Investigation of the Best Placement for Voltage Stability by STATCOM

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Abstract

The study is related to the identification of optimal point for Static Synchronous Compensator (STATCOM) for static voltage stability. The study undertaken in IEEE 14 buses systems utilized analysis for relationships in voltage maximum loading parameters of STATCOM placed between lines and analysis for change in the bus voltage. Maximum loading parameter values obtained for each line and the improvements in weak buses that provided the best results were given in tables and figures. The results of the study show that STATCOM improves the voltage instability cases that can occur in optimal place selection.

1. Introduction

Voltage instability has been an important matter in power system operation since it has been the reason for many power blackouts around the world and hence resulted in large finance losses. Voltage instability incidents and hence power blackout can be avoided if early detection leading to voltage collapse and identification of weak areas are application. Voltage instability phenomenon has been known to be caused by heavily loaded system where large amounts of real and reactive power are transported over long transmission lines. This situation becomes worst in the absence of reactive power support in order to maintain normal voltage profiles at the receiving end buses [1-2]. Small signal stability, damping oscillations, loading problems, bifurcation instability, chaos, voltage sags and incorrect coordination of breakers are problems related to voltage instability. Flexible Alternative Current Transmission System (FACTS) devices are used in order to minimize voltage instability problems. FACTS devices generally consist of Static Synchronous Compensator (STATCOM), Static VAR Compensator (SVC), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Control (UPFC). Examining the studies on FACTS devices in the literature shows that these devices have helped solve negative situations in signal stability analysis caused by static and dynamic loads in multi bus power systems [3]. It was also seen that voltage instability problems caused by deactivation of lines can be successfully managed by FACTS devices [4, 5]. FACTS devices have also been found effective in increasing system safety in negative cases of bifurcation analysis and voltage sags [6,7]. It has also been identified in studies that parallel FACTS can regulate maximum loading parameters compared to the cases in which the system does not use bus voltage [8,9] and it has been observed in the comparison of voltage-maximum loading parameters that parallel and series FACTS devices are effective and successful for system safety [10-12]. It can be argued that power-electronics based STATCOM is more effective on the system since it is more comprehensive and advanced compared to the other series and parallel FACTS devices. The study aims to analyze the optimum point between lines for voltage stability of STATCOM in the IEEE 14 bus power system.

2. Static Synchronous Compensator (STATCOM)

The circuit modeling of an STATCOM is shown in Fig.1, which was described in STATCOM consists of voltage sourced converter and coupling transformer.

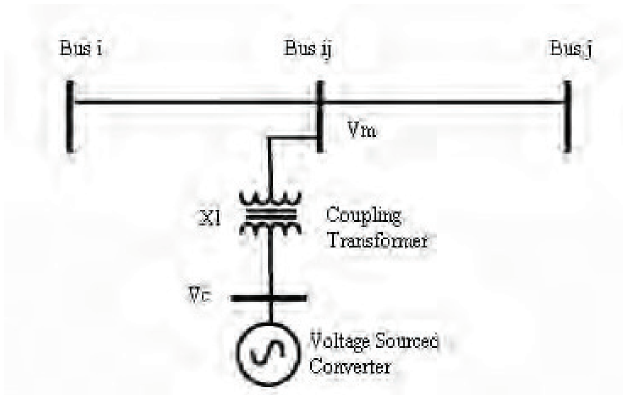

Fig. 1. STATCOM circuit modeling

The STATCOM is modeled by a voltage source connected to the power system through a coupling transformer. The voltage of the source is the output of a voltage-sourced converter (VSC) realizing the STATCOM. As shown in Fig. 1, the connection is assumed at the midpoint of the transmission line. The phase angle of the source voltage is the same as that of the midpoint voltage. This ensures that there is exchange of only reactive power and no real power between the STATCOM and the AC system [13]. The expressions for the current flowing from the STATCOM to the system and the reactive power injection are given as,

$$I_S = \frac{V_c - V_m}{Xl} \tag{1}$$

$$Q_S = \frac{V_m^{\,2} \times (V_c / V_m - 1)}{Xl} \tag{2}$$

is expressed in the form [13]. During power flow added STATCOM in the system new power flow equations.

$$P_S - V_m \times I_S \times \cos(\theta_i - \theta_j) = 0 \tag{3}$$

$$Q_S - V_m \times I_S \times \sin(\theta_i - \theta_j) = 0 \tag{4}$$

DC capacitor, conductance and suseptance added new power flow equations,

$$\begin{aligned} &P_S - V_m^2 \times G_S + V_m \times V_{dc}(G_S \times \cos(\theta_i - \theta_j) \\ &+ B_S \times (\sin(\theta_i - \theta_j)) = 0 \end{aligned} \tag{5}$$

$$\begin{aligned} &Q_S + V_m^2 \times B_S - V_m \times V_{dc}(B_S \times \cos(\theta_i - \theta_j) \\ &+ G_S \times (\sin(\theta_i - \theta_j)) = 0 \end{aligned} \tag{6}$$

V_{dc} link voltage respectively,

$$V_{dc} = V_c \tag{7}$$

$$V_{dc} = \frac{P_S}{C \times V_{dc}} + \cos(\theta_i - \theta_j) - \frac{1}{R \times C} \times V_{dc} - \frac{R}{C} \times \frac{I_S^2}{V_{dc}} \tag{8}$$

is expressed in the form [14]. R and C filter component.

3. Static Voltage Stability

The point where Jacobean matrix is singular according to continuous loading flow in static voltage stability analysis gives us the voltage stability limit. The voltage stability limit is also called critical voltage or critical point. The continuation power flow analysis uses iterative predictor and corrective steps given fig. 2.

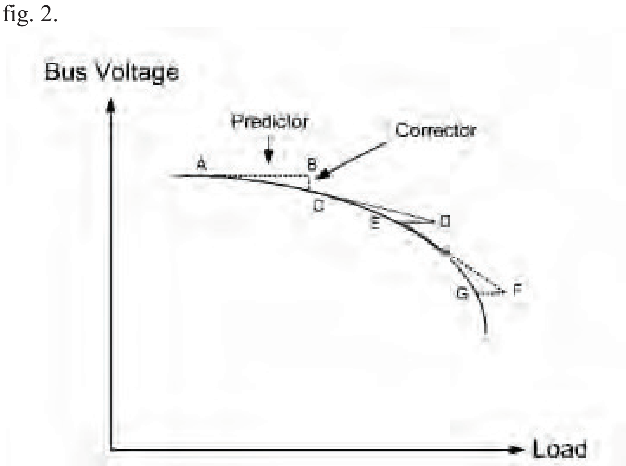

Fig. 2. Predictor-corrector used continuation power flow

The predictor step Static voltage stability, slowly developing changes in the power system occur that eventually lead to a shortage of reactive power and declining voltage. The load flow equation consists of load factor λ can be written as,

$$PF(\delta, V, \lambda) = 0 \tag{9}$$

Load flow calculation is writing,

$$P_i - \sum_{j=1}^{n} |V_i| \times |V_j| \times |Y_{ij}| \times \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \tag{10}$$

$$Q_i - \sum_{j=1}^{n-ng} |V_i| \times |V_j| \times |Y_{ij}| \times \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \tag{11}$$

The new load flow equations consists of load factor, are respectively,

$$P_L = P_{LO}(1 + \lambda) \tag{12}$$

$$Q_L = Q_{LO}(1 + \lambda) \tag{13}$$

where, P_{LO} and Q_{LO} represent the initial active and reactive loads at bus and constants P_L and Q_L respectively represent the active and reactive load increase direction of bus, λ system maximum loading parameter [15].

4. System of Study

In the study, 1 slack bus, 4 generator buses and 9 loading buses were used. Static voltage stability of this system was investigated with 100 MVAr STATCOM. In this study, maximum load parameter values investigated at different operating point conditions STATCOM. Power flow analysis of system has been examined by has been Power System Analysis Toolbox (PSAT) program [16]. First of all, power flow was provided to identify the weak bus voltage in the 14 buses power system. Table 1 shows the values obtained from all buses in order to determine the best case scenario where STATCOM system loading parameter value is the highest in the IEEE 14 buses system. Figures were also provided to display the relationship between the voltage-maximum loading parameters obtained by not utilizing STATCOM and utilizing it at the optimum point.

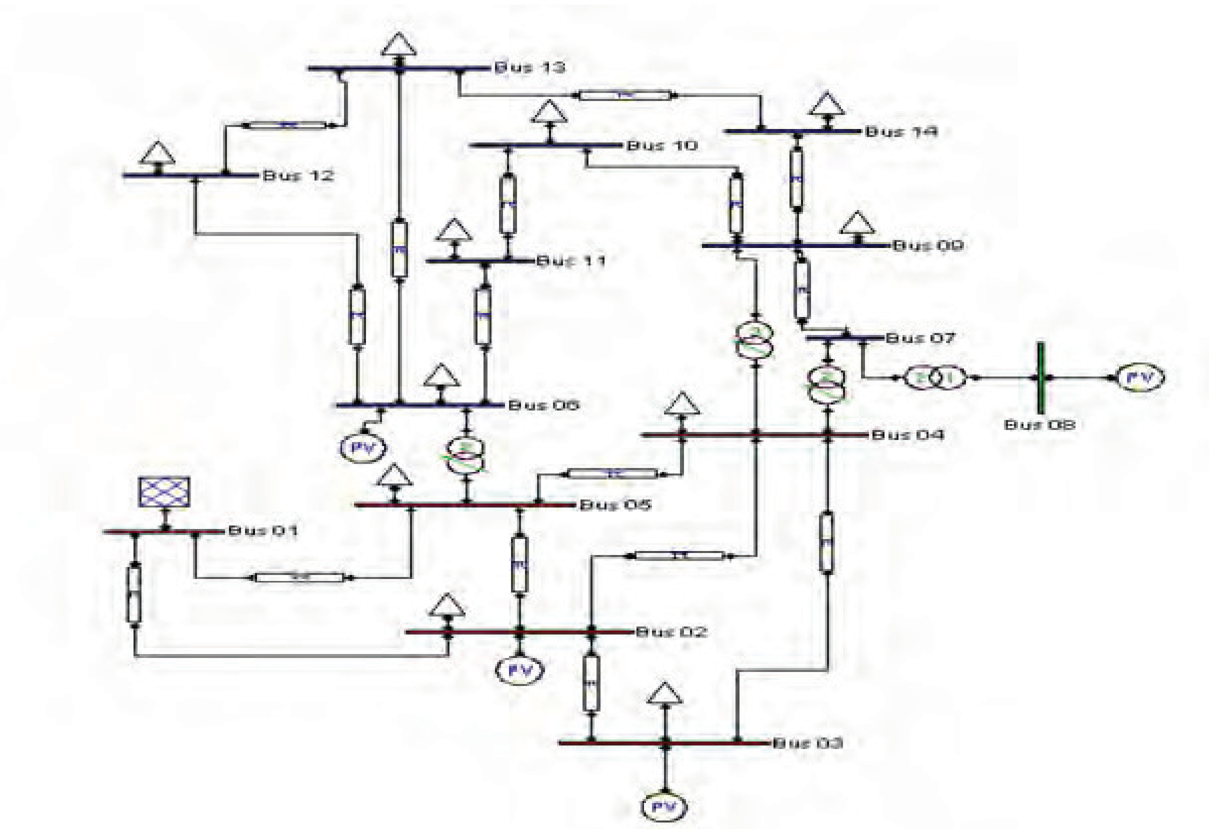

Fig. 3. IEEE 14 Buses System

5. Simulation of Study

The system maximum loading parameter value for the 14 buses power system when STATCOM is not utilized was found to be 3.9738. Also buses 4,5,7,9,10 and 14 were found to be the weakest buses at the end of the power flow in terms of voltage. The relationships between voltage-maximum loading parameters in the weak buses when STATCOM was not used was given n Figure 4 and 5 and Figure 6 displays the changes in the bus voltage.

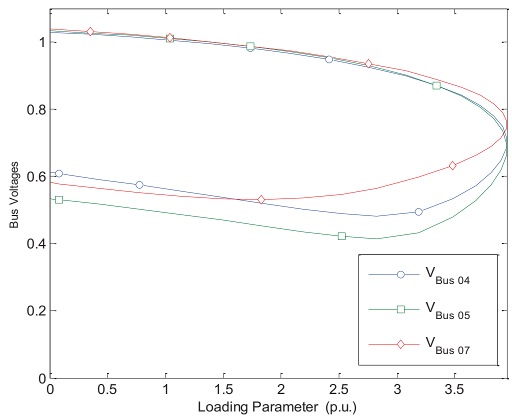

Fig. 4. Without STATCOM bus 4, 5, 7 maximum loading parameter values

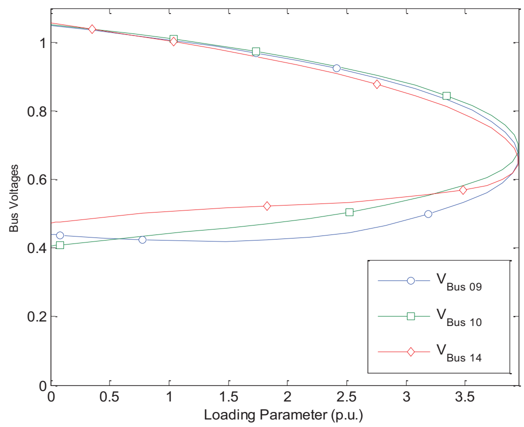

Fig. 5. Without STATCOM bus 9, 10, 14 maximum loading parameter values

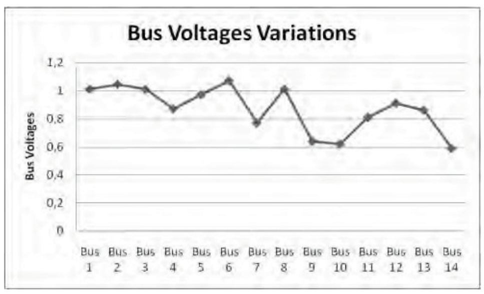

Fig. 6. Without STATCOM bus voltage variations

Table 1 shows the maximum loading parameter values obtained by using STATCOM connected to the buses on a one-on-one basis

Table 1. Maximum loading parameter values with STATCOM

Connected STATCOM	Maksimum Loading Parameter (p.u.)
2	4.0115
3	3.9962
4	4.9473
5	**5.2503**
6	4.0566
7	4.3833
8	4.0445
9	4.3717
10	4.2030
11	4.0368
12	3.9581
13	3.9813
14	4.0904

At the end of the analysis it is seen that the system's best loading parameter is obtained by connecting STATCOM to bus 5. Relationships between voltage-maximum loading parameters obtained by connecting STATCOM to bus 5 is given in Figures 7 and 8 and Figure 9 displays the changes in bus changes.

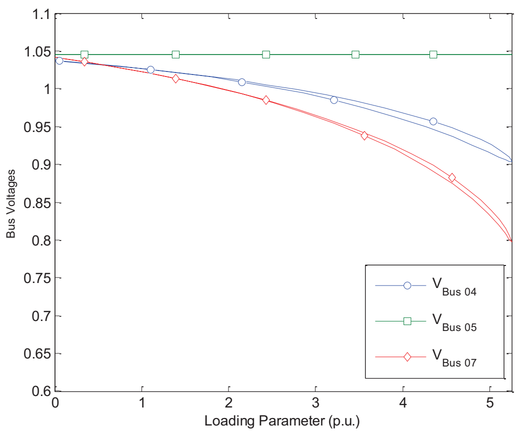

Fig. 7. With STATCOM bus 4, 5, 7 maximum loading parameter values

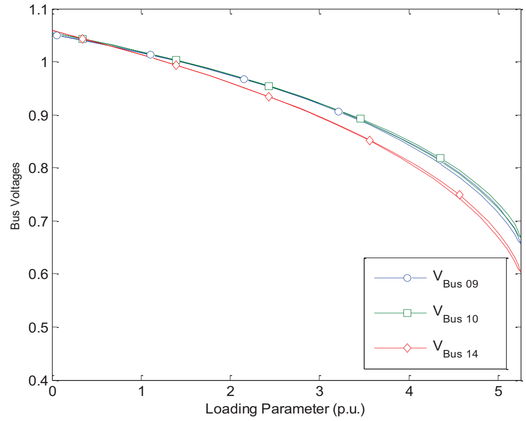

Fig. 8. With STATCOM bus 9, 10, 14 maximum loading parameter values

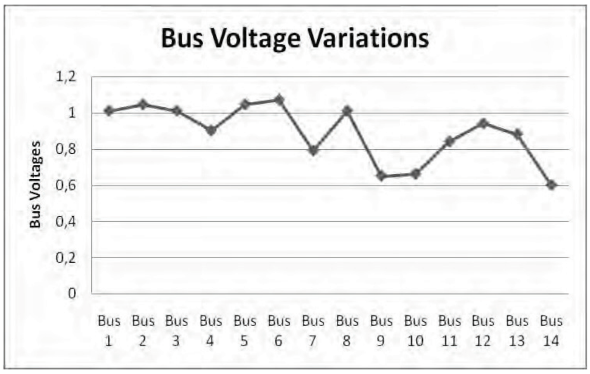

Fig. 9. With STATCOM bus voltage variations

Results show that connecting STATCOM to each bus increases the loading parameters of the system and bus voltage values.

6. Conclusion

The increases in loads where STATCOM is absent in power flow analysis will cause problems such as voltage instability and voltage sags. This study identifies the optimal point for STATCOM to determine the most powerful situation for the system. The analysis undertaken in bus 14 of IEEE shows that by connecting STATCOM to bus 5 causes the system to receive the highest loading parameters. Voltage levels also increase in line with loading parameters and the system is able to keep working in a safer manner by being protected against negative conditions.

7. References

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