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Research Article

Robust AGC based on Fuzzy Logic Controller: Design, Comparison and Ratification

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Abstract: Increasing the oscillations in the affected eclectic power system caused by the growth of loading conditions and occurrence of various distributions leads to losing the synchronism in the first-swing. A maiden effort is led to attain a novel Fuzzy Logic Automatic Generation Controller (FLAGC) to provide appropriate damping low frequency power oscillations. In order to guarantee the effectiveness and robustness of the proposed FLAGC controller, it has been thoroughly compared with Proportional Integral Derivative (PID) controller considering 2% step load perturbation in thermal area of the studied power system. The Real Coded Genetic Algorithm (RCGA) optimization technique due to have high sufficiency to solve the very non-linear objective is implemented for solution of the optimization problem. The obtained results of non-linear time-domain simulation reveal the high dynamical performance of proposed FLAGC controller.

Keywords: FLAGC controller, low frequency oscillations, PID controller, RCGA-technique

INTRODUCTION

In recent years, the sustaining growth of electrical power systems in size and complexity as well as increase of the interconnected system is the main problem in the field of electric quality and dynamic stability (Bevrani *et al*., 2008). The dynamic behavior of power systems is highly affected by operating conditions and load perturbation that might lead to growing the amplitude of oscillations and consequently loss of synchronism (Falehi, 2012). Damping of low frequency oscillations is attained by controlling the active and reactive powers generated via the controllable sources of the system. Automatic Generation Control (AGC) is an important subject in power system operation and control which plays a key role in adjusting generation to alleviate frequency deviation during small perturbation (Pradhan and Panda, 2009). Owing to high non-linear of power systems, it is essential for systems to equip with nonlinear controllers. Recently, fuzzy controllers have been successfully implemented as fundamental and supplementary controllers in various industrial processes (Yassami *et al*., 2010). A maiden effort is led to attain a novel robust Fuzzy Logic Automatic Generation Controller (FLAGC) in order to dynamic enhancement of power systems. Indeed, FLAGC has been designed to pursue three prominent targets: zeroing of the steady state errors of frequency deviations, acquiring good tracking performance without sustained oscillations during the load disturbances and minimizing the oscillations of tie-line power and frequency deviations.

A variety of conventional techniques have been employed for tuning the controllers' parameters. Most of these methods are based on the pole placement method, eigenvalues sensitivities, residue compensation and also the current control theory. Unfortunately, such methods are time consuming as they are repetitive and need heavy computation burden with slow convergence. In addition, process is sensitive to be trapped in local minima and the obtained response may not be optimal (Falehi *et al*., 2012). The progressive methods develop a technique to search for the optimum solutions via some sort of directed random search processes (Haupt and Haupt, 2004). A suitable trait of the evolutionary methods is that they search for solutions without prior problem perception.

In recent years, a number of stochastic optimization methods such as: Simulated Annealing (SA), Evolutionary Programming (EP), Genetic Algorithm (GA), Differential Evolution (DE) and Particle Swarm Optimization (PSO) have been applied by scholars to solve the different optimization problems of electrical engineering. The high performance of GA technique to solve the non-linear objectives has been approved in many literatures. In this study, RCGA optimization technique is selected to solve the optimization problem in order to dynamic enhancement of power system.

To ensure the efficiency and robustness of FLAGC, it has been compared with conventional AGC (PID controller). In this regard, dynamic performance of these controllers has been thoroughly assessed and analyzed under 2% step load perturbation in thermal area of the studied power system. To sum up, non-linear

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time-domain simulation results unveil that the proposed FLAGC provides robust dynamic performance as compared with PID controller.

DESCRIPTION OF RCGA TECHNIQUE

The Genetic Algorithm (GA), which is a model of biological evolution based on Charles Darwin's theory of natural selection (Holland, 1975), had been developed by John Holland and his collaborators in the 1960s and 1970s. A GA is founded by a cycle of three stages, namely: assessment of each chromosome, selection of chromosome, creation of a new population. GA maintains and controls a population of solutions and enhances performance of fitness function in their search for better solutions. Reproducing the generation and keeping the best individuals for next generation, the best gens will be obtained. The RCGA optimization process can be described as below (Falehi and Rostami, 2011):

Initialization: To commence the RCGA optimization process, commence the RCGA optimization process, initial population shall be specified. An initial population can stochastically be generated or obtained from other methods (Haupt and Haupt, 2004):

$$p = (p_{hi} - p_{lo})p_{norm} + p_{lo} \tag{1}$$

where, p_{lo}, p_{hi} and p_{norm} are: highest number in the variable range, lowest number in the variable range and normalized value of variable, respectively.

Objective function: Each chromosome represents a possible solution to optimize the fitness function. The fitness for each individual in the population is evaluated by taking objective function. Eliminating the worst individuals, a new population is created, while the most highly fit members in a population are selected to pass information to the next generation:

$$chromosome(variables) = [P_1, P_2, ..., P_{N\,var}] \tag{2}$$

$$cos\,t = f(chromosome) = f(P_1, P_2, ..., P_{N\,var}) \tag{3}$$

Selection function: The selection function attempts to implement pressure on the population like natural biological systems. The selection function decides which of the individuals can survive and transfer genetic characteristic to the next generation. The selection function specifies which individuals are selected for crossover. Several methods exist that parents are chosen according to efficiency of their fitness. In this study, roulette wheel selection method is considered and is described in details in (Goldberg, 1989).

Genetic operator: There are two main operators in GA optimization process which are basic search mechanism of the GA techniques: crossover and mutation. They are used to create new population based on acquirement the best solution.

Crossover: Crossover is the core of genetic operation, which helps to achieve the new regions in the search space. Conceptually, pairs of individuals are chosen randomly from the population and fit of each pair is allowed to mate. Thus, where crossover occurs is expressed by:

$$\alpha = roundup\{\, random * N_{var} \,\} \tag{4}$$

Each pair of mates creates a child bearing some mix of the two parents:

$$parent1 = [p_{m1}p_{m2}\cdots p_{m\alpha}\cdots p_{mNvar}] \tag{5}$$

$$parent2 = [p_{d1}p_{d2}\cdots p_{d\alpha}\cdots p_{dNvar}] \tag{6}$$

where, the m and d subscripts discriminate between the mom and the dad parent. Then the selected variables are combined to form new variables that will appear in the children:

$$p_{new\,1} = p_{m\alpha} - \beta\,[p_{m\alpha} - p_{d\alpha}] \tag{7}$$

$$p_{new\,2} = p_{d\alpha} + \beta\,[p_{m\alpha} - p_{d\alpha}] \tag{8}$$

where, β is also a random value between 0 and 1. The final step is to complete the crossover with the rest of the chromosome as before:

$$offspring\_1 = [\,p_{m1}p_{m2}\cdots p_{new1}\cdots p_{dNvar}] \tag{9}$$

$$ofspring\_2 = [\,p_{d1}p_{d2}\cdots p_{new2}\cdots p_{mNvar}] \tag{10}$$

Mutation: The mutation process is used to avoid missing significant information at a special situation in the decisions. Mutation is usually considered as an auxiliary operator to extend the search space and cause release from a local optimum when used cautiously with the selection and crossover systems. With added a normally distributed random number to the variable, uniform mutation will be obtained:

$$p_n' = p_n + \sigma\, N_n\,(0,1) \tag{11}$$

where,

σ = Standard deviation of the normal distribution

$N_n(0, 1)$ = Standard normal distribution

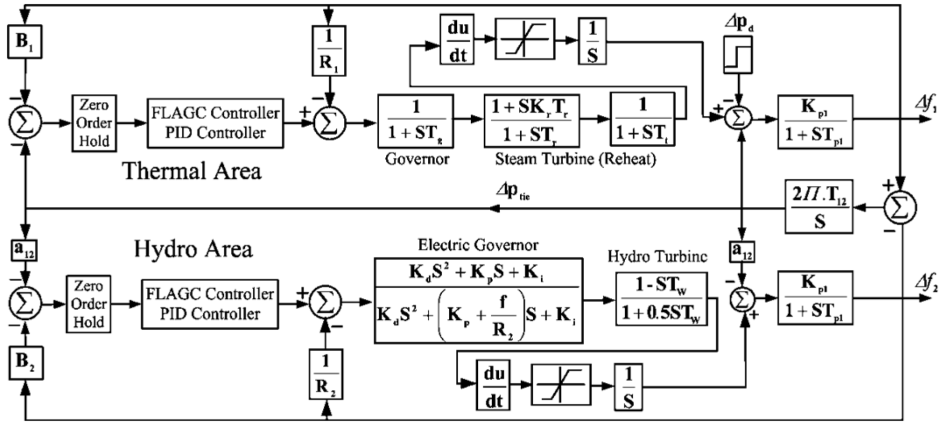

Fig. 1: Transfer function model of two area power system

Stopping criterion: The stopping scale can be considered as: the maximum number of generation, population convergence criteria, lack of improvement in the best solution over a specified number of generations or target value for the objective function. With ending of generation the best individuals will be obtained.

ANALYZING THE BEHAVIOR OF POWER SYSTEM WITH PRESENCE OF AGCS

Power system: The studied power system consists of two equal generating areas; reheat thermal system for area 1 and hydro system for area 2. Aforementioned system which is shown in Fig. 1 has been simulated in MATLAB/SIMULINK environment. Generation Rate Constraint (GRC) is considered 3%/min in thermal area and also 270%/min (4.5%/s) for raising and 360%/min (6%/s) for lowering generation in hydro area. A bias setting of B_i is chosen for both thermal and hydro areas.

Configuration of AGC system: Zeroing of the Area Control Error (ACE) of each area of interconnected two-area hydrothermal is scheduled as the main target of AGC system. That is to say, the system frequency and tie-line power exchange deviations are the two control variables, which deal with the AGC scheme. Aforementioned variables are related with ACE by following equation (Ghoshal, 2004):

$$ACE_i = \Delta \mathbf{P}_{\mathbf{tie}} + B_i \Delta f_i \tag{12}$$

where, *i* is number of areas in power system.

Also, the output of AGC controller in Laplace domain will be obtained by:

$$G_{AGC}(s).ACE(s) \tag{13}$$

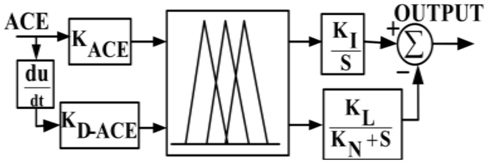

Fig. 2: Schematic of proposed FLAGC

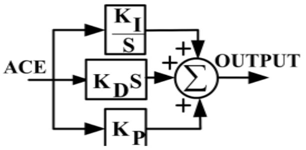

Fig. 3: Structure of the PID

Modeling of FLAGC controller: Fuzzy logic has been widely used in many filed of engineering sciences to unravel the control and optimization problems. Recently, it has been successfully applied in power system areas namely: power system stability, active and reactive compensation, unit commitment, etc. The strife in the fuzzy logic area was propelled to attain robust FLAGC controller to damp out low frequency oscillations. The structure of this controller is given in Fig. 2. The parameters of FLAGC controller which should be determined by RCGA technique consist of: K_{ACE}, $K_{D\text{-}ACE}$, K_I, K_L and K_N.

Conventional AGC controllers: In many literatures, classical controllers such as: PI and PID have been engaged as supplementary control of AGC systems (Tan, 2009; Bevrani and Hiyama, 2008). In this study, PID structure which is shown in Fig. 3 has been taken into account AGC controller. The parameters of PID controller which should be determined by RCGA technique, including: K_P, K_D and K_I.

Optimum tune the parameters of proposed FLAGC controller and PID controllers: To verify the robustness and effectiveness of these controllers, 2% step load perturbation has been taken into account in thermal area of power system. Meanwhile, RCGA optimization technique is applied to solve the optimization problem and optimum tune controllers'

Table 1: Optimal parameter of the FLAGC and PID controllers

Thermal Area				
K_N	K_L	K_I	$K_{D\text{-}ACE}$	K_{ACE}
1.364	0.025	0.010	0.132	6.857
K_D		K_I	K_P	
0.312		0.361	0.235	
Hydro Area				
K_N	K_L	K_I	$K_{D\text{-}ACE}$	K_{ACE}
0.306	0.030	0.001	0.047	2.964
K_D		K_I	K_P	
0.052		0.142	0.150	

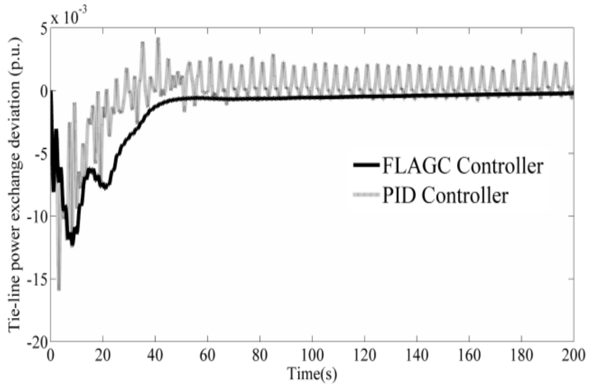

Fig. 4: Tie-line power exchange deviation under 2% SLP

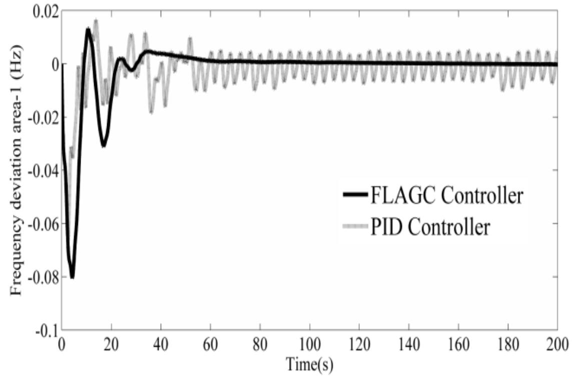

Fig. 5: Frequency deviation of area-1 under 2% SLP

parameters. Integration Time Absolute Error (ITAE) of the system frequency deviation and tie-line power deviation is chosen as objective function:

$$J = \int_{t=0}^{t=t_{sim}} \left[|\Delta f_1| + |\Delta f_2| + |\Delta p_{tie}| \right] t.dt \qquad (14)$$

The time-domain simulation of the non-linear system model is performed for the simulation period. It is aimed to minimize this fitness function in order to damp out the system oscillations. The problem constraints are the optimized parameter bounds. Therefore, the design problem of FLAGC and PID controllers is formulated by minimizing the objective function (*J*).

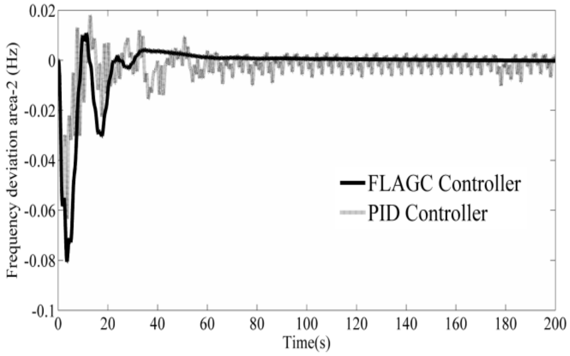

Fig. 6: Frequency deviation of area-2 under 2% SLP

SIMULATION RESULTS

From small signal stability viewpoint, 2% step load perturbation is sufficient to test dynamic performance of these controllers. Step Load Perturbation (SLP) of $0.01^{p.u.}$ is considered for thermal area. By evaluating the objective function and subsequently finishing the optimization process, optimal parameters of FLAGC and PID controllers have been obtained, which are presented in Table 1.

The system response under this perturbation is exhibited in Fig. 4 to 6.

These figures confirm that the proposed FLAGC controller has high efficiency in mitigation of power system oscillations as compared with PID controller.

CONCLUSION

In this study, a novel FLAGC controller is proposed as supplementary control of AGC systems to provide appropriate damping low frequency power oscillations, in other words, zeroing of the ACE in each area of interconnected two-area hydrothermal system. To approve the dynamic performance of proposed FLAGC controller, it has been thoroughly compared with PID controller considering 2% step load perturbation in thermal area of studied power system. The RCGA optimization technique due to have high efficiency in solution of non-linear objective has been engaged to optimally tune the parameters of these controllers in order to minimize the system frequency and tie-line power exchange deviations. The obtained results of non-linear time-domain simulation unveil the high dynamical performance of proposed FLAGC controller.

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