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# Enhancement the stability of power system using optimal location of FACTS devices

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**ABSTRACT**

This paper proposes a steady-state of the Static Var Compensator (SVC) & Thyristor Controlled Series Capacitor (TCSC) set up for enhancing the damping overall performance and growing the integral clearing time (CCT) of a power network. The indispensable clearing time is carried out through increasing the time fault interval until the gadget loses stability. Increasing the CCT can be contribute to reliability of the safety gadget, decrease the protection machine ranking and cost. In order to attain most enhancement of machine stability via optimizing location, sizing and control modes of SVC and TCSC. Models and methodology for putting and designing shunt FACT's units SVC (injected reactive strength Q) and series FACT's devices TCSC (chose capacitive region) are examined in a 6-bus system. Performance factors are described to show validation of SVC and TCSC on extraordinary conditions. It is proven that the SVC is better than TCSC.



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## 1. INTRODUCTION

In late decades, with the deregulation of the power market, because of the opposition between utilities the quantity of unplanned conveyed power increments. On the off chance that these trades are not controlled, a few lines may get to be over-burden. This has come about into the trouble in damping low recurrence motions which restricts the ability to transmit power and prompts framework division. Then again, the quick development of power demand prompts the responsive power arranging issue particularly under possibilities. subsequently, there is an issue in compensating touchy force prerequisite and keeping up the bus voltage inside tasteful cutoff points.

Voltage stability of energy structures is one of the noteworthy perspectives in electric powered energy framework operation. Influential damping is sure the modes of electromechanical damping or motions amongst of Synchronous turbines interconnected in a PS framework [1]. While the excitation of generator framework for PSS to keep up excitation succeed and steadiness, however it is now not very good to manage the dependability of force framework because of deficiencies or over-burdening close to the generator terminals [2-3]. Accordingly, analysts have been dealing with this issue for quite a whilst trying to find an answer. One of the influential techniques for improving transient strength is to make use of the bendy AC transmission gadget (FACTS) controller devices [4-6]. Anyway, influential damping will improve with the use of the damping stabilizer [7-8]. Flexible AC Transmission System (FACTS) gives more interest at final years. It uses high current energy digital gadgets to manipulate of a transmission system such as voltage, power flow and stability, etc. FACTS gadgets can be linked with transmission line in different ways series, shunt, or a combination between them. The definition and time period of a type of FACTS are described in references [9-10]. Two types of FACTS gadgets are very efficient and successful to increase the energy switch functionality of a line, in so a long way as the thermal limitations allow while preserving the equal level stability [11-12]. It is essential to locate the position, measurement and type of these controller devices due to the fact of its substantial costs. The Studies, investigation and realizations already have achieved their abilities in a constant kingdom or dynamic preconditions [13-14]. The voltage stability trouble is coupled with reactive electricity must be tackled by giving enough reactive energy lower back to the discriminating nodes. The reactive power management can be achieved by an exchanged capacitor financial institution in nature generally is discreted. The late pattern is to supplant the banks of capacitor for SVC to have a delicate manipulate in reactive strength (Q). SVC has the capability of presenting alterably movable reactive energy inside the minimum and maximum limits [15-16].

To improve stability of power system and to tackle the reactive power planning issue, flexible AC transmission system (FACTS) devices (FACTS) are broadly utilized by power framework utilities. FACT'S are controllers utilized as a part of electric power frameworks radiating from late improvement of power electronics hardware that are extremely useful in improving the proficiency of power framework operation. Finally, in this paper, test the approval of Fact's devices SVC & TCSC to managing the power stream of a TL, damping the power oscillations, and improving power system stability. Simulation results have been completed in the (6-bus) framework. To validate the presented models.

## 2. MATHEMATICAL MODELS

### 2.1. Mathematical Model of Power System

The two next equations describe the power flow (PF) with FACTS devices:

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j| \left(G_{ij} - \text{FACTS } \sin(\delta_{ij}) + B_{ij} - \text{FACTS} \sin(\delta_{ij})\right) = 0 \quad (1)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} |V_i||V_j| \left(G_{ij} - \text{FACTS } \sin(\delta_{ij}) - B_{ij} - \text{FACTS} \sin(\delta_{ij})\right) = 0 \quad (2)$$

$$|V_j|_{min} \le |V_j| \le |V_j|_{max}$$

$$\delta_{ij} \le \delta_{ij}^{\ max}$$

Where,
$P_{Gi}$, $Q_{Gi}$: Generated real and reactive power at bus i;
$P_{Di}$, $Q_{Di}$: Real power and reactive power of load at bus i;
n: Bus number;
$G_{ij}$ , $B_{ij}$FACT's: Real & Imaginary parts of (i,j)th element of matrix admittance network with FACTS controller;
$\delta_{ij}$: phase angle Difference between (i and j);
$|V_j|_{min}$, $|V_j|_{max}$: Max. and min. voltage magnitude at bus i.

### 2.2. Steady State Models of Fact's Devices SVC

The most important motive of SVC is regulated voltage at vulnerable factors in the power system network. Figure 1 suggests the single line format of a transmission line that is compensated included SVC at bus j, the model for strength injection SVC can be illustrated as in Figure 2. In this case study, the SVC is dealt with a variable capacitance, the place $I_{SVC}$ is the complicated injected cutting-edge of SVC at node j [17-18]. It can be achieved as follows:

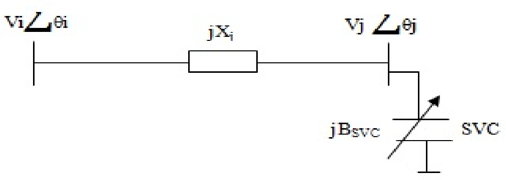


Figure 1. Single line diagram of compensated TL

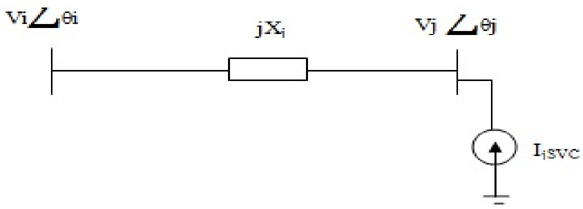


Figure 2. Power injected model of SVC

The SVC can be actes as a capacitive behavior or as inductive mode for absorbing or to generate the reactive power (VAr). The SVC is appeare as a variable shunt susceptance connected to the end bus of TL or at the midpoint of it [19]. The SVC device is a voltage managed system and its susceptance ought to be specified for the rules of bus voltage at the preferred value. The normal values of the SVC are identical to the power system values. In this work, we can be discribted as below:

$$-100 \leq Q_{SVC} \leq +100 \tag{3}$$

$$\mathrm{I}_{\mathrm{SVC}} = -jB_{SVC}V_K \tag{4}$$

The fundemantal frequency TCR equivalent reactance $X_{TCR}$.

$$X_{TCR} = \frac{\pi X_L}{\sigma - sin\sigma} \tag{5}$$

Where $\sigma = (\pi - \alpha)$, $X_L = \omega L$

At $\alpha = 90^{o}$, TCR will be fully conducts and the $X_{TCR}$ becomes $X_L$, while at $\alpha = 180^{o}$, TCR is blocked and its $X_{TCR}$ becomes infinite. The combination of $X_C$ and $X_{TCR}$ in parallel will be cause to determine SVC effective reactance $X_{SVC}$.

$$X_{SVC} = \frac{\pi X_C X_L}{X_C\,[2(\pi-\alpha)+sin2\alpha]-\pi X_L} \tag{6}$$

Where $X_C = 1/\omega c$

$$Q_K = -V_K^2\left(\frac{X_C\,[2(\pi-\alpha)+sin2\alpha]-\pi X_L}{\pi X_C X_L}\right) \tag{7}$$

### 2.3. Model of FACTS Devices TCSC (Steady State)

Figure 3 shows the Single line diagram of transmission line together with TCSC, its performed by lumped $\pi$ equivalent parameters.

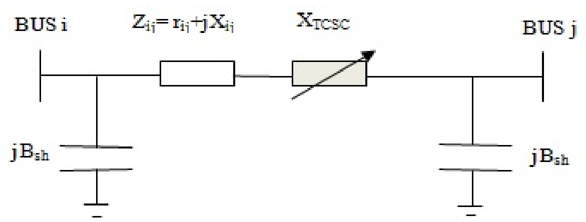


Figure 3. Single line diagram of compensated transmission line together with TCSC

The TCSC acts as capacitor or inductor behavior in steady state condition, in order to change the branch impedance. The value of TCSC with variable series reactance as a function of line reactance of $X_L$, where the device is located [20]. The minimum and maximum value of reactance of TCSC can be determined from (8).

$$-0.8X_L \leq X_{TCSC} \leq 0.2X_L\ p.u \tag{8}$$

The power injection of TCSC incorporated within the TL as shown in Figure 4 [20]. The difference of line admittance of TCSC is given in (9).

$$X_{TCSC} = -X_C + K_1(2\sigma + sin2\sigma - K_2cos2\sigma(\omega^{-}tan\omega^{-}\sigma) - tan\sigma) \tag{9}$$

Where; $\sigma = (\pi - \alpha)$, $\omega^{-} = \sqrt{\frac{X_C}{X_L}}$

$$X_{LC} = \frac{X_C X_L}{X_C - X_L}, K_1 = \frac{X_C + X_{LC}}{\pi}, K_2 = \frac{(X_{LC})^2}{\pi X_L} \quad (10)$$

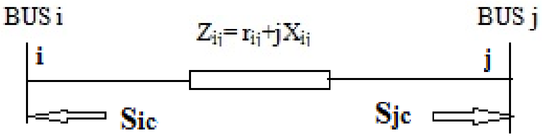


Figure 4. Power Injection model of TCSC

$$\Delta y_{ij} = y_j - y_{ij} = (g'_{ij} + jb'_{ij}) - (g_{ij} + jb_{ij}) \quad (11)$$

Where,

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}};\ b_{ij} = \frac{-x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}} \quad (12)$$

$$g'_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_{TCSC})^2}};\ b_{ij} = \frac{-(x_{ij} + x_{TCSC})}{\sqrt{r_{ij}^2 + (x_{ij} + x_{TCSC})^2}} \quad (13)$$

When TSCS is installed between (i & j) buses the admittance matrix can be obtained from (14).

$$ybus = ybus + \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 \ldots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 \cdots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (14)$$

## 3. SIMULATION RESULTS AND ANALYSIS (10 PT)

The 6-bus test system is used to evaluate the effectiveness of SVC and TCSC models developed in this paper. Figure 5 shows the Six bus 3 Generator systems, with 400 kv and 100MVA base has been considered. The data of system [14] shown in APPENDIX A. two cases are considered, SVC is connected at bus 5 and, then at bus6, TCSC connected between line2 (1-4). After that we made fault on many line in 6 bus system to see the validation of FACTS devices (SVC& TCSC). And which one is better to minims losses and reduction the damping.

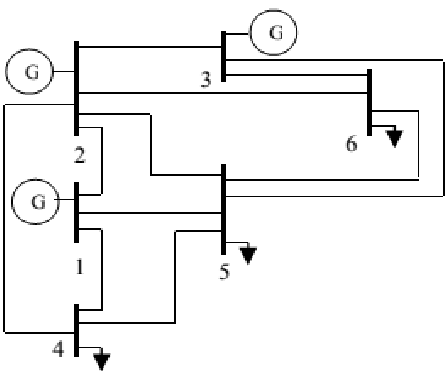


Figure 5. Six bus 3 Generator systems

### 3.1. SVC Set Up

The SVC connected for many objectives by utilities in transmission applications. The main role is as a rule for fast voltage control at powerless focuses in a system. The SVC may be established at the midpoint or at the end of transmission line. In this paper SVC is associated at transport 5 and the all out losess was (10.069MW) as shown in Figure 6.

The total loses after installed SVC at bus 5 was (–68 MVAR, 10.069 MW). As shown in Figure 7. And the Optimal Location and Size of SVC with details shown in Table 1.

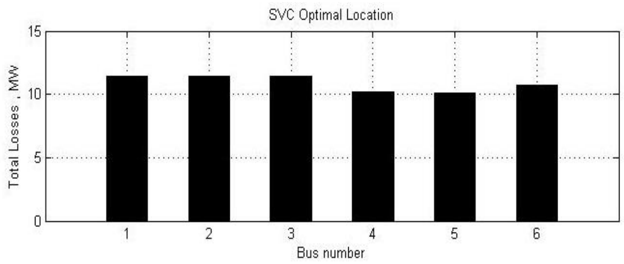


Figure 6. SVC Optimal Location

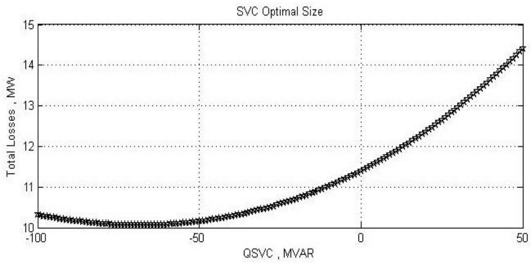


Figure 7. SVC Optimal size

Table 1. Optimal Location and Size of SVC

| Optimal Location and Size of SVC | | | | | | |
|---|---|---|---|---|---|---|
| Bus no. | 1 | 2 | 3 | 4 | 5 | 6 |
| $Q_{SVC}$ in MVAR | … | … | … | -66 | -68 | -66 |
| Total Losses in MW | 11.397 | 11.397 | 11.397 | 10.226 | 10.069 | 10.681 |

### 3.2. The Installation of TCSC

TCSC is one of the most significant FACTS family, Which has been used for many years for improving power transfer and system stability. TCSC is connected on line2 (1-4), and the total losess was (11.02MW).as shown in Figure 8.

The total loses after installed TCSC on line2 (1-4) was (-0.086 P.u, 11.02MW). As shown in Figure 9. And the Optimal Location and Size of TCSC with details shown in Table 2.

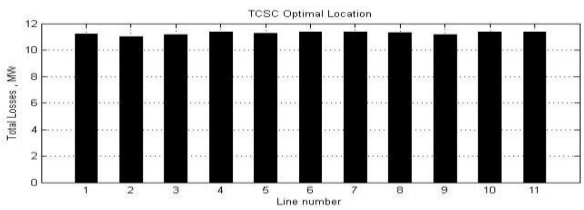


Figure 8. TCSC Optimal Location

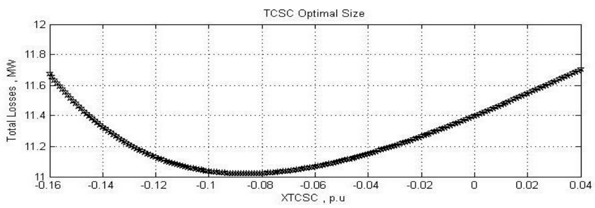


Figure 9. TCSC Optimal size

Table 2. Optimal Location and Size of TCSC

| Optimal Location and Size of TCSC | | |
|---|---|---|
| Line Number | $X_{TCSC}$ in p.u | Total Losses in MW |
| 1 | 0.04 | 11.193 |
| 2 | - 0.086 | 11.02 |
| 3 | - 0.094 | 11.149 |
| 4 | - 0.102 | 11.372 |
| 5 | 0.02 | 11.282 |
| 6 | -0.029 | 11.39 |
| 7 | 0.04 | 11.352 |
| 8 | 0.052 | 11.336 |
| 9 | - 0.06 | 11.173 |
| 10 | 0.08 | 11.378 |
| 11 | - 0.25 | 11.369 |

### 3.3. Evaluation of Critical Clearing Time CCT

To achieve the Critical clearing time exhibitions of the PS, the heap is expanded bit by bit and burden stream consider is executed for the strength examine. The CCT can be gotten by expanding the time interim of the shortcoming step by step until the conscious framework loses its security. To contemplate the incredible of the FACT's devices (SVC and TCSC). Deficiency shows up on bus2 line1(1-2) and this line expelled as appeared in Figures 10 and 11, Fault shows up on bus3 line4(2-3) and this line expelled as appeared in Figures 12 and 13. The flaw interim time increments bit by bit up till the framework loses its security and afterward the CCT can be resolved. Table 3. demonstrates the examined power framework basic clearing time with and without introducing FACT's gadgets (SVC and TCSC). The impact of introducing SVC and TCSC in expanding the CCT was clear. This will support to pick the reasonable security framework.

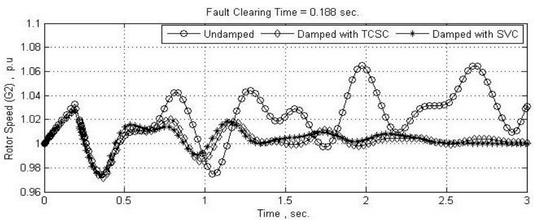


Figure 10. Fault Clearing Time 0.188sec at Bus2. Rotor speed for G2

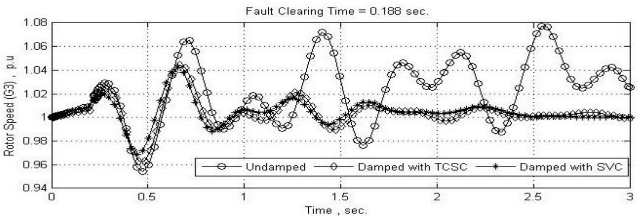


Figure 11. Fault Clearing Time 0.188sec at Bus2, Rotor speed for G3

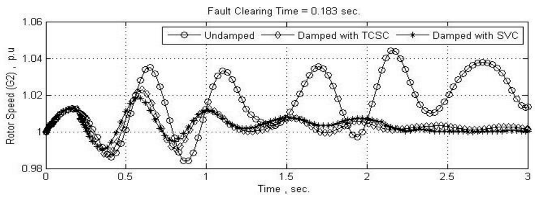


Figure 12. Fault Clearing Time 0.183sec at Bus3. Rotor speed for G2

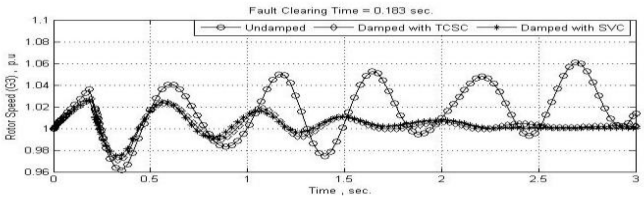


Figure 13. Fault Clearing Time 0.183sec at Bus. Rotor speed for G2

Table 3. Critical Clearing Time (CCT ) in M.Sec

| | Critical Clearing Time (CCT ) in m.sec. | | |
|---|---|---|---|
| Fault Locations | Undamped | Damped with TCSC | Damped with SVC |
| At Bus 2 Line 1 | 188 | 221 | 234 |
| At Bus 3 Line 4 | 183 | 207 | 219 |
| At Bus 2 Line 5 | 242 | 291 | 297 |
| At Bus 1 Line 3 | 192 | 232 | 276 |
| At Bus 2 Line 6 | 251 | 284 | 294 |
| At Bus 3 Line 9 | 186 | 226 | 287 |

## 4. CONCLUSION

In this paper steady-state of FACT’s devices for power system network solution was developed for desired power transferred capabilities discussed in details. In order to find the optimal location and size of FACT’s devices and to evaluate the effects of these devices on a power system network. A proposed idea has been tested on 6- bus system. To make obvious the performance of the proposed models, it shows as the minimizing the losses of power system (real power) with best size & optimal location of FACTS devices. Real and reactive power improved after placing FACTS devices. It is shown that the SVC is better than TCSC.

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