Design of Optimal PID Controller using Improved Genetic Algorithm for AGC including SMES Units

S. Pothiya[*], C. Khamsum, W. Kongprawechnon and I. Ngamroo

Abstract— *This paper is proposed a new optimization approach of a proportional-integral-derivative (PID) controller by the improved genetic algorithm (IGA) for automatic generation control (AGC) including superconducting magnetic energy storage (SMES) of a two-area interconnected reheat thermal system. Conventionally, the gains of PID controller are obtained by trial and error method or experiences of designers. To overcome this problem, the IGA is applied to simultaneously tune PID gains to minimize frequency deviations of the system against load disturbances. The IGA algorithm introduces additional techniques for improvement of search process such as initialization, adaptive search, multiple searches, external crossover and restarting process. Simulation results explicitly show that the performance of the proposed PID controller is superior to the conventional PID controller in terms of the overshoot, settling time and robustness.*

Keywords— **Automatic generation control, Genetic algorithm, Power system, Superconducting magnetic energy storage**

1. INTRODUCTION

Automatic generation control (AGC) is synonymous with load frequency control (LFC), it is a very important problem in power system operation and control. A power system has a dynamic characteristic meaning that it can be affected by area load change and abnormal conditions lead to unpredicted in frequency and scheduled tie-line power flows between areas. These problems are corrected by control the frequency. In the past, a governor, may no longer be able to compensate for such load changes due to its slow response [1].

To solve this problem, superconducting magnetic energy storage (SMES) [2–4], which is capable of controlling active and reactive power simultaneously [5], has been proposed as one of the most effective and significant stabilizers of power oscillation modes [6–8]. Besides oscillation control, SMES allows a power quality improvement [9], a load leveling [10] and a load frequency control [11–16], which are not possible at all with other power system controllers such as a power system stabilizer, a static-var compensator etc.

Several design methods of AGC, which is equipped with SMES, have been successfully proposed, such as a proportional control [11, 12], a digital control [13], an adaptive control [14], and a fuzzy control [16] etc. Despite the potential of modern control techniques with different structures [13–16], power system utilities still prefer the fixed structure controller.

In this paper proposes a new optimization technique, which is called improved genetic algorithm (IGA) to optimize the gains of PID controller to control frequency for a two-area interconnected reheat thermal system including SMES units. The results compare with the conventional PID controller with and without SMES in term of settling time, overshoot and robustness.

This paper is organized as follows: Section 2, a comprehensive mathematical model of AGC problem for a two-are interconnected reheat thermal system including SMES is presented. The PID controller is described in Section 3. An application of proposed IGA algorithm to optimize the gains of PID controller is presented in Section 4. The simulation results in the two-area interconnected reheat thermal system are presented in Section 5. Finally, the conclusion is provided in Section 6.

2. PROBLEM FORMULATION

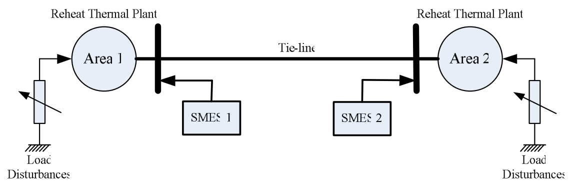

Fig. 1. A two area interconnected power system with SMES

A two area interconnected power system [12] including reheat steam turbines, governor deadbands, boiler dynamics, and SMES units shown in Fig. 1, is used to explain the motivation of the proposed method. Both areas have installed SMES1 and SMES2 in order to stabilize frequency oscillations. It is assumed that large loads with sudden changes, such as large steel mills, arc -

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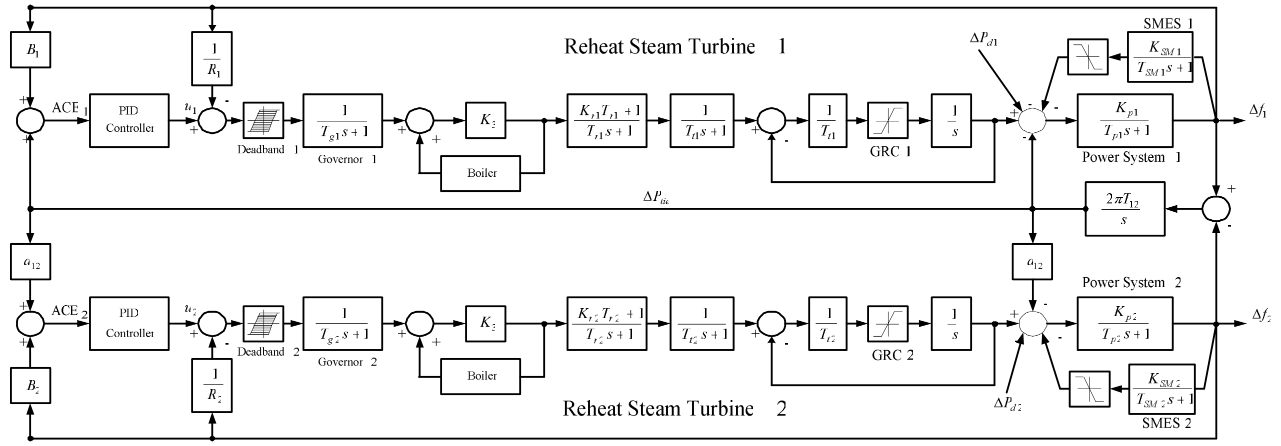

Fig. 2. Block diagram of two area interconnected power system.

furnace factories, magnetic levitation transporters and testing plants for nuclear fusions etc., have been placed in both areas. This results in a serious problem of frequency oscillations. The detailed block diagram of the interconnected power system model is depicted in Fig. 2 and the system parameters are given in Appendix.

The detailed transfer function models of the speed governors and turbines are discussed in Ref. [12]. In order to project physical constraints, a generation rate constraint (GRC) of 0.0017 [puMW/s] is considered. The transfer function of the governor, taking a deadband into account, can be expressed by

$$G_{gi}(s)=\frac{0.8-\frac{0.2}{\pi}s}{1+T_{gi}s} \quad , \qquad i=1,2 \tag{1}$$

Fig. 3 shows the model to represent the boiler dynamics [12]. This includes the long term dynamics of the fuel and steam flows on the boiler drum pressure. For a SMES unit, the limiter of $-0.01\leq \Delta P_{SMi,\,i=1,2}\leq 0.01$ [puMW] based on a system MW base is equipped at a power output terminal. Parameters values of SMES1 and SMES2 are set at $K_{SM1}=K_{SM2}=0.12$ and $T_{SM1}=T_{SM2}=0.03$ sec.

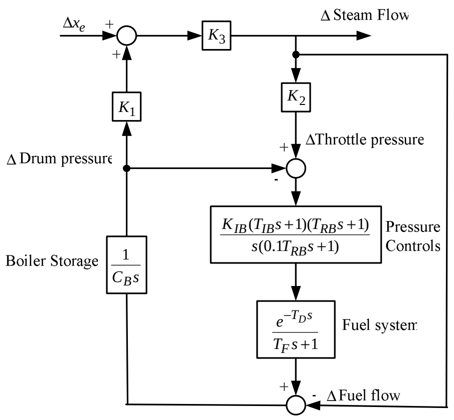

Fig. 3. Block diagram of boiler dynamics.

3. PID CONTROLLER

Designing PID controller, even for non-linear plants such as power system, can be a difficult problem. Consider the system illustrated in Fig. 4 where the PID controller obey the following control law:

$$M(s)=\left(k_p+\frac{k_i}{s}+k_d s\right)E(s) \tag{2}$$

where k_p, k_i and k_d are proportional, integral, and derivative gains, respectively.

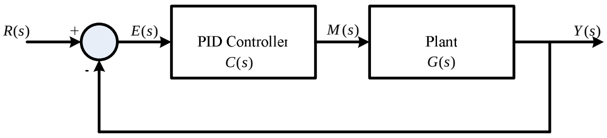

Fig. 4 A typical PID control system

The objective of PID controller design is to determine a set of gains (k_p, k_i and k_d) of the control law such that the set of roots of the characteristic equation chosen by the designer are obtained. The three gain parameters of the PID control law interact with the plant parameters $P(s)$ in a complex fashion when the designer attempts to obtain the specified roots of the characteristic equation. These roots are chosen in order to obtain the desired transient response of the closed loop, while taking the resultant zeros into account. PID controller increase the order of the characteristic equation by one. The controller introduces a new pole at original of the s-plane, and they shift the original compensated root of the closed loop system to new positions on s-plane, In addition to these effects, PID controllers introduce a pair of zeros, usually a complex conjugate pair, which will normally have a significant effect on the transient behavior of the compensated system.

The efficiency of the system can be measured by calculating the integral of time-multiplied absolute error

(ITAE) for the unit step response during [0,T]:

$$Error = \int_0^T t|e(t)|dt \qquad (3)$$

The problem confronting the designer, therefore, is to calculate the three gains of the PID controller while ensuring that transient response (minimum error, overshoot, rising time, settling time and steady-state error) specification are met.

4. IMPROVED GENETIC ALGORITHM

4.1 Genetic algorithm

A genetic algorithm (GA) is a robust optimization technique based on natural selection. The basic goal of GA is to optimize functions call fitness functions. GA-based approaches differ from conventional optimization methods in several ways. First, GA search work with a coding of the parameter set rather than the parameters themselves. Second, GA search from a population of points rather than a single point. Third, GA use payoff (objective function) information, not other auxiliary knowledge. Finally, GA use probabilistic transition rules, not deterministic rules. These properties make GA robust, powerful, and data-independent.

A simple GA starts with a population of solution encoded in one of many ways. Binary encoding are common and are used in this report. The GA determines each string's strength based on an objective function and performs one or more of three genetic operators on certain strings in population.

1. Reproduction (also called selection) is simply retaining a fit string in the following generation.
2. Crossover involves swapping partial strings of random length between two parent strings.
3. Mutation involves flipping a random bit in a string.

These three operations primarily involve random number generation, copying, and partial string exchange. Thus GA is simple to implement.

4.2 Improved Genetic algorithm

A new proposed approach is called improved genetic algorithm (IGA) based on the GA algorithm as shown in Fig 5, which has several GA algorithms independently. This algorithm consists of five mechanisms; namely, *initialization, adaptive search, multiple searches, external crossover* and *restarting process* as follows:

i) Initialization

IGA algorithm uses the feasible solutions for random in the determination of the several groups of initial solutions, which contrast with GA algorithm. Because the probability for reaching the optimal solution is higher than single group of initial solution of the GA algorithm so that IGA can quickly be converged to the global optimum solution.

ii) Adaptive search

The step size is range of variation of current solution which is the importance factor for searching process, so that should be appropriately chosen. Low values to uses long computational time. On the other hand, high values result in may be not getting global optimum. Consequently, the adaptive search mechanism has been developed to suitably adjust the step size during the searching process. This earlier process helps to speed up the move to the vicinity of the global solution. Once the searching process approaches the near global solution, the small step size is then employed in order to move to the solution in a high resolution of solution.

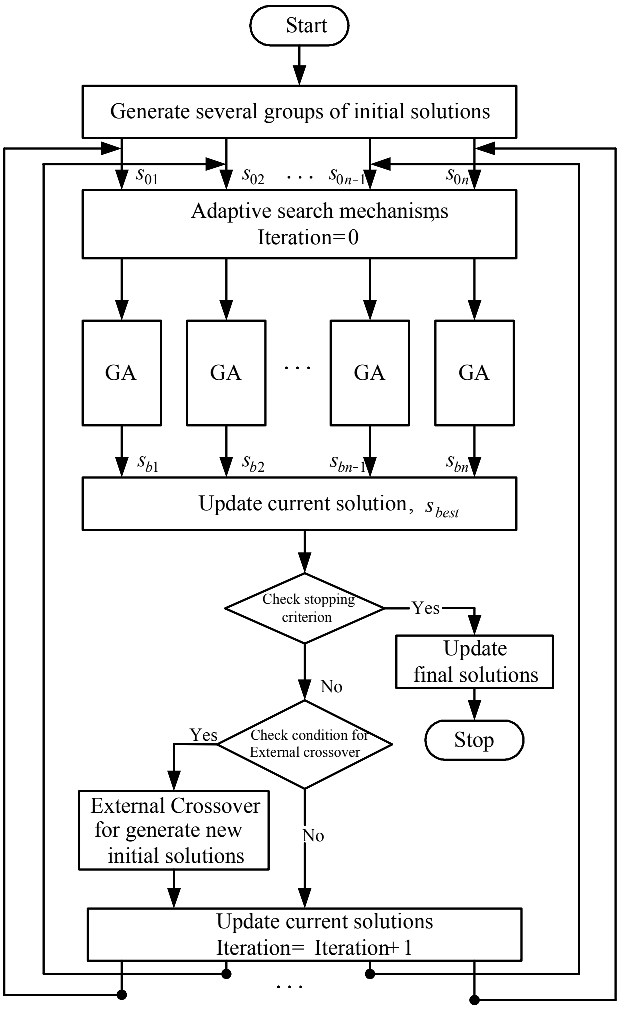

Fig. 5. Procedure of Improved Genetic Algorithm

iii) Multiple searches

In recently, the personal computer has high speed for computational. For solving the large scale problem may be uses several computers run in parallel called *parallel search*. For *multiple-search* are executed by a personal computer. This process helps the GA algorithm find the promising region of the search very quickly.

iv) External Crossover

After the iteration of the searching process satisfies, all independent GA algorithms are stopped. The external crossover process uses for compare and exchange the solutions which found by these GA, and generate the best initial solutions for next iteration.

v) Restarting process

When the searching is stroke on the local solution for a long time and procedure of GA algorithm can not escape from local solution. The restarting process is applied for help to continue searching and find a new solution.

5. NUMERICAL EXAMPLE & RESULTS

Simulations were performed using the conventional PID and the proposed optimal PID controllers applied to a two-area interconnected reheat thermal system as shown in Fig. 2, when applying 0.01 p.u.MW step load disturbances into both areas. The implementation worked with MatLab® 7.0 and Simulink. The simulation was ran on a personal computer Pentium 4, 2.66 GHz, 256 Mbytes RAM, under Window XP.

In the optimization, the integral of time-multiplied absolute error (ITAE) of the frequency deviation of the first area is selected as the performance index. Accordingly, the objective function J is set by

$$\text{Minimize } J = \int_0^{\infty} t\left|\Delta f_1\right| dt \qquad (4)$$

After design, the appropriate parameters value as showed in Table 1.

Table 1. Parameter value of PID controllers

Controller	k_p	k_i	k_d
Conventional PID no SMES	0.0098	0.0985	0.2075
Optimal PID no SMES	3.0008	0.5995	1.7975
Conventional PID with SMES	1.9105	0.4217	0.2089
Optimal PID with SMES	2.9910	0.5995	2.0028

The frequency deviations of first areas after a sudden load change are shown in Fig. 6. The proposed PID controller is gives the best performance than other controllers in term of settling time, overshoot and ITAE.

Next, the robustness of each controller against system parameters variations are evaluated by the settling time, overshoot, and ITAE. These values are calculated under an occurrence of load disturbances while all system parameters are varied from −30% to 30% of the nominal values. The comparison results are shown in Fig. 7, Fig. 8, and Fig. 9 show the values of settling time, overshoot, and ITAE of the first areas, respectively.

Considering Fig. 7-9, these clarifies that the robustness of the optimal PID controller against parameters variations is superior to that of the other controllers.

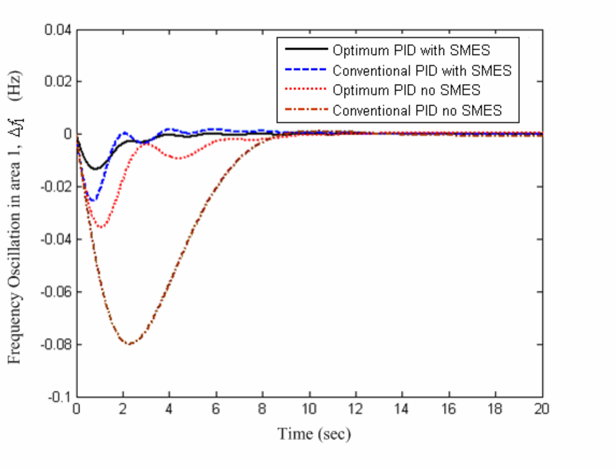

Fig. 6 The frequency deviation of first area of different controller types.

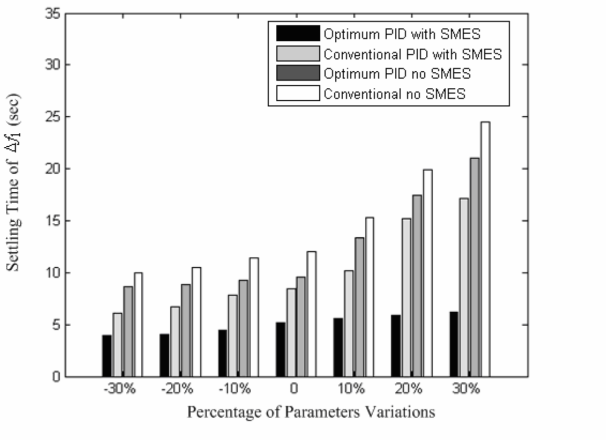

Fig. 7 Comparison results of settling time of Δf_1 under parameter variations.

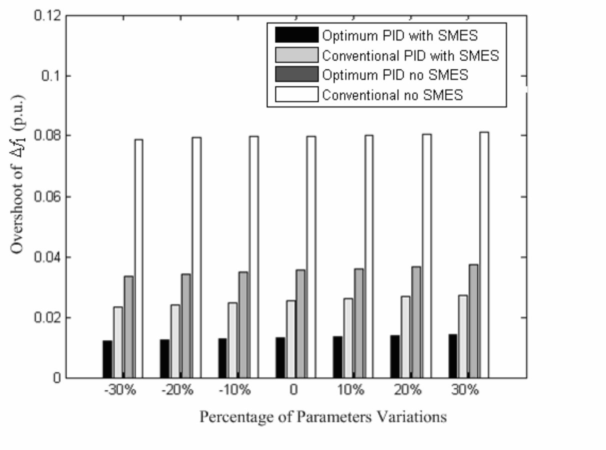

Fig. 8 Comparison results of overshoot of Δf_1 under parameter variations.

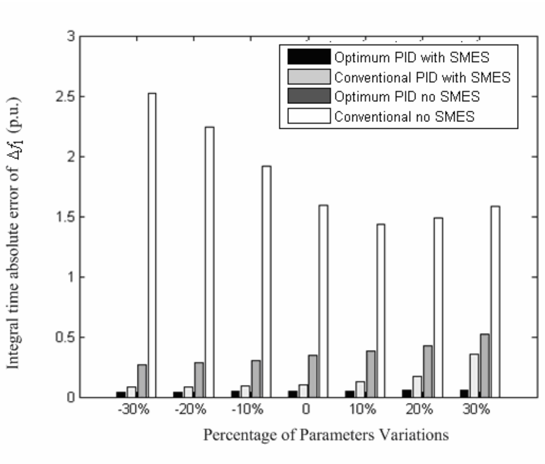

Fig. 9 Comparison results of ITAE of Δf_1 under parameter variations.

6. CONCLUSION

In this paper, a new approach, called IGA algorithm has been used for developing an optimal PID controller for AGC of a two-area interconnected reheat thermal system. The proposed technique for designing the PID controller helps us save time when compared to those from conventional trial and error design procedures. Another benefit of this approach is that it does not require experts for the design of PID controller. A number of studies have been performed with the proposed PID controller to test the effectiveness and robustness. Finally, the simulation results show that the proposed PID controller performs significantly better than other controller in the settling time, overshoot, and ITAE. Therefore, this proposed PID controller is effective, efficient and robust over a wide range of operating conditions.

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APPENDIX

The system parameters are following:

$K_{p1} = K_{p2} = 120$, $T_{p1} = T_{p2} = 20$, $K_{r1} = K_{r2} = 0.333$

$T_{r1} = T_{r2} = 20$

$T_{g1} = T_{g2} = 0.2$, $R_1 = R_2 = 2.4$

$B_1 = B_2 = 0.425$, $T_{t1} = T_{t2} = 0.3$

$T_{12} = 0.0707$, $a_{12} = -1$

Boiler system (gas fired type)

$K_1 = 0.85$, $K_2 = 0.095$ $K_3 = 0.92$, $CB = 200$

$T_D = 0$, $T_F = 10$, $K_{IB} = 0.03$, $T_{IB} = 26$

$T_{RB} = 69$