Enhancement of Voltage Profile By Using Static Synchronous Compensator (Statcom) in Power System Networks

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Publication Info

Article history :
Received : 20th Nov. 2016
Accepted : 13th Dec. 2016
DOI : 10.18090/samriddhi.v8i2.7144

Keywords :
Transmission System, Voltage Stability, STATCOM, Load Flow Analysis.

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Abstract

Voltage Profile is one of the concerned issues in power system network studies. The Voltage Profile decay can be experienced by the system when system is subjected to load increment or disturbances. Unscheduled increment of load variation in a power transmission system has driven the system to be stressful, leading to potential cascading trip on the entire system. and capacitor placement. In this paper, we introduced the Static Synchronous Compensator (STATCOM), a shunt connected Flexible AC Transmission System (FACTS) device which is capable to regulate the Voltage Profile by generating or observing the reactive power. Our objective has been tested with different size and different location of STATCOM on IEEE-4 Bus System and IEEE-9 Bus System by using the Newton-Raphson load flow method in MATLAB environment. In this work, firstly we have analysed IEEE-4 bus system and IEEE-9 bus system under the standard test data and after that analysed IEEE-4 bus system and IEEE-9 bus system with STATCOM under the standard test data. After that, we have compared all the load flow results and observed the effect of STATCOM on Voltage Profile The different sizes of STATCOM used in the test systems are 20,40,60,80and 100MVAr.

1. INTRODUCTION

Electric utilities of today are facing more problems than ever before with trying to provide economical electric power to their customers and trying to allow an increase in the amount of power that is transferred between interconnected utilities and independent power producers. This increases in power flow leads to transmission networks becoming heavily loaded causing the thermal capacity of the line to reach their limits. In the event of emergency in the system reactive power losses increase dramatically; this loss of reactive power may eventually leads to voltage instability response of the electromechanical system controller, and the inability to rapidly determine the system state and to compute appropriate control response [2].

Conventional reactive power control can be used to provide steady state voltage control as well as to minimize transmission losses and enhance power system stability. These devices, however, are based on electro-mechanical mechanisms, thus preventing high speed control. As a consequence of this lack of fast and reliable control, they do not satisfy the operational flexibility and adaptability requirements to meet the changing needs to modern power systems. Moreover, extensive use of these devices may cause some of the voltage control problems found today as pointed out by several investigators [3].The recently developed FACTS technology provides a way to relieve the stability problem imposed by increasing load demand. FACTS controllers provide fast and reliable control over the three main transmission parameters: voltage magnitude, phase angle and line impedance. For this reason, control of FACTS devices has received a lot of attention in power system stability enhancement [4].

In this paper we introduced the Static Synchronous Compensator (STATCOM), a shunt connected Flexible AC Transmission System (FACTS) device which is capable to regulate the Voltage Profile by generating or observing the reactive power. Our objective has been tested with different size and different location of STATCOM on IEEE-4 Bus System and IEEE-9 Bus System by using the Newton-Raphson load flow method in MATLAB environment. In this work, firstly we have analysed IEEE-4 bus system and IEEE-9 bus system under the standard test data and after that analysed IEEE-4 bus system and IEEE-9 bus system with STATCOM under the standard test data. After that, we have compared all the load flow results and observed the effect of STATCOM on Voltage Profile The different sizes of STATCOM used in the test systems are 20,40,60,80and 100MVAr.

1.1 Principal Causes Of Voltage Stability Problems

Some of the causes for occurrence of voltage instability are :

- Difference in Transmission of Reactive Power Under Heavy Loads.
- High Reactive Power Consumption at Heavy Loads.
- Occurrence of Contingencies.
- Voltage sources are too far from load centers.
- Due to unsuitable locations of FACTS controllers.
- Poor coordination between multiple FACTS controllers.
- Presence of Constant Power Loads.
- Reverse Operation of ON Load Tap-Changer (OLTC).

1.2 Prevention of Voltage Instability

Some of the prevention of voltage instability by following:

- Placement of Series and Shunt Capacitors.
- Installation of Synchronous Condensers.
- Placement of FACTS Controllers.
- Coordination of Multiple FACTS Controllers.
- Under-Voltage Load Shedding.
- Blocking ofTap-Changer under Reverse Operation.
- Generation Rescheduling.

2. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) CONTROLLERS

The FACTS devices represent a relatively new technology for power transmission systems. They provide the same benefits as conventional compensators with mechanical switches (circuit breaker) in steady state power system operation; in addition, they improve the dynamic and transient performance of the power system. This is achieved by fast switching time and repeatable operation of solid state switches as compared to mechanical switches. The switching time of solid state switch is a portion of a periodic cycle; and this is much faster than that of a circuit breaker with a switching time of a number of cycles. Generally, the main objectives of FACTS are to increase the useable transmission capacity of lines and control power flow over designated transmission routes.

S-JPSET : Vol. 8, Issue 2, ISSN : 2229-7111 (Print) & ISSN : 2454-5767 (Online)

The power flow over a transmission line depends mainly on three important parameters, namely voltage magnitude of the buses (*V*), impedance of the transmission line (Z) and phase angle between buses (θ). The FACTS devices control one or more of the parameters to improve system performance by using placement and coordination of multiple FACTS controllers in large-scale emerging power system networks to also show that the achieve significant improvements in operating parameters of the power systems such as, small signal stability, transient stability, damping of power system oscillations, security of the power system, less active power loss, Voltage Profile, congestion management, quality of the power system, efficiency of power system operations, power transfer capability through the lines, dynamic performances of power systems, and the loadability of the power system network also increased. As FACTS devices are fabricated using solid state controllers, their response is fast and accurate. Thus, these devices can be utilized to improve the Voltage Profile of the system by using coordinated control of FACTS controllers in multi machine power systems.

The following definition for FACTS and FACTS Controllers is defined by IEEE:

- “Flexible AC Transmission System (FACTS): Alternating current transmission system incorporating power electronic based and other static controller to enhance controllability and increase power transfer capability.”
- “FACTS Controller: A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters.

2.1 Classification of FACTS Controller

1. Based on Generation, FACTS Controllers divided into two generation:

- **First Generation:** Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), and Thyristor Controlled Phase Shifting Transformer (TCPST) are developed in the first generation of FACTS controllers
- **Second Generation:** Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), and Interline Power Flow Controller (IPFC) are developed in the second generation of FACTS controllers.

2. Based on Technological features , FACTS Controllers can be divided into two group:

- Thyristor based FACTS controllers.
- Converter based FACTS controllers.

3. Based on the connection Diagram to the network, FACTS Controllers can be divided into four category:

- Series connected FACTS Controllers
- Shunt connected FACTS Controllers
- Series- Series connected FACTS Controllers
- Series- Shunt connected FACTS Controllers

2.2Possible Benefits from FACTS Controllers over Conventional Controller

- Control of power flow(both active and reactive), as desired and within limits, is possible.
- Reduction of voltage drop in power lines is possible. Regulation can be improved.
- Reduction of reactive of burden on line allows more flow of active power in lines.
- Loadablity of lines is increased.
- Elimination or deferral of the need for new transmission lines.
- Voltage stability and voltage security are enhanced.
- Security of tie lines connecting two sub grids is increased.
- Transient stability is increased.

- Short circuit currents and overloads can be controlled up to certain limits.
- Generation cost reduces.
- Passive compensation requirement reduces
- Upgrade of transmission lines.

2.3 Static Synchronous Compensator (Statcom)

STATCOM is a shunt device of the FACTS family using power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive). The variation of reactive power is performed by means of a VSC connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_2 from a DC voltage source.

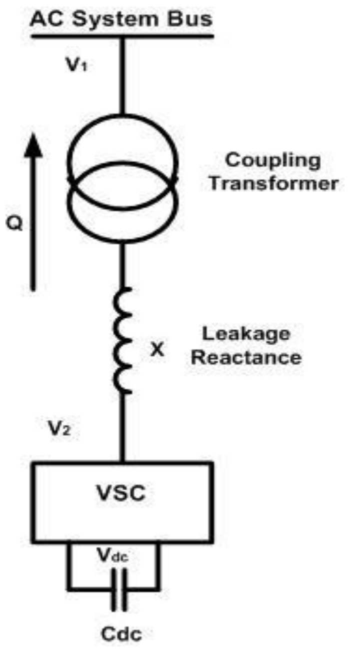

Fig.2.1: Basic Structure of STATCOM

$$P = \frac{V_1 V_2 \sin\delta}{x} \quad (2.1)$$

$$Q = \frac{V_1 (V_1 - V_2 \cos\delta)}{x} \quad (2.2)$$

Where: V_1 = System voltage to be controlled

V_2 = Voltage generated by VSC

X = Reactance of interconnection transformer

δ = Angle of V_1 with respect to V_2

The principle of operation of the STATCOM is explained in the Fig.2.1 showing the active and reactive power transfer between a source V_1 and a source V_2. In this figure, V_1 represents the system voltage to be controlled and V_2 is the voltage generated by the VSC. In steady state operation, the voltage V_2 generated by the VSC is in phase with V_1 (δ=0), so that only reactive power is flowing (P=0). If V_2 is lower than V_1, Q is flowing from V_1 to V_2 (STATCOM is absorbing reactive power). On the reverse, if V_2 is higher than V_1, Q is flowing from V_2 to V_1 (STATCOM is generating reactive power). The amount of reactive power is given by,

$$Q = \frac{V_1 (V_1 - V_1)}{x} \quad (2.3)$$

Operating modes of STATCOM are:

2.3.1 Over Excited Mode of Operation (V_1<V_2):

That is, if the amplitude of the output voltage is increased above that of the ac system voltage, then the current flows through the reactance from the STATCOM to the ac system and the STATCOM generates reactive (capacitive) power for the ac system.

2.3.2 Under Excited Mode of Operation (V_2<V_2):

On the other hand, if the amplitude of the output voltage is decreased below that of the ac system, then the reactive current flows from the ac system

S-JPSET : Vol. 8, Issue 2, ISSN : 2229-7111 (Print) & ISSN : 2454-5767 (Online)

to STATCOM, and the STATCOM absorbs the reactive (inductive) power.

2.3.3 Normal (Floating) Excited Mode of Operation ($V_1 = V_2$):

If the output voltage is equal to the ac system voltage, the reactive power exchange is zero.

The technical advantages of a STATCOM over a SVC are:

- Faster response.
- Requires less space as bulky passive components (such as reactors) are eliminated.
- Inherently modular and re-locatable.
- It can be interfaced with real power sources such as battery, fuel cell or SMES (superconducting magnetic energy storage).A STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit (of capacitive susceptance).
- In STATCOM, there is no harmonic problem as compare to the SVC, which faces harmonic problem.
- STATCOM can operate better in unbalanced AC System.
- Attainable response time and band width of the closed voltage regulation loop of STATCOM are significantly better than that of SVC.

The steady state control characteristics of a STATCOM are shown in Fig. 2.2

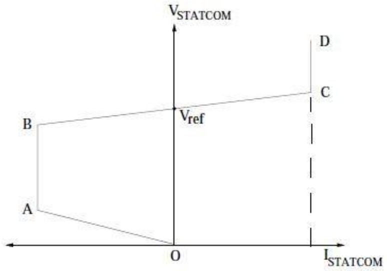

Fig.2.2: Control characteristics of STATCOM.

The losses in the STATCOM are neglected and STATCOM is assumed to be purely reactive. As in the case of a SVC, the negative current indicates capacitive operation while positive current indicates inductive operation. The limits on the capacitive and inductive currents are symmetric (+Imax and -Imax). The positive slope BC is provided for the V-I characteristic to (i) prevent the STATCOM hitting the limits often and (ii) to allow parallel operation of two or more units. The reference voltage (Vref) corresponds to zero current output and generally, the STATCOM is operated close to zero output during normal operating conditions, such that full dynamic range is available during contingencies. This is arranged by controlling the mechanically switched capacitors/reactors connected in parallel with a STATCOM.

3. NEWTON-RAPHSON METHOD

Newton-Raphson method is an iterative method which approximates the set ofnon linear simultaneous equations to a set of linear simultaneous equations using Taylor's series expansion and the terms are limited to first approximation. Let the unknown variables be (x1, x2…xn) and the specified quantities are y1, y2...yn.

These are related by set of non linear equations:

$$y_1 = f_1\,(x_1, x_2\ldots\ldots x_n)$$

$$y_2 = f_2\,(x_1, x_2\ldots\ldots x_n)$$

$$\vdots$$

$$y_n = f_3\,(x_1, x_2\ldots\ldots x_n) \qquad (3.1)$$

To solve these equations, we start with an approximate solution $(x_1^0, x_2^{0\ldots\ldots\ldots} x_n^0)$. Here superscript zero means zeroth iteration in the process of solving the above non-linear Eq. (4.8).

It is to be noted that the initial solution for the equations should not be very far from the actual solution. Otherwise, there are chances of the solution diverging rather thwn converging and it may not be possible to achieve a solution whatever be the computer time utilized. The equations are linearized about the initial guess.

Assume $\Delta x_1^0, \Delta x_2^0 \cdots \Delta x_n^0$ are the correction required for $x_1^0, x_2^0 \ldots x_n^0$ respectively for the next better solution.

$$y_1 = f_1(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0 \cdots x_n^0 + \Delta x_n^0)$$

$$y_1 = f_1(x_1^0, x_2^0 \ldots x_n^0) + \Delta x_1^0 \frac{\partial f_1}{\partial x_1}\bigg|_{x^0}$$

$$x^0 + \Delta x_2^0 \frac{\partial f_1}{\partial x_2}\bigg|_{x^0} + \phi_1$$

Where ϕ_1 is function of higher order of Δx^s and higher derivatives which are neglected according to Newton-Raphson method. If all the equations are linearized and arranged in a matrix form as given below:

$$\begin{bmatrix} y_1 - f_1(x_1^0, x_2^0 \cdots x_n^0) \\ y_2 - f_2(x_1^0, x_2^0 \cdots x_n^0) \\ \vdots \\ y_n - f_n(x_1^0, x_2^0 \ldots x_n^0) \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_1} \\ \vdots & \vdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} \end{bmatrix} \begin{bmatrix} \Delta x_1^0 \\ \Delta x_2^0 \\ \vdots \\ \Delta x_n^0 \end{bmatrix} \quad ..(3.2)$$

Equation (3.2) can be represented as:

$$B = J.C$$

Where

J is the first derivative matrix known as the Jacobian matrix.

B is difference of the specified quantities and calculated quantities.

C is increment matrix

The better solution is obtained as follows:

$$\begin{aligned} X_1^1 &= X_1^0 + \Delta X_1^0 \\ X_2^1 &= X_2^0 + \Delta X_2^0 \\ X_n^1 &= x_n^0 + \Delta x_n^0 \end{aligned} \qquad (3.3)$$

When referred to power system problem, considering first bus as a slack bus, the above set of linearised equation (3.3) becomes:

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \cdot \\ \cdot \\ \Delta P_n \\ \Delta Q_2 \\ \Delta Q_3 \\ \cdot \\ \cdot \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial e_2} & \frac{\partial P_2}{\partial e_3} \cdots & \frac{\partial P_2}{\partial e_n} & \frac{\partial P_2}{\partial f_2} & \frac{\partial P_2}{\partial f_3} \cdots & \frac{\partial P_2}{\partial f_n} \\ \frac{\partial P_3}{\partial e_2} & \frac{\partial P_3}{\partial e_3} \cdots & \frac{\partial P_2}{\partial e_n} & \frac{\partial P_3}{\partial f_2} & \frac{\partial P_3}{\partial f_3} \cdots & \frac{\partial P_3}{\partial f_n} \\ & & \cdot & & & \\ \frac{\partial P_n}{\partial e_2} & \frac{\partial P_n}{\partial e_3} \cdots & \frac{\partial P_n}{\partial e_n} & \frac{\partial P_n}{\partial f_2} & \frac{\partial P_n}{\partial f_3} \cdots & \frac{\partial P_n}{\partial f_n} \\ \frac{\partial Q_2}{\partial e_2} & \frac{\partial Q_2}{\partial e_3} \cdots & \frac{\partial Q_2}{\partial e_n} & \frac{\partial Q_2}{\partial f_2} & \frac{\partial Q_2}{\partial f_3} \cdots & \frac{\partial Q_2}{\partial f_n} \\ \frac{\partial Q_3}{\partial e_2} & \frac{\partial Q_3}{\partial e_3} \cdots & \frac{\partial Q_3}{\partial e_n} & \frac{\partial Q_3}{\partial f_2} & \frac{\partial Q_3}{\partial f_3} \cdots & \frac{\partial Q_3}{\partial f_n} \\ & & \cdot & & & \\ \frac{\partial Q_n}{\partial e_2} & \frac{\partial Q_n}{\partial e_3} \cdots & \frac{\partial Q_n}{\partial e_n} & \frac{\partial Q_n}{\partial f_2} & \frac{\partial Q_n}{\partial f_3} \cdots & \frac{\partial Q_n}{\partial f_n} \end{bmatrix} \begin{bmatrix} \Delta e_2 \\ \Delta e_3 \\ \cdot \\ \cdot \\ \Delta e_n \\ \Delta f_2 \\ \Delta f_3 \\ \cdot \\ \cdot \\ \Delta f_n \end{bmatrix}$$

In short form it can be written as :

Where J_1, J_2, J_3 and J_4 are Jacobian elements.

3. RESULTS

For our proposed thesis work we have taken two Test system namely- IEEE-4 bus system and IEEE-9 bus system for Voltage Profile analysis. With the objective to improve the Voltage Profile, we introduced the Static Synchronous Compensator

(STATCOM), a shunt connected Flexible AC Transmission System (FACTS) device is implemented in these test systems to improve the Voltage Profile. We use the Newton-Raphson load flow method to calculate the voltage of each bus without STATCOM and with STATCOM and observe the effect of STATCOM on Voltage Profile after placement of it. Also observe the optimal location of STATCOM from Voltage Profile point of view and deviation in Voltage Profile. The effect of STATCOM on Voltage Profile has been studied for ten cases with different size and location of SATACOM. The sizes of STATCOM used in different case study are 20,40,60,80 and 100MVAr.

Table-4.1: Load Flow Results for IEEE 4 Bus System with 20 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage with STATCOM At 1	Bus Voltage with STATCOM At 2	Bus Voltage with STATCOM At 3	Bus Voltage with STATCOM At 4
Bus 1	1.000	1.000	1.000	1.000	1.000
Bus 2	0.9824	0.9824	0.9868	0.9824	0.9824
Bus 3	0.9690	0.9690	0.9690	0.9738	0.9690
Bus 4	1.0200	1.0200	1.0200	1.0200	1.0200
Deviation in Voltage	0.0686	0.0686	0.0642	0.0638	0.0686

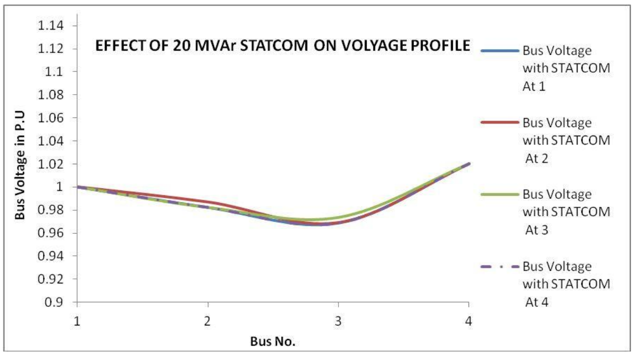

Fig.4.1: Graphical Comparisons between the results of Voltage Profile in IEEE-4 bus System without and with 20 MVAr STATCOM at Different Location

4.1 Case Study 1: IEEE-4 bus system with 20 MVAr STATCOM

From the above graphical comparisons it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 2 and 3 but the improvement in Voltage Profile with minimum deviation is observed only at bus no.3. Therefore the optimal location of 20 MVAr STATCOM is at bus no 3.

Table-4.2 : Load Flow Results for IEEE 4 Bus System with 40 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage with STATCOM At 1	Bus Voltage with STATCOM At 2	Bus Voltage with STATCOM At 3	Bus Voltage with STATCOM At 4
Bus 1	1.0000	1.0000	1.0000	1.0000	1.0000
Bus 2	0.9824	0.9824	0.9911	0.9824	0.9824
Bus 3	0.9690	0.9690	0.9690	0.9785	0.9690
Bus 4	1.0200	1.0200	1.0200	1.0200	1.0200
Deviation in Voltage	0.0686	0.0686	0.0555	**0.0444**	0.0686

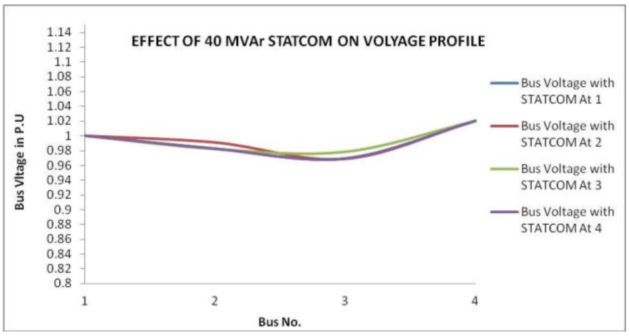

Fig. 4.2: Graphical comparisons between the results of Voltage Profile in IEEE-4 bus system without and with 40 MVar STATCOM

4.2 Case study 2:IEEE-4 bus system with 40 MVAr STATCOM

From the above graphical comparisons it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 2 and 3 but the improvement in Voltage Profile with minimum deviation is observed only at bus no.3. Therefore the optimal location of 40 MVAr STATCOM is at bus no 3.

4.3 Case Study 3:IEEE-4 bus system with 60 MVAr STATCOM

Table-4.3: Load Flow Results for IEEE-4 Bus System with 60 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage with STATCOM At 1	Bus Voltage with STATCOM At 2	Bus Voltage with STATCOM At 3	Bus Voltage with STATCOM At 4
Bus 1	1.0000	1.0000	1.0000	1.0000	1.0000
Bus 2	0.9824	0.9824	0.9956	0.9824	0.9824
Bus 3	0.9690	0.9690	0.9690	0.9834	0.9690
Bus 4	1.0200	1.0200	1.0200	1.0200	1.0200
Deviation in Voltage	0.0686	0.0686	0.0554	0.0542	0.0686

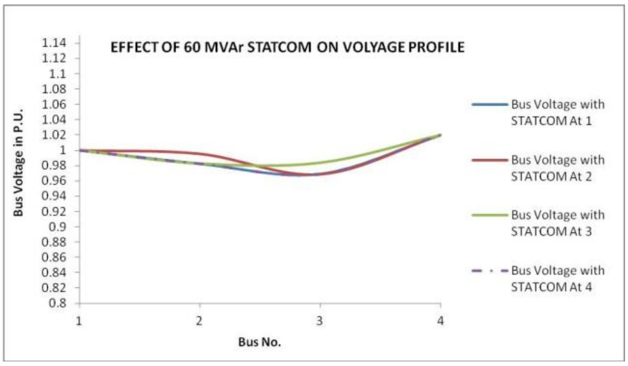

Fig.4.3: Graphical comparisons between the results of Voltage Profile in IEEE-4 bus system with 60 MVar STATCOM At Different Location

From the above graphical comparisons it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 2 and 3 but the improvement in Voltage Profile with minimum deviation is observed only at bus no.3. Therefore, the optimal location of 60 MVAr STATCOM is at bus no 3.

4.4 Case study 4: IEEE-4 bus system with 80 MVAr STATCOM

Table-4.4 : Load Flow Results for IEEE 4 Bus System with 80 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage with STATCOM At 1	Bus Voltage with STATCOM At 2	Bus Voltage with STATCOM At 3	Bus Voltage with STATCOM At 4
Bus 1	1.0000	1.0000	1.0000	1.0000	1.0000
Bus 2	0.9824	0.9824	1.0000	0.9824	0.9824
Bus 3	0.9690	0.9690	0.9690	0.9883	0.9690
Bus 4	1.0200	1.0200	1.0200	1.0200	1.0200
Deviation in Voltage	0.0686	0.0686	0.051	0.0493	0.0686

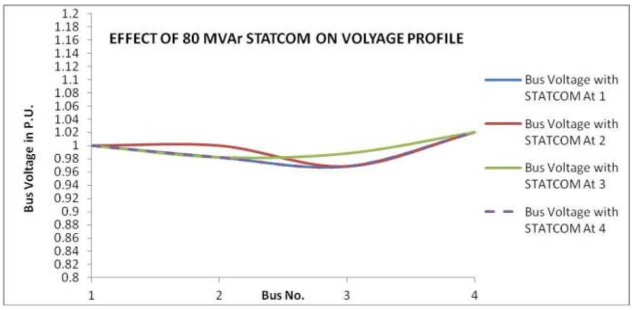

Fig. 4.4: Graphical comparisons between the results of Voltage Profile in IEEE-4 bus system with 80 MVar STATCOM At Different Location

Fig 4.4 shows that the Voltage Profile has been improved with STATCOM as compared to the Voltage Profile without STATCOM. Maximum improvement with minimum deviation is observed at bus no 3. Therefore, bus no 3 is the optimal location of STATCOM from Voltage Profile point of view.

4.5 Case Study 4:IEEE-4 bus system with 100 MVAr STATCOM

Table-5.5 : Load Flow Results for IEEE 4 Bus System with 100 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage with STATCOM At 1	Bus Voltage with STATCOM At 2	Bus Voltage with STATCOM At 3	Bus Voltage with STATCOM At 4
Bus 1	1.0000	1.0000	1.0000	1.0000	1.0000
Bus 2	0.9824	0.9824	1.0045	0.9824	0.9824
Bus 3	0.9690	0.9690	0.9690	0.9932	0.9690
Bus 4	1.0200	1.0200	1.0200	1.0200	1.0200
Deviation in Voltage	0.0686	0.0686	0.0555	0.0444	0.0686

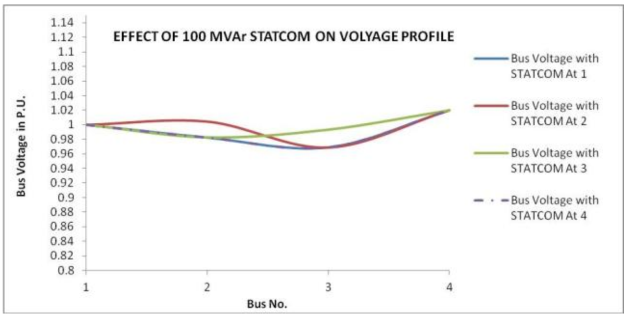

Fig. 4.5 : Graphical comparisons between the results of Voltage Profile in IEEE-4 bus system with 100 MVar STATCOM at different location

From the above graphical comparisons it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 2 and 3 but the improvement in Voltage Profile with minimum deviation is observed only at bus no.3. Therefore, the optimal location of 100 MVAr STATCOM is at bus no.3

4.6 Case Study 1: IEEE-9 bus system with 20 MVAr STATCOM

Table-4.6 : Load Flow Results for IEEE-9 Bus System with 20 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage With 20 MVAr STATCOM								
		At Bus 1	At Bus 2	At Bus 3	At Bus 4	At Bus 5	At Bus 6	At Bus 7	At Bus 8	At Bus 9
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.9870	0.9870	0.9870	0.9870	0.9958	0.9936	0.9889	0.9890	0.9890	0.9937
5	0.9755	0.9755	0.9755	0.9755	0.9821	0.9939	0.9800	0.9787	0.9778	0.9808
6	1.0034	1.0034	1.0034	1.0034	1.0051	1.0076	1.0120	1.0084	1.0057	1.0054
7	0.9856	0.9856	0.9856	0.9856	0.9876	0.9887	0.9907	1.0002	0.9921	0.9892
8	0.9962	0.9962	0.9962	0.9962	0.9981	0.9983	0.9985	1.0025	1.0052	1.0006
9	0.9576	0.9576	0.9576	0.9576	0.9645	0.9630	0.9598	0.9614	0.9624	0.9753
Voltage Deviation										
	0.1015	0.1015	0.1015	0.1015	0.0770	0.0683	0.0941	0.0820	0.0896	0.0670

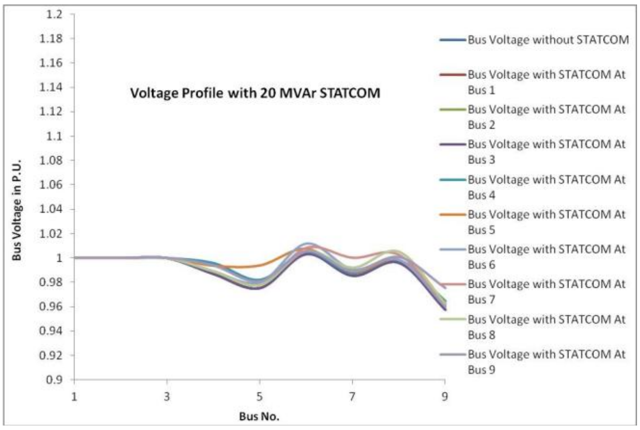

Fig. 4.6 : Graphical comparisons between the results of Voltage Profile in IEEE-9 bus system without and with 20 MVAr STATCOM

From the above graphical Comparison it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 4, 5,6,7,8 and 9 but the improvement of Voltage Profile with minimum deviation in voltage is observed at bus no 9 only. Therefore, the optimal location of 20 MVAr STATCOM is at bus no. 9

4.7 Case study 2: IEEE-9 bus system with 40 MVAr STATCOM

Table-4.7 : Load Flow Results for IEEE- 9 Bus System with 40 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage With 40 MVAr STATCOM								
		At Bus 1	At Bus 2	At Bus 3	At Bus 4	At Bus 5	At Bus 6	At Bus 7	At Bus 8	At Bus 9
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.9870	0.9870	0.9870	0.9870	1.0048	1.0004	0.9908	0.9910	0.9911	1.0006
5	0.9755	0.9755	0.9755	0.9755	0.9889	1.0129	0.9845	0.9820	0.9801	0.9862
6	1.0034	1.0034	1.0034	1.0034	1.0069	1.0119	1.0207	1.0135	1.0081	1.0075
7	0.9856	0.9856	0.9856	0.9856	0.9895	0.9919	0.9959	1.0152	0.9986	0.9928
8	0.9962	0.9962	0.9962	0.9962	1.0001	1.0005	1.0010	1.0090	1.0143	1.0052
9	0.9576	0.9576	0.9576	0.9576	0.9714	0.9686	0.9621	0.9653	0.9673	0.9937
Voltage Deviation										
	0.1015	0.1015	0.1015	0.1015	0.062	0.0733	0.0884	0.0994	0.0853	0.046

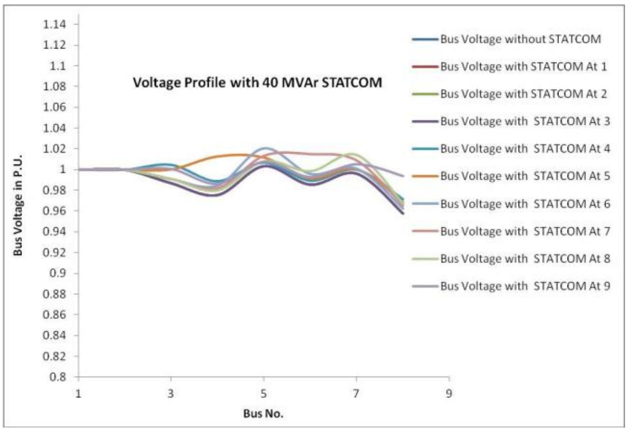

Fig. 4.7 : Graphical comparisons between the results of Voltage Profile in IEEE-9 bus system without and with 40 MVAr STATCOM

From the above graphical Comparison it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 4, 5,6,7,8 and 9 but the improvement of Voltage Profile with minimum deviation in voltage is observed at bus no 9 only. Therefore the optimal location of 40 MVAr STATCOM is at bus no. 9

4.8 Case Study 3: IEEE-9 bus system with 60 MVAr STATCOM

Table-4.8 : Load Flow Results for IEEE 9 Bus System with 60 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage With 40 MVAr STATCOM								
		At Bus 1	At Bus 2	At Bus 3	At Bus 4	At Bus 5	At Bus 6	At Bus 7	At Bus 8	At Bus 9
1	1.0 000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0 000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0 000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.9 870	0.9870	0.9870	0.9870	1.0140	1.0075	0.9927	0.9932	0.9932	1.0077
5	0.9 755	0.9755	0.9755	0.9755	0.9958	1.0327	0.9891	0.9855	0.9824	0.9919
6	1.0 034	1.0034	1.0034	1.0034	1.0088	1.0165	1.0296	1.0189	1.0106	1.0096
7	0.9 856	0.9856	0.9856	0.9856	0.9915	0.9952	1.0012	1.0306	1.0053	0.9966
8	0.9 962	0.9962	0.9962	0.9962	1.0020	1.0028	1.0034	1.0157	1.0236	1.0099
9	0.9 576	0.9576	0.9576	0.9576	0.9785	0.9743	0.9644	0.9693	0.9722	1.0126
Voltage Deviation										
	0.1 015	0.1015	0.1015	0.1015	0.05 9	0. 09	0.0356	0.1203	0.0917	0.0513

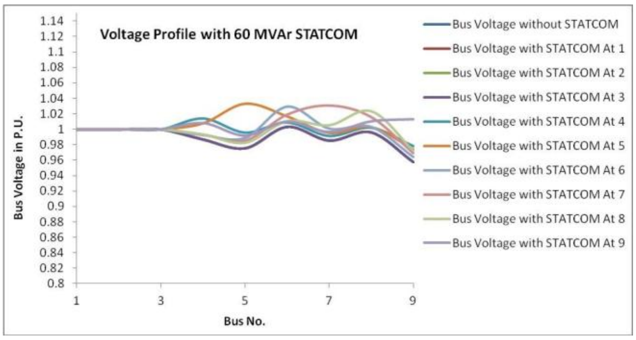

Fig.4.8: Graphical comparisons between the results of Voltage Profile in IEEE-9 bus system without and with 60 MVAr STATCOM

From the above graphical Comparison it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 4, 5,6,7,8 and 9 but the improvement of Voltage Profile with minimum deviation in voltage is observed at bus no 9 only. Therefore the optimal location of 40 MVAr STATCOM is at bus no.9

4.9 Case Study 4: IEEE-9 bus system with 80 MVAr STATCOM

Table-4.9: Load Flow Results for IEEE 9 Bus System with 80 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage With 40 MVAr STATCOM								
		At Bus 1	At Bus 2	At Bus 3	At Bus 4	At Bus 5	At Bus 6	At Bus 7	At Bus 8	At Bus 9
1	1.0 000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0 000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0 000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.9 870	0.9870	0.9870	0.9870	1.0233	1.0148	0.9947	0.9953	0.9954	1.0151
5	0.9 755	0.9755	0.9755	0.9755	1.0028	1.0532	0.9938	0.9890	0.9848	0.9978
6	1.0 034	1.0034	1.0034	1.0034	1.0106	1.0212	1.0386	1.0243	1.0131	1.0119
7	0.9 856	0.9856	0.9856	0.9856	0.9935	0.9987	1.0066	1.0465	1.0120	1.0005
8	0.9 962	0.9962	0.9962	0.9962	1.0041	1.0051	1.0059	1.0225	1.0330	1.0148
9	0.9 576	0.9576	0.9576	0.9576	0.9857	0.9803	0.9667	0.9734	0.9773	1.0323
Voltage Deviation										
	0.1 015	0.1015	0.1015	0.1015	0.0616	0.1153	0.0959	0.1356	0.1006	0.0768

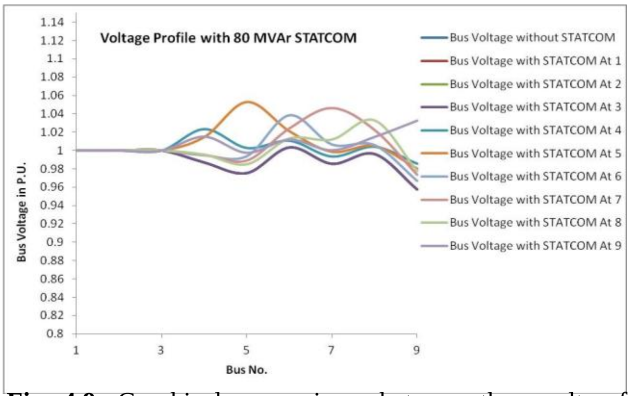

Fig. 4.9: Graphical comparisons between the results of Voltage Profile in IEEE-9 bus system without and with 80 MVAr STATCOM

From the above graphical Comparison it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 4, 5,6,7,8 and 9 but the improvement of Voltage Profile with minimum deviation in voltage is observed at bus no 4 only. Therefore the optimal location of 40 MVAr STATCOM is at bus no. 4

4.10 Case Study 10: IEEE-9 bus system with 100 MVAr STATCOM

Table-4.10: Load Flow Results for IEEE 9 Bus System with 100 MVAr STATCOM

Bus No.	Bus Voltage without STATCOM	Bus Voltage With 40 MVAr STATCOM								
		At Bus 1	At Bus 2	At Bus 3	At Bus 4	At Bus 5	At Bus 6	At Bus 7	At Bus 8	At Bus 9
1	1.0 000	1.0000	1.0000	1.0000	1.00 00	1.0000	1.0000	1.0000	1.0000	1.0000
2	1.0 000	1.0000	1.0000	1.0000	1.00 00	1.0000	1.0000	1.0000	1.0000	1.0000
3	1.0 000	1.0000	1.0000	1.0000	1.00 00	1.0000	1.0000	1.0000	1.0000	1.0000
4	0.9 870	0.9870	0.9870	0.9870	1.03 28	1.0225	0.9967	0.9976	0.9975	1.0228
5	0.9 755	0.9755	0.9755	0.9755	1.01 00	1.0745	0.9986	0.9926	0.9873	1.0038
6	1.0 034	1.0034	1.0034	1.0034	1.01 25	1.0260	1.0478	1.0299	1.0156	1.0142
7	0.9 856	0.9856	0.9856	0.9856	0.99 56	1.0022	1.0120	1.0628	1.0189	1.0045
8	0.9 962	0.9962	0.9962	0.9962	1.00 61	1.0076	1.0084	1.0296	1.0427	1.0198
9	0.9 576	0.9576	0.9576	0.9576	0.99 31	0.9866	0.9691	0.9776	0.9824	1.0527
Vo ltage Deviation										
	0.1 015	0.1015	0.1015	0.1015	0.07 27	0.1462	0.1038	0.1545	0.11	0.1178

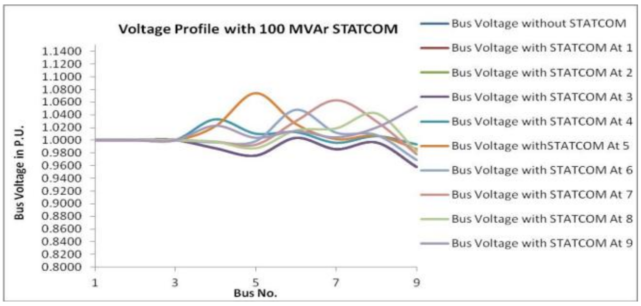

Fig.4.10: Graphical comparisons between the results of Voltage Profile in IEEE-9 bus system without and with 100 MVAr STATCOM

From the above graphical Comparison it is observed that the Voltage Profile has been improved after the placement of STATCOM. The overall Voltage Profile of the system has been improved when the STATCOM placed at bus no. 4, 5,6,7,8 and 9 but the improvement of Voltage Profile with minimum deviation in voltage is observed at bus no 4 only. Therefore the optimal location of 40 MVAr STATCOM is at bus no. 4

5. FUTURE SCOPE

The future scope of this thesis work is as follows:

- Two or more than two Facts controller can be used in coordinated manner to enhance the Voltage Profile.
- Other member of FACTS controller such as UPFC, HPFC is also used for shunt compensation to improving the Voltage Profile and minimizing the real and reactive power losses.
- Artificial intelligence techniquesused for verification of OPF result and improvement in Voltage Profile in power system networks.
- Hybrid artificial intelligence technique used for verification of OPF result and improvement in Voltage Profile in power system networks

6. CONCLUSION

From the above load flow results and graphical representation of Voltage Profile in test systems, It is concluded that the Voltage Profile has been improved after the placement of STATCOM in the test systems. The maximum improvement of Voltage Profile is obtained at bus no. 03 with minimum voltage deviation for all size of STATCOM in IEEE-4 Bus Test System. Therefore the optimal location of STATCOM in IEEE-4 Bus Test System for all sizes Is at bus no. 3.

In IEEE-9 Bus System the maximum improvement of Voltage Profile with minimum voltage deviation is obtained at bus no. 9 for 20, 40 and 60 MVAr size of STATCOM and at bus no.4 for 80 and 100 MVAR size of STATCOM. The optimal location of STATCOM is at bus no 9 for sizes 20, 40 and 60 MVAr and at bus no. 4 for size 80and 100 MVAr.

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