Voltage Stability Enhancement by Optimal Allocation of STATCOM and SVC

Shubham Sharma, Ajay Bhardwaj, Sarfaraz Nawaz
Department. of Electrical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan Jaipur, India
Email: Sharmamani912@gmail.com
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Abstract: The current deregulated power system structure demands stability, accuracy and rapid response day by day. The protection and reliability of the electric power system cannot be compromised by voltage instability. Flexible AC transmission systems (FACTS) are therefore used with weak buses to recover and control voltage. Static Synchronous Compensator (STATCOM) and Static Var Compensator (SVC) provide fast working dynamic compensation when a significant fault arises. This article presents the enhancement of voltage stability by minimizing the voltage deviation of the IEEE14 bus test system. For this, the SVSI index is used with STATCOM and SVC.

Keywords: Voltage Stability Index, STATCOM (Static Synchronous Compensator, SVSI (Simplified Voltage Stability Index), RED (Relative Electrical Distance).

1. INTRODUCTION

One of the main challenges for planning and operation is voltage regulation concerns in electric power systems. The stability of voltage is related to the potential of power systems to retain voltages at the appropriate point for all nodes of the system in normal conditions and in case of any disturbances in the system [1]. The voltage stability issue has arisen in recent decades, it gained more focus mainly due to several accidents of stability in many countries has occurred. In Germany, Japan, France, Belgium, Sweden, and the United States, some of the most common cases of voltage stability accidents have been recorded [2-3].

As power systems, along with environmental and economic limitations, become heavier and more complicated, voltage instability is an increasingly important issue, causing devices to operate near their limits.

Mainly SVC (Static Var Compensators) and STATCOM (Static Synchronous Compensators) can be used to improve the stability of voltage.

One of the key applications of voltage stability indices is the detection of poor transmission lines and buses in power grids. [4-8]. Therefore, the line or bus nearest to the critical value is chosen as the weakest line and bus. Different VSI methods for DG positioning and size calculation, capacitor allocation and power planning are used in different situations [9-13].

2. FORMULATION OF PROBLEM

Voltage stability problem has a very harmful impact on electrical power system reliability. The main purpose of this paper is to minimize the deviation of voltage, problem V_D from the power system. The voltage difference in the load bus for voltage improvement is must be as minimal as possible. The minimization of V_D at load bus is the objective mechanism, which is is defined as:

$$V_D = \min \left(\sum_{1}^{n} |V_n - V_{refn}|\right)$$

Where

V_D is the voltage deviation
n is the number of buses
V_n is the voltage of nth bus
V_{refn} Reference voltage at nth Bus, basically it is set at 1

The primary objective is to increase the voltage on load buses and can be calculated by optimizing FACTS allocation at weak buses. For a study of both stable and dynamic systems conditions, the FACT device's control system can be designed, calculated and configured optimally.

3. VOLTAGE STABILITY INDICES

Various methods are available to determine whether a system is stable or not and how much close to instability. These methods are referred to as the voltage stability index. It indicates how close the device is to the failure of voltage or uncertainty. The indexes should be quick, easy to use and computational cost is cheap.

The VSIs determine the weakest bus of the system and also determine stability condition of any transmission line connected between two buses. The voltage stability analysis of a given PSN should generally be as follows:

- Identify proximity to the failure of the systems.
- Determine when voltage instability can happen.
- Identify the critical bus of the System.

3.1 Simplified Voltage Stability Index (SVSI)

Perez-Londono et al. developed SVSI on the basis of VLSB concept. The SVSI is an improved voltages stability index preferable for determining voltage stabilization in the power system. This index is described by the Relative Electrical Distance (RED), so that the generator nearest to a given load bus is defined as well as the variation of power variables to boost its performance.

3.1.1 Relative Electrical Distance (Red)

The RED concept is based on the generator's theory of relative distances from the load bus in the network. The next generator should primarily obey the load, but it includes all restrictions as far as possible.

The relation of the generator bus (G) to a load bus (L) of a complex current (I) and voltage vectors (V) is defined for other system, as shown in the admittance matrix:

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (1)$$

Where

I_G = the current injected of generator Buses

I_L = the current injected of Load Buses

V_G = complex bus voltages of generator

V_L= complex bus voltage of Load

The related components of the Y-bus matrix network are $[Y_{GG}]$ $[Y_{GL}]$, $[Y_{LG}]$,and $[Y_{LL}]$. Revamp equation (1), (2) can be given as:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (2)$$

The matrix, which provides relationship between the load and the source bus voltage is F_{LG}= -$[Y_{LL}]^{-1}$ $[Y_{LG}]$, that is a complex matrix that provides the. The Relative Electric Distance Theorem indicates the equation (3) which implies that the F_{LG} matrix gives the relative location from load buses to generator buses.

$$R_{LG}=[A]\text{-ab } [F_{LG}]=[A]\text{-abs } ([Y_{LL}]^{-1}[Y_{LG}]) \quad (3)$$

The SVSI definition is the following:

$$SVSI_r = \frac{\Delta V_r}{\beta V_r} \quad (4)$$

Where β is the correction factor that can be estimated by equation (5).

$$\beta = 1\text{- } [\max (|V_m|\text{-}|V_l|)]^2 \quad (5)$$

The decrease in the voltage of Thevenin impedance is expressed in ΔV_r, and can be defined by

$$\Delta V_r \cong |\ V_g\text{-}V_r\ | \quad (6)$$

Here, x and y are the voltage phasor between the t, the loading bus and the generator. The RED theory is used to determine this. If the SVSI value is closer to 1 for a particular bus, this bus is the principal bus and this is the bus where we allocate the FACTS.

4. STATIC SYNCHRONOUS CONDENSER (STATCOM) & STATIC VAR COMPENSATOR (SVC)

4.1 STATCOM

The implementation of high-power electronic equipment is necessary in order to improve the operation and control of energy systems. These devices are called the flexible AC transmission systems (FACTS) such as STATCOM [14] and SVC. We are using STATCOM and SVC to boost the voltage profile in this article. It is a reactive power compensator that can produce and consume reactive power and the STATCOM is a shunt connected device. The STATCOM will vary its output voltage to change a particular electricity network parameter. In STATCOM (Voltage Source Inverter) VSI plays a vital role because it can operate effectively with the higher frequencies. STATCOM can develop networks for transmission and distribution. The basic structure of STATCOM is shown by figure 1.

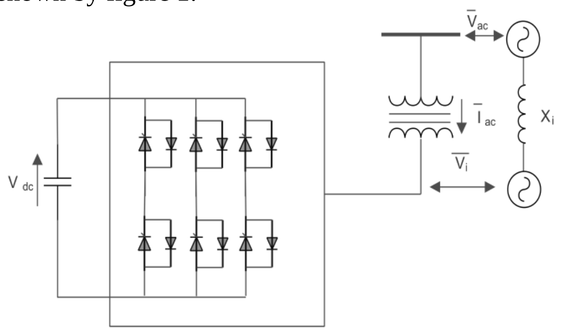

Figure 1. Basic Structure of STATCOM

4.2 SVC

In the electrical energy transmission and delivery industry, developments of power electronics have introduced powerful tools. The Thyristor-Controlled Reactive Power Compensators or Static Var Compensators (SVC) [15] are among the main products recently used. In the power system, the excellent performance of such economical and flexible equipment has been confirmed. Such equipment has been successfully used [16-18].

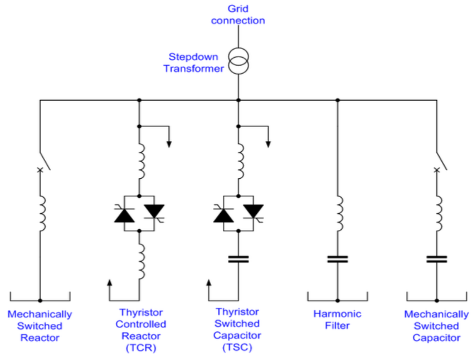

Figure 2. Basic Structure of SVC

5. RESULTS OF SIMULATION AND COMPARISONS

The IEEE14 bus system in PSCAD 4.5.0.0. Version is used for simulation results of SVSI with STATCOM and SVC. The figure (3) shows the single line diagram of the IEEE 14 bus system. That is having 17 transmission lines, 3 synchronous condensers, and bus no 1 is named by slack bus having a constant voltage 1 in every condition. The base case voltage for IEEE 14 Bus system is shown by table below.

Table 1: Base Voltage of IEEE 14 Bus System

Bus Number	Bus Voltage
1	1
2	1.001
3	0.9999
4	0.971
5	0.9702
6	1.008
7	0.993
8	1.005
9	0.988
10	0.9835
11	0.991
12	0.991
13	0.9862
14	0.968

5.1. Simplified Voltage Stability Index

The SVSI is a bus voltage stability index, firstly by the calculation of SVSI we find out the optimal location of the STATCOM and SVC. The SVSI for all load buses is now enlightens in table 2.

Table 2: SVSI for load Buses

Bus No.	Voltage
4	0.0309
5	0.0317
7	0.0221
9	0.0172
10	0.0249
11	0.0163
12	0.0163
13	0.0221
14	0.043

Bus 14 has the maximum value from SVSI, so bus number 14 is the system's weak bus. STATCOM and SVC are therefore can be situated at bus number 14. Thus, after attachment of these devices the voltage profile was upgraded for all buses.

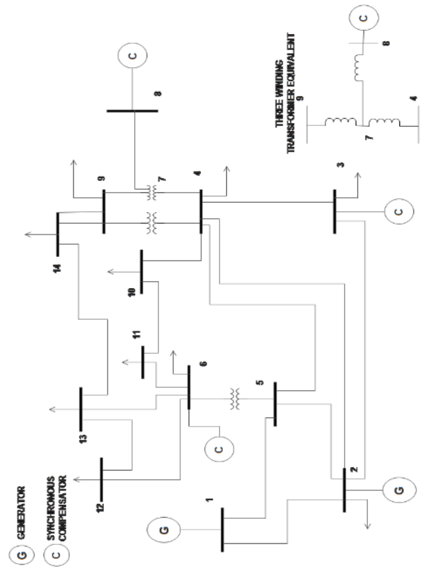

Figure: 3 14 Bus system single line diagram

Table 3: Voltage with and without STATCOM

Bus No	Voltage (with -out STATCOM)	Voltage (with STATCOM)
1	1	1
2	1.001	1.002
3	0.9999	1.001
4	0.971	0.9735
5	0.9702	0.9722
6	1.008	1.012
7	0.993	0.9994
8	1.005	1.006
9	0.988	0.9996
10	0.9835	0.9938
11	0.991	0.9989
12	0.991	0.9985
13	0.9862	0.9856
14	0.968	0.9986

The voltage profile of each bus is improved after STATCOM is installed. The voltage deviation can now be calculated as:

Condition	Without STATCOM	With STATCOM
Voltage Deviation	0.1441	0.0489

Now the SVC will be allocated at the weakest bus 14, which was already found out by SVSI. So, after the allocation of SVC the voltage with SVC and without SVC is shown below.

Table 4: Voltage with and without SVC

Bus No	Voltage (with -out SVC)	Voltage (with SVC)
1	1	1
2	1.001	1.002
3	0.9999	1.001
4	0.971	0.9734
5	0.9702	0.9722
6	1.008	1.012
7	0.993	0.9993
8	1.005	1.006
9	0.988	0.9996
10	0.9835	0.9838
11	0.991	0.9988
12	0.991	0.9988
13	0.9862	0.9854
14	0.968	0.998

The voltage profile of each bus is improved after SVC is installed. The voltage deviation can now be calculated as:

Condition	Without SVC	With SVC
Voltage Deviation	0.1441	0.0697

Table 5: Comparison of Voltage Deviation

Sr. No.	Name of Device	Name of Technique	Location of Bus	Voltage Deviation
1	STATCOM	SVSI	14	0.0489
2	SVC	SVSI	14	0.0697
3	STATCOM	DA [2018][19]	9	0.3529
4	STATCOM	TLBO [2017][20]	5	0.4993
5	STATCOM	PSO [2013][21]	12	0.8952

The table number 5 shows comparison of Bus allocation with STATCOM and SVC. Figure (4) show PSCSD model with STATCOM allocation and figure (5) shows PSCAD model with SVC allocation.

6. CONCLUSION

In this article, a bus VSI, SVSI (Simplified Voltage Stability Index) has been presented here to find weakest bus of the IEEE 14 Bus system. Voltage stability Enhancement and minimization of voltage deviation are the objectives of this article. STATCOM and SVC are FACTS devices, which are used to minimize the voltage deviation by allocating these devices at weakest bus of the system. The results shows that SVSI gives superior results in comparison to other technique as shown in Table 5. Also it has been shown that voltage deviation is minimum in the case of application of STATCOM.

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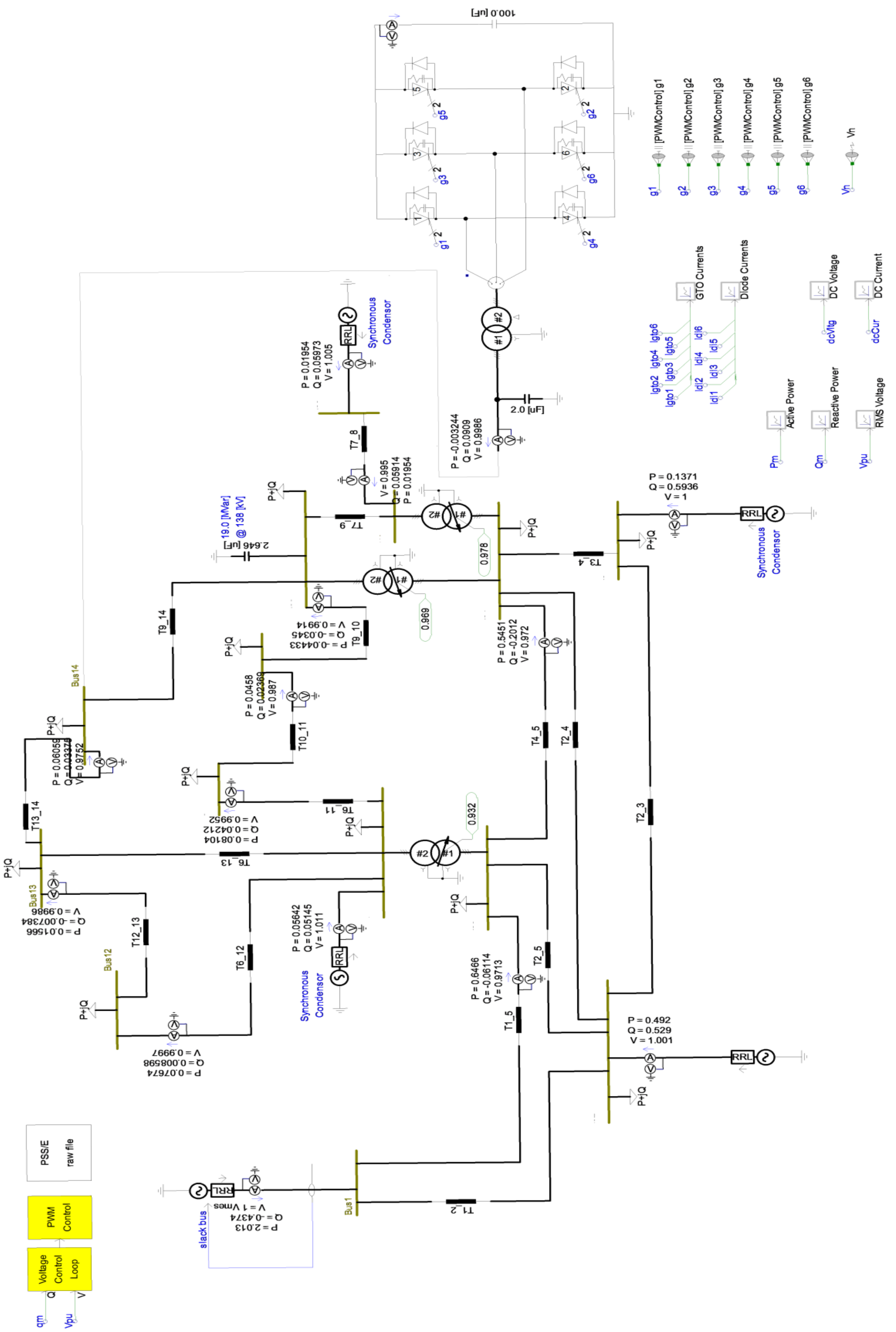

Figure 4: With STATCOM 14 Bus PSCAD Model for SVSI

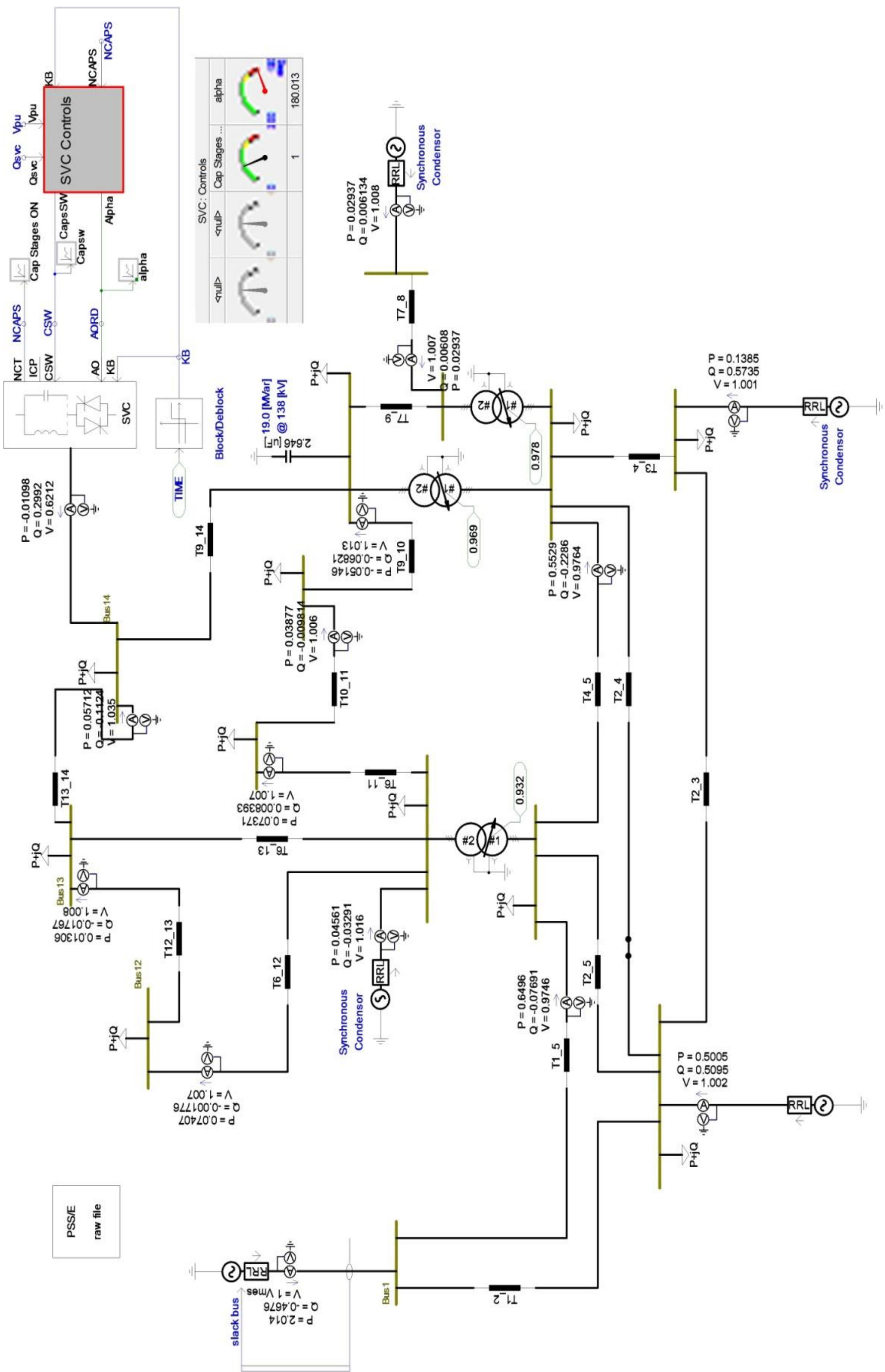

Figure 5: With SVC 14 Bus PSCAD Model for SVSI

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