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TIME VARYING ACCELERATION COEFFICIENTS WITH DOMINANT SOCIAL COMPONENT PARTICLE SWARM OPTIMIZATION FOR INTERCONNECTED POWER SYSTEM

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ABSTRACT

In this paper, Time Varying Acceleration Coefficients with Dominant Social Component (TVACDSC), Time Varying Acceleration Coefficients (TVAC) and Fixed Acceleration Coefficients (FAC) Particle Swarm Optimization (PSO) techniques are proposed to optimize the proportional, integral and derivative gains of PID controller for two equal area interconnected power system. The performance index is considered as minimization of Integral of Time weighted Absolute value of Error (ITAE). Main purpose of this interconnected power system is to provide better quality of power to consumers. For this reason, the responses are analyzed and compared with the responses of Gravitational Search Algorithm (GSA) in terms of rise time, settling time, peak overshoot, peak undershoot and peak time. Finally, suggested the better optimization technique to provide better quality of supply to consumers in interconnected power system.

Keywords: interconnected power system, PID controller, PSO, acceleration coefficient, cognitive, social components.

INTRODUCTION

The importance of interconnected power system is to meet continuous power supply without deviating frequency and tie line power flow thereby all the consumers will have been obtaining continuous power supply. The interconnected power system consists of several control areas. If any sudden perturbations occurred in the load of interconnected power system then frequency deviations occurred in all areas.

For achieving better quality of power system, the frequency must be maintained at constant. If any deviations happened in frequency of interconnected power system, it will lead to reduce the reliability and efficiency of system. So, frequency deviations must be eradicated as soon as possible. If the frequency deviation is not eradicating with control action then high frequency deviation arose for every next load perturbations. During high frequency deviations occurred in interconnected power system, it will disgrace the performance of load, distress the performance of system protection schemes and harm equipment. These high frequency deviations leads to the interconnected power system crumble. Discrepancy in frequency harmfully affects the operation and speed control of induction and synchronous motors. In domestic area, when the power supply frequency retards, refrigerator's efficiency goes down; television and air conditioners reactive power consumption increases considerably. For this reason, it is very significant to maintain the frequency at rated value or within tolerable range. The adjustment of generation for continuous load change, the system frequency has to maintain within adequately small tolerance level. So, Load Frequency Control (LFC) plays a very vital role in an interconnected power system for supplying electric power with better quality.

The real power flow between the different control areas are regulated by the Load Frequency Control (LFC) at constant frequency. The ancient method to control the balance between the net generation and load demand by using one generating unit designed as the regulated unit and it was manually adjusted to Control. At present, several units are involved in load frequency control and it leads to improve the regulation, efficiency and economy in overall system.

Initially, speed governor adjusts the input to the turbine, will try to reduce the frequency deviation and tie line power flow deviation to zero when load is subjected to changes itself. Results were not tolerable one when the high obstacles implied on the frequency constancy. In this circumstance it is very essential to attain much better frequency constancy than obtained by the speed governor system. The additional control techniques have been developed in accompanying with speed governing mechanism to minimize the frequency deviation and make tie line power flow deviation to zero.

Many control strategies for Load Frequency Control in interconnected power systems have been proposed by researchers as follows. O.I.Elgerd and C.E.Fosha [2] developed a dynamic system model of multi area interconnected power system. Integral gain (K_i) and frequency bias (B) parameters discovered from classical optimization theory in the astuteness of minimizing the Integral Square Error (ISE) criterion. C.E.Fosha and O.I.Elgerd [3] again developed state variable model of the multi area interconnected power system MW - frequency control problem. Modern control techniques were used to develop optimal controllers for interconnected power

ARPN Journal of Engineering and Applied Sciences

system that significantly improved the transient response for corresponding load perturbations. C.T.Pan and C.M.Liaw [4] presented an adaptive controller for load frequency control. Aleksandar M.Stankovic *et al.*, [5] presented a physically motivated augmentation of the standard integral controller in LFC. Janardan Nanda *et al.*, [6] investigated continuous discrete mode interconnected hydro thermal system using conventional integral and proportional integral controllers (system works in continuous mode, controller works in discrete mode). Seyed Abbas Taher and Reza Hematti [7] presented quantitative feedback theory for load frequency control. I. A. Chidambaram and B. Paramasivam [8] designed a Genetic Algorithm (GA) based controllers with Integral Square Error criterion for the decentralized load frequency control of two area interconnected thermal reheat power systems with and without Redox Flow Batteries (RFB) considering Thyristor Controlled Phase Shifter (TCPS) in the Tie-line. H. A. Shayanfar *et al.*, [9] described a Multi Input Multi Output (MIMO) design technique based on the Characteristic Loci (CL) method applied to load frequency control of interconnected power system. Wen Tan [10] discussed a unified PID tuning method for load frequency control of interconnected power system. Gayadhar Panda *et al.*, [11] presented a modified genetic algorithm based optimal selection of integral gain and frequency bias constant for load frequency control of multi area interconnected power system. K. P. Singh Parmar *et al.*, [12] presented output feedback controller design for two area interconnected power system. Armin Ebrahimi Milani and Babak Mozafari [13] presented new genetic algorithm based method for achieving optimal gains in two area interconnected power system. Serhat Duman and Nuran Yorukeren [14] presented GSA method for determination of optimal PID parameters in two area interconnected power system. Rita Saini *et al.*, [15] presented Bacterial Foraging Optimization (BFO) method for two area interconnected power system.

Mostly, many researchers followed the Integral, PI and PID control strategies. The dominance of Integral, PI and PID control strategies have a simple structure, long-standing, successful design technique, high ability of solving many practical control problems. Among these strategies, PID control strategy gives better response than Integral and PI control strategies. So, the PID controller parameters are tuned by using different tuning techniques.

The Ziegler–Nichols technique is one of the most well-known ancient PID tuning techniques. This tuning approach works fairly well for a wide range of practical processes. However, sometimes it does not provide good tuning and tends to produce a vast overshoot. Therefore, this method usually needs retuning before applied to load frequency control.

Several intelligent approaches such as Genetic Algorithm [8, 11, 13], Particle Swarm Optimization [20, 21, 22, 23], Bacterial Foraging Optimization Algorithm [15] and etc. have been suggested to enhance the capabilities of traditional PID parameter tuning techniques. Rania Hassan *et al.*, [16] investigated the superiority of PSO over GA and statically proved that 99% confidence level in 7 out of 8 test problems. Emad Elbeltagi *et al.,* [17] investigated that the PSO method was generally found to perform better than genetic algorithm, memetic algorithm, ant colony optimization and shuffled frog leaping algorithm in terms of success rate and solution quality. M.A.Panduro *et al.*, [18] investigated that the particle swarm optimization and differential evolution algorithm gave a better performance in terms of the side lobe level with respect to the genetic algorithm under equal computational time. Rega Rajendra and Dilip K. Pratihar [19] investigated the performance of PSO algorithm and it gives better results due to its inherent ability to carry out the global and local searches simultaneously. On the other hand, the GA is a potential tool for global search, although it may not be so much powerful in local search. From the above investigations, PSO is better optimization technique than GA.

Some advantages of PSO algorithms are derivative free algorithm, easy to implementation, limited number of parameters, simple calculation and simple concept compared from other optimization algorithms like BFO algorithm [15].

PSO Algorithm can be applied to the tuning of PID controller gains (K_p, K_i and K_d) to ensure optimal control performance. The best values of PID controller parameters can yield a best system response and its values are obtained from the performance index. Many number of performance indices are used in load frequency control. Fernando G. Martins [24] investigated about ITAE criterion based PID parameters tuning gave better performance than Ziegler-Nichols tuning. Serhat Duman and Nuran Yorukeren [14] demonstrated that ITAE criterion gave better performance of convergence than ISE criterion. Gayadhar Panda *et al.*, [11] found that superiority in responses are obtained from minimizing the ITAE criterion compared from ISE criterion. R. Krishna kumar [25] observed that the performance index ITAE criterion gave better dynamic performance compared from ISE criterion. Jeevithavenkatachalam and Rajalaxmi. S [26] demonstrated the superiority of the ITAE criterion in the damping and settling of the transient responses compared to ISE criterion. From the above investigations, it is concluded that the minimization of ITAE criterion gives better performance compared from minimization of ISE criterion and Ziegler-Nichols tuning.

In this paper, TVACDSC, TVAC and FAC PSO techniques are proposed for tuning the proportional, integral and derivative gains of PID controller in two equal area interconnected power system with 10% step load perturbation in area 1. The proposed TVACDSC PSO and TVAC PSO techniques increases the acceleration coefficients from initial value to final value (constriction factor is decreased) and FAC PSO algorithm acceleration coefficients are fixed (constriction factor is constant). These proposed PSO technique responses are compared with responses obtained from GSA in ref. [14] and

ARPN Journal of Engineering and Applied Sciences

analyzed in terms of rise time, 5% of settling time, peak overshoot, peak undershoot and peak time.

MODELING OF TWO AREA INTERCONNECTED POWER SYSTEM

Frequency deviation (ΔF_i)

The net surplus power in the area following a disturbance ΔP_D equals $\Delta P_G - \Delta P_D$ MW, and the power will be absorbed by the system in three ways:

a) By increasing the area kinetic energy W_{kin} at the rate

$$\frac{dW_{kin}}{dt} = \frac{d}{dt}\left[W_{kin}^{*}\left(\frac{f}{f^{*}}\right)^{2}\right] = 2\frac{W_{kin}^{*}}{f^{*}}\frac{d}{dt}(\Delta f) \qquad (1)$$

b) By increased load consumption: All typical loads (because of the dominance of motor load) experience an increase $D \triangleq \partial P_D / \partial f$ MW/Hz with speed or frequency. This D parameter can be found empirically;

c) By increasing the export of power, via tie lines, with the total amount ΔP_{tie} MW defined positive out from the area.

From the above aspects, the power equilibrium equation in i^{th} area is given in equation (2).

$$\Delta P_{Gi} - \Delta P_{Di} = 2\frac{W_{kin\,i}^{*}}{f^{*}}\frac{d}{dt}(\Delta f_i) + D_i \Delta f_i + \Delta P_{tie\,i} \qquad (2)$$

From equation (2), all terms dimensions are in MW. These dimensions are converted into per unit representation by dividing the total rated area power (P_{ri}) expressed in MW in i^{th} area. Equation (3) represents the dimensions in per unit.

$$\Delta P_{Gi} - \Delta P_{Di} = 2\frac{H_i}{f^{*}}\frac{d}{dt}(\Delta f_i) + D_i \Delta f_i + \Delta P_{tie\,i} \qquad (3)$$

Where,

Inertia constant $H_i = W_{kin\,i}^{*}/P_{ri}$ in sec.

* indicates the nominal values

The equation (3) is simplified into equation (4).

$$[\Delta P_{Gi}(s) - \Delta P_{Di}(s) - \Delta P_{tie\,i}(s)]\frac{K_{pi}}{1+sT_{pi}} = \Delta F_i(s) \qquad (4)$$

Where,

$K_{pi} = \frac{1}{D_i}$ Hz/puMW and

$T_{pi} = \frac{2H_i}{f^{*}D_i}$ sec.

Block diagram model of equation (4) is shown in Figure-1.

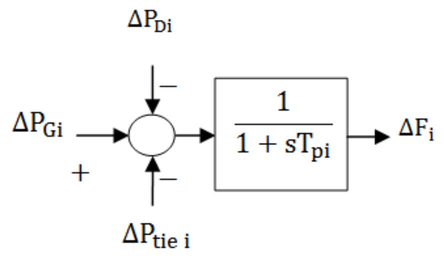

Figure-1. Block diagram model of control area.

Incremental generated power (ΔP_{Gi})

Real power generation in a synchronous machine is controlled by changing the prime mover torque. This change in torque is based on opening or closing the steam valve in a steam turbine. Process of opening or closing the steam valve is based on the functional diagram. Functional diagram is shown in Figure-2.

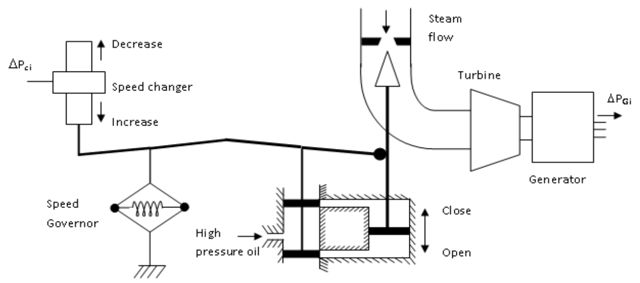

Figure-2. Functional diagram of turbine control arrangement.

From this Figure-2 incremental generated power is obtained from change in speed changer position and speed governor. This functional diagram of Figure-2 is modified into block diagram model. The block diagram model of turbine control arrangement is shown in Figure-3.

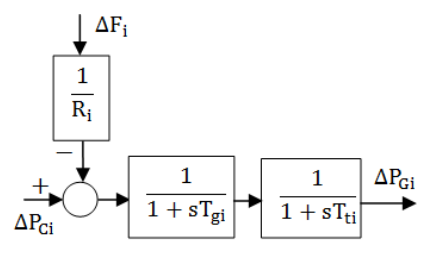

Figure-3. Block diagram model of turbine control arrangement.

In this block diagram has been represented by two time constants T_{gi} and T_{ti}. The former represents the time constant of the governor, and the latter represents the time lag of the turbine in i^{th} area.

ARPN Journal of Engineering and Applied Sciences

Incremental tie-line power (ΔP_{tiei})

The total real power exported from ith area ($P_{tie\,i}$) is equal to sum of all out flowing line powers ($P_{tie\,iv}$) in the lines connecting ith area with vth areas, i.e.,

$$P_{tie\,i} = \sum_V P_{tie\,iv} \quad (5)$$

If the tie-line losses are neglected, then the individual tie-line powers expressed in mathematical form is shown in equation (6).

$$P_{tie\,iv} = \frac{|V_i||V_v|}{X_{iv}P_{ri}}\sin(\delta_i - \delta_v) \approx P_{tie\max iv}\sin(\delta_i - \delta_v) \quad (6)$$

Where, $V_i = |V_i|e^{j\delta_i}$, $V_v = |V_v|e^{j\delta_v}$ are the terminal bus voltages of the tie-line and X_{iv} is reactance between ith area and vth area. The maximum value $P_{tie\max iv}$ represents the maximum real power (here expressed in per unit of the rated area power (P_{ri})) that can be transmitted via the tie-line. The tie-line is termed as "weak" because $P_{tie\max iv} \ll P_{ri}$. $\Delta\delta_i$ and $\Delta\delta_v$ are phase angle deviation from their nominal values δ_i^* and δ_v^*. If the phase angles deviate from its nominal values, then the tie-line power flow is also deviate from its nominal value. Deviation of tie-line power flow is mathematically expressed in equation (7).

$$\Delta P_{tie\,iv} = \frac{\partial P_{tie\,iv}}{\partial(\delta_i - \delta_v)}(\Delta\delta_i - \Delta\delta_v) = \frac{|V_i||V_v|}{X_{iv}P_{ri}}\cos(\delta_i^* - \delta_v^*)(\Delta\delta_i - \Delta\delta_v) \quad (7)$$

The relationship between the phase angle deviation and area frequency deviation is expressed in equation (8).

$$\Delta\delta_i = 2\pi\int \Delta f_i dt \text{ and } \Delta\delta_v = 2\pi\int \Delta f_v dt \quad (8)$$

From equations (7) and (8),

$$\Delta P_{tie\,iv} = T_{iv}^*(\int \Delta f_i dt - \int \Delta f_v dt) \quad (9)$$

Where, $T_{iv}^* = 2\pi\frac{|V_i||V_v|}{X_{iv}P_{ri}}\cos(\delta_i^* - \delta_v^*)$

Taking Laplace Transform of equation (9)

$$\Delta P_{tie\,iv}(s) = \frac{T_{iv}^*}{s}[\Delta F_i(s) - \Delta F_v(s)] \quad (10)$$

The total increment in exported power from ith area is finally obtained from equation (10) is expressed in equation (11).

$$\Delta P_{tie\,i}(s) = \frac{1}{s}\sum_V T_{iv}^*[\Delta F_i(s) - \Delta F_v(s)] \quad (11)$$

The total increment in exported power from ith area in two area system is obtained from equation (11) is expressed in equation (12).

$$\Delta P_{tie\,i}(s) = \frac{T_{iv}^*}{s}[\Delta F_i(s) - \Delta F_v(s)] \quad (12)$$

Diagrammatic representation of the equation (12) is shown in Figure-4.

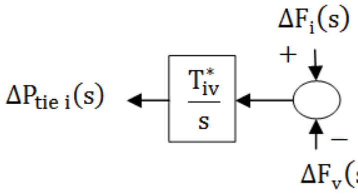

Figure-4. Block diagram model of incremental tie-line power exported from ith area.

The total increment in exported power from vth area in two equal area interconnected power system is obtained from total increment in exported power from ith area is expressed in equation (13).

$$\Delta P_{tie\,v}(s) = -\frac{P_{ri}}{P_{rv}}\Delta P_{tie\,i}(s) = -\Delta P_{tie\,i}(s) \quad (13)$$

Because, two equal area interconnected power system, the rated area powers P_{ri} and P_{rv} are equal.

Area Control Error (ACE)

When systems are interconnected, tie-line power flows as well as frequency must be controlled. The sum of tie-line and frequency errors can be expressed as Area Control Error (ACE) in equation (14).

$$ACE_i = \Delta P_{tie\,i} + b_i\Delta F_i \quad (14)$$

Diagrammatic representation of equation (14) is shown in Figure-5.

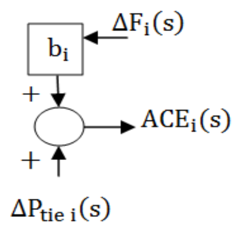

Figure-5. Block diagram model of Area Control Error.

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ARPN Journal of Engineering and Applied Sciences

Two area interconnected power system model is obtained from the block diagram models of Figures-1, 3, 4 and 5 is shown in Figure-6.

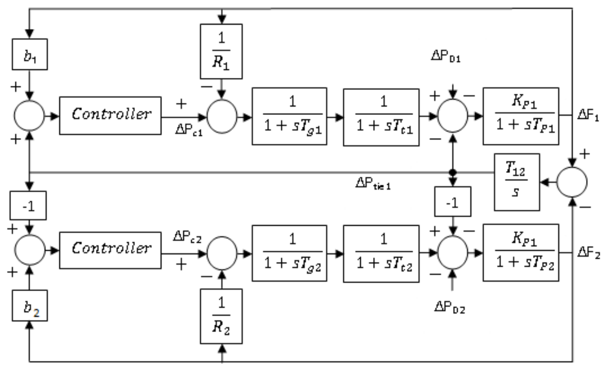

Figure-6. Block diagram representation of uncontrolled two area interconnected power system.

PID CONTROLLER AND PERFORMANCE INDEX

The classical PID controller can be expressed in two area interconnected power system as given in equations (15) and (16).

$$\Delta P_{c1}(s) = -(K_p + \frac{K_i}{s} + K_d s)(ACE_1) \quad (15)$$

$$\Delta P_{c2}(s) = -(K_p + \frac{K_i}{s} + K_d s)(ACE_2) \quad (16)$$

K_p, K_i and K_d are the proportional, integral and derivative gains respectively. Individual performance of each controller has some individual characteristics i.e., integral controller nullify the steady state error and reduces the rise time, proportional controller reduces the rise time and steady state error and derivative controller improves the transient response, reduces the settling time and overshoots.

These PID gain parameters are optimally tuned by using particle swarm optimization technique. The optimization process is based on the performance index. The performance index is considered as the 'Integral of the Time multiplied Absolute value of Error' (ITAE). The performance index (J) commonly used for optimizing the PID gain setting of the supplementary controller and it is based on the frequency deviations of two areas and tie line power flow deviation between two areas. Performance Index is given in equation (17).

$$J = \int t(|\Delta P_{tie12}| + |\Delta f_1| + |\Delta f_2|)dt \quad (17)$$

PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

Particle swarm optimization (PSO) algorithm was invented by Dr. James Kennedy and Dr. Russell Eberhart in 1995 and its elementary idea was originally inspired by mock of the social behavior of birds flocking. It is based on the natural process of group communication to share individual knowledge. When a group of birds search food in a searching space, although all birds do not know where the best position is. But from the nature of the social behavior, if any member can find out a desirable path to go, the rest of the members will follow quickly.

In PSO, each member of the population is considered as particle and the population is considered as swarm. All particles are initiated randomly and moving in randomly chosen directions, each particle goes through the searching space to find the personal best (best position of each particle) and the position yielding the lowest value amongst all the personal best that is global best (best position of particle in the entire swarm). Particles velocity is updated by using personal and global best positions and then each particle positions are updated by the present velocity. The process is repeated up to the stopping criterion while predetermined in advance.

Positions of particle are updated by using equation (18).

$$x_i^{itr+1} = x_i^{itr} + v_i^{itr+1} \quad (18)$$

Velocity of particle is updated by using equation (19).

$$v_i^{itr+1} = v_i^{itr} + c_1 r_1^{itr}[P_{best\,i}^{itr} - x_i^{itr}] + c_2 r_2^{itr}[G_{best}^{itr} - x_i^{itr}] \quad (19)$$

Where,

x_i^{itr} = Position of particle i at iteration itr.

v_i^{itr} = Velocity of particle i at iteration itr.

$P_{best\,i}^{itr}$ = Personal best position of particle i at iteration itr.

G_{best}^{itr} = Global best position at iteration itr.

c_1 and c_2 = Cognitive and Social parameters respectively.

r_1^{itr} and r_2^{itr} = Random numbers in between 0 and 1 at iteration itr.

In this optimization technique, updated velocity is increased over iteration. The high value of updated velocity respond poor optimization result (skipped the optimal value). Due to this reason, velocity clamping, inertia weight factor and constriction factor are introduced. Velocity clamping is limiting the total velocity only. Inertia weight is only concentrate the previous iteration velocity but unable to concentrate the acceleration components. Constriction factor concentrates the acceleration components and limits the total velocity. For this reason, constriction factor is taken as main role of this paper. This algorithm is discussed in to three ways.

Fixed Acceleration Coefficients (FAC)

Constriction factor 'χ' is extremely important to control the exploration and exploitation tradeoff, to ensure

ARPN Journal of Engineering and Applied Sciences

convergence behavior, and also to exclude the inertia weight ω and the maximum velocity v_{max}.

Velocity updates equation of the particle i is modified from equation (19) and is given in equation (20).

$$v_i^{itr+1} = \chi(v_i^{itr} + c_1 r_1^{itr}[P_{besti}^{itr} - x_i^{itr}] + c_2 r_2^{itr}[G_{best}^{itr} - x_i^{itr}]) \quad (20)$$

Where, $\chi = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}$, $\varphi = c_1 + c_2$

From the above expressions, constriction factor is obtained from acceleration coefficient. If $\varphi < 4$, then all particles would slowly spiral toward and around the best solution in the searching space without convergence guarantee. If $\varphi \geq 4$, then all particles converge quickly and guaranteed. For this reason, c_1 and c_2 are taken as 2 and more than 2. This paper suggests the values for c_1 and c_2 as 2.25. For this reason, 50% updated velocity is controlled by each iteration.

Time Varying Acceleration Coefficients (TVAC)

Time (or Iteration) varying acceleration coefficients are to enhance the global search in the beginning of the optimization and to move forward the particles to converge towards the best optimum solution at the end of search. The variable accelerating coefficients are obtained from the equations (21) and (22) and discover the updated velocity using equation (20).

$$c_1 = c_{1i} + (c_{1f} - c_{1i})\frac{itr}{itr_{max}} \quad (21)$$

$$c_2 = c_{2i} + (c_{2f} - c_{2i})\frac{itr}{itr_{max}} \quad (22)$$

Where, c_{1i} and c_{1f} are initial and final values of cognitive acceleration factors, c_{2i} and c_{2f} are initial and final values of social acceleration factors, itr_{max} is the maximum number of iterations, itr is the number of current iterations.

In this paper, the suggested initial values of cognitive and social parameters 2 and final values of cognitive and social parameters are 2.5. Because at the initial stage the constriction factor is high and then gradually reduced to reach low value for final stage. This strategy controls the updated velocity.

Time Varying Acceleration Coefficients with Dominant Social Component (TVACDSC)

Compared with the social component, high value of the cognitive component will result in excessive wandering of individuals through the search space. In contrast, a relatively high value of the social component may lead particles to hurry prematurely toward a local optimum. For this reason, proper control action of these two components is very important to discover the optimum solution exactly and efficiently. So velocity update equation is slightly modified from equation (20) and is given by equation (23).

$$v_i^{itr+1} = \chi(v_i^{itr} + c_1(r_1^{itr} - frn_1)[P_{besti}^{itr} - x_i^{itr}] + c_2(r_2^{itr} + frn_2)[G_{best}^{itr} - x_i^{itr}]) \quad (23)$$

Where, frn_1 and frn_2 - fractional values incorporated in cognitive and social components.

In this paper, the suggested fractional values 1 and 2 are 0.25. These values dominate the social component compared from cognitive component. The updated velocity is found from equations (21), (22) and (23). The initial and final values of cognitive and social parameters are same in TVAC.

SIMULATION RESULTS AND DISCUSSION

The Simulation was carried out using MATLAB programming and simulink toolbox. In this simulation 50 iterations are taken. Population size of particle swarm optimization is taken as 10. The system parameters are given in appendix.

The proportional, integral and derivative gains of PID controller with occurrence of 10% of step load perturbation in area 1 of two equal area interconnected power system are optimized by using proposed particle swarm optimization techniques with ITAE criterion.

Fixed Acceleration Coefficients (FAC)

Cognitive and social parameters c_1 and c_2 are considered as 2.25. Constriction coefficient is obtained as 0.5 from the values of cognitive and social parameters. Incase c_1 and c_2 are considered as 2, the constriction coefficient is obtained as 1.

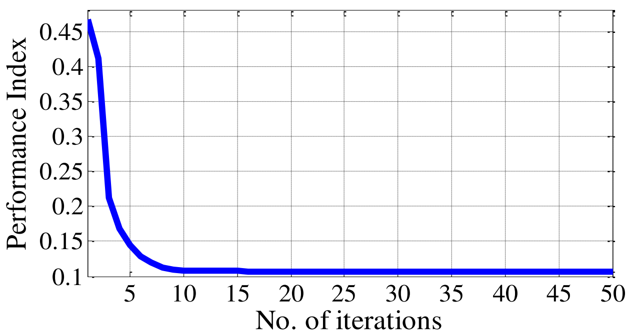

Figure-7. Fitness function for FAC PSO with 10% step load perturbation in area 1.

If χ is 1, then the current velocity increases over iteration and particles can hardly change their direction to move back towards optimum, and the swarm diverges. If χ< 1, then the current velocity increases as a fractional

ARPN Journal of Engineering and Applied Sciences

value of previous velocity and then quickly changes its direction to move towards optimum. For this reason, χ is set to 0.5; this situation gives the velocity update 50% only. So the optimal performance is obtained moderately. Figure-7 shows fitness function for 10% step load perturbation in area 1.

Time Varying Acceleration Coefficients (TVAC)

Cognitive and social parameters $c_1$and c_2 are obtained by using initial and final values of cognitive and social parameters. The initial values of cognitive and social parameters c_{1i} and c_{2i} are 2. The final values of cognitive and social parameters c_{1f} and c_{2f} are 2.5. If the initial values c_{1i} and c_{2i} are 2 and final values c_{1f} and c_{2f} are 2.5, then the constriction coefficient is obtained as 0.8682 at first iteration and 0.3820 at 50^{th} iteration. The constriction coefficient is gradually reduced from 0.8682 to 0.3820. At 25^{th} iteration, the constriction coefficient is 0.5. For the first 25 iterations, the constriction coefficient is gradually reduced from 0.8682 to 0.5. This value is higher than that of FAC. For the next 25 iterations, the constriction coefficient is gradually reduced from 0.5 to 0.3820. This value is lower than that of FAC. Figure-8 shows fitness function for 10% step load perturbation in area 1.

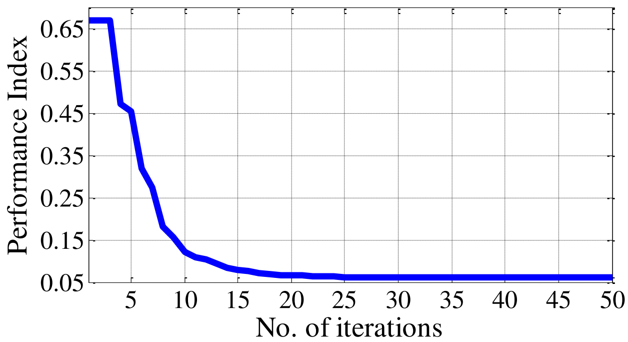

Figure-8. Fitness function for TVAC PSO with 10% step load perturbation in area 1.

Time Varying Acceleration Coefficients with Dominant Social Component (TVACDSC)

The fractional number is taken as 0.25. This value reduces the effect of cognitive component and increases the effect of social component. Among the three terms (previous iteration velocity, cognitive component and social component), social component is more dominant compared from other two terms. This dominance effect gives better response. Figure-9 shows fitness function for 10% step load perturbation in area 1.

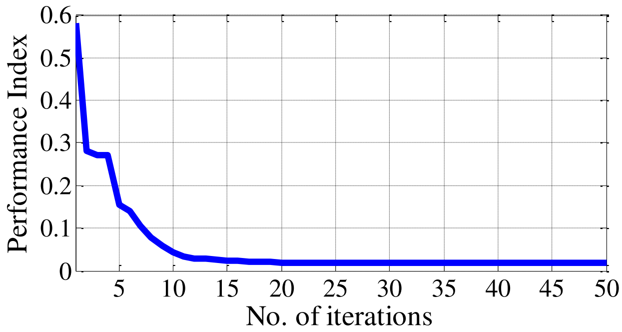

Figure-9. Fitness function for TVACDSC PSO with 10% step load perturbation in area 1.

The responses obtained from TVACDSC PSO, TVAC PSO and FAC PSO techniques are compared with the responses obtained from gravitational search algorithm in ref. [14]. Figures-10, 11 and 12 show the comparative responses of frequency deviations in area 1, frequency deviations in area 2 and tie line power flow deviations in two equal area interconnected non-reheat thermal power system.

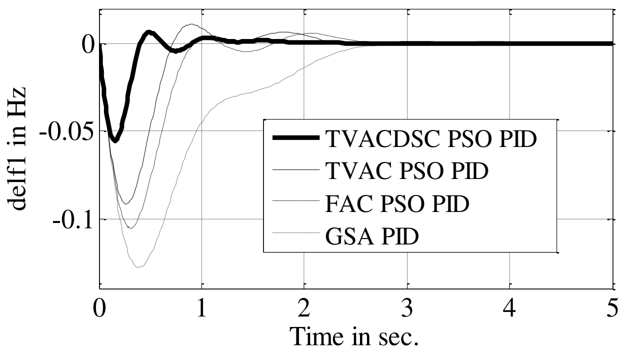

Figure-10. Frequency deviation in area 1.

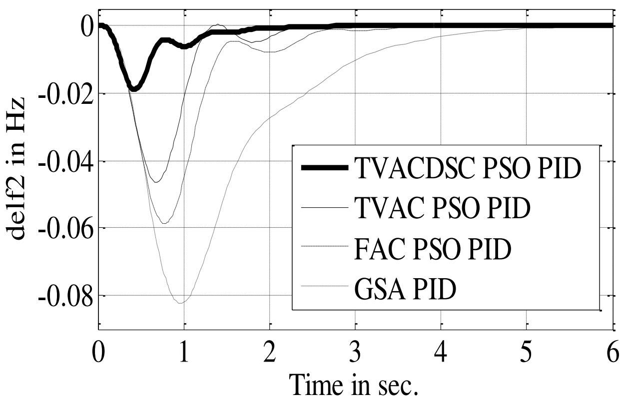

Figure-11. Frequency deviation in Area 2.

VOL. 11, NO. 3, FEBRUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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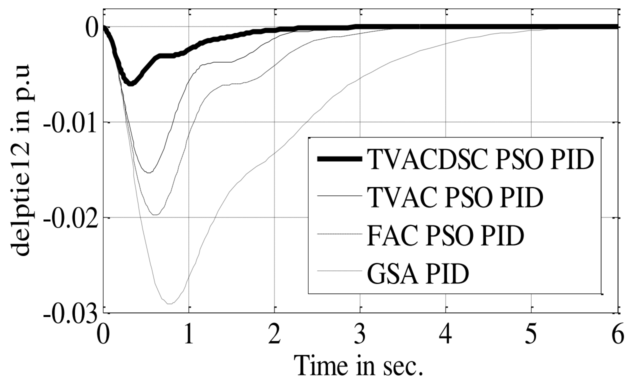

Figure-12. Tie line power flow deviation.

Figures-13 and 14 show the comparative responses of Area Control Error in Area 1 and Area 2. Figures-15 and 16 show the comparative responses of PID Controller Output in Area 1 and its closest view. Figures-17 and 18 show the comparative responses of PID Controller Output in Area 2 and its closest view.

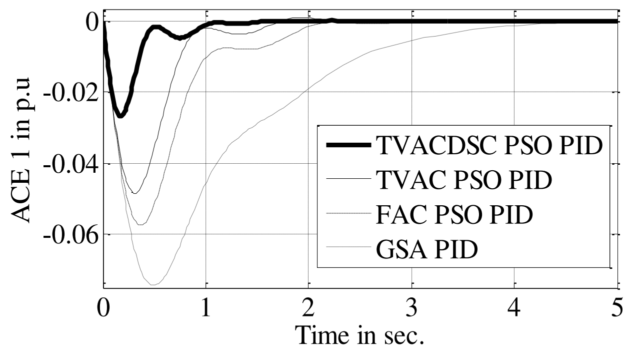

Figure-13. Area Control Error in Area 1.

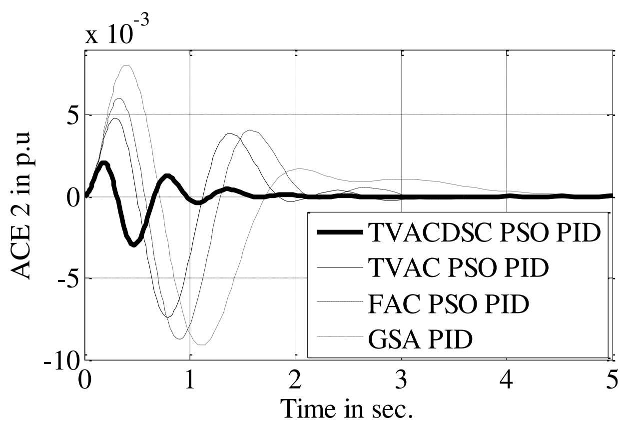

Figure-14. Area Control Error in Area 2.

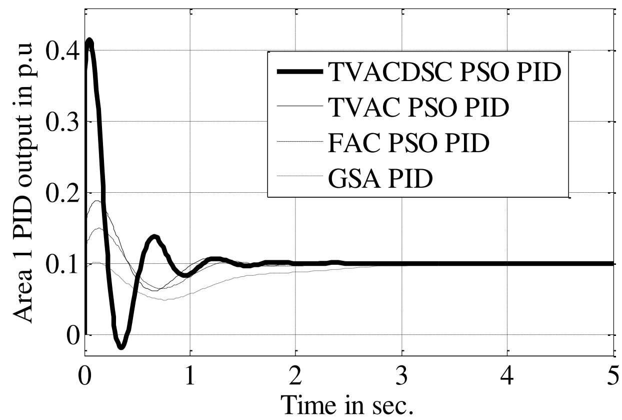

Figure-15. PID Controller Output in Area 1.

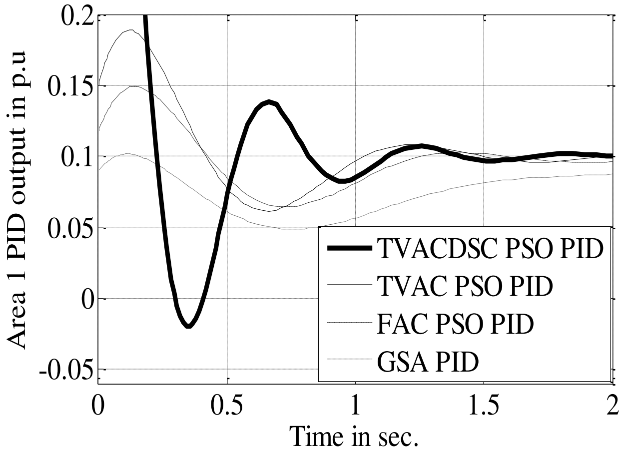

Figure-16. Closest view of PID Controller Output in Area 1.

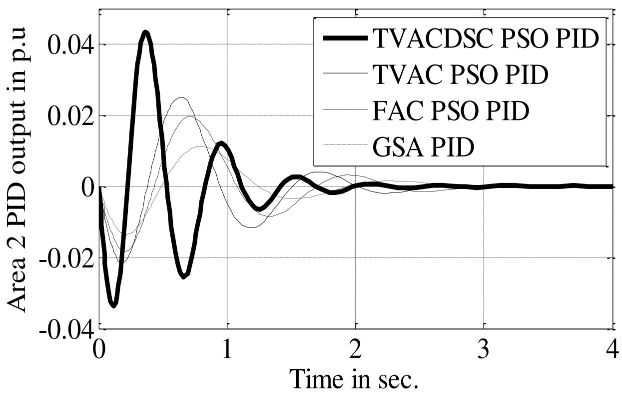

Figure-17. PID Controller Output in Area 2.

VOL. 11, NO. 3, FEBRUARY 2016 ISSN 1819-6608
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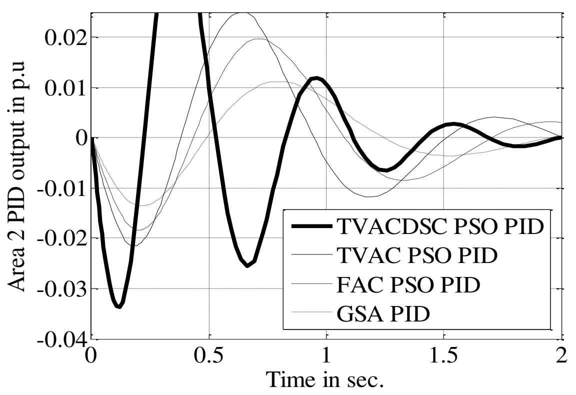

Figure-18. Closest view of PID Controller Output in Area 2.

Table-1 shows the frequency deviation in area 1 comparative responses of 5% tolerance of settling time, peak overshoot, peak undershoot and peak time in the TVACDSC PSO, TVAC PSO, FAC PSO and Gravitational Search Algorithm techniques for two equal area interconnected non-reheat thermal power system.

From Figure-10 shows TVACDSC, TVAC and FAC PSO reduce the frequency deviation within one second than Gravitational Search Algorithm. Gravitational Search Algorithm takes more than 2 seconds.

From Figures-10, 11 and 12 show the FAC PSO improves the response than GSA. TVAC PSO slightly improves the response than FAC PSO. TVACDSC PSO drastically improves the response than TVAC PSO.

From Figures-10, 11, 12 and Table-1 show the reduction of rise time, settling time, peak overshoot and peak time in the order of GSA, FAC PSO, TVAC PSO and TVACDSC PSO.

From Figures-15, 16, 17 and 18 show the Speed Changer Position input from PID Controller output based on ACE in area 1 and 2 of Figures-13 and 14.

CONCLUSIONS

Optimization of PID controller for Interconnected Power System using Time Varying Acceleration Coefficients with Dominant Social Component Particle Swarm Optimization technique gives better performance compared from Time Varying Acceleration Coefficients PSO, Fixed Acceleration Coefficients PSO and Gravitational Search Algorithm in terms of rise time, 5% of settling time, peak overshoot, peak undershoot and time taken to reach peak overshoot.

TVACDSC, TVAC and FAC PSO techniques are given better response than Gravitational Search Algorithm. Time Varying Acceleration Coefficients with Dominant Social Component Particle Swarm Optimization technique is better optimizing technique for PID controller parameter optimization in Interconnected Power system.

Table-1. Frequency deviation responses for Area 1.

Controller types	Settling time in sec.	Peak overshoot	Peak undershoot	Peak time in sec.
TVACDSC PSO PID	0.5421	-0.0556	0.0063453	0.1554
TVAC PSO PID	1.973	-0.0916	0.0106	0.2616
FAC PSO PID	2.1932	-0.1051	0.0058017	0.3109
GSA PID	2.3267	-0.1276	0.0010331	0.3964

APPENDIX

Two areas interconnected power system parameters

$P_{r1} = P_{r2} = 2000$ MW
$H_1 = H_2 = 5$ Sec.
$D_1 = D_2 = 8.33X10^{-3}$ puMW/Hz
$T_{g1} = T_{g2} = 0.08$ Sec.
$T_{t1} = T_{t2} = 0.3$ Sec.
$T_{P1} = T_{P2} = 20$ Sec.
$K_{P1} = K_{P2} = 120$ Hz/puMW
$R_1 = R_2 = 2.4$ Hz/puMW
$P_{tie\ max} = 200$ MW
$T_{12} = 0.545$ puMW/Hz
$b_1 = b_2 = 0.425$ puMW/Hz

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