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Improvement of Power System Performance by Application of shunt FACTS Device STATCOM

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ABSTRACT
For better utilization of available capacities of transmission lines and improvement of power system performance, FACTS devices are used as a solution. This paper suggests a suitable location to enhance the Power System Performance with static synchronous compensator (STATCOM) .The methodology based on Reactive power sensitivity approach with respect to STATCOM shunt control parameters. The effectiveness of the proposed algorithm is tested and illustrated on 5-bus system. The simulation is performed using Matpower 4.0 in MATLAB 7.1 environment.

Keywords
FACTS, Static Synchronous Compensator

1. INTRODUCTION
A Power system consist of three main components i.e. generating units which supplies power to the system, loads which consumes power and transmission & distribution network which interconnects various buses in the system and carries power from the generating points to the load points[1] . In a competitive electricity market with the rapid development of society, the load demand has grown quickly. A s a result, transmission networks are becoming highly loaded which threatens the power system incurring greater losses, security and reliability[1],stability, ultimately make certain generation patterns economically undesirable. Though building new transmission lines can relive the severe situation, it is hard to implemented due to various limitations such as environmental, right-of-way and cost[1,2,6].

Flexible A.C. Transmission Line, which are power electronics based devices can change parameters like impedance, voltage and phase angle. FACTS devices also helps to reduce flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flows in the network. They provide control facilities, both in steady state power flow control and dynamic stability control. The possibility of controlling power flow in an electrical power system without generation rescheduling or topological changes can improve the performance considerably [6].

FACTS devices can play a major role in congestion management, enhancement of security, transfer capability and reliability. FACTS devices can be connected to a transmission line in various ways, such as in series, shunt or a combination of series and shunt. The static VAR compensator (SVC) and static synchronous compensator(STATCOM)are connected in shunt, static synchronous compensator(SSSC)and thyristor controlled series capacitor(TCSC) are connected in series. Thyristor controlled phase shifting transformer (TCPST) are connected in series and shunt combination. The reactive power support in the system plays a very important role in maintaining an acceptable system voltage profile and helping in improvement of security.

In this paper STATCOM is considered for improvement of power system performance and results are obtained by using MATLAB programming with and without STATCOM.

2. ABOUT STATCOM
STATCOM is a self commutated switching power converter supplied from an electric energy source. Operated to produce a set of adjustable multiphase voltage, which may be coupled to ac system for purpose of exchanging active and reactive power. static: based on solid state switching devices. Synchronous analogous to an ideal synchronous generator with 3 phase sine wave at fundamental frequency. Compensator provided with reactive power compensator.

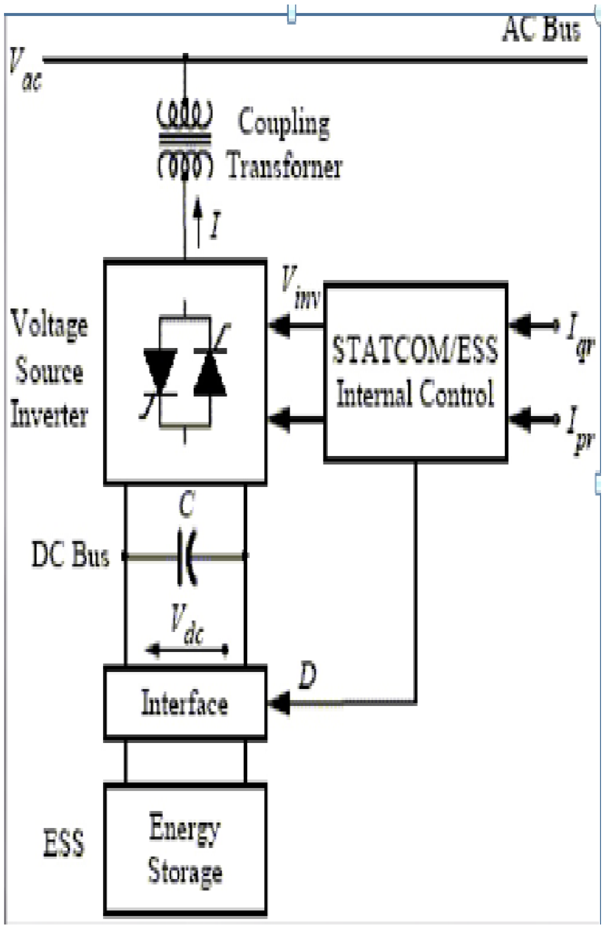

Fig.1 Functional Diagram Of STATCO

3. MODELLING OF STATCOM

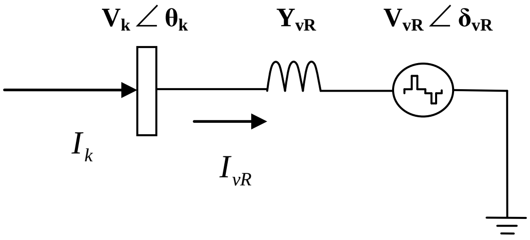

Fig.2 Equvalent Circuit Of STATCOM

A STATCOM consist of one VSC and its associated transformer. It is the static counterpart of rotating synchronous condenser but it generates or absorbs reactive power at a faster rate because no moving part is involved. In principle it performs the same voltage regulation function as the SVC but in a more robust manner. The Equvalent Circuit Of STATCOM is shown in Fig.2.In steady state fundamental frequency studies the STATCOM may be represented in the same way as asynchronous condenser, which in most cases is the model of synchronous generator with zero active power generation A more flexible model may be realized by representing STATCOM as a variable voltage source E_{vR}, for which the magnitude and phase angle may be adjusted using a suitable iterative algorithm to satisfy a specified voltage magnitude at the point of connection with the AC network. The shunt voltage source of the three phase STATCOM may be represented by;

$$E_{vR}^{\rho} = V_{vR}^{\rho}\left(\cos\delta_{vR}^{\rho} + j\sin\delta_{vR}^{\rho}\right) \quad \text{------------(1)}$$

Where ρ indicate phase quintiles a, b, c. The voltage magnitude, V_{vR}^{ρ} is given maximum & minimum limits, which are function of STATCOM capacitor rating. However δ_{vR}^{ρ} may take any value between 0 and 2πradian. With reference to the equivalent circuit assuming three phase parameters, the following transfer admittance equation can be written as:

$$\left[I_k\right] = \left[Y_{vR}\right]\begin{bmatrix} V_k \\ E_{vR} \end{bmatrix} \quad \text{---------------(2)}$$

Where,

$$I_k = \left[I_k^a \angle \gamma_k^a \quad I_k^b \angle \gamma_k^b \quad I_k^c \angle \gamma_k^c\right]^t,$$

$$V_k = \left[V_k^a \angle \theta_k^a \quad V_k^b \angle \theta_k^b \quad V_k^c \angle \theta_k^c\right]^t$$

$$E_{vR} = \left[V_{vRk}^a \angle \delta_{vRk}^a \quad V_{vRk}^b \angle \delta_{vRk}^b \quad V_{vRk}^c \angle \delta_{vRk}^c\right]^t$$

$$Y_{vR} = \begin{bmatrix} Y_{vRk}^a & 0 & 0 \\ 0 & Y_{vRk}^b & 0 \\ 0 & 0 & Y_{vRk}^c \end{bmatrix}$$

4. STATCOM POWER FLOW MODEL

The power flow equation for the STATCOM are derived below the first principle and assuming the following voltage source representation:

$$E_{vR} = V_{vR}\left(\cos\delta_{vR} + j\sin\delta_{vR}\right) \quad \text{---------------------(3)}$$

Based on the STATCOM equivalent circuit, the following may be written:

$$S_{vR} = V_{vR} I_{vR}^{*} = V_{vR} Y_{vR}^{*}\left(V_{vR}^{*} - V_k^{*}\right) \quad \text{------------------ (4)}$$

After performing some complex operations, the following active and reactive power equations are obtained for the converter bus k , respectively

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR}V_k\left[G_{vR}\cos\left(\delta_{vR} - \theta_k\right) + B_{vR}\sin\left(\delta_{vR} - \theta_k\right)\right],$$

$$Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR}V_k\left[G_{vR}\sin\left(\delta_{vR} - \theta_k\right) + B_{vR}\cos\left(\delta_{vR} - \theta_k\right)\right],$$

$$P_k = V_k^2 G_{vR} + V_k V_{vR}\left[G_{vR}\cos\left(\theta_k - \delta_{vR}\right) + B_{vR}\sin\left(\theta_k - \delta_{vR}\right)\right],$$

$$Q_k = -V_k^2 B_{vR} + V_k V_{vR}\left[G_{vR}\sin\left(\theta_k - \delta_{vR}\right) - B_{vR}\cos\left(\theta_k - \delta_{vR}\right)\right],$$

Using this power equations, the linearised STATCOM model is given below, where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables.

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{kR} \\ \Delta P_{kR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k}V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}}V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k}V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}}V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k}V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}}V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k}V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}}V_{vR} \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \frac{\Delta V_k}{V_k} \\ \Delta\delta_{vR} \\ \frac{\Delta V_{vR}}{V_{vR}} \end{bmatrix}$$

5. 5-Bus System

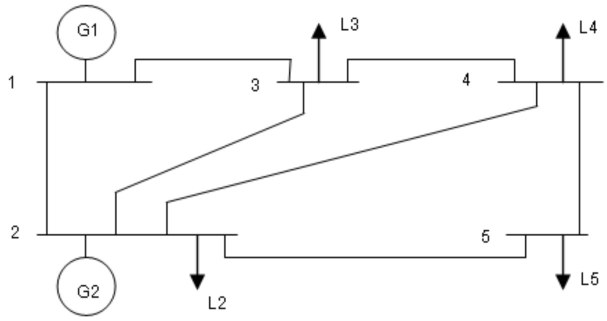

Fig 3. 5 Bus Test System

The IEEE 5 Bus system consist of one slack bus,one p-v bus and three load buses as shown.

6. METHOD FOR OPTIMAL LOCATION OF STATCOM

Sensitivity Approach: A sensitivity approach is the Conventional approach which could be applied for finding the optimal location of shunt FACTS devices.

Reactive transmission congestion distribution factor (QTCDF):

The real power flow & reactive power flow in a line k connected between bus i & bus j can be written as

$$P_{ij} = V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) - V_i^2 Y_{ij} \cos\theta_{ij} \text{-----------------(6.1)}$$

$$Q_{ij} = -V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) - V_i^2 Y_{ij} \sin\theta_{ij} - V_i^2 Y_{sh/2} \text{-----(6.2)}$$

Where

V_i-magnitude of voltage at bus i

V_j- magnitude of voltage at bus j

δ_i-angle at bus i

δ_j- angle at bus j

Reactive transmission congestion distribution factor(QTCDF) are defined as the change in the reactive power flow (ΔQ_{ij}) in a transmission line k connected between bus i & bus j due to unit change in the reactive power injection(ΔQ_n) at bus-n & can be written as

$$QTCDF_n^k = \frac{\Delta Q_{ij}}{\Delta Q_n} \text{-----------------(6.3)}$$

Similarly, PTCDF for line K can be calculated as

$$PTCDF_n^k = \frac{\Delta P_{ij}}{\Delta P_n} \text{--------------------(6.4)}$$

Using Taylor series approximation Eq.3 & 4 can be written a

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial P_{ij}}{\partial \delta_i}\Delta\delta_j + \frac{\partial P_{ij}}{\partial V_i}\Delta V_i + \frac{\partial P_{ij}}{\partial V_j}\Delta V_j \text{--(6.5)}$$

$$\Delta Q_{ij} = \frac{\partial Q_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial Q_{ij}}{\partial \delta_i}\Delta\delta_j + \frac{\partial Q_{ij}}{\partial V_i}\Delta V_i + \frac{\partial Q_{ij}}{\partial V_j}\Delta V_j \text{-----------(6.6)}$$

Eq.(5) &(6) can be written as

$$\Delta P_{ij} = a_{ij}\Delta\delta_i + b_{ij}\Delta\delta_j + c_{ij}\Delta V_i + d_{ij}\Delta V_j \text{---------------------(6.7)}$$

$$\Delta Q_{ij} = a'_{ij}\Delta\delta_i + b'_{ij}\Delta\delta_j + c'_{ij}\Delta V_i + d'_{ij}\Delta V_j \text{----------------------(6.8)}$$

The coefficient appearing in above eq. Can be obtained using partial derivative of real &reactive power flow with respect to variable δ and V as

$a_{ij} = V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i)$

$b_{ij} = -V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i)$

$c_{ij} = V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) - 2V_i Y_{ij} \cos\theta_{ij}$

$d_{ij} = V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i)$

$a'_{ij} = V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i)$

$b'_{ij} = -V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i)$

$c'_{ij} = -V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) + 2 V_i Y_{ij} \cos\theta_{ij} - V_i Y_{sh}$

$d'_{ij} = -V_i Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i)$

For determining of congetion distribution factor following jacobian relation has been used:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = [J]\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix} = \begin{bmatrix}J11 & J12\\ J21 & J22\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix}; \text{----------(6.9)}$$

Neglecting P-V & Q-V above eq. Can be simplified as

$$\Delta P = [J_{11}][\Delta\delta]$$
$$\Delta Q = [J_{22}][\Delta V]$$

Therefore

$$\Delta\delta = [J_{11}]^{-1}[\Delta P] = [M][\Delta P] \text{-----------(6.10)}$$
$$\Delta V = [J_{22}]^{-1}[\Delta Q] = [N][\Delta Q] \text{-----------(6.11)}$$

Above eq. Can be written as

$$\Delta\delta i = \sum_{l=1}^{n} m_{il}\Delta P_l \qquad i=1,2\text{---}n,\ i\neq s$$

$$\Delta V i = \sum_{l=1}^{n} n_{il}\Delta Q_l \qquad i=1,2\text{---}n,\ i\neq s$$

It is assumed that change in the bus voltage on real power flow & bus angle on active power flow is negligible therefore above eq. Becomes

$$\Delta P_{ij} = a_{ij}\Delta\delta_i + b_{ij}\Delta\delta_j$$

$$\Delta Q_{ij} = a'_{ij}\Delta V_i + b'_{ij}\Delta V_j$$

Substituting the values of Δδi & ΔVi in above both eq. & expanded as

$$\Delta P_{ij} = (a_{ij}m_{i1} + b_{ij}m_{j1})\Delta P_1 + (a_{ij}m_{i2} + b_{ij}m_{j2})\Delta P_2 + \text{---------} + (a_{ij}m_{in} + b_{ij}m_{jn})\Delta P_n \text{--------- (6.12)}$$

$$\Delta Q_{ij} = (a'_{ij}n_{i1} + b'_{ij}n_{j1})\Delta Q_1 + (a'_{ij}n_{i2} + b'_{ij}n_{j2})\Delta Q_2 + \text{----------} + (a'_{ij}n_{in} + b'_{ij}n_{jn})\Delta Q_n \text{-------(6.13)}$$

Eq. Can be written as

$$\Delta P_{ij} = PTCDF_1^k\,\Delta P_1 + PTCDF_2^k\,\Delta P_2 + \text{---------} + PTCDF_n^k\,\Delta P_n$$

$$\Delta Q_{ij} = QTCDF_1^k\,\Delta Q_1 + QTCDF_2^k\,\Delta Q_2 + \text{-------} + QTCDF_n^k\,\Delta Q_n$$

Where

$$PTCDF_n^k = (a_{ij}m_{in} + b_{ij}m_{jn})$$

$$QTCDF_n^k = (a'_{ij}n_{in} + b'_{ij}n_{jn})$$

These are real & Reactive transmission congestion distribution factor corresponding to the bus n & line K connected between bus i & j.

The optimal location of STATCOM can be considered at a bus having most negative QTCDF.

Table 1:Line Flow Limit For 5-Bus System

From Bus-To Bus	Line Flow Limit(pu)
1-2	1.20
1-3	0.55
2-3	0.55
2-4	0.55
2-5	0.55
3-4	0.55
4-5	0.55

By using these Network data Newton-Raphson load flow programme for 5 Bus System is ran in Matpower 4.0 and the load flow results are obtained. The sensitivity factors are calculated for different buses. The results are shown in table 2.

Table 2 : Transmission Congestion Distribution Factor

Bus Number	QTCDF
3	**-0.761141**
4	-0.481845
5	-0.436032

The optimal placement of shunt fact device has been considered at a bus having most negative transmission congestion distribution factor (QTCDF) i.e. at Bus no. 3.

7. RESULTS

With STATCOM placed at bus-3 again the load flow of 5 bus system is obtained. Following Table shows the comparison of results with and without STATCOM.

Line	Without STATCOM		With STATCOM	
	P loss	Q loss	P loss	Q loss
1	0.0538	0.0295	**0.0537**	**0.0293**
2	0.0443	0.0248	**0.0414**	**0.015**
3	0.0247	-0.0062	**0.0239**	**-0.0095**
4	0.0263	-0.0011	**0.0249**	**-0.006**
5	0.0271	0.0213	**0.0267**	**0.0198**
6	0.0104	-0.0066	**0.012**	**-0.0037**
7	0.0238	-0.0221	**0.0246**	**-0.0231**
Total Losses	**0.2103**	**0.0397**	**0.2072**	**0.0218**

8. CONCLUSION

FACTS devices are a powerful tool to improve the voltage profile of the system. In this paper STATCOM is simulated using Matpower 4.0 in MATLAB 7.1 environment. STATCOMs are responsible for the parts dealing with the voltages, active and reactive power losses. Finally, after compensation results shows
1] Improvements of the voltage profile
2]Active and reactive power losses are reduced. STATCOM has been tested on 5 Bus system and the results obtained found to be satisfactory.

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