Simultaneous(Simulation) Design of the PSS Parameters and SVC Control System by the VURPSO Algorithm to Increase the Stability of the Power System

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ABSTRACT:
In this paper, the multi-machine power system is simulated and in addition, VURPSO optimization algorithm is used to optimize the parameters of the simultaneous controllers of the Static Var Compensator (SVC) and power system stabilizer (PSS) to increase the power system stability. By SVC, the transmittable power in the steady state can be increased and the voltage profile can be controlled along the line. The main role of the PSS is to damp the generator oscillations controlling its stimulation by the use of auxiliary supplementary signals. If it is assumed that a three phase short circuit fault with the ground has occurred in a four-machine power system, SVC and PSS simultaneous controllers are used to damp the oscillations and stabilize the system.

KEYWORDS: Multi-Machine, SVC, VURPSO, PSS, Stability.

1
. INTRODUCTION

By the quick improvement of the semi-conductor in the voltage and power level and the development of the control systems, the compensators with high flexibility and operation domain have been designed, made and installed in the power systems. These compensators known as flexible AC transmission systems (FACTS) are the alternative current transmission systems that are used based on the synthesis of the power electronics and other static controllers to improve the control and increase the capacity of the transmission power. These devices can handle the dynamic control of the line impedance, line voltage, active power currency and reactive power currency all of which are done in a fast speed [1-5].

One of the very important FACTIS devices is the SVC [6-9]. This device is successfully used to damp the oscillations in the power system and it also regulates the voltage in the terminals by controlling the reactive power injected to the system or absorbed by the power system [10]. When the system voltage is low, the SVC creates the reactive power (capacitor SVC) and when the system voltage is high, the SVC absorbs the reactive power (inductive SVC). The reactive power changes are made by switching the capacitor banks and three-phase inductive banks.

When evaluating the stability, the system behavior is understood if it is affected by a transient disturbance. The disturbance may be small or large. The small disturbances happen as the permanent changes in load And the system self-regulates according to the resulted variable situation. The system should be able to operate acceptably in this situation and can produce the maximum load and also should remain resistant against the large disturbances such as the short circuit of one of the transmission lines losing a large generator or load or losing the connective line between the two sub systems.

The main role of the PSS is to damp the oscillations of the rotor of the synchronous generator by controlling its stimulation; therefore, the power system stabilizer should create an electric torque factor in the coherent as the rotor speed deviation [11-14]. If there is no power system stabilizer, the system power is not stable dynamically but the generator doesn't lose its synchronism. Regarding the power system stabilizer which has not been regulated accurately, the system becomes unstable after the fault occurrence. Therefore, the acceptable operation of the power system stabilizer is depended on its accurate regulation.

In this paper, the VURPSO algorithm is used to optimize the parameters of the PSS and SVC simultaneous controllers. In the previous researches, the PSO and genetic algorithms were used in the PSS, respectively shown in [15, 16] and in the SVC, respectively shown in [17, 18]. Application of the real code genetic algorithm (RCGA) in the PSS and SVC simultaneous controllers is described in [19]. PSO algorithm is a social searching algorithm which is modeled based on the social behavior of the bird groups [20, 21]. The particles in the PSO flow into the searching area. The change of their locations in the searching area is influenced by their experience, knowledge and their adjacent particles. Therefore, the position of the other particles in the group influences the way one particle is searched.

Modeling of this social behavior results in the searching process of the particles going through the successful areas. The particles in the groups learn from each other and approach their best adjacent particles based on the resulted knowledge. The basis of the PSO algorithm is the principle that each particle in every moment regulates its location in the searching area regarding the best location where it had ever been and the best existing location around it.The VURPSO algorithm complements the PSO algorithm and is a population based algorithm in a computer environment to solve the problem [22]. In this paper, the parameters of the PSS and SVC simultaneous controllers are optimized by VURPSO optimization algorithm and as it is shown in the simulation results, by the use of this optimization algorithm, the system stability improves more after the occurrence of three phase short circuit fault with the ground.

2. STATIC VAR COMPENSATOR (SVC)

SVC is a basically shunt connected static var generator/load that its output is adjusted to exchange the capacitive or inductive current to maintain or control specific power system variables; typically, the controlled variable is the SVC bus voltage. One of the main reasons of installing a SVC is to improve dynamic voltage control and thus, to increase the system loadability.

SVC is a variable susceptance that its value can continuously be changed in two inductive and capacitive areas. SVC power circuit is a kind of control thyristor reactor shown in Fig. 1.

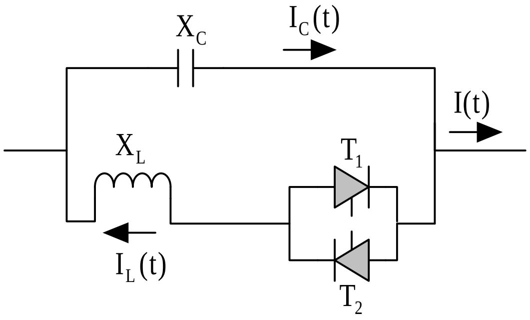

Fig. 1. SVC power circuit

The controller element consists of the two thyristors which are set as parallel and reverse, each thyristor transfers the current in a semi cycle. If the fire angles of both thyristors delay in comparison to the complete conducting state in the same pace, the reactor current is no more continuous. The more the fire angle increases, the more the domain of the main factor decreases. The current decrease with the increase in the fire angle can be justly assigned to the increase of the inductor inductance with the increase in the fire angle.

Therefore, inductor inductance changes with the change in the fire angle of the circuit. So, we created a controllable susceptance and we can use it as a static compensator. By setting a capacitor as parallel with this collection to an appropriate extent, the changes in the compensator susceptance in the two positive and negative areas are always possible.

A SVC connected to the node J is shown in Fig. 2 and the model of the injection current of SVC compensator is presented in Fig. 3. In Figures 2 and 3, I_{JSVC} stands for the injection current in node J and $V_I\angle\delta_I$ and $V_J\angle\delta_J$ respectively stand for the complex voltages of nodes I and J.

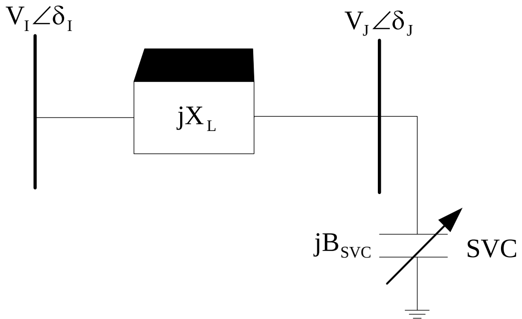

Fig. 2. Presentation of SVC

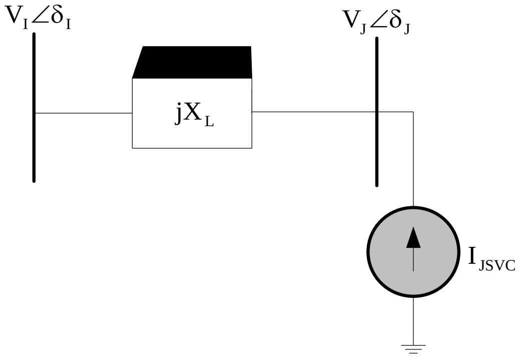

Fig. 3. Current injection model for SVC

As we can see in figures 2 and 3:

$$\bar{I}_{JSVC} = -j\bar{V}_J B_{SVC} \quad (1)$$

We have a d-q reference frame.

$$\bar{I}_{JSVC} = I_{JSVCd} + jI_{JSVCq} \quad (2)$$

$$\bar{V}_J = V_{Jd} + jV_{Jq} \quad (3)$$

Substituting (2) and (3) into (1), the algebraic equations (4) and (5) are concluded.

$$I_{JSVCd} = B_{SVC} V_{Jq} \quad (4)$$

$$I_{JSVCq} = -B_{SVC} V_{Jd} \quad (5)$$

The diagram V-I is related to the SVC shown in Fig. 4.

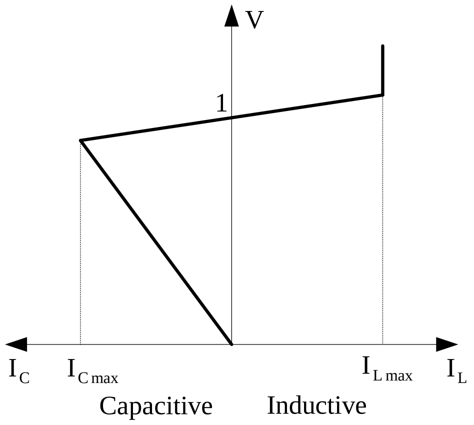

Fig. 4. Diagram V-I related to SVC

SVC is connected to the network as parallel. As it can be seen in Fig. 4, it can appear in two inductor or capacitor reactor modes. If the capacitor current is bigger than $I_{C\max}$, the SVC is transformed to a capacitor and its reactive power changes as a function of the network voltage. The slope of the diagram V-I between $I_{C\max}$ and $I_{L\max}$ is usually assumed from 2% to 5%. The structure of the SVC controller is shown in Fig. 5.

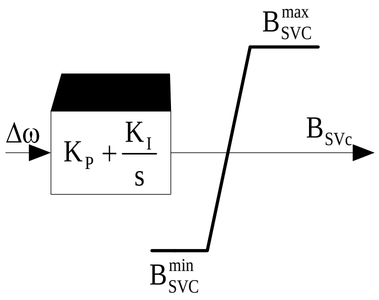

Fig. 5. SVC control model

In Fig.5 B_{SVC} stands for the SVC susceptance . In this paper K_P and K_I as PI controller gains are calculated by using the VURPSO optimization algorithm.

3. PSS AND STRUCTURE OF THE POWER SYSTEM

The phenomenon of the angle instability causes the power transmission limitation especially where transmission intervals are long. This process is well known and many methods have been created to improve the stability and increase the allowable transmission power. The quick elimination of the fault by the PSS has resolved the problem of the synchronous stability. The main role of PSS is to damp the oscillations of the rotor of the generator by controlling its stimulation by the use of auxiliary stabilizer signal. PSS produces a supplementary signal to damp the oscillations of a power system quickly after a disturbance. The generator is represented by the third order model consisting of the swing equation and the generator internal voltage equation. The swing equation can be written as:

$$\dot{\delta} = \omega_b(\omega - 1) \quad (6)$$

$$\dot{\omega} = [P_m - P_e - D(\omega - 1)]/M \quad (7)$$

In the above equations, δ and ω respectively stand for angle and speed of the rotor and ω_b stands for the synchronous speed. P_m and P_e respectively stand for the generator input and output power. The stimulation system operating by the IEEE ST1 type system is shown in Fig. 6 and is defined as follows.

$$\dot{E}_{fd} = [K_A(V_{ref} - v + U_{PSS}) - E_{fd}]/T_A \quad (8)$$

In the above equation, K_A and T_A respectively stand for gain and time constant of the stimulation system. In Fig. 6, gain K and time constants T_1 and T_2 and T_3 and T_4 are calculated by the VURPSO algorithm.

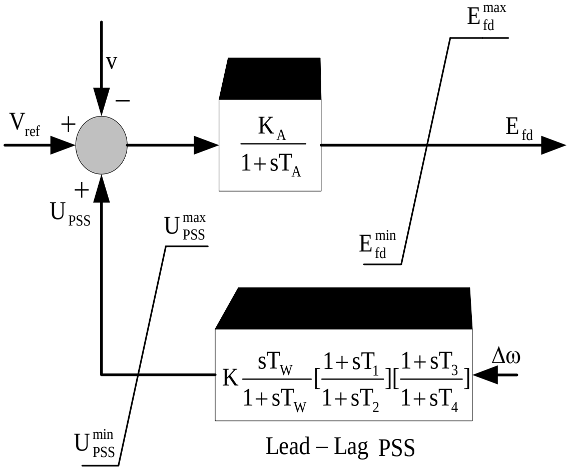

Fig. 6. IEEE ST1 type excitation system with PSS

The model consists of a low pass filter, a general gain, a washout high pass filter, a phase compensation system and an output limiter. The general gain K determines the amount of damping produced by the stabilizer. The washout high pass filter eliminates present low frequencies in the $d\omega$ signal and allows the PSS to respond only to the speed changes.

In several cases, instability and then loss of synchronism commence by disturbances in the system resulting in the oscillations. If these oscillations don't be damped, they will finally be intensified. Therefore, in such situations, a power system should be able to maintain its stability by the use of control methods. The stability of the power systems can be considered as a feature of the power system which make them to be in balance in a normal situation and if they are affected by a disturbance, an acceptable situation is made again. In Fig.7 the structure of the power system in this paper is shown. The power system used in this paper consists of two different areas that two synchronize generators are in both of them. G1 and G2 generators are in the first area and G3 and G4 generators are in the second area. All four generators are 900MVA and 20KV.The SVC in the second line is between bus 7 and bus 10 and PSS is installed on all the four generators.

The first and the second areas are connected to each other by two 230KV lines and 220Km length. In Fig.7 the power of the first area is 413MWand transfer it to the second area.

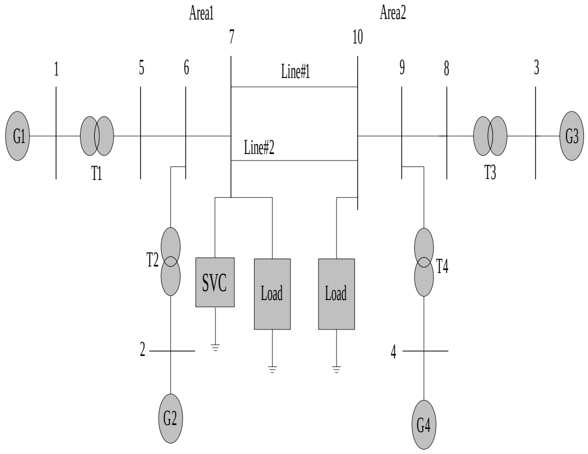

Fig. 7. The power system of the two areas of four- machine with SVC

4. THE VURPSO ALGORITHM

The VURPSO algorithm complements the PSO algorithm. The PSO algorithm is modeled based on the behavior of the attacking particles like the crow groups; in the movement of a group of crows, one crow (leader) is in the best position and the other crows try to reach a better position and approach the leader regarding their position and the position of the adjacent crows. If one member can find a better position than the leader, it is chosen as the leader.

A PSO algorithm operates in this way as a group of particles (as variables of the optimization problem) are distributed in the searching environment. It is clear that some particles are in a better position than the others. As a result, according to the attacking particles behavior, the other particles attempt to reach the position of the best particles, while the positions of the best particles are changing. It is noteworthy that the changes of the position of each particle are made based on the experience of the particle in previous movements and the experience of the adjacent particles. In fact, each particle is informed about its superiority or lack of superiority over the adjacent particles and also the particles of the whole group. In this algorithm, p_best stands for the best position of each particle and g_best represents the best position of all particles in the algorithm. $Rand1$ and $Rand2$ are the random numbers in the interval $[0,1]$. c_1 and c_2 are the acceleration coefficients and positive constant numbers. Considering a parameter called inertia weight (w), the equation of speed change is obtained as follows.

$$v_{j,g}^{(t+1)} = wv_{j,g} + c_1 \cdot Rand1(p\_best_{j,g} - x_{j,g}^{(t)}) + c_2 \cdot Rand2(g\_best_{j,g} - x_{j,g}^{(t)}) \quad (9)$$

In the equation (10), we have:

$$v_{min} \le v_{j,g}^{(t)} \le v_{max}$$

$$j = 1,2,\dots,n$$

$g = 1,2,\ldots,m$

And position updating equation is as follows:

$$x_{j,g}^{(t+1)} = x_{j,g}^{(t)} + v_{j,g}^{(t+1)} \tag{10}$$

In the above equations, x value represents the position of the particle, n stands for the number of the particles and m stands for the number of the particles components. In these equations, it should be regarded that large value for v_{max} may cause the particles to pass the minimum point and the small value for it makes the particles to orbit around their locations and they cannot be searched through the test area. v_{max} value is usually chosen from between 10% and 20% of the variable range. On the other hand, the appropriate choice of w causes the algorithm to replicate less to reach the optimal point. In the normal PSO algorithms, w coefficient decreases based on the relation below from 0.9 to 0.4 during the implementation of the algorithm and based on the following equation.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \tag{11}$$

In the PSO algorithm, credit information and position of the particles are reviewed and then termination of the position of a range during the entire replication cycle is added to the algorithm roles. In the VURPSO algorithm, the credit of factor particles is reviewed in the velocity border without reviewing the position credit in each replication cycle [22]. In the PSO algorithm, the velocity during each replication is updated, but in the VURPSO algorithm, the velocity of each particle remains unchanged if its fitness function in the current replication is better than the previous replication, otherwise the particles are updated. The velocity equation in VURPSO algorithm is obtained by the following relation.

$$\begin{aligned} v_{j,g}^{(t+1)} &= v_{j,g} + c_1 \cdot \text{Rand } 1(p\_best_{j,g} - x_{j,g}^{(t)}) \\ &+ c_2 \cdot \text{Rand } 2(g\_best_{j,g} - x_{j,g}^{(t)}) \end{aligned} \tag{12}$$

And position updating equation is as follows:

$$x_{j,g}^{(t+1)} = (1 - mf)x_{j,g}^{(t)} + (mf)v_{j,g}^{(t+1)} \tag{13}$$

mf is the movement factor and its value is between 0 and 1. In this paper, c_{1max} and c_{2max} equal 2.05 and mf equals 0.3. Also, this algorithm is replicated for 100 and 200 particles.

5. SIMULATION RESULTS

The occurred short circuit in the system not only causes the energy charge to switch down, but also causes the energy to increase in some parts of the system. The domain of these disturbances may be larger than the current of the system generators and transformers. The continuous charge of these currents increases the temperature of the equipment and damages the power system and generator equipments.

In this paper, the worst fault i.e. the three phase short circuit fault with the ground, is studied. It is assumed in Fig.7 that this fault has occurred in the line one between the bus 7 and bus 10 in 0.5s and after 100ms, it is disappeared in 0.6s. The optimized values of the parameters of the PSS and SVC controllers are shown in table 1. As shown in table 1, the values are between these limitations: $5 \langle K_G \langle 60$ and $0.01 \langle T_G \langle 10$ and $0.1 \langle K_P \langle 10$ and $10 \langle K_I \langle 500$

Table 1. Optimized values of the parameters of the PSS and SVC controllers

parameters	values
K_{G1}	15.3661
K_{G2}	14.1836
K_{G3}	21.2256
K_{G4}	11.1394
$T_{1G1} = T_{3G1}$	0
$T_{2G1} = T_{4G1}$	0
$T_{1G2} = T_{3G2}$	3.1877
$T_{2G2} = T_{4G2}$	2.6680
$T_{1G3} = T_{3G3}$	3.9534
$T_{2G3} = T_{4G3}$	4.4529
$T_{1G4} = T_{3G4}$	2.9823
$T_{2G4} = T_{4G4}$	3.2825
K_P	3.5719
K_I	101.9322

The convergence of the objective function for g_best is shown in Fig. 8.

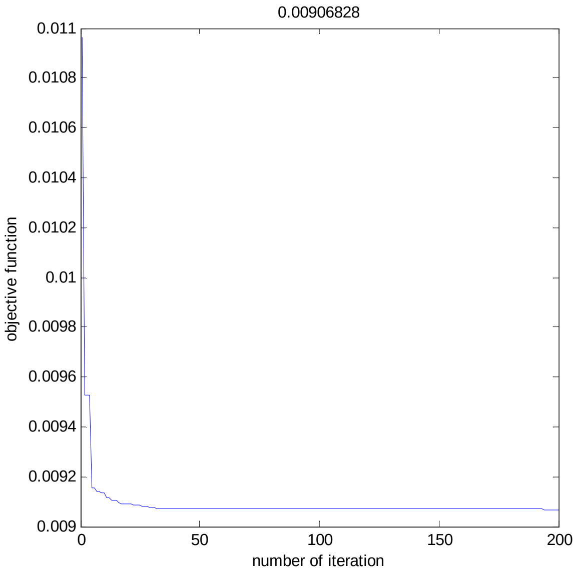

Fig. 8. The convergence of the objective function For g_best

Regarding the previous figure, g_ best is convergent at the value 0.0091. In Fig. 9, two states of the SVC susceptance with controllers and VURPSO are compared and it can be seen that by the designed VURPSO in this paper, the susceptance oscillations decreases remarkably after the fault occurrence.

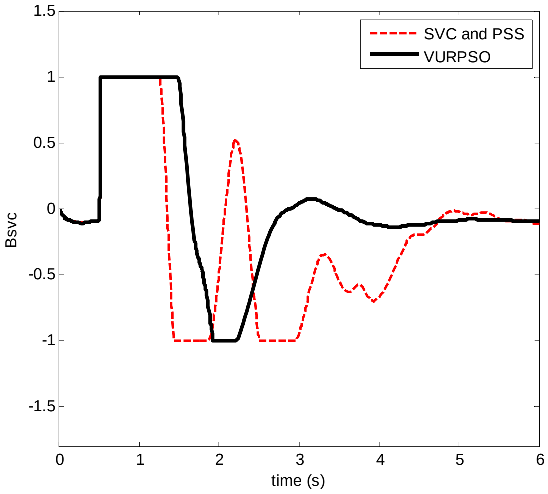

Fig. 9. SVC susceptance

The transmission of power from the first area to the second area is shown in Fig. 10.

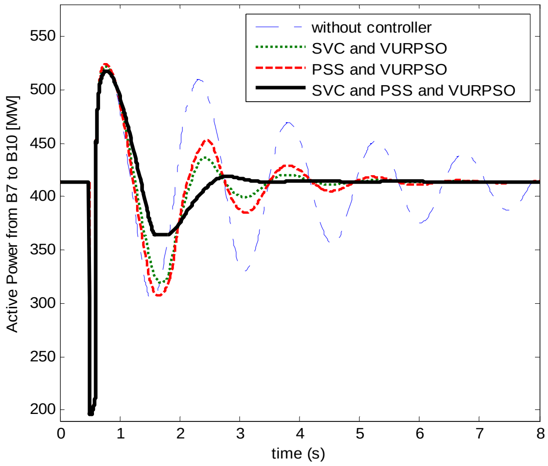

Fig. 10. The transmission of power from The first area to the second area

The transmission of power from the first area to the second area is damped about 3.2s at amount before the fault i.e. 413MW by SVC and PSS simultaneous controllers and VURPSO algorithm.

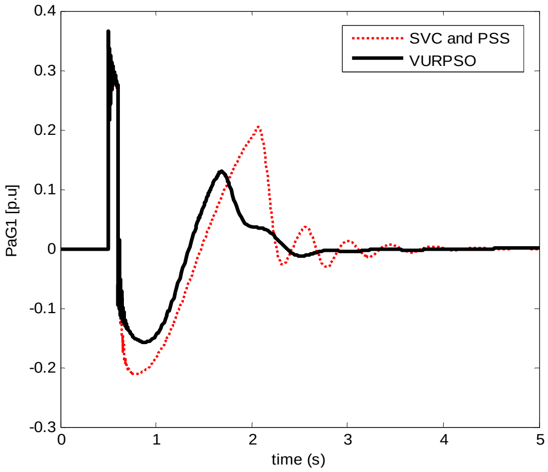

Fig. 11. The accelerator power of the generator 1

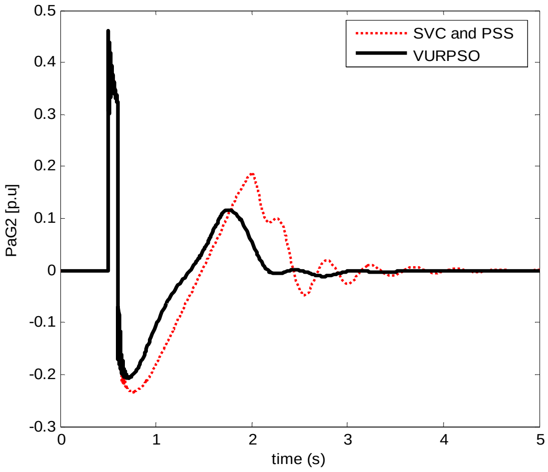

Fig. 12. The accelerator power of the generator 2

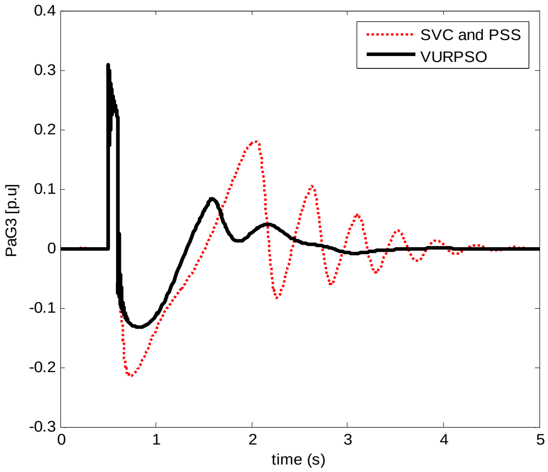

Fig. 13. The accelerator power of generator 3

Regarding figures 11 to 13, the accelerator power of generators 1 and 2 and 3 are damped about 3.5s by theVURPSO algorithm. In figures 14 to 16, the output power or electrical power of the generators 1 , 2 and 3 are shown.

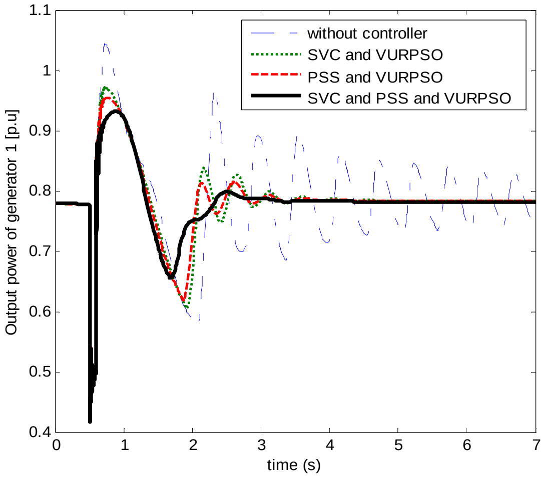

Fig. 14. The output power of generator 1

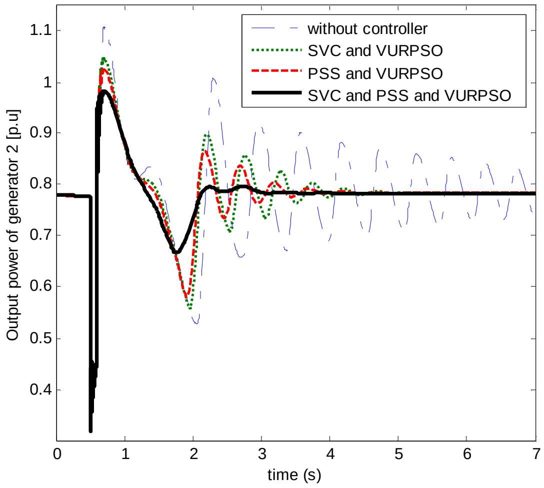

Fig. 15. The output power of generator 2

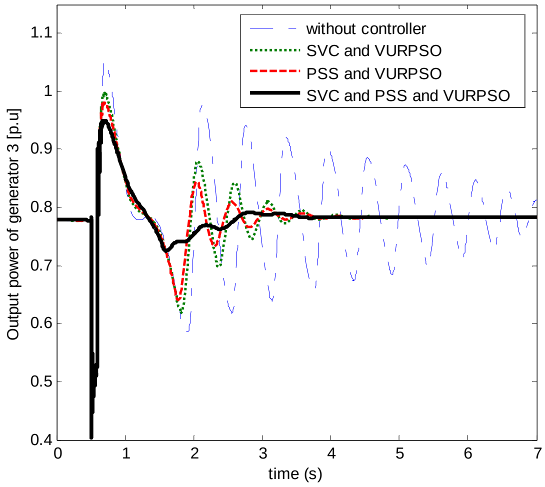

Fig. 16. The output power of generator 3

The output power of the generators 1, 2 and 3 are made very oscillating, but they are damped in less than 4.5s at the amount before the fault by the use of the PSS controller and SVC controller alone and the VURPSO optimization algorithm. The duration of damping less than 3s at the amount before the fault i.e. 0.78p.u and the oscillations angle step down by the use of the SVC and PSS simultaneous controllers and VURPSO optimization algorithm.

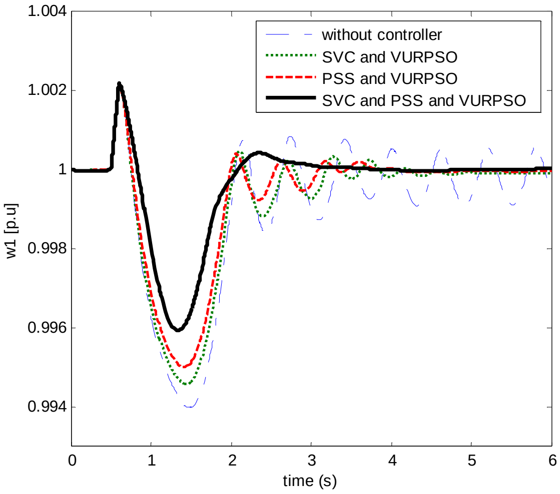

Fig.17. The speed of generator 1

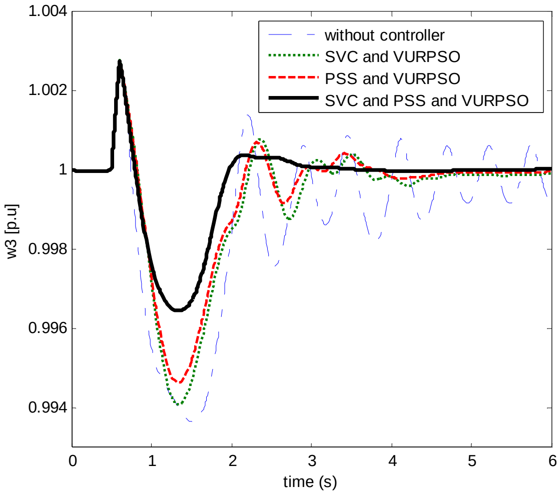

Fig. 18. The speed of generator 3

Damping and stability of the speed of the generators 1 and 3 improve by the use of the SVC and PSS simultaneous controllers and VURPSO optimization algorithm .They are damped about 3.5s at the amount before the fault i.e. 1p.u. Regarding Fig. 19, the speed of the generator 4 becomes unstable after the occurrence of the faults, but they are damped about

3.5s by the use of SVC and PSS simultaneous controllers and VURPSO optimization algorithm.

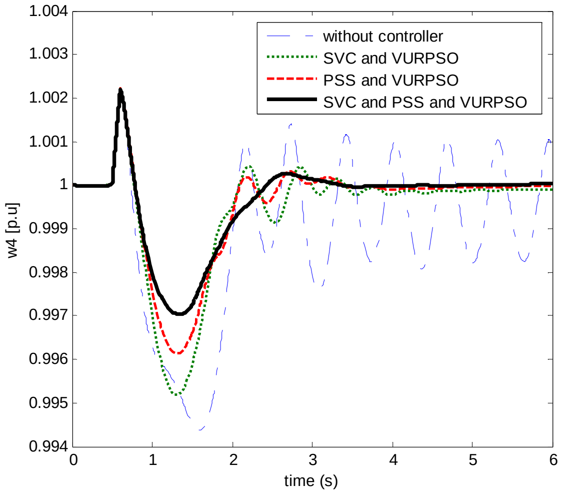

Fig.19. The speed of generator 4

The speed deviation of the generators 1,3 and 4 are shown in figures 20 to 22.

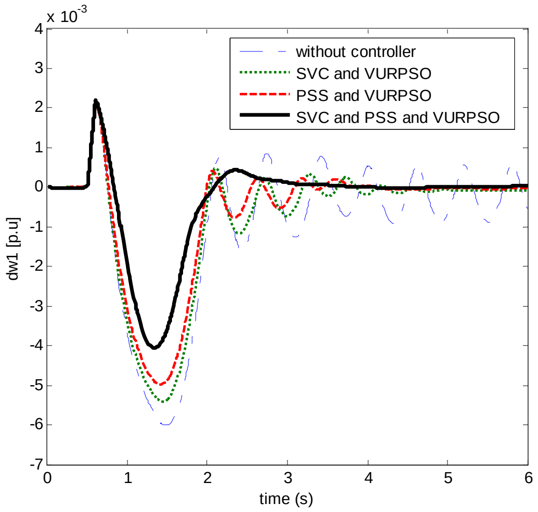

Fig. 20. The speed deviation of the generator 1

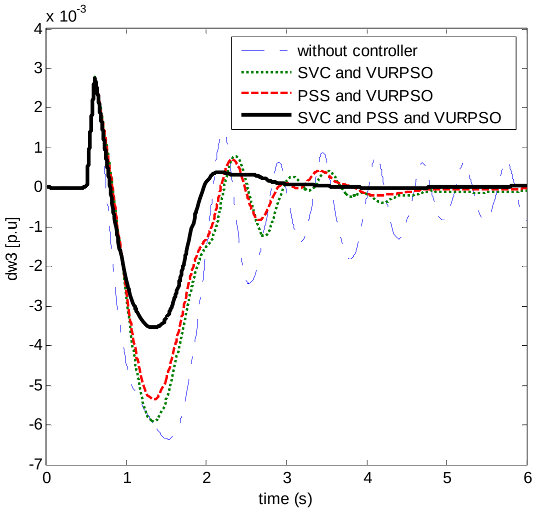

Fig.21. The speed deviation of the generator 3

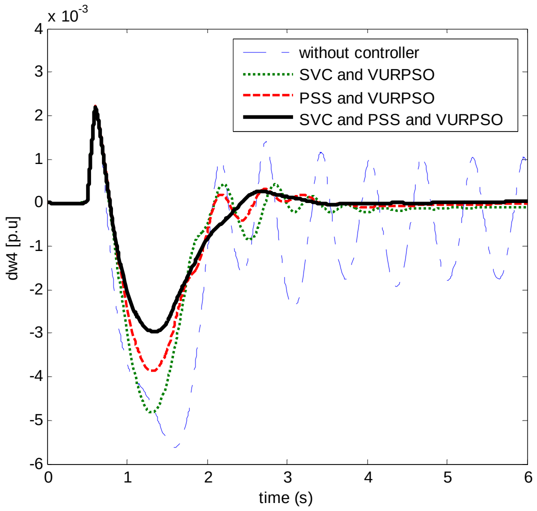

Fig. 22. The speed deviation of the generator 4

Regarding figures 20 to 22, the speed deviation of the generators 1, 3 and 4 are damped about 3.5s by the SVC and PSS simultaneous controllers and VURPSO optimization algorithm.

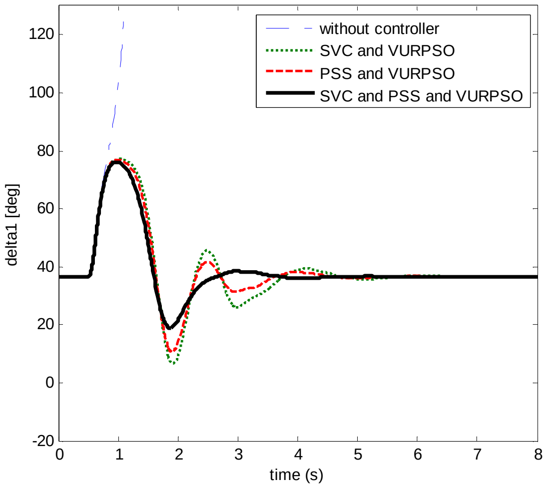

Fig.23. The angle of the rotor of the generator 1

As it can be seen in Fig. 23, the angle of the rotor of the generator 1 is unstable because of the three phase short circuit fault with the ground, but it is damped less than 5.5s by the use of PSS and TCSC controllers alone and VURPSO. The duration of damping reaches less than 4s and the oscillations angle step down using the SVC and PSS simultaneous controllers and VURPSO optimization algorithm after the occurrence of the fault.

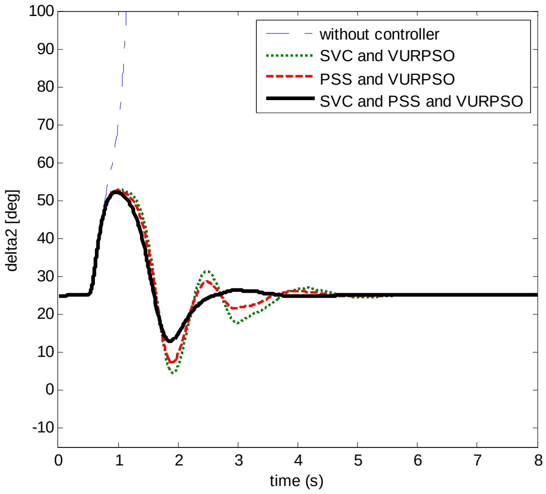

Fig.24. Angle of rotor of generator 2

As it can be seen in Fig. 24, the angle of the rotor of the generator 2 is unstable because of the three phase short circuit fault with the ground, but they are damped less than 6s by the use of the PSS controller and SVC controller alone and VURPSO optimization algorithm. The duration of damping is about 4s and the oscillations angle step down by the use of SVC, PSS simultaneous controllers and VURPSO optimization algorithm.

As it can be seen in figures 25 and 26, the voltage of the buses 10 and 7 are made very oscillating because of the three phase short circuit fault with the ground, but using the SVC, PSS simultaneous controllers and VURPSO optimization algorithm are damped about 2.1s at the amount before the fault i.e. 1p.u.

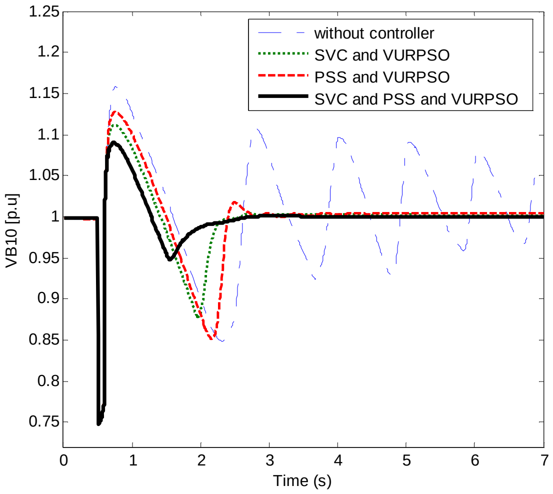

Fig. 25. The voltage of the bus 10

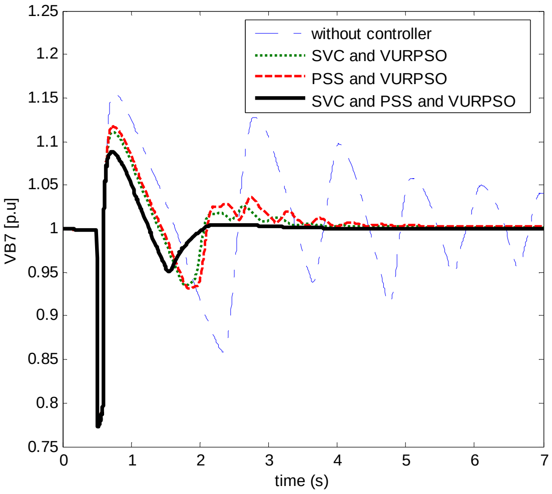

Fig.26. The voltage of the bus 7

In figures 27 and 28, the terminal voltages of the generators 1 and 3 are shown.

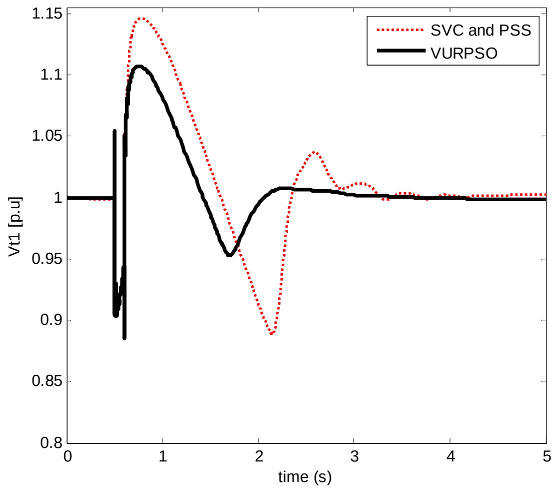

Fig. 27. The terminal voltage of generator 1

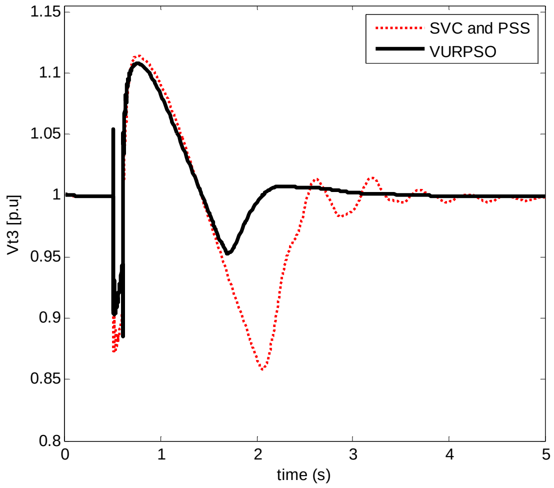

Fig.28. The terminal voltage of generator 3

As it can be seen in figures 27 and 28, the terminal voltage of the generators 1 and 3 are damped in 3s at 1p.u by the use of the SVC, PSS simultaneous controllers and VURPSO optimization algorithm. The above figures show the acceptable operation of the simultaneous controller of the SVC and PSS control system. As it can be seen, using the VURPSO algorithm affects the optimization of the controller parameters and by this method, the stability of the power system increases.

6. CONCLUSION

Power system is a very non-linear system that its dynamic operation is influenced by a large collection of the equipment components each of which has a different reaction and feature. The stability of the system should not be considered as a problem but should be regarded from the different viewpoints. Almost, the feature of each main component of the power system influences its stability. Full information about these features is necessary to understand and study the stability of the power system. In this paper, the four-machine system has been used to review the operation of the PSS and SVC controllers in the system. Then the parameters of these controllers were optimized by the VURPSO algorithm so that the efficiency of these controllers in four-machine non-linear system increased. As it is shown in the simulated results of this paper, the power system stability has been improved after the fault occurrence in the system by the use of controllers and VURPSO algorithm.

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