IMPROVEMENT OF TRANSIENT STABILITY THROUGH SVC

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ABSTRACT

With the growing stress on today's power systems, many utilities are increasingly and there is a need for inclusion of security analysis capabilities in the energy management systems. Transient Stability analysis is the evaluation of the ability of the power system to withstand to a set of severe but credible contingencies and to survive transition to an acceptable steady state condition. The performance of a power system during a transient period can be obtained from the network performance equations. In transient stability studies a load flow calculation is made first to obtain system conditions prior to the disturbances. After the load flow calculations, the admittance matrix of the network must be modified to reflect the changes in the representation of the network. FACTS technology is a collection of controllers which can be applied individually or in coordination with others to control one or more of the interrelated system parameters, voltage, impedance and phase angle. Static Var Compensator (SVC) is a FACTS device, which can control voltage at the required bus by means of reactive power compensation, thereby improving the voltage profile of the system. SVCs have been used for high performance steady state and transient voltage control compared with classical shunt compensation. The effectiveness of the proposed method is analysed with IEEE 14-bus test system.

KEYWORDS: *FACTS, SVC, Transient Stability, Optimal Power Flow*

I. INTRODUCTION

A power system is a complex network comprising numerous generators, transmission lines, variety of loads and transformers. As a consequence of increase in demand for power, some transmission lines are more loaded than was planned when they were built. So with the increased power transfer, transient stability also increasingly has become important for secure operation. Transient stability evaluation of large scale power systems is an extremely intricate and highly non-linear operation. An important function of transient evaluation is to appraise the capability of the power system to withstand serious contingency in time, so that some emergencies or preventive control can be carried out to prevent system breakdown. In practical operations, correct assessment of transient stability for given operating states is necessary and valuable for power system operation.

Transient stability of a system refers to the stability [1] when subjected to large disturbances such as faults and switching of lines. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power angle relationship. Stability depends upon both the initial operating conditions of the system and the severity of the disturbance. The voltage stability, and steady state and transient stabilities of a complex power system can be effectively improved by the use of FACTS devices.

Transient stability studies place an important role in power systems, which provide information related to the capability of a power system to remain in synchronism during major disturbances resulting from either the loss of generation or transmission facilities, sudden or sustained load changes, in the voltages, currents, powers, speeds and torques of the machines of the power systems as explained in [2].

For most of the faults in a multi-machine system [3], it was observed that only one machine (or a small group of machines) becomes severely disturbed and is called the critical machine (or critical group). The critical machine (or critical group) is usually responsible to initiate instability for an unstable situation. FACTS devices [4, 5] are capable of controlling the network condition in a very fast manner and this unique feature of FACTS devices can be exploited to enlarge the decelerating area and hence improving the first swing stability limit of a system. SVC and STATCOM are members of FACTS family that are connected in shunt with the system.

Continuous and discontinuous types of control are very commonly used for shunt FACTS devices to improve the transient stability and damping of a power system [6].The transient stability of a generator [8] depends on the difference between mechanical and electrical power. During a fault, electrical power is reduced suddenly while mechanical power remains constant, thereby accelerating the rotor. To maintain transient stability, the generator must transfer the excess energy toward the system. For this purpose, the existing FACTS devices can be employed.

Due to FACTS device placement in the main power transfer path of the critical machine, the output power of the machine and hence its first swing stability limit can be increased by operating the FACTS device at its full capacitive rating [9]. Such an operation should continue until the machine speed reaches a reasonable negative value during the first return journey. Control strategy was proposed based upon local input signals can be used for series and shunt compensator devices (TCSC, and SVC) to damp power swings [10, 11]. Using the proposed control strategies, the series and shunt connected compensators can be located in several locations.

In transient stability studies a load flow calculation is made first to obtain system conditions prior to disturbance. In this calculation, the network is composed of system buses, transmission lines and transformers. The network representation for transient stability studies include, in addition to those components, equivalents circuits for machines and static impedances or admittances to ground for loads. A transient stability analysis is performed by combining a solution of the algebraic equations describing the network with a numerical solution of the differential equations. In this paper also the RUNGA-KUTTA method is used for the solution of differential equations in transient stability studies. Transient stability analysis, fault analysis and power angle characteristics have been calculated without FACTS devices and after inserting FACTS device SVC the improvements in transient stability have been discussed.

The modelling of SVC and transient stability solution formation for single and multiple machine systems discussed in session II. Results for the IEEE 14-bus power system are discussed with respect to transient stability solution during the faults at different buses without and with SVC device in section III. Finally in the session IV discussed the conclusion of the proposed method

II. Modelling of SVC and Transient Stability Solution Formation

2.1. Modelling of SVC

SVC is a Shunt FACTS device which is considered a variable impedance type device. The SVC uses conventional thyristors to achieve fast control of shunt-connected capacitors and reactors. The configuration of the SVC is shown in Fig.1, which basically consists of a fixed Capacitor (C) and a thyristor controlled reactor (L). The firing angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system.

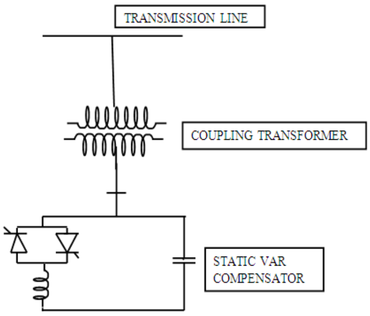

Fig. 1 SVC connected to a transmission line

$$I_{SVC} = jB_{SVC}V_m \tag{1}$$

The reactive power injected at bus m is

$$Q_{SVC} = Q_m = I_{SVC}V_m = -V_m^2 B_{SVC} \tag{2}$$

Where

$$B_{SVC} = \frac{1}{X_C X_L}\frac{X_L - X_C}{\Pi}\left[2(\Pi - \alpha_{syc}) + \sin 2\alpha_{syc}\right] \tag{3}$$

A Jacobian matrix that accounts for the SVC is given as

$$\begin{bmatrix} \Delta P_m \\ \Delta P_k \\ \Delta Q_m \\ \Delta Q_k \end{bmatrix} = \begin{bmatrix} \frac{\partial P_m}{\partial \delta_m} & \frac{\partial P_m}{\partial \delta_k} & 0 & V_k \frac{\partial P_m}{\partial V_k} \\ \frac{\partial P_k}{\partial \delta_m} & \frac{\partial P_k}{\partial \delta_k} & 0 & V_k \frac{\partial P_k}{\partial V_k} \\ \frac{\partial Q_m}{\partial \delta_m} & \frac{\partial Q_m}{\partial \delta_k} & \frac{\partial Q_m}{\partial \alpha_{SVC}} & V_k \frac{\partial Q_m}{\partial V_k} \\ \frac{\partial Q_k}{\partial \delta_m} & \frac{\partial Q_k}{\partial \delta_k} & 0 & V_k \frac{\partial Q_n}{\partial V_k} \end{bmatrix} \begin{bmatrix} \Delta \delta_m \\ \Delta \delta_k \\ \Delta \alpha_{SVC} \\ \Delta |V_k| / |V_k| \end{bmatrix} \tag{4}$$

Where

$$\frac{\partial Q_m}{\partial \alpha_{SVC}} = \frac{2V_k^2}{\Pi XL}\left[\cos(2\alpha_{SVC}) - 1\right] \tag{5}$$

$\Delta\alpha_{SVC}$ is found from inversion of the Jacobian matrix. The variable is then updated by

$$\alpha_{SVC}^{n+1} = \alpha_{SVC}^{n} + \Delta\alpha_{SVC}^{n} \tag{6}$$

The control strategy of SVC is considered as

$$B_{SVC} = \begin{cases} B_{SVC}^{MAX}, if\ \omega \geq -\beta\omega_{max}\ during\ the\ first\ swing \\ K\omega, B_{SVC}^{MIN} \leq K\omega \leq B_{SVC}^{MAX} : IN\ SUB\ SEQUENT\ SWINGS \end{cases} \tag{7}$$

Here ω_{max} is the maximum speed of the machine and it is usually at fault clearing and β is a small positive constant. K is a positive gain and its value depends on SVC rating.

2.2. Development of Transient Stability Solution

In order to determine the angular displacement between the machines of a power system during transient conditions, it is necessary to solve the differential equations describing the motion of the machine rotors. The swing equation can be represented using the single synchronous machine connected to infinite bus bars, governed by the nonlinear differential equation

$$M\ d^2\delta / dt^2 = p_m - p_e \tag{8}$$

Where

$$p_e = p_{max} \sin \delta$$

$$M\ d^2\delta / dt^2 = p_m - p_{max} \sin \delta \tag{9}$$

To determine load flow solution, Newton - Raphson Method is employed. A fault at or near a bus is simulated by appropriately changing the self-admittance of the bus. For a three-phase fault, the fault impedance is zero and the faulted bus has the same potential as the ground. This involves placing infinite shunt admittance, so that the bus voltage in effect is zero. The fault is removed by restoring the shunt admittance to the appropriate value depending on the post fault system configuration.

In the application of the Runga-Kutta fourth-order approximation, the changes in the internal voltage angles and machine speeds, again for the simplified machine representation, are determined from

$$\Delta\delta_{i(t+\Delta t)} = \frac{1}{6}(k_{1i} + 2k_{2i} + 2k_{3i} + k_{4i})$$
$$\Delta\omega_{i(t+\Delta t)} = \frac{1}{6}(l_{1i} + 2l_{2i} + 2l_{3i} + l_{4i}) \quad (10)$$

Where i = 1,2,…,no. of generators.

The k's and l's are the changes in δ_i and ω_i respectively, which are obtained using derivatives evaluated at predetermined points. For this procedure the network equations are to be solved four times.

2.3. Transient Stability Analysis for Multi machine system

In multi-machine case, two steps are required, they are:

a. The steady state pre-fault conditions for system are calculated using load flows.
b. The pre-fault network representation is determined and then modified to account for the fault and for the post-fault conditions.

From the first step it is possible to know the values for power, reactive power and voltage at each generator terminal and load bus with all angles measured with respect to swing bus. The transient internal voltage of each generator is calculated by using

$$E' = V_t + jXd' I \quad (11)$$

Where

V_t – Terminal voltage
I – Output current

Each load is converted into a constant admittance to ground at its bus using the equation:

$$Y_L = P_L - jQ_L / |V_L|^2 \quad (12)$$

The bus admittance used for pre-fault load flow calculation is augmented to include the transient reactance of generator and shunt load admittance.

The second step determines the modified bus admittance matrices corresponding to the faulted and post-fault conditions. Since only generator internal buses have injections, all other buses can be eliminated to reduce the size of matrix and matrix size is equal to number of generators.
For elimination of n^{th} bus

$$Y_{ij(new)} = Y_{ij(old)} - Y_{in} Y_{nj} / Y_{nn} \quad (13)$$

During and after the fault, the power flow into the network from each generator is given by

$$P_{ei} = \Sigma |E_i| |E_j| |Yij| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (14)$$

Where $Y_{ij} = |Yij| < \theta_{ij}$
Y_{ij}= Admittance between i^{th} and j^{th} nodes, now the swing equation is given by,

$$2H_i\, d^2\delta_i / \omega_s\, dt^2 = P_a = P_{mi} - P_e \quad (15)$$

to represent the motion of each rotor for during fault and post-fault periods.

In a multi-machine system a common system base must be chosen.
Let

G_{mech} = machine rating (base)

G_{system} = system base

Then the swing equation can be written as

$$(H_{system}/\pi f)\ (d^2\delta / dt^2) = P_m - P_e \text{ pu in system base} \quad (16)$$

Consider the swing equations of n machines on common base

$$(H_{eq} / \pi f)\ (d^2\delta / dt^2) = P_m - P_e \quad (17)$$

Where

$$P_m = P_{m1}+P_{m2}+\ldots\ldots\ldots\ldots+P_{mn}$$
$$P_e = Pe1+P_{e2}+\ldots\ldots\ldots\ldots+P_{en}$$
$$H_{eq} = H_1 + H_2 +\ldots\ldots\ldots\ldots+H_n \quad (18)$$

Then machines swinging coherently are thus reduced to a single machine.

III. RESULTS AND ANALYSIS-CASE STUDIES AND DISCUSSIONS

3.1. IEEE 14-Bus model

A three-phase fault is considered at two locations in IEEE 14-bus Model [10]. One of them is on line 2-4 to the generating station 2, which has the smallest inertia value. The second is on line 13-14, very close to bus 13 and far away from all the generating station. Thus, the effect of the distance between the fault location and the generating stations and the effect of fault clearing time is analysed.

3.2 Critical clearing time

3.2.1 When fault on line 2-4 without FACTS devices

The study is performed with the intention of analyzing the effect of fault location in conjunction with the fault clearing time. A three-phase fault at bus 2 near generating station on line 2-4 is shown with a learing time of 0.4 sec. It is observed from fig. 2. that generator 2 is severely disturbed. The results of the angle differences of the machines in the system, when fault occurred on line 2-4 and the fault is cleared in 0.5 sec are shown in fig. 2.

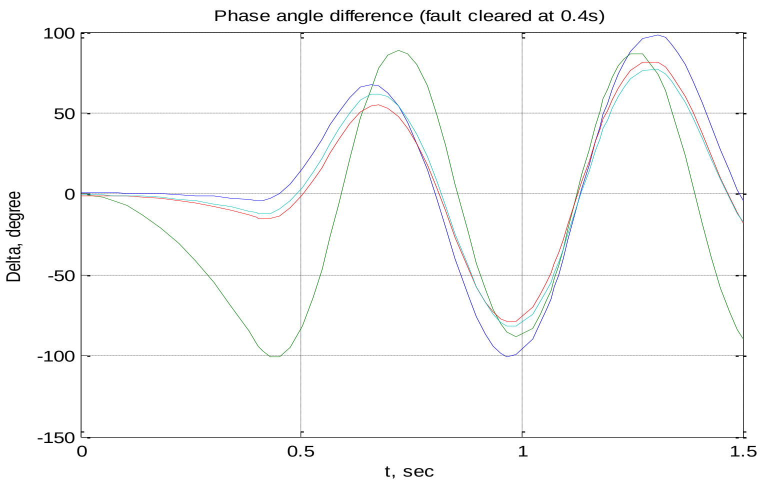

Fig. 2 Plots of angle differences for machines 2, 3, 4 & 5 when fault on bus 2 cleared at 0.4sec

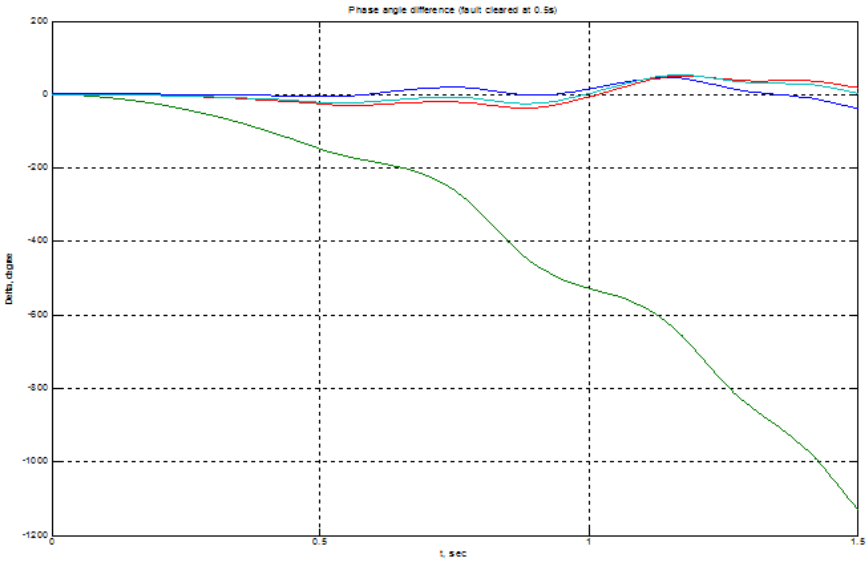

Fig. 3 Plots of angle differences for machines 2, 3, 4 & 5 when fault on bus 2 cleared at 0.5sec.

It is clear that the comparing the swing curves in fig 2 and fig.3, critical clearing time of the system is 0.4 sec. Since after 0.4 sec, the machines go out of step, the fault should be cleared in 0.4 sec.Fig.3 shows the swing curves for machines fall out of synchronism if fault is cleared in 0.5sec, as the critical clearing time here is 0.4 sec. the fault should be cleared in 0.4 sec.

3.2.2 When fault on line 2-4 with FACT device (SVC)

The swing curves for all five generators represented by classical models are shown in fig. 4, when svc is placed in line 2-4 to determine clearing time. Fig.4 shows the results of the angle differences of the machines in the system, when three-phase fault is occurred on line 2-4 after svc is placed. The clearing time of fault that is 0.6 sec. is increased when svc is placed. Fig 4 and Fig.5 shows the comparing of the swing curves, critical clearing time of the system at 0.6 sec. When svc is placed clearing time of fault is more when compared to not placing of any device in the earlier situation.

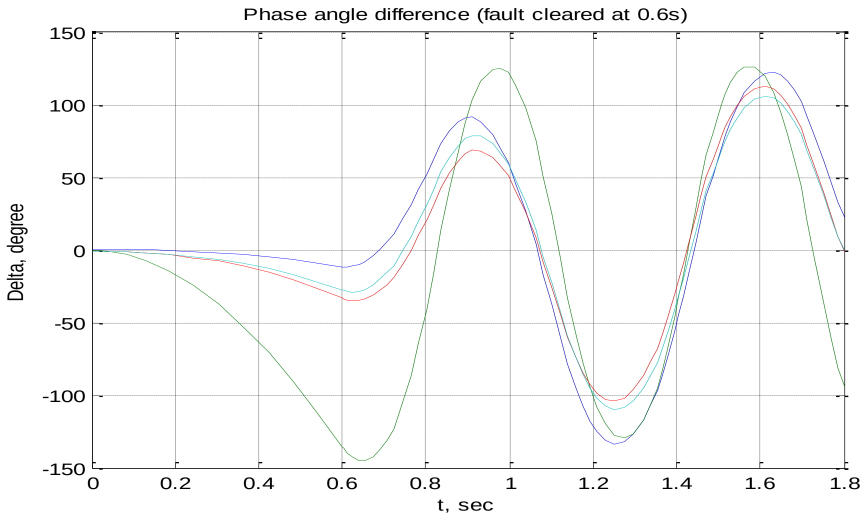

Fig. 4 Plots of angle differences for machines 2, 3, 4 & 5 when Fault on bus 2 cleared at 0.6sec

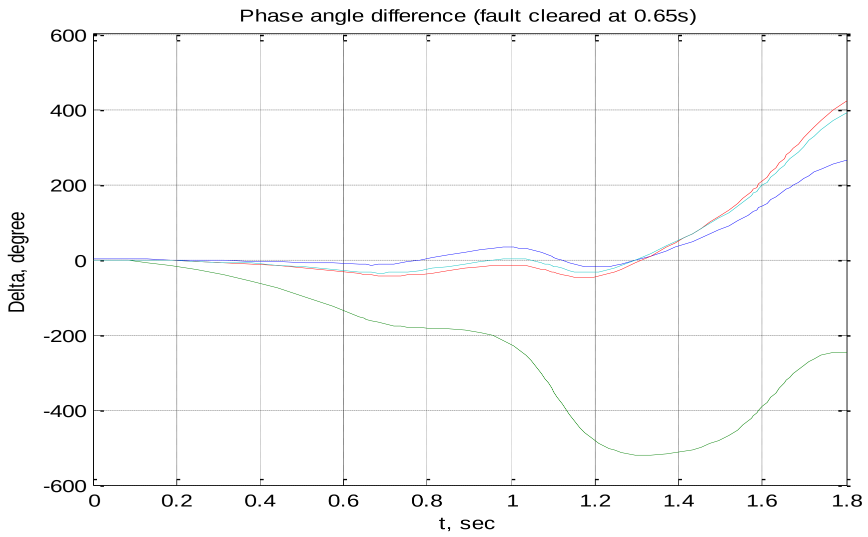

Fig. 5 Plots of angle differences for machines 2, 3, 4 & 5 when fault on bus 2 leared at 0.65sec

Now if the fault is cleared after 0.6 sec, the machines go out of synchronism as shown in fig.5.There fore critical clearing time is increased to 0.6 sec when svc is placed in line 2-4., where the clearing time of fault is 0.4sec before the device was placed.

Table 1 Critical clearing time without and with FACTs device when fault on line 2-4

Fault on line 2-4	Critical clearing time (sec)
Without FACTS device	0.4
SVC	0.6

Table 1 gives critical clearing time of fault with and without FACTS device. When FACTS device is placed clearing time is more. So, FACTS devices protect the system until fault is cleared. When SVC is placed clearing time is more compared to without using FACTS device.

3.2.3 When Fault on line 13- 14 without FACTS devices

This study is performed with the intention of analyzing the effect of fault location in conjunction with the fault clearing time. Two faults located on two different lines are considered. One is closer to the generating stations and the other one is far from the generating stations. Now consider fault located far from the generating stations. Fig.6 shows the results of the angle differences of the machines in the system. When fault is occurred on line 13-14, the clearing time of faults is 0.6 sec.

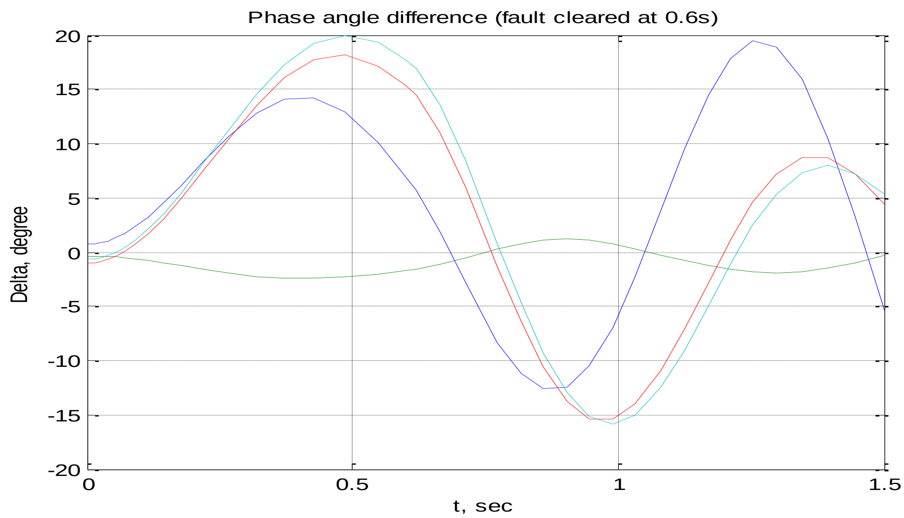

Fig. 6 Plots of angle differences for machines 2, 3, 4 & 5 when fault on bus 13 cleared at 0.6sec.

3.2.4 Fault on line 13-14 with FACTS device (SVC)

The swing curves for all five generators represented by classical models are shown in Fig.7, when SVC is placed in line 13-14 to determine clearing time. The clearing time of fault is shown from swing curves. Fig.7 shows the results of the angle differences of the machines in the system, when fault is occurred on line 13-14 after svc is placed. The clearing time of faults is 0.7 sec. When no device is placed clearing time is 0.6 sec but when svc is placed clearing time is increased to 0.7 sec.

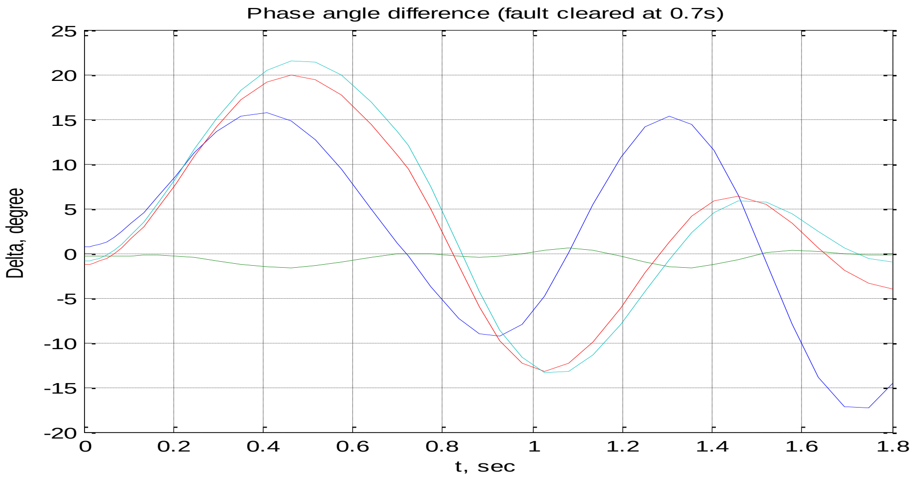

Fig. 7 Plots of angle differences for machines 2, 3, 4 & 5 when fault on bus 13 cleared at 0.7sec

Table 2 Critical clearing time without and with FACTs device when fault on line 13-14

Fault on line 13-14	Critical clearing time (sec)
Without FACTS device	0.6
SVC	0.7

From table 2, it is observed that critical clearing time of fault is given for with and with out FACTS device. When FACTS device is placed clearing time is more. FACTS devices protect the system until fault is cleared. When SVC is placed clearing time is more compared to without FACTS device.
There are many factors affecting the critical clearing time. Here, the effect of distance between the fault location and the generating stations is studied. Two fault locations for the same values of the damping and inertia constants are considered. One of the faults is on line 2-4, very close to bus 2, which is connected to machine 2, and the second fault is on line (10, 11), very close to bus 10. Machines 4 and 5 have the smallest value of inertia, so they are expected to go out of step first. The fault that is closer to the generating station must be cleared rapidly than the fault on the line far from the generation station. Rapid clearing of the faults promotes power system stability.

3.3 Power Angle Characteristics

The curve power versus delta (δ) is known as power angle curve. The power angle curves explain the performance before fault, during fault and after fault. It determines critical clearing angle.

3.3.1 Without FACTS device

In Fig.8, it shows power angle characteristics showing application of equal area criteria to a critically cleared system when FACTS device is not placed.

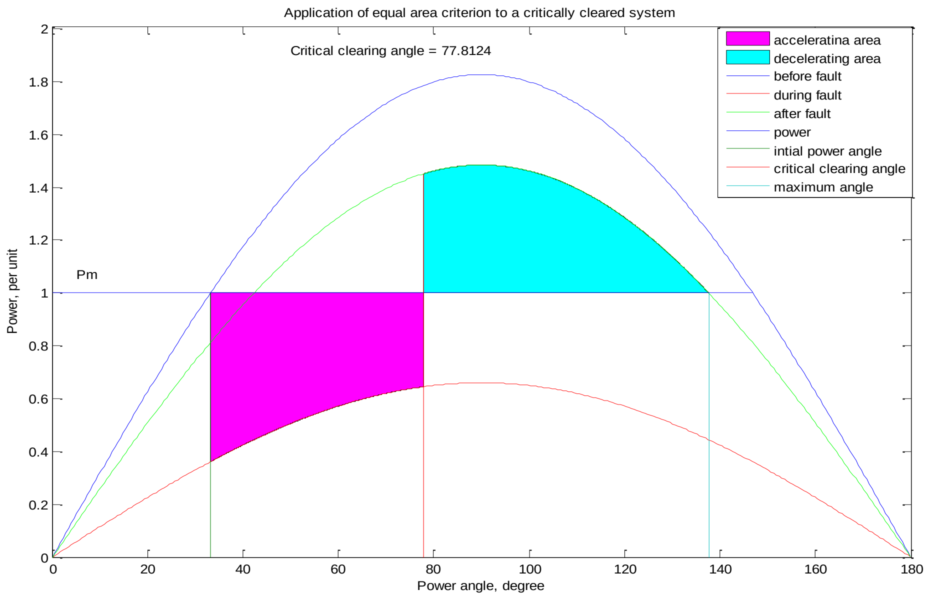

Fig. 8 Power angle characteristics without FACTS devices

The system behaviour before fault, during fault and after fault is shown in fig.8. The initial rotor angle, the new operating angle and maximum rotor angle swing are shown.

3.3.2 With FACTS Device - SVC

Fig.9, shows power angle characteristics showing application of equal area criteria to a critically cleared system when FACTS device SVC placed, the power angle curve corresponding to before fault, during fault and after fault. When SVC is placed, the clearing time of fault is increased and critical clearing angle also is increased. The accelerating area and decelerating area are shown in Fig. 9. The Fig. 9 shows the system behaviour before fault, during fault and after fault. The initial rotor angle, the new operating angle and maximum rotor angle swing are shown.

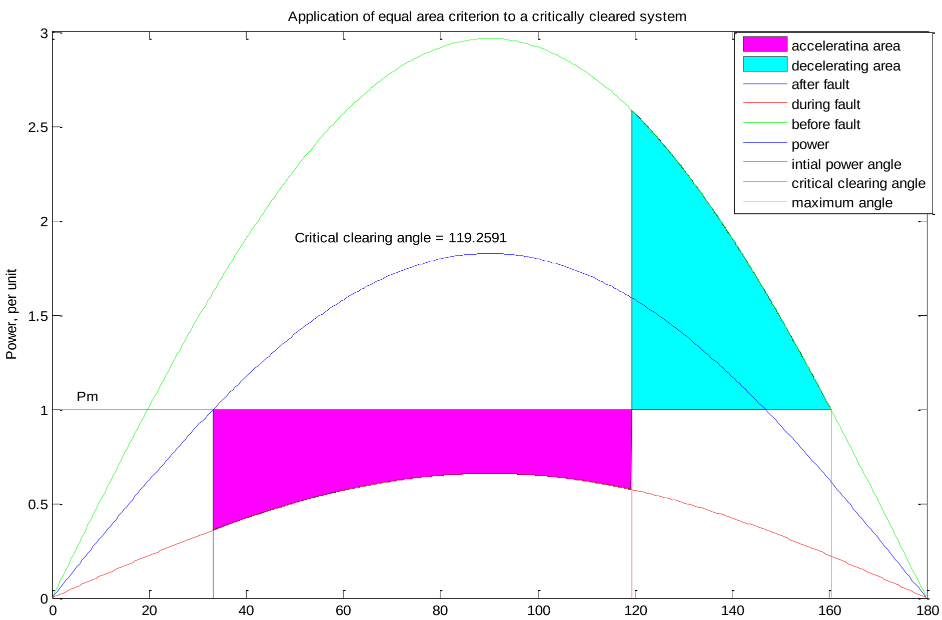

Fig. 9 Power angle characteristics with facts device SVC

Table 3 Critical clearing angle without and with FACTs device

Power angle curve	Critical clearing angle (Degrees)
Without FACTS device	77.81
SVC	119.26

From table 3, critical clearing time of fault and critical clearing angle are given for with and without FACTS devices. When FACTS device is placed, clearing time is more and FACTS devices protect the system until fault is cleared. When SVC is placed clearing time is more compared to without placing a FACTS device.

IV. CONCLUSIONS

The developed program with SVC is tested for several cases and major conclusions are the transient stability is improved by decreasing first swing with FACTS devices. FACTS devices help in improving transient stability by improving critical clearing time. The fault that is closer to the generating station must be cleared rapidly than the fault on the line far from the generation station. FACTS device must be placed in the main power transfer of the critical machine. The effectiveness of the proposed method has been shown with IEEE 14-bus system and compared the critical clearing angle and critical clearing angle without and with SVC device. From the result it has been observed that there is a improvement in critical clearing time and critical clearing angle with the help of the SVC device.

V. FUTURE WORK

The present work is analysed with respect to SVC but there is various types of FACTS devices are available and can model for the transient stability analysis purpose and can be observe the effectiveness of the other FACTS devices during the fault in the power system.

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