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# Application of GA Optimization for Automatic Generation Control in Realistic Interconnected Power Systems

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***Abstract*— This paper proposes a more realistic model for automatic generation control (AGC) design in an interconnected power system by considering the generation rate constraint (GRC), dead band, and time delays. These physical constraints imposed to power system by governor-turbine, filters, thermodynamic process, and communication channels. The simplicity of structure and acceptable response of the well-known integral controller make it attractive for power system AGC issue.**

**In this paper, a genetic algorithm (GA) approach is employed to calculate the controller parameters to achieve an optimal performance. Importance of considering the physical constraints is demonstrated by examination of the closed loop performance in a 3-control area power system. It is shown that neglecting above physical constraints, simultaneously or in part, leads to impractical and invalid results. Taking to account the advantages of the GA besides considering a more complete dynamic model provides a flexible and more realistic AGC system in comparison of existing conventional schemes.**

***Keywords*—AGC, GRC, GA, Speed governor dead band, Time delay.**

## NOMENCLATURE

| | |
|---|---|
| i, k, j | Subscripts referred to areas i, k, j |
| $H_i$ | Inertia constant of area i (sec) |
| $D_i$ | $\frac{\Delta P_{Di}}{\Delta f_i}$ (p.u./Hz) |
| $\Delta f_i$ | Incremental change in frequency of area (Hz) |
| $\Delta P_{tie,i}$ | Incremental change in the power of tie-line (p.u.) |
| $T_{gi}$ | Steam governor time constant (sec) |
| $K_{ri}$ | Steam turbine reheat constant |
| $T_{ri}$ | Steam turbine reheat time constant (sec) |
| $T_{ti}$ | Steam turbine time constant (sec) |
| $T_{pi}$ | $\frac{2H_i}{fD_i}$ (sec) |
| $KI_i$ | Gain of integral controller |
| $R_i$ | Governor speed regulation parameter (Hz/p.u.MW) |
| $T_{gi}$ | Steam governor time constant (sec) |
| P | Weighted frequency and tie-line power deviation from other areas |
| $ACE_i$ | $\Delta P_{tie,i} + \beta_i \Delta f_i$ (Area control error) |
| $\beta_i$ | $\frac{1}{R_i} + D_i$ (Frequency bias) |

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## I. INTRODUCTION

Time variant inherent of power system and disturbances due to the load or generation losses causes changes in operating point of power system, i.e. frequency deviation from nominal one. Frequency changes recognized as a direct result of mismatch between load demand plus losses and generation from generating units in interconnected power systems and causes undesirable effects.

The frequency control strategies are employed to maintain the system frequency at the scheduled value by keeping balance between generation and demand plus losses [1-4].

Three control loops are employed in frequency control strategies to conduct the frequency to the nominal value, named primary, secondary and tertiary controls. Small frequency deviations (smaller than the speed governor dead band) can be attenuated by the governor natural autonomous response, called primary frequency control. The secondary frequency control (AGC) can be used to restore area frequency to nominal one, i.e. net tie-line power, if it deviates more than speed governor dead band. Tertiary frequency control refers to the economic dispatch [5-7].

Due to increased exchange of power through tie-lines between interconnected areas, the AGC design strategies have been recently became an emerged research area. The balance between connected control areas is achieved by detecting frequency and net tie-line power to generate the area control error (ACE) signal which is in turn utilized in a dynamic controller. Ideally, in an interconnected power system, the frequency deviation following a load variation becomes zero, after ACE signals have been zeroed [7]. The AGC systems usually employed proportional-integral or a simple integral controller to achieve zero ACE signal. The main issue towards the use of the integral controller is how to optimize controller gain. Several approaches for finding optimum parameters of secondary frequency control loop are introduced in [2-6, 8-16]. Crude approaches such as trial and error method cannot guarantee the optimum result and therefore, meta-heuristic search methods (e.g. GA) seem to be the appropriate choice [9, 13].

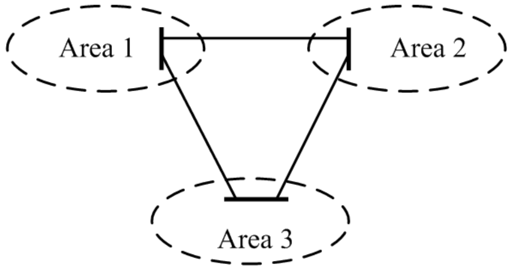


Fig. 1: Three control areas power system

Dynamics of power systems and sequentially AGC response are affected by the physical constraints which imposed to the power system by governor-turbine, filters, communication channels and crossover elements in a thermal unit. The important constraints affect the power system dynamics are generation rate constraint (GRC), time delay, and speed governor dead band.

An important physical constraint is the rate of power generation due to the limitation of thermal and mechanical movements. The AGC study without taking into account the delays caused by the crossover elements in a thermal unit in addition to the sampling interval of the data acquisition system, results an ideal situation that the frequency and tie-line power can be returned to their scheduled value within one second. By changing the input signal, the speed governor may not immediately react until the input reaches a specified value. This limitation called speed governor dead band. Finally in practical AGC, rapid responses and varying components of frequency are almost unobservable due to various filters involved in the AGC process. Any signal processing and data gathering introduces a time delay as well, that should be considered [7].

It is noteworthy that to get an accurate perception of the AGC subject it is necessary to consider the basic physical constraints [7]. However, in some of previous studies governor dead band, GRC, and delays associated with signal processing are often neglected. In [8], a system is modeled a system with non-commensurate communication delays. The models for interconnected power system which consider the GRC to synthesis and analysis of the AGC strategy are introduced in [9-12]. In [16] the previous models are improved and GRC and speed governor dead band are considered.

This paper proposes a new realistic model for the power system which considers all mentioned physical constraints, simultaneously. Similar to real AGC systems, an integral controller is used to optimize the system performance. To achieve an optimum operating point, the GA is implemented to calculate the controller gain.

The rest of this paper is organized as follows. In Section 2, the proposed model is introduced. Section 3 discusses the applied GA. In Section 4, simulation details and simulation results are explained and finally Section 5 concludes the paper.

## II. INVESTIGATED SYSTEM

A 3-control area with aggregated loads, single reheat turbines and integral controllers is used as a test system. The physical constraints are assumed as shown in Table 1.

The nominal parameters of systems are taken from [7] and represented in appendix. The schematically model of 3-control area power system is shown in Fig. 1. The proposed model for area i is depicted in Fig. 2.

A very fast response for the AGC system is neither possible nor desirable. A useful control strategy must be able to maintain sufficient levels of reserved control range and control rate [7]. Thus, in the performed model, a low pass filter is employed to reject the fast control signal variation.

## III. GENETIC ALGORITHM

The GA is a population-based search method. The algorithm begins with a set of initial random population represented in chromosomes; each one consists of some binary bits. These binary bits are suitably decoded to provide

Table 1: Physical constraints

| GRC | Time delay | Dead-band |
|---|---|---|
| 3%[p.u.MW/min] | 2[sec] | 0.036[Hz] |

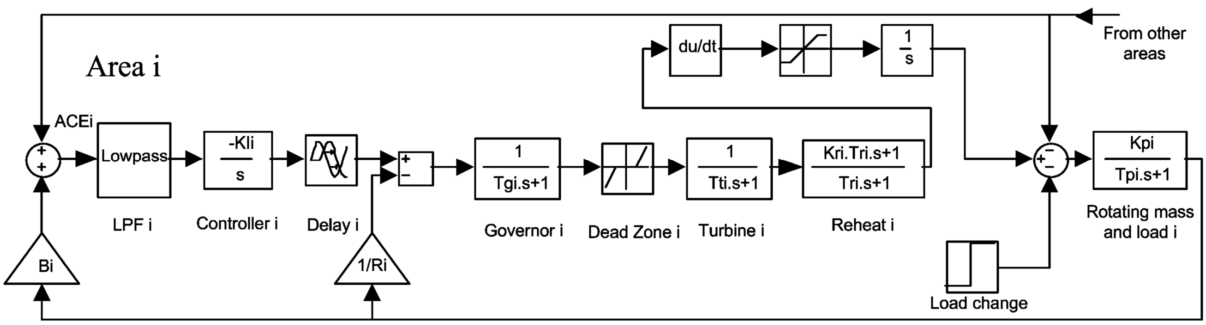


Fig. 2: Proposed model for Area i

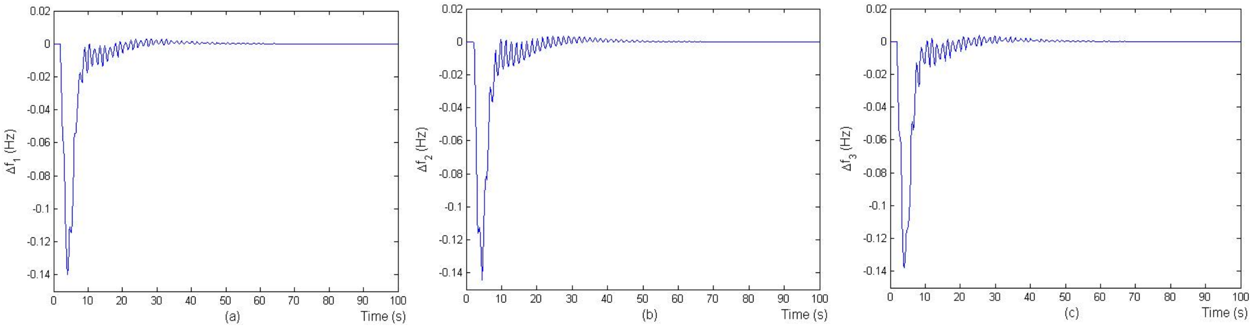


Fig. 3: Frequency deviation for Scenario A; a) Area 1, b) Area 2, and Area 3

proper string for the optimization problem. The GA goes on by generating of new population from older one until terminated conditions are satisfied. A function called fitness function is employed to aid this process. Fitness function assigns a value to each chromosome (solution candidate) which specifies its fitness. Some of chromosomes with greater fitness are participated in the generation of new population. In this paper, the initial population consists of 100 chromosomes; each one contains 48 binary bits (each controller gain by 16 bits). The crossover and mutation probability are considered as 0.8 and 0.2, respectively. The cost function which must be minimized is considered as follow.

$$J = \int_0^T (ACE_i)^2 \quad (1)$$

## IV. Simulation results and Discussion

The GA is applied to the power system case study to obtain the optimum value for integral gains in 3-control area. To investigate the importance of considering of physical constraints, three simulation scenarios are performed.
In scenario A, only speed governor dead band is considered and the GRC and time delay are neglected. In the next step time delay is added to scenario A (as scenario B) and finally, GRC is added to scenario B (as scenario C) and a complete model is obtained. For each scenario, 0.02 p.u. step load perturbation (SLP) is simultaneously applied to areas 1 and 3 at 2 seconds. In scenario A, the GA attempts to minimize the cost function, while only the speed governor dead band is considered as a constraint. The effect of the governor dead band is to increase the apparent steady-state speed regulation. The optimum calculated parameters are reported in Table 2. The frequency response in each area is shown in Fig. 3. It is obvious that the frequency deviation is minimized via AGC loop in steady-state.

The optimum parameters which obtained for scenario A, are applied to scenario B, and the results are compared in Fig. 4. It can be seen that the calculated integral gains for scenario A (to achieve the optimum operating point) are not suitable for scenario B. In the presence of time delay, the impact of disturbance is amplified during the two second delay in controller response to the related control action. Sequentially, settling time increased and the power system encounters with high magnitude oscillation and low damping

Table 2: optimum value of integral gains

| Gain | scenario A | scenario B | scenario C |
|---|---|---|---|
| $KI_1$ | 0.5800 | 0.1332 | 0.2594 |
| $KI_2$ | 0.1920 | 0.3395 | 0.2780 |
| $KI_3$ | 0.1740 | 0.1711 | 0.0010 |

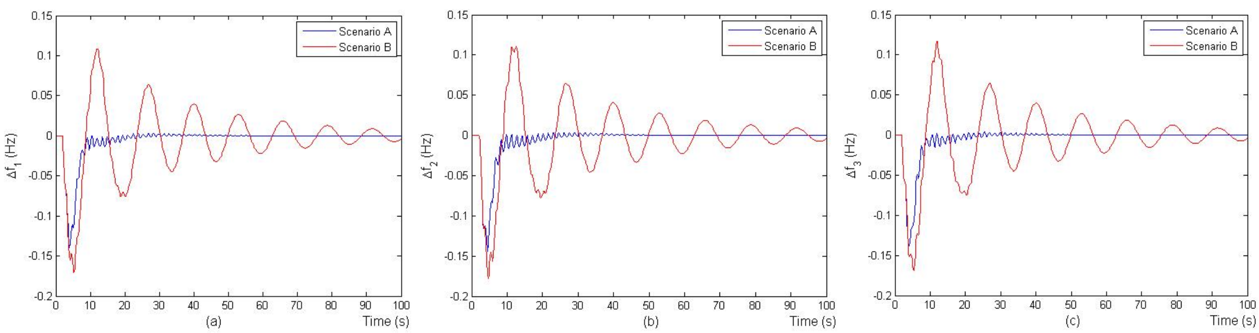


Fig. 4: Frequency deviation in three control areas with designed optimal controllers for Scenario A (solid), and response for Scenario B

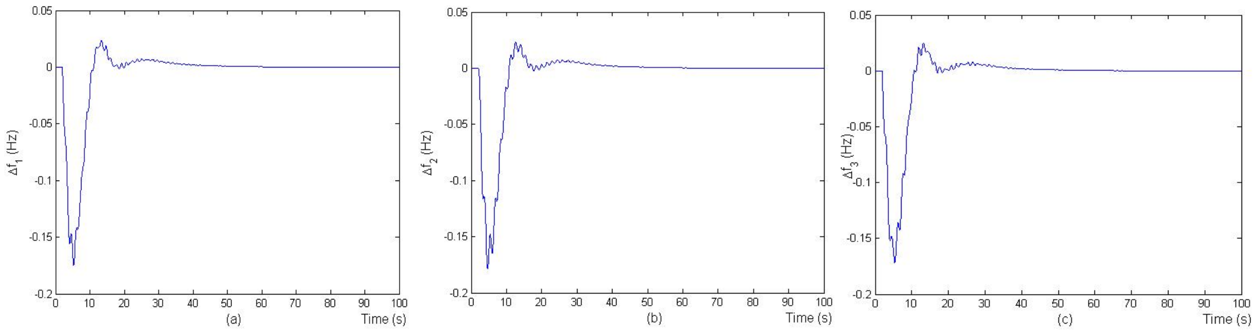


Fig. 5: Frequency deviation for Scenario B; a) Area 1, b) Area 2, and Area 3

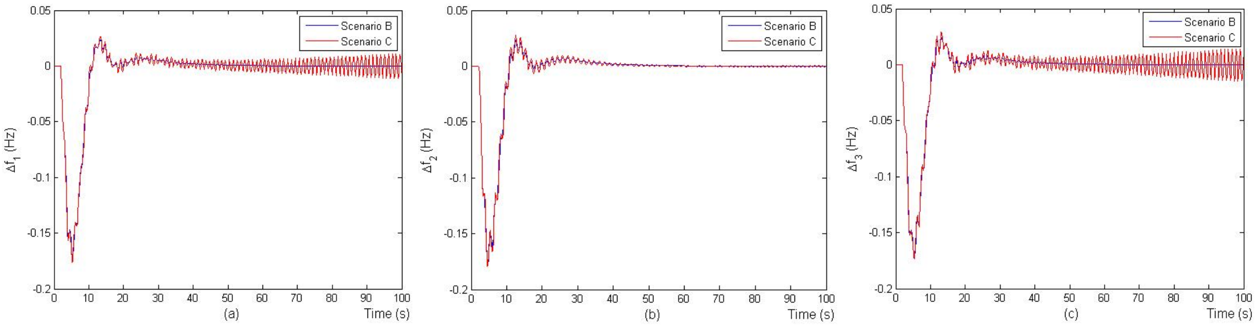


Fig. 6: Frequency deviation in three control areas with designed optimal controllers for Scenario B (solid) and response for Scenario C

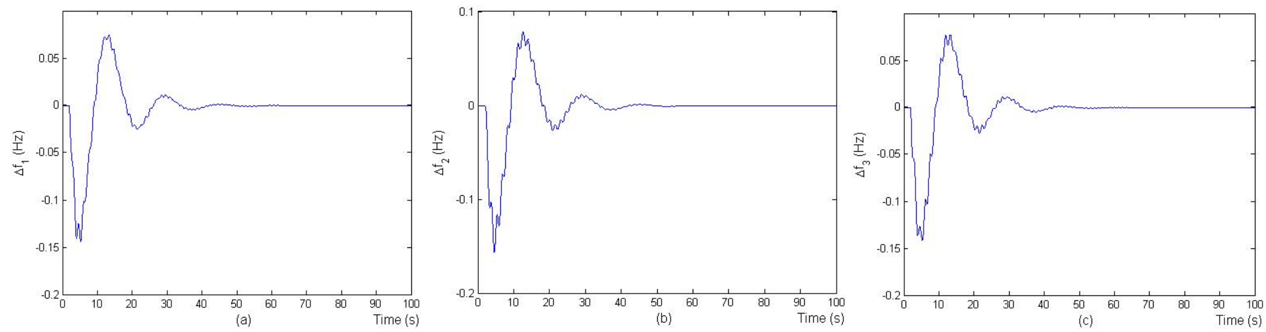


Fig. 7: Frequency deviation for Scenario C; a) Area 1, b) Area 2, and Area 3

characteristics. The optimum operating point for scenario B is achieved by retuning of parameters (the results are shown in Table 2). The updated parameters conduct the system in a stable mode with satisfactory settling time and desirable performance. The frequency deviation becomes zero at steady-state as shown in Fig. 5.

The updated control parameters for scenario B are applied to the complete model with three physical constraints, and the corresponding results are shown in Fig. 6. The later parameters could encounter the system with oscillation characteristic at steady-state and hence reliability and security of the system is reduced.

In the presence of the physical constraints, optimization is done and results are shown in Fig. 7. Effect of GRC will be noticeable when the system encounter with greater SLP or increasing in time delay. In this way, system responses to disturbances faster but the GRC limit the response of the system by reducing the rate of increasing the required power to reject the disturbances. Results of scenario B show that the obtained parameters in [9] which consider GRC (only) as a physical constraint are not appropriate for a realistic power system. Neglecting the speed governor dead band and time delay decreases efficiency of the controller in rejection of the disturbances. These constraints result in a greater overshoot and settling time.

Scenario C shows that considering time delay without GRC and speed governor dead band which introduced in [8] cannot guarantee the power system reliability. Speed governor dead band and GRC limit the immediate response of the power system to disturbances. The GRC also limits the response of generating units to compensate the required power to track the disturbances.

## V. CONCLUSION

A more complete model is performed for AGC systems in interconnected power systems. The model considers three physical constraints including time delay, GRC and speed governor dead band. By considering these constraints the dynamic behavior of realistic interconnected power systems is represented. The GA is used to calculate the integral controller gain which conducts the system to a normal condition following disturbances.

The GA was applied to a 3-control area power system and was tested for different scenarios. Three scenarios are considered to demonstrate the impact of physical constraints on the dynamic behaviour of interconnected power system. The results show that the models introduced in recently published literatures to analysis AGC strategies are almost crude one, and they considered only one or rarely two aspects of constraints. Therefore, they implemented controllers which cannot guarantee reliability of the practical power system. Neglecting of constraints and doing more simplification provide non-accurate and even incorrect results.

## APPENDIX

$D_1=D_3=0.015$, $D_2=0.016$ [p.u./Hz]; $2H_1=0.1667$, $2H_2=0.2017$, $2H_3=0.1247$ [p.u. s]; $R_1=3$, $R_2=2.73$, $R_3=2.82$ [Hz/p.u.]; $T_{g1}=0.08$, $T_{g2}=0.06$, $T_{g3}=0.07$ [s]; $T_{t1}=0.4$, $T_t2=0.44$, $T_{t3}=0.3$ [s]; $\beta_1=0.3483$, $\beta_2=0.3827$, $\beta_3=0.3692$; $T_{12}=0.20$, $T_{13}=0.25$, $T_{23}=0.12$ [p.u./Hz]; $K_{r1}=K_{r2}=K_{r3}=0.5$; $T_{r1}=T_{r2}=T_{r3}=10$ [s].

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