

## Investigation of Static Voltage Stability Using Multiple STATCOM in Power Systems

M. Kenan DÖŞOĞLU\*  
Asst. Prof. Düzce  
University,  
Düzce

Mustafa DURSUN  
Asst. Prof. Düzce  
University,  
Düzce

Gökhan POYRAZ  
Exp. Bilecik Şeyh  
Edebali University,  
Bilecik

Bayram KÜÇÜK  
Res. Assit. Gazi  
University,  
Ankara

### *Abstract*

Enhancing the Maximum Loading Parameter (MLP) value in power system is very significant in terms of voltage stability. In this study, the relation between voltage and MLP in IEEE 14 buses system. Static Synchronous Compensator (STATCOM), a device of Flexible AC Transmission System (FACTS), is used for enhancing the MLP. Newton Raphson algorithm has been enhanced according to the admittance and jacobian matrix. In the analysis of continuous power flow, the comparisons of the cases without STATCOM, with STATCOM and multiple STATCOM have been done depending on the active and reactive power equations. This comparison has been done in the buses that have the lowest voltage profile in the continuous power flow. According to the results of this study it has been showed that the multiple use of STATCOM is very effective in terms of voltage stability in power systems.

*Keywords: MLP, STATCOM, Newton raphson algorithm, jacobian matrix*

## INTRODUCTION

The voltage stability is very effective for the operation and reconstruction of power systems. As a result of transient cases and changing operation conditions, such instable events as changing voltage profiles in power systems have occurred. For this reason reactive power support is needed to arrange the bus voltages. FACTS devices are utilized to provide reactive power support for buses. When the previous studies in literature related to FACTS devices utilized in power systems (Messina, et. al. 2003).

Various critical clearing time and maximum loading conditions have been taken as the base in investigating voltage regulation and rotor angle stability in (Abido, 2005). (Sahoo, et. al. 2004; Soto and Ruben, 2004) includes a feedback nonlinear controller design for a STATCOM installed in a single machine infinite bus system, and it indicates that the proposed controller supplies a coordinated control of ac-dc bus voltage as well as good damping under transient conditions. STATCOM modeling for voltage and angle stability studies is included in (Canizares, et. al. 2003). The effect of control mode of STATCOM is given in (Padiyar and Nagesh 2006) and it is shown that STATCOM operation in damping power, synchronizing power and transient stability was of a higher limit than control mode. Comparable results were obtained in (Norouzi and Sharaf 2005; Moursi and Shara 2006) where the optimal control schemes are given for dynamic voltage regulation. It has been demonstrated that STATCOM plays a positive role in developing transient stability in infinite-multi machine power systems. Certain studies on STATCOM are as follows: (Norouzi and Sharaf 2005; Moursi and Shara 2006) deals with dynamic operation of STATCOM under various load excursions. In the analysis of steady-state and transient stability in an infinite bus system, (Norouzi and Sharaf 2005; Moursi and Shara 2006) is used. STATCOM provides voltage support and it is effective in damping oscillations (Gu and Jie 2007; Sahoo, et. al. 2004). Chatterjee and Arindam 2011 demonstrates the application of STATCOM in damping interarea oscillations. Trajectory sensitivity analysis (TSA) has been instrumental in identifying optimal locations of STATCOM devices. A method was suggested for the evaluation of first swing stability of a large power system in the presence of STATCOM (Haque 2006). Observation of machine angles and active reactive power changes was taken as the base in testing multi machine system. Another study deals with the effect of STATCOM device on developing angle stability in the presence of local and interarea oscillations (Zarghami and Crow 2008).

Voltage stability analysis besides transient stability analyses is crucial in power systems. A lot of studies in literature are concerned with the use of STATCOM in voltage stability analysis (Sode-Yome and Mithulananthan 2004; Kamarposhti and Lesani 2011; Shaygan and Morteza 2011). However, the single use of FACTS devices may not suffice due to the changes in operation conditions of power systems. Certain studies (Domínguez-Navarro, et. al. 2007; Radman and Raje 2007; Lahaçani, et. al. 2010) dealing with static voltage stability analysis demonstrated the use of different test systems employing newton raphson algorithm. Newton raphson algorithm used in this analysis has been enhanced through mathematics. This enhancement process has been done by using STATCOM. In this study, the effects of STATCOM on voltage stability have been investigated. The evaluation of the relation between the use of multiple STATCOM and voltage-MLP in multiple buses power systems has been done. The enhancement of voltage profiles by using multiple STATCOM has been showed in the figures below.

### STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM, one of the FACTS devices, provides reactive power support to arrange voltage which is connected to the bus. The enhancement of MLP takes place depending on reactive power support. The terminal characteristics of FACTS devices have been showed in equation 1 and 4.

$$x_c = f_c(x_c, x_s, V, Q, u) \quad (1)$$

$$x_s = f_s(x_c, x_s, V, Q) \quad (2)$$

$$P = g_p(x_c, x_s, V, Q) \quad (3)$$

$$Q = g_q(x_c, x_s, V, Q) \quad (4)$$

where  $x_c$  are the control system variables,  $x_s$  are the controlled state variables, and the algebraic variables  $V$  and  $\theta$  are the voltage amplitudes and phases at the buses at which the components are connected, they are vectors in case of series components. Finally, the variable  $u$  represents the input control parameters, such as reference voltages or reference power owns (Kamarposhti and Lesani 2011).

The power flow equations of the system with STATCOM connected to bus  $i$  can be given below:

$$P_i = P + \sum_{j=1}^N [V_i] \times [V_j] \times [Y_{kj}] \cos(\delta_k - \delta_j - \theta_{kj}) \quad (5)$$

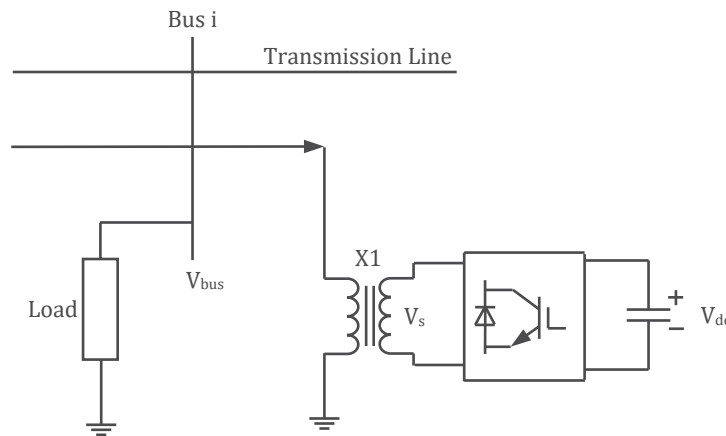
$$Q_i = Q + \sum_{j=1}^N [V_i] \times [V_j] \times [Y_{kj}] \sin(\delta_k - \delta_j - \theta_{kj}) \quad (6)$$

where  $P$  and  $Q$  are found to be:

$$P = G \times [V_k]^2 - [V_k] \times [E] \times [Y] \cos(\delta_k - \delta_j - \theta) \quad (7)$$

$$Q = -G \times [V_k]^2 - [V_k] \times [E] \times [Y] \sin(\delta_k - \delta_j - \theta) \quad (8)$$

As shown in Figure 1, The STATCOM is connected in parallel with Bus  $i$ , STATCOM consist of a voltage source converter connected to the system through a coupling transformer, therefore modelled as a controllable voltage source series with a leakage reactance excluding ohmic losses.



**Figure 1:** STATCOM Circuit Modelling

By adjusting the magnitude of the injected voltage, the reactive power exchange can be controlled. STATCOM connection is ac system bus. AC system voltage and the voltage-sourced converter terminal voltage is the same. This ensures that there is sending of only reactive power and no real power between the STATCOM and the AC system (Chatterjee and Arindam 2011). The expressions for the current, reactive power injection, voltage and DC link voltage are given as.

$$I_s = \frac{V_s - V_{bus}}{jX_1} \quad (9)$$

$$Q_s = V_{bus}^2 \frac{V_s / V_{bus} - 1}{X_1} \quad (10)$$

$$V_{inj} = m \times k \times V_{dc} (\cos \delta - j \sin \delta) \quad (11)$$

$$I_s = I_d + jI_q \quad (12)$$

$$\frac{dV_{dc}}{dt} = \frac{m \times k}{C_{dc}} (I_d \cos \delta + I_q \sin \delta) \quad (13)$$

### STATIC VOLTAGE STABILITY

Static voltage stability gets the value by directly depending on reactive power change. The spread of the loading limit of the loading bus and the operation conditions of the power system can be enhanced by providing reactive power support. The system collapses when the reactive power support is below the limit and the voltage drop starts to cut down. In order to prevent this, it is very important to arrange voltage according to the reactive power. The relation between MLP of the system and active-reactive power value of the bus has been showed in equation 14 and 15.

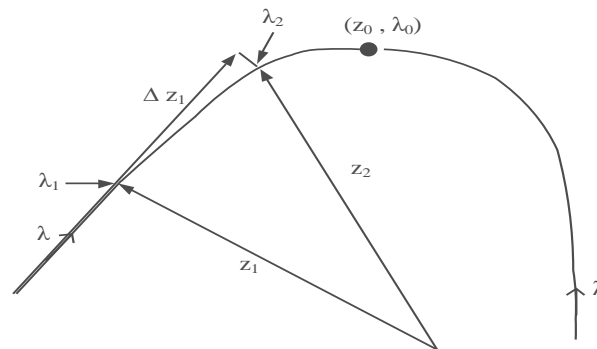
$$P_L = P_{L0}(1 + \lambda) \tag{14}$$

$$Q_L = Q_{L0}(1 + \lambda) \tag{15}$$

$P_{L0}$  and  $Q_{L0}$  Initial active and reactive power values,  $P_L$  and  $Q_L$  active and reactive power of the load  $\lambda$  MLP (Leonidaki, et. al. 2005).

#### Continuous Load Flow

Continuous load flow method is used for the analysis of voltage and MLP. Continuous load flow is very effective in analyzing certain difficulties without the support of certain system models. The voltage has the ability to automatically change against the adverse situation that may be caused by single analysis of the system equations. The use of strategy in continuous load flow has been shown in Fig. 2.



**Figure 2:** Continuation Power Flow Method

Here,  $(z_1, \lambda_1)$  is known as balance point,  $\Delta \lambda_1$  is used for parameter value change and  $\Delta z_1$  is used for vector analysis. At the first stage, prediction is done.  $z_1 + \Delta z_1 + \Delta \lambda_1$  values are produced initially. These values are used for correcting  $z_2 + \Delta z_2$  which are the new balance points in the system profile (Kazemi and Badrzadeh 2004).

#### Configuring Admittance and Jacobian Matrix through Newton Raphson

That STATCOM is connected to the line and bus, and admittance matrix is modified as in Fig. 1. The new admittance matrix is constituted through the elements which are parallel connected to the bus. The new admittance matrix and STATCOM have been shown in equations 16 and 17.

$$Y_{new}^{line} = \begin{bmatrix} y_{ij} + y_{i0} + y_{STATCOM} & -y_{ij} \\ -y_{ij} & -y_{ij} + y_{ij} + y_{j0} \end{bmatrix} \tag{16}$$

$$y_{STATCOM} = \frac{1}{X_{STATCOM}} \tag{17}$$

The admittance matrix between buses when the admittance matrix components are used with STATCOM has been shown between equation 18 and 20.

$$Y_{ii} = \frac{4y_{ij}^2 + y_{ij}(2y_{STATCOM} + y_{i0} + y_{j0})}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} + \frac{1}{2}y_{i0} \quad (18)$$

$$Y_{jj} = \frac{4y_{ij}^2 + y_{ij}(2y_{STATCOM} + y_{i0} + y_{j0})}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} + \frac{1}{2}y_{j0} \quad (19)$$

$$Y_{ij} = \frac{4y_{ij}^2}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} \quad (20)$$

The matrix presentation of the line is shown according to the equation 18 and 20.

$$Y_{new}^{line} = \begin{bmatrix} \frac{4y_{ij}^2}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} + y_{i0} + y_{STATCOM} & -\frac{4y_{ij}^2}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} \\ -\frac{4y_{ij}^2}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} & -\frac{4y_{ij}^2}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} + \frac{4y_{ij}^2}{4y_{ij} + y_{STATCOM} + \frac{1}{2}y_{i0} + \frac{1}{2}y_{j0}} + y_{j0} \end{bmatrix} \quad (21)$$

The generator active and reactive power equations have been added to the admittance matrix while using lines in the continuous load flow analysis of STATCOM in multiple buses power systems. The relation of admittance matrix between buses by using multiple STATCOM has been shown in equation 22.

$$Y_{new}^{multiple} = \begin{bmatrix} y_{i1} & y_{ii} + y_{STATCOM} & y_{in} \\ y_{j1} & y_{jj} + y_{STATCOM} & y_{jn} \\ y_{k1} & y_{kk} + y_{STATCOM} & y_{kn} \end{bmatrix} \quad (22)$$

The admittance is expanded by using multiple STATCOM in power systems. There are not any changes while this expansion is added to the admittance of the buses.

The continuous load flow is calculated again while connecting STATCOM to the bus to arrange voltage profile. These calculations take place in Jacobian matrix. The calculations of the buses where STATCOM is connected have been done according to the bus voltage control. That the STATCOM provides reactive power to the circuit and absorbs reactive power from the circuit depends on the voltage. Therefore it is very significant to use trigger angle of the converter circuit in STATCOM (Lahaçani, et. al. 2010). The situation of Jacobian matrix without STATCOM has been shown in equation 23.

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_n \\ \Delta Q_1 \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \frac{\partial P_1}{\partial \delta_n} & \frac{\partial P_1}{\partial V_1} & \frac{\partial P_1}{\partial V_n} \\ \frac{\partial P_n}{\partial \delta_1} & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial V_1} & \frac{\partial P_n}{\partial V_n} \\ \frac{\partial Q_1}{\partial \delta_1} & \frac{\partial Q_1}{\partial \delta_n} & \frac{\partial Q_1}{\partial V_1} & \frac{\partial Q_1}{\partial V_n} \\ \frac{\partial Q_n}{\partial \delta_1} & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial V_1} & \frac{\partial Q_n}{\partial V_n} \end{bmatrix} = \begin{bmatrix} \Delta \delta_1 \\ \Delta \delta_n \\ \Delta V_1 \\ \Delta V_n \end{bmatrix} \quad (23)$$

The matrix expression of Jacobian matrix with STATCOM use has been shown in equation 24.

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_k \\ \Delta P_n \\ \Delta Q_1 \\ \Delta Q_k \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \frac{\partial P_1}{\partial \delta_k} & \frac{\partial P_1}{\partial \delta_n} & \frac{\partial P_1}{\partial V_1} & 0 & \frac{\partial P_1}{\partial V_n} \\ \frac{\partial P_k}{\partial \delta_1} & \frac{\partial P_k}{\partial \delta_k} & \frac{\partial P_k}{\partial \delta_n} & \frac{\partial P_k}{\partial V_1} & 0 & \frac{\partial P_k}{\partial V_n} \\ \frac{\partial P_n}{\partial \delta_1} & \frac{\partial P_n}{\partial \delta_k} & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial V_1} & 0 & \frac{\partial P_n}{\partial V_n} \\ \frac{\partial Q_1}{\partial \delta_1} & \frac{\partial Q_1}{\partial \delta_k} & \frac{\partial Q_1}{\partial \delta_n} & \frac{\partial Q_1}{\partial V_1} & 0 & \frac{\partial Q_1}{\partial V_n} \\ \frac{\partial Q_k}{\partial \delta_1} & \frac{\partial Q_k}{\partial \delta_k} & \frac{\partial Q_k}{\partial \delta_n} & \frac{\partial Q_k}{\partial V_1} & \frac{\partial Q_k}{\partial \alpha_1} & \frac{\partial Q_k}{\partial V_n} \\ \frac{\partial Q_n}{\partial \delta_1} & \frac{\partial Q_n}{\partial \delta_k} & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial V_1} & 0 & \frac{\partial Q_n}{\partial V_n} \end{bmatrix} = \begin{bmatrix} \Delta \delta_1 \\ \Delta \delta_k \\ \Delta \delta_n \\ \Delta V_1 \\ \Delta \alpha \\ \Delta V_n \end{bmatrix} \quad (24)$$

While calculating the derivation of single STATCOM depending on reactive power trigger angle, the other values becomes 0. The matrix expression of Jacobian matrix with multiple STATCOM use has been shown in equation 25.

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_k \\ \Delta P_{k1} \\ \Delta P_n \\ \Delta Q_1 \\ \Delta Q_k \\ \Delta Q_{k1} \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \frac{\partial P_1}{\partial \delta_k} & \frac{\partial P_1}{\partial \delta_{k1}} & \frac{\partial P_1}{\partial \delta_n} & \frac{\partial P_1}{\partial V_1} & 0 & 0 & \frac{\partial P_1}{\partial V_n} \\ \frac{\partial P_k}{\partial \delta_1} & \frac{\partial P_k}{\partial \delta_k} & \frac{\partial P_k}{\partial \delta_{k1}} & \frac{\partial P_k}{\partial \delta_n} & \frac{\partial P_k}{\partial V_1} & 0 & 0 & \frac{\partial P_k}{\partial V_n} \\ \frac{\partial P_{k1}}{\partial \delta_1} & \frac{\partial P_{k1}}{\partial \delta_k} & \frac{\partial P_{k1}}{\partial \delta_{k1}} & \frac{\partial P_{k1}}{\partial \delta_n} & \frac{\partial P_{k1}}{\partial V_1} & 0 & 0 & \frac{\partial P_{k1}}{\partial V_n} \\ \frac{\partial P_n}{\partial \delta_1} & \frac{\partial P_n}{\partial \delta_k} & \frac{\partial P_n}{\partial \delta_{k1}} & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial V_1} & 0 & 0 & \frac{\partial P_n}{\partial V_n} \\ \frac{\partial Q_1}{\partial \delta_1} & \frac{\partial Q_1}{\partial \delta_k} & \frac{\partial Q_1}{\partial \delta_{k1}} & \frac{\partial Q_1}{\partial \delta_n} & \frac{\partial Q_1}{\partial V_1} & 0 & 0 & \frac{\partial Q_1}{\partial V_n} \\ \frac{\partial Q_k}{\partial \delta_1} & \frac{\partial Q_k}{\partial \delta_k} & \frac{\partial Q_k}{\partial \delta_{k1}} & \frac{\partial Q_k}{\partial \delta_n} & \frac{\partial Q_k}{\partial V_1} & \frac{\partial Q_k}{\partial \alpha} & \frac{\partial Q_k}{\partial \alpha_1} & \frac{\partial Q_k}{\partial V_n} \\ \frac{\partial Q_{k1}}{\partial \delta_1} & \frac{\partial Q_{k1}}{\partial \delta_k} & \frac{\partial Q_{k1}}{\partial \delta_{k1}} & \frac{\partial Q_{k1}}{\partial \delta_n} & \frac{\partial Q_{k1}}{\partial V_1} & \frac{\partial Q_{k1}}{\partial \alpha} & \frac{\partial Q_{k1}}{\partial \alpha_1} & \frac{\partial Q_{k1}}{\partial V_n} \\ \frac{\partial Q_n}{\partial \delta_1} & \frac{\partial Q_n}{\partial \delta_k} & \frac{\partial Q_n}{\partial \delta_{k1}} & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial V_1} & 0 & 0 & \frac{\partial Q_n}{\partial V_n} \end{bmatrix} = \begin{bmatrix} \Delta \delta_1 \\ \Delta \delta_k \\ \Delta \delta_{k1} \\ \Delta \delta_n \\ \Delta V_1 \\ \Delta \alpha \\ \Delta \alpha_1 \\ \Delta V_n \end{bmatrix} \quad (25)$$

While calculating the derivation of multiple STATCOM depending on reactive power trigger angle, the other values becomes 0.

$$Q_k = Q_k^{old} + Q_{STATCOM} \quad (26)$$

$$Q_{k1} = Q_{k1}^{old} + Q_{STATCOM1} \quad (27)$$

The reactive power of Jacobian matrix depending on the trigger angle of the STATCOM has been shown in equation 24 and 25.

$$\frac{\partial Q_k}{\partial \alpha} = \frac{Q_k^{old}}{\partial \alpha} + \frac{\partial Q_{STATCOM}}{\partial \alpha} \quad (28)$$

$$\frac{\partial Q_{k1}}{\partial \alpha_1} = \frac{Q_{k1}^{old}}{\partial \alpha_1} + \frac{\partial Q_{STATCOM1}}{\partial \alpha_1} \quad (29)$$

While active powers become 0 by adding STATCOM to the Jacobian matrix, reactive power values are obtained as derivations depending on trigger angle. The trigger angles of the STATCOM

are used synchronous. By using STATCOM several times in power systems, operation conditions have been improved. The STATCOM is connected to the buses that have weak voltage profile so reactive power support is completely provided.

### ANALYSIS APPROACH

The load flow analysis is required for static voltage stability analyses. The results of the load flow are important for making decision in determining the location of the STATCOM. The following steps are considered in analyzing static voltage stability effects of the system with multiple STATCOM.

Level 1) Perform load flow

Level 2) List the buses from the lowest voltage to the second lowest voltage based on the load flow results.

Levels 3) Without STATCOM continuous load flow.

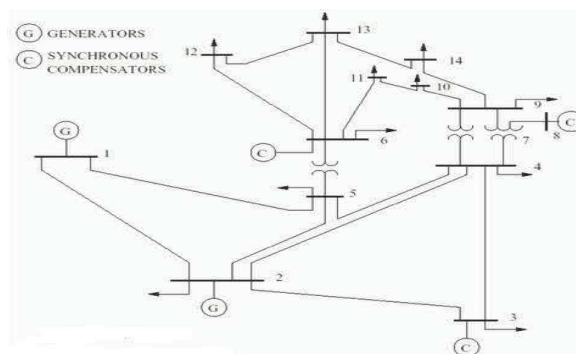
Level 4) Locate a STATCOM on the bus with the lowest voltage.

Level 5) Locate a STATCOM on the bus with the second lowest voltage.

Level 6) Comparison of different scenarios on continuous load flow.

### CASE STUDY

A modeling and simulation study has been carried out on IEEE 14 bus system shown in Fig. 3. The system has 1 slack bus (bus 1), 9 load buses (buses 4, 5, 7, 9, 10, 11, 12, 13, 14) and 4 generator buses (buses 2, 3, 6, 8).

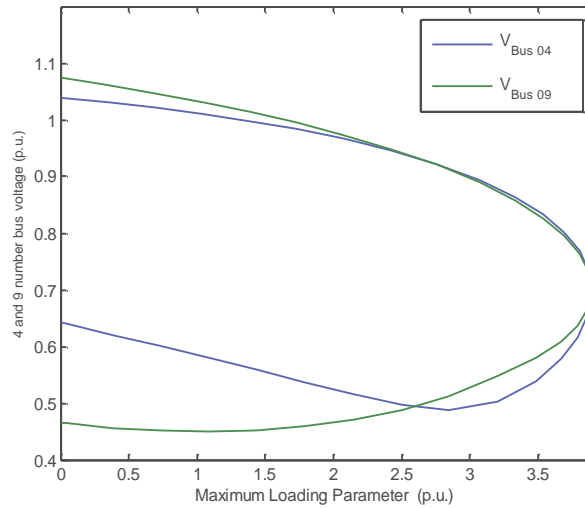


**Figure 3: IEEE 14 Bus System**

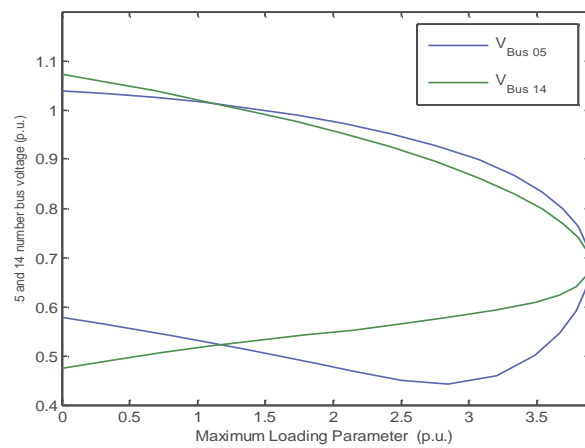
A load flow analysis is performed to determine the buses with the lowest voltage and second lowest voltage (Milano 2005). While determined bus 8 has the lowest voltage, determined bus 8 has the second lowest voltage. Without STATCOM, with STATCOM and multiple STATCOM devices in the system are simulated and effects are analyzed through observing voltage-MLP.

### SIMULATION RESULTS

Firstly, the continuous load flow analysis has been done in IEEE 14 buses power system. According to the results of this analysis it is understood that the 5<sup>th</sup> and 14<sup>th</sup> buses have the lowest voltage value. It is also observed that 4<sup>th</sup> and 9<sup>th</sup> buses have the low voltage level as well as 5<sup>th</sup> and 14<sup>th</sup> buses. The relation between voltage-MLP and 4<sup>th</sup>, 5<sup>th</sup>, 9<sup>th</sup> and 14<sup>th</sup> buses has been shown in Fig. 4 and 5.

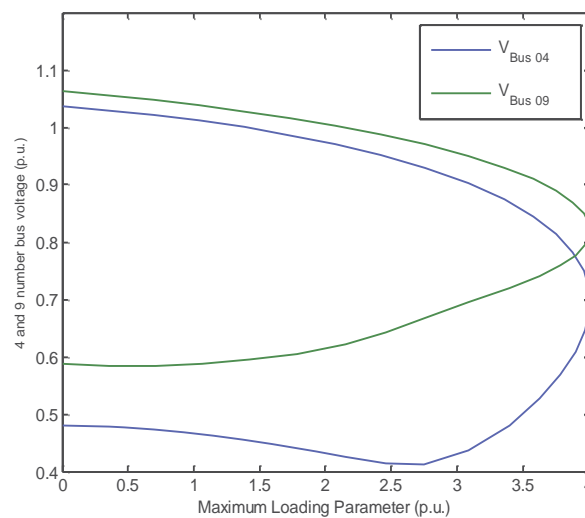


**Figure 4:** 4 and 9 Number Bus Voltage-MLP without STATCOM

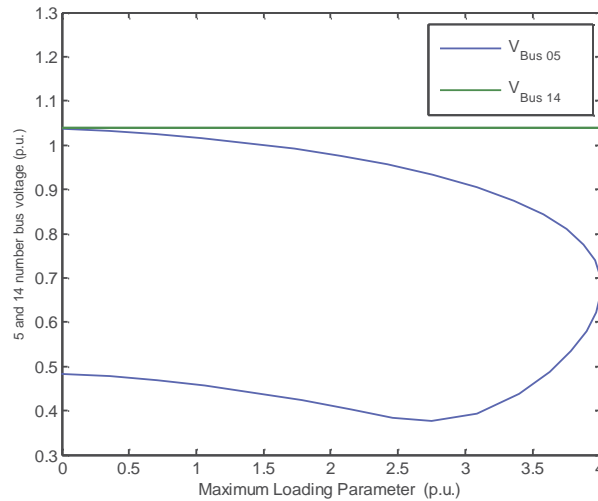


**Figure 5:** 5 and 14 Number Bus Voltage-MLP without STATCOM

According to the result of continuous load flow in 14 buses power system of IEEE, MLP value is obtained as 3.8927. In consequence of continuous load flow, the lowest voltage is on the 5<sup>th</sup> bus. The relation between voltage-MLP and 4<sup>th</sup>, 5<sup>th</sup>, 9<sup>th</sup> and 14<sup>th</sup> buses as a result of connecting 100 MVA STATCOM to the 5<sup>th</sup> bus has been shown in Fig. 6 and 7.

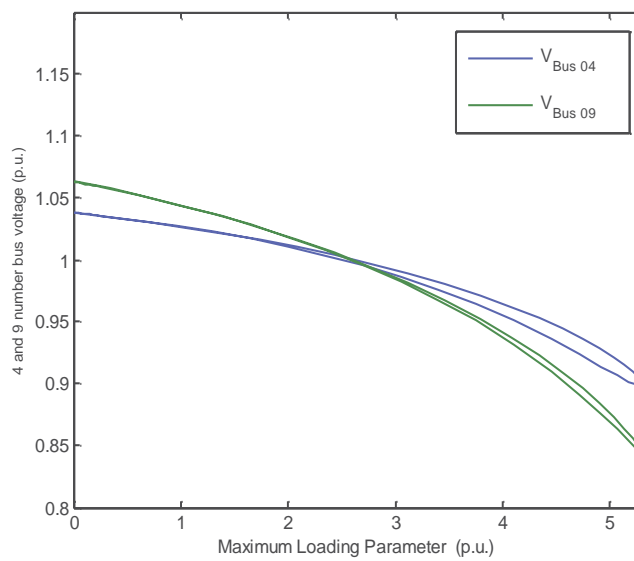


**Figure 6:** 4 and 9 Number Bus Voltage-MLP with STATCOM

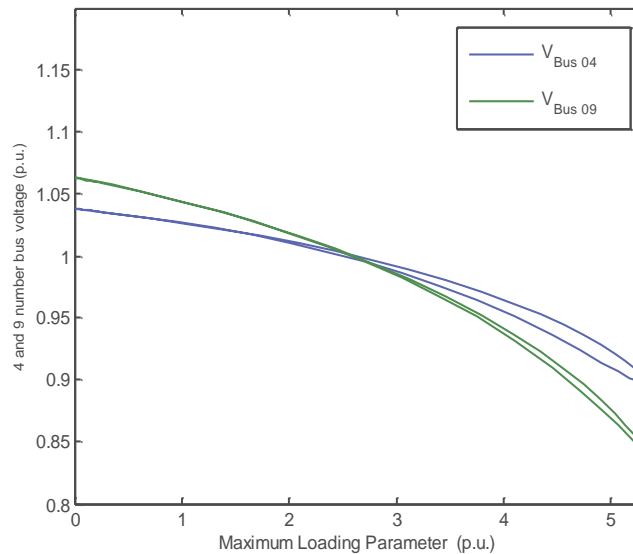


**Figure 7:** 5 and 14 Number Bus Voltage-MLP with STATCOM

According to the result of continuous load flow in 14 buses power system of IEEE by connecting STATCOM to the 14<sup>th</sup> bus, MLP value is obtained as 4.01. In consequence of continuous load flow, the lowest voltage is on the 5<sup>th</sup> bus. The relation between voltage-MLP and 4<sup>th</sup>, 5<sup>th</sup>, 9<sup>th</sup> and 14<sup>th</sup> buses as a result of connecting 100 MVA STATCOM to the 5<sup>th</sup> and 14<sup>th</sup> buses has been shown in Fig. 8 and 9.



**Figure 8:** 4 and 9 Number Bus Voltage-MLP with Multiple STATCOM



**Figure 9:** 4 and 9 Number Bus Voltage-MLP with Multiple STATCOM

According to the result of continuous load flow in 14 buses power system of IEEE by connecting STATCOM to the 5<sup>th</sup> and 14<sup>th</sup> buses, MLP value is obtained as 5.3022.

The power flow has been utilized in IEEE 14 buses power systems for optimal placement of STATCOM. According to the load flow analysis, 5<sup>th</sup> and 14<sup>th</sup> buses have the lowest voltage profile.

## CONCLUSIONS

In this study, the effects of STATCOM on static voltage stability in IEEE 14 buses power system have been investigated. The analyses of continuous load flow without STATCOM, with STATCOM and with multiple STATCOM have been evaluated. The admittance matrix and Jacobian matrix in Newton Raphson algorithm have been enhanced mathematically according to the STATCOM. As a result of this study, it has been seen that the relation between connecting STATCOM to the buses and voltage-MLP gives relatively good results. It has been also seen that STATCOM increases all load bus voltages. It has been shown in this study that the use of multiple STATCOM in larger power systems gives effective results in terms of stability in power systems.

## REFERENCES

- Abido, M.A. (2005). Analysis and Assessment of STATCOM-Based Damping Stabilizers for Power System Stability Enhancement, *Electr. Power Syst. Res.*, 73, 177-185.
- Canizares, C.A., Pozzi, M., Corsi, S., and Uzunovic, E. (2003). STATCOM Modeling for Voltage and Angle Stability Studies, *Electr. Power Energy Syst.*, 25, 431-441.
- Chatterjee, D., and Arindam, G. (2011). Improvement of transient stability of power systems with STATCOM-controller using trajectory sensitivity, *Electr. Power Energy Syst.*, 33, 531-539.
- Domínguez-Navarro, J.A., Bernal-Agustín, J.L., Díaz, A., Requena, D., and Vargas, E.P. (2007). Optimal parameters of FACTS devices in electric power systems applying evolutionary strategies, *Electr. Power Energy Syst.*, 29, 83-90.
- Gu, L., and Jie, W. (2007). Nonlinear coordinated control design of excitation and STATCOM of power systems, *Electr. Power Syst. Res.*, 77, 788-796.
- Haque M.H. (2006). Damping improvement by FACTS devices: A comparison between STATCOM and SSSC, *Electr. Power Syst. Res.*, 76, 865-872.
- Kamarposhti, M., and Lesani, H. (2011). Effects of STATCOM, TCSC, SSSC and UPFC on static voltage stability, *Electr. Eng.*, 93, 33-42.
- Kazemi, A., and Badrzadeh, B. (2004). Modeling and Simulation of SVC and TCSC to Study Their Limits on Maximum Loadability Point, *Electr. Power Energy Syst.*, 26, 381-388.

- Lahaçani, N.A., Aouzellag, D., and Mendil, B. (2010). Contribution to the improvement of voltage profile in electrical network with wind generator using SVC device, *Renew. Energy*, 35, 243-248.
- Lahaçani, N.A., Aouzellag, D., and Mendil, B. (2010). Static compensator for maintaining voltage stability of wind farm integration to a distribution network, *Renew. Energy*, 35, 2476-2482.
- Leonidaki, E.A., Manos, G.A., and Hatziaargyriou, N.D. (2005). An Effective Method to Locate Series Compensation for Voltage Stability Enhancement, *Electr. Power Syst. Res.*, 74, 73-81.
- Messina, A.R., Perez, M.A., and Hernandez E. (2003). Co-ordinated application of FACTS devices to enhance steady-state voltage stability, *Electr. Power Energy Syst.*, 25, 259-267.
- Milano, F. (2005). An open source power system analysis toolbox, *IEEE Trans. on Power Syst.*, 20, 1199-1206.
- Moursi, M.S.E., and Sharaf, A.M. (2006). Novel Reactive Power Controllers for the STATCOM and SSSC, *Electr. Power Syst. Res.*, 76, 228-241.
- Norouzi, A.H., and Sharaf, A.M. (2003). A novel control scheme for the STATCOM stability enhancement, *Transmission and Distribution Conference and Exposition, 2003 IEEE PES*, Dallas USA.
- Norouzi, A.H., and Sharaf, A.M. (2005). Two Control Schemes to Enhance the Dynamic Performance of the STATCOM and SSSC, *IEEE Trans. Power Delivery*, 20, 435-442.
- Padiyar, K.R., and Nagesh, P. (2006). Design and performance evaluation of subsynchronous damping controller with STATCOM, *IEEE Trans. Power Delivery*, 21, 1398-1405.
- Radman, G., and Raje, R.S. (2007). Power flow model/calculation for power systems with multiple FACTS controllers, *Electr. Power Syst. Res.*, 77, 1521-1531.
- Sahoo, N.C., Panigrahi, B.K., Dash, P.K., and Panda, G. (2004). Multivariable nonlinear Control of STATCOM for Synchronous Generator Stabilization, *Electr. Power Energy Syst.*, 26, 37-48.
- Sahoo, N.C., Panigrahi, B.K., Dash, P.K., and Panda, G. (2004). Multivariable nonlinear control of STATCOM for synchronous generator stabilization, *Electr. Power Energy Syst.*, 26, 37-48.
- Shaygan, M.S., Gh, S., and Morteza, R. (2011). Study the Effects of STATCOM on the Static Voltage Stability Improvement and Reduction of Active and Reactive Losses, *Int. Rev. of Electr. Eng.*, 6, 214-218.
- Sode-Yome, A., and Mithulananthan, N. (2004). Comparison of shunt capacitor, SVC and STATCOM in static voltage stability margin enhancement, *Int. J. of Electr. Eng. Educ.*, 41, 158-171.
- Soto, D., and Ruben, P. (2004). Nonlinear control strategies for cascaded multilevel STATCOMs, *IEEE Trans. Power Delivery*, 19, 1919-1927.
- Zarghami, M., and Crow, M.L. (2008). Damping inter-area oscillations in power systems by STATCOMs, *Power Symposium, 2008. NAPS '08. 40th North American*, USA Canada.