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Flow Analysis of Transmission System Incorporating STATCOM

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Abstract- In this modern age of technological development demand of the electrical energy is increasing where generation and transmission capacity is not increasing at same rate. This gives constraints on the power system. The erection of a new transmission line is not an easy task especially in the developing countries like India. So a power system engineer must try to use existing transmission lines up to their stability limits. Operating the lines near or above thermal stability limits makes system vulnerable to faults moreover it also increases the losses in the system. One way to increase the transmission capacity of the system without operating it to its thermal stability limit is to provide reactive power compensation at various locations. Reactive power compensation improves the voltage profile of the system, increase the power transfer in the lines and reduce losses. STATCOM is one such device that is used for reactive power compensation. It provides reactive power compensation thereby improving the voltage profile of the system.In this thesis reactive power compensation is attempted using STATCOM. To study its affect Load flow study is performed on IEEE 5 bus, IEEE 14 bus and IEEE 30 bus with and without STATCOM incorporated and the results are then compared to show the effect of STATCOM on the system. NEWTON RAPHSON method is used for the load flow study of the system.

Keyword: STATCOM, FACTS, IEEE-5 bus ,IEEE-14 bus,IEEE_30 bus

I. INTRODUCTION

Over the time human race has become very much dependent upon electrical energy, to fulfill their daily needs. This has resulted in the rapid growth of power system. There are few problems that we face. They are power disruption and individual power outrages. To maintain the urban lifestyle there is enormous demand of power so transmission systems are being pushed to operate closer to their stability limit and also reaching close to their thermal limits. These constraints can be controlled by FACTS devices. FACTS devices mean Flexible AC Transmission Systems devices. To establish the match between the demand and supplies of power, control over the power flow and enhancement in system stability is important which can be achieved by the FACTS devices. FACTS devices have now became the need of the hour. It is now becoming our necessity to use FACTS devices to improve the efficiency of the power system. FACTS devices are cost effective alternatives to new transmission line construction.

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To minimize the power transmission loss reactive power compensation is used. Reactive power compensation is also used to maintain power transmission capability and to maintain the supply voltage. STATCOM (Static Compensator) is a shunt compensator and comes under FACTS device category that is being applied to long transmission lines. They are used for the control of power system. Applications such as scheduling of power flow, decreasing unsymmetrical components, decreasing the power oscillations and increasing the transient stability.

II. POWER FLOW ANALYSIS AND SOLUTION METHOD

A load flow study on a power system network will give us information on whether or not the Nodal voltages ,active and reactive power flow of the bus will remain in the permissible limits or not. For example, in a power system a generator has to be synchronized with the system, load flow study will determine whether or not the nodal voltages and power flows will be in the permissible limits or not and in turn will show that the addition of generator in the system will be feasible or not. If the values comes out to be out of the prescribed limit the power system engineer can take steps to make the addition feasible.

A. The Newton Raphson Load Flow Algorithem

Newton Raphson method is very popular due to its very strong convergence characteristic. This method uses iteration to solve the non linear equations of power system. A value is assumed and it is corrected in continuous steps or iteration until the required value falls in permissible limit. An example is shown for how Newton raphson method can be used to solve a set of non linear equations the vector of state variable is determined by performing an expansion of F(X) by Taylor's series by taking an initial estimate $X^{(0)}$

$$F(X)=F\,(X^{(0)}) + J\,(X^{0})(X - X^{0}) + \text{higner order terms} \qquad (1)$$

$$\begin{bmatrix} f_1(X^{(1)}) \\ f_3(X^{(1)}) \\ \cdot \\ \cdot \\ f_n(X^{(1)}) \end{bmatrix} \approx \begin{bmatrix} f_1(X^{(0)}) \\ f_3(X^{(0)}) \\ \cdot \\ \cdot \\ f_n(X^{(0)}) \end{bmatrix} + \begin{bmatrix} \frac{\partial f_1\,(X)}{\partial x_1} & \frac{\partial f_1\,(X)}{\partial x_3} & \cdots & \frac{\partial f_1\,(X)}{\partial x_n} \\ \frac{\partial f_3\,(X)}{\partial x_1} & \frac{\partial f_3\,(X)}{\partial x_3} & \cdots & \frac{\partial f_3\,(X)}{\partial x_n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & & \cdot \\ \frac{\partial f_n\,(X)}{\partial x_1} & \frac{\partial n(X)}{\partial x_3} & \cdots & \frac{\partial f_n\,(X)}{\partial x_n} \end{bmatrix} \begin{bmatrix} X_1^{(1)} - X_1^{(0)} \\ X_3^{(1)} - X_3^{(0)} \\ \cdot \\ \cdot \\ \cdot \\ X_n^{(1)} - X_n^{0} \end{bmatrix} \qquad (2)$$

Final solution that

$$\Delta X^{(i)} = -J(X^{(i-1)})(X^{(i)} - X^{(i-1)} \qquad (3)$$

This was the generalized form of Newton Raphson method, its incorporation in load flow should be in the form of equation 3 so

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$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}^{(i)} = -\begin{bmatrix}\frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V}V\\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V}V\end{bmatrix}^{(i)} \begin{bmatrix}\Delta \theta\\ \frac{\Delta V}{V}\end{bmatrix}^{(i)} \quad (4)$$

This is the form of the equation

$$F\left(X^{(i-1)}\right) = J\left(X^{(i-1)}\right)\Delta X^{(i)}$$

(5)

After calculating the phase angle and voltage magnitude by continuous iteration process, active and reactive power can be calculated easily. An important aspect of this equation is that the mismatch power equation ΔP and ΔQ are not included in the equation 5. The unknown variable P_{slack} and Q_{slack} can be calculated after all the system power flows and power losses has been determined. The Newton Raphson method has a very strong convergence characteristic. For practically all the power flow problems this method possesses quadratic convergence characteristics too

III. STATCOM INCORPORATION IN LOAD FLOW STUDY

It is designed based on Voltage source converter (VSC) electronic device with Gate turn off thyristor and dc capacitor coupled with a step down transformer tied to a transmission line as shown in figure 4.6. It converts the dc input voltage into ac output voltages to compensate the active and reactive power of the system.

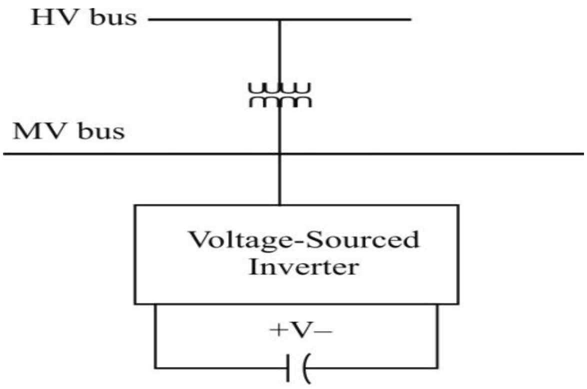

Fig. 1: Circuit Diagram of Static Synchronous Compensator (STATCOM)

A. Power Flow Analysis with STATCOM

Usually, STATCOM consists of a coupling transformer, a converter and a DC capacitor, as shown in the figure 2

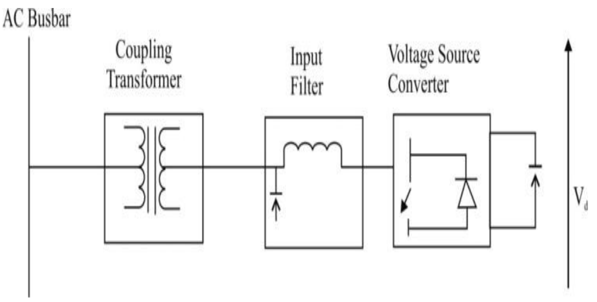

Fig. 2: Components of a STATCOM

Then the power flow constraints of the STATCOM are given by

$$P_{st} = V_p^2 g_{st} - V_p V_{st}(g_{st}\cos(\theta_p - \theta_{st}) + b_{st}\sin(\theta_p - \theta_{st})) \quad (6)$$

$$Q_{st} = -V_p^2 b - V_p V_{st}(g_{st}\sin(\theta_p - \theta_{st}) - b_{st}\cos(\theta_p - \theta_{st})) \quad (7)$$

STATCOM is used to control the reactive power at one of the buses to see its effect on the performance of the transmission system and infer useful conclusions from this. This is done by the control of the voltage at the required bus. The main constraint of the STATCOM while operating is that, the active power exchange via the DC link should be zero.

$$PE_x = \mathrm{Re}(V_{st} I_{st}^*) = 0 \quad (8)$$

Where

$$\mathrm{Re}(V_{st} I_{st}^*) = V_p^2 g_{st} - V_p V_{st}(g_{st}\cos(\theta_p - \theta_{st}) - b_{st}\sin(\theta_p - \theta_{st})) \quad (9)$$

B. Control Function of STATCOM

The control of the STATCOM voltage magnitude should be such that the specified bus voltage and the STATCOM voltage should be equivalent and there should be no difference between them. By proper design procedure, knowing the limits of the variables and the parameters, but not exactly knowing the power system parameters, simultaneous DC and AC control can be achieved.

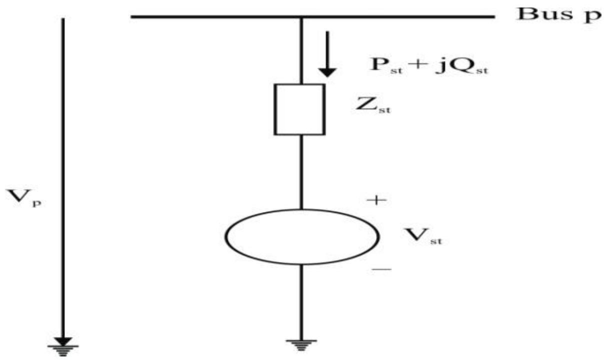

Fig. 3: Bus Line Diagram for STATCOM

C. Implementation of STATCOM to a Bus Network

The Newton Raphson power flow equations for a bus system containing "n" number of buses, including a STATCOM are developed as follows

$$\begin{bmatrix}\Delta P_2\\ \Delta P_3\\ \vdots\\ \Delta P_n\\ \Delta Q_2\\ \Delta Q_3\\ \vdots\\ \Delta Q_n\\ \Delta PE_x\\ \Delta F\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_3}{\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}\\
\vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots\\
\frac{\delta P_n}{\delta e_2} & \frac{\delta P_n}{\delta 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{\delta Q_2}{\delta e_2} & \frac{\delta Q_2}{\delta 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{\delta Q_3}{\delta e_2} & \frac{\delta Q_3}{\delta 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}\\
\vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots\\
\frac{\partial Q_n}{\partial e_2} & \frac{\partial Q_2}{\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}\\
\frac{\partial PE_X}{\partial e_2} & \frac{\partial PE_X}{\partial e_3} & \cdots & \frac{\partial PE_X}{\partial e_n} & \frac{\partial PE_X}{\partial f_2} & \frac{\partial PE_X}{\partial f_3} & \cdots & \frac{\partial PE_X}{\partial f_n}
\end{bmatrix} \begin{bmatrix}\Delta e_2\\ \Delta e_3\\ \vdots\\ \Delta e_n\\ \Delta f_2\\ \Delta f_3\\ \vdots\\ \Delta f_n\\ \Delta V_{st}\\ \Delta \delta_{st}\end{bmatrix} \quad (10)$$

D. Algorithm for Load Flow with STATCOM

The steps to incorporate STATCOM are as follows:

Step 1 Read the system database.

Step 2 The system buses, at which STATCOM are assumed to be placed are made PV buses.

Step 3 The specified real power and reactive power at which STATCOM is placed is calculated using eq. (5.18) and eq. (5.19).

Step 4 On the buses with STATCOM, the specified voltage is set according to the desired voltage and upper and lower limits of reactive power are set according to the STATCOM ratings.

Step 5 Modify Jacobian elements as described in section 3.3 and using eq. (5.20) to eq. (5.23).
Step 6 Carry Newton-Raphson load flow with modified Jacobian elements
Step 7 Voltages and angles of system and STATCOM are updated.

IV. CASE STUDY AND RESULTS

Case -1 Study for an IEEE 5 Bus System

Consider a standard IEEE 5 bus system for load flow study by Newton Raphson load flow method. It has 5 buses namely North, South, Lake, Main and Elm. The source impedance is $X_{vr} = 0.1$ p.u.

Bus 3, 4 and 5 are considered load bus. Bus 1 is slack bus while bus 2 is voltage controlled bus.

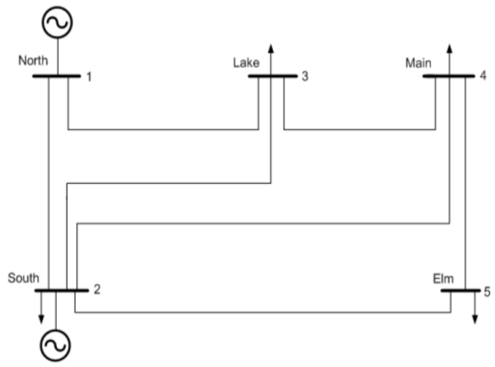

Fig. 4: An IEEE 5 bus system

A. Bus voltages and phase angle

The Newton raphson load flow IEEE 5 bus system implemented on MATLAB return following results

For Iteration count = 6

Table 1.Bus Voltage and Phase Angle, IEEE 5 Bus without STATCOM

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
	1.0600	1.0000	0.9872	0.9841	0.9717
Phase angle (degree)	0.000	-2.0612	-4.6367	-4.9670	-6.764

Table2 Bus Voltage and Phase Angle, IEEE 5 Bus with STATCOM

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
	1.0600	1.0000	1.0000	0.9944	0.9762
Phase angle (degree)	0.000	-2.0633	-4.8379	-6.1073	-6.7976

From the results it can be seen that voltage profile has been improved with the inclusion of STATCOM in the network.

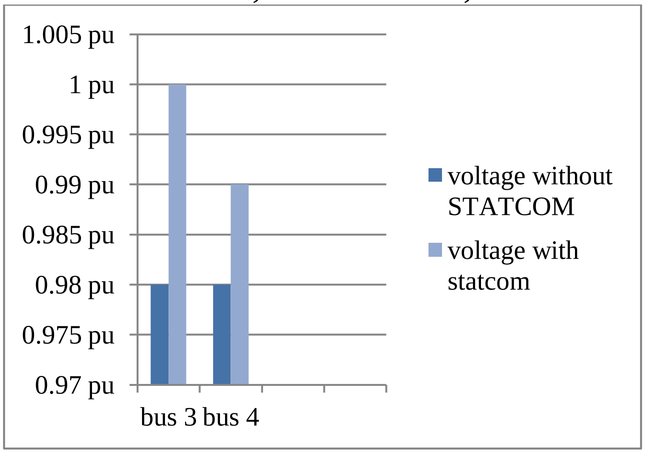

Fig. 5: Graphical Representation of Improved Voltage Profile with STATCOM (IEEE 5 Bus)

B. Real and Reactive Power Flows

The Newton raphson load flow on this system implemented on MATLAB return following results for real and reactive power flows in the network Line flows without STATCOM.
For iteration count = 6

Table.3 line flows without STATCOM, IEEE 5 Bus System

Buses	Sending end		Receiving end	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1-2	89.33	74.00	-86.86	-72.91
1-3	41.79	16.82	-40.27	-17.61
2-3	24.47	-2.62	-24.11	-0.36
2-4	27.71	-1.72	-27.26	-0.83
2-6	64.66	6.66	-63.44	-4.83
3-4	19.39	2.86	-19.36	-4.69
4-6	6.6	0.62	-6.66	-6.17

Table.4 line flows with STATCOM, IEEE 5 Bus System

Buses	Sending end		Receiving end	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1-2	89.11	74.06	-86.83	-72.99
1-3	41.96	11.28	-40.66	-12.41
2-3	24.49	-9.69	-24.09	6.69
2-4	27.66	-7.32	-27.18	4.77
2-6	64.88	2.76	-63.29	-2.09
3-4	19.66	11.19	-19.69	-13.02

4-6	6.78	3.26	-6.71	-7.91

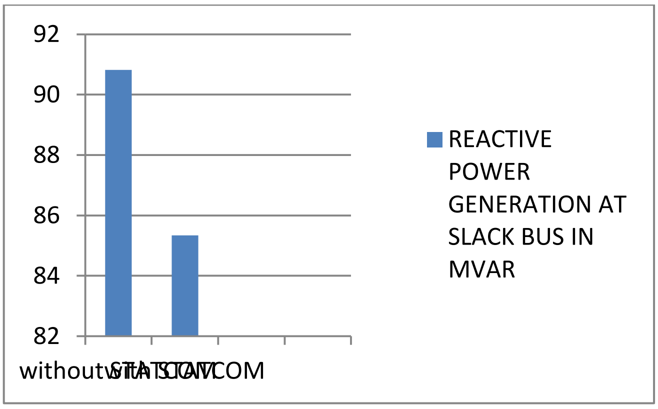

Fig. 6 : Comparative Reactive Power Generation at Slack Bus of IEEE 5 Bus System

Case-2 Study for IEEE -14 Bus System

Figure.7 shows the single line diagram of an IEEE-14 bus system. This system has four generator bus viz. Bus 2, 3, 6 and 8. Bus 1 is the slack bus and the load buses are bus 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14.

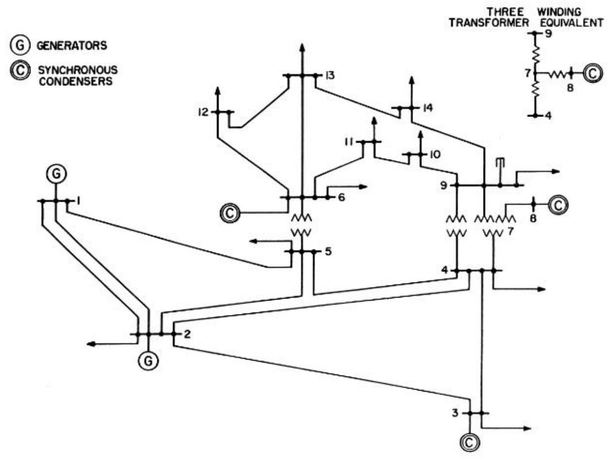

Fig.7: An IEEE 14 Bus System

A. Bus Voltage and Phase angles

The Newton raphson load flow IEEE 14 bus system implemented on MATLAB return following results for iteration = 7

Table 5 Bus Voltages and Phase Angle, IEEE 14 bus without STATCOM

	Bus voltage without STATCOM				
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 6
Nodal Voltage Magnitude (p.u.)	1.0600	1.0460	1.0100	1.0136	1.0192
Phase angle (degree)	0.000	-4.9800	-12.760	-10.260	-8.760

Table5 cont…

	Bus voltage without STATCOM				
	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10
Nodal Voltage Magnitude (p.u.)	1.0164	1.0166	1.0666	0.9946	0.9904
Phase angle (degree)	-14.86	-13.68	-13.68	-16.37	-16.69

Table5 cont…

	Bus voltage without STATCOM			
	Bus 11	Bus 12	Bus 13	Bus 14
Nodal Voltage Magnitude (p.u.)	.9991	.9992	0.9938	0.9761
Phase angle (degree)	-16.36	-16.79	-16.86	-16.70

Table 6. Bus Voltages and Phase Angle, IEEE 14 Bus with STATCOM

	Bus voltage with STATCOM				
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
Nodal Voltage Magnitude (p.u.)	1.0600	1.0450	1.0100	1.0011	1.000
Phase angle (degree)	0.000	-5.0400	-12.8871	-10.1553	-8.614

Table 6. cont…

	Bus voltage with STATCOM				
	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10
Nodal Voltage Magnitude (p.u.)	1.0700	1.0000	1.0900	.9949	1.0004
Phase angle (degree)	-15.1197	-13.2696	-13.2696	-14.9175	-15.23

Table 6.cont…

	Bus voltage without STATCOM			
	Bus 11	Bus 12	Bus 13	Bus 14
Nodal Voltage Magnitude (p.u.)	1.0310	1.0505	1.0414	.9964

Phase angle	-15.2778	-15.9602	-15.9239	-16.4336

From the table 6 it is clear that the bus voltages at bus 5 and bus 7 where STATCOM are placed have become 1 p.u. The bus voltages at other buses are also improved and it can be seen more clearly in the graph shown below. Clearly with the inclusion of STATCOM bus voltage profile of the network is greatly improved and is visible from the results.

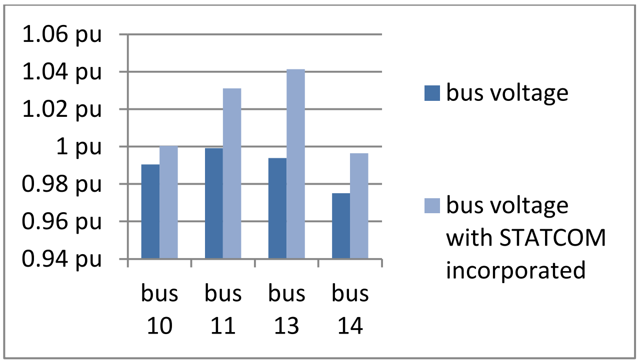

Fig. 8: Graphical Representation of Improved Voltage Profile with STATCOM (IEEE 14 Bus)

B. Real and Reactive Power Flows

The Newton raphson load flow on this system implemented on MATLAB return following results for real and reactive power flows in the network

Line flows without STATCOM. For iteration count = 7

Table 7 Line Flows Without STATCOM, IEEE 14 Bus Systems

Buses	Sending end		Receiving end	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1-2	167.01	-20.43	-162.70	27.73
1-6	76.48	4.00	-72.72	2.08
2-3	73.44	3.64	-71.11	1.68
2-4	66.09	0.82	-64.41	0.67
2-6	41.47	1.36	-40.67	-2.29
3-4	-23.09	6.84	23.48	-7.16
4-6	-61.66	6.84	62.16	-6.26
4-7	28.62	-0.63	-28.62	2.30
4-9	16.16	4.18	-16.16	-2.68
5-6	43.64	3.87	-43.64	0.77
6-11	6.96	6.01	-6.89	-4.87
6-12	7.79	2.72	-7.71	-2.66
6-13	17.60	8.01	-17.36	-7.64
7-8	0.00	-23.09	-0.00	24.00
7-9	28.62	20.79	-28.62	-19.46
9-10	6.64	2.81	-6.63	-2.77
9-14	9.64	2.73	-9.61	-2.46
10-11	-3.37	-3.03	3.39	3.07
12-13	1.61	0.96	-1.60	-0.94
13-14	6.46	2.68	-6.39	-2.66

Table8. Line Flows with 2 statcom, IEEE 14 Bus Systems

Buses	Sending end		Receiving end	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1-2	158.62	-20.81	-154.22	28.38
1-5	74.99	12.95	-72.17	-6.52
2-3	74.18	3.47	-71.80	1.94
2-4	56.16	8.04	-54.43	-6.35
2-5	42.18	12.51	-41.15	-12.96
3-4	-22.40	14.08	22.88	-14.17
4-5	-57.12	21.48	57.61	-19.19
4-7	26.01	1.21	-26.01	0.20
4-9	14.87	1.73	-14.87	-0.48
5-6	48.10	-25.04	-48.10	32.45
6-11	9.40	16.48	-9.10	-15.85
6-12	8.43	4.14	-8.34	-3.94
6-13	19.07	13.91	-18.75	-13.27
7-8	0.000	-51.09	0.000	55.69
7-9	26.01	5.01	-26.01	-4.24
9-10	3.60	-7.78	-3.57	7.84

9-14	7.78	-4.10	-7.68	4.31
10-11	-5.43	-13.64	5.60	14.06
12-13	2.24	2.34	-2.22	-2.32
13-14	7.46	9.79	-7.22	-9.31

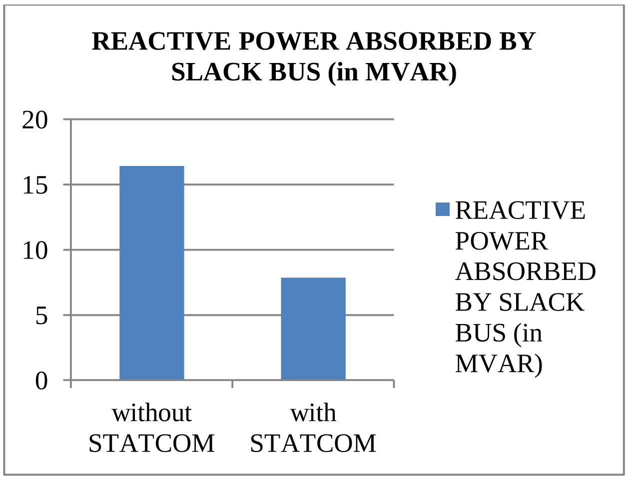

Fig. 9: Comparative Reactive Power absorbed by Slack Bus, IEEE 14 BusCase -3 Study for IEEE- 30 Bus Systems

A single line diagram of IEEE 30 bus is shown in the fig 6.7. This system consists of five generator buses (bus numbers 2, 6, 8, 11, 13) bus 1 is taken as slack bus. There are 27 load buses in the system viz. 2, 3, 4, 6, 6, 7, 8, 9, 10, 12, 14, 16, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 26, 27, 28, 29, 30. This system will be subjected to Newton Raphson load flow study via MATLAB.STATCOM is placed at bus 4, bus 7, bus 14 and bus 29. Bus Data and Line Data are given below for the IEEE 30 bus systems. The Nodal Voltage and phase angle with reference to slack bus is given.

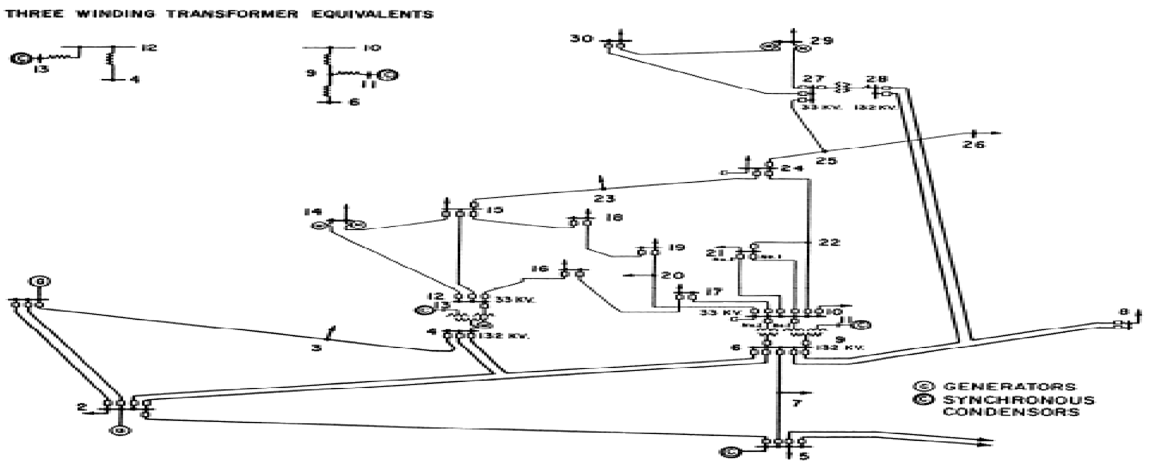

Fig. 10: an IEEE 30 Bus System

A. Bus Voltage and Phase Angle

Table 9 bus voltages and phase angle, IEEE 30 Bus without STATCOM

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 6
	1.0600	1.0430	1.0206	1.0122	1.0100
Phase angle	0	-6.60	-7.99	-9.66	-14.42

Table 9 cont…

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus6	Bus7	Bus8	Bus9	Bus10
	1.0082	1.0007	1.0100	1.0091	0.9860

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Phase angle (degree)	-11.36	-13.14	-12.16	-14.66	-16.44

Table 9 cont…

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 11	Bus 12	Bus 13	Bus 14	Bus 16
	1.0664	1.0061	1.0376	0.9884	0.9826
Phase angle (degree)	-14.66	-16.91	-16.91	-16.86	-16.90

Table 9 cont…

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
	0.9896	0.9814	0.9709	0.9673	0.9712
Phase angle (degree)	-16.43	-16.67	-17.61	-17.66	-17.42

Table 9 cont…

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 21	Bus 22	Bus 23	Bus 24	Bus 26
	0.9726	0.9730	0.9689	0.9696	0.9644
Phase angle (degree)	-16.92	-16.90	-17.20	-17.22	-16.87

Table 9 cont…

	Bus voltage without STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 26	Bus 27	Bus 28	Bus 29	Bus 30
	0.9468	0.9766	1.0046	0.9666	0.9436
Phase angle	-17.34	-16.36	-12.01	-17.72	-18.69

Table 10 Bus Voltages and phase angle, IEEE 30 Bus with STATCOM

	Bus voltage with 4 STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 6
	1.0600	1.0430	1.0106	1.0000	1.0100
Phase angle (degree)	0	-6.63	-7.88	-9.63	-14.47

Table 10 cont…

	Bus voltage with 4 STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10
	1.0067	1.0000	1.0100	1.0208	0.9976
Phase angle (degree)	-11.40	-13.20	-12.23	-14.61	-16.32

Table 10 cont…

	Bus voltag e with 4 STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 11	Bus 12	Bus 13	Bus 14	Bus 16
	1.0820	1.0200	1.0710	1.0000	0.9964
Phase angle (degree)	-14.61	-16.82	-16.82	-16.64	-16.77

The data for IEEE 30 bus system from bus number 17 to bus number 30 is continued below, as shown above the row 1 and 2 are the nodal voltage magnitude at that bus and row 2 is the phase angle in degree with reference to the slack bus

Table 10 cont…

	Bus voltage with 4 STATCOM				
Nodal Voltage Magnitude (p.u.)	Bus 16	Bus 17	Bus 18	Bus 19	Bus 20
	1.0031	0.9937	0.9841	0.9801	0.9837

Phase angle (degree)	-16.32	-16.66	-17.37	-17.62	-17.28

Table 10 cont…

	Bus voltage with 4 STATCOM				
Nodal Voltage	Bus 21	Bus 22	Bus 23	Bus 24	Bus 26
Magnitude (p.u.)	0.9849	0.9866	0.9834	0.9748	0.9847
Phase angle (degree)	-16.80	-16.78	-17.09	-17.13	-16.88

Table 10 cont…

	Bus voltage with 4 STATCOM				
Nodal Voltage	Bus 26	Bus 27	Bus 28	Bus 29	Bus 30
Magnitude (p.u.)	0.9664	0.9997	1.0062	1.000	0.9796
Phase angle (degree)	-17.33	-16.44	-12.11	-18.34	-18.97

Comparing table9 and table 10 the nodal voltages at the buses where STATCOM are placed that is at 4,7,14 and 29 the bus voltages are maintained at 1.00 p.u. and at other buses the nodal voltages are either close to 1 or 1. The voltage profile of the network is hence improved with the incorporation of STATCOM in the network.

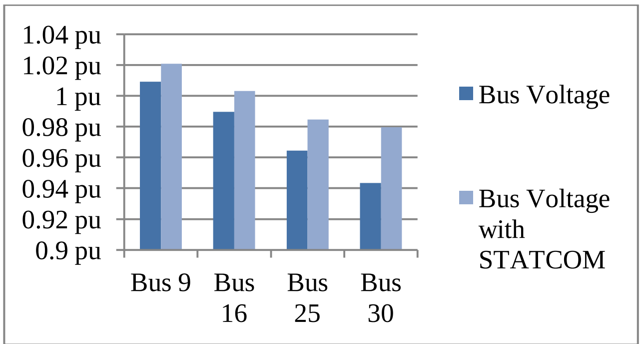

Fig .11 Graphical Representation of Improved Voltage Profile with STATCOM

B. Real and Reactive Power Flows

The Newton raphson load flow on this system implemented on MATLAB return following results for real and reactive power flows in the network
Line flows without STATCOM.
For iterations = 8

Table 11 Line flows without STATCOM, IEEE 30 Bus System

Buses	Sending end		Receiving end	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1-2	178.10	-20.74	-172.62	34.24
1-3	83.17	6.80	-80.36	2.60
2-4	46.67	4.10	-44.66	-2.67
3-4	77.96	-3.70	-77.19	6.48
2-6	83.26	2.82	-80.24	7.64
2-6	61.99	2.29	-69.93	1.99
4-6	70.87	-9.69	-70.27	11.19
6-7	-13.96	13.36	14.13	-13.96
6-7	37.30	-2.78	-36.93	3.06
6-8	29.76	-12.94	-29.64	12.92
6-9	28.10	0.33	-28.10	1.29
6-10	16.81	4.71	-16.81	-3.22
9-11	0.00	-22.93	-0.00	24.00
9-10	28.10	21.64	-28.10	-20.28
4-12	43.29	6.18	-43.29	-0.43
12-13	-0.00	-23.26	0.00	24.00
12-14	7.84	2.91	-7.76	-2.73
12-16	17.44	8.60	-17.19	-8.11
12-16	6.81	4.68	-6.74	-4.64
14-16	1.66	1.13	-1.66	-1.12
16-17	3.24	2.74	-3.23	-2.71
16-18	6.87	2.39	-6.82	-2.30
18-19	2.62	1.40	-2.62	-1.39
19-20	-6.88	-2.01	6.90	2.06
10-20	9.19	2.96	-9.10	-2.76
10-17	6.79	3.13	-6.77	-3.09

10-21	16.62	10.61	-16.49	-10.23
10-22	7.61	4.92	-7.46	-4.80
21-22	-2.01	-0.97	2.01	0.97
16-23	4.67	4.34	-4.63	-4.26
22-24	6.44	3.83	-6.39	-3.74
23-24	1.43	2.66	-1.41	-2.63
24-26	-1.90	-0.33	1.90	0.34
26-26	3.66	2.37	-3.60	-2.30
26-27	-6.46	-2.71	6.60	2.80
28-27	18.81	7.81	-18.81	-6.18
27-29	6.20	1.69	-6.11	-1.61
27-30	7.11	1.69	-6.93	-1.36
29-30	3.71	0.61	-3.67	0.64
8-28	-0.36	1.80	0.37	-3.96
6-28	-19.24	-2.60	-19.18	-3.86

The real and reactive power flows in the IEEE 30 Bus system when 4 STATCOM are incorporated in the system at bus 4,7,14 and 29. The following results are obtained.

Table 12 Line Flows with 4 STATCOM, IEEE 30 Bus Systems

Buses	Sending end		Receiving end	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1-2	178.97	-20.94	-173.44	34.61
1-3	82.66	12.48	-79.82	-3.11
2-4	46.86	11.23	-44.67	-9.66
3-4	77.42	1.91	-76.66	-0.10
2-6	83.63	2.80	-80.49	7.74
2-6	62.36	3.60	-60.27	0.78
4-6	70.01	-32.91	-69.30	34.93
6-7	-13.71	13.84	13.89	-14.42
6-7	37.06	-4.86	-36.69	6.13
6-8	29.84	-18.71	-29.69	18.76
6-9	27.66	-6.49	-27.66	8.16
6-10	16.49	2.14	-16.49	-0.80
9-11	0.00	-30.06	-0.00	31.68
9-10	27.66	21.91	-27.66	-20.60
4-12	43.71	-6.41	-43.71	10.38
12-13	-0.00	-37.16	0.00	39.01
12-14	7.72	4.36	-7.63	-4.16
12-16	17.74	9.66	-17.49	-9.06
12-16	7.06	6.36	-6.98	-6.21
14-16	1.43	0.23	-1.42	-0.22
16-17	3.48	3.41	-3.46	-3.36
16-18	6.01	2.67	-6.96	-2.68
18-19	2.76	1.68	-2.76	-1.67
19-20	-6.76	-1.73	6.76	1.77
10-20	9.06	2.66	-8.96	-2.47
10-17	6.66	2.47	-6.64	-2.44
10-21	16.38	9.80	-16.27	-9.66
10-22	7.36	4.46	-7.30	-4.36
21-22	-2.23	-1.66	2.23	1.66
16-23	4.70	4.10	-4.66	-4.02
22-24	6.07	2.70	-6.03	-2.64
23-24	1.46	2.42	-1.46	-2.40
24-26	-2.22	-1.66	2.24	1.68
26-26	3.66	2.37	-3.60	-2.30
26-27	-6.79	-4.06	6.84	4.16
28-27	19.16	2.12	-19.16	-0.67

27-29	6.26	-3.26	-6.16	3.46
27-30	7.06	-0.26	-6.90	0.66
29-30	3.76	2.64	-3.70	-2.46
8-28	-0.31	1.42	0.31	-3.68
6-28	19.64	-7.80	-19.47	1.46

The bus 1 is considered as slack bus. It is clear from the tables 11 and 12 that the reactive power generation at the bus is reduced. The reactive power absorption at slack bus without STATCOM was 13.94 MVAR while after inclusion of STATCOM the generator is absorbing 8.46 MVAR of reactive power, this shows that the remaining reactive power is absorbed by STATCOM. The graph below shows that the reactive power that was being absorbed by the slack bus is reduced as the excess reactive power is absorbed by the STATCOM places at that bus. STATCOM

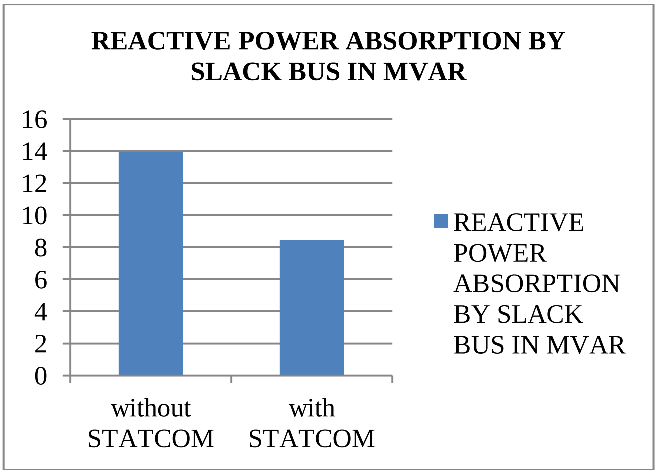

Fig. 6.9: Comparative Reactive Power Generation at Slack Bus, IEEE 30 Bus Systems

V. CONCLUSION

Power-flow problem ,which is the determination of the voltage magnitude and angle at each bus of the power network under specified condition of operation .The Nweton-Raphson iterative procedure has been used for solving the power-flow problem.The study of the basic principal of the STATCOM is carried out as well as the basic og recative power compensation using STATCOM .A power flow model of the STATCOM is attempted and it is seen that the modified load flow equation helps the system in better performance.The bus system shows improved plots and the thus we can conclude that the addition of a STATCOM controls the output of a bus in a robust manner.Load flow result for all three considered(5-bus,IEEE-14 and IEEE-30 bus test system)cases are shown .We see that voltage magnitude of that particular bus at which STATCOM is placed is maintained at 1 p.u. This is possible of recative power compensation provided by STATCOM

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