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Automatic Generation Control using Genetic Algorithm Based PID Controller

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Abstract: ***In this paper Automatic Generation Control (AGC) of a single-area thermal power plant without reheat turbine is introduced using a Proportional Integral Derivative (PID) controller. The gains of the controller are optimized using Genetic Algorithm (GA). The problem of tuning the PID controller is formulated as optimization problem with constraints on proportional, derivative and integral gains. The proposed algorithm uses Darwin's law of natural selection and survival of the fittest to reach the optimal solution. The simulation results confirm the system's ability to retain frequency while handling sudden load disturbances. The second part of the investigation includes robustness testing of the system against plant parameter variations. The results are verified and the system performance is found to be robust against parameter uncertainties.***

Keywords: AGC, PID controller, genetic algorithm, robustness.

I. INTRODUCTION

Design of strategy for automatic generation control of a power system has always been a challenging task for a control engineer, considering the complex involvement of the power system components and errors introduced in the modeling due to change in system parameters with aging. Automatic generation control refers to the deviation in frequency resulting from a sudden step change in the load of the system. This frequency deviation affects the quality of the power delivered by the system since nearly 90% of the load is comprised of induction motor load which is highly frequency sensitive. Hence maintaining system frequency of a power system in spite of sudden load variations is the main aim of the AGC. With the due importance of the problem, rigorous research is been carried out in this field in industry as well as academia and researchers are constantly coming up with innovative techniques and ideas to curb this problem. The term frequency is a direct indication of the balance between active power generated and load. When the load on the system increases suddenly, the extra energy required to supply the load is take from the kinetic energy of rotating rotor. As a result, the speed of the rotor decreases and hence frequency. Hence the main aim of the designed control strategy is to control the steam flow rate to the steam turbine so as to maintain the balance between generated power and the load. So far numerous different techniques have been used by researchers in the field of AGC.

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The integral controller is one of the simplest and efficient control strategies as it leads to zero steady state error. However the use of the integral controller is mainly limited by the controller gain, as it may lead to system instability. Moreover the power system is subjected to various uncertainties such as system parameter changes which lead to modeling errors. Hence due to change in the system dynamics, the controller designed to operate under one condition may no longer be efficient. Hence under such situation, a robust controller design is essential which can reject disturbances while handling parameter uncertainties.

In view of the above need, Swati Sondhi and Yogesh Hote [1] have designed a fractional order PID controller for Load Frequency Control (LFC). The controller was designed by application of Kharitonov's theorem and the system was found to perform satisfactorily for nominal as well as 50% uncertain system parameters thus confirming the robustness of the system. Control approach based upon two-degree-of – freedom Internal Model Control (IMC) was proposed by Sahaj Saxena and Yogesh Hote [2]. The complexity of the dynamic model representing the power system was reduced by unifying the model-order-reduction concepts like Routh and Pade approximations, and modified IMC filter design. The system was found to perform satisfactorily for nominal as well uncertain system parameters. A PID controller has been implemented by Dola Padhan and Somnath Majhi [3] for load frequency control problem. The controller parameters were estimated by using Laurent series to expand controller transfer function. The developed controller was found to perform satisfactorily for nominal system parameters as well as for bounded uncertainties.

In spite of large advancement in the field of control theory and controllers, mostly in the industrial controllers, conventional controllers such as Proportional Integral (PI) or PID controller are preferred owing to their ease of implementation, simplicity and robustness. In the present research we have preferred PID controller for the same reasons. The power systems being complex, the mathematical model representations for the dynamics of the system are not very accurate. The systems are also subjected to various disturbances and parameter uncertainties. Hence the controller designed is vaild only within a specific operating range. In the wake of system uncertainties and modeling errors, the controller should exhibit a robust performance while neglecting sudden disturbances appearing at the system. Hence with the advent of intelligent methods, evolutionary algorithms have helped to solve this problem to a greater extent.

GA is one of the evolutionary algorithms that have been used widely by the researchers in finding optimal solution to a variety of problems irrespective of the problem complexity.

Lokman Hassan et al. [4] has presented the use of GA for finding optimal parameters of unified power flow controller and has also used it to optimize its location within the network. Dulal Das in [5] has used GA for optimizing the controller gains in a hybrid power generation system comprising of diesel engine generator, fuel cell, flywheel, ultra capacitors, wind turbine generators and aqua electrolyzers. The controller was used in the system for automatic generation control purpose. GA has been implemented by Rene Barrera- Cardenas [6] for optimization of Linear Quadratic Gaussian control used in double-fed induction generator in a wind power system. Thus GA serves the purpose of designing an intelligent and robust control technology, in spite of nonlinearity, load disturbances and system parameter variations.

Therefore in the proposed approach GA has been used to optimize the gains of the PID controller. The main out comings of this work are;

1. The proposed controller helps in rejecting the disturbance appearing at the system as a result of step load disturbance by restoring the frequency.

2. The controller shows robust performance in spite of system parameter variations.

3. The system is optimal in terms of minimization of performance indices.

II. DYNAMIC REPRESENTATION OF a POWER SYSTEM MODEL

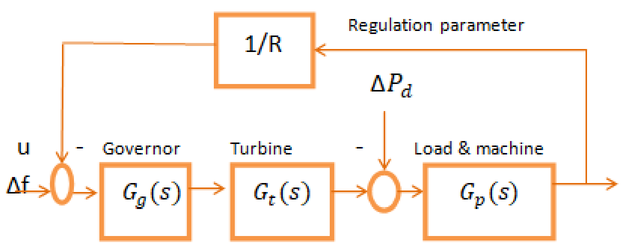

Fig. 1. Power system model

Electric power systems are inherently non-linear and complex, comprising of several generators and loads. However for the purpose of modeling, all the loads are lumped together to represent a single load as well as a single generator is used for representing all the generators. The basic power system notations are represented in the Table I.

TABLE-I: Basic power system nomenclature

ΔP_d	Load disturbance (P. U. MW)
K_p	Power system gain (Hz/P. U. MW)
T_p	Power system time constant (Sec)
T_t	Turbine time constant (Sec)
T_g	Governor time constant (Sec)
R	Regulation parameter (Hz/P.U.MW)
$\Delta P_c(s)$	Incremental change in reference power setting (P. U. MW)
$\Delta X_e(s)$	Incremental change in governor valve position
Δf	Incremental frequency deviation (Hz)
$\Delta P_g(s)$	Incremental change in generator power output (P. U. MW)

Various units comprising a power system are governor $G_g(S)$, turbine $T_t(s)$, load and machine $G_p(s)$ and regulation parameter R. The function of regulation is to stabilize the system while regulating the frequency. The transfer function models of various units associated with the power system are given by;

$$G_g(S) = \frac{1}{T_g S+1} \tag{1}$$

$$T_t(S) = \frac{1}{1+T_t S} \tag{2}$$

$$G_g(S) = \frac{1}{1+T_p S} \tag{3}$$

Using 1-3 the plant transfer function can be written as;

$$\frac{\Delta f(s)}{u(s)} = \frac{G_g(S)G_t\ (S)G_p(S)}{1+G_g(S)G_t\ (S)G_p(S)/R} \tag{4}$$

Since AGC being a frequency restorative problem while rejecting disturbances, our objective is to find a control law u(s) = -C(s) Δf(s) such that$\lim_{s\to 0} s\Delta f(s) = 0$, for all ΔP_d.

The typical values for the system parameters are;

$K_p = 120$, $T_g = 0.08$, $T_t = 0.3$, $T_p = 20$, R=2.4

III. STRUCTURE OF A PID CONTROLLER

A PID controller incorporates proportional, derivative and integral action and is a robust controller. The proportional action provides a speedy response, integral action helps in reducing steady state error to zero while derivative action stabilizes the transient response [7]. If the gains of the controller viz. proportional gainK_p, derivative gain $K_d$and integral gain K_i are optimally designed, the controller provides a robust control. The expression for transfer function representing a controller is given as:

$$G_c(s)=K_p+\frac{K_i}{S}+K_d S \tag{5}$$

Here an attempt is made to design controller gains K_p, K_i and K_d using integral of absolute error (IAE) as the objective function. The mathematical expression for the objective function is given as;

$$\text{IAE}= \int_0^t |\Delta f|\ dt \tag{6}$$

$$\text{ISE} = \int (e(t))^2\ dt \tag{7}$$

The controller gains are subjected to constraints given below;

$0\leq K_p \leq 30$; $0\leq K_d \leq 30$; $0\leq K_i \leq 30$

IV. GENETIC ALGORITHM

Genetic algorithms have been used broadly as search and optimization tools in various fields including science and engineering. The main reasons of their wide applicability are ease of implementation and broad perspective. The concept of genetic algorithm was first introduced by John Holland of the Michigan University.

These are heuristic search algorithms that are a part of evolutionary algorithms. GAs are developed based on the principle of natural selection. Fundamental ideas concerning selection, mutation and transmission of genes from parents to further generations for producing better offspring are borrowed and used artificially to construct robust search algorithm.

A. ***Controller Gains Optimization Using GA***

For application of optimization using GA the solution has to be represented in genetic form and the fitness function essential for evaluation of the solution is required. The algorithm starts with population initialization. The individuals represent the solution which constitutes PID controller gainsK_p, K_i and K_d . The steps performed by GA in reaching the optimal solution can be given as:

1. Population of individuals: The population of chromosomes representing the solutions is generated by the algorithm to create a mating pool. The solutions are created randomly considering upper and lower bound on the variables. The three controller gains that represent decision variables are used to construct genes which represent a chromosome.
2. Objective function: The objective function is necessary for evaluation of the solution in the context of the desired objective subjected to the constraints. The fitness function value is determined by unit step response of the system to a step input that represents a sudden load disturbance. The performance indices used for optimization are Integral of Absolute Error (IAE) and Integral of Square Error (ISE).

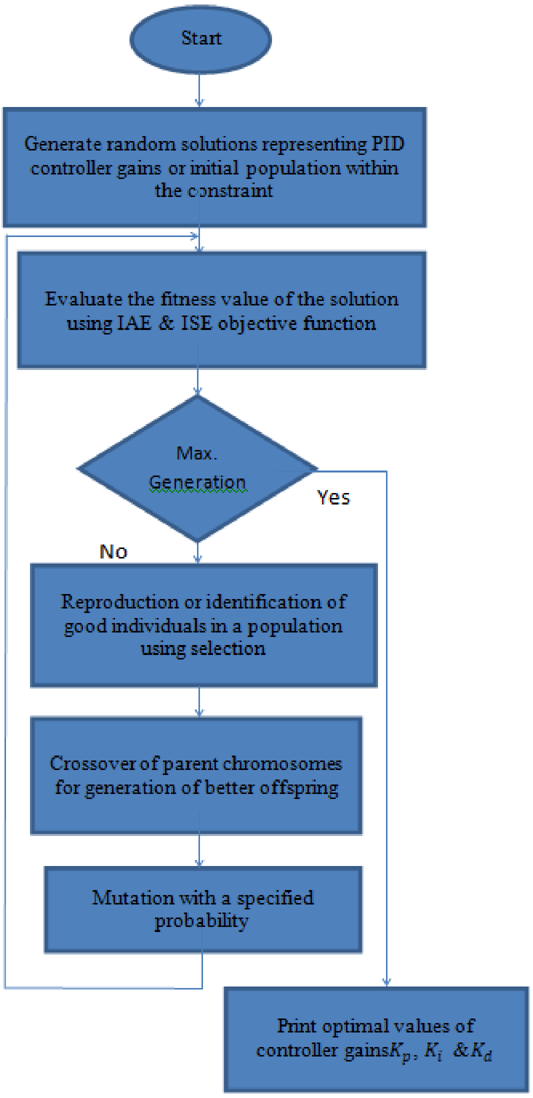

Fig. 2. Genetic Algorithm

3. Selection or reproduction: The main motive behind the selection operator is to duplicate the solutions with higher fitness while the population size is maintained constant. The three main techniques used for selection are: tournament selection, roulette wheel selection and proportionate selection.
4. Crossover: Crossover operation is used for creating new solutions in the population thus maintaining variety. In a crossover operation, two strings are picked at random from the two chromosomes representing parents and some parts of the strings are interchanged to create totally new offspring.
5. Mutation: Mutation operator helps to create diverse population. In a mutation operation, the chromosome representing an individual solution is modified by changing 1 to 0 or vice-versa. Mutation operator aids in the avoidance of getting a solution trapped in local optima or premature convergence of the solution.

V. RESULTS AND DISCUSION

Case1: System with nominal system parameters with PID controller: - This section emphasizes the effectiveness of load frequency control using GA based PID controller for a single-area thermal power system without reheat turbine. The performance analysis of the optimization technique is guided by the objective function. In our case we have considered two objective functions viz: Integral of Square Error (ISE) and Integral of Absolute Error (IAE). In this part of analysis, the system is subjected to a step load disturbance of magnitude 0.01 p. u. and the simulation response of the system is analyzed. The response analysis as seen from Fig. 3 and Fig. 4 prove the ability of the given technique to successfully nullify the static error in frequency.

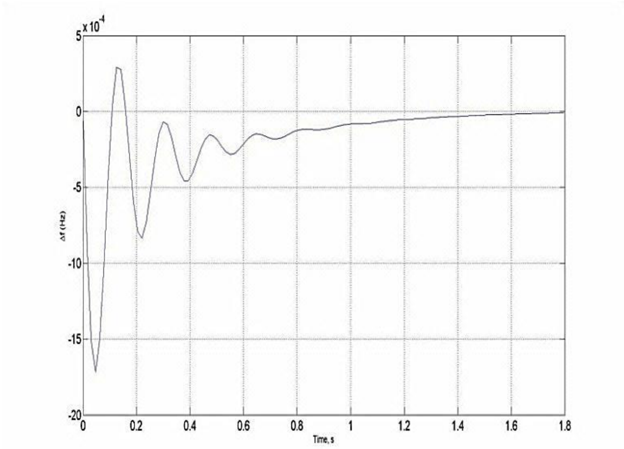

Fig. 3 System transient response to a step load change with IAE as objective function

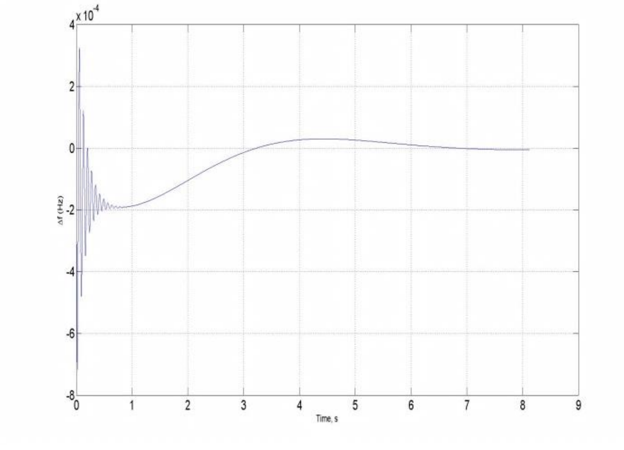

Fig. 4 System transient response to a step load change with ISE as objective function

TABLE-II: Comparison of performance indices

Sr. No.	Techniques (Year)	Settling Time (Sec)	Performance Index (J)
1	Internal model control scheme and model –order reduction (2013)	--	IAE1=0.08061 (SOPDT) IAE2=0.08166 (Routh Approximation) IAE3=0.08183 (Pade Approxiamtion)
2	IMC in LFC (2017)	--	ISE=1.38 ITAE=0.0023
3	Fractional order controller and reduced order modeling (2019)	--	ISE=0.000616 ITAE=0.004468 IAE=0.00294
4	LMI based PID approach (2017)	2.274	ISE=0.00002117
5	AGC using Quasi-oppositional harmony search algorithm (2015)	19.81	ISE=0.00562 ITAE=0.009932 ITSE=0.0000273
6	AHP based optimized tuning of modified active disturbance rejection control- (2018)	1.838	ITAE=0.003754 ISE-=0.00000027
7	LFC using Fractional order PID controller for perturbed system by Khartinovo's theorem (2016)	--	ISE= 0.0007097 ITAE=0.4562 IAE=0.0817
8 a. b.	Proposed approach IAE ISE	1.5665 6.0954	0.0003515 0.0000001

From the results tabulated in Table II, it is clear that GA based PID controller has given a low settling time with IAE criterion compared with the settling time offered by other techniques mentioned in the recent literature. The comparison of the performance indices IAE and ISE confirms the supremacy of the implemented technique as better values are obtained for performance indices for both of the error criteria. The comparison of settling times for IAE criterion shows that we have obtained 31.11% improvement in settling time over the settling time obtained by LMI based PID approach. Similarly there is 92.09% and 14.77%improvement of settling time over the settling time obtained by QOHS algorithm and modified active disturbance rejection control respectively. The ISE criterion has given a 69.23% improvement in settling time over the settling time obtained by QOHS algorithm.

The transient response analysis as observed from Table III shows all poles location in the left half of S-plane thus confirming the stability of the system. The observations show that the value of performance index obtained by ISE criterion is lower than that obtained by IAE criteria. However the transient response with IAE criterion gives lower settling time than that obtained with ISE criterion indicating speedy settling of frequency transients after the system is subjected to step load perturbation.

TABLE-III: Transient response specifications

Sr. No	objective Function	Eigen values	Controller gains	Settling Time ?? (Sec)	Performance Index (J)
1	IAE	- 6.0118+41.7055i - 6.0118- 41.7055i - 1.9299 + 0.7068i - 1.9299 – 0.7068i	??= 27.1905 ?? = 29.9999 ??= 7.1346	1.5665	0.0003515
2.	ISE	- 7.4373 + 86.4352i - 7.4373 – 86.4352i - 0.5043 + 0.8615i - 0.5043 – 0.8615i	??= 29.9999 ?? = 29.9985 ?? = 29.9996	6.0954	0.0000001

Case 2: System with 50% parameter variations:

In this part of analysis, we consider the system with 50% variation in system parameters in upper and lower limit to test for robustness against system parameter variations. The interval for the system parameters is given as:

$K_p \rightarrow [60, 180]$, $T_P \rightarrow [10, 30]$, $T_t \rightarrow [0.15, 0.45]$,
$T_g \rightarrow [0.04, 0.12]$, $R \rightarrow [1.2, 3.6]$

The system is subjected to parameter variations in upper extremity as well as lower extremity and the system response to a step load disturbance is plotted considering IAE and ISE error criteria. The simulation response of the system with parameter uncertainty shows successful reduction of frequency deviations to zero thus affirming the robustness of the system to parameter variations.

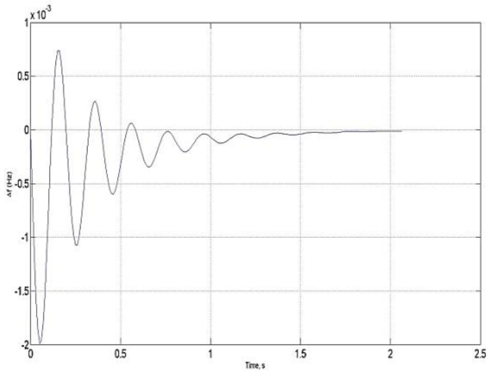

Fig. 5 System transient response to a step load change with IAE error criterion with 50% upper bound system parameters

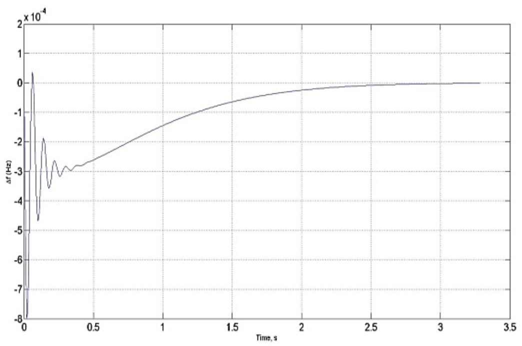

Fig. 6 System transient response to a step load change with IAE error criterion with 50% lower bound system parameters

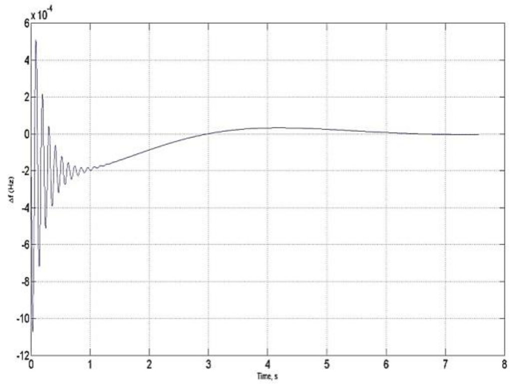

Fig.7 System transient response to a step load change with ISE error criterion with 50% upper bound system parameters

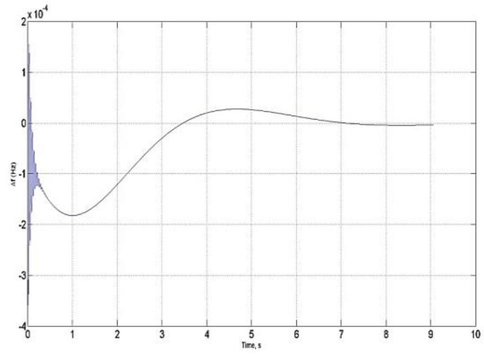

Fig. 8 System transient response to a step load change with ISE error criterion with 50% lower bound system parameters

The observations tabulated in Table IV show that the value of the performance index obtained by ISE criterion is lower and hence better than that obtained by other researchers. Similarly the value of performance index given by IAE criterion is lower than obtained by other researchers for both upper and lower bound system parameters.

TABLE- IV: Performance index comparison for upper & lower limit

	Nominal system parameters		50% parameter extremity			
			Lower limit		Upper limit	
	IAE	ISE	IAE	ISE	IAE	ISE
Implemented scheme	0.000352	1E-07	0.000352	1E-07	0.000352	1E-07
Shiva & Mukherjee [16]	--	0.00562	--	--	--	--
Sondhi & Hote [1]	0.01014	4.32E-05	--	--	--	--
Saxena [10]	0.00249	0.00061	0.00118	0.000133	0.00406	0.000012
Saxena & Hote [2]	0.08061	0.000823	0.08247	0.000866	0.07827	0.00081

VI. CONCLUSION

A power system is primarily accompanied by governor for frequency regulation. However the regulation provided by the governor is restricted. Hence secondary control action is required. In our case, we have used a PID controller for initiating secondary control action on a single-area thermal power plant without reheat turbine. Genetic algorithm has been used for optimization of controller gains. The simulation studies are carried out for a system with nominal system parameters. The system performs satisfactorily while rejecting the disturbances and restoring the frequency to its nominal value. The system is also tested for robustness against 50% parameter variations and the response is found to be acceptable with minimum variations in settling time.

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