

Power loss reduction in power system using optimal location of STATCOM

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Abstract— In this paper, we studied the integration of shunt Static Synchronous Compensator (STATCOM) in the electrical networks for a main objective is the reduction of total active power losses of the network 5-bus, we relied on the algorithm of Newton-Raphson (N-R) for load flow and to find optimal sizing and allocation of STATCOM, the simulation results obtained clearly show the beneficial effect of the optimum location of STATCOM on the performance of the power system reliability and feasibility by minimize the voltage deviations such for minimum power loss, voltages of the all buses are found in the allowable margin ($\pm 10\%$) by injecting reactive power at the point where it is implanted, the power flow and power loss before and after placing the STATCOM have been compared the effect of the STATCOM on the power flow remains moderate. Proposed algorithm is implemented in MATLAB.

Keywords— STATCOM; Optimal location; Newton-Raphson; Power flow; Power loss.

I. INTRODUCTION

Currently and in the decades to come, public utilities will be forced to operate the system close to its thermal and stability limits due to major obstacles such as, the dominance of environmental law and over all the problems of cost. The cost of the lines and the power losses, as well as the difficulties encountered in the construction of new transmission lines, would often limit the available transport capacity, there are many cases where economic energy or reserve sharing is limited by transmission capacity, and the situation does not improve[1], [2]. Moreover, in a liberalized electricity service environment, an efficient power grid is essential to the competitive environment of reliable electricity service, in the present days, and with the deregulation of the electricity market, the traditional power system practices have completely changed. Better use of existing power system resources with economic cost has become essential[3]. FACTS devices (Flexible AC Transmission Systems) could be a way to carry out this function without the disadvantages of electromechanical devices such as slowness, the increased

intent for these devices is largely due to the recent development of high power electronics, combined with the deregulation of the energy sector, which has made the use of FACTS cost-effective in power transmission business. In addition, for economic reasons[4], [5], the installation of FACTS devices in all nodes or branches of the power network is impossible and is not necessary therefore the placement of FACTS devices in a network is necessary. In this work, the approach taken for calculating power flow and solving the optimal placement problem of STATCOM relies on Newton Raphson algorithm, we tried to put the STATCOM in three nodes to find the optimal location and its size in a power system 02 machines 5-bus, it will be shown that power losses is greatly affected by presence of a STATCOM in transmission system has been presented to increase the transfer capability and it will be concluded that the voltage profile can be improved effectively, so STATCOM is one of the most effectiveness custom power devices (CPDs) [6] is applied to improve the power system operation.

II. PRINCIPLE OF STATCOM

The STATCOM is the SVC version consisting of a high-tech semiconductor-based voltage converter associated with a capacitor as a DC voltage source and the set connected in parallel to the system network as shown in the Fig.1, The STATCOM is connected through a filter circuit to the grid at the point of common coupling (PCC).[7]

Power S_f at the output of STATCOM can be expressed by the following expression:

$$S_f = P_f + jQ_f \quad (1)$$

The expressions of the active and reactive powers in the reference of Park are given by:

$$P_f = V_d i_{cd} \quad (2)$$

$$Q_f = -V_d i_{cq} \quad (3)$$

Such as:

V_d : Voltage of the point common coupling (PCC) in the reference of Park.

i_{cd}, i_{cq} : Direct and quadratic current of STATCOM.

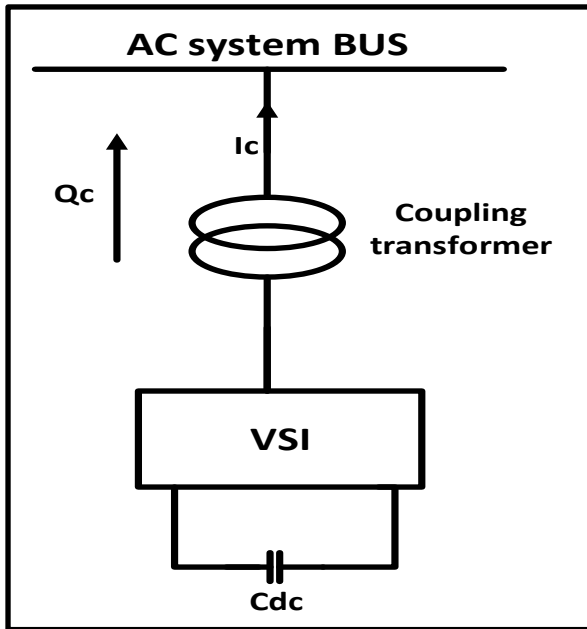


Fig. 1 STATCOM diagram.

We then notice that the component i_{cq} allows to control the reactive power and the component i_{cd} to control the active power. If the current is late, as shown in the Fig. 2 the sign of the quadratic component of the current is negative so the result is positive reactive power means the STATCOM absorbs reactive power (inductive mode)[7]

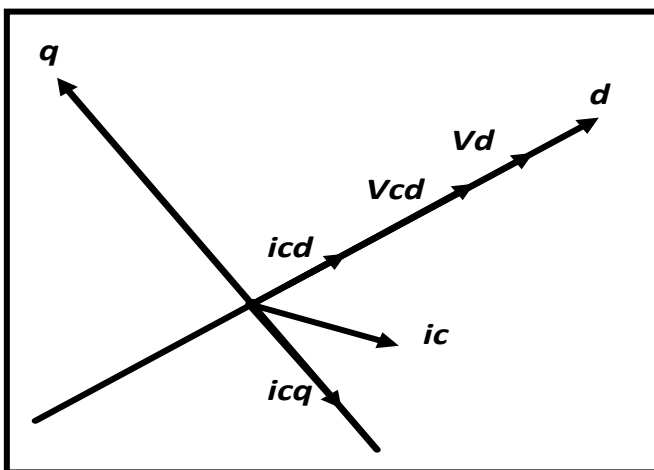


Fig. 2 Operation in inductive mode.

When the sign of the quadratic component of the current is positive, the current is in advance, as shown in Fig. 3, the result is a negative reactive power[8], which means the STATCOM provides reactive power to the network (capacitive mode)

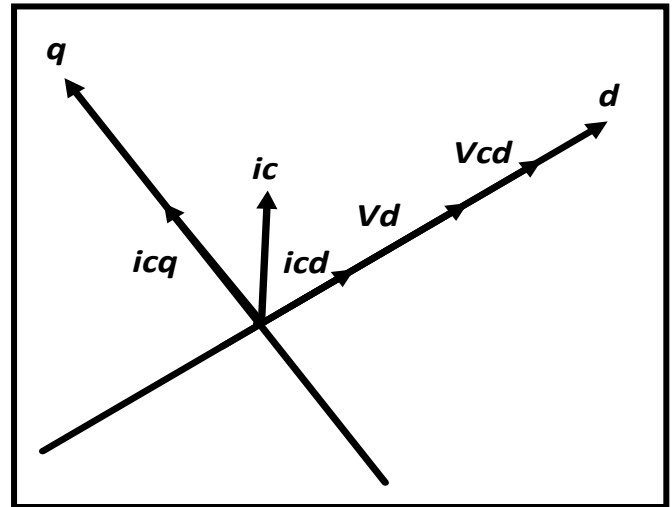


Fig. 3 Operation in capacitive mode.

III. BASIC CONCEPTS OF NEWTON – RAPHSON

The search for the optimal configuration of STATCOM, to be installed on a power network, requires the call of a program, one of these programs, the load-flow calculation program. The calculation of the load flow of a given power network consists in calculating the nodal voltages, the powers passing through the lines[9], as well as the reactive powers generated by the different generators. In this work the Newton-Raphson load flow calculation program is performed on the MATLAB platform, simulations are applied on a network 2 machines 5 bus which is presented in the fig. 5.

The main parts of the load flow calculation program (LF) are:

- Reading the network database.
- Constitution of the admittance matrix Ybus.
- Program launch calculates nodal voltages.
- Calculation of the energy flow P and Q in the lines and the total losses.
- Display of results.

A .constitution of the admittance matrix

The nodal admittance matrix Y, is a square matrix of order n describing the power system consisting of n buses[10], it presents the nodal matrix of the buses of the power systems, and each bus in a real power system is usually connected only to a few other buses through the transmission lines. Matrix Y is also one of the data needed to formulate a power flow study.

Form of the admittance matrix presented in system of equation (4):

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1n} \\ Y_{21} & Y_{22} & \dots & Y_{2n} \\ \dots & \dots & \dots & \dots \\ Y_{n1} & Y_{n2} & \dots & Y_{nn} \end{bmatrix} \quad (4)$$

The shunt or series admittances are calculated by the formula:

$$Y_{ij} = \begin{cases} y_{ii} + \sum_{i \neq j} y_{ij} & , Si i = j \\ -y_{ij} & , Si i \neq j \end{cases} \quad (5)$$

B. Newton-Raphson method for load-flow calculation

Newton Raphson's method is the most important method for solving the power flow problem. It's the most important method for solving the power flow problem. Among the important steps of this method is the formation of the Jacobian matrix.[1] So the method of Newton Raphson consists in calculating the voltages (module and phase) of the nodes of a given network. These nodes belong to three types, (PV, PQ, slack bus). The node PQ has two unknowns (modulus and phase of the voltage), while a node PV has a single unknown which is the phase of the voltage. The reference node or the slack bus has no unknowns.

The formation of the Jacobian matrix requires the computation of partial derivatives:

$$\frac{\partial f_1(x)}{\partial \theta_j}, \frac{\partial f_1(x)}{\partial V_j}, \frac{\partial f_2(x)}{\partial \theta_j}, \frac{\partial f_2(x)}{\partial V_j} \quad (6)$$

$$\begin{cases} \frac{\partial f_1(x)}{\partial \theta_i} = \sum_{k=1}^n |V_i| |V_k| (-G_{ik} \sin \theta_{ik} + B_{ik} \cos \theta_{ik}) \\ \frac{\partial f_1(x)}{\partial V_i} = \sum_{k=1}^n |V_k| (G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) \\ \frac{\partial f_2(x)}{\partial \theta_i} = \sum_{k=1}^n |V_i| |V_k| (-G_{ik} \sin \theta_{ik} + B_{ik} \cos \theta_{ik}) \\ \frac{\partial f_2(x)}{\partial V_i} = \sum_{k=1}^n |V_k| (G_{ik} \cos \theta_{ik} + B_{ik} \sin \theta_{ik}) \end{cases} \quad (7)$$

IV. THE APPLIED ALGORITHM

The Newton Raphson (N-R) algorithm is an iterative numerical method that tries to find a solution to the nonlinear equation system, by an iterative solution in fig. 4:

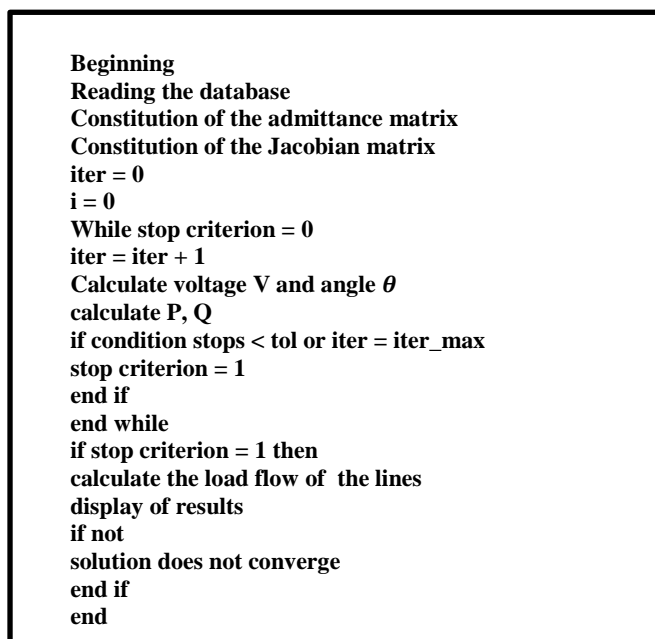


Fig. 4 different steps of the algorithm used.

V. TEST NETWORK AND LOAD FLOW SIMULATION

A model of the network used for 5 of its buses have 2 generators, as shown in Fig.5. Firstly without the integration of STATCOM we extract the voltage and the nodal angles, the active and reactive power of the lines also the total active power losses, by using the load flow program of the fig. 4

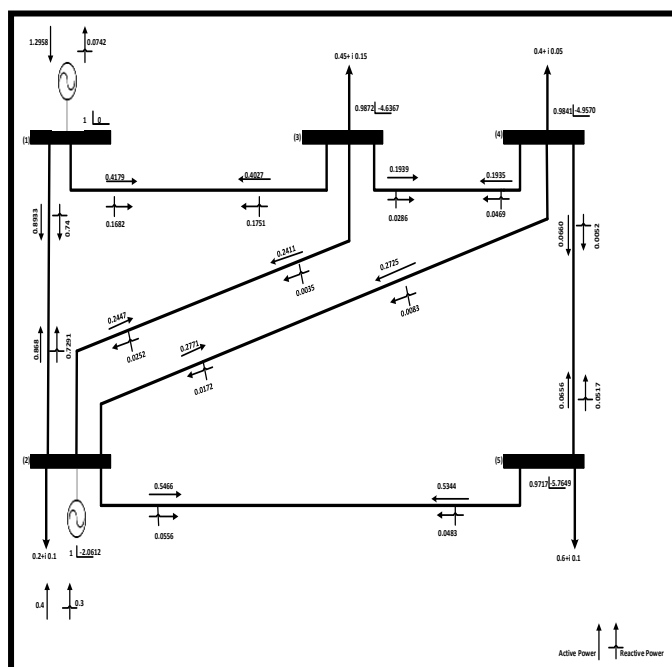


Fig. 5 Network 02 machines 05 buses without STATCOM.

Program result also gave us the total active losses without the integration of STATCOM:

Such as:
 $P_{loss} = 0.0612 \text{ Pu}$.
 Maximum iteration number = 100.

TABLE I
 EXTRACTS DATA OF LINES OF THE 5-BUS TEST NETWORK

Line	From bus	To bus	R(Pu)	X (pu)	B(pu)
1	1	2	0.02	0.06	0.06
2	1	3	0.08	0.24	0.05
3	2	3	0.06	0.18	0.04
4	2	4	0.06	0.18	0.04
5	2	5	0.04	0.12	0.03
6	3	4	0.01	0.03	0.02
7	4	5	0.08	0.24	0.05

VI. METHODOLOGY FOR PROPOSED WORK

- Step 01: Network data must be collected for 02 machines 05 bus
- Step02: Apply Newton-Raphson method for load flow in MATLAB program is carried out from which nodal voltages, nodal angles, active and reactive power and determine the total active losses without STATCOM.
- Step03: The network comprises five nodes, on the three load nodes we successively place the STATCOM, at each installation we extract the curve of the active power loss according to the reactive power injecting or absorbing between: [-0.5 Pu, +0.5 Pu].
- Step04: Then, we locate the exact STATCOM location relative to the minimum active power loss according to a single value of the reactive power between: [-0.5 Pu, +0.5 Pu].
- Step05: For the value of the reactive power injecting or absorbing which gave us a minimum of power losses and about which, we will be able to determine if this value will give us the voltage of all the three nodes in the allowable margin.
- Step06: Finally, the impact of STATCOM upon load flow, before and after optimal localization

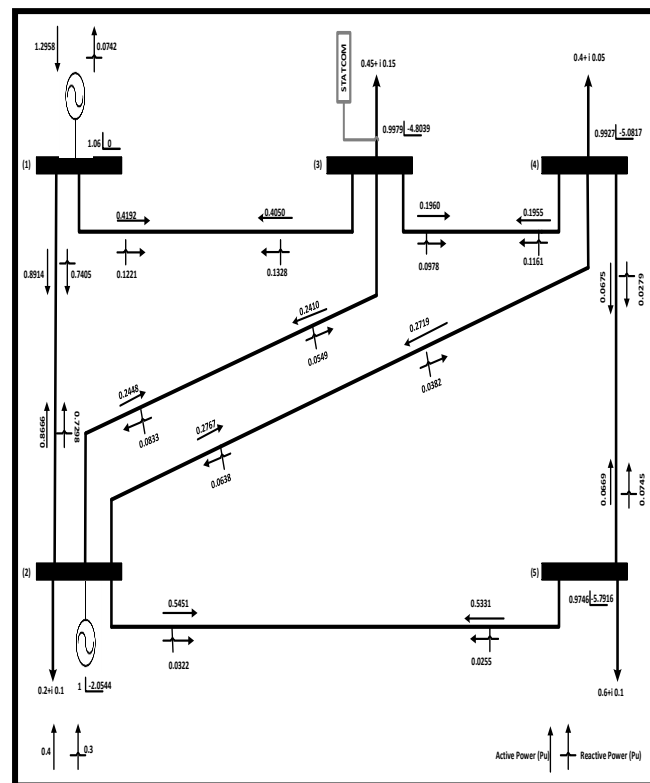


Fig. 7 Network with STATCOM in Bus N°3

The result of the program of total active losses with the integration of STATCOM is:
 $P_{loss} = 0.0605$ Pu.

VII. SIMULATION RESULTS

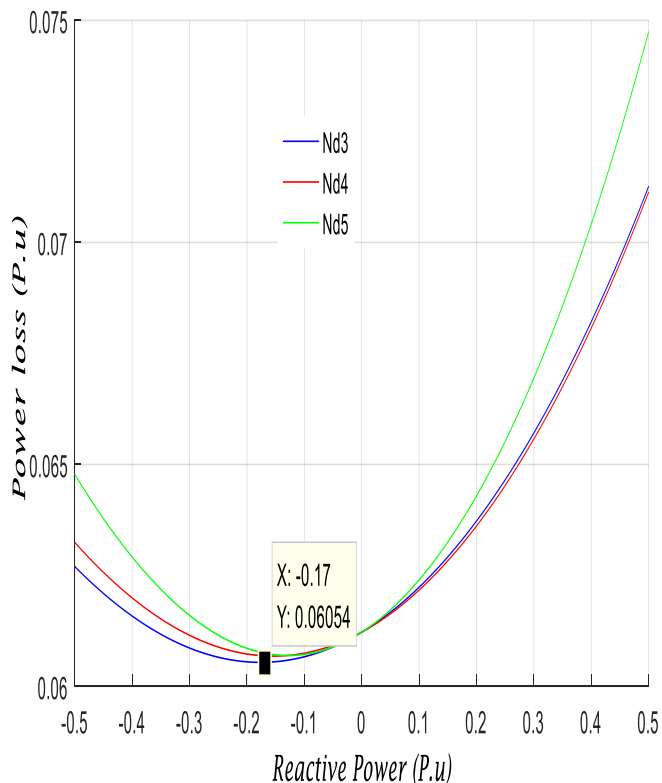


Fig. 6 Power Losses according to Reactive Power (injecting and absorbing)

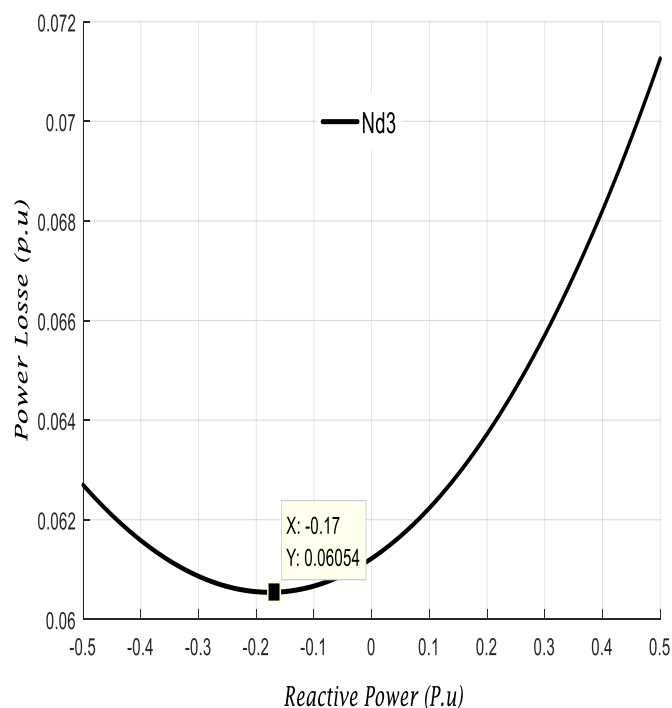


Fig. 8 Power Losses according to Reactive Power (injecting and absorbing), STATCOM in Bus N°3

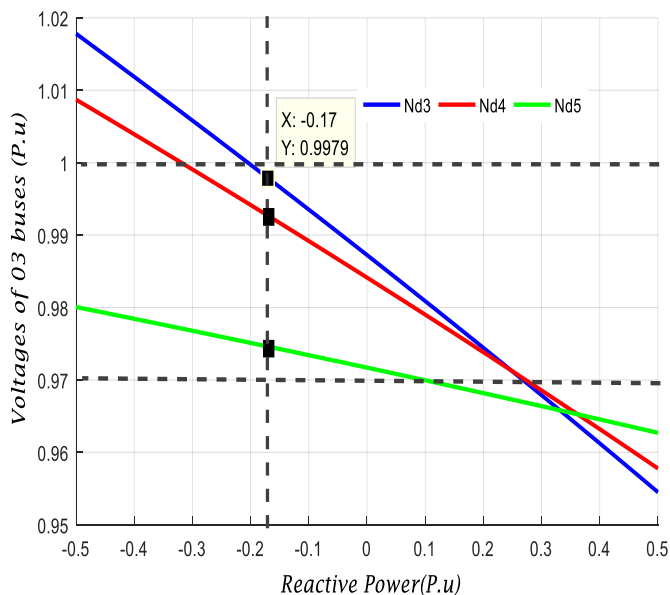


Fig. 9 Voltages of the three Buses: 03,04,05, STATCOM in Bus N°3

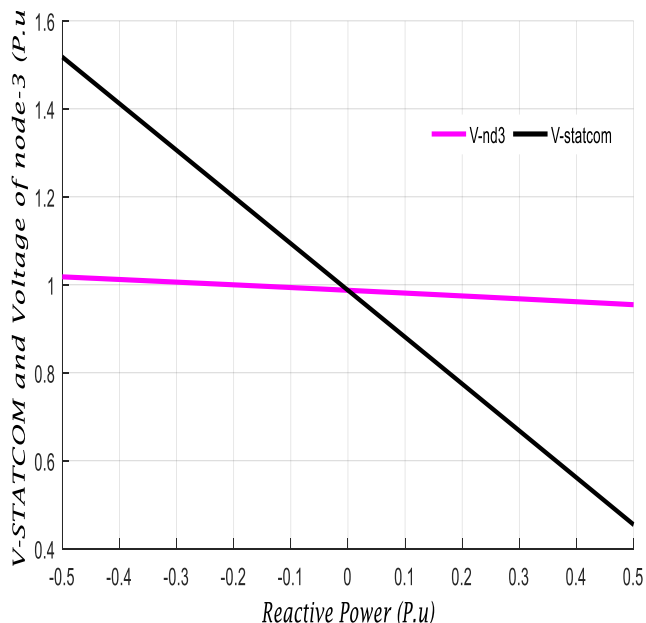


Fig.10 STATCOM and Point Common Connection (PCC) voltages.

In the beginning, we started the simulation without STATCOM results of the power flow shows in fig.5, in this case the total power losses is: $P_{loss} = 0.0612$ Pu. To improve network power losses, the STATCOM is installed in the three load nodes are: “03”, “04” and “05”, in fig.6 it is noted that the placement of STATCOM in the bus 03 gives the best result compared to the other buses, such that for a minimum of power losses the reactive power delivered to the network is: $Q_C = -0.17$ Pu. In Fig.8, it seems very clear that the optimal location to get the minimum power losses: $P_{loss} = 0.0605$ Pu for a single value of reactive power injected is $Q_C = -0.17$ Pu is to place the STATCOM in the load node “03”.

Fig. 9 proves the effectiveness of the optimal location of the synchronous static compensator to maintain the voltages of the all buses in the allowable margin ($\pm 10\%$)

In “Fig.10”, it is noted that the voltage of STATCOM is greater than the voltage of the point common of coupling (v-nd3) between $[-0.5pu, 0pu]$, therefore STATCOM operated in capacitive mode and provides the reactive power to the network, and between $[0Pu, 0.5Pu]$ the voltage of STATCOM is smaller than the voltage of the point common of coupling (v-nd3) therefore STATCOM operated in inductive mode and absorbs the reactive power from the system.

Fig.5 and fig.7 shows the power flow before and after placing the STATCOM so the effect of the STATCOM on the power flow remains moderate.

VII. CONCLUSION

Power demands will keep increasing more and more, consequently the power system network is become less secure, it is concluded from many research that by placing FACTS controllers the power system security is improved, This work mainly helps in understanding the principles of STATCOM and also the basics of reactive power compensation using STATCOM, we have used MATLAB coding for Newton-Raphson load flow method to calculate the active power losses before and after STATCOM’S allocation, From above obtained results, it is clearly understood that STATCOM can providing appropriate amount of reactive power for reducing the power losses and maintaining voltage in allowable margin.

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