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Optimal Load Frequency Control in a Single Area Power System Based Genetic Algorithm

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Abstract—This paper proposes a Real-valued genetic algorithm optimization technique (RGA) to tune the PID controller for load frequency control of single area power system. This work has a large importance due to the wide range of disturbance that may happen in the power system. The RGA is applied to tune the gains of a PID controller and minimizing the error through different performance criteria algorithms such as: Mean of the Square of the error (MSE), Integral of Time multiplied by Absolute Error (IAE), Integral of the Square of the error (ISE) and Integral of Time multiplied by Absolute error (ITAE). The RGA is applicable to power system with non-reheated and reheated turbines. The simulation results using MATLAB R20112a shows that the performance criteria algorithm (ITAE) provides the best convergence and response than the other performance criteria based on settling time and peak overshoot of frequency deviation signal.

Index Terms— Load Frequency Control, Single Area of power system, PID controller, Genetic Algorithm

1 INTRODUCTION

THE problem of controlling the real power output of generating units in response to changes in system frequency and tie-line power inter-change within specified limits is known as load frequency control (LFC) [1]. LFC is a very important issue in power system operation and control for supplying sufficient and both good quality and reliable power. To improve the stability of the power system, it is necessary to design LFC systems that control the power generation and active power [2]. Conventional LFC uses an integral controller. The main drawback of this controller is that the dynamic performance of the system is limited by its integral gain. A high gain may deteriorate the system performance causing large oscillations and instability [1]. Thus the integral gain must be set to a level that provides a compromise between a desirable transient recovery and low overshoot in the dynamic response of the overall system [3]. A lot of approaches have been reported in the literature to tune the gain of the fixed parameter PI controller [2, 4].

To overcome these drawbacks and to solve the load frequency control problem effectively, neural network, Fuzzy logic, and optimization algorithms as intelligent techniques are proposed by many authors [5-10].

Some control strategies have been suggested based on the conventional linear control theory; because of the complexity of the power systems these controllers may be improper in some operating conditions. In the integral controller, if the integral gain is very high, undesirable and unacceptable large overshoots will be occurred. However, adjusting the maximum and minimum values of proportional (Kp), integral (Ki) and integral (Kd) gains respectively, the outputs of the system (voltage, frequency) could be improved.

In [11] the author proposed a load frequency control based Fuzzy, Particle swarm, and genetic algorithms for one and two area in power system. Comparison of performance responses of conventional PID controller with PID controller using different intelligent techniques for the both cases show that the fuzzy tuned controller has better satisfactory generalization capability, feasibility and reliability, as well as accuracy than GA and the PSO algorithms. Simulation results are carried out by 1 to 10% system disturbances in both of one and two areas power system.

This paper presents real-valued genetic algorithm to tune the PID controller parameters. In order to guarantee the best results as well as to ensure the robustness of the proposed controller, different search criteria are implemented. This includes Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), Integral of the Square of the Error (ISE), and Mean of the Square of the Error (MSE).

2 SINGLE AREA MODELING

Detailed

The frequency of a system is dependent on active power balance. As frequency is a common factor throughout the system, a change in active power demand at one point is reflected throughout the system by a change in frequency. Because there are many generators supplying power into the system, some means must be provided to allocate change in demand to the generators [1]. The block diagram of LFC of a single area power system is shown in Figure (1). It's obvious that the plant for LFC consist of three parts [1- 3]:

- $G_g(s)$ is the governor with dynamics:

  $$G_g(s) = \frac{1}{T_G S+1} \quad \text{.……………. (1)}$$

- $G_t(s)$ is the non-reheated turbine dynamics:

  $$G_t(s) = \frac{1}{T_T S+1} \quad \text{……………. (2)}$$

  For reheated turbine:

  $$G_t(s) = \frac{(F_{HP} T_{RH} S+1)}{(T_{CH} S+1)(T_{RH} S+1)} \quad \text{……………… (3)}$$

- $G_p(s)$ is the power system dynamics:

  $$G_p(s) = \frac{K_p}{T_p S+1} \quad \text{……………. (4)}$$

And $1/R$ is the droop characteristics.
Where:
ΔP_L Load power disturbance (p.u. MW)

K_p Electric power system gain

T_p Electric power system time constant (s)

T_T Turbine time constant (s)

T_G Governor time constant (s)

F_{HP} Fraction of total turbine power generated by High pressure section.

T_{RH} Reheater time constant

T_{CH} Steam chest time constant

R Speed regulation due to governor action (Hz/p.u. MW)

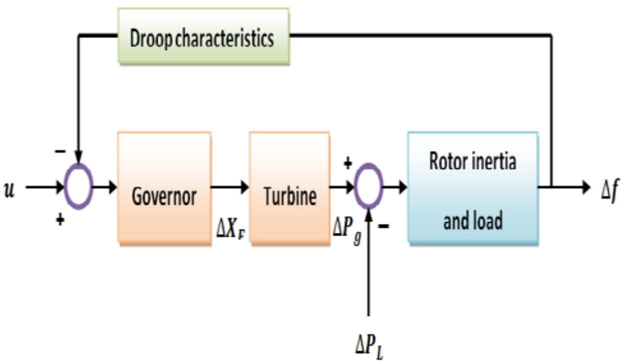

Fig. 1.Block Diagram of LFC Loop for Single Area power system

The power system can be described by the state-space equation as following [4, 13]:

$$\dot{X} = AX + BU + \Gamma p \qquad \text{.................. (5)}$$

Where A state matrix, B and Γ are input and disturbance matrices, U and p are input and disturbance vectors, and X is the state vector, given as:

$$x(t) = [x_1\ x_2\ x_3] = [\Delta f\ \Delta P_G\ \Delta X_E]^T \qquad \text{.................. (6)}$$

$$A = \begin{bmatrix} -1/T_p & K_p/T_p & 0 \\ 0 & -1/T_t & 1/T_t \\ -1/RT_g & 0 & -1/T_g \end{bmatrix} \qquad \text{.................. (7)}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 1/T_g \end{bmatrix}^T \qquad \text{.................. (8)}$$

$$\Gamma = \begin{bmatrix} -K_p/T_p & 0 & 0 & 0 \end{bmatrix}^T \qquad \text{.................. (9)}$$

Also

Δf Incremental frequency change.

ΔP_G Incremental change in generator output (p.u. MW).

ΔX_E Incremental change in governor valve position.

3 Design of RGA-PID Controller

The genetic is a robust optimization technique based on natural selection. The basic goal of GA is to optimize functions called fitness functions. A possible solution to a specific problem is seen as an individual. A collection of a number of individuals is called a population. The current population reproduces new individuals that are called the new generation. The new individuals of the new generation are supposed to have better performance than the individuals of the previous generation [14]. GA have been successfully implemented in the area of industrial electronics, for instance, parameter and system identification, control robotics, pattern recognition, planning and scheduling and classifier system [14-16].

The structure of the control system with RGA-PID controller is shown in Figure (2). It consists of a conventional PID controller with auto-tuning its gain coefficients based on GA and a control plant [17].

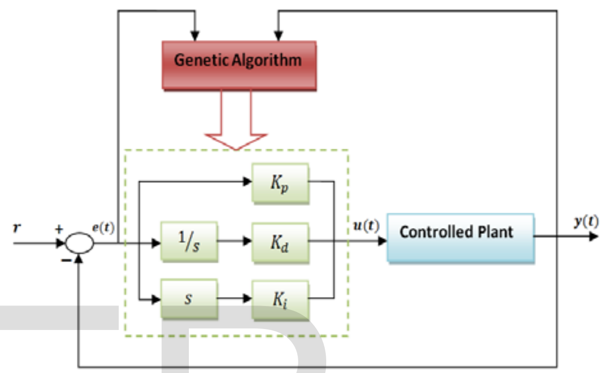

Fig. 2.Structure of RGA-PID controller

An auto-tuning RGA-PID controller can be implemented as follows:

A. Encoding:
   A real (floating point) numbers will be used to encode the population. In this paper it is aimed to apply RGA to optimize the gains of a PID controller, hence three strings will be assigned to each number of the population. The boundaries for the PID constants are chosen to ensure that not too many of the generated PID constants lead to an unstable system.

B. Initialization:
   Initialize RGA by setting the number of individuals, the number of generations, the crossover probability, and the mutation probability.

C. Fitness Function:
   The fitness of an individual is calculated from four different objective functions. To optimize the performance of a PID controlled system, the PID gains of the system are adjusted to maximize and minimize a certain performance index. The four performance indices can be shown in Table 1. The minimization fitness function becomes:

$$\textit{Fitness Function} = \frac{1}{J} \qquad \text{.................. (10)}$$

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TABLE 1
MATHEMATICAL DESCRIPTION FOR DIFFERENT SEARCH CRITERIA [12]

Performance Criteria	Symbol	Mathematical description of the error
Mean of the Square of the Error	MSE	$J_{MSE} = \frac{1}{n}\sum_{i=1}^{n}(e(t))^2$
Integral of the Square of the Error	ISE	$J_{ISE} = \int_0^T e^2(t)dt$
Integral of Absolute Magnitude of the Error	IAE	$J_{IAE} = \int_0^T \lvert e(t)\rvert dt$
Integral of Time multiplied by Absolute Error	ITAE	$J_{ITAE} = \int_0^T t\lvert e(t)\rvert dt$

D. Selection:

The Normalized geometric selection is applied to select individuals in the current population pool.

E. Crossover:

Two parent chromosomes are crossed to produce one child. Arithmetic crossover was chosen as the crossover procedure.

F. Mutation:

Mutation changes the structure of the string by changing the value of a bit chosen at random. The multi non-uniform mutation function was chosen as mutation operator.

The object of the proposed auto-tuning RGA-PID controller is to search the optimal values of the gain coefficients Kp, Ki and Kd on-line in order to obtain a minimum fitness function value and to speed up the convergence of position tracking error and to improve the overall performance of controller. The block diagram of single area LFC system model controlled by the PID controller can be expressed by Figure (3).

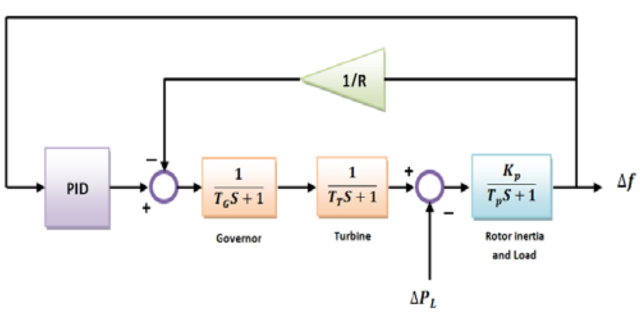

Fig. 3.Single Area Power Generation Model [11]

4 SIMULATION RESULTS

In this section the proposed RGA-PID controller is applied to the system for LFC. In order to evaluate which of the previously mentioned four performance criteria produce the best results when used in conjunction with a real-valued genetic algorithm. The RGA was initialized with a population of 400 and was iterated for 100 generations. The probability of crossover was set to 0.05 and probability of mutation was set to 0.4%. The bounds of each individual were set to lie between -100 to +100. The simulation results shown in Figures (4, 5, and 6) are carried out for four performance criteria such as; IAE, ISE, MSE, and ITAE. From Figure (4), the results of Non-reheated turbine can be concluded as illustrated in Table (2, 3). Table (2) demonstrates that settling time and peak overshoot of different control schemes uses by other researchers, Table (3) show that settling time and peak overshoot of for RGA-PID controllers using different performance criteria, It is seem that the ITAE has the shortest settling time and the lowest overshoot. The proposed controller has the best performance in damping of system oscillations compared to the other controllers.

TABLE 2
PERFORMANCE OF THE DIFFERENT TUNING ALGORITHM PID CONTROLLER FOR LFC OF NON-REHEATED TURBINE

Controller	Settling time (sec)	Peak overshoot
Fuzzy PID tuned [11]	7	0.0004
Binary GA-PID using ISE [11]	11	0.002083
PSO PID tuned [11]	16	0.0005
ANN Controller [18]	47	0.31

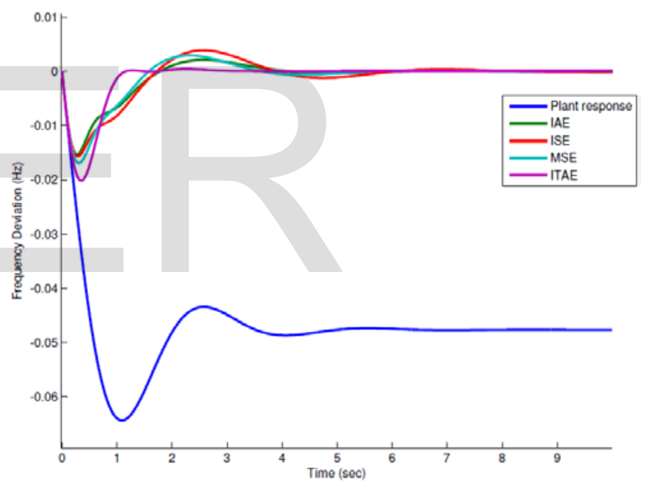

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Fig. 4.Frequency deviation step response of LFC for Non-Reheated turbine

In case of 10% step increase in power demand shown in Figure (5). This Figure indicates the capability of proposed controller in damping oscillations. Moreover, the settling time of these oscillations is approximately 1.09 second so the designed controller are capable of providing sufficient damping to the system oscillatory modes. From Figure (6), the results of Reheated turbine can be

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concluded as illustrated in Table (3). The Table (3) demonstrates that settling time and peak overshoot of the performance criteria ITAE has best response among other performance criteria.

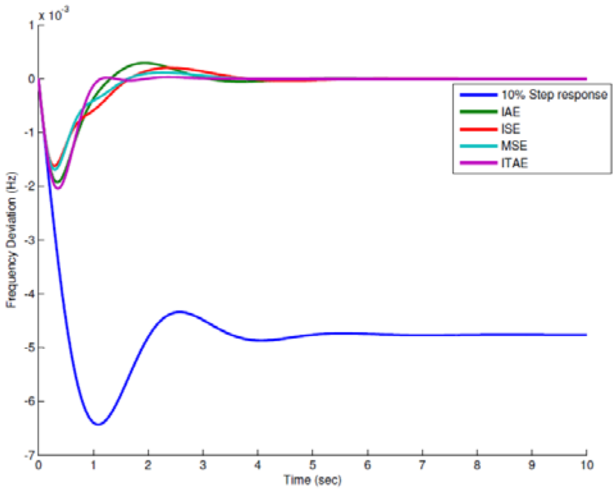

Fig. 4.Frequency deviation 10% step response of LFC for Non-Reheated turbine

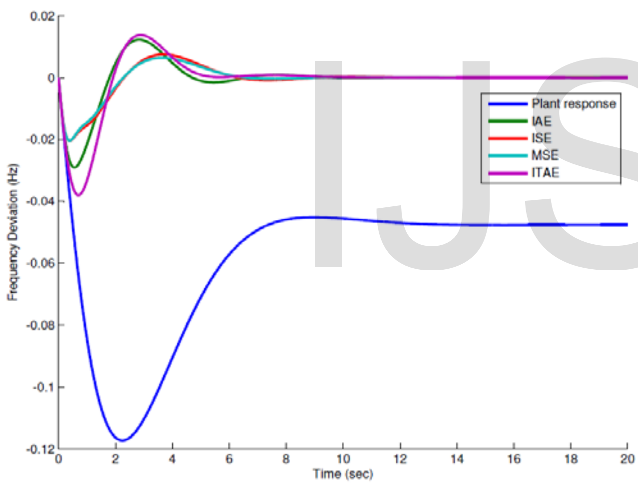

Fig. 4.Frequency deviation step response of LFC for Reheated turbine

TABLE 1
PERFORMANCE OF THR RGA-PID CONTROLLER WITH DIFFERNET PERFORMANCE CRITERIA OF LFC FOR REHEATED TURBINE

Controller	Settling time (sec)	Peak overshoot
RGA-PID controller using IAE	8.62	0.0123
RGA-PID controller using ISE	8.42	0.007536
RGA-PID controller using MSE	6.28	0.006442
RGA-PID controller using ITAE	5	0.01383

5 CONCLUSION

In this paper a PID controller which is tuned by the RGA has been successfully suggested for the load frequency control problem. The proposed algorithm was applied to single area of power system with Non-reheated and Reheated turbines. From the simulation results obtained for load disturbances of RGA-PID controller with four performance indices IAE/ISE/MSE/ITAE that the RGA-PID controller with performance criteria ITAE is faster than the other in damping oscillations, Peak overshoot and Settling time were reduced.

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APPENDIX:

The nominal values of the single area power system model parameters are:

T_G = 0.2 sec
F_{HP} = 0.3
T_{RH} = 7.0 sec
T_{CH} = 0.3 sec
R = 0.05 (Hz/p.u. MW)
T_p = 10 sec
K_p = 1.0