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STABILITY ENHANCEMENT OF POWER SYSTEM WITH FACTS BASED DAMPING CONTROLLER USING BFOA

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ABSTRACT

Static Synchronous Series Compensator (SSSC)based damping controller is designed for the improvement of small signal stability of power system. Since the implementation of damping controller in SSSC exhibit better performance in damping the oscillations. The proposed controller is implemented in the single machine system. Bacterial foraging optimization algorithm(BFOA) is employed for optimal parameter selection of the damping controller. Simulation is done for three cases namely single machine system without power oscillation damping controller, with SSSC and without damping controller, with SSSC based damping controller. Simulation results show that the SSSC based damping controller provide efficient damping and improves the small signal stability for the local mode of oscillations in power system when compared to SSSC without damping controller.

Keywords - Static Synchronous Series Compensator (SSSC), Bacterial Foraging Optimization Algorithm(BFOA)

1. INTRODUCTION

During power exchange of large power systems interconnected by weak tie lines, low frequency oscillations are observed. These oscillations lead to islanding if no adequate damping is provided. The development of power electronics introduces the use of Flexible Alternating Current Transmission System (FACTS) controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this feature of FACTS can be used to improve the stability of a power system. Static Synchronous Series Compensator (SSSC) is one of the important members of FACTS family which can be installed in series in the transmission line[5]. The influence of degree of compensation and mode of operation of SSSC on small disturbance and transient stability is reported in the literature [8,9]. An auxiliary stabilizing signal superimposed on the power flow control function of the SSSC so as to improve power system oscillation stability [10] .The small signal stability of a power system is improved by SSSC based damping controller where it is optimally tuned using BFOA. The performance of the proposed controller is evaluated for single-machine system which has efficient damping for local mode of oscillations under three phase to ground fault. To minimize the power system oscillations due to the disturbances ,the SSSC based damping controller is designed in order to improve stability of the system. The oscillations results in deviations of power angle, rotor speed and tie-line power. Minimizing any one of the above deviation is taken as the objective function.

In this paper ,the speed deviation which is nothing but the remote signal is taken as the objective function for single machine system. Even though there is a delay in obtaining the remote signal, the control action is better than choosing the power angle deviation of local signal[1]. Moreover the local signal is not highly observable and controllable. Therefore speed deviation of remote signal is considered as the objective function where

$$\Delta\omega = {}^{1}\!/_{H}\,(p_e - p_m) \qquad (1)$$

$\Delta\omega$ is the speed deviation of rotor,
H is the rotor inertia,
p_e is the electrical power,
p_m is the mechanical power.

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2. GENERAL SYSTEM DESCRIPTION

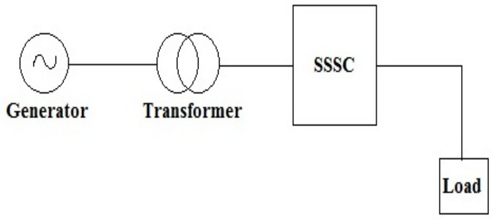

Figure 1. Single Line Diagram of Proposed System

The single line diagram shown above consists of a generator connected to a three phase transformer , a Series FACTS controller called SSSC is placed at the midpoint of the transmission line and the load. In the proposed system, three phase to ground fault is applied in the time interval of 50 to 60 seconds in the transmission line. The rating of all the components in the proposed system is given in the appendix.

3. STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

SSSC provides the virtual compensation of transmission line impedance by injecting the controllable quadrature voltage (Vq) in series with the transmission line [5]. Vq is in quadrature with the line current, and emulates an inductive or a capacitive reactance so that it influence the power flow in the transmission lines. The virtual reactance inserted by Vq influences electric power flow in the transmission lines independent of the magnitude of the line current

The variation of Vq is performed by means of a voltage source converter(VSC) connected on the secondary side of a coupling transformer. The SSSC injects the compensating voltage in series with the line irrespective of the line current. The series reactive compensation scheme, using a switching power converter (voltage-source converter) as a synchronous voltage source to produce a controllable voltage in quadrature with the line current where the compensation level can be controlled dynamically by changing the magnitude and polarity of Vq where the device can be operated both in capacitive and inductive mode. Thus the series capacitive compensation works by increasing the voltage across the impedance of the given physical line, which in turn increases the corresponding line current and the transmitted power. To keep the capacitor charged and to provide transformer and VSC losses, a small active power is drawn from the line. The VSC uses forced-commutated power electronic devices to produce an AC voltage from a DC voltage source.

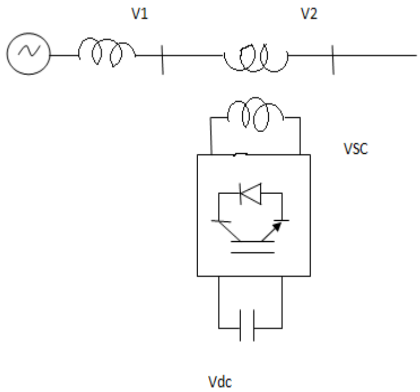

Figure 2.Block diagram of SSSC

4. DAMPING CONTROLLER

It consist of delay block, gain block , signal washout block and two-stage phase compensation block. Depending on the type of signal at the input the time delay is introduced in the delay block[3]. The gain block is used to dampen the oscillations. The washout block act as a high-pass filter, with the time constant Tw and it is high enough to allow signals associated with oscillations in input signal to be pass unchanged which may be in the range of 1–20s .The two stage phase compensation blocks (time constants T1, T2 and T3, T4) which provide the phase-lead characteristics in order to compensate for the phase lag takes place between input and the output signals and used to modulate the injected quadrature voltage. Quadrature reference voltage namely Vqref as desired by the steady state power flow control loop. Here the Vqref is assumed to be constant during the disturbance period.

$$V_q = V_{qref} + \Delta V_q \quad (2)$$

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According to the change in the SSSC-injected voltage which is added to the reference quadrature voltage ,the desired value of compensation is obtained.

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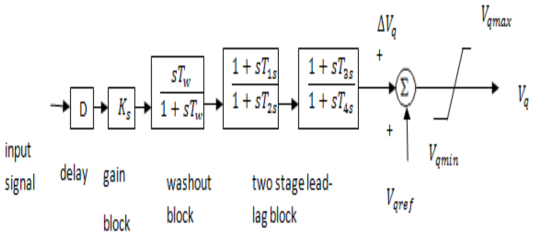

Figure 3.Block diagram of SSSC based damping controller

During dynamic conditions the series injected quadrature voltage is modulated to damp the system oscillations. The objective function for the single machine system is expressed as follows,

$$J = \int_{t=0}^{t=tsim} \Delta\omega . t . dt \qquad (3)$$

where Δw is the speed deviation, $tsim$ is the time range of the simulation. For objective function calculation, the time-domain simulation of the power system model is carried out for the simulation period. It aims to minimize this objective function in order to improve the system response in terms of the settling time and overshoots. Therefore, the design problem can be formulated below

minimize J ,subject to the constraint

$$K_i^{\min} \leq K_i \leq K_i^{\max}$$
$$T_{1i}^{\min} \leq T_{1i} \leq T_{1i}^{\max}$$
$$T_{2i}^{\min} \leq T_{2i} \leq T_{2i}^{\max}$$
$$T_{3i}^{\min} \leq T_{3i} \leq T_{3i}^{\max}$$
$$T_{4i}^{\min} \leq T_{4i} \leq T_{4i}^{\max}$$

5. BACTERIAL FORAGING OPTIMIZATION ALGORITHM

The algorithm mimic the social behavior of Echerichia coli bacterium found in nature . It is used for multi optimal function optimization [7] .The optimization technique helps to determine the minimum of the objective function . The negative value of the objective function indicates that the bacterium is in nutrient environment, zero value indicates the neutral environment and the positive value indicates the noxious environment. The bacteria always move towards the nutrient environment and avoid noxious substances and also leave the neutral environment as soon as possible. The optimization technique consists of four basic steps namely Swarming and tumbling , Chemo taxis , Reproduction and Elimination and Dispersal.

A. swarming and tumbling via flagella (Ns):
The bacterium move in two different directions namely swim and tumble .In harmful place it tumble frequently in order to find a nutrient gradient**.**

B. Chemo taxis (Nc):
It simulates the movement of an *E.coli* cell for swimming and tumbling through flagella.

C. Reproduction (Nre):
In this process where the unhealthy bacteria will die and the healthy bacteria give better objective function values by asexually splitting into two bacteria**.**

D. Elimination and dispersal (Ned):
In this process in which it destroy the chemo tactic progress and make the bacteria to disperse in a good food resources.

E. Algorithm steps:
- Initialize the parameters
- set the elimination and dispersal loop $l=l+1$
- Reproduction loop: $k=k+1$
- Chemo taxis loop: $j=j+1$
- Compute fitness function, $J\ (i, j, k, l)$.
- For tumbling, generate a random vector with each element $\Delta_m(i)$, m 1,2,..., p, a random number on [-1, 1].
- Move the bacterium up to the swim length and Compute $J\ (i, j+1, k, l)$
- If j □Nc , repeat step 4
- Perform reproduction and sort the bacteria and chemo tactic parameters
- For i = 1,2..., S , eliminate and disperse each bacterium. If a bacterium is eliminated, disperse another one to a random location on the optimization domain.

F. Parameters of BFOA :
- Dimension of search space ,p=5
- The number of bacteria ,s =10
- Number of chemotactic steps Nc=4
- Limits of length of the swim Ns=4
- The number of reproduction steps Nre=4
- The number of elimination-dispersal events Ned=2
- The number of bacteria reproductions (splits) per generation Sr =s/2

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6. RESULTS AND DISCUSSION

Case 1:Without SSSC based damping controller

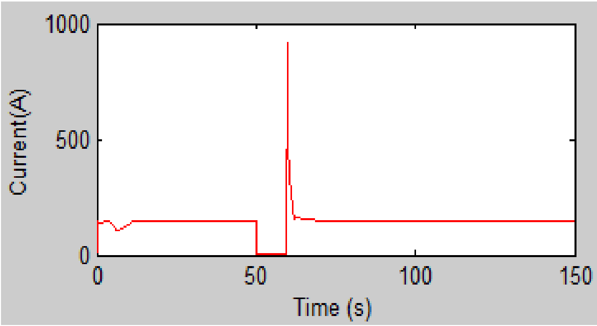

Figure 4.load current response

The graph represents the load current response without any controller. The overshoot of oscillation is very high and also draws high current at the load side as shown in fig 4.

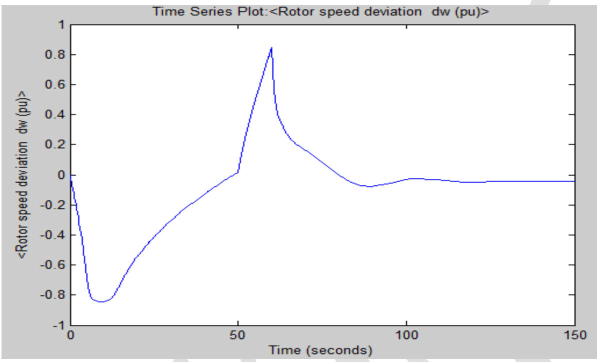

Figure 5.characteristics of speed deviation

The above graph represents the characteristics of speed deviation in rotor. The overshoot of oscillation is high and it takes long time to recover steady state as shown in fig 5.

Case 2:With SSSC and without damping controller

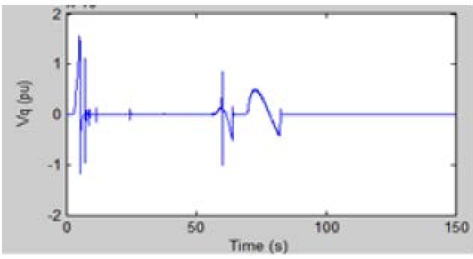

Figure 6. Quadrature voltage injected by SSSC controller

The graph represents the quadrature voltage waveform for SSSC controller which is shown in the fig 6.The overshoot of oscillations are high due to insufficient damping.

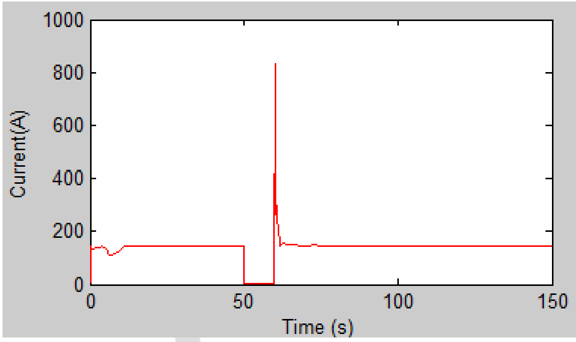

Figure 7.load current response

The fig 7 shows the load current response after implementing SSSC controller.The overshoot of oscillation is slightly reduced after implementing SSSC than the previous case of without any controller

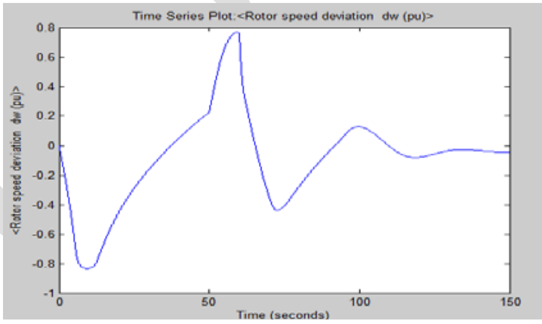

Figure 8. Characteristics of speed deviation

The above graph represents the characteristics of speed deviation in rotor. The overshoot of oscillation is reduced than the previous case as shown in fig 8

Case 3:With SSSC based damping controller

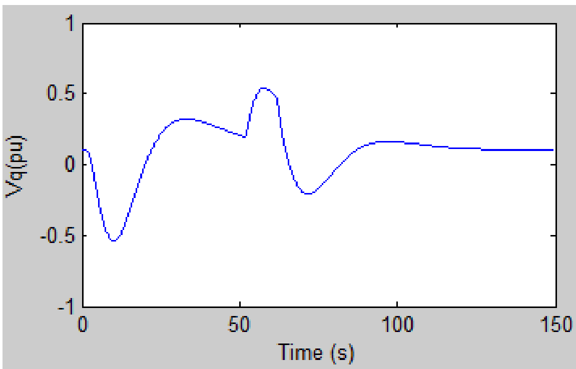

Figure 9. Quadrature voltage injected by SSSC based damping controller

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The graph represents the quadrature voltage waveform for SSSC based damping controller. The overshoot of oscillations are reduced due to damping controller implemented in the SSSC which is shown in the fig 9 .

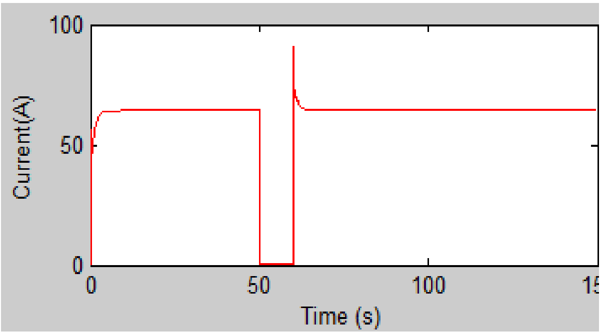

Figure 10. load current response

The fig 10 shows the load current response after implementing SSSC based damping controller.The current is controlled to 50A compare to previous case of SSSC without damping controller.

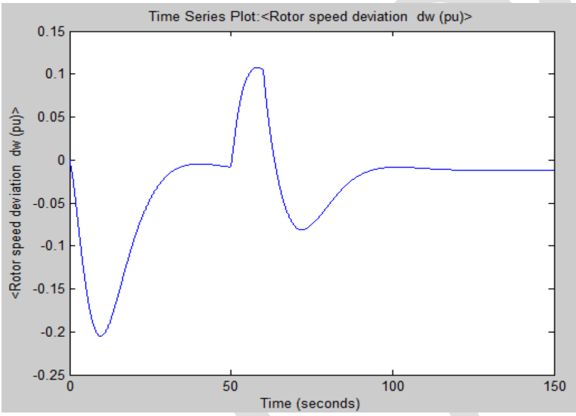

Figure 11. Characteristics of speed deviation

The above graph represents the characteristics of speed deviation in rotor. The overshoot of oscillation is highly reduced due to implementation of damping controller as shown in fig 11

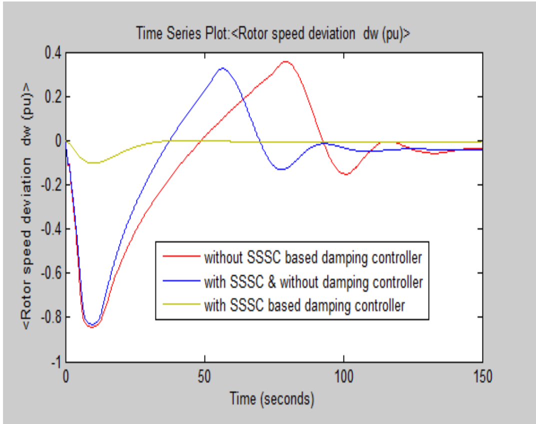

Figure 12. speed deviation characteristics for three cases

The graph is drawn between the speed deviation of the rotor to the time of settling at steady state for the three cases namely,

- without SSSC based damping controller
- with SSSC and without damping controller
- with SSSC based damping controller

The local mode of oscillation due to three phase fault in the single machine system is well damped by SSSC based damping controller as shown in the fig 12 .The overshoot of the oscillation is very high in the first case of without SSSC damping controller where the zero speed deviation takes place at 150th second. By implementing the SSSC in the three phase transmission line the overshoot of oscillation is slightly reduced and its zero speed deviation takes place at 120th second. After implementing the power oscillation damping controller in SSSC ,there is no overshoot of oscillation and its zero speed deviation takes place at 80th second .

7. CONCLUSION

The designed SSSC based damping Controller is found to exhibit better performance characteristics by reducing speed deviation when compared to other two cases .

From fig.10 it is observed that after implementing SSSC based damping controller the load side current characteristics has less overshoot of the oscillation. From the fig.12 the characteristics of settling time of first case without any controller takes more time to settle at zero speed deviation. The designed SSSC based damping controller quickly react for the change in operating conditions and recover the system to steady state within few seconds when compared to second case of SSSC without damping controller. Thus the proposed damping controller provide much better damping characteristics to low frequency oscillations under three phase to ground fault and improve the small signal stability by modulating the SSSC injected quadrature voltage.

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APPENDIX

Elements	Rating
Generator	Sb=10MVA, H=3.7s, Vb=13.8Kv, f=60Hz, xd=1.305, xd’=0.296, xd’’=0.252,xq=0.243, xq’=0.18, , xq’’=0.18
Transformer	10MVA, step up voltage is 13.8/ 50Kv, f=60Hz, R1=R2=0.02, L1=0, L2=0.12, delta/star connection, Rm=500 ,Lm=500
Transmission line	3-ph, 60 Hz, Length=5Km each, R1=0.02546 ohm/Km, L1=0.9337e-3H/Km, L0=4.1264e-3H/Km, c1=12.74e-9 F/Km, c0=7.751e-9F/Km.
Load	V=50Kv,P=50MW,Q=15MVAR, f=60Hz
Converter rating	dc Voltage regulator gains: Kp = 0.1×e-3,Ki=20e-3,injected voltage magnitude limit ,Vq= 0.2pu, Snom= 10 MVA, system nominal voltage: Vnom =50KV, f=60Hz, maximum rate of change of reference voltage (Vqref) = 3pu/s, converter impedances: R=0.00533, L=0.16, Vdc= 40KV,C = 375×e-6F