# Power System Security Improvement by Optimal Location of Fact's Devices

Gassan Abdullah Salman
Diyala University, Electrical Power and Machines Engineering,
Collage of Engineering,
Diyala Iraq.

***Abstract*-This paper proposes a combination of the Static VAR Compensator (SVC) & Thyristor Controlled Series Capacitor (TCSC) installation for enhancing the security of an electrical power system. This combination during single contingencies (N-1) is investigated. A TCSC connected in series with a line and SVC connected across the matching buses between which the line is connected. A formulation Based on Voltage Security Index (VSI) & Apparent Power Security Index (PSI) in order to ensure the optimal location of FACTS when Dealing with security criteria. Security index values are calculated for every branch & bus in the network. This index is used to decide on the best location and size for the multi type devices. Once located and size, the type and optimal settings of FACTS devices (TCSC and SVC) with respect To single contingency can be obtained by optimization. Contingency investigation is performed to detect and rank the severest one-line fault Contingency in a PS network. The objectives used in this problem are eliminating the line overloads and outside bus voltages in power system networks. The results have been achieved on IEEE 6-bus test system. Test result shows that both SVC and TCSC can determine optimal placement.**
***Keywords: FACT's location; SVC; TCSC; contingencies (N-1); security index.***

## I. INTRODUCTION

Because the reorganization of electrical power industry, significant technological improvements have been made in the field of power electronics which led to the development of a new and revolutionary technology to enhance transmission networks controllability. Known as Flexible Alternating Current Transmission Systems (FACT's), this equipment is gradually replacing electromechanical devices, filling the main gaps present in those devices, such as slowness and wear. FACTS have high control capabilities, allowing a fast and efficient way to act on network parameters.

In emerging electric power systems, increased transactions may often lead to the situations where the systems no longer remain in the secure operating region. The security of a power system [1, 2] can be defined as its ability to withstand a set of severe, but credible contingencies and remain in an acceptable new steady state condition. Various factors, such as environmental, right-of way and high installation cost, limit the expansion of the transmission network. Utilities try to maximize the utilization of the existing transmission asset that may, sometimes, lead to insecure operation of the system [3]. Increased loading in power systems, combined with deregulation of the power industry, motivate the use of Flexible AC Transmission Systems (FACTS) controllers [4-5] such as Thyristors Controlled Series Compensator, Unified Power Flow Controller (UPFC), and Thyristor Controlled Phase angle Regulator for power flow control as a cost–effective means of dispatching specified power transaction and maintain systems security.

In power system without violating specified power dispatch addition of controllable components such as controllable series FACTS devices can changed line flows in such a way that, losses minimized, thermal limits are not violated, stability margin increased, contractual requirement fulfilled etc. FACTS devices have considerable high cost, so placement of FACTS devices at optimal location is a very important concept, so as to recover the overloaded system economically and regain the system security as early as possible [5-6].

Finally, the purpose of this paper is to locate the FACTS devices at optimal location and size for eliminating the insecurity of power system. A method to determine the optimal locations of Static VAR Compensator and TCSC has been suggested. The proposed algorithm has been demonstrated on a modified IEEE 6- bus system. Figure (1) & Figure (2) Shows the schematic diagrams of TCSC &SVC, respectively.

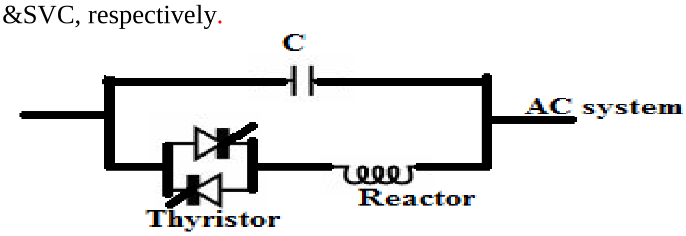


Figure (1) schematic diagrams of TCSC

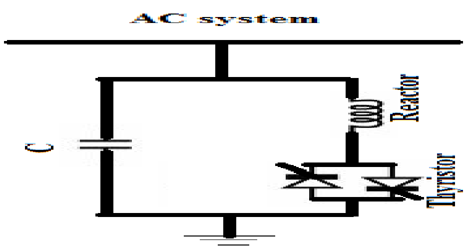


Figure (2) schematic diagrams of SVC

## II. MODELING OF FACTS DEVICES

### A- TCSC

Here an injection model has been used to calculate the sensitivity of real power flow performance index with respect to control parameters [7]. The model of a T.L. with Z series $z_{ij} = (r_{ij} + jx_{ij})$ and a Thyristors Controlled Series Compensator connected between bus-i and bus-j is shown in Figure (3). Let complex voltages at bus-i and bus-j are Vi ∠δ i, V j ∠δj respectively. During the steady state the Thyristors Controlled Series Compensator can be considered as a static reactance – jXc.

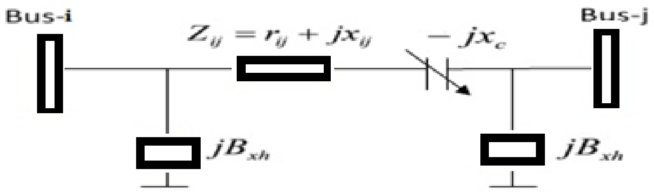


Figure (3) Model of TCSC

The change in the line flow due to series capacitance can be represented as a line without series capacitance with power injected at the receiving and sending ends of the line as shown in **Figure(4).** The real power injections (Pic) (Pjc) at bus-i and bus-j can be expressed as [8].

$$Pic = v_i^2 \Delta Gij - ViVj[\Delta Gij \cos \delta ij + \Delta Bij \sin \delta ij]$$
(1)

$$Pjc = v_j^2 \Delta Gij - ViVj[\Delta Gij \cos \delta ij - \Delta Bij \sin \delta ij]$$
(2)

Where

$$\Delta Gij = \frac{Xc\ rij(Xc-2Xij)}{\left(r_{ij}^2+X_{ij}^2\right)\left(r_{ij}^2+(Xij-Xc)^2\right)} \quad \text{and}$$

$$\Delta Bij = \frac{-Xc\ (r_{ij}^2+X_{ij}^2+XcXij)}{\left(r_{ij}^2+X_{ij}^2\right)\left(r_{ij}^2+(Xij-Xc)^2\right)}$$

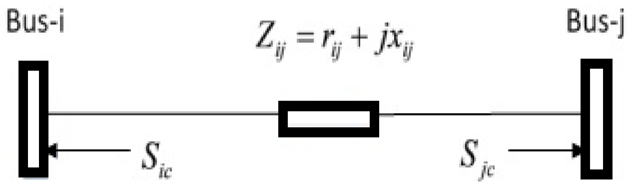


Figure (4) Injection model of TCSC

### B- SVC

The SVC is defined as a shunt connected static VAR generator or consumer whose output is adjusted to exchange capacitive or inductive so as to maintain or control specific parameters of electrical power system, typically a bus voltage. Like the TCSC, the SVC combines a series capacitor bank shunted by thyristor controlled reactor. In this paper, the SVC is considered as a synchronous compensator modeled as PV bus, with Q limits. SVC model and its structure have been specified in Figure (5) as follows:

**$\Delta Qi$ = QSVC**
(3)

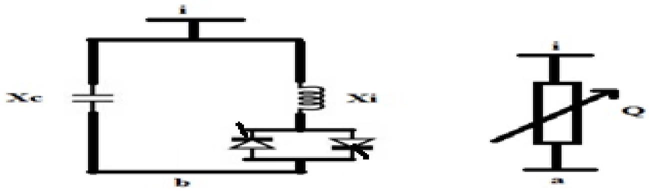


Figure (5) a) SVC Model, B) basic block diagram

The chosen parameters for TCSC and SVC equipments are shown in Table (1).

TABLE (1) PARAMETERS OF FACTS DEVICES

| | Parameter | Min. | Max. |
|---|---|---|---|
| **TCSC** | **$X_{TCSC}$** | **-0.8XL** | **0.2XL** |
| **SVC** | **$Q_{SVC}$** | **-200MVAR** | **200MVAR** |

` A Simple and direct method of determining the steady state voltage stability limit of a power system is presented in ref.[9]. Consider a simple Two-Bus system as shown in **Figure (6)** The generator at bus 1 transfers power through a transmission line having an impedance of Z = R +jX to a load center at bus 2. Bus 1 is considered as a swing bus where both the voltage magnitude V2, and δ2 , are kept constant.

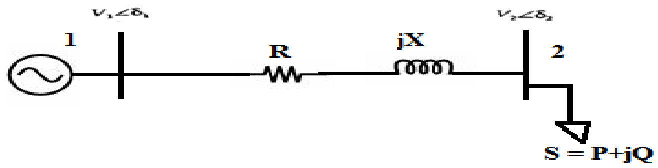


Figure (6) A Simple Two-Bus System

The load voltage magnitude and the load power
S = P +jQ
(4)
Can readily be written as

$$V1 = V2 + IZ = V2 + I\sqrt{R^2 + X^2}$$
(5)

Critical loading is found as follows

$$Sm = \frac{V_1^2}{2} \frac{Z-(R\cos\theta + X\sin\theta)}{(R\sin\theta + X\cos\theta)^2}$$
(6)

**Where Z =$\sqrt{R^2 + X^2}$**

The maximum reactive power loading (with P =0) and the corresponding voltage can be obtained from the above equations by setting θ = 90.

$$Qm = \frac{V_1^2(Z-X)}{2R^2}$$
(7)

$$Vcr = \sqrt{\frac{V_1^2 - 2QmX}{2}}$$
(8)

After Placement of SVC A Simple and direct method of determining the steady state voltage stability limit of a power system after the placement of Static Var Compensator (SVC) is presented in[10-11].A SVC of finite reactive power rating is placed at the load center in two bus equivalent model and it is shown in **Figure(7).**

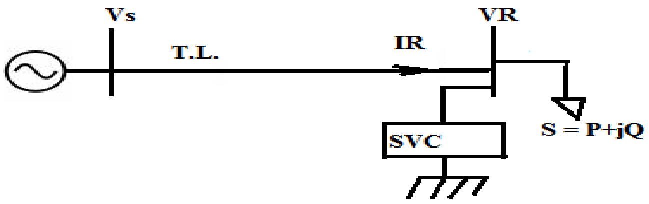


Figure (7) Simple Two bus system with SVC

The receiving end voltage decreases as the load increases and reactive power will be injected by SVC to boost the voltage. Voltage collapse occurs when there is further increase in load after SVC hits its maximum limit. In order to prevent voltage collapse, SVC is considered as fixed Receiving end current from Figure (7) is given by:

$$IR = jBcVR + \left(\frac{SL}{VR}\right)^*$$
(9)

## III. METHODOLOGY AND SOLUTION TECHNIQUE

There are three functions to make the control system for power system security is efficient

- System monitoring.
- Contingency analysis ,and
- Corrective action plan.

The observation was that there are several methods for finding the optimal location of FACTS devices like Sensitivity Approach, Line Outage Distribution Factor methods. In this paper the whole process divided into two parts. First the contingency analysis will be perform by line outage distribution factor and after that for removing the effect of contingency conditions from the system optimal location of FACTS devices are done by Voltage Security Index (VSI)( load bus voltage deviation ) & Apparent Power Security Index (PSI) methods(overload line limits). Voltage Security Index (VSI) & Apparent Power Security Index (PSI) methods Equations are shown below:

Voltage Security Index (VSI)

$$VSI = \sum_{i=1}^{nb} w_i \left|V_i - V_{ref,i}\right|^p$$
(10)

Where:

**nb** : Number of load buses
$w_i$ : Weighting factor
$V_i$ : Voltage magnitude at bus *i*
$V_{ref,i}$ : Reference voltage magnitude at bus *i*

Apparent Power Security Index (PSI)

$$PSI = \sum_{j=1}^{nl} w_j \left(\frac{S_j}{S_{max,j}}\right)^q$$
(11)

Where:

$S_j$: Apparent power flow in branch *j*
$S_{max,j}$ : Overload limit of branch j
$w_j$ : Weighting factor
**nl** : Number of branches

SI=VSI+PSI
(12)

## IV. SIMULATIONS RESULTS

The solutions for best possible location of FACTS devices to minimize the setting up cost of FACTS devices and overloads for IEEE 6 bus test systems was obtained and discussed in this section. The data of system [12] shown in APPENDIX A.

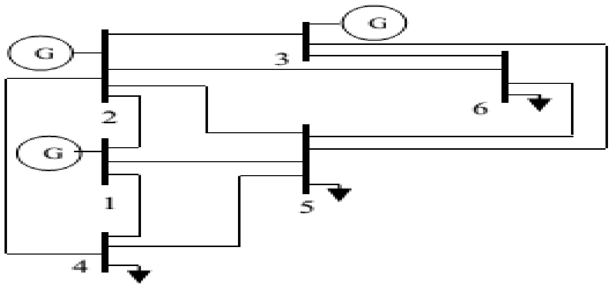


Figure (8) Six bus 3 Generator systems.

The six bus test system consists of 6 busses, 11 lines and three generators. The results for the system are presented as follows:

The location of FACTS devices (TCSC and SVC) depend upon Out Side Bus Voltage, and Over Line Limit values which are calculated for 11 branches by considering all single contingencies. Then the branches are ranked according to their values of Contingency security index(SI) which are given in Table (2). And Table (3).

Table (2): Line Outage Ranking.

| Rank | Line Outage | Over Line Limit | Out Side Bus Voltage | Security Index ( SI ) |
|---|---|---|---|---|
| 1 | Line 2 ( 1 – 4 ) | ( 1 – 2 ) , ( 2 – 4 ) | V4 | 11.039 |
| 2 | Line 3 ( 1 – 5 ) | ( 1 – 4 ) , ( 2 – 4 ) | V5 | 9.996 |
| 3 | Line 5 ( 2 – 4 ) | ( 1 – 4 ) | V4 , V5 | 9.839 |
| 4 | Line 8 ( 3 – 5 ) | ( 2 – 4 ) , ( 3 – 6 ) | V5 | 8.054 |
| 5 | Line 6 ( 2 – 5 ) | ( 2 – 4 ) | V5 | 7.982 |

Table (3): Location and Size of TCSC & SVC When Line Outage.

| Line Outage | TCSC | | SVC | |
|---|---|---|---|---|
| | Location | Size ( p.u ) | Location | Size ( Mvar ) |
| Line 2 ( 1 – 4 ) | Line 3 ( 1 – 5 ) | -0.166 | Bus 4 | -122 |
| Line 3 ( 1 – 5 ) | Line 6 ( 2 – 5 ) | -0.144 | Bus 5 | -166 |
| Line 5 ( 2 – 4 ) | Line 3 ( 1 – 5 ) | -0.169 | Bus 4 | -130 |
| Line 8 ( 3 – 5 ) | Line 6 ( 2 – 5 ) | -0.14 | Bus 5 | -168 |
| Line 6 ( 2 – 5 ) | Line 2 ( 1 – 4 ) | -0.102 | Bus 5 | -165 |

Table (2) show s the ranking of the line outage, Over Line Limit, Out Side Bus Voltage, and the Security Index ( SI ) for each case. While Table (3) shows the branch number Line 3 (1 – 5), Line6 (2 – 5), Line 3 (1 – 5), Line 2 (1 – 4), is chosen as the best location to place the TCSC and the best location of SVC types on bus (4,5) of FACT's devices for single Line Outage.

All line outage ranking for Ieee6-bus shown in Figures(9-13).

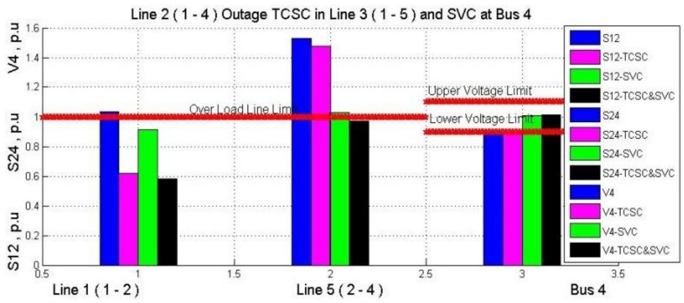


Figure (9): Line2 (1-4) outage TCSC in line3 (1-5) and SVC at bus 5.

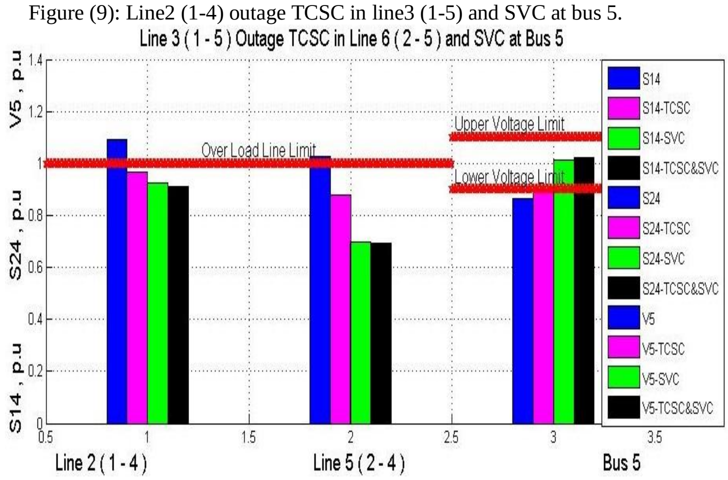


Figure (10): Line3 (1-5) outage TCSC in line6 (2-5) and SVC at bus 5.

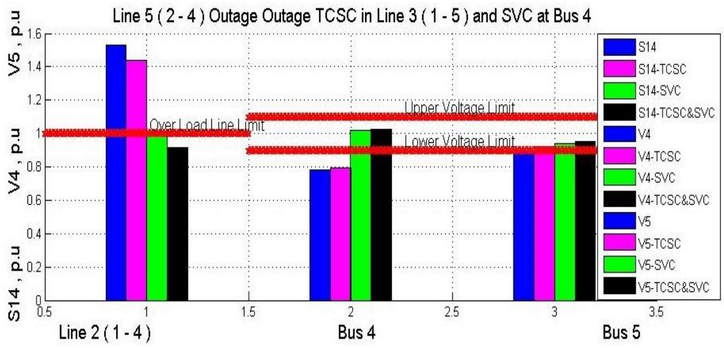


Figure (11): Line5 (2-4) outage TCSC in line3 (1-5) and SVC at bus 4.

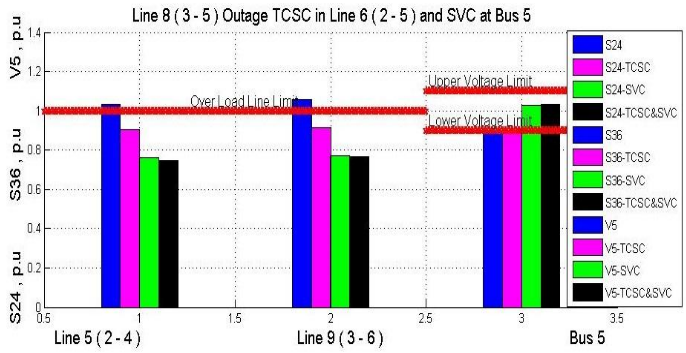


Figure (12): Line8 (3-5) outage TCSC in line6 (2-5) and SVC at bus 5.

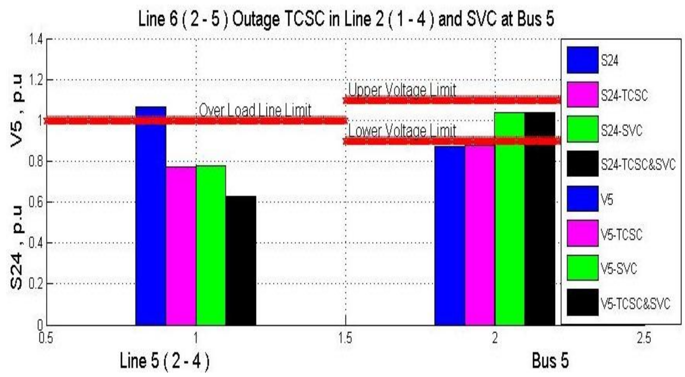


Figure (13): Line 6(2-5) outage TCSC in line2 (1-4) and SVC at bus 5.

The Table (4) shows the overloading line and Outside Bus Voltage before and after Placing TCSC & SVC When Line Outage of branches occur in the system and the Security Index (SI) for each case before and after Placing TCSC & SVC. And as compare between the network with and without connected TCSC & SVC and with connected two types together. The Security Index (SI) for Line2 (1-4) are reduced from 11.039 to 7.167 with connected TCSC & SVC at same time. And it is reduced for other lines outage as shown below.

Table (4): Over Load Line and Outside Bus Voltage before and after Placing TCSC & SVC When Line Outage

| Line Outage | Without TCSC & SVC: Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) | With TCSC: Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) | With SVC: Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) | With TCSC & SVC: Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line 2 (1-4) | (1-2) | 103.652 | | | | --- | --- | | | | --- | --- | | | | --- | --- | | | |
| | (2-4) | 152.832 | V4 | 0.894 | 11.039 | (2-4) | 147.762 | V4 | 0.898 | 10.387 | (2-4) | 102.842 | --- | --- | 7.591 | --- | --- | --- | --- | 7.167 |
| Line 3 (1-5) | (1-4) | 109.384 | | | | --- | --- | | | | --- | --- | | | | --- | --- | | | |
| | (2-4) | 102.628 | V5 | 0.865 | 9.996 | --- | --- | V5 | 0.896 | 9.561 | --- | --- | --- | --- | 6.667 | --- | --- | --- | --- | 6.661 |
| Line 5 (2-4) | | | V4 | 0.782 | | | | V4 | 0.792 | | | | --- | --- | | | | --- | --- | |
| | (1-4) | 153.013 | V5 | 0.893 | 9.839 | (1-4) | 143.597 | --- | --- | 9.343 | (1-4) | 100.461 | --- | --- | 5.436 | --- | --- | --- | --- | 5.268 |
| Line 8 (3-5) | (2-4) | 103.476 | | | | --- | --- | | | | --- | --- | | | | --- | --- | | | |
| | (3-6) | 105.773 | V5 | 0.86 | 8.054 | --- | --- | V5 | 0.893 | 7.741 | --- | --- | --- | --- | 5.184 | --- | --- | --- | --- | 5.081 |
| Line 6 (2-5) | (2-4) | 106.266 | V5 | 0.872 | 7.982 | --- | --- | V5 | 0.877 | 7.673 | --- | --- | --- | --- | 5.08 | --- | --- | --- | --- | 4.967 |

Table (5) shows the ranking of the Generator Outage Ranking, and the Security Index (SI) for each case of Generators.

Table (6) shows the branch number Line 3 (1 – 5), Line6 (2 – 5), Line 3 (1 – 5), are chosen as the best location to place the TCSC and the best location of SVC types on bus (4,5) of FACT's devices for single Generator Outage.

Table(5): Generator Outage Ranking

| Rank | Generator Outage | Over Line Limit | Out Side Bus Voltage | Security Index ( SI ) |
|---|---|---|---|---|
| 1 | Generator 2 | ( 1 – 4 ) , ( 3 – 6 ) | V4 , V5 | 10.68 |
| 2 | Generator 1 | ( 2 – 4 ) , ( 3 – 6 ) | V5 | 9.882 |
| 3 | Generator 3 | ( 1 – 4 ) , ( 2 – 4 ) | V5 | 9.372 |

Table (6): Location and Size of TCSC & SVC When Generator Outage

| Generator Outage | TCSC: Location | TCSC: Size ( p.u ) | SVC: Location | SVC: Size ( Mvar ) |
|---|---|---|---|---|
| Generator 2 | Line 3 ( 1 – 5 ) | -0.16 | Bus 5 | -190 |
| Generator 1 | Line 6 ( 2 – 5 ) | -0.162 | Bus 4 | -127 |
| Generator 3 | Line 3 ( 1 – 5 ) | -0.139 | Bus 5 | -168 |

All generator outage ranking for IEEE 6-bus shown in Figures(14-16).

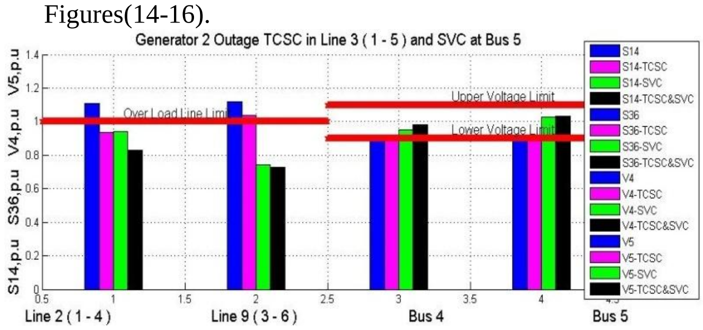


Figure (14): Generator2 outage TCSC in line3 (1-5) and svc at bus 5.

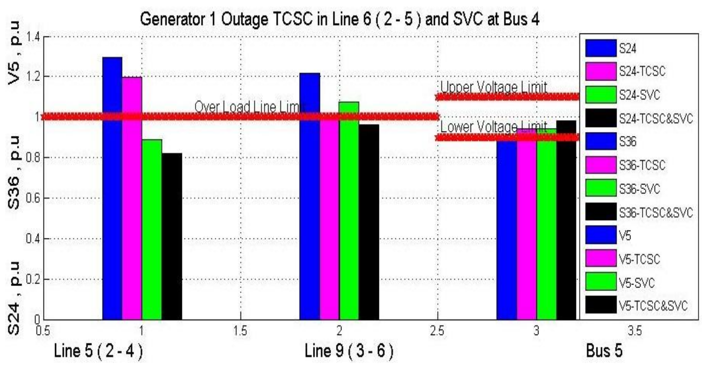


Figure (15): Generator1 outage TCSC in line6 (2-5) and svc at bus 4.

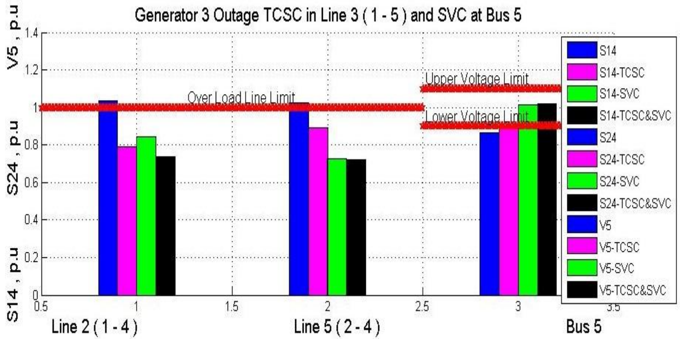


Figure (16): Generator3 outage TCSC in line3 (1-5) and svc at bus 5.

The Table (7) shows the Over Load Line and Outside Bus Voltage before and after Placing TCSC & SVC When Generator Outage occur in the system and the Security Index (SI) for each case before and after Placing TCSC & SVC. And as compare between the network with and without connected TCSC & SVC and with connected two types together. The Security Index (SI) for Generator 2 (1-4) are reduced from 10.68 to 6.346 with connected TCSC & SVC at same time. And it is reduced for other lines outage as shown below.

Table (7): Over Load Line and Outside Bus Voltage before and after Placing TCSC & SVC When Generator Outage

| | Without TCSC & SVC | | | | | With TCSC | | | | | With SVC | | | | | With TCSC & SVC | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generator Outage | Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) | Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) | Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) | Over Line Limit | | Out Side Bus Voltage | | Security Index(SI) |
| Generator 2 | (1-4) | 110.754 | V4 | 0.896 | | --- | --- | --- | --- | | --- | --- | | | | --- | --- | | | |
| | (3-6) | 111.634 | V5 | 0.883 | 10.68 | (3-6) | 103.506 | --- | --- | 9.843 | --- | --- | --- | --- | 7.032 | --- | --- | --- | --- | 6.846 |
| Generator 1 | (2-4) | 129.581 | | | | (2-4) | 119.858 | | | | --- | --- | | | | --- | --- | | | |
| | (3-6) | 121.417 | V5 | 0.891 | 9.882 | --- | --- | --- | --- | 9.527 | (3-6) | 107.358 | --- | --- | 7.246 | --- | --- | --- | --- | 7.141 |
| Generator 3 | (1-4) | 103.598 | | | | --- | --- | | | | --- | --- | | | | --- | --- | | | |
| | (2-4) | 102.387 | V5 | 0.865 | 9.372 | --- | --- | V5 | 0.891 | 8.791 | --- | --- | --- | --- | 6.306 | --- | --- | --- | --- | 6.272 |

## V. CONCLUSION

This paper presents a procedure to place two types of FACTS devices TCSC& SVC along the system branches and buses based on the voltage security index and apparent power index values to alleviate system overloads and to improve the system security margin during (N-1) contingency and voltage limits. The combination of TCSC and SVC were considered in this work as well as connected each type alone. Simulations were performed on IEEE 6-bus. The best location of FACTS devices can be very effective to improved power system network. From results observed that the system security margin improved after placing (TCSC& SVC) FACTS devices along the electrical power system. These settings can be effectively used to enhance the system security margin without investing in additional transmission resources.

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## APPENDIX A

The six bus test system consists of 6 busses, 11 lines and three generators. The parameters of the systems are given below.

Table A. Line Data for six bus system.

| Line No. | From | To | Impedance | | Bcap(PU) |
|---|---|---|---|---|---|
| | | | R(PU) | X(PU) | |
| 1 | 1 | 2 | 0.10 | 0.20 | 0.020 |
| 2 | 1 | 4 | 0.05 | 0.20 | 0.020 |
| 3 | 1 | 5 | 0.08 | 0.30 | 0.030 |
| 4 | 2 | 3 | 0.05 | 0.25 | 0.030 |
| 5 | 2 | 4 | 0.05 | 0.10 | 0.010 |
| 6 | 2 | 5 | 0.10 | 0.30 | 0.020 |
| 7 | 2 | 6 | 0.07 | 0.20 | 0.025 |
| 8 | 3 | 5 | 0.12 | 0.26 | 0.025 |
| 9 | 3 | 6 | 0.02 | 0.10 | 0.010 |
| 10 | 4 | 5 | 0.20 | 0.40 | 0.040 |
| 11 | 5 | 6 | 0.10 | 0.30 | 0.030 |

bcap = Half line charging suseptance

Table B. Bus Data for six bus system.

| Bus No. | Voltage (PU) | $P_{gen}$(PU MW) | $Q_{gen}$(PU MVAR) | $P_{load}$(PU MW) | $Q_{load}$(PU MVAR) |
|---|---|---|---|---|---|
| 1 | 1.05 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 1.05 | 0.5 | 0.0 | 0.0 | 0.0 |
| 3 | 1.07 | 0.6 | 0.0 | 0.0 | 0.0 |
| 4 | 1.0 | 0.0 | 0.0 | 0.7 | 0.7 |
| 5 | 1.0 | 0.0 | 0.0 | 0.7 | 0.7 |
| 6 | 1.0 | 0.0 | 0.0 | 0.7 | 0.7 |

Table C. Generation Data for six bus system.

| Generator Bus No. | Transiet reactance | Inertia constant H |
|---|---|---|
| 1 | 0.0+j0.608 | 23.64 |
| 2 | 0.0+j0.1198 | 6.4 |
| 3 | 0.0+j0.1813 | 3.01 |