

PERFORMANCE ANALYSIS AND LOCATION IDENTIFICATION OF STATCOM ON IEEE-14 BUS SYSTEM USING POWER FLOW ANALYSIS

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ABSTRACT

FACTS devices open up wide and new opportunity for the enhancement of usable capacity in the power system. This paper presents a comprehensive analysis of STATCOM (STATIC synchronous COMPensator) with IEEE-14 bus system concerning the problem of variable loading and losses. The power flow analysis is performed on a IEEE-14 bus system with and without STATCOM. Due to unequal loading, the most affected bus is identified and the compensation is done in order to improve the voltage for all the buses. The detailed investigations are carried out with different loading and the performance of the IEEE-14 bus system is examined. The voltage regulation and the reactive power compensation upto critical point of voltage stability in the system is shown through proper output curves. These investigations indicate the need of power flow analysis and location of STATCOM on the proposed system.

Keywords: *Flexible AC Transmission Systems (Facts), Static Synchronous Compensator(STATCOM), Power Flow Analysis, Ranking Analysis, Voltage Regulation*

1. INTRODUCTION

The power flow studies are very common in power system analysis. Load flow allows us to know the present state of a system, given previous known parameters and values. The power that is flowing through the transmission line and its generated by the generators, the power that is being consumed by the loads, the losses occurring during the transfer of power from source to load and so on all are iteratively decided by the load flow solution or also known as power flow solution. In any system, the most important quantity is known as the voltage at different points throughout the system. Flexible AC transmission system (FACTS) controllers are able to change the power system parameters in an effective way. In FACTS controller , the STATCOM is used for enhancing the performance of power system. The voltage and angle stability are improved by the concern of STATCOM.

2. NEED OF COMPUTATIONAL ALGORITHM

The mathematical algorithms are used to compute the unknown quantities from the known ones through a process of successive trial and error methods and consequently produce a result. The initial values of the system are assumed and the program computes the successive quantities. The load flow solution is needed to determine the overloading of particular elements in the system. It is also used to make sure that the generators run at the ideal operating point, which ensures that the demand will be met without overloading the facilities and either maintains them without compromising the security of the system or the demand. The objectives of any load flow analysis is to produce the following information

- Voltage magnitude and phase angle at each bus.
- Real and reactive power flowing in each element.
- Reactive power loading on each generator.

2.1 Power Flow Equations of n Bus System with STATCOM

The STATCOM is connected in parallel with bus 'S' in the power system. The bus 'S' is heavily affected by voltage regulation. The

controllable voltage source of STATCOM is denoted as V_t in series with Z_t impedance.

The power flow equations of the system with STATCOM connected to bus 'S' are the same as power flow equations of the system without STATCOM for all buses except STATCOM connected bus 'S'. The following equations are power flow equations for bus 'S'.

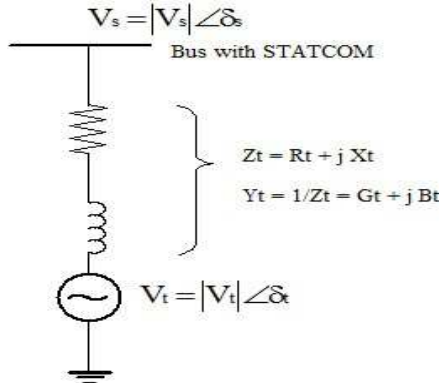


Figure 1: STATCOM connection in a bus

$$P_s = P_t + \sum_{j=1}^n |V_s| |Y_{sj}| |V_j| \cos(\delta_s - \delta_j - \theta_{sj}) \quad (1)$$

$$Q_s = Q_t + \sum_{j=1}^n |V_s| |Y_{sj}| |V_j| \sin(\delta_s - \delta_j - \theta_{sj}) \quad (2)$$

The summation terms of the injected active and reactive power for the system,

$$P_t = +G_t |V_s|^2 - |V_s| |Y_t| |V_t| \cos(\delta_s - \delta_t - \theta_t) \quad (3)$$

$$Q_t = -B_t |V_s|^2 - |V_s| |Y_t| |V_t| \sin(\delta_s - \delta_t - \theta_t) \quad (4)$$

Where $|V_t|$, δ_t , $|Y_t|$ and θ_t are noted in figure 1 and other variables were given in equations (3) and (4).

One more equation is needed to solve the power flow problem. This equation is needed to find the power consumed by the source V_t . The power must be zero in steady state condition.

$$P_t = \text{Real}[V_t^*] = -G_t |V_t|^2 + |V_s| |Y_t| |V_t| \cos(\delta_t - \delta_s - \theta_t) = 0 \quad (5)$$

2.2 Jacobian Equation with STATCOM

As per the above equations, the new power flow problem with STATCOM has to be solved. The linearized Jacobian equation is extended and modified as per new Jacobian equation below.

$$\begin{pmatrix} \Delta P_i \\ \Delta Q_i \\ \Delta P_{vt} \\ \Delta F \end{pmatrix} = \begin{pmatrix} J_{11} & J_{12} & J_{13} & J_{14} \\ J_{21} & J_{22} & J_{23} & J_{24} \\ J_{31} & J_{32} & J_{33} & J_{34} \\ J_{41} & J_{42} & J_{43} & J_{44} \end{pmatrix} \begin{pmatrix} \Delta \delta_i \\ \Delta V_i \\ \Delta V_t \\ \Delta \delta_t \end{pmatrix} \quad (6)$$

where control variable for jacobian matrix, $F=V_s$.

3. IEEE 14 BUS SYSTEM

IEEE 14 bus system is used to test the power flow analysis without and with STATCOM. The IEEE14 bus test system is shown in figure 2. Here, the STATCOM is connected randomly at different buses. The voltage of all buses is heavily affected for the increasing load. The STATCOM is randomly connected and power flow losses for various buses are calculated to improve the voltage profile and also compensate the reactive power of whole system. Using the Newton Raphson method, the following analysis are made,

- i) To find base load losses of all buses and also total losses of IEEE 14 bus system.
- ii) To find load losses of all buses and also total losses for different load variation without STATCOM
- iii) To find load losses of all buses and also total losses for different load variation with STATCOM

Initially the 14 bus system is tested without STATCOM. The real and reactive power flow is analysed by using the Newton Raphson method.

Then all the buses are analysed the same with the STATCOM. This Power Flow approach for voltage stability analysis of unbalanced power systems has been proposed. The approach can be taken into account for the unbalances of both network and load in 14 bus system [1]. Now the loads of the other buses are considered and overall power generation is varied with increasing percentage from 40% to 100%. IEEE 14 bus system is now used to test the load flow analysis without and with STATCOM. For this analysis, the STATCOM is connected randomly in different buses there by verifying the real and reactive power variation.

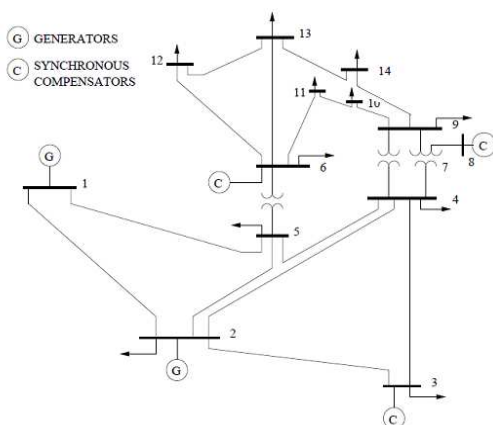


Figure 2: IEEE 14 Bus Test System

Initially the system is investigated during steady state. A comparative analysis is made with different loading conditions. The load is increased keeping 40% of the load at the start.

4. STABILITY OF POWER SYSTEM

Modern electric power system is a complex network of synchronous generators, transmission lines and loads. Electric utilities first acted as isolated systems, and then gradually neighboring utilities began to join forming large interconnected networks. This enabled the utilities to draw on each other's generation reserves during the time of need.

Three phase fault or sudden load switching which creates transients. This makes the system to be unstable which is very worse. A good power system should possess the ability to regain its normal operating condition after a disturbance. Since the ability to supply uninterrupted electricity determines the quality of electric power supplied to the load, stability is regarded as one of the important topics of power system research [2, 3, 4].

5. OPTIMAL ALLOCATION OF STATCOM

STATCOM devices can be used to control power flows in large power system networks. STATCOM types and locations should be reasonably chosen according to their contribution to the general objective of power system economic generation and dispatch. In this research, using the MATLAB m-file program, the locations of the STATCOM devices are optimized simultaneously along with the rated values. The objective cost

function, is to minimize the investment costs for STATCOM devices and the generation costs. [5]

5.1 Rating of STATCOM

The nature and the type of faults that the system need to overcome decides the size of the STATCOM. Although the final rating of the STATCOM is determined based on system economics, the rating chosen must be at least adequate for the system to be stable after a fault or temporary system disturbances. The STATCOM ratings are based on many parameters which are mostly governed by the amount of reactive power the system needs to recover and ride through system faults on the power system and to reduce the interaction of other system causing disturbances. This causes out of synchronism with the grid. The nature and the type of faults that the system need to overcome decides the size of the STATCOM. For example, a three phase fault of low impedance requires a very high rating STATCOM. A high impedance short circuit fault needs a lower rating device [5]. This support is needed to stabilize the system after a disturbance. The capability of the STATCOM is also decided based on the converter current ratings and the size of the capacitor. The devices in a voltage source converter are clamped against over-voltages across the DC link capacitor bank to minimize losses and not have to withstand large spikes in reverse over-voltage [5].

5.2 Effective Location of STATCOM

Simulation results show that STATCOM provides effective voltage support at the bus to which it is connected to. The STATCOM is placed as close as possible to the load bus for various reasons. There are two important reason for choosing the location of STATCOM.

i) The location of the reactive power support should be as close as possible to the point at which the support is needed.

ii) The location of the STATCOM at the load bus is more appropriate.

The location of the STATCOM is based on quantitative benefits evaluation. The main benefits of using a STATCOM in the system are reduced losses and increased maximum transfer capability. [6]

Placing a STATCOM at any load bus compensates the reactive power flow through the lines, which automatically reduces line current and also the

I^2R losses. The location of STATCOM is generally chosen to be the location in the system which needs reactive power. Shipping of reactive power at low voltages in a system running close to its stability limit is not very efficient.[6]

Also, the transmission line power factor limiting factors decides the total amount of reactive power transfer available in the system. This proves that sources and compensation devices are to be kept as close as possible to the load.

6. REACTIVE POWER SUPPORT FROM COMPENSATING DEVICE

The amount of reactive power supplied by any compensating device depends on the voltage drop at the bus and its capabilities. For example, a STATCOM can supply its maximum rated compensating current even at lower voltages. The reactive power that can be supplied, but usually they have some extra capability called the transient capability which is available to the system for a short period of time. The reactive power supplied is also dependent on the immediate reactive power sources in the system [6].

7. SIMULATION AND TEST RESULTS

7.1 Real and Reactive Power Variation

The following results are shown to compensate the real power and reactive power losses for the load variation. Here due to the reactive power variation, the voltage of all buses are improved with rated value by connection of STATCOM. The change in real and reactive power for different load variation is shown in Figure 3 and Figure 4 respectively. The position of STATCOM is varied and adjusted slightly for the real and

reactive power compensation and losses for the load variation are calculated.

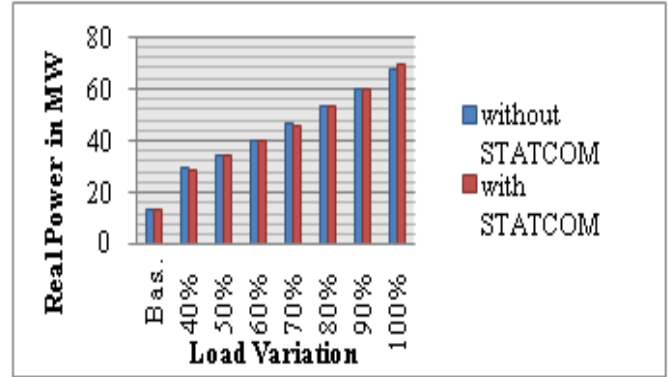


Figure 3: Real Power variation without and with STATCOM

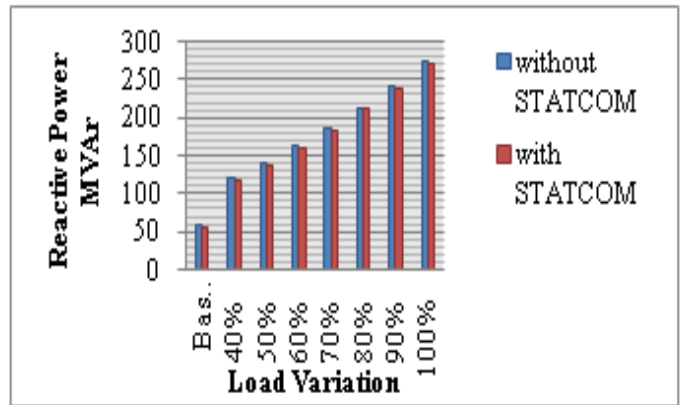


Figure 4: Reactive Power variation without and with STATCOM

Table 1: Ranking List for Voltage Variation

Load	Losses without STATCOM		Losses with STATCOM	
	MW	MVar	MW	MVar
Base load	13.555	57.077	13.443	56.632
40% Load	29.413	120.407	28.946	117.123
50% Load	34.487	140.676	34.044	136.477
60% Load	40.078	162.885	39.594	158.802
70% Load	46.200	187.134	45.898	182.359
80% Load	52.866	213.541	53.128	210.427
90% Load	60.124	242.216	60.402	239.061
100% Load	68.000	273.300	69.509	272.13



Table 2: Ranking List for Reactive Power Variation

Rank → Load	1	2	3	4	5	6	7	8
40%	5 th Bus	4 th Bus	9 th Bus	10 th Bus	7 th Bus	14 th Bus	11 th Bus	13 th Bus
50%	5 th Bus	4 th Bus	9 th Bus	10 th Bus	14 th Bus	7 th Bus	11 th Bus	13 th Bus
60%	4 th Bus	5 th Bus	9 th Bus	10 th Bus	7 th Bus	14 th Bus	11 th Bus	13 th Bus
70%	5 th Bus	4 th Bus	9 th Bus	10 th Bus	7 th Bus	14 th Bus	11 th Bus	13 th Bus
80%	4 th Bus	5 th Bus	9 th Bus	10 th Bus	7 th Bus	14 th Bus	11 th Bus	13 th Bus
90%	5 th Bus	4 th Bus	9 th Bus	10 th Bus	7 th Bus	14 th Bus	11 th Bus	13 th Bus
100%	4 th Bus	5 th Bus	9 th Bus	10 th Bus	7 th Bus	14 th Bus	11 th Bus	13 th Bus

Rank → Load	1	2	3	4	5	6	7
40%	14 th Bus	9 th Bus	10 th Bus	7 th Bus	4 th Bus	5 th Bus	13 th Bus
50%	14 th Bus	9 th Bus	10 th Bus	7 th Bus	4 th Bus	5 th Bus	13 th Bus
60%	14 th Bus	9 th Bus	10 th Bus	4 th Bus	7 th Bus	5 th Bus	13 th Bus
70%	14 th Bus	9 th Bus	10 th Bus	4 th Bus	7 th Bus	5 th Bus	13 th Bus
80%	14 th Bus	9 th Bus	10 th Bus	4 th Bus	7 th Bus	5 th Bus	13 th Bus
90%	14 th Bus	9 th Bus	10 th Bus	4 th Bus	7 th Bus	5 th Bus	13 th Bus
100%	14 th Bus	9 th Bus	10 th Bus	4 th Bus	7 th Bus	5 th Bus	13 th Bus

The affected buses are ranked in 14th, 9th and 10th buses respectively by voltage variation. Here rank list is only analysed and verified for finding the real and reactive power variation. The variation in power with increasing loads is listed with and without STATCOM in Table 3. The transmission losses are reduced and reactive power is compensated with the help of STATCOM. The ranking is prepared for reactive power compensation in various loads by STATCOM. The ranking list is given in Table 2. This ranking analysis is very useful in analyzing the effective location of STATCOM.

7.2 Voltage Curve for Load Variation

By connection of STATCOM, the voltage of all buses are improved and is found to be above 1 p.u. The voltage regulation performance of the STATCOM is clearly shown in figure 5. Here due to the reactive power variation, the voltage of all buses are improved with rated value by connection of STATCOM. From the graph, it is inferred that the system performance can be improved to a greater extent with the connection of STATCOM.

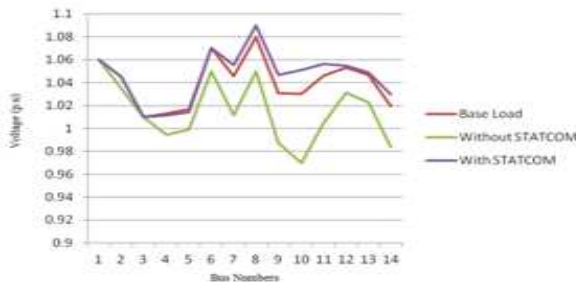


Figure 5: Voltage Curve for Load Variation

Table 3: Real and Reactive Power Losses

Without the connection of STATCOM, the system performance is not in a appreciable level hence the losses are more. By connecting the STATCOM in a effective location the real and reactive power losses are reduced.

CONCLUSION

The power flow analysis without and with STATCOM is performed on IEEE-14 bus system. The IEEE-14 bus system and STATCOM are modeled using MATLAB m-file. By injecting the additional voltage and power angle, the transmission losses are analyzed for various buses. The STATCOM is connected in different buses for

different loads. The transmission losses are calculated and compared with other buses which is connected with STATCOM. The location of STATCOM on IEEE-14 bus system are identified by ranking analysis for voltage variation and reactive power compensation. The STATCOM gives better reactive power compensation and voltage regulation in 4th, 5th, 9th and 10th buses respectively.

APPENDIX:

As per the above Jacobian matrix, the elements are

$$J_{11} = \frac{\partial P_i}{\partial \delta_i}, \text{ (Diagonal elements)}$$

$$J_{11} = \frac{\partial P_i}{\partial \delta_j}$$

$$J_{12} = \frac{\partial P_i}{\partial |V_i|} \quad J_{12} = \frac{\partial P_i}{\partial |V_j|}$$

$$J_{13} = \frac{\partial P_i}{\partial |V_t|} \quad J_{14} = \frac{\partial P_i}{\partial \delta_t}$$

$$J_{21} = \frac{\partial Q_i}{\partial \delta_i}, \text{ (Diagonal elements)}$$

$$J_{21} = \frac{\partial Q_i}{\partial \delta_j}$$

$$J_{22} = \frac{\partial Q_i}{\partial |V_i|} \text{ (Diagonal elements)}$$

$$J_{22} = \frac{\partial Q_i}{\partial |V_j|}$$

$$J_{23} = \frac{\partial Q_i}{\partial |V_t|} \quad J_{24} = \frac{\partial Q_i}{\partial \delta_t}$$

$$J_{31} = \frac{\partial P_{vt}}{\partial \delta_t} \quad J_{33} = \frac{\partial P_{vt}}{\partial |V_i|}$$

$$J_{32} = \frac{\partial P_{vt}}{\partial |V_i|} \quad J_{34} = \frac{\partial P_{vt}}{\partial \delta_t}$$

$$J_{41} = 0 \quad J_{43} = 0$$

$$J_{42} = \frac{\partial F}{\partial |V_i|} \quad J_{44} = 0$$

where control variable for jacobian matrix, $F = V_s$.



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