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Multiobjective Optimization of Load Frequency Control using PSO

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***Abstract*— This paper presents a practical model for load frequency control (LFC) of two-area interconnected power system. The proposed model is a non-linear power system and is framed with thermal generating units including security constraint governor dead band imposed by the governor. A Proportional Integral Derivative (PID) controller is used for the design and analysis of the proposed model. The Particle swarm optimization (PSO) algorithm is developed to obtain suitable control parameters to achieve the optimum performance. A unique objective function is also formulated considering the transient specifications. The closed loop performance is examined in the presence of constraint scenario and the results and characteristics show that the developed algorithm gives better performances.**

***Keywords*—load frequency control; two area power system; governor dead band; PID controller; particle swarm optimization**

I. Introduction

For large scale interconnected power system, load frequency control (LFC) is important to keep the system frequency and the inter-area tie-line power as close as possible to the schedule values. The frequency of a system is dependent on active power balance. In an interconnected system, with two or more independently controlled areas, the generation within each area has to be controlled so as to maintain scheduled power interchange. The control of tie-line power and frequency is commonly known as load frequency control (LFC). Recent growth and development of power system industry and increased power demand has necessitated intelligent methodologies for practical control of the power system. In modern days, smart grid predicts and intelligently responds to actions of all suppliers, consumers in order to efficiently deliver reliable, economic electricity services. In smart grids, the use of renewable sources results in frequent variations of frequency in the system as the power supplied is not constant. Regulation of frequency can be done by control of load as well as the governor at the generating stations.

LFC using controller based Dynamic Demand Control (DDC) can be used to maintain the frequency at nominal value. This will reduce the burden on generating station alone to regulate the frequency.

In general, LFC is accomplished by two different control actions: primary control and supplementary control. When load changes, the primary speed control perform the initial re-adjustment of the frequency and tie-power by the action of governor itself. The governor will try to minimize the frequency and tie line power deviation to zero by manipulating input to the turbine. The supplementary control action is used to minimize the frequency deviation, if persist after primary control, to zero through integral control action [1]. A systematic way of P, PI and PID controller parameters tuning based on Ziegler-Nichols method for distributed generation system (DGS) was proposed in [2]. In recent past, advance control engineering techniques were used to design LFC system of large scale complex and uncertain power system. A robust control design that utilizes loopshaping ideas for LFC regulation was proposed in [3] considering large uncertainty. Khodabakhshian and Edrisi [4] used a new tuning algorithm which was based on maximum peak resonance specification supported by Nichols chart to tune the PID controller. In [5], a detail structured singular value method and eigen value method were proposed for local area and tie-line robustness analysis. A multi area adaptive LFC based on Self-Tuning Regulator (STR) for Automatic Generator Control Simulator (AGCS) was investigated in [6]. Alireza et al. [7] proposed a new robust optimal MISO-PID controller for LFC. In [8], two robust decentralized control design methodologies were proposed. The first one was based on H∞ control design using LMI technique and the second controller was a PI type, and was tuned by GALMI technique to mimic the same robust performance of the first one. Yao Zhang et al. [9, 10], developed an active disturbance rejection control (ADRC) based robust decentralized LFC solution considering wide range of parameter variations, model uncertainty and large disturbances.

The controllers designed so far using traditional and advanced control techniques for LFC system are model based controller. The performance of the controller is better on the specific model. The performance of such controllers is not good enough for large power systems like power systems with non-linearities and not-defined parameters. Therefore, the design of intelligent controller which is robust and adaptive had been introduced to design the LFC system [11-19]. In [11], Takaki-Sugeno fuzzy model of the power system was constructed for designing the fuzzy model based LFC. Bevrani et al. addressed a new decentralized fuzzy-logic based LFC scheme for minimization of frequency deviation and tie-line power changes in the presence of high penetration wind turbines [12]. An adaptive fuzzy gain scheduling scheme for conventional PI and optimal controllers was proposed in [13]. Genetic algorithm (GA) based parameter optimization of PID sliding mode LFC used in automatic generating control (AGC) of multi-area power systems with non-linear elements, was proposed in [14]. The decentralized LFC was formulated as multi-objective optimization problem in [15] and GA was used to tune the PI controller parameters of multi-area power system. The Particle Swarm Optimization (PSO) algorithm, in its different form, have assumed much importance in recent years for optimization of complex control problems and it is being widely used in LFC design. The LFC analysis for single and multi area power system using PSO were reported in [16, 17]. PID gains of Sugeno fuzzy logic based automatic generation control of multi-area thermal generating plants were optimized using classical particle swarm optimization, hybrid particle swarm optimization, hybrid genetic algorithm simulated annealing and was reported in [18]. In [19], load frequency stabilization by coordinated control of thyristor controlled phase shifters (TCPS) and super conducting magnetic energy storage (SMES) were investigated using craziness-based particle swarm optimization (CRPSO). From the above discussions, it is obvious that PSO is a power full tool which can be effectively used to design the LFC system.

For quality electric power services, LFC is an important factor. The PID parameters of LFC system must be designed in such a way that it ensures safe, reliable and uninterrupted power supply. The classical/conventional approaches provide very poor performance for large network under practical constraints like governor dead band, generation rate constraint, time delay etc. The short comings of the conventional approaches are the motivating factor of applying soft computing techniques for the designing of LFC system.

Soft computing techniques are not model specific but it is robust in nature and can give multi solutions. Under critical situation and security constraints, soft computing techniques can give highly satisfactory results.

This paper presents a realistic approach to optimize the proportional integral derivative gains of load frequency control system. A two area thermal-thermal power system is considered for the design purpose. For the two area case, the effect of governor dead band non-linearity is taken into account to make this approach a bit realistic one. The PSO algorithm is developed to optimize the PID gains and a novel objective function is designed to calculate the optimal controller gains more accurately in least time. The transient performance shows the significant superiority of the proposed design approach.

II. SYSTEM MODEL

A. LFC Model

For understanding the control action of LFC, consider the non-reheat thermal power system shown in Fig.1. The basic block of power generating unit consists of the combination of governor, turbine and generator. As the load varies, the speed/frequency of the generator changes. The speed governor helps to match active power generation with the demand by controlling the throttle valves which monitor the steam input to the turbine. Governors are used to sense the frequency bias caused by load change and cancel it by varying the input of the turbine. The turbine unit is used to transform the natural energy, such as the energy from steam or water, into mechanical power which is supplied to the generator. The generator unit of the power systems converts the mechanical power received from the turbine into electrical power. But for LFC, the focus is on the rotor speed output (frequency of the power systems) of the generator instead of the energy transformation. The linear model of the LFC system is shown in fig.1 where the blocks are: non-reheat steam turbine = $1/(T_t s+1)$; load and machine = $K_p/(T_p s+1)$; governor = $1/(T_g s+1)$;

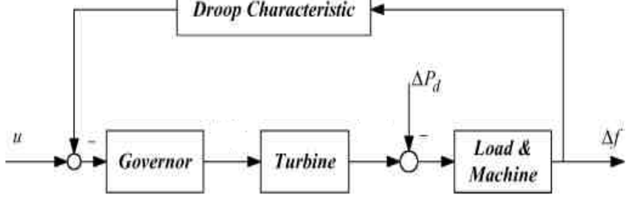

Fig.1. Model of single area power system

In the above configuration, T_g and T_t are the governor and turbine time constant. K_p=1/D and T_p =2H/fD where D is the ratio of load changes percentage to the frequency changes percentage and H is the inertia coefficient of generator. u is the load reference and ΔP_d is the load change.

B. System Under Study

As an example of multi area power system, we have considered two area interconnected power system for LFC analysis. In multi area power system, the primary objectives of the LFC are to keep the system frequency at nominal value, to provide load sharing between generators proportionately and to maintain the tie line power exchange at schedule value. For an interconnected system, each area connected to others via tie line which is the basis for power exchange between them. When there is change in power in area one, that will be met by the increase in generation in all the areas associated with a change in the tie line power and a reduction in frequency. But the normal operating state of the power system is that the demand of each area will be satisfied at a normal frequency and each area will absorb its own load changes. There will be area control error (ACE) for each area and this area will try to reduce its own ACE to zero. The ACE of each area is the linear combination of the frequency and tie line error, i.e. ACE = Frequency error + Tie line error. The transfer function model of two area non-reheat thermal power system is depicted in fig. 2 and the system parameters are given in appendix A. To make the analysis realistic one, the governor dead band is considered in this model which make the system non-linear. A governor dead band is defined as the total magnitude of a sustained speed change where there is no change in valve position of the turbine. The governor dead band non-linearity tends to produce a continuous sinusoidal oscillation of natural period of about T_0 = 2 s. The transfer function of governor with non-linearity [17] can be expressed as:

$$G(s) = [0.8 - (0.2/\pi)]/(sT_g + 1) \qquad (1)$$

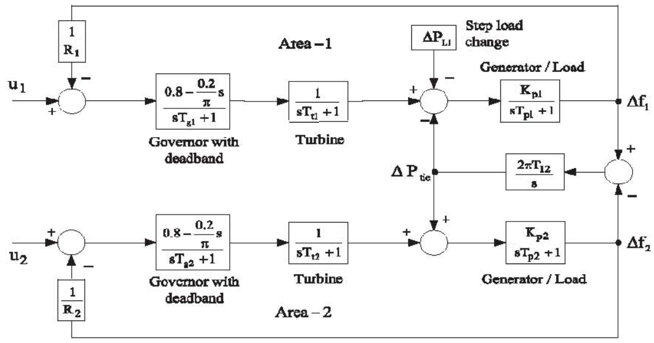

Fig. 2. Transfer function model of two area interconnected power system with governor dead band

III. PID CONTROLLER

In this study PID controller is used as a supplementary control for LFC. The PID controllers are widely used in industry because of its clear functionality, easy implementation, applicability, robust performance and simplicity. The transfer function of PID controller is

$$G_{PID}(s) = Y(s)/E(s) = K_p + K_i/s + K_d s \qquad (2)$$

Where Y(s) and E(s) are the controller output and tracking error signals in s-domain respectively. K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain. In PID controller, proportional part reduces the error responses to disturbances, the integral part minimizes the steady-state error and the derivative term improves the transient response and stability of the system. To get the optimum performance from the considered system, the gains of the PID controller must be tuned in such a way that the close loop system produces desired result. The desired result should have minimum settling time, no overshoot and zero steady state error. The parameters of the PID controller have been designed using developed PSO algorithm.

IV. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a population based stochastic optimization technique which is introduced by Kennedy and Eberhart in 1995 [20].

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This computational technique is developed inspired by social behavior of bird flocking or fish schooling. In this technique, a group of random particles (solutions) are generated. According to fitness value the best solution is determined in the current iteration and also the best fitness value is stored. The best solution is known as pbest. Another best fitness value is also tracked in the iterations obtained so far. This best fitness value is a global best and its corresponding particle (solution) is called gbest. In every iteration all the particles will be updated by following the best previous position (pbest) and best particle among all the particles (gbest) in the swarm. The each particle updates its velocity and positions with following equations:

$$v_i^{k+1} = w*v_i^k + c1*rand()*(pbest_i^k - x_i^k) + c2*rand()*(gbest_i^k - x_i^k)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (3\&4)$$

where i = 1, …n and n is the size of the swarm, k represent the no. of iteration.

x_i^k : current position of i^th particle at k^th generation

v_i^k : current velocity of i^th particle at k^th generation

$pbest_i^k$: pbest of i^th particle for k^th generation

$gbest_i^k$: gbest of i^th particle considering the whole generation i.e. upto the k^th generation

v_i^{k+1} : updated velocity of i^th particle

w : inertia weight for i^th particle

c1 & c2 : constriction factors

$rand()$: random number between 0 and 1.

For the optimization process, if c1 & c2 are not selected properly according to the problem, the PSO system might not converge at all. Usually c1 equals to c2 and ranges from [0,4]. Inertia weight is another important factor for swarm optimization problems. Inertia weight (w) must not be constant for better results. It is randomly selected within a certain range. Random selection of w provides successful tracking for a dynamic optimization problem. The inertia weight w is determined according to the following equation:

$$w = w_{\max} - \frac{(w_{\max} - w_{\min})*present\_iteration}{\max imum\_iteration} \qquad (5)$$

At the end of the iteration, the best position of the swarm will be the solution of the problem. A simple PSO may not provide always the optimal solution. The performance of the PSO can be improved by modifying the algorithm and proper selection of constriction factors and inertia weight.

V. CONTROL STRATEGY

The control configuration for multi area power system is depicted in fig. 3. The error input to the controllers are the respective area control errors (ACE) given by

$$ACE_i = B_i \Delta f_i + \Delta P_{tie} \qquad (6)$$

where i = 1,2, B_i = frequency bias factor = $(1/R_i) + D_i$

Control input to the power system is obtained by use of PID controller together with the area control errors ACE_1 and ACE_2. The control input of the power system u_1 and u_2 are the output of the controllers and these are obtained as

$$u_1 = K_{p1}ACE_1 + K_{i1}\int ACE_1 dt + K_{d1} d(ACE_1)/dt \qquad (7)$$

$$u_2 = K_{p2}ACE_2 + K_{i2}\int ACE_2 dt + K_{d2} d(ACE_2)/dt \qquad (8)$$

In LFC system, in order to convergence to the optimal solution, two different unique objective functions are formulated. The objective functions are derived considering steady state and transient response specifications and proper selection of weighting factors. Wrong selection of weighting factors leads to incompatible numerical value of each term of objective functions which gives erroneous result. To meet the design specifications, following objective functions are used.

$$J_1 = (e_1 + M_{p1})*10^{-04} + (SSE_1) \qquad (9)$$

$$J_2 = (e_2 + M_{p2})*10^{-04} + (SSE_2) \qquad (10)$$

Where e1 and e2 = square integral of ACE_1 and ACE_2, M_{p1} and M_{p2}= Maximum overshoot of area-1 and 2 and SSE_1 and SSE_2 = Steady state error of area-1 and 2.

In this paper, multi objective optimization using PSO algorithm is used to tune the PID control parameters. In multi objective optimization, simultaneous optimization of multiple objectives is carried out. Unlike single objective optimization, the solution is not a single point, but a group of solutions are obtained which may be useful for design and analysis.

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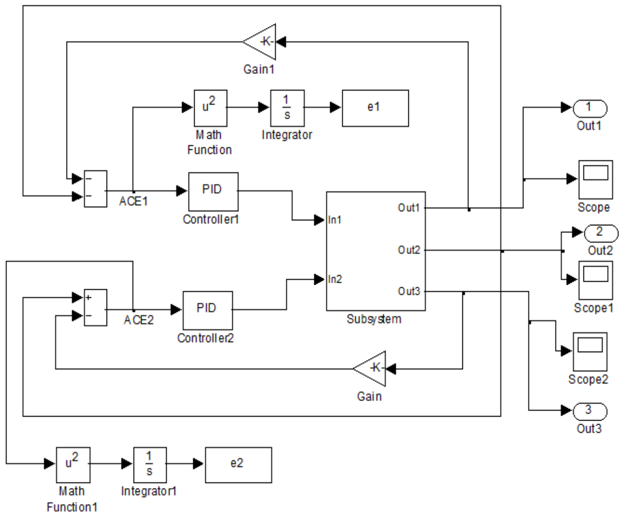

Fig. 3. Simulink model of the LFC system

VI. Result And Discussion

The simulation is carried out by MATLAB 7.9 software run on a PC of dual core processor with 2 GHz speed and RAM of 2 GB. For the multi area LFC system, the population size is chosen as 40 and the maximum no. of iterations for optimization are 40. Best value of constriction factors c1 and c2 are taken as c1=c2=1.5 and w_{max} = 0.95 and w_{min} = 0.45. The simulation is realized in case of step load change, ΔP_L = 0.2 pu MW in area-1, occurring at t = 1 sec and the frequency change in area-1, area-2 and tie-line power change is observed. Fitness function plot shown in fig 4, show the convergence characteristic of the proposed method. Fitness function plot indicates that the proposed algorithm requires around 30 iterations to converge. No significant change of the objective function values are observed after 30 iterations.

The tuned parameters of the control system and the transient response specifications are shown in table 1. The results are compared with Zeigler – Nichols tuning PID control method and PSO-PID method with standard cost function ISE [17].The observations show that the proposed control strategy with developed objective function produces good dynamic performances of the considered power system. Specially, the proposed objective function extract better solution compared to Zeigler – Nichols tuning method and PSO-PID method with standard cost function ISE where,

$$\text{Integral Square Error (ISE)} = \int (ACE_i)^2 dt \qquad (11)$$

The transient response characteristics of different methods are depicted in Figs. 5-7. Fig. 5 shows that Zeigler-Nichols tuning method is able to make steady state error zero. But it is incapable of making the maximum overshoot and settling time minimum. The number of oscillation is also more in this case which make the system relatively unstable. It is observed from Fig. 6 that PSO-PID with standard objective function produces good result compared to Zeigler-Nichols tuning method. The maximum overshoot and settling time becomes low and the no. of oscillations is also reduced. It is clearly seen from the Fig. 7 and Table 1 that the proposed PSO based PID controller with the derived cost function gives better control performance by minimizing frequency and tie line power deviation to zero compared to other two techniques. There is no oscillation in the transient part which make the system relatively more stable one.The proposed method yields true optimal gains, minimum settling time and zero overshoot of the transient responses compared to others and establishes its superiority over the others.

Table 1
Controller parameters and transient specifications of two area power system by PSO-PID method

		K_p	K_i	K_d	t_s	M_p
Ziegler-Nichols	Area-1	0.054	1	0.25	12	0.078
	Area-2	0.054	1	0.25	12	0.07
	Tie-power	-	-	-	14.5	0.0068
PSO-PID [with standard cost function ISE]	Area-1	0.0924	0.6240	0.4806	9	0.0117
	Area-2	0.0924	0.6240	0.4806	7.8	0.0027
	Tie-power	-	-	-	10.5	0.0003
Proposed PSO-PID	Area-1	0.001	0.5350	0.1831	5.2	0
	Area-2	1.4785	1.7496	1.0342	7.5	0
	Tie-power	-	-	-	8.2	0

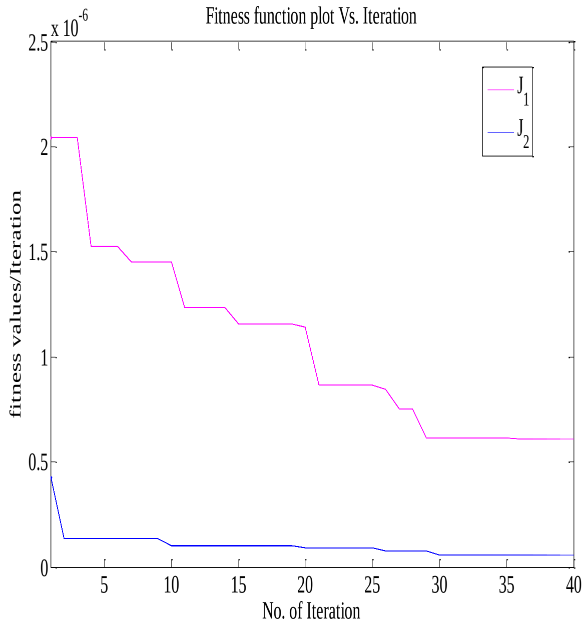

Fig.4. Plot of objective functions vs iteration of proposed method

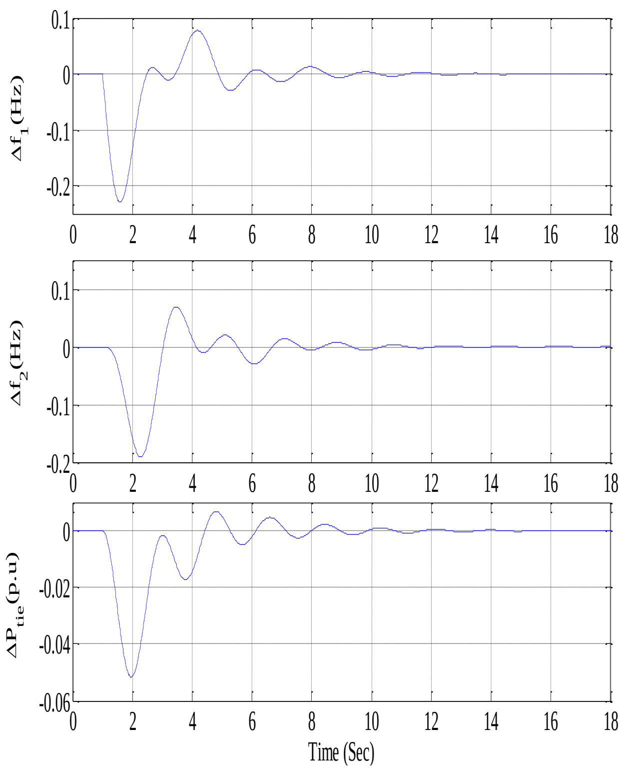

Fig.5. Frequency deviation of area- 1 and 2 and tie line power change with Zeigler – Nichols method

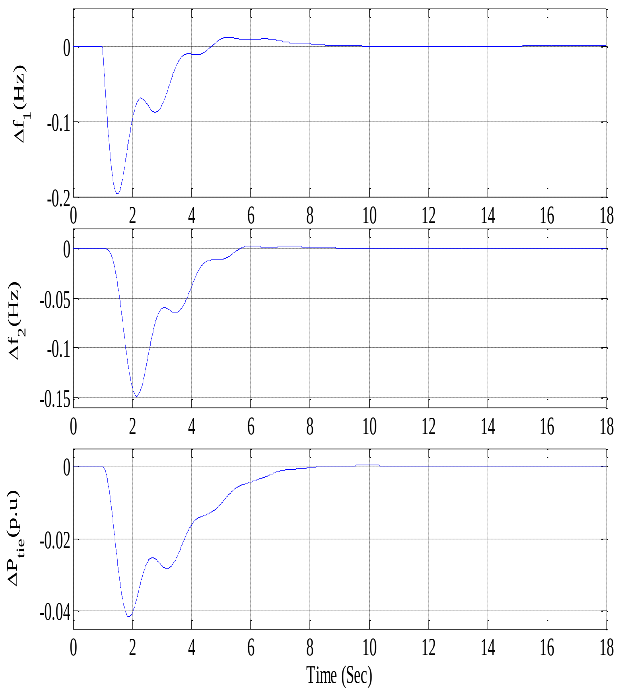

Fig.6. Frequency deviation of area- 1 and 2 and tie line power change with objective function ISE using PSO-PID method

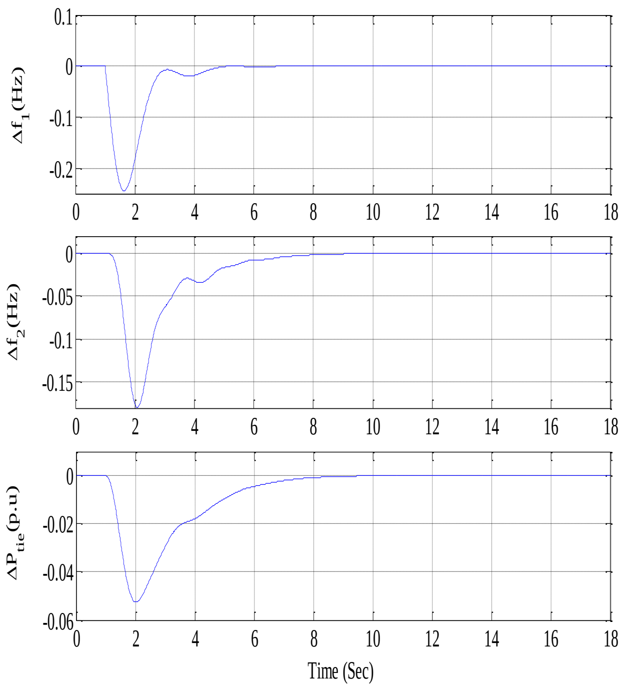

Fig. 7. Frequency deviation of area- 1 and 2 and tie line power change with proposed method

VII. CONCLUSION

In this paper, PSO based PID controller design using multi objective optimization has been proposed for the LFC. It has formulated to optimize a composite set of objective functions. A two area power system with governor dead band has been considered to demonstrate the proposed methodology. The objective functions are uniquely formulated by considering the transient specifications and appropriate selection of weighting factors.

Simulation results prove that the designed PSO based PID controller gives very good transient and steady state performance for frequency and tie line power deviation compared to Zeigler-Nichols tuned PID controller and PSO based PID controller with standard objective function ISE. Due to its simple structure and superiority, this methodology can be applied to other control system problems.

APPENDIX A

The typical values of the system parameters are given bellow.

$T_{g1} = T_{g2} = 0.2$s; $T_{t1} = T_{t2} = 0.3$s; $T_{p1} = T_{p2} = 20$s; $K_{p1} = K_{p2} = 120$ Hz/pu MW; $T_{12} = T_{21} = 0.0707$ pu; $R_1 = R_2 = 2.4$ Hz/pu MW; $B_1 = B_2 = 0.425$ pu MW/ Hz.

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