Model

In the restructured power systems, the Vertically Integrated Utility (VIU) no longer exists. However, the common AGC goals, i.e. restoring the frequency and the net interchanges to their desired values for each control area, still remain. Generalized dynamical model for the LFC scheme has been developed in Ref. [8] based on the possible contracts in the restructured environments. This section gives a brief overview on this generalized model that uses all the information required in a VIU industry plus the contract data information. In the restructured power system, Generation Companies (GENCOs) may or may not participate in the AGC task. On the other hand, Distribution Companies (DISCOs) have the liberty to contract with any available GENCOs in their own or other areas. Thus, there can be various combinations of the possible contracted scenarios between DISCOs and GENCOs. The concept of an Augmented Generation Participation Matrix (AGPM) is introduced to express these possible contracts in the generalized model. The rows and columns of AGPM is equal with the total number of GENCOs and DISCOs in the overall power system, respectively. For example, the AGPM structure for a large scale power system with N control area is given by:

$$AGPM = \begin{bmatrix} AGPM_{11} & \cdots & AGPM_{1N} \\ \vdots & \ddots & \vdots \\ AGPM_{N1} & \cdots & AGPM_{NN} \end{bmatrix} \tag{1}$$

Where,

$$AGPM_{ij} = \begin{bmatrix} gpf_{(s_i+1)(z_j+1)} & \cdots & gpf_{(s_i+1)(z_j+m_j)} \\ \vdots & \ddots & \vdots \\ gpf_{(s_i+n_i)(z_j+1)} & \cdots & gpf_{(s_i+n_i)(z_j+m_j)} \end{bmatrix}, s_i = \sum_{k=1}^{i-1} n_i \;,\; z_j = \sum_{k=1}^{j-1} m_j \;,\; s_1 = z_1 = 0$$

Where, n_i and m_i are the number of GENCOs and DISCOs in area i and gpf_{ij} refer to '*generation participation factor*' and shows the participation factor GENCO i in total load following requirement of DISCO j based on the possible contract. The sum of all entries in each column of AGPM is unity. To illustrate the effectiveness of the modeling strategy and proposed control design, a three-control area power system is considered as a test system. It is assumed that each control area includes two GENCOs and a DISCO. Block diagram of the generalized LFC scheme for a three-area restructured power system is shown in Fig. 1. The power system parameters same Ref. [9] are given in Tables 1 and 2.

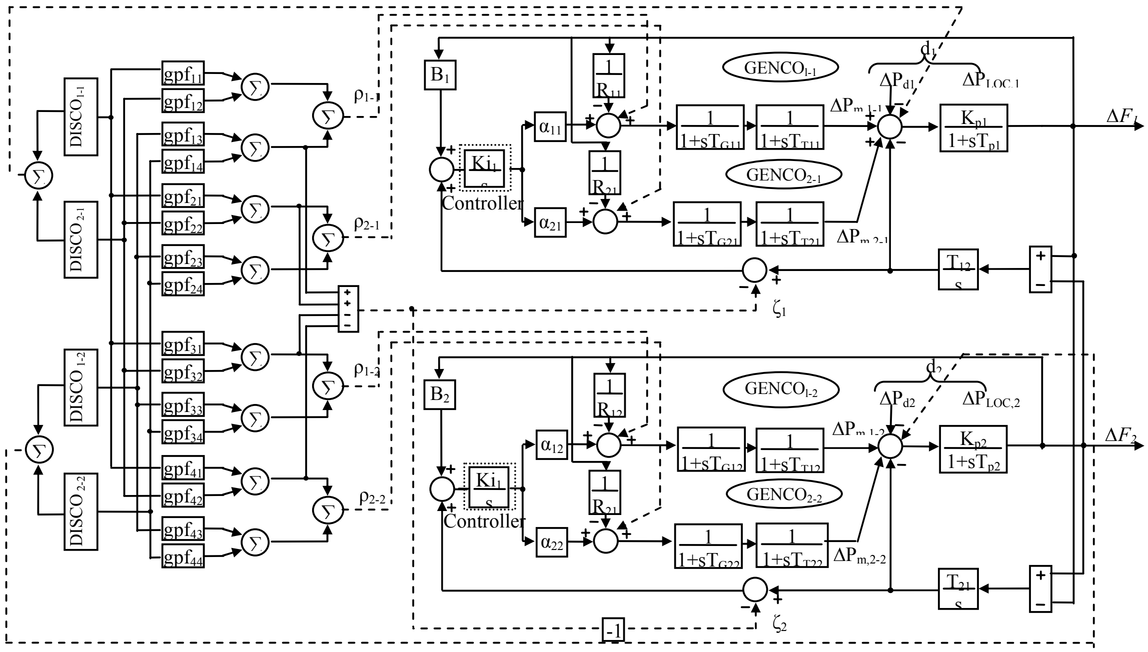

Fig. 1. Modified control area in a deregulated environment

Table 1. Control area parameters

Parameter	Area -1	Area -2
K_P *(Hz/pu)*	*120*	*120*
T_P *(sec)*	*20*	*20*
B (pu/Hz)	*0.4250*	*0.4250*
T_{ij} *(pu/Hz)*	$T_{12} = 0.545$	

Table 2. GENCOs parameter

MVA_{base} (1000MW) Parameter	GENCOs (*k in area i*)			
	1-1	*2-1*	*1-2*	*2-2*
Rate (MW)	*1000*	*800*	*1100*	*900*
T_T *(sec)*	*0.30*	*0.30*	*0.30*	*0.30*
T_G *(sec)*	*0.10*	*0.10*	*0.10*	*0.10*
R (Hz/pu)	*2.4*	*2.4*	*2.4*	*2.4*
α	*0.5*	*0.5*	*0.5*	*0.5*

The dotted and dashed lines show the demand signals based on the possible contracts between GENCOs and DISCOs which carry information of which GENCO has to follow a load demanded by which DISCO. These new information signals were absent in the traditional AGC scheme. As there are many GENCOs in each area, ACE signal has to be distributed among them due to their ACE participation factor in the LFC task and $\sum_{j=1}^{n_i} apf_{ji} = 1$. We can write [8]:

$$d_i = \Delta P_{Loc,j} + \Delta P_{di}, \Delta P_{Loc,j} = \sum_{j=1}^{m_i} (\Delta P_{Lj-i} + \Delta P_{ULj-i}) \tag{2}$$

$$\Delta P_{tie,ik,sch} = \sum_{j=1}^{n_i}\sum_{i=1}^{m_k} apf_{(s_i+j)(z_k+i)} \Delta P_{L(z_k+i)-k} - \sum_{i=1}^{n_k}\sum_{j=1}^{m_i} apf_{(s_k+i)(z_i+j)} \Delta P_{L(z_i+j)-l} \tag{3}$$

$$\Delta P_{tie,i-error} = \Delta P_{tie,i-actual} - \zeta_i \tag{4}$$

$$\Delta P_{m,k-i} = \sum_{j=1}^{z_{N+1}} gpf_{(s_i+k)j} \Delta P_{Lj-i} + apf_{ki} \sum_{j=1}^{m_i} \Delta P_{ULj-i}, k = 1,2,...,n_i \tag{5}$$

3.0 Genetic Algorithms

GA's are search algorithms based on the mechanism of natural selection and natural genetics. They can be considered as a general-purpose optimization method and have been successfully applied to search and optimization [10]. In the GA just like natural genetics a chromosomes (a string) will contain some genes. These binary bits are suitably decoded to represent the character of the string. A population size is chosen consisting of several parent strings. The strings are then subjected to evaluation of fitness function. The strings with more fitness function will only survive for the next generation, in the process of the selection and copying, the string with less fitness function will die. The former strings now produce new offsprings by crossover and some offsprings undergo mutation operation depending upon mutation probability to avoid premature convergence to suboptimal condition. In this way, a new population different from the old one is formed in each genetic iteration cycle. The whole process is repeated for several iteration cycles until the fitness function of an offspring is reached to the maximum value. Thus, that string is the required optimal solution. For our optimization problem, the new following fitness function is proposed as:

$$f(Performance\ Index) = \frac{1}{1 + MSE(Performance\ Index)} \tag{6}$$

Where

$$MSE(Performance\ Index) = \frac{\sqrt{\sum_{i=1}^{3} Performance\ Index_i}}{3}$$

Where, a string of 42 binary bits reprints gains of PID controller in two areas as shown in Fig. 2, population size and maximum generation are 20 and 100, respectively. The less the MSE is the better string. The better string survives in the next population. Based on roulette wheel, some strings selected to make the next population. After the selection and copying the usual mutual crossover of the string (crossover probability is chosen 97%) and mutation of some of the string (mutation probability is chosen 8%) are performed. In this way, new offspring of PID gain sets are produced in the total population and then system performance characteristics and corresponding fitness value are recomputed for each string. Thus, the sequential process of evaluation of fitness function- Selection- Crossover- Mutation completes genetic iteration cycle.

4.0. Simulation Results

In the simulation study, a nonlinear model of Fig. 3 with ±0.1 replaces the linear model of turbine $\Delta P_{Vki}/\Delta P_{Tki}$ in Fig. 1. This is to take GRC in

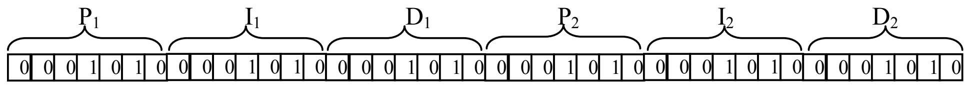

Fig. 2. Encoding for fuzzy rule table

to account, i.e. the practical limit on the rate of the change in the generating power of each GENCO. The proposed PID controller based on GA is applied for each control area of the restructured power system as shown in Fig. 1 to illustrate its robustness against parametric uncertainties and contract variations,

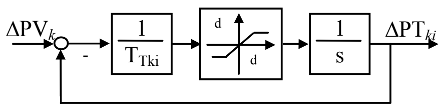

Fig. 3. Nonlinear turbine model with GRC.

It is assumed that each DISCOs demands 0.1 puMW power from GENCOs. Moreover, it may happen that a DISCO violates a contract by demanding more power than that of specified in the contract. This excess power must be reflected as a local load of the area but not as the contract demand and taken up by the GENCOs in the same area. Consider that DISCOs 1, 2 and demand 0.05 and 0.05 puMW of excess power. Due to Eq. (2), the total load in areas is computed as:

$$\Delta P_{LOC,1} = \Delta P_{L,1-1} + \Delta P_{L,2-1} + \Delta P_{U,1-2} = 0.1 + 0.1 + 0.05 = 0.25$$

$$\Delta P_{LOC,2} = \Delta P_{L,1-2} + \Delta P_{L,2-2} + \Delta P_{U,1-2} = 0.1 + 0.1 + 0.05 = 0.25$$

For the desired performance of the PID controller against uncertainty due to load variations and changing of the power system structure, it is important to find the optimal gains. For the optimization problem, performance indices such as ISE, ITAE based on ACE_i and FD based on system responses characteristic defined as:

$$ISE = 100\int_0^{10} (ACE_1^2 + ACE_2^2)dt \qquad (7)$$

$$ITAE = 100\int_0^{10} t\ (|ACE_1(t)| + |ACE_2(t)|)dt \qquad (8)$$

$$\mathrm{FD} = (\mathrm{OS}\times 100)^2 + (\mathrm{US}\times 40)^2 + (\mathrm{Ts}\times 3)^2 \qquad (9)$$

Where, Overshoot (OS), Undershoot (US), and settling time (for 3% band of the total load demand in area1) of frequency deviation area 1 is considered for evaluation of the FD. The fitness function is choose as Eq.(6).

Case 1: Fitness function based on ISE

In this case, the plot of fitness function value is obtained as shown in Fig. 4. From this figure, it can be seen that: the fitness value increases monotonically from 0.12502 to 0.24679 in 54 generation. The optimal gains of PID controller are listed in Table 3 for this case.

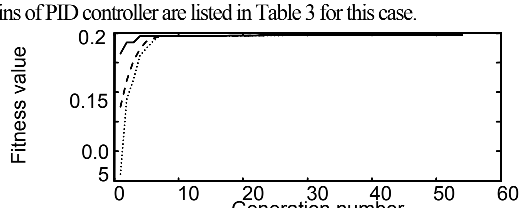

Fig. 4. Plot of fitness function value, solid (Max), dashed (Mean) and dotted (Min)

Table 3. PID controller gains

	ISE chosen as fitness function		
	K_P	K_I	K_D
Area1	0	0.09449	0.74016
Area2	0.37795	0.07087	0.75591

Case 2: Fitness function based on ITAE

Fig. 5. shows plot of fitness function value for this case. From this figure, it can be seen that, the fitness value increases monotonically from 0.1097 to 0.3498 in 44 generation. The optimal gains of PID controller are listed in Table 4 for this case.

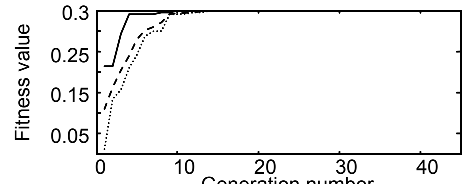

Fig. 5. Plot of fitness function value, solid (Max), dashed (Mean) and dotted (Min)

Table 4. PID controller gains

	ITAE chosen as fitness function		
	K_P	K_P	K_P
Area1	0	0	0
Area2	0.93701	0.93701	0.93701

Case 3: Fitness function based on FD

In this case, the fitness function value is depicted in Fig. 6. From this figure, it can be seen that, the fitness value increases monotonically from 0.0199 to 0.0723 in 40 generation. The optimal gains of PID controller are listed in table 5 for this case.

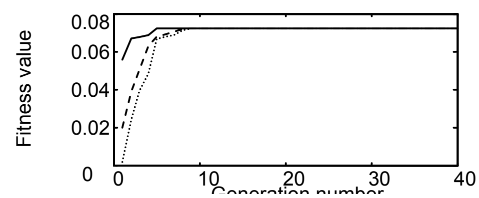

Fig. 6. Plot of fitness function value, solid (Max), dashed (Mean) and dotted (Min)

Table 5. PID controller gains

	FD chosen as fitness function		
	K_P	K_P	K_P
Area1	0.18110	0.18110	0.18110
Area2	0.29921	0.29921	0.29921

The system performances based on three above cases are compared with each other. Figs. 7 and 8 depict the power system responses.

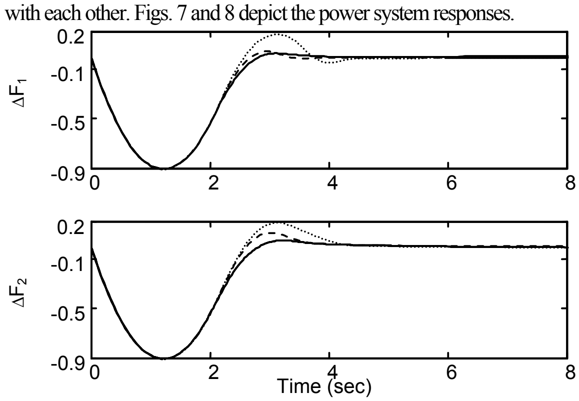

Fig. 7. Frequency derivation,
Solid (opt. based FD), dashed (opt. based ITAE) and dotted (opt. based ISE)

The frequency deviation of the two areas (Fig. 7) is quickly driven back to zero and has very small settling time and overshoot. Also the tie-line power flow (Fig. 8) properly converges to the specified value, of Eq. (5), in the steady state, i.e.; $\Delta P_{tie12,sch}=-0.05$ pu. The actual generated powers of GENCOs properly reach the desired value in the steady state as given by Eq. (8). $\Delta P_{M,1-1}=0.105$ pu.MW, $\Delta P_{M,2-1}=0.045$ pu.MW. $\Delta P_{M,1-2}=0.195$ pu.MW, $\Delta P_{M,2-2}=0.055$ pu.MW.

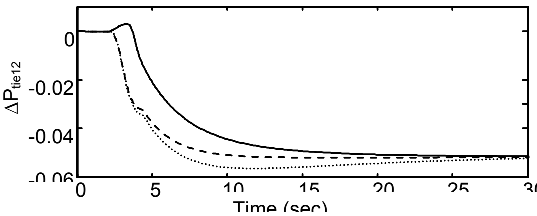

Fig. 8. Tie line power flow
Solid (opt. based FD), dashed (opt. based ITAE) and dotted (opt. based ISE)

The optimization based on FD provides much better result than other optimization performance indices. Numerical result of performance indices for the above cases in various operating conditions are listed in Tables 6, 7 and 8. Where, PPC stands for parameter percent variations from nominal values. In this Tables value of performance index is compared according to optimization fitness function with selecting each of the other performance indices.

Table 6. ISE performance Indices

No Test	%	Opt. base FD	Opt. base ITAE	Opt. base ISE
0	0	425.4	412.3	416.8
1	+5	471.8	456.6	462.1
2	-5	382.7	371.3	374.8
3	+10	520.8	504.1	511.0
4	-10	343.4	333.6	336.3
5	+15	573.6	554.7	563.5
6	-15	573.6	554.7	563.5
7	+20	629.7	608.6	619.5
8	-20	273.6	267.0	268.8
9	+25	689.5	665.8	679.1
10	-25	243.0	237.8	239.5

Table 7. ITAE performance Indices

Test No	PPC	Opt. base FD	Opt. base ITAE	Opt. base ISE
0	0	607.24	674.7	807.0
1	+5	664.8	749.5	898.2
2	-5	552.1	603.3	720.1
3	+10	725.6	827.5	993.4
4	-10	499.1	535.8	637.9
5	+15	790.4	908.6	1092.6
6	-15	449.3	472.5	561.2
7	+20	859.4	992.9	1195.8
8	-20	403.6	415.5	490.4
9	+25	931.5	1080.0	1302.1
10	-25	361.8	366.5	428.5

Table 8. FD performance Indices

Test No	PPC	Opt. base FD	Opt. base ITAE	Opt. base ISE
0	0	1467.9	1521.4	1697.9
1	+5	1568.3	1561.6	2066.6
2	-5	1525.4	1537.6	1545.4
3	+10	1704.1	1689.2	2384.8
4	-10	1601.4	1601.8	1600.1
5	+15	1829.4	1897.8	2681.9
6	-15	1702.6	1695.3	1692.3
7	+20	1944.5	2086.2	2945.1
8	-20	1829.7	1821.3	1822.3
9	+25	2048.4	2293.4	3152.6
10	-25	1986.3	1977.5	1984.9

Examination of this Tables reveals that selection of the fitness function based on FD has the best performance. Figs. 9, 10 and 11 demonstrate the max derivation of ISE, ITAE and FD from nominal value.

Remark 1: According to Fg. 9, it can be seen that the selection of the ISE as the performance index to evaluate the power system responses, does not have satisfactory results as the fitness function.

Remark 2: Figs. 10 and 11 show that if the ITAE or FD is chosen as the performance index to evaluate the power system responses, the selection of FD as the fitness function not only can guarantee the optimal performance for a wide range of load changes and parametric uncertainties, but other system performance indices are extremely improved using this method.

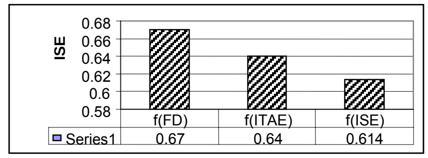

Fig. 9. Max derivation ISE from nominal value

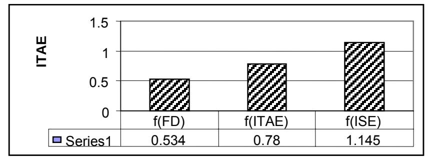

Fig. 10. Max derivation ITAE from nominal value

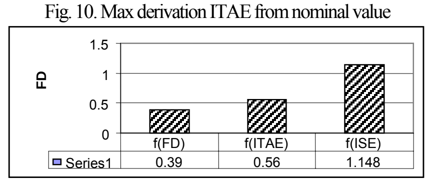

Fig. 11. Max derivation FD from nominal value

5.0 Conclusion

In this paper, parameters of AGC controller is tuned according to GAs based performance index optimization in the restructured power system. It is well known that the conventional method to tune gains of the PID controller with numerical analysis may be tedious and time consuming. In order to overcome to this drawback, we have proposed a new method to find optimum gains of PID controller by using GA. Genetic algorithms have been successfully applied to tune the automatic generation controller parameters. A two area restructured power system is considered to demonstrate effectiveness of this method and a new fitness function is developed for optimization problem. Simulation studies show that the obtained optimum parameters of PID controller based on the FD index optimization achieve good robust performance under parametric uncertainties and large load demands. In addition, it is superior to other performance indices.

6.0 References

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