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Frequency Stabilization for Thermal-Hydro Power System with Fuzzy Logic Controlled SMES unit in Deregulated Environment

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Abstract— **This paper deals with the Automatic Generation Control (AGC) of two-area power system with SMES unit under deregulated environment. PID controller is used for AGC, three different tuning and optimization techniques are analyzed for effectively stabilize the frequency and tie-line power oscillations and these techniques are Ziegler - Nichols tuning (ZN), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). Results show PSO is more effective techniques to produce desired response. Superconducting Magnetic Energy Storage (SMES) is also emerging solution for suppression of frequency and tie-line oscillations. This paper also presents fuzzy logic controlled SMES in order to effectively suppress frequency and tie-line power oscillations. The effectiveness of proposed fuzzy logic controlled SMES justified in comparison of proportional plus integral (PI) controlled SMES.**

Keywords- Automatic Generation Control, Deregulated Environemnt, Superconducting Magnetic Energy Storage, Fuzzy Logic Controller, Particle Swarm Optimization, Genetic Algorithm.

I. INTRODUCTION

After disintegration of vertical integrated unit into independent entities Generation Companies (GENCOs), Transmission Companies (TRANSCOs) and Distribution Companies (DISCOs), reliability and economical efficiency of power system enhanced but due to increasing complexity of integrated power system maintaining system stability and security has become a tough challenge. Now it is Automatic Generation Control's (AGC) responsibility to maintain system stability, security and reliability. Several control techniques have applied for AGC[1] [2].

SMES device is very significant in order to damping oscillations in interconnected power system and improving power system dynamics performance. For damping fast oscillations, ACE is fed as input signal to SMES controller. Apart from frequency oscillation damping, it also helps in damping tie-line power oscillations. In general, conventional PI controller is being utilized for control of SMES unit [3]. But due to day by day increasing complexity, nonlinearity and abruptly changing load, operating point of system is varying and fixed gain controllers are hampered for limited performance. To overcome these problems, recently some control strategy proposed, but still they gives oscillatory results [4]. In this paper fuzzy logic control technique is proposed for control of SMES device in objective of frequency stabilization.

II. SYSTEM EXAMINED

A. Two-Area Power System in Deregulated Environment

The system examined consists of two control areas and having two GENCOs and two DISCOs. The control area 1 is composed of reheat type thermal GENCO and control area 2 is composed of hydro GENCO and these two control areas are connected by tie-lines. The contracts between GENCO and DISCO are shown in CPFM matrix [5]. The purpose of CPFM makes the visualization of contracts.

The CPFM is:

$$CPFM = \begin{bmatrix} cpf_{11} & cpf_{12} \\ cpf_{21} & cpf_{22} \end{bmatrix}$$

In AGC, the difference between actual generation and scheduled generation is termed as Area Control Error (ACE) for interconnected power system.

$$\mathrm{ACE_i} = \Delta \mathrm{P_{tie,i}} + \mathrm{b_i} \Delta \mathrm{f_i} \tag{1}$$

Where, $\mathrm{b_i}$ is frequency bias constant, $\Delta \mathrm{f}$ is frequency deviation and $\Delta \mathrm{P_{tie}}$ is change in tie- line power.

Contracted generated powers in area-1 and in area 2 are $\Delta \mathrm{P_{g1\_Cont}}$ and $\Delta \mathrm{P_{g1\_Cont}}$ respectively. Contracted generated powers calculated from contracted demand and CPFM, as shown in equation below,

$$\Delta \mathrm{P_{G\_Cont}} = \mathrm{CPFM} * \Delta \mathrm{P_{LD\_Cont}} \tag{2}$$

The scheduled tie line power flow between area-i to area-j is represented as:

$$\Delta P_{L,Ai \rightarrow Aj} = \sum_{m,n=1}^{M,N} (CPFM * \Delta P_{Ld(n)\_Cont}) \tag{3}$$

Where m is mth GENCO in control area Ai and n is nth DISCO in control area Aj, M is total number of GENCOs in area Ai and N is total number of DISCOs in area Aj.

So, scheduled tie line power flow between area-1 and area-2 is:

$$\Delta \mathrm{P_{tie12,sch}} = \Delta \mathrm{P_{L,A1 \rightarrow A2}} - \Delta \mathrm{P_{L,A2 \rightarrow A1}} \tag{4}$$

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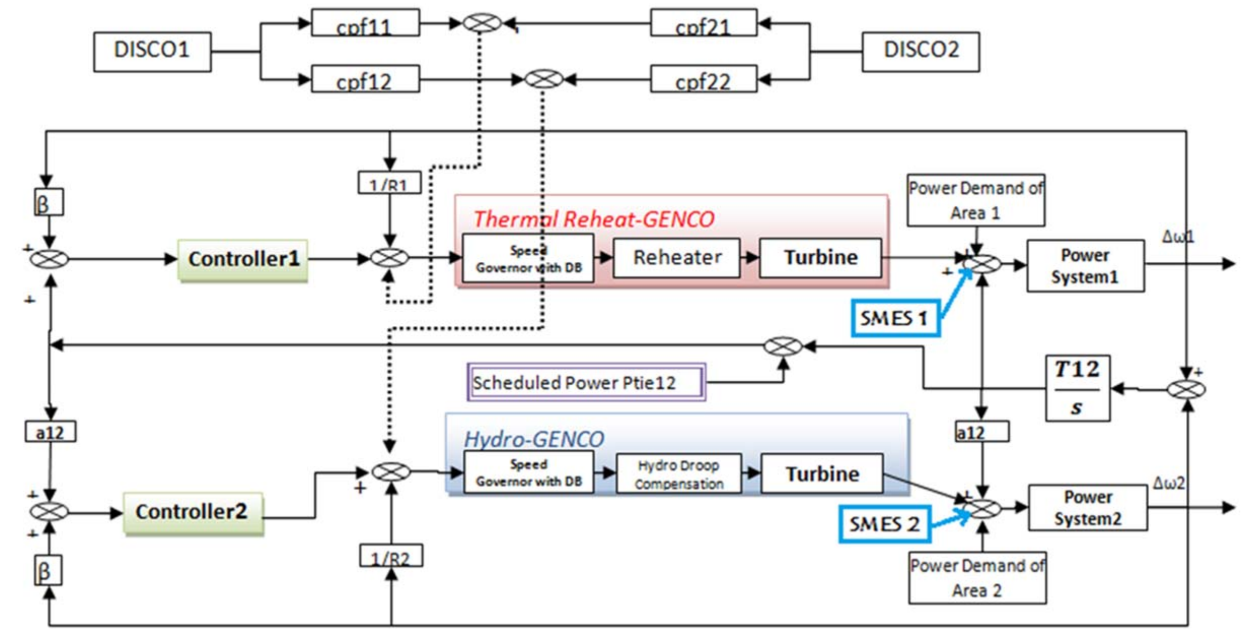

Figure 1. Complete System model of LFC of Two Area Thermal-Hydro Power System in Deregulated Environment

B. SMES

SMES as energy storage system can charge and discharge very fast with high quantities of power for short span of time. During normal operation superconducting coil is charged to a set value of charge from utility grid. When there is a sudden rise in a load demand then the stored energy is almost released through Power Conversion System (PCS). And when there is a sudden release in a load then the coil immediately gets charged towards full value through PCS, then excess energy is released as system returns to steady state. As soon as system returns to steady state coil returns to normal charged state [6][7].

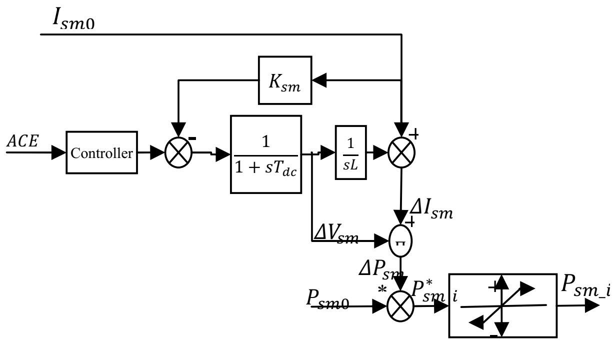

Figure 2. SMES Unit

III. CONTROL STRATEGY FOR FREQUENCY CONTROL

In this paper, PID controller is selected as controller for AGC. Following tuning and optimization methods are used for selection of gain parameters. PID controller for AGC, in which ACEi selected controller input and Kp. Ki and Kd are gains of controller and Upid is output of controller.

$$U_{pid} = K_p(ACE_i) + K_i(\int ACE_i\, dt) + K_d(\frac{dACE_i}{dt}) \tag{5}$$

A. Zigler Nicholas Tuning

ZN tuning method is a heuristic type approach for PID Controller. This method is based on selection of proportional gain to get sustained oscillation, from which ultimate gain Ku and oscillation period Tu are obtained [8]. Controller gains are calculated from Ku and Tu as per given in Table I.

Table I

PID Controller Gains from ZN tuning method

	ZN Tuned PID	Area-1PID Gains	Area-2 PID Gains
Kp	0.6Ku	1.074	1.074
Ki	2Kp/Tu	0.74068	0.74068
Kd	KpTu/8	0.3893	0.3893

1) Genetic Algorithm

GA is stochastic search/optimization algorithm based on natural genetics mechanics, capable of find optimal solution.

This optimization is an iterative procedure, in which every iteration constant population size is maintained [9].

Objective function for PID optimization is aimed for minimization of peak undershoots and settling time of frequency and tie line deviation. This objective function selected for GA as well as for PSO, is:

$$J_{OBJ} = \int_0^T (\lambda(|PU_{\Delta f1}| + |PU_{\Delta f2}| + \mu |PU_{\Delta ptie12}|) + (ST_{\Delta f1} + ST_{\Delta f2} + ST_{\Delta ptie12}))dt \tag{6}$$

Here, λ, μ and T are selected 2000, 5 and 50 respectively.

2) *Particle Swarm Optimization*

PSO is a robust population based stochastic optimization algorithm. This technique of optimization first developed by[10], inspired by social behavior of birds swarm. It converged to global solution in faster time in compare of other stochastic optimization methods like GA and SA.

PSO is an iterative process which starts with randomly created particles in group (population) and set in motion. In swarm each particle fly in multi dimensional search space with a velocity, which keep on adjusting based on momentum, social experience and personal experience.

Algorithm steps for PSO implementation are given below,

1) Setting for PSO
    a. Define dimensions of search space
    b. Boundaries of search space
    c. Range of velocities of particles
2) Initialize Population
    a. Initialize random population of swarm
    b. Set random velocities to particles of swarm
3) Evaluate the fitness of each particle position
    a. Identify the Pbest of particles
    b. Identify the Gbest of swarm
    c. Update the velocities of particles
    d. Update the positions of particles
4) Repeat (3) up to either Max. Iterations or convergence criteria satisfied.

Following equations are utilized for implementation of this algorithm,

$$v_i^d(iter+1) = w * v_i^d(iter) + C_1 * R_1(0,1) * \left(Pbest(iter) - x_i^d(iter)\right) + C_2 * R_2(0,1) * \left(Gbest(iter) - x_i^d(iter)\right) \tag{7}$$

$$x_i^d(iter+1) = x_i^d(iter) + v_i^d(iter+1) \tag{8}$$

$iter$	Iteration number
i	Particle index
d	Dimension
v_i^d	Velocity of i^{th} particle in d^{th} dimension
x_i^d	i^{th} Particle position in d^{th} dimension
w	Momentum
C_1, C_2	Acceleration constants
R_1, R_2	Random numbers with uniform distribution [0, 1]
$Gbest$	Swarm global best position
$Pbest$	Particle best position

Table II

PID Controller gains from optimization method

S.N.			Area-1PID Gains	Area-2 PID Gains
1.	***GA optimized PID Controller Gains***	Kp	3.048	0.378
		Ki	4.488	1.172
		Kd	2.848	0.593
2.	***PSO optimized PID Controller Gains***	Kp	6.41	0.12
		Ki	15.71	1.92
		Kd	8.65	0.87

IV. SMES CONTROL

A. *Fixed Gain PI Controller*

Conventional PI controller for SMES control, in which ACEi selected as controller input and Kp and Ki are gains of controller and U_{pi} is output of controller.

$$U_{pid} = K_p(ACE_i) + K_i(\int ACE_i\, dt) \tag{9}$$

B. *Fuzzy Logic Controller Optimized by PSO*

A dual input and single output type FLC is designed for SMES control. These two inputs are ACE_i and $dACE_i/dt$ and one output is Ui for each SMES unit, as shown in Fig.3. Mamdani type fuzzy logic design is used for FLC design [11]. There are 3 triangular and 2 trapezoidal type membership functions are considered for both inputs, as shown in Fig.4.

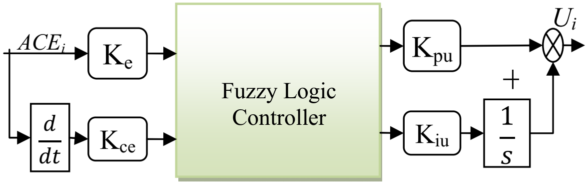

Figure 3. FLC for SMES Control

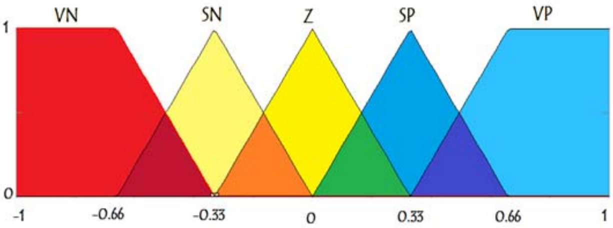

Figure 4: Membership Functions for input and output variables

Table.1 presents the view of rules for FLC utilized to design controller. In rule base 25 rules are designed to get the desired response. There are two scaling factors (K_e & K_{ce}) for both input variables (ACE_i,$dACE_i$) respectively and two gain factors K_{pu} & K_{iu} as proportional and integral gains respectively.

Here also PSO used for find out optimum value of scaling parameters and gain parameters and objective function used

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for same shown in (6). Optimum values of scaling and gain parameters are shown in Table IV.

Table III

Rule Base for FLC Controller

		ΔACE				
ACE		**VN**	**SN**	**Z**	**SP**	**VP**
	VN	VN	VN	SN	SN	Z
	SN	VN	SN	SN	Z	SP
	Z	SN	SN	Z	SP	SP
	SP	SN	Z	SP	SP	VP
	VP	Z	SP	SP	VP	VP

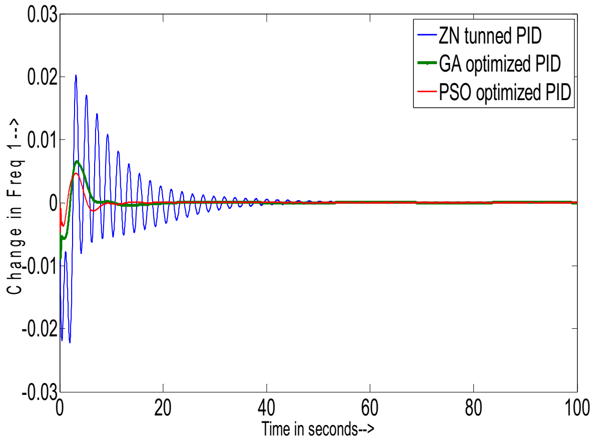
Table IV

Optimum Value of Scaling and Gain Parameters

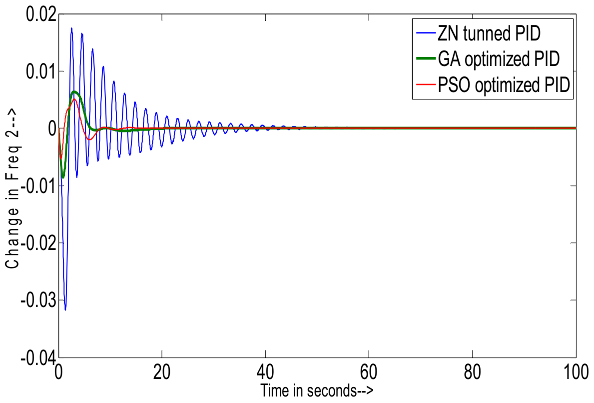
	Scaling Parameters		**Gain Parameters**	
	Ke	***Kce***	***Kpu***	***Kiu***
FLC for Area-1	0.08	1.14	0.68	0.70
FLC for Area-2	0.21	0.21	0.75	0.55

V. RESULTS & DISCUSSIONS

In this paper, PID Controller is used for AGC for both of areas. Different methods for tuning and optimization are examined here for PID gains setting, which are ZN, GA and PSO respectively. Frequency deviations of both areas and tie line deviation after a sudden load change in each area for test cases are shown in Fig.5. Results show that PSO optimization method is more effective to damp out oscillations in comparison of conventional ZN tuning method and GA optimization method. A comparative analysis is also carried out between AGC without SMES support, conventional PI controlled SMES and proposed FLC controlled SMES, as shown in Table V.



(a)



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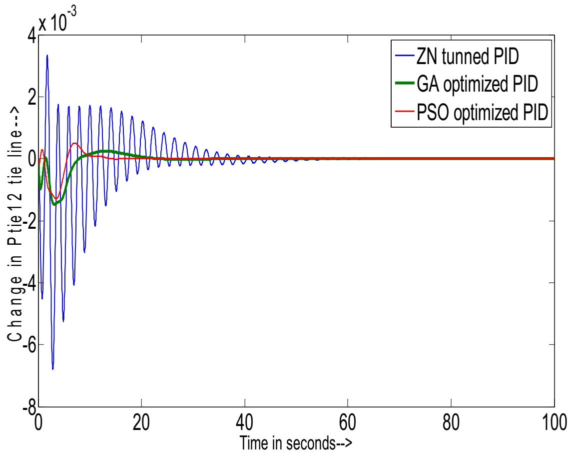
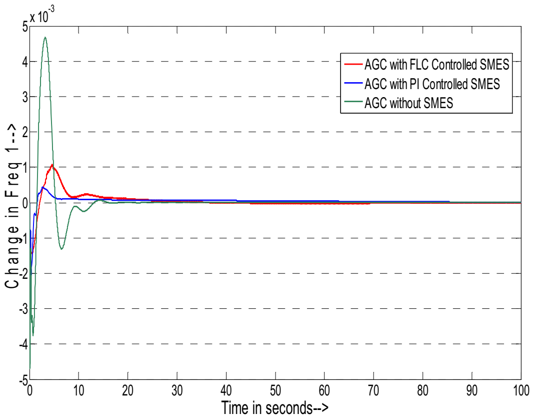


(c)

Figure 5. Comparison of ZN tuned PID, GA optimized PID and PSO optimized PID for two area thermal-hydro power system (a) Δf_1, (b) Δf_2, (c) $\Delta Ptie_{12}$



(a)

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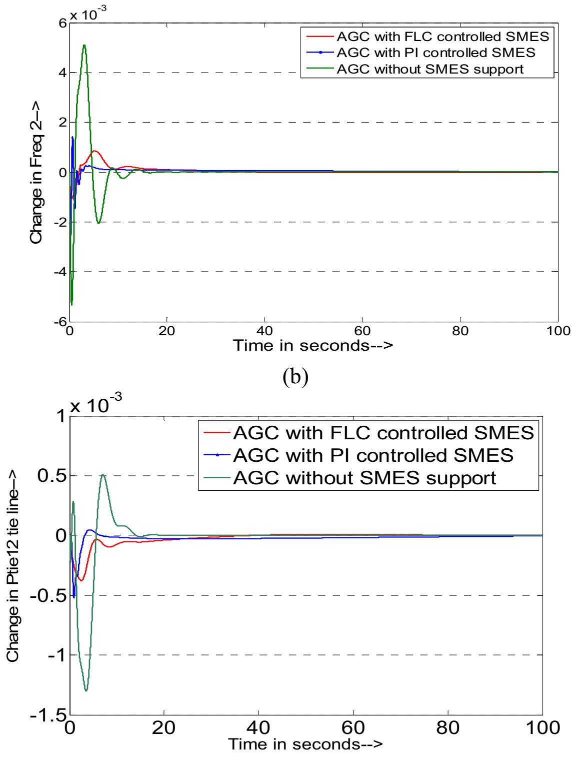

(b)

(c)

Figure 6. Comparison of AGC with FLC controlled SMES, AGC with PI controlled SMES and AGC without SMES support (a) Δf_1, (b) Δf_2, (c) $\Delta Ptie_{12}$

VI. CONCLUSION

In this paper, different tuning and optimization method examined for gain setting of PID controller for automatic generation control of interconnected thermal-hydro power systems in a deregulated environment. Results of simulation show that PSO optimized controller provides a better performance compared to ZN tuned PID controller and GA optimized PID. Apart from this additionally frequency stabilization method proposed using FLC controlled SMES. A comparative study is also carried out between proposed FLC controlled SMES and PI controlled SMES. The simulation results shows that proposed FLC controlled SMES provides less dip in frequency variation in both areas as well as less dip in tie-line power variation.

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Table V

Comparison of Peak Undershoot of Δf_1, Δf_2 and $\Delta Ptie_{12}$ for different control strategies

Maximum dip in	**AGC with SMES support**		**AGC without SMES support**		
	AGC with FLC Controlled SMES	***AGC with PI Controlled SMES***	***PSO optimized PID Controller for AGC***	***GA optimized PID Controller for AGC***	***ZN tuned PID Controller for AGC***
Frequency of Area-1	0.001528	0.003555	0.004697	0.008887	0.022191
Frequency of Area-2	0.001061	0.002559	0.005323	0.008577	0.031691
Tie-line Power	0.000381	0.000523	0.001302	0.001474	0.006789

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