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An Optimization of Four Area Power System Using PI Controller with Genetic Algorithm

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***Abstract*- This paper illustrates a four area power system and optimizes the frequency deviation and tie-line power flow during dynamic condition. Since a dynamic load changes may affect an isolated power system usually in the area operating frequency. An interconnected power system is to avoid this problem during transient, due to interchange of power between interconnected areas until the system reached to the steady state condition. This technique is known as load frequency control (LFC) or automatic generation control (AGC). Here a PI controller is use to optimize the frequency deviation using genetic algorithm with integral time weighted absolute value error (ITAE) criterion. A simulation result show how frequency may be affected in whole area when change in demand in all the area and GA technique gives the best value of PI controller for steady state condition.**

Keywords - Four area power system; Automatic Generation Control (AGC); PI controller; Genetic Algorithm (GA); frequency deviation.

I INTRODUCTION

In a modern power system, a complexity and dynamic nature is to create many adverse and transient effects into the operation of power system. It may direct affect the power system operating frequency as well as voltage. During the optimization, the primary objective of power system operation and control is to maintain continuous supply of power with an acceptable quality (frequency and voltage) to the entire consumer. In this paper illustrates a four area power system model and optimizes the frequency deviation and tie-line power flow during disturbance. At first understand a single area/ isolated area, the power output of the generator is closely coupled with an electrical area is to maintain the operating frequency to the entire load. The entire generator under this area make a coherent group, means all the generator are speed up or speed down monotonously and maintained their relative power angle during load change. Such an area is defined as single area/isolated area or control area. For the stable operation of any isolated area, demand and generation will be in equilibrium during dynamic. The dynamic condition causingcan be load change or generation failure across any generators. When the demand is more than the generation, the area operating frequency is decreased and it may affect the performance of frequency dependent load. Under the stable operating condition, the optimal change frequency nearly zero or under desirable limit (maximum permissible change in frequency is ±0.5Hz) [16]. Under this limit a frequency change ensures constancy of speed of induction motor, synchronous motors and an active power flow (because frequency of a system is dependent on active power) in a network. When a demand/load is increased, turbine speed is decreased and then governor come into action and adjust the steam input to the turbine till the frequency deviation not came to the desired limit because of the generating frequency is directed proportional to the speed of turbine. One way to restore the frequency or speed with zero offset is to add an integrator. The integral unit monitors the average error over the complete time period and will ensure zero offset. This technique is known as automatic generation control (AGC) or load frequency control (LFC).

Since a single area have many problems to ensure the zero offset during dynamic condition and it gave deviation in frequency during disturbance. It may take more time to ensure zero offset and then normal frequency deviation beyond desirable limits can directly impact on power system operation and system reliability. A large frequency deviation can damage equipments, adverse load performance because the transmission lines to be overloaded and can lead to disturbance with system protection schemes and ultimately the power system goes to unstable state. An interconnected power system ensures the frequency response would not be affected during disturbance. The main advantage of an interconnected power system, sustain the system operation under stable condition. A multi area power system plays an important role for the operation and control of power system, is to minimal change in frequency very close to a zero offset. A multi area interconnected power system is to rescheduled interchange the power (tie line flow) between interconnected area during disturbance and it would happen that time when power system goes to the steady state and frequency restored to the previous value. Means a multi area power system is to maintain generation of individual generating unit's at the most economical operation and to keep the correct value tie line flow at their scheduled values during normal condition but also regain zero steady state error in frequency deviation when small step load disturbance or fault subjected to at any point.

The conventional AGC depends upon control area parameter and is not more effective and reliable for modern power systems (distributed generation) because of it would be controlled by governor action and slow response. Hence in AGC system, PI controller (under integral control action) is used to perform an input control signal for AGC and derive ACE, where each area eliminates our own load changes. In a multi area system PI controller parameters for each area must be designed in such manner that it will ensure safe, reliable and uninterrupted power supply. The PI controllers increase the order of system and nullify the effect of load change, maintain steady state frequency and tie-line power between the control areas. The most recent research trend for optimize the control area using soft computing techniques such as neural networks, fuzzy logic, genetic algorithm (GA), PSO, BF etc. to tackle the difficulties associated with the design of controller with higher order nonlinear models and insufficient knowledge about the system [7]. In this paper GA is used is one of the most popular and widely used algorithm of all the soft computing techniques. It is widely use to solve higher order nonlinear optimization problems in a number of engineering disciplines in general and usually in the area of AGC of power systems. GAs optimization technique is used to tune the control parameters of the PI controller and regulate the area performance during abnormal condition.

II MULTI-AREA AGC SYSTEM

In multi area system a number of generating unit in a single area are connected, those are further connected to different control area through tie line, thus improve the overall system reliability and stability [11]. In a single area all generating unit controlled by own load frequency characteristics those effect the frequency response. According to a paper title, a multi area system considers a four area system means even if some generating units in one area fail or load changes than affected area drawn power to another three area through tie line and compensate the frequency change as well as load demand with respect to prior disturbance and rescheduled power interchanges across different control areas. For analyzing the multi area AGC system, it is very important for steady-state frequency deviation and tie-line. In four areas LFC system, it is divide the loads in three control area, stations and generations to achieve maximum economy and correctly control the schedule interchanges of the tie-line power while maintaining zero offset in frequency. Of course, we are implicitly assuming the system is stable, so the steady state is achievable. During large transient disturbances and emergencies, LFC is bypassed and other emergency controls are applied.

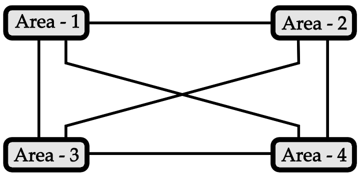

Fig 1. Four Area Interconnected System

In an AGC based multi-area power system, where generators are closely coupled internally and swing monotonously then overall frequency of complete four areas are same under dynamic condition and simultaneously reschedule the tie line flow. Since, according the AGC concept the tie line flow in or out from all area for balancing the power equation of each area under scheduled manner. Thus, we can maintain the constant frequency operation irrespective of load change. Tie line control system must use two pieces of information: the system frequency and the net power flowing in or out over the tie lines.

- If frequency decreases and net interchange power leaving the system also increases then the load increased outside the system.
- If frequency decreases and net interchange power leaving the system also decreases, then the load increased inside the system.

To understand the basis for supplementary control action of interconnected power system, let us first study the performance with primary speed control only.

The power transfer through the tie line between area i and j is given by

$$\Delta P_{ij} = T_{ij}\Delta\delta_{ij} = \frac{2\pi}{s} T_{ij}\left(\Delta f_i - \Delta f_j\right) \quad [1]$$

Where, $\Delta\delta_{ij} = \Delta\delta_i - \Delta\delta_j$

δ_i, δ_j = equivalent power angle of voltage source (equivalent generating unit)

X_{ij} = tie line impedance between area i and area j

So the total tie line power exchange between areas 1 to other three areas can be calculated as

$$\Delta P_1 = \Delta P_{12} + \Delta P_{13} + \Delta P_{14}$$

$$\Delta P_1 = \frac{2\pi}{s}\sum_{j=2}^{4} T_{1j}\ (\Delta f_1 - \Delta f_j) \quad [2]$$

Similarly for n control areas, the total tie line power change between areas 1 to other (n-1) area is

$$\Delta P_i = \sum_{\substack{j=1 \\ j\neq i}}^{n} \Delta P_{ij}$$

$$\Delta P_i = \frac{2\pi}{s}\sum_{\substack{j=2 \\ j\neq i}}^{n} [T_{ij}\ (\Delta f_i - \Delta f_j)]$$

$$\Delta P_i = \frac{1}{s}\sum_{\substack{j=2 \\ j\neq i}}^{n} [T_{ij}\ (\Delta\omega_i - \Delta\omega_j)] \quad [3]$$

For using a same value of synchronizing torque coefficient (T_{ij})in all the tie line (for studying in given model T_{ij} = 2)

Then $\Delta P_i = \frac{1}{s}\sum_{\substack{j=2 \\ j\neq i}}^{n}[2\,(\Delta\omega_i - \Delta\omega_j)]$

$$\Delta P_i = \frac{2}{s}\sum_{\substack{j=2 \\ j\neq i}}^{n}(\Delta\omega_i - \Delta\omega_j) \quad [4]$$

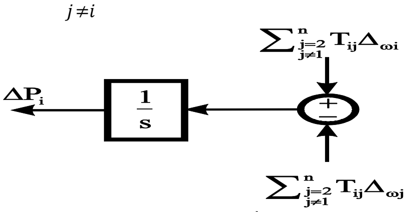

Fig.2 Tie line flows from i[th] area to n area

The mathematical model of Multi-Area AGC system used for analysis is a four-area interconnected power system, where all areas without reheat steam turbine. There will be an area control error (ACE) for each area and it will try to reduce its own ACE to zero. The ACE of each area is the linear combination of the frequency deviation with bias factor and total tie line power deviation from one area to other three areas. Therefore ACEs considering for n area is given by,

$$ACEi = \sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta P_{ij} + B_i \Delta f \qquad [5]$$

Where B_i is the frequency bias constant

III PI CONTROLLER WITH GENETIC ALGORITHM

Genetic Algorithm (GA) is one of the soft computing technique is used to find out a best solution in a given search space, was developed by John Holland in 1970 [4]. In GA technique, is used to generate a population for given problem and compare with best fittest value. Where GA used some genetic operators like selection, reproduction, crossover and mutation. Genetic Algorithm is used to solve a higher order problem having multiple variables of any domain. Its only requires the ability to develop a mathematical model of a set of input (the variables) according a model to finding an optimal solution. Initially, the GA performs parallel, statistically and direct search to the fittest population of given fitness functions for a multivariable problem called initialization. After the initializing process the fitness population, each string (individual) determines the performance of the string of new population. In that case the higher order string of a new population are mate each other is called crossover. During crossover a string having partial solutions combined each other. The algorithm gave a priority of fittest strings as parents, where better strings having more number of offspring. The GA explores the regions of the search space, because iteratively generations of reproduction and crossover produce more numbers of strings in those regions. Finally, mutations reproduce a small fraction of the strings.

Tuning of a PI controller follows a tuning of proportional and integral parameter to find a best value with minimum error. The basic aim required for the dynamic condition in this paper will be the least frequency deviation, less rise time, less peak time and minimum overshoot. Different dynamic conditions have different responses where it gives best controller value which can be achieved by meaningful tuning of the controller parameters. If the system can be taken offline, the tuning method analyzed the step input disturbance in the system. The objective function for the proposed model for dynamic condition is shown in figure 3. In this study the fitness function is in term of area control error (ACE) with "the integral of the time multiplied absolute value of the error" criterion (ITAE) is to be minimized. The fitness function for a proposed model of multi area is shown in equation (7).

In this paper, the error criterion considered is given by:

$$ITAE = \int_0^{\infty} t(e(t))\, dt \qquad [6]$$

The objective functions of four area interconnected system for ITAE criterion is, where the error signal is ACE for each area and for each area it will try to reduce zero. Hence

$$ITAE = \int_0^{\infty} t(ACE_i)\, dt \qquad [7]$$

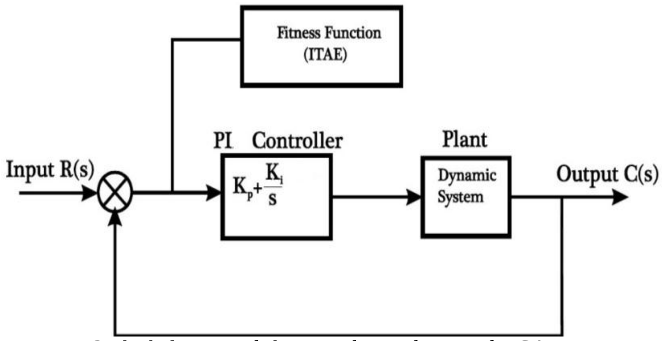

Fig.3 Block diagram of obtaining fitness function for GA

IV SIMULINK MODEL AND RESULTS

A systematic block diagram of four area power systems has shown in fig. 4, where isolated areas have a turbine model, governor model and generator model. All the blocks (model) of an isolated system are shown within time constant form like as a first order system. Since in all area have a three dynamic model than it can form as a third order system. When an integral controller added before the dynamic system than order of the system increased by one and formed fourth order system. Here the 0.1pu is the change in load across control area, is the disturbance for proposed model. Where the –ve sign shows the demand decreases, means the frequency is increased then tuned controller parameter come to the operation and eliminate the change in frequency. Here PI controller with GA is used to optimize the four order system for given disturbance under ITAE error criterion.The tuned controller model (PI) parameter for this dynamic condition is shown in table 1. Where the PI controller is tuned by Genetic Algorithm and gives the best value. PI controller with GA based model compare with without controller based model and shows the effectiveness of PI with GA with respect to without controller is shown in fig.5 to fig.8 in term of frequency deviation.

TABLE I : PARAMETERS FOR PI CONTROLLER

Parameter	Area 1	Area 2	Area 3	Area 4
K_i	0.12	0.41	0.23	0.24
K_p	0.12	0.28	0.51	0.09
Overshoot Δω (PI with GA)	0.0070	0.0080	0.0080	0.0085
Overshoot Δω (Without Controller)	0.0078	0.0085	0.0100	0.0110

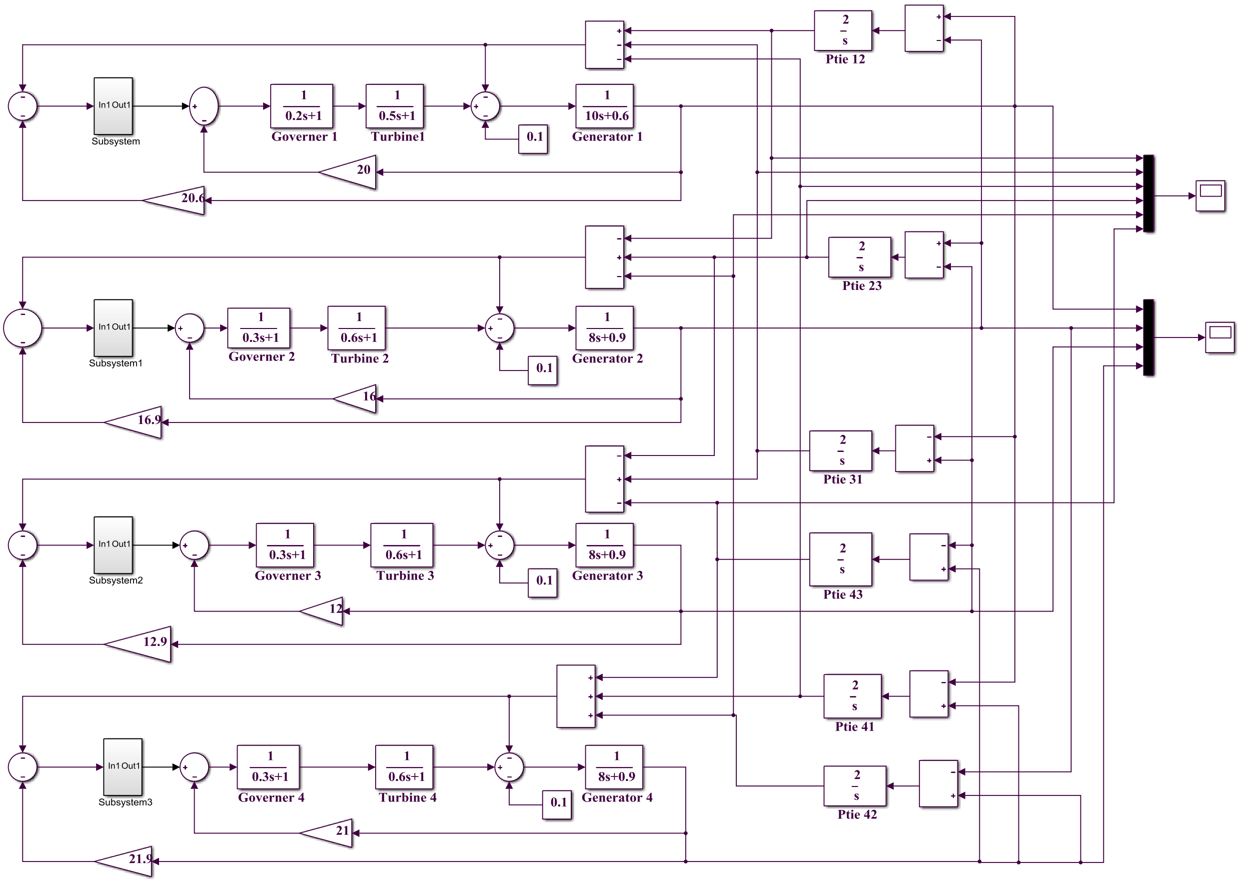

Fig.4 Simulink model of four area LFC system

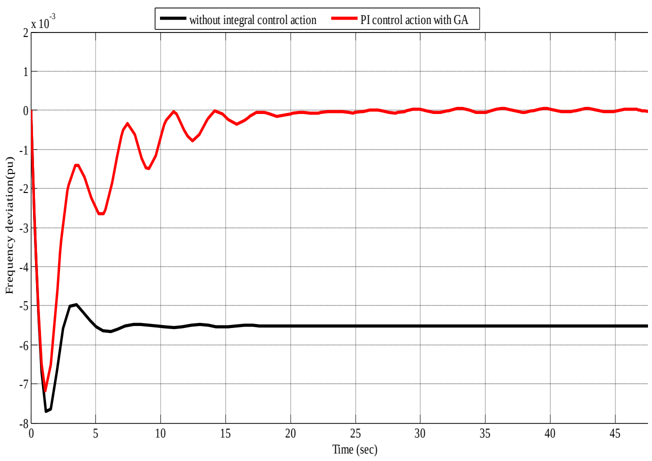

Fig.5 Frequency deviation in area 1 for 0.1pu change in demand

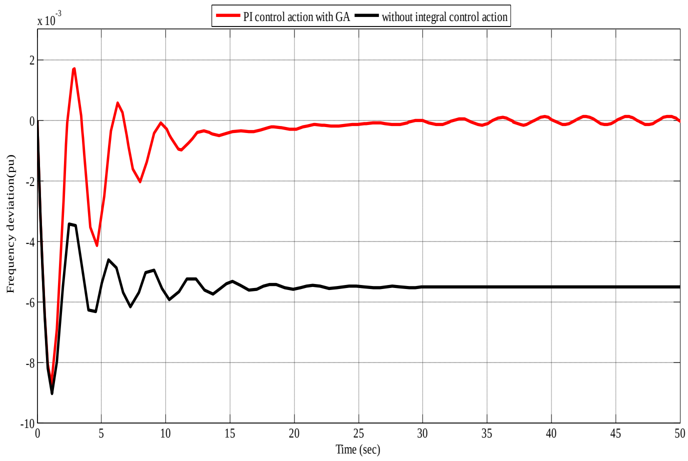

Fig.6 Frequency deviation in area 2 for 0.1pu change in demand

In the fig.5 shows that, the third order system with proportional plus integral controller with GA is compared with without controller action for an area 1 is studied. When the change in load 0.1pu decreases then the frequency across the area 1 is increases up to 0.0055pu without controller action and completely avoided by PI with GA. In the above plot the controller action is to be performed under ITAE error criterion and restore the frequency as per nominal value. Here the controller models also minimize the first peak over shoot from 0.0078 to 0.0070.

In the fig.6 shows that, the dynamic response of area 2 when change in load is 0.1pu, and compare without controller action and with proportional plus integral controller GA technique for ITAE criterion. It gives same response like as area 1 and show the effectiveness of PI controller with GA. Where area-2 shows 0.0055pu frequency deviation for 0.1pu load change for without controller action and reduce the peak over shoot from 0.0085 to 0.0080.

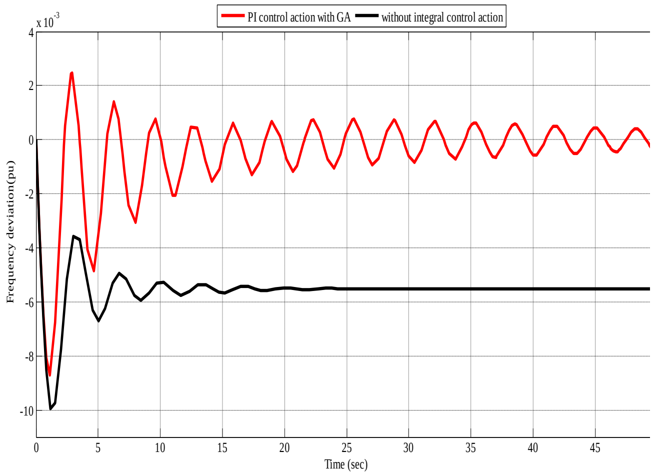

Fig.7 Frequency deviation in area 3 for 0.1pu change in demand

In the fig.7 shows that, the dynamic response of area 3 when change in load 0.1pu for without controller action and with proportional plus integral controller GA technique for ITAE criterion is studied. The plot shows the peak over shoot from 0.0100 to 0.0085 for PI controller with GA with respect to without controller model shows the effectiveness of PI controller with GA. An area-3 also shows 0.0055pu frequency deviation for 0.1pu change in load for without controller. In the above plot the frequency is also vary for PI with GA but it is in 10^{-4} order those are very small and it can't be effected the frequency dependent load performance.

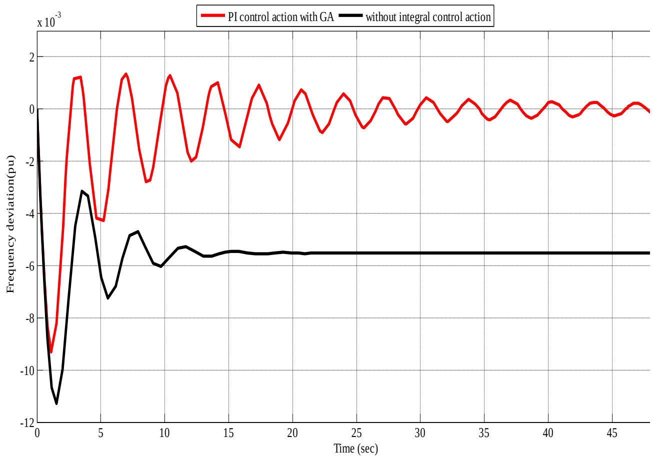

Fig.8 Frequency deviation in area 4 for 0.1pu change in demand

In the fig.8 shows that, the frequency response of area 4 same as area 3, when change in load 0.1pu for without controller action and with proportional plus integral controller GA technique using ITAE criterion. And the peak overshoot analysis shows its change from 0.0110 to 0.0085 for PI controller with GA with respect to without controller model shows the effectiveness of PI controller with GA. And net change in frequency from 0.0055pu to zero for PI controller with GA.

V CONCLUSION

It's concluding from above plot analysis, a PI controller with GA is completely eliminating the frequency deviation of all area with respect to without controller action and also minimize the first peak over shoot. Here it shows in the plot a PI controller with GA having small fluctuation in steady state frequency is in the order of 10^{-4}, those are very low value and it could not affect the area stability. We also improve the area frequency response and eliminate the fluctuation if we include another controller with different soft computing technique.

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