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Voltage Stability Enhancement Using SVC in PSCAD Software

Mohammad Shabir, Sarfaraz Nawaz, and Ankit Vijayvargiya

Abstract In the modern power system, the need for flexibility, accuracy and fast response is growing every day. Voltage instability affects the system's reliability and security. FACTS devices are used to restore voltage and to control the weak bus. SVC provides the fast acting dynamic compensation in case of severe fault. This paper is focused on voltage stability improvement of IEEE-14 bus test system. Simplified voltage stability index (SVSI) is calculated to identify the weakest bus of the system. All the analysis is being performed using PSCAD simulation software.

Keywords Voltage stability · Voltage deviation · Static VAR compensator · Simplified voltage stability index · Relative electric distance

1 Introduction

The demand for electrical energy is very much intense in the present scenario. Approximately 27% of energy is lost in distribution and transmission in India. India is the top most country in the list of T&D losses [1], which has led the energy system to the transmission and distribution limitation crisis. Such constraints have an even greater impact on stable and safe power supply in energy transmission, typically in

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the electric power transmission and distribution network, acceptable voltage variability is much smaller, but due to heavy charging, the voltage rating is not held to the mark [2]. Each time the load or fault increases, and the voltage rate of the system changes. With the voltage fall, the need for reactive power increases. If the demand for reactive energy is not satisfied, the voltage of the bus will decrease further, resulting in a cascading effect on the native regions [3]. Because of any unusual state of fault, the disruption arises in the process, and it goes to transient oscillations. Such unwanted oscillations can alter application performance characteristics. This is therefore essential for monitoring and is accomplished by using the static VAR compensator (SVC) shunt FACTS device designed with auxiliary controllers. SVC will dampen the swings and improve the overall stability of the system [4]. This paper mainly deals with identifying the critical bus by calculating the simplified voltage stability index (SVSI), and voltage enhancement is justified on the critical bus after installation of SVC.

Power system stabilizers (PSS), static VAR compensator (SVC) and shunt static synchronous comparator (STATCOM) addressed various control strategies for damping unwanted oscillations in the power system [5]. Overloaded circuits and buses limit the total transmission power. FACTS technology can control bus voltage, while improving total transmission power (TTC) is a favorable process [6]. A genetic algorithm is used to optimize the FACTS device location. Optimization depends mostly on three parameters: device position, form (shunt or series) and size/value of devices [7]. In [8], many reactive power compensation technologies are summarised and compare the characteristics, operation and applications. The static VAR generators are used in the transmission and distribution network to improve voltage control, stability and power factor [8]. Two forms of FACTS, shunt and series compensation, are efficiently installed using a basic algorithm dependent on heuristic and practical rule that allows us to select the type of FACTS, to determine where FACTS is positioned and managed [9]. The use of PSO to investigate the optimum position and setting parameters of SVC and TCSC controllers eliminates small signal oscillations [10]. This paper explains how SVC's function and structure contain TCR and how it affects the power system's voltage stability. The model has impedance variable that changes with the TCR's firing angle [11].

In this paper, SVC device is used to improve voltage stability of the system. The optimal location of SVC is determined by SVSI. The IEEE 14 bus system is used as test system to check the efficiency of proposed SVSI.

2 Problem Formulation

The voltage instability has a very untoward effect on the reliability of the power system. The aim of this paper study is to eliminate the system's voltage deviation (VD) problem. Voltage deviation is made as small as possible to improve voltage at load bus. Objective function of VD minimization at load bus is defined as

$$VD = \min\left(\sum_{1}^{n}\left|V_{n-V_{\text{refn}}}\right|\right) \tag{1}$$

where

n no. of load buses
V_n voltage magnitude of nth bus
V_{refn} reference voltage of nth bus, usually set to 1 p.u

This improvement of voltage at load buses of the power system is the primary aim, which may be achieved by the connection of SVC at the optimal location. SVC control system is modeled, tuned and optimally placed to analyze the behavior in both steady and dynamic conditions of the system.

3 Mathematical Modeling of SVC

The word SVC was used for shunt linked compensator based on a thyristor without gate turn-off [12]. According to the IEEE standard, SVC is defined as a shunt connected static VAR generator or an absorber whose output is modified to exchange capacitive or inductive current in order to maintain or regulate different electrical power system parameters (Fig. 1).

To explore the effect of SVC on the power system, suitable SVC model is necessary. Here SVC is observed as shunt connected variable susceptance (B_{svc}) that transforms automatically to achieve voltage power. As regards sinusoidal voltage, algebraic equations are defined as

$$I_{\text{SVC}} = jB_{\text{SVC}}V \tag{2}$$

The fundamental frequency TCR equivalent reactance X_{TCR} is

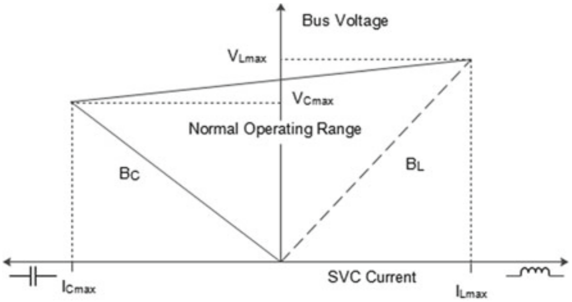

Fig. 1 V–I characteristics

$$X_{\text{TCR}} = \pi X_L/(\delta - \text{Sin}\delta) \tag{3}$$

where $\delta = 2(\pi - \alpha)$, δ is conduction angle and α is firing angle. TCR equivalent reactance X_{TCR} is firing angle (α) terms

$$X_{\text{TCR}} = \frac{\pi X_L}{2(\pi - \alpha) - \sin\alpha} \tag{4}$$

$$X_C = \frac{1}{W_c} \tag{5}$$

at $\alpha = 90°$, $X_{\text{TCR}} = X_L$ means TCR is in fully conducting mode, while at $\alpha = 180°$, $X_{\text{TCR}} = \infty$ means TCR is in blocking mode. Functional reactance of SVC is the parallel combination of X_{TCR} and X_C as.

$$X_{\text{SVC}} = \frac{\pi X_c X_L}{X_C[2(\pi - \alpha) + \sin 2\delta] - \pi X_L} \tag{6}$$

$$Q_{\text{SVC}} = -V_K^2 \left\{ \frac{X_C[2(\pi - \alpha) + \sin 2\alpha] - \pi X_L}{\pi X_C X_L} \right\} \tag{7}$$

As the demand for reactive energy in the bus differs, the susception (B_{SVC}) varies between the boundaries. The reactive energy is, however, proportional to the bus voltage square (V_K). As voltage changes, therefore, the reactive power generated changes.

4 Simplified Voltage Stability Index

In order to detect the loadability of the system, stability indices are introduced. In a power system, indices provide data on the location of voltage instability. Such indices can either show a power system's critical bus or the stability of each line linked in an interconnected network between two buses or measure a system's voltage stability margins. This method is based on the RED theory, which informs us about the nearest generator to load bus.

4.1 Relative Electrical Distance

Assume a system of n bus, where 1, 2,……, g are generator buses and ($g + 1$),……, n are load buses. The admittance matrix of for a given system is

$$\begin{bmatrix} I_S \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{\mathrm{SS}} & Y_{\mathrm{SL}} \\ Y_{\mathrm{LS}} & Y_{\mathrm{LL}} \end{bmatrix} \begin{bmatrix} Y_S \\ Y_L \end{bmatrix} \tag{8}$$

here

$[I_S] = [I_1,\ldots, I_g]t$ = injected currents of generator buses, $[I_L] = [I_{g+1},\ldots, I_n]$ = injected load bus currents,

$[V_S] = [V_{11},\ldots, V_g]$ = complex generator bus voltage, $[V_L] = [V_{g+1},\ldots, V_n]$ = complex load bus voltage and $[Y_{\mathrm{SS}}]$, $[Y_{\mathrm{SL}}]$, $[Y_{\mathrm{LS}}]$, $[Y_{\mathrm{LL}}]$ = the relevant parts of the Y-Bus matrix network.

The relationship between generator bus and load bus voltages is interpreted mathematically, and we have to drive the matrix $F_{\mathrm{LS}} = -[\mathrm{Y}_{\mathrm{LL}}]^{-1}\ [Y_{\mathrm{LS}}]$ as shown in below equation.

$$[D_{\mathrm{LS}}] = \mathrm{abs}[F_{\mathrm{LS}}] \tag{9}$$

$[D_{\mathrm{LS}}]$ tells about the location of load buses with respect to generators that is called the relative electrical distance [RED]. The [RED] is obtained from $[D_{\mathrm{LS}}]$ matrix as

$$[\mathrm{RED}] = \mathrm{I} - [D_{\mathrm{LS}}] \tag{10}$$

where I is the unity matrix of size $L \times S$. As electrical distance is found with the [RED], the voltage drop (ΔV_n) is

$$\Delta V_n = \sum_{b-1}^{n_j-1} \left| \vec{V}_b - \vec{V}_{b+1} \right| \cong \left| \vec{V}_g - \vec{V}_l \right| \tag{11}$$

where

V_g Nearest generator voltage
V_1 Analyzed load voltage

In Fig. 2, it is clear that the proposed SVSI index is a measurement-based VSI that needs information from monitoring buses. Clearly, the proposed technique expects of voltage phasors at all the buses of the examined power system to find an area inclined to voltage unsteadiness.

ΔV_n is a simplification of the actual approach defined in [13]. Mostly, voltage stability indices have some degree of inaccuracy due to the different approximation [14]. But SVSI relies on other physical parameters (amplitude and phase of voltage or power) to upgrade its accuracy. To improve the condition of voltage drop in any bus, correction factor (β) for the SVSI is introduced as

$$\beta = 1 - \max(|V_m| - |V_l|)^2 \tag{12}$$

The correction factor on voltage magnitude is correlated with the largest gap. Now the SVSI is given as

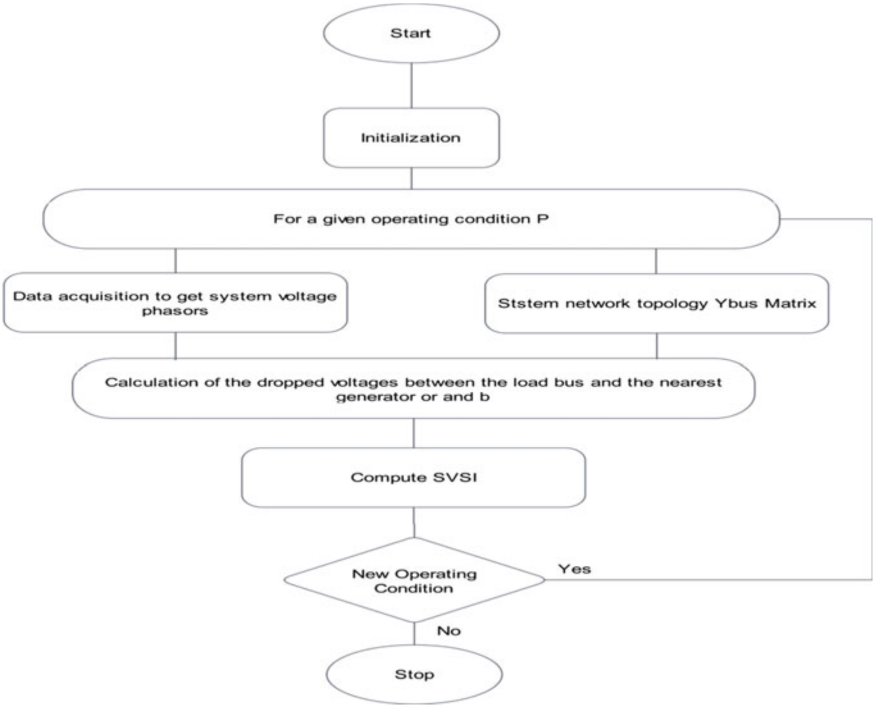

Fig. 2 Flowchart of SVSI

$$\mathrm{SVSI}_i = \frac{\Delta V_i}{\beta * V_i} \tag{13}$$

Due to the depletion in the computational effort, the whole process became simple, so it is called 'simplified' voltage stability index.

5 Simulation Results and Discussions

The IEEE 14 bus system (Fig. 3) was used as a test system to validate SVSI's proposed effectiveness. The PSCAD software simulated the IEEE 14 bus model (Fig. 4). A brief knowledge about the characteristics of each source is given with a base of 100 [MVA] for per unitizing.

Base Case: In base case simulation, we obtain the power flow solution of system as shown in Table 1 and obtained results are tabulated to calculate SVSI of each load bus under steady-state condition.

Step-1: Determine the nearest generator of the load bus by using RED concept. R_{LG} matrix helps in calculating the related electrical distance.

Table 1 Voltage profile under normal condition (in pu)

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Voltage (base case)	1	1.001	0.999	0.971	0.9702	1.008	0.993	1.005	0.988	0.9835	0.991	0.991	0.9862	0.968

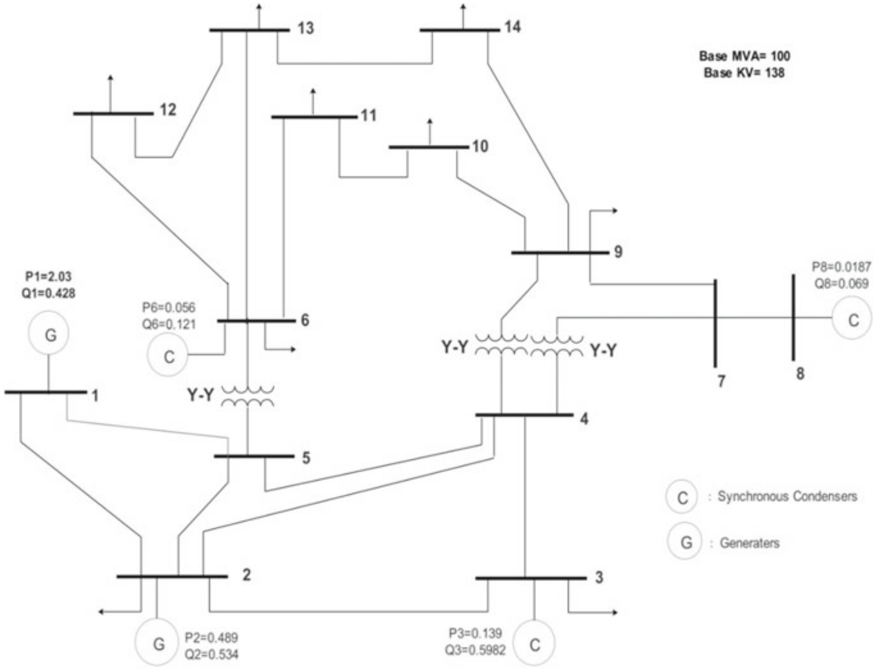

Fig. 3 Single line diagram of 14 BUS system

Step-2: Estimating the SVSI. According to the RLGMatrix, Bus 4 is nearest to the GEN 2. So the voltage drop from GEN 2 to Bus x is calculated as:

$$\Delta V_x^2 = \left|\vec{V}_2 - \vec{V}_x\right|$$

$$\Delta V_x^2 = 1.021 - 0.9969$$

Correction factor is calculated by using the highest difference of voltages as

$$\beta = 1 - (|V_m| - |V_t|)^2$$

$$\beta = 0.9914$$

Here $x =$ Bus 4. Similarly, SVSI is calculated for other load buses as shown in Table 2.

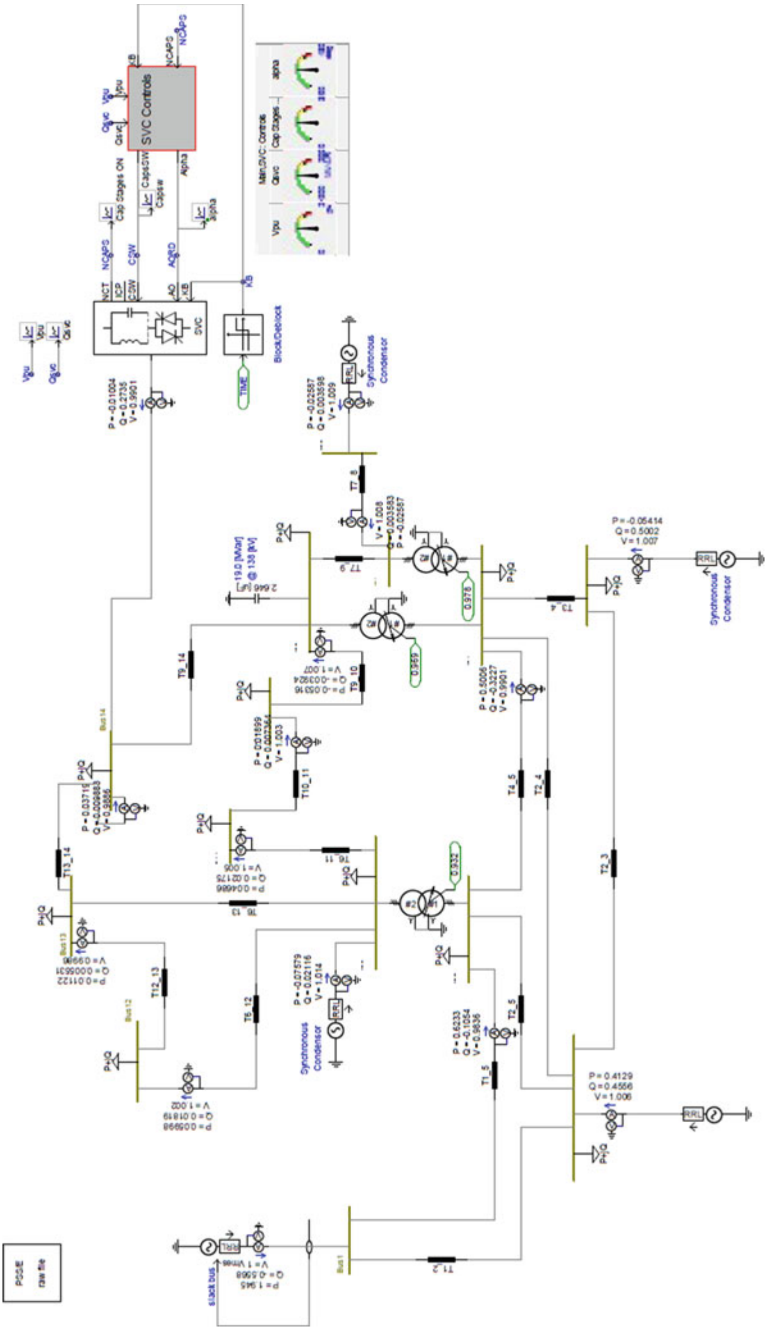

Fig. 4 IEEE 14 bus simulation model in PSCAD software

Table 2 SVSI of load buses

Load bus (x)	4	5	7	9	10	11	12	13	14
SVSI	0.0309	0.0317	0.0121	0.0172	0.0249	0.0163	0.0163	0.0221	0.043

In Table 2, SVSI for all the load buses calculated is shown. The minimum SVSI value is found at bus no 14 (0.043). Hence, the bus no 14 will be the optimal location for SVC installation. After connecting, the SVC voltage profile is improved as we can see in Table 3. From Table 3, it is found that the voltage profile of each bus is enhanced after SVC installation. Voltage deviation without SVC is 0.1442, and voltage deviation after installation of SVC up to 0.0697 is also reduced.

In Table 4, the results of proposed method are compared with the results of latest techniques. It has been observed that SVSI gives better results than any other mentioned technique. Table 4 shows that the voltage deviation of the proposed technique was found to be superior to other techniques.

Voltage deviation of each bus is also decreased after SVC allocation. Now the results of proposed SVSI technique are compared with others [16–18]. Table 4 exhibits the comparison of proposed techniques with other ones.

6 Conclusions and Future Scopes

In this paper, a new index (SVSI) has been presented to determine the location of SVC. The objective of the paper is to improve voltage stability by reducing the voltage deviation. To check the efficacy of the proposed technique, the IEEE 14 bus system has been used as a test system. The voltage deviation of the IEEE 14 bus system is also calculated after SVC installation and compared with other techniques. It has been observed that SVSI gives the optimal location of SVC (i.e., bus no. 14) for IEEE 14 bus system than any other technique. The IEEE 14 bus system has been simulated in PSCAD software.

Table 3 Voltage enhancement after connecting SVC in normal condition

Bus No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Voltage (without SVC)	1	1.001	0.999	0.971	0.9702	1.008	0.993	1.005	0.988	0.9835	0.991	0.991	0.9862	0.968
Voltage (with SVC)	1	1.002	1.001	0.9734	0.9722	1.012	0.9993	1.006	0.9996	0.9838	0.9988	0.9988	0.9854	0.998

Table 4 Comparison of proposed SVSI with other techniques

S. No.	Name of technique	Location of SVC	Voltage deviation
1.	Proposed SVSI	14	0.0697
2.	FVSI [2017] [15]	10	0.3667
3.	DA [2018] [16]	9	0.3529
4.	TLBO [2015] [17]	5	0.4993
5.	PSO [2013] [18]	12	0.8952

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