INVESTIGATING THE PSS AND STATCOM SIMULTANEOUS OPERATION IN TRANSIENT STABILITY OF POWER SYSTEMS

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Abstract. Power system stability is necessary to guaranty its right operation. In early years using FACTS devices as a one of effective methods for improving the performance of system controllability and power transmission limitations is presented. Considering the non linear characteristic of power system the linear methods are not convenient for designing the stabilizers. In this paper, the non linear method of power system is considered for simultaneous designing of power system stabilizer (PSS) and static synchronous compensator (STATCOM). Moreover, simultaneous designing of power system stabilizer (PSS) and static synchronous compensator (STATCOM) is represented by PSO algorithm. Comparing this algorithm with other intelligent algorithms existing in Condor four-machine system, Indicates the more efficiency of this algorithm.

Key words: static synchronous compensator (STATCOM), power system stabilizer (PSS), PSS and STATCOM coordination, PSO algorithm

1. Introduction

One the most important issues in truly applying power system, is power system stability. Considering this issue that load of grid is variable, it is necessary to system keep its stability and synchronism in facing with this variations which are known as disturbance. Therefore, in recent decades different methods for designing the stabilizer were center of attention. According to increasing use of FACTS devices and their effect in improving damping of power system oscillations, operation synchronization of these controllers by power system stabilizer is necessary (Hingorani , 2000). As a power system is a non linear system, the stabilizer and FACTS device controller parameters should be designed for non linear models. In this way, in recent years, using evolutionary algorithm for solving optimizing problems is considered. Intelligent algorithms such as genetic algorithm (Kundur, 1994), (PSO) particle swarm optimization (Bomfim and Taranto, 2000), simulated annealing, are used for designing and adjusting the PSS parameters. Moreover, in PSS designing is done by Particle swarm optimization PSO and bacterial foraging algorithm BFA and results are compared with each other.

Coordinated designing of PSS and TCSC is studied in (Shayeghi et al. 2010; Abido, 2000). In simultaneous design of PSS and SSSC is investigated by Multi-Objective Evolutionary Programming. Coordinated design of SVC and PSS by Probabilistic theory is suggested in (Das et al. 2008). In this research stabilizer coordinated designing of power system and STATCOM considering non linear power system model is considered in four-machine system. For adjusting the coordination of PSS and STATCOM parameters the mentioned algorithm is used and the result of simulation shows the power of PSO algorithm for coordinating the PSS and STATCOM for improving the stability of system.

2. STATCOM modeling

In figure (1) the single machine power system with STATCOM is shown.

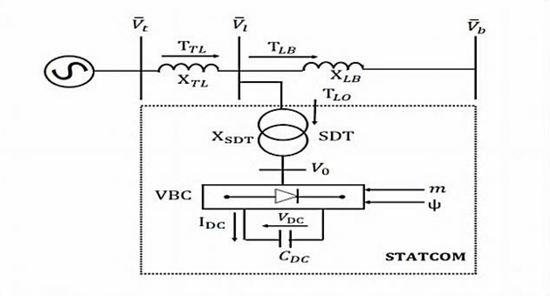

Figure 1: single machine power system connected to an infinite bus with STATCOM connection

In STATCOM, for controlling the injected reactive power, an inverter of voltage source with voltage of Vp is used. In steady condition, the DC bus voltage is constant and in the condition of Vs bus voltage the ac is in same phase with Vp main component. If Vs >Vp then STATCOM absorbs reactive power from AC bus and vice versa. Cai and Erlich (2005) first the STATCOM equations are provided in the reference frame of q and d, but considering this issue that the reference of reactive current is determined by AC bus voltage. The q'd' frame is chosen in a way that d' axis is tangent with AC bus voltage. The vector diagram of q and d reference frame and q' and d' frame is shown in figure 2 (Aziz et al. 2013).

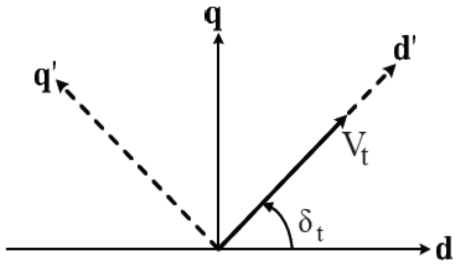

Figure 2: vector diagram of q and d reference frame and q' and d' frame

The dynamic equations of current of STATCOM q and d' components are as following:

$$\frac{di_{pd'}}{dt} = -\frac{R_p}{L_p} i_{pd'} + \omega i_{pd'} + \frac{1}{L_p}\left(V_s - V_{pd'}\right) \qquad (1)$$

$$\frac{di_{pq'}}{dt} = -\frac{R_p}{L_p} i_{pq'} - \omega i_{pd'} + \frac{1}{L_p}\left(-V_{pq'}\right) \qquad (2)$$

In which Vpq′ and Vpd' are the voltage of q' and d' components of voltage source. The Vpq' and Vpd' voltages are defined as following:

$$V_{pq'} = V_{pq} \cos\delta_t - V_{pd} \sin\delta_t \qquad (3)$$

$$V_{pd'} = V_{pd} \cos\delta_t - V_{pq} \sin\delta_t \qquad (4)$$

By replacing equation 3 in equation 1 the differential equation of STATCOM can be obtained as following:

$$\omega = \omega_0 + \frac{d\delta_t}{dt} \qquad (5)$$

In which the ω is the frequency of STATCOM voltages angles. The Vpq' and 'Vpd can be obtained from following equations:

$$V_{pq'} = -\left(\omega L_p i_{pq'} + L_p u_{q'}\right) \quad (6)$$

$$V_{pd'} = \omega L_p i_{pq'} + V_s - L_p u_{q'} \quad (7)$$

$$\frac{di_{pd'}}{dt} = -\frac{R_p}{L_p} i_{pd'} + u_{d'} \quad (8)$$

$$\frac{di_{pq'}}{dt} = -\frac{R_p}{L_p} i_{pq'} + u_{q'} \quad (9)$$

In which ud' and uq' are controlling signals that are obtained by PI controller.

Moreover, the dynamic equation of DC bus voltage is as following:

$$\frac{dV_{dc}}{dt} = \frac{3}{2CV_{dc}}\left[V_s i_{pq'} - \left(i_{pd'}^2 + i_{pq'}^2\right) R_p\right] - \frac{V_{dc}}{CR_{dc}} \quad (10)$$

In which Vdc is capacitor voltage, C is the value of dc capacitor, and Rdc is resistance parallel with dc capacitor which is equal to STATCOM switching losses. The above equations are three dynamic STATCOM equations. Figure 3 illustrates the STATCOM controller structure (Hashemi et al. 2013).

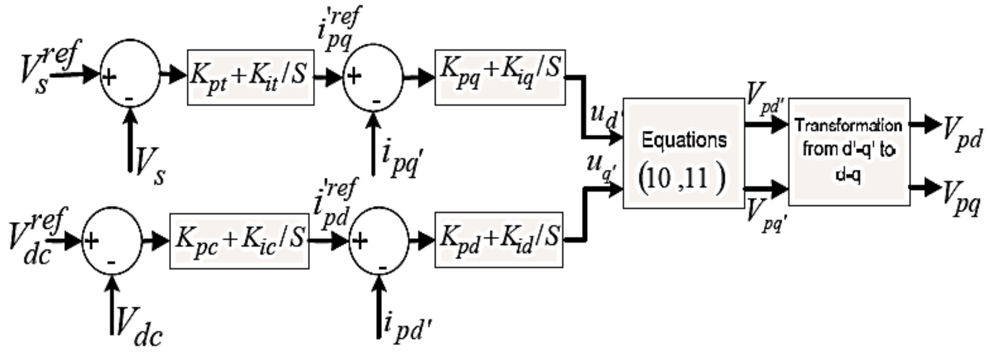

Figure 3: STATCOM controller structure

3. Synchronous machine model

A synchronous machine with an appropriate approximation is modeled by three stator coil and three coils over rotor (one field coil and damper coil). The dynamic equations which define the machine behavior are consisting of electromagnetic equation between coils and electromechanical equation of dynamic of rotor.

Electrical equations: natural linear electrical differential equations (regardless of magnetic saturation) and time variable. By definition of new variables and using a transformation named Park's transformation not only these equations will be very simpler than before, but they loss the characteristic of being time variable (Afzalan and joorabian, 2013). These simplified equations are very applicable in different power system studies.

For obtaining a model with least order, unimportant phenomenon in low frequency oscillations are neglected.

The most considerable phenomenon is:

1) by the time of low frequency oscillation the converted current in damper coils is low therefore; these coils are neglected in modeling.

2) since the special stable rates corresponding to q and d coils (stator coils) are adequately far from imaginary axis; these equations are considered in algebraic form. Only the remaining electric differential equation is related to synchronous machine field which is kept because of importance of its dynamic and applying control by excitation system.

Mechanical equations (oscillation):

This equation indicates the dynamic of circular motion of rotor and in a descriptive way is: The resultant of electrical and mechanical torque on rotor is equal to moment of inertia multiplied by the angular acceleration. The above equation is a non linear second order differential equation. Considering the desired topic meaning the answer of power system to small changes, the differential equations are defined around an operating point, linear, and with K1 to K6 coefficients. Using these equations not only leads to a physical view, but simplifies the appearance of equation. The above coefficients depend on machine, transmission grid, and operating point. The figure 4 shows the synchronous machine connected to Infinite bus in form of block diagram. In this block diagram the machine excitation system is modeled in the form of a first order transmission function. Two main mechanical and electrical loops can be seen in up and down of figure.

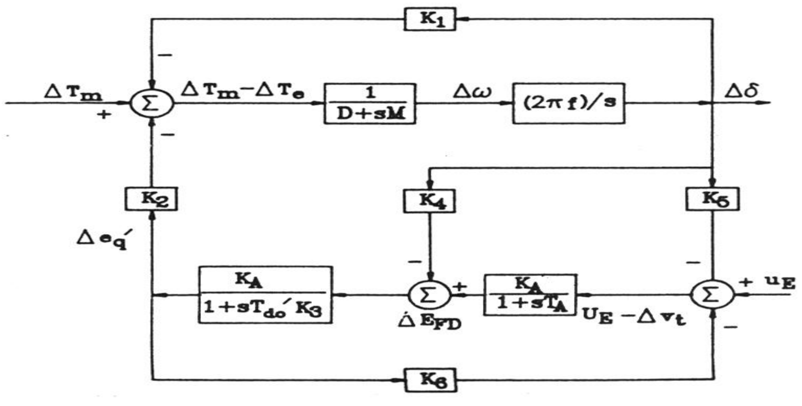

Figure 4: the block diagram of transmission function for studying low frequency oscillation phenomenon

The characteristic equation of mechanical loop is:

$$\left(Ms^2 + Ds + K_1\omega_b\right)\Delta\delta = 0 \qquad (11)$$

Roots of above equation are the oscillation modes of system and are very important. Difference of electrical and mechanical torque is input of this loop and velocity, and rotor angle are output of this loop.

Transmission functions corresponding to excitation and circuit of synchronous machine field are placed in electrical loop. This block diagram is beautifully analyzed in reference (Singh and Kadagala, 2012) and the effect of different dynamics on K1 and K6 coefficients and following that on stability of synchronous machine is explained. The system state equations can be obtained easily from this block. By choosing state vector in a following way:

$$X = \left[\Delta\omega \quad \Delta\delta \quad \Delta e'_q \quad \Delta E_{fd}\right]^T \qquad (12)$$

It can be written that:

$$\dot{X} = AX + B_{UE} \qquad (13)$$

In which A and B matrixes are:

$$A = \begin{bmatrix} 0 & -K_1/M & -K_2/M & 0 \\ \omega_b & 0 & 0 & 0 \\ 0 & -K_4/T'_{do} & -1/T'_{do}K_3 & 1/T'_{do} \\ 0 & K_AK_5/T_A & -K_AK_6/T_A & -1/T_A \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ K_A/T_A \end{bmatrix}$$

4. PSS designing stages

The phase lead circuit and PSS gain is down like following respectively:

4.1. Calculating ω_n frequency of electromechanical mode

Regardless of natural damping, the mechanical characteristic equation is obtained in following form that by solving it the natural immortal frequency can be obtained.

$$Ms^2 + K_1\omega_b = 0 \qquad (14)$$

$$s = \pm j\omega_n \qquad \omega_n = \sqrt{\frac{K_1\omega_b}{M}}$$

4.2. Designing phase compensator

First the transmission function between $\Delta e'_q$ and u$_E$ in electrical loop is calculated (G$_E$ (s)). The value of phase delay of this transmission function in exchange for ω_n should be compensated by a phase lead circuit. A normal form for phase compensator is:

$$G_c(s) = \left(\frac{1+sT_1}{1+sT_2}\right)^K \quad K = 1 \text{ or } 2 \qquad T_1 > T_2 \qquad (15)$$

In which the K is the number of first rank blocks and for compensating large angles two blocks are used. For T$_2$ usually a characteristic value is selected. The only remaining parameter is the T1 compensator circuit which is determined by equation (16).

$$\angle G_E(s)\,\big|_{s=j\omega_n} + \angle G_c(s)\,\big|_{s=j\omega_n} = 0 \qquad (16)$$

4.3. Gain designing

The value of D$_E$ in equation (17) can be controlled by PSS.

$$X = \left[\Delta\omega \quad \Delta\delta \quad \Delta e'_q \quad \Delta E_{fd}\right]^T \qquad (17)$$

The PSS gain called K$_C$ is equal to:

$$D_E = K_2K_C\left|G_C(s)\right| \; \left|G_E(s)\right| \Big|_{s=l\omega_n} \qquad (18)$$

On the other hand regardless of D and considering standard form of characteristic equation:

$$s^2 + 2\xi\omega_n s + \omega_n{}^2 = 0 \qquad (19)$$

$$D_E = 2\xi\omega_n M \qquad (20)$$

By removing D$_E$ between (18) and (20) equation the value of gain of PSS can be obtained based on camping coefficient.

$$K_C = 2\xi\omega_n M / \left(K_2 \; \left|G_2(j\omega_n)\right| \; \left|G_E(j\omega_n)\right|\right) \qquad (21)$$

Figure 5 shows the block diagram of a PSS.

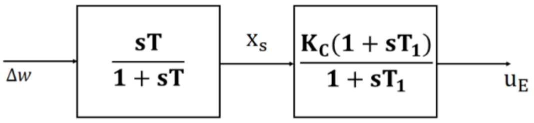

Figure 5: PSS block diagram

5. Simulation results

Figure 6 shows the general simulation structure in Simulink environment. Simulation is done in two levels, first parameters is found by PSO algorithm without optimization then the effect of optimization on value of studying parameters is investigated by PSO algorithm. In studying process and finding the results six parameters are investigated and compared which are: the velocity of generator G1, the velocity of generator G2, the velocity of generator G4, STATCOM injected voltage, generator velocity difference of G4 and G1, and generator velocity difference of G4 and G3.

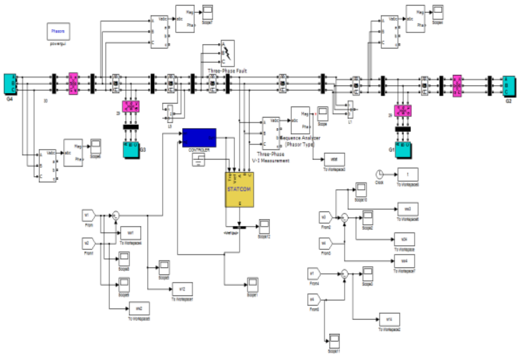

Figure 6: general structure of simulation in simulink environment

Overall, simulation is done in two levels, first the optimum value is obtained by PSO algorithm by coding in mfile environment of

MATLAB then the output of this section is linked to simulink of MATLAB software.

Table 1: the values of STATCOM block parameters

parameter	Unit	value
Maximum reference vltatage changing rate (V_{ref})	perunit	0
drop	perunit	0.03
regulator gains V_{ac} (Kp,Ki)	-	12,100
regulator gains V_{dc} (Kp,Ki)	-	50,1000
Current regulator gains (Kp,Ki,Kf)	-	3,1,4

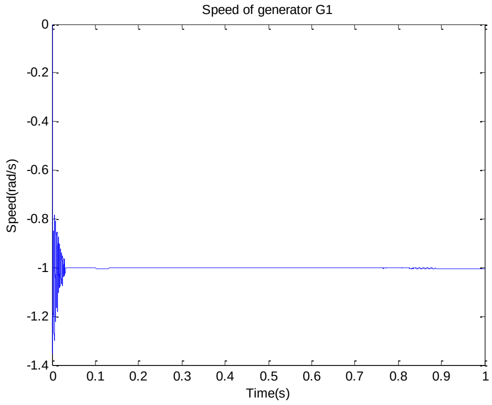

Figure 7: the velocity of generator G1 without optimization by PSO

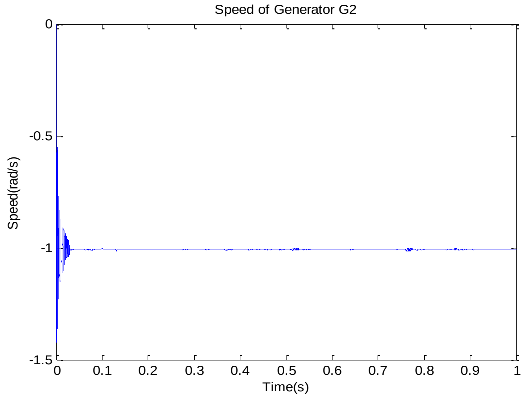

Figure 8: the velocity of generator G2 without optimization by PSO

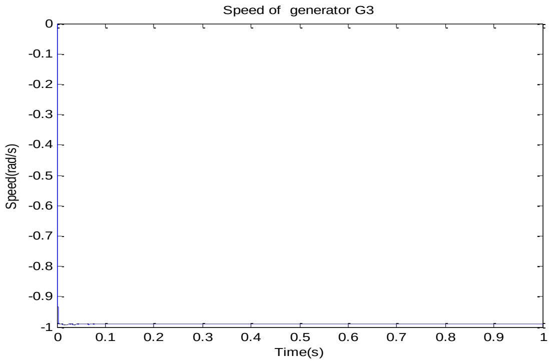

Figure 9: the velocity of generator G3 without optimization by PSO

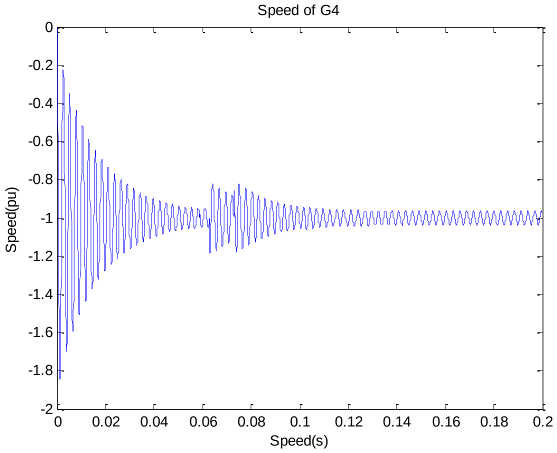

Figure 10: the velocity of generator G4 without optimization by PSO

By a close look at the figures it can be said that the most and least change domain occurs in G3 and G4 generators respectively. Behavior pattern of G1 and G2 are very similar. The G3 generator gets damped in least possible time. Figure 11 shows the injected voltage by STATCOM.

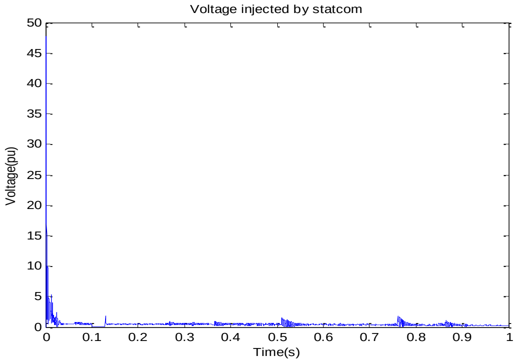

Figure 11: the injected voltage by STATCOM without optimizing by PSO

By a close look at the figure 11 it can be claimed that in some initial cycles of voltage domain decreases from 50 to less than 1 per unit quickly. The behavior of this voltage after passing the transient was not so linear and has distortion and domain changes.

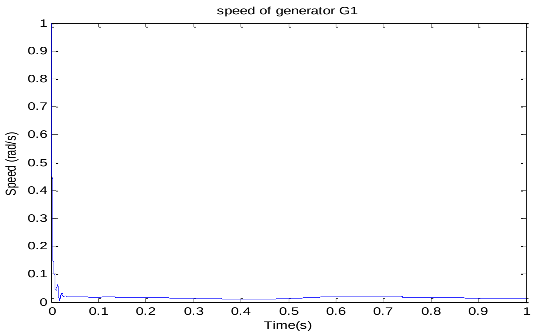

Figure 12: the velocity of G1 generator with PSO

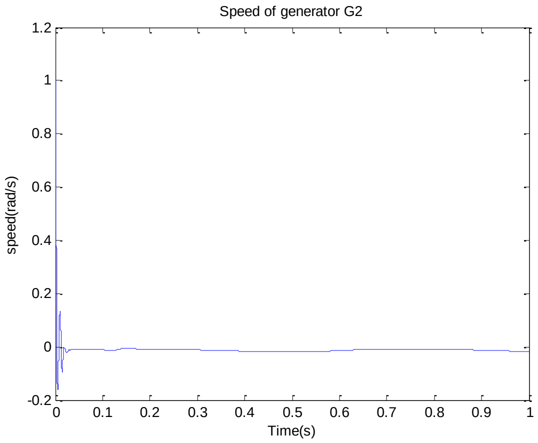

Figure 13: the velocity of G2 generator with PSO

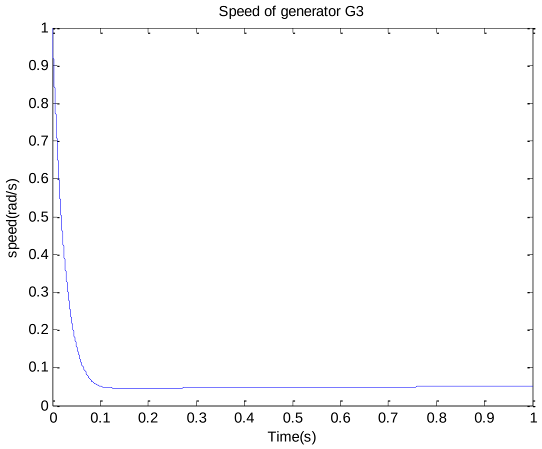

Figure 14: the velocity of G3 generator with PSO

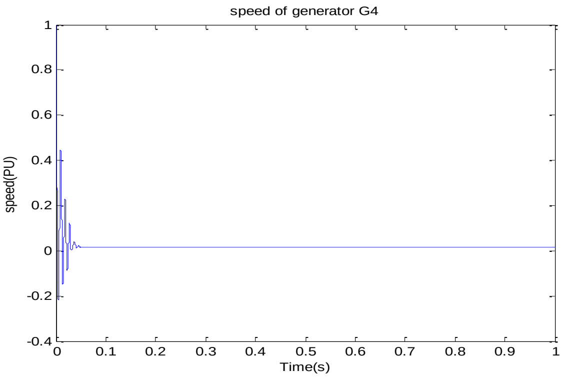

Figure 15: the velocity of G4 generator with PSO

By attention to above figures, the G1 and G2 generators have least and most velocity domain change respectively. the G1 and G3 generators have similar behavior and G2 and G4 generators have similar behavior. Except G1 generator in other conditions in stable condition the distortion is low and neglect able. The injected voltage by STATCOM can be seen in figure 15.

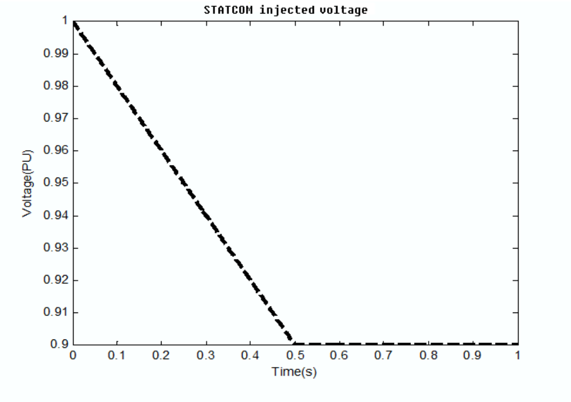

Figure 16: STATCOM injected voltage with PSO

Considering the figure 16 curve, this curve can be divided in two independent parts. Up to 0.5 second the curve is completely descending and after 0.5 second it is direct and linear.

6. Conclusion

In this paper, coordinated designing of power system stabilizer and STATCOM for increasing damping is done by PSO. The results of simulations by PSO algorithm are indicative of positive effect of this algorithm on velocity of generators for error state. Moreover, by attention to desirable performance of designed controller against system changes the improvement of accuracy and velocity of process of investigating determining optimum parameters of system is proven.

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