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Research Article

# Enhancement of Power System Transient Stability Using Static Var Compensator

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***Abstract***

*Power systems are continuously subjected to various types of disturbances which in turn cause the problem of losing stability. As the problem of transient stability is a crucial issue, the tools for mitigating such a sensitive problem have an important significance. Static VAR Compensator (SVC) can control reactive power and therefore is used to improve transient stability as well as the voltage profile. In this paper the mathematical model of the power system equipped with an SVC is systematically derived and the parameters of the SVC are modeled into the power flow equations and used in the control strategy, the SVC is modeled in a 5-bus system and a 30-bus system and implemented in Newton-Raphson load flow algorithm in order to control the voltage of the bus to which the SVC is connected to in a MATLAB written program, the contribution of the SVC to transient stability was tested and verified.*

***Keywords:*** *Load flow analysis, Newton-Raphson, SVC.*

## 1. Introduction

Rapid development of power systems especially with the increased use of transmission facilities has necessated new ways of maximizing power transfer in existing transmission facilities while at the same time maintaining the same level of stability (Mohammed osman hassen et al, 2009). To enhance the power system's stability and improve the quality of the transmission of electric power, it is necessary to provide reactive power and stable voltage for the power system. As a main reactive power compensation device especially for the distribution system, shunt capacitor reactive power compensation has gotten a wide range of applications (Yue Long et al, 2011).

Recent development of power electronics has introduced the use of Flexible Alternating Current Transmission Systems (FACTS) devices in electric power systems, FACTS devices are capable of controlling the network conditions in a very fast manner and are recognized as viable solution for controlling transmission voltage, power flow, and dynamic response. As a result FACTS represent a new era for the transmission of electric power (M. Kowsalya et al, 2009).

The innovative FACTS have been proposed during the last three decades for improving transient stability of a power system (Prechanon Kumkratug, 2010). There are various forms of FACTS devices namely Static VAR Compensator SVC, Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Compensator (TCSC), Static Synchronous Compensator (STATCOM), Unified Power Flow controller (UPFC) (Naryana Parasad et al,2005).

SVC based on Thyristor Control Reactor (TCR) is one of the shunt FACTS devices that are used for voltage regulation by controlling the production, absorption, and power flow of reactive power through the network. Power flow solution of the network that contains such devices is a fundamental requirement, many research works have been carried out in the literature for developing load flow algorithms for such devices (P. Yan et al,2005).

Even though the primary purpose of shunt FACTS devices is to support bus voltage by injecting (or absorbing) reactive power, they are also capable of improving transient stability by increasing (or decreasing) the power transfer when the machine angle increases (or decreases) which is achieved by operating the shunt FACTS devices in a capacitive (or inductive) mode (M. Kowsalya et al 2009).

## 2. Network with an SVC

The principal advantages of shunt capacitors are their low cost and flexibility of installation and operation. They are readily applied at various points in the system, thereby contributing to efficiency of power transmission and distribution, however, the principal disadvantage of shunt capacitors is that their reactive power output is proportional to the square of the voltage. Consequently,

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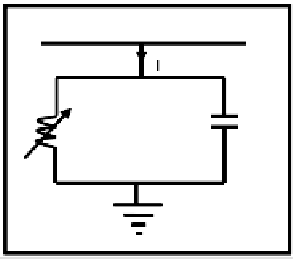
the reactive power is reduced at low voltages when it is likely to be needed most (P. Kundur, 1994). Early SVC models for power flow analysis treat the SVC as a generator behind an inductive reactance, the reactance accounts for voltage regulation characteristics (Erinmez I.A, 1986).

To study the impact of SVC device into a network, changes in the nodal admittance matrix and in the Jacobean matrix will have be made (Prechanon Kumkratug,2010). Initially the introduction of the FACTS is carried out by modifications of the admittance matrix and based on these modifications a new modified Jacobean matrix will be implemented and by varying the control parameter of the SVC while fixing the voltage, a value for the control parameter will eventually be reached (Nrimen Aouzellag, 2008).

### 3. Characteristics of an ideal SVC

From the view point of power system operation, an SVC is equivalent to a shunt capacitor and a shunt reactor Figure (1) that can be adjusted to control the voltage and reactive power at its terminals in a prescribed manner [7].



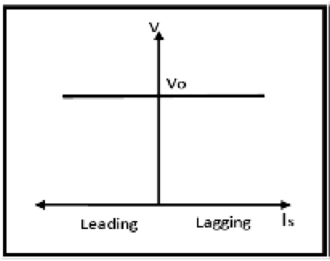
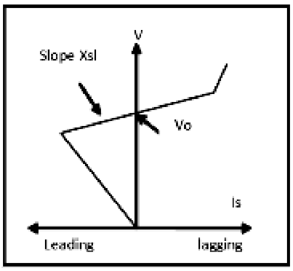




Figure 1: Idealized static VAR system

Figure 2: Characteristic of ideal compensator

Ideally, an SVC should hold constant voltage, posses unlimited VAR generation/absorption capability with no active and reactive power loses and provide instantaneous response. The performance of the SVC can be visualized on a graph of controlled AC bus voltage plotted against SVC reactive current (Is), see Figure (2).

However the characteristics of a realistic SVC with a practical controllable reactor are as shown in Figure (3).



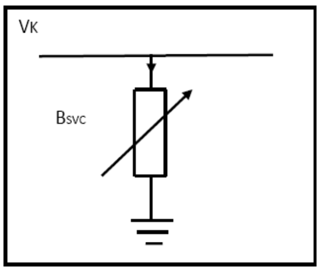




Figure 3: Characteristic of a given system condition

Figure 4: Variable shunt susceptance

Where $V = V_0 + X_{sl} * I_s$ ---------------------- (1)

Generally there are two configurations of the SVC:

A. SVC total susceptance. A changing susceptance $B_{SVC}$ represents the fundamental frequency equivalent of all shunt models making up the SVC as shown in Figure (4).

B. SVC firing angle model. The equivalent susceptance which is a function of the firing angle α is made up of the parallel combination of TCR equivalent admittance and a fixed capacitive reactance, as shown in Figure (5).

With reference to Figure (4), the following equations can be written [9]

$.I_{SVC} = jB_{SVC}V_k$ ------------------------------------------(2)

$Q_{SVC} = Q_k = -{V_k}^2 B_{SVC}$ ------------------------------(3)

The linearized equation is given by equation (4) where the equivalent susceptance is taken to be the state variable.

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & Q_k \end{bmatrix} \begin{bmatrix} \Delta \delta_k \\ \Delta B_{SVC}/B_{SVC} \end{bmatrix} \text{-------------------------(4)}$$

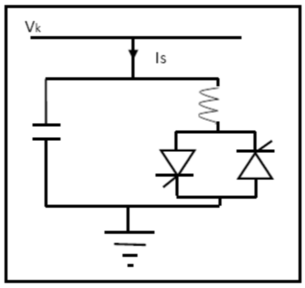



Figure 5: SVC firing angle model

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value.

In this paper the firing angle model is implemented, which handles the TCR firing angle as a state variable in the power flow formulation (Ampriz-perez et al,2000).

$$B_{SVC} = \frac{1}{X_c\, X_l}\left\{\mathrm{X}_l - \frac{Xc}{\pi[2(\pi-\alpha)+ \sin 2\alpha]}\right\} \text{----------------------(5)}$$

Where

$X_c = \dfrac{1}{W_c}$

$X_l = W_l$

$\alpha : is\ the\ firing\ angle$

$$Q_k = \frac{-{V_k}^2}{X_c X_l}\left\{\mathrm{X}_l - \frac{X_c}{\pi[2(\pi-\alpha)+ \sin 2\,\alpha]}\right\} \text{------------------------(6)}$$

From equation (6) the linearized SVC equation is given as

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2Vk^2}{\pi X_l}[\cos(2\alpha) - 1] \end{bmatrix} \begin{bmatrix} \Delta \delta_k \\ \Delta \alpha \end{bmatrix} \text{--------------- (7)}$$

At the end of iteration(i), the variable firing angle is updated according to

$\alpha(i) = \alpha(i-1) + \Delta\alpha$ -----------------------------------(8)

## 4. Results and Discussion

A five bus test system shown in Figure (6), the data for this system can be found in [9], is used to verify the effectiveness of the proposed algorithm, where the SVC is connected to bus lake in order to control it's voltage to 1pu.

The SVC is connected to bus Lake so as to control this bus voltage to a value of 1pu. The original results after applying Newton-Raphson method, for the system without the SVC connected are obtained in five iterations as shown in table (1). While the results of this system when the SVC is connected to bus 3 (Lake) are obtained in six iterations and are shown in table (2)

It can be seen that the SVC upholds the voltage magnitude of bus3 to a value of 1pu by injecting a reactive power of 20.47MVAR into bus Lake. The action of the SVC results in an overall improved voltage profile.

To test the contribution of the SVC to the stability of the system, a fault is created near bus 1(North) and is cleared by removing the transmission line (1-3) after Critical Clearing Time (CCT)=0.456sec. Figure (7) which a plot of the power angle difference between generator at bus2 (South) and the slack at bus1 (North) namely $\delta_{21}$. As can be seen the system is stable, while for CCT=0.457sec the system loses it's stability.

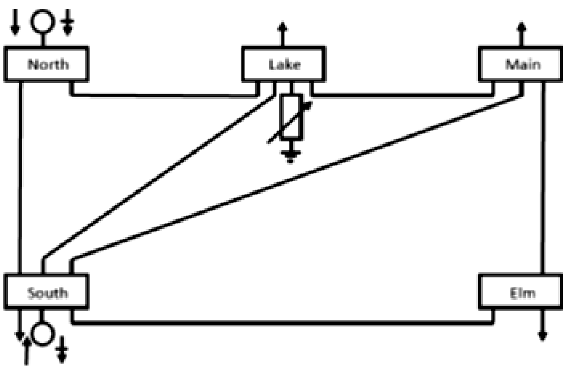



Figure 6: Five bus power system with SVC connected to bus Lake

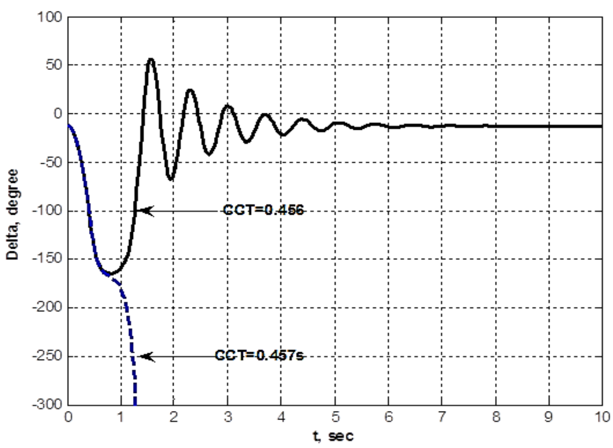



Figure 7: Power angle difference for 5 bus system without SVC

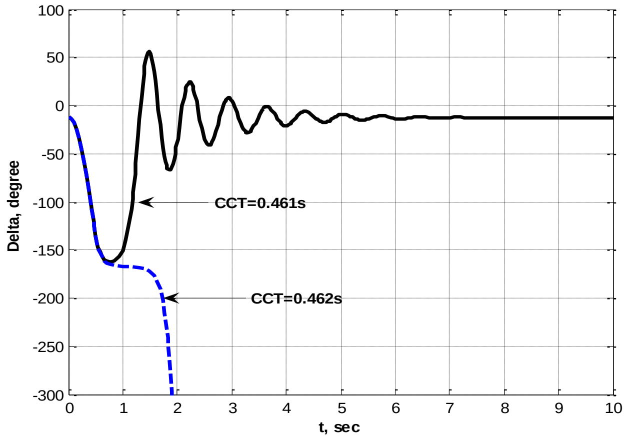



Figure 8: Power angle difference for 5 bus system with SVC

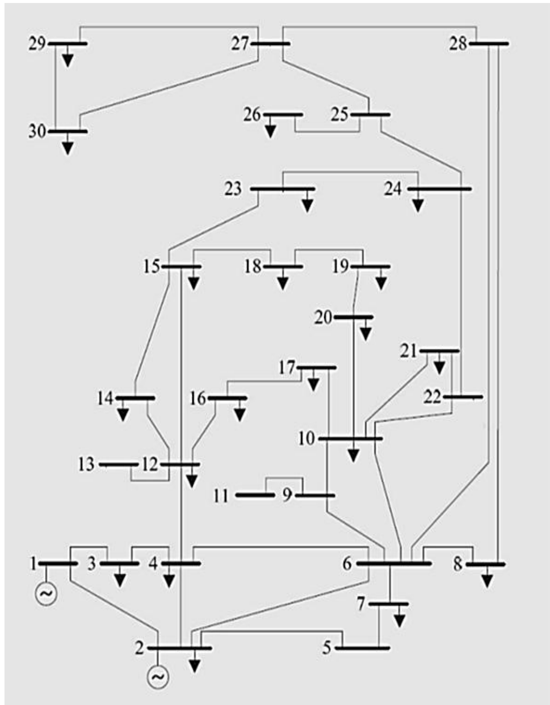


Figure 9: IEEE-30bus power system

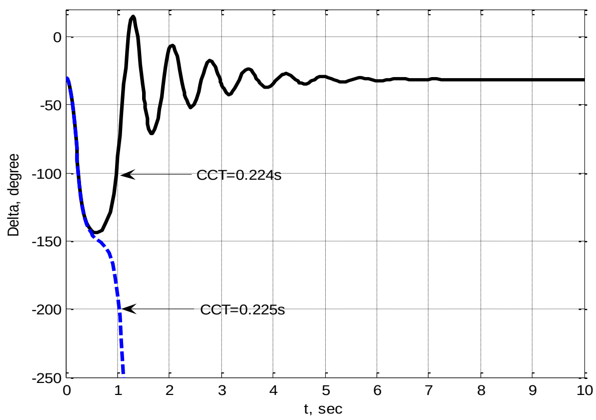



Figure 10: Power angle difference for 30 bus system without SVC

However when the SVC is connected at bus 3 (Lake) and the same fault was applied and then removed by the removal of the same transmission line i.e. (1-3). The critical clearing time is increased to CCT=0.461sec. As can be seen in Figure (8) the system is considered to be stable and loses stability for CCT=0.462sec.

Table 1: Newton-Raphson load flow results of the 5-bus system without SVC

| Power Flow Solution by Newton-Raphson Method | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Maximum Power Mismatch = 2.84495e-015 | | | | | | | | |
| Bus | Voltage | Angle | ------Load------ | | ---Generation--- | | Injected |
| No. | Mag. | Degree | MW | Mvar | MW | Mvar | Mvar |
| 1 | 1.060 | 0.000 | 0.000 | 0.000 | 131.122 | 90.816 | 0.000 |
| 2 | 1.000 | -2.061 | 20.000 | 10.000 | 40.000 | -61.593 | 0.000 |
| **3** | **0.987** | **-4.637** | **45.000** | **15.000** | **0.000** | **0.000** | **0.000** |
| 4 | 0.984 | -4.957 | 40.000 | 5.000 | 0.000 | 0.000 | 0.000 |
| 5 | 0.972 | -5.765 | 60.000 | 10.000 | 0.000 | 0.000 | 0.000 |
| Total | | | 165.00 | 40.000 | 171.122 | 29.223 | 0.000 |

Table 2: Newton-Raphson load flow results of the 5-bus system with SVC

| Power Flow Solution by Newton-Raphson Method | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum Power Mismatch = 6.05072e-015 | | | | | | | |
| Bus | Voltage | Angle | ------Load------ | | ---Generation--- | | Injected |
| No. | Mag. | Degree | MW | Mvar | MW | Mvar | Mvar |
| 1 | 1.060 | 0.000 | 0.000 | 0.000 | 131.056 | 85.343 | 0.000 |
| 2 | 1.000 | -2.053 | 20.000 | 10.000 | 40.000 | -77.067 | 0.000 |
| **3** | **1.000** | **-4.838** | **45.000** | **15.000** | **0.000** | **0.000** | **0.000** |
| 4 | 0.994 | -5.107 | 40.000 | 5.000 | 0.000 | 0.000 | 0.000 |
| 5 | 0.975 | -5.797 | 60.000 | 10.000 | 0.000 | 0.000 | 0.000 |
| Total | | | 165.00 | 40.000 | 171.056 | 8.276 | 0.000 |

The second case taken is for the IEEE 30-bus system shown in Figure (10), the data of which can be found in [12]. The SVC is connected to bus number three.

Again a fault is created near bus 1 and then removed by the removal of transmission line (1-3) after CCT=0.224sec. As can be seen from Figure 10 the system is stable, while for CCT=0.225sec the system loses it's stability.

When the SVC is connected at bus3 (to keep its voltage magnitude fixed to a value of 1pu) and the same fault was applied and then removed by the removal of the same transmission line i.e. (1-3) after an even more increased CCT=0.229sec, the system is found to be stable, and loses stability at CCT=0.230sec as can be seen in Figure (11).

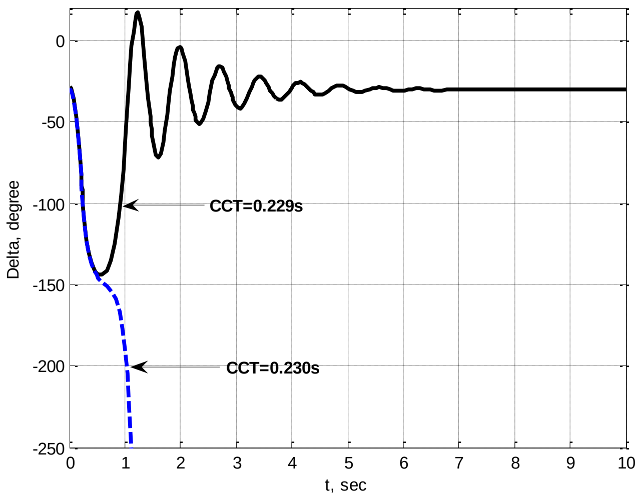



Figure 11: Power angle difference for 30 bus system with SVC

## Conclusion

In this paper the firing angle model of the SVC for the power flow solution was developed. The effectiveness of the proposed model was incorporated through the development of Newton-Raphson method for the desired bus voltage. The proposed model was tested on a five bus system and a thirty bus system. The results show that bus voltage to which the SVC was connected was held at the desired value of 1pu and that the transient stability was indeed enhanced by 0.5% for the IEEE 5bus power system and the IEEE 30bus power system.

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