Load Flow Analysis on Statcom Incorporated Interconnected Power System Networks using Newton Raphson Method

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Abstract- With the advancement of technology the demand of electrical energy has also increased. The demand of electricity has become the parameter of development of a nation. An electrical utility company has to use its existing transmission capacity to feed the ever increasing demand of electricity, due to that the transmission lines has to be operated near its thermal 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. In this paper reactive power compensation is attempted using STATCOM. To study its effect Load flow study is performed on IEEE (Institute of Electrical & Electronics engineer) 5 bus, IEEE 14 bus and IEEE 30 bus with and without STATCOM 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. Simulation is done using MATLAB (Matrix Laboratories).

Keywords – FACTS, STATCOM, SVC, jacobian, Newton Raphson Load Flow

I. INTRODUCTION

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. In a transmission line, control of line impedance is known as Series compensation. When the impedance of a line changes it means that either capacitive or inductive compensation can be obtained thus controlling active power. TCSC (Thyristor Controlled Series Capacitor) is connected in series with the transmission line to enhance the power transfer capability. To increase the steady state transmittable power and to control the voltage profile shunt compensation is used. 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. DEVELOPMENT OF POWER FLOW EQUATION

A. Power Flow Equation

The most basic step toward formulating a power flow equation is to draw a relation between the bus current and bus voltage.

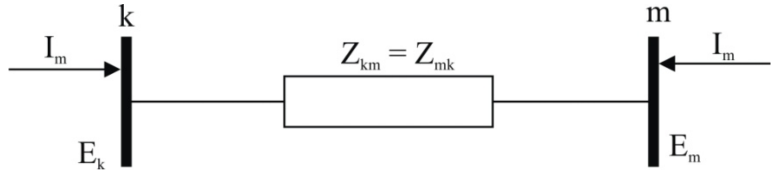

Fig 1 A single line diagram of power system network

$$I_k = \frac{1}{Z_{km}}(E_k - E_m)$$
$$I_k = Y_{km}(E_k - E_m)$$

Similarly for bus m

Now writing this equation in matrix form

Now complex power can also be written in the form of voltage and current and can be expressed as follows

$$S_k = P_k + jQ$$

That will take the form

$$P_k^{Cal} = V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - $$

$$Q_k^{Cal} = -V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_K - \theta$$

That will take a more generalized form

$$\Delta P_k = P_{gk} - P_{lk} - \{V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + \}$$

$$\Delta Q_k = Q_{gk} - Q_{lk} - \{-V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_K - \theta_m) - E]\}$$

III. CLASSIFICATION OF BUS VARIABLE

There are four variables used to describe a bus they are

Active power, Reactive power, Voltage phase angle and Voltage magnitude. The variable specified for a bus determines the type of the bus

Load bus – As the generator is not connected the generated injected real and reactive injected powers P_G and Q_G are zero. Whereas real and reactive power drawn by the load P_L and $Q_L$are the known variable. So for a load bus the real and reactive power drawn by the load are specified and voltage magnitude (V) and phase angle (θ) remains the quantity to be calculated.

Generator PV bus – generator is connected to this bus. As we know that for a synchronous generator the nodal voltage magnitude can be controlled by adjusting the field current that is DC in nature, also the real power at the generator bus can be controlled by setting its specified value. So the two quantities that can be controlled for a generator bus are real power and nodal voltage magnitude. The other two quantities to be calculated are generator reactive power and phase angle . For constant voltage operation the reactive power should be kept in specified limits and that should not be violated.

Generator PQ bus – if the generator is unable to provide a constant voltage operation due to reactive power limit violation. In this case the reactive power is set to a value and the voltage magnitude value is set free. In this bus P and Q thus became the specified quantity and the variables to be calculated are the voltage magnitude and phase angle.

Slack bus – The normal practice in a power flow study is to choose one of the generator bus as slack bus. There should be only one slack bus in a power system. It is assumed that slack generator bus should supply sufficient power to any number of load and losses. The voltage phase angle at the slack bus is taken as reference angle against all other phase angle at the buses. The voltage phase angle is assumed to be zero. For a slack bus voltage magnitude and phase angle are the specified quantity and the other two variables the real power P and the reactive power Q has to be calculated. The variables to be specified and the variables to be calculated are given below

IV. FACTS IN POWER SYSTEM

Active (real) and reactive power in a transmission line depend on the voltage magnitudes and phase angles at the sending and receiving ends as well as line impedance
Where

=

$$Q_R = \frac{V_S V_R \cos\delta - V_R^2}{X}$$

Where and are the magnitudes (in RMS values) of sending and receiving end voltages, respectively, where "δ" is the phase-shift between sending and receiving end voltages. The system is assumed to be a lossless system and so the equations for sending and receiving active power flows, and , are equal. The maximum active power transfer occurs, for the given system, at a power or load angle d equal to 90°

V. FACTS CONTROLLER

FACTS controllers are categorized as follows
First Generation of FACTS Controllers Static VAR Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) Second Generation of FACTS Controllers: Static Synchronous Series Compensator (SSSC) and Static Synchronous Compensator (STATCOM) Third Generation of FACTS Controllers Unified Power Flow Controller (UPFC) Fourth Generation of FACTS Controllers Interline Power Flow Controller (IPFC) and Generalized Power Flow Controller (GUPFC)

VI. STATCOM IN POWER FLOW STUDY

STATCOM incorporated bus is taken as PV bus and in case of violation it is taken as PQ bus. The load flow
Then the power flow constraints of the STATCOM are given by

= (
= (

Based on these equation the STATCOM power flow equation take the following form and is written as

= ( )
= ( )
= ( )
= ( )

These equations can be solved to calculate STATCOM real and reactive power input

VII. CASE STUDY AND RESULT

a) On IEEE 5 bus system

STATCOM is incorporated at bus number 2 and following results are obtained after performing newton raphson load flow study on MATLAB

The graph shows that the bus voltage profile of the system is greatly enhanced. The bus voltage at which the STATCOM is placed is improved to 1p.u. while the overall voltage profile of the system is improved. It was also seen that the bus placed far away from the STATCOM are not affected.

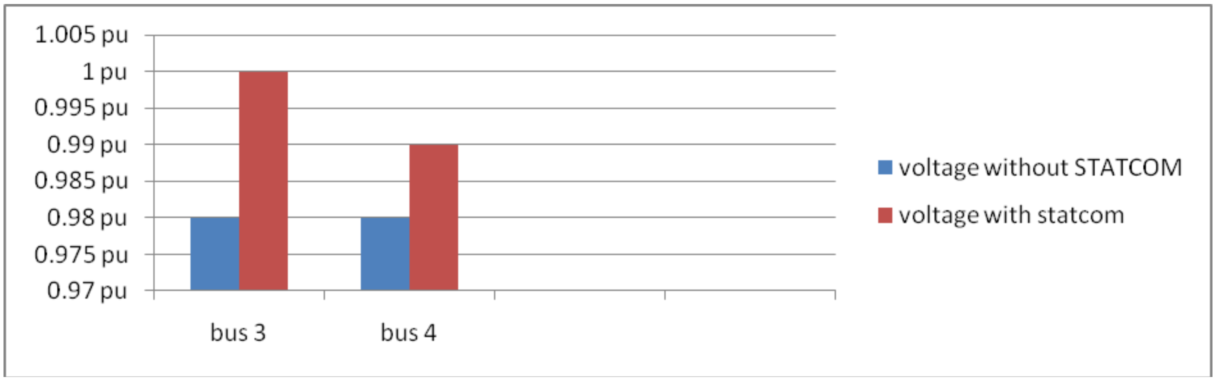

Fig 2 graphical representation of improved bus voltage profile with STATCOM (IEEE 5 bus)

The reactive power flows in the system was also increased and it is shown that the reactive power generation at slack bus was reduced from 90.82 MVAR to 86.34 MVAR.

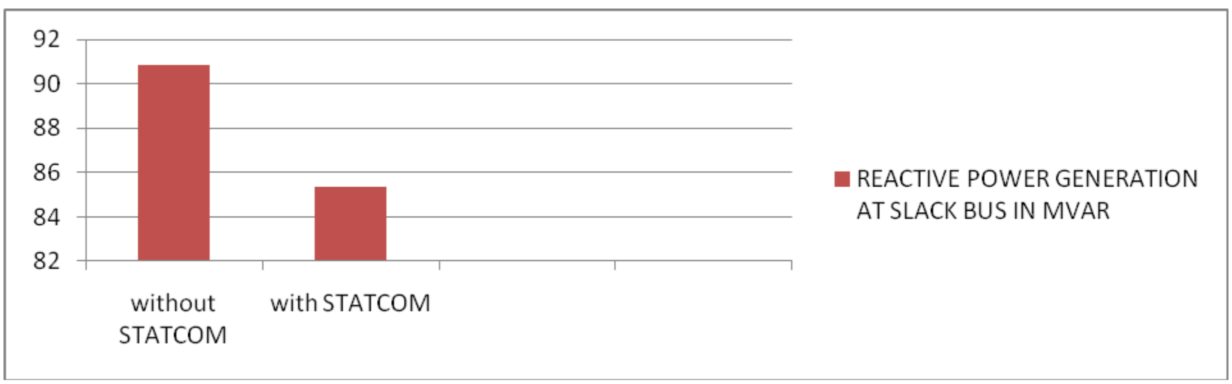

Fig 3 Comparative Reactive Power Generation at Slack Bus of IEEE 5 Bus System

It was shown in the test results that the STATCOM is injecting 20.6 Mvar of reactive power to the system. Real power was unaffected by the inclusion of STATCOM in the system.

b) On IEEE 14 Bus system

STATCOM is incorporated at bus number 5 and 7; following results are obtained after performing newton raphson load flow study on MATLAB

The graph shows that the bus voltage profile of the system is greatly enhanced. 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 4 Graphical Representation of Improved Voltage Profile with STATCOM (IEEE 14 Bus)

From the given results, the maximum power transfer is through bus 1 to bus 2 that is 158.62 MW. Reactive power transfer from bus 12 to bus 13 and from 13 to bus 14 is increased. The slack bus generator at bus 1 is absorbing lesser reactive power as compared to the base case. Reactive power absorbed by slack bus without STATCOM was 16.43 Mvar while after the inclusion of STATCOM, the Reactive Power absorbed by the slack bus is reduced to 7.86Mvar. The real power generation although remains the same.

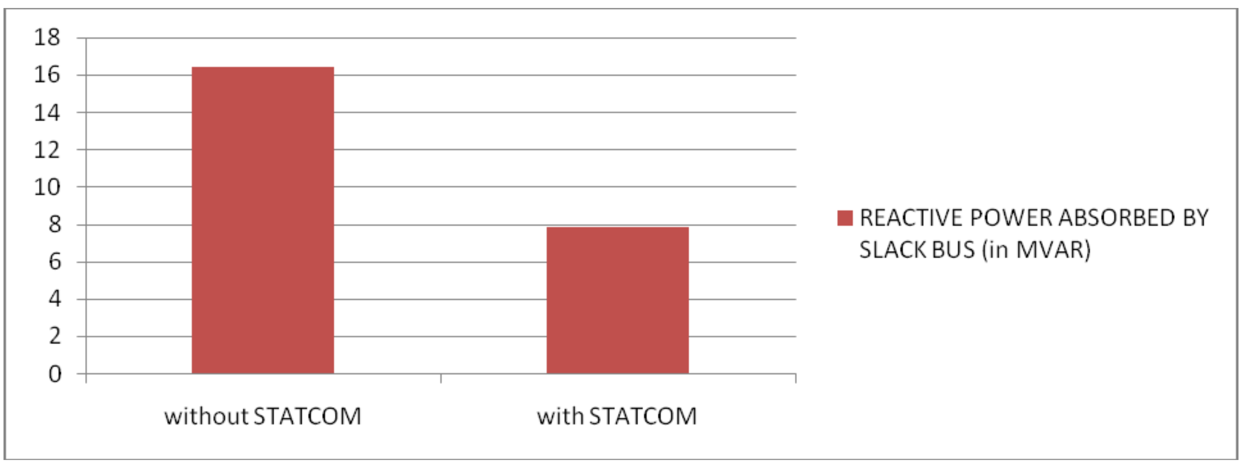

Fig 5 Comparative Reactive Power absorbed by Slack Bus, IEEE 14 Bus

From the calculation it is clear that the STATCOM at bus 5 is absorbing 62.11 MVAR of reactive power so as to keep the nodal voltage magnitude at 1 p.u. while the STATCOM at bus 7 is absorbing 45.79 Mvar of reactive power

c) On IEEE 30 bus system

STATCOM is incorporated at bus number 5,7, 14 and 29; following results are obtained after performing newton raphson load flow study on MATLAB

The graph shows that the bus voltage profile of the system is greatly enhanced. it is clear that the bus voltages at buses 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.

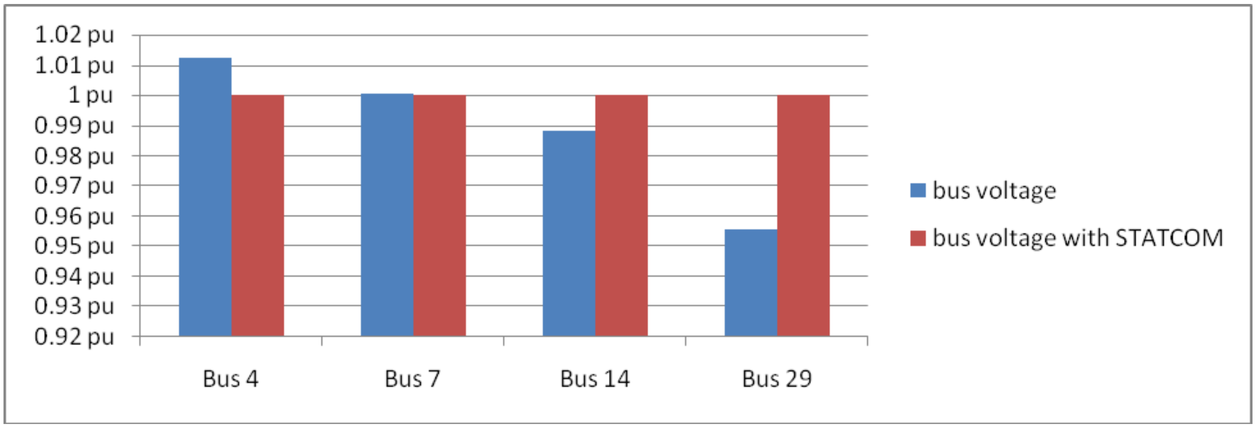

Fig 6 Graphical Representation of Improved Voltage Profile with STATCOM

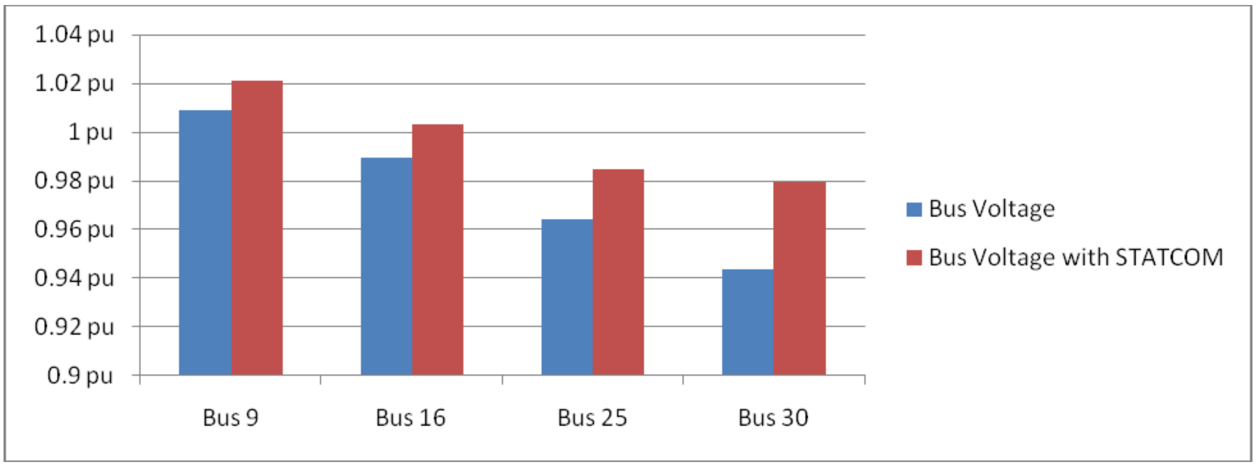

Fig 7 Graphical Representation of Improved Voltage Profile with STATCOM

From the results it is shown that 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

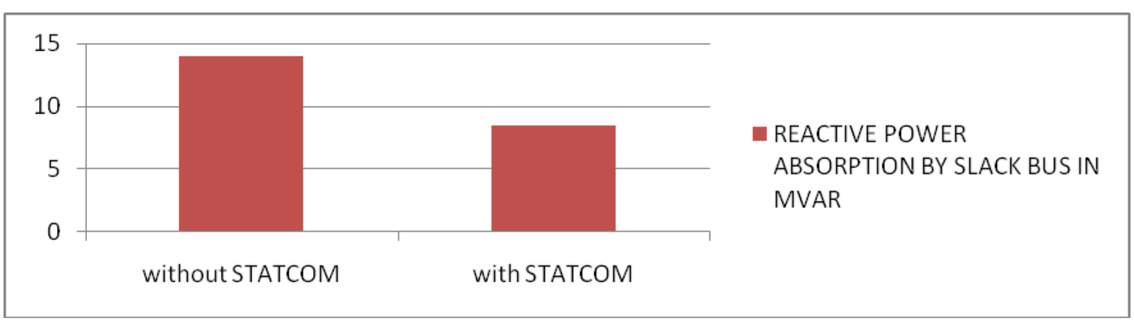

Fig 8 Comparative Reactive Power Generation at Slack Bus, IEEE 30 Bus Systems

The STATCOM injected powers associated with the buses are

For bus 4, the absorbed power by STATCOM is 46.38 Mvar

For bus 7, the STATCOM injected power is 1.61 Mvar

For bus 14, the STATCOM injected power is 2.33 Mvar

For bus 29, the STATCOM injected power is 6.90 Mvar

In this case too, the effect of STATCOM on Real Power was negligible

IV.CONCLUSION

Power flow study determines the best operating condition of a Power System Network. Newton- Raphson load flow method has been used for solving the power-flow equation. To study the effect of STATCOM on power system, a modified power flow model of the STATCOM is attempted. STATCOM is placed at different locations in various bus systems and the modified load flow program is used to access the effect of STATCOM on the system. The simulation is done using MATLAB.

Load flow study of all three bus (IEEE 5, IEEE 14 & IEEE 30) is considered and it is shown that the voltage profile of the system is improved and it is shown using plots. It was also evident that the voltage magnitude of that particular bus at which STATCOM is placed is maintained at 1 p.u. The reactive power generation and absorption of the slack bus generator is reduced. The buses placed far away from the STATCOM are least effected while there was no effect of STATCOM on the real power.

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