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GENETIC ALGORITHM BASED OPTIMAL LOAD FREQUENCY CONTROL IN TWO-AREA INTERCONECTED POWER SYSTEMS

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Abstract
Load frequency control in power systems introduces as one of the most important items in order to supply reliable electric power with good quality.
The goals of the Load Frequency Control (LFC) are to maintain zero steady state errors in a two area interconnected power system. To achieve this goal a fast controller with having no steady-state error will be necessary to be included in power systems. In this paper a new genetic algorithm based method is presented to obtain optimal gains of this controller included in two-area interconnected power system.
Simulation results in comparison with correspondence methods confirm the efficiency of proposed method through fast-damping steady-state deviations in power and frequency with presence of step load disturbance.

Keywords: Two-area interconnected power systems, Load Frequency Control, Optimal controller design, Genetic Algorithm.

1. Introduction

One of the principle aspect of Automatic Generation Control (AGC) of power system is the maintains of frequency and power change over the tie-lines at their scheduled values and due to the fact that modern power systems with industrial and commercial loads need to operate at constant frequency with reliable power, the load frequency control (LFC) of an interconnected power system is being improved over the last few years.

In LFC problem, each area has its own generator or generators and it is responsible for its own load and scheduled interchanges with neighboring areas. The tie-lines are utilities for contracted energy exchange between areas and provide inter-area support in abnormal conditions. Area load changes and abnormal conditions lead to mismatches in frequency and scheduled power interchanges between areas. These mismatches have to be corrected by LFC, which is defined as the regulation of the power output of generators within a prescribed area [1]. Therefore, the LFC task is very important in interconnected power systems.

Over the past decades, many techniques have been developed for the LFC problem. A number of state feedback controllers based on linear optimal control theory, robust and conventional adaptive controller have been proposed to achieve better performance [2,3,4 and 5] state adaptive controllers [6] involve large computational burden and time. Also, Most of proposed techniques were based on the classical proportional and integral (PI) or proportional, integral and derivative (PID) controllers. Its use is not only for their simplicities, but also due to its success in a large number of industrial applications. In Classical methods, such as Ziegler-Nichols and Cohen-Coon, these controllers are tuned based on trial-error approaches and, therefore, have not good performance. Meanwhile, these controllers may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. Due to these facts using a flexible algorithm to obtain optimal gains in designing control feedbacks will be an important matter. Also, because there should be a sudden feedback to restore the frequency to its desire point that had before, a fast response should be considered as the main goal.

In this paper genetic algorithm is used to solve this non-liner optimization problem which will cause a fast response to two-area interconnected power system load frequency controllers with determining optimal gains in LFC feedbacks.

2. Modeling of a two-area interconnected power system

A two-area system consists of two single areas connected through a power line called the tie-line. Each area feeds its user pool and the tie-line allows electric power to flow between areas. Since both areas are tied together, a load agitation in one area affects the output frequencies of both areas as well as the power flow on the tie-line.

The frequency control is accomplished by two different control actions in interconnected two area power systems: The primary speed control and supplementary or secondary speed control actions. The primary speed control makes the initial vulgar readjustment of the frequency. By its actions the various generators in the control area track a load variation and share it in proportion to their capacities. The speed of response is limited only by the natural time lags of the turbine and the system itself. Depending upon the turbine type the primary loop typically responds within 2 to 20 seconds. The supplementary speed control takes over the fine adjustment of the frequency by resetting the frequency error to zero through an integral action.
The control system of each area needs information about the transient situation of both areas in order to brings the local frequency back to its steady state value. Information about the other areas found in the output frequency fluctuation of that area and in the tie-line power fluctuation. Therefore, the tie-line power is sensed and the resulting tie-line power signal is feed back into both areas by determined gains.
A two-area interconnected power system is shown in figure 1. This kind of system can be represented for the load frequency control in terms of its components like governor system, turbine, generator, load and tie line between two-area, where Δf_1 and Δf_2 are the frequency deviations in area 1 and area 2 respectively. Also ΔP_{D1} and ΔPD_2 represent sudden load demand increments:
In this block diagram parameters of power system are H, D, R which indicates "inertia constant", "load sensitivity to frequency factor", "regulator slope" respectively.
Meanwhile, transfer function for turbine and governor is assumed as follow:

$$TF_{Turbine} = \frac{1}{1+S.T_T}$$

$$TF_{Governor} = \frac{1}{1+S.T_G} \quad (1)$$

Where:
T_T: Turbine Time constant
T_G: Governor Time constant

With these base definitions it is convenient to obtain the dynamic model in state variable form from the transfer function model.

Transfer function for system illustrated in figure 1 can be written as:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) + Fd(t) \\ y(t) &= Cx(t) \end{aligned} \quad (2)$$

Where:

$$x = \begin{bmatrix} \Delta P_{C1} \\ \Delta X_{G1} \\ \Delta P_{R1} \\ \Delta P_{T1} \\ \Delta_{F1} \\ \Delta P_{tie} \\ \Delta P_{C2} \\ \Delta X_{G2} \\ \Delta P_{R2} \\ \Delta P_{T2} \\ \Delta_{F2} \end{bmatrix}$$

$$\begin{aligned} u &= [u_1 \quad u_2]^T \\ d &= [\Delta P_{d1} \quad \Delta P_{d2}{}^T] \end{aligned} \quad (3)$$

and A, B, C and F are the system matrix, input, output and disturbance distribution matrices, respectively, where x(t), u(t) and d(t) are the state, control and load changes disturbance vectors, respectively.
These matrix and vectors are obtained using
the nominal parameters of the system. A step load of 1 P.U has been considered as a disturbance in the two-area interconnected power system.

3. Application of genetic algorithm to solve LFC problem
Genetic algorithm (GA) is one of the optimization methods based on heredity and evolution. This algorithm is one of the statistic searching methods and as it mentioned before due to the fact that load frequency control involves with inconstant loads and we face to a non-liner problem, real coded GA can be considered as an appropriate method for reaching optimal gains with fast response to system

Considering "y" as output vector we can assume that:

$$y = [ACE_1 \quad ACE_2]^T \quad (4)$$

Where ACE_i is Area Control Error signal due to step type load disturbance can be calculated as:

$$ACE_i = \Delta P_{tie,i} + B_i \Delta F_i \quad (5)$$

Note that in this equation, B_i is the frequency bias, Δf_i is the frequency deviation and $\Delta P_{tie,i}$ is the change in tie-line power for the i-th area.

In designing the controller, cost function can be assumed as minimization of "Integral of Absolute Error"(IAE), "Integral of Square Error(ISE)" or "Integral of Time Multiplied Square Error"(ITSE) for step response of load deviation:

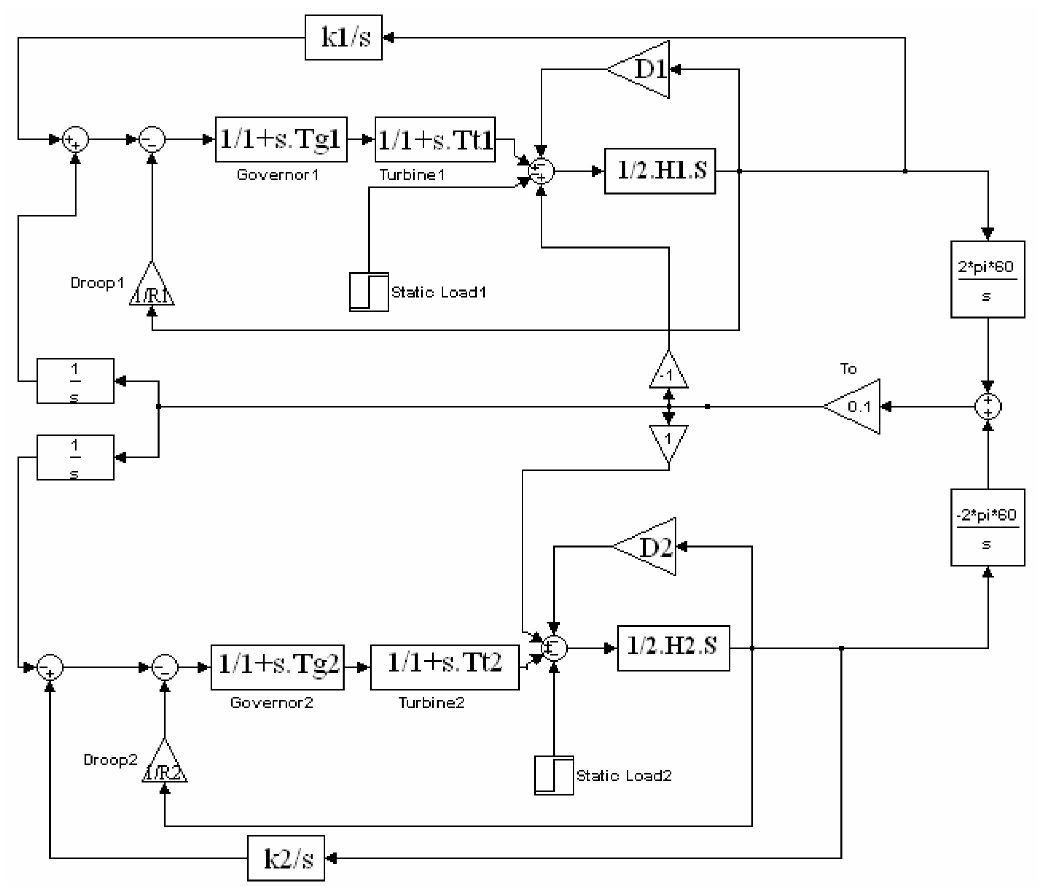

Figure 1: A two-area interconnected power system block-diagram

- $.\ IAE = \int_0^\infty |e(t)dt|$
- $ISE = \int_0^\infty e^2(t)dt$
- $ITSE = \int_0^\infty te^2(t)dt$

Practical cases show that "IAE" and "ISE" functions will cause more minimization in overshot than "ITSE" and due to the fact that "ISE" will cause fast response with shorter settling time we consider this cost function as our objective function in this essay:

$$F_{Cost} = \int_0^t ACE^2{}_i.dt \quad \text{, For i =1,2} \tag{6}$$

In GA algorithm -considering the cost function- a fitness function is considered for each string of values, so that in the next stage the initial population will be chosen in a way that we can use the probability of roulette for this choice.
The suggested fitness function for creating the initial population can be written as:

$$F_{Fitness} = \frac{1}{1+F_{Cost}} \tag{7}$$

Consequently the roulette is divided in according to the quantities of fitness function of each real coded string and with each circulation one string for creating a new generation is selected. Then the act of creating a new generation is done by the genetic operators such as cross-over and mutation.
Afterward the fitness quantity for each one of the newly created strings is calculated and strings with more fitness are chosen as the next generation. Absolutely the strings with high fitness values are more probable to be transferred to the next generation.
This process will be continued until the best answer in successive repetitions has minimum variance to unit (So J will have minimum variance to zero) and the best solution does not change for a pre-specified interval of generations. The resulted string shows the information of the final optimized gains.
Following flow chart illustrates basic steps in real coded genetic algorithm used for load frequency control. Meanwhile, real coded GA parameters are given in table 1.

4. Schematic results in implementation of suggested method

For examining the efficiency and improvement, the presented model is developed in MATLAB, on a Pentium-4 PC (1.86GHz & 2GB RAM), and is performed on a sample two-area interconnected power system with system parameters included in table 2 and a step load disturbance in one of these areas.
Changes in frequencies after load deviation are illustrated on figure 3 for two areas when there is no LFC in system. As it is clear system can not compensate frequency deviation by its self.

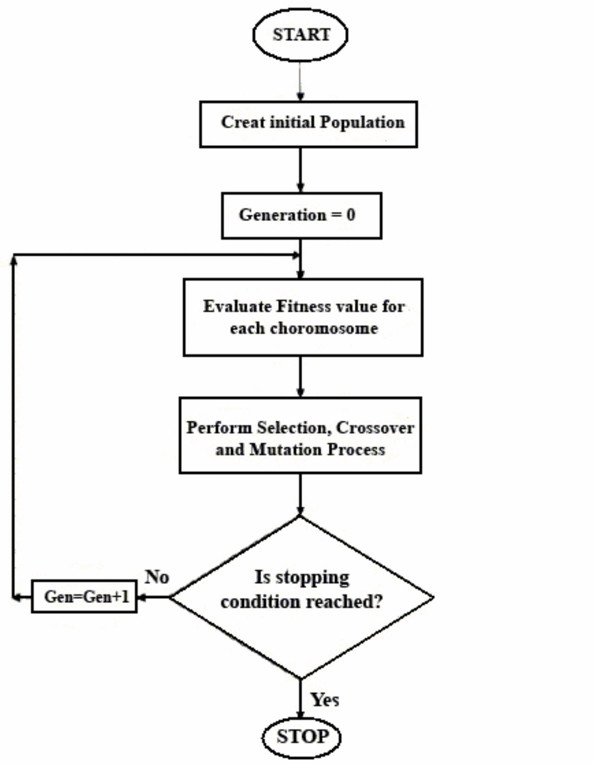

Figure 2: Flowchart of basic real coded genetic algorithm

Table 1: Main GA parameters used in this paper

Option	Number / Type
Number of variables	2
Total number of generation	30
Population size	100
Cross over	Scattered
Cross over probability	0.4
Mutation probability	0.001
Fitness scaling	Rank
Elite count	2

Table 2: Sample two-area interconnected power system parameters

Parameter	Area 1	Area 2
T_T	0.3	0.3
T_G	0.08	0.08
D	0.8	0.4
H	5	2
R	0.05	0.05

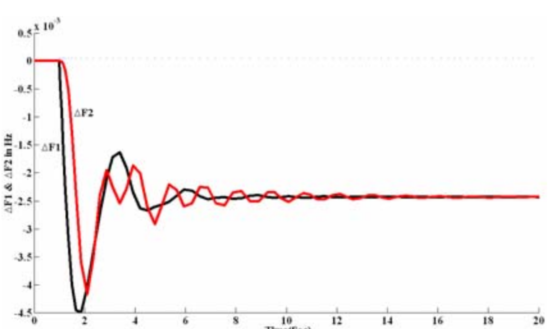

Figure 3: Frequency deviation in area 1 & 2 without LFC

Figure 4 shows frequency deviation for area 1 with GA based optimized gain and without optimization (with random gain selection).

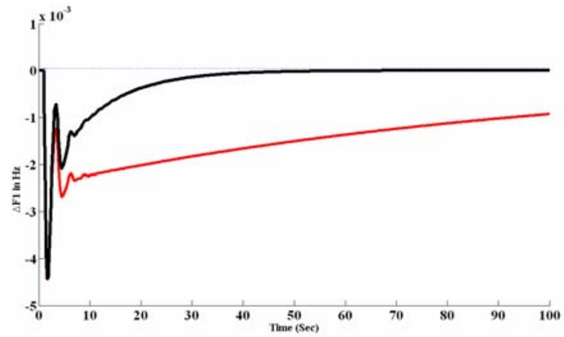

Figure 4: Frequency deviation in area 1 with optimized gains and without optimization

As it was clear proposed method caused faster response with minimum agitation where without optimization frequency response damps in a longer time with inappropriate response to load variations. Figure 5 depicts these results much more clear for second area.

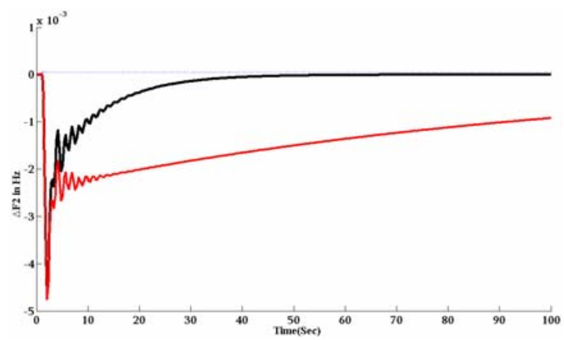

Figure 5: Frequency deviation in area 2 with optimized gains and without optimization

Moreover, changes in power of tie-line before and after optimal AFC are shown in figure 6. With presence of optimal controller error in power transfers between two areas will be zero after some seconds where without AFC control we will have error in steady-state response.

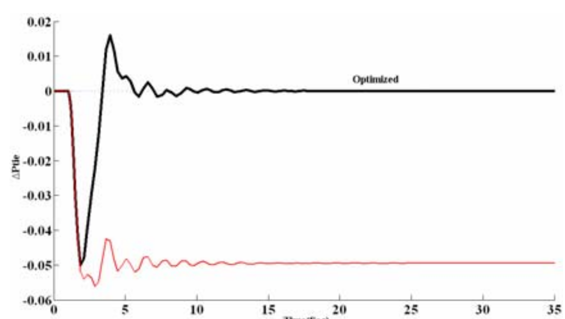

Figure 6: Tie line power deviation before/after optimization

As a comparison to other correspondence papers the suggested method shows less agitation in frequency deviation whit much more faster response. Figure 7 campers suggested method with result of reference [7] for frequency deviation in area2 with same system parameters.

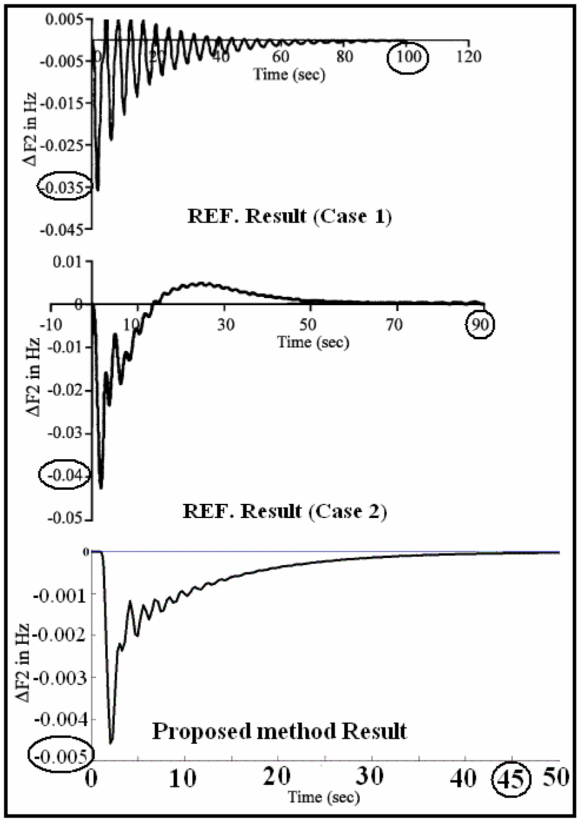

Figure 7: Comparison between Frequency deviation in area 2 with proposed OLFC and proposed method in ref.[7]

5. Conclusion

A new method for Optimal Load Frequency Control (OLFC) in interconnected power systems has been discussed in this paper which a real coded Genetic Algorithm used to solve this non-liner problem.

Also suggested method implemented on a simple two-area interconnected system and the results showed reasonable fast response with no steady-state error to a step load disturbance. This is while, the efficiency and improvement of suggested method examined with comparing its results whit correspondence methods for LFC.

This investigation can be extended for optimizing the gains including penalty factors in fitness function for future investigations. These penalty factors can indicate some extra constraints such as governor saturation and can be model by means of “Maximum Speed” and “Maximum Rotation”.

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