

# Study the best location of STATCOM to improve the voltage

K. Merini, F.Z. Gherbi, S. Hadjeri, K.F. Elatrech

*Intelligent Control and Electrical Power Systems Laboratory ICEPS*

*Electrical Engineering Department*

*Djillali Liabes university, Sidi Bel Abbes, Algeria*

[k\\_controle@yahoo.fr](mailto:k_controle@yahoo.fr)

[fz\\_gherbi@yahoo.fr](mailto:fz_gherbi@yahoo.fr)

**Abstract**— This paper aims to investigate the best location of static Synchronous Compensator (STATCOM) controlled for power flow studies has been represented and improving voltage in the network. STATCOM is modeled as a controllable voltage source. To validate the effectiveness of the Newton–Raphson method algorithm was implemented to solve power flow equations in presence of STATCOM. Case studies are carried out on 26-bus system to demonstrate the performance of proposed models. Simulation results show the effectiveness and capability of STATCOM in improving voltage regulation in transmission systems; moreover the power solution using the Newton-Raphson algorithm developed. The STATCOM and the detailed simulation are performed using Matlab program.

**Keywords** –Power flow, Static synchronous compensator, Newton-Raphson, Matlab.

## I. INTRODUCTION

As the world wide electric utility industry grow up with deregulation, utility transmission systems are reaching their limits, making the need for reliable power greater than ever. Due to deregulation, the need for new power flow controllers capable to increase transmission line capability through predefined corridor will certainly increase. Ideally, these new controllers should be able to control voltage level and increase power flow capability of transmission line to their secure loading with no reduction of system stability and security margins. The FACTS controllers come out with the ability of enhancing transmission system control, reliability, and operation, and also improve the distribution-system power quality [1]. The development and use of FACTS controllers in power transmission systems has led to many applications of these controllers to improve the

stability of power networks [2,3]. Thus, many studies have been carried out and reported in the literature on the use of these controllers in a variety of voltage and angle stability applications, proposing diverse control schemes and location techniques for voltage and angle oscillation control [3]. The STATCOM is one of the new generation flexible AC transmission systems (FACTS) devices with a promising future application, which is recognized to be one of the key advanced technologies of future power system. The technology of STATCOM improving system transmission capability has been successfully applied in power systems in developed countries, such as Japan, USA and Britain. In china, electrical resources mainly centralize in the west region, while electric power consumers centralize in southern foreland where developed. The inconsistency between the geography distribution of power resources and that of consumers demands long distant and high capable power transmission. The 500KV and even higher rank voltage power grid has been developed due to the requirements for long distant and high capable power transmission. The installation of STATCOM is suggested to support voltage at the middle of distant power transmission lines by the North China Power System (NCPS)[4].

The successful application of STATCOM home and abroad means the STATCOM is mature in technique. At present the researches on STATCOM mainly concentrate on modeling and controller design to STATCOM[5].

Now, for maximum utilization of any FACTS device in power system planning, operation and control, power flow solution of network that constraints of these devices is a fundamental requirement. As a result, many excellent research studies have been carried out in the literature for developing efficient load flow algorithm for FACTS devices ( Narayana and Abdel Moamen, 2005; Yan and Skar , 2005).

The paper is organized as follows: first power flow equation derives the mathematical model of

STATCOM based on switching functions. Then the mathematical model is linearized using the method of Jacobian and the controllability for arbitrary operating point of STATCOM is proved. Finally the best location of STATCOM.

## II. POWER FLOW EQUATION

Basically load flow problem involves solving the set of non-linear algebraic equations which represent the network under steady state conditions. The reliable solution of real life transmission and distribution net works is not a trivial matter and Newton-type methods, with their strong convergence characteristics, have proved most successful. To illustrate the power flow equations, the power flow across the general two-port network element connecting buses k and m shown in "Fig.1," is considered and the following equations are obtained. The injected active and reactive power at bus-k ( $P_k$  and  $Q_k$ ) is:

$$P_k = G_{kk} V_k^2 + (G_{km} \cos \delta_{km} + B_{km} \sin \delta_{km}) V_k V_m \quad (1)$$

$$Q_k = -B_{kk} V_k^2 + (G_{km} \sin \delta_{km} - B_{km} \cos \delta_{km}) V_k V_m \quad (2)$$

$$P_k = G_{mm} V_m^2 + (G_{mk} \cos \delta_{mk} + B_{mk} \sin \delta_{mk}) V_k V_m \quad (3)$$

$$Q_k = -B_{mm} V_k^2 + (G_{mk} \sin \delta_{mk} - B_{mk} \cos \delta_{mk}) V_k V_m \quad (4)$$

Where:

$$\delta_{km} = \delta_k - \delta_m = -\delta_m$$

$$Y_{kk} = Y_{mm} = G_{kk} + jB_{kk} = Y_{k0} + Y_{km}$$

$$Y_{km} = Y_{mk} = G_{mk} + jB_{km} = -Y_{mk}$$

The nodal power flow equations:

$$\begin{aligned} P &= f(V, \theta, G, B) \\ Q &= g(V, \theta, G, B) \end{aligned} \quad (5)$$

And their linearization around a base point, ( $P^0, Q^0$ ):

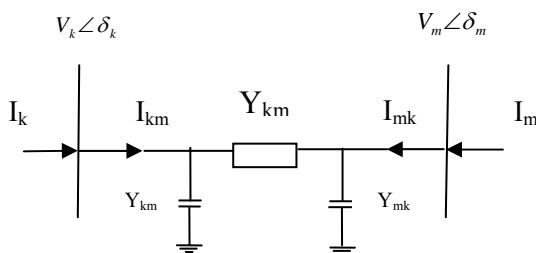


Fig. 1 General two-port network

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}^i = [J]^i \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix}^i \quad (6)$$

Where, P and Q are vectors of real and reactive nodal power injections as a function of nodal voltage magnitudes V and angles  $\theta$  and network conductances G and susceptances B.

$\Delta P = P_{\text{spec}} - P_{\text{cal}}$  is the real power mismatch vector,  $\Delta Q = Q_{\text{spec}} - Q_{\text{cal}}$  is the reactive power mismatch vector,  $\Delta \theta$  and  $\Delta V$  are the vectors of incremental changes in nodal voltage magnitudes and angles, J is the matrix of partial derivatives of real and reactive power with respect to voltage magnitudes and angle i indicates the iteration number.

Incorporation of FACTS devices in an existing load flow algorithm results in increased complexity of programming due to the following reasons (Suman et al., 2007):

- New terms owing to the contributions from the FACTS devices need to be included in the existing power flow equations of the concerned buses. These terms necessitate modification of existing power flow codes

- New power flow equations related to the FACTS devices come into the picture, which dictate formulation of separate subroutine(s) for computing them

- The system Jacobian matrix contains entirely new Jacobian sub-blocks exclusively related to the FACTS devices. Therefore, new codes have to be written for computation of these Jacobian sub-blocks

The increase in the dimension of Jacobian matrix, compared with the case when there are no power system controllers, is proportional to the number and kind of such controllers. The simultaneous equations for the networks and power system state variables are (Acha et al., 2004):

$$f(X_{\text{nsys}}, R_{\text{nf}})$$

$$(7)$$

$$g(X_{\text{nsys}}, R_{\text{nf}})$$

Where:

$X_{\text{nsys}}$  = Network state variables i.e., (voltage magnitudes and phase angles)

$R_{\text{nf}}$  = Power system controller variables.

### III. THE STRUCTURE OF A STATCOM

#### 1. The voltage converter

The simplest structure of a STATCOM is given in "Fig. 2".

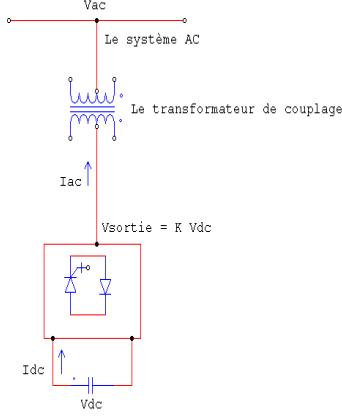


Fig. 2 The model of a STATCOM

The STATCOM consists of a coupling transformer, a voltage converter, and a source of storage for the DC side [6], [7]. The coupling transformer has two roles [6]:

- Linking the system with STATCOM AC
- The link inductor has the advantage that the source DC is not short-circuited

The STATCOM can consist of a power inverter "CSI: current source inverter", but for cost and current is unidirectional, it is preferable to use a voltage converter; virtually is the most used [6], [8], [9]. The inverter constituting the STATCOM can be composed of GTO or the IGBT.

#### 2. The static characteristic of a STATCOM

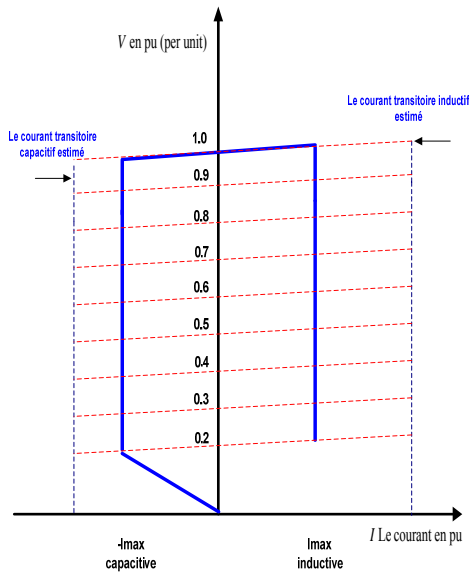


Fig. 3 The static characteristic of STATCOM

"Fig. 3," show the static characteristic of a STATCOM. It is capable of controlling its current estimated maximum regardless of system voltage AC is a medium voltage in case of major system disturbances. "Fig. 3," show the ability of STATCOM to maintain as the capacitive current at voltages very low system [10], [11]. The estimated value of the current spike in the inductive side is greater than the rated capacitive switching is the natural GTO used in the inductive side, it is limited by the current of the diode, but in the side this capacitive current is determined by switching drilled GTO used[8], [12].

### IV. POWER SYSTEM WITH STATCOM

"Fig. 4," shows the circuit model of a STATCOM connected to Bus k of an N-Bus power. The STATCOM is modeled as acontrollable voltage source ( $E_{stat}$ ) inseries with impedance (Ying et al.,2002). The real part of this impedance represents the ohmic losses of the power electronics devices and the coupling transformer, while the imaginary part of this impedance represents the leakage reactance of the coupling transformer. Assume that the STATCOM is operating in voltage control mode. This means that the STATCOM absorbs proper amount of reactive power from. the power system to keep  $|V_k|$  constant for all power system loading within reasonable range. The ohmic loss of the STATCOM is accounted by considering the real part of  $Y_{stat}$  in power flow calculations. The net active/raective power injection at. Bus k including the local load, before addition of the STATCOM, is shown by  $P_k + jQ_k$ .

The power flow equatios of the system with STATCOM connected to Bus k, can written as:

$$P_k = P_{stat} + \sum_{j=1}^N |V_k| |V_j| |Y_{kj}| \cos(\delta_k - \delta_j - \theta_{kj}) \quad (8)$$

$$Q_k = Q_{stat} + \sum_{j=1}^N |V_k| |V_j| |Y_{kj}| \sin(\delta_k - \delta_j - \theta_{kj}) \quad (9)$$

$$P_{stat} = G_{stat} + |V_k|^2 - |V_k| |E_{stat}| |Y_{stat}| \cos(\delta_k - \delta_{stat} - \theta_{stat}) \quad (10)$$

$$Q_{stat} = B_{stat} + |V_k|^2 - |V_k| |E_{stat}| |Y_{stat}| \sin(\delta_k - \delta_{stat} - \theta_{stat}) \quad (11)$$

Where,

$|E_{stat}|$ ,  $|Y_{stat}|$  and  $\theta_{stat}$  are shown in "Fig. 4".

Addition of STATCOM introduces two new variables  $|E_{stat}|$  and  $\delta_{stat}$ ; however,  $|V_k|$ , is now known. Thus, one more equation is needed to solve the power flow problem.

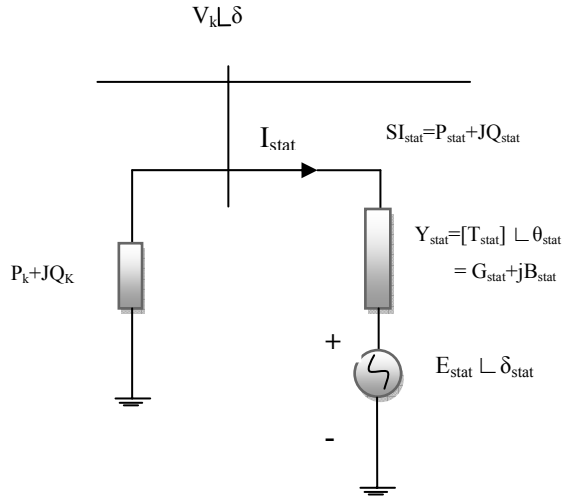


Fig. 4 steady state model of STATCOM

Equation (11) is found using the fact the power consumed by the source  $E_{stat}$  ( $P_{Estat}$ ) must be zero in steady state. Thus the equation for  $P_{Estat}$  is can written as:

$$P_{Estat} = \text{Rea}[E_{stat} I^*] = -G_{stat} |E_{stat}|^2 + |V_k| |E_{stat}| |Y_{stat}| \cos(\delta_k - \delta_{stat} - \theta_{stat}) = 0 \quad (12)$$

Using these power equations, The linearized STATCOM model is given below:

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{stat} \\ \Delta Q_{stat} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} & \frac{\partial P_k}{\partial \delta_{stat}} & \frac{\partial P_k}{\partial V_{stat}} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} & \frac{\partial Q_k}{\partial \delta_{stat}} & \frac{\partial Q_k}{\partial V_{stat}} \\ \frac{\partial P_{stat}}{\partial \theta_k} & \frac{\partial P_{stat}}{\partial V_k} & \frac{\partial P_{stat}}{\partial \delta_{stat}} & \frac{\partial P_{stat}}{\partial V_{stat}} \\ \frac{\partial Q_{stat}}{\partial \theta_k} & \frac{\partial Q_{stat}}{\partial V_k} & \frac{\partial Q_{stat}}{\partial \delta_{stat}} & \frac{\partial Q_{stat}}{\partial V_{stat}} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \Delta V_k \\ \Delta \delta_{stat} \\ \Delta V_{stat} \end{bmatrix} \quad (13)$$

## V. SIMULATION RESULTS

The system without the STATCOM has 7 buses with voltages below 0.98 p.u. Once the STATCOM is connected to the buses 10 and 24 the voltages improve at the all buses except one bus below at 0.98 Per-Unit (p.u). Table 1 and "fig. 5," shows the results for the voltage before and after the STATCOM placement.

Table 1: Voltage results with and without STATCOM

Bus N°	V Per-Unit (pu) without STATCOM	V Per-Unit (pu) with STATCOM
1	1,0250	1,0250
2	1,0200	1,0200
3	1,0194	1,0194
4	1,0444	1,0477
5	1,0450	1,0450
6	0,9997	1,0000
7	0,9959	0,9967
8	1,0000	0,9900
9	1,0080	1,0146
10	0,9867	0,9996
11	1,0000	0,9900
12	0,9901	0,9961
13	1,0000	1,0100
14	0,9902	0,9926
15	0,9830	0,9872
16	0,9757	0,9844
17	0,9853	0,9894
18	1,0076	1,0082
19	1,0034	1,0100
20	0,9775	1,0000
21	0,9765	0,9854
22	0,9754	0,9911
23	0,9755	0,9860
24	0,9669	0,9783
25	0,9744	0,9815
26	0,9958	0,9958

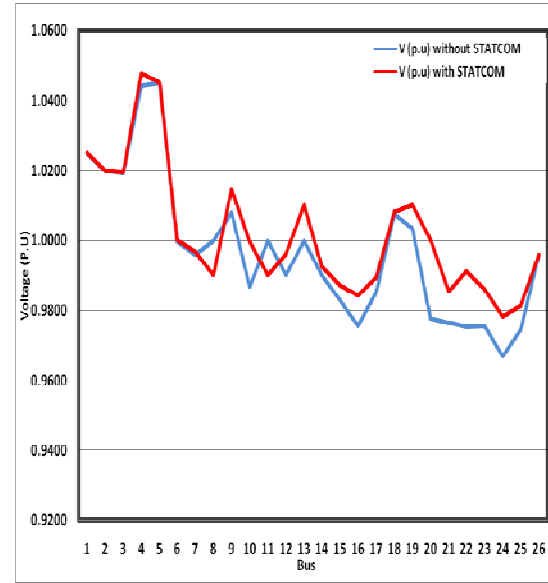


Fig. 5 Location of STATCOM at bus 10-20

Case 2: When the STATCOM is connected to buses 20 and 24. Note also that voltage value of the bus which the STATCOM is connected is sufficient to improve all other voltages and all buses superior to 0.98 Per-Unit (p.u). Table 2 and "fig. 6," shows the results of simulation. We concluded that location of STATCOM at the bus 20-24 gives a better result as the first case.

Table2: Voltage results with and without STATCOM  
(best location)

Bus N°	V Per-Unit (pu) without STATCOM	V Per-Unit (pu) with STATCOM
1	1,0250	1,0250
2	1,0200	1,0200
3	1,0194	1,0194
4	1,0444	1,0480
5	1,0450	1,0450
6	0,9997	1,0029
7	0,9959	0,9972
8	1,0000	0,9900
9	1,0080	1,0154
10	0,9867	1,0080
11	1,0000	1,0100
12	0,9901	0,9966
13	1,0000	1,0100
14	0,9902	0,9928
15	0,9830	0,9875
16	0,9757	0,9847
17	0,9853	0,9905
18	1,0076	1,0092
19	1,0034	1,0174
20	0,9775	1,0000
21	0,9765	0,9923
22	0,9754	0,9952
23	0,9755	0,9913
24	0,9669	1,0000
25	0,9744	0,9862
26	0,9958	0,9958

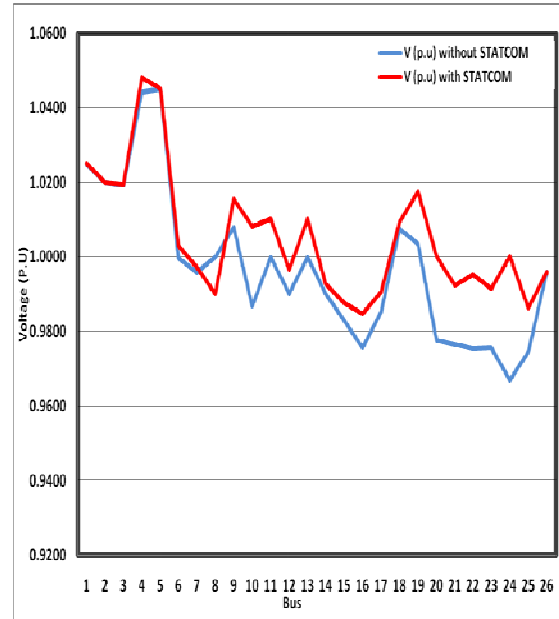


Fig. 6 Location of STATCOM at bus 20-24

## VI. CONCLUSION

Modern power systems, which have several generating plants and an extremely high number of consumers, employ a variety of transmission and distribution voltages. They cover large geographic territories and have a number of interconnection and distribution points through which the electric energy is transmitted or delivered. At any point where a range of voltage level is required, transformer or/and static compensators can be used. Transformers and static compensators are used for voltage regulation at different points in the transmission system with static compensator being seen as the more economical and faster approach.

This paper aims to investigate the best location of static Synchronous Compensator (STATCOM) controlled for power flow studies has been represented and improving voltage in the network. STATCOM is modelled as a controllable voltage source. To validate the effectiveness of the Newton-Raphson method algorithm was implemented to solve power flow equations in presence of STATCOM. Case studies are carried out on 26-bus system to demonstrate the performance of proposed models. Simulation results show the effectiveness and capability of STATCOM in improving voltage regulation in transmission systems; moreover the power solution using the Newton-Raphson algorithm developed. The STATCOM and the detailed simulation are performed using Matlab program.

## REFERENCES

- [1] M.O. Hassan, S.J. Cheng and Z.A. Zakaria "Steady-state modeling of static synchronous compensator and thyristor controlled serie compensator for power flow analysis". Information Technology Journal 8(3), 2009, pp. 347-353.
- [2] N.Mithulanathan, C. A. Cañizares and J. Reeve, 'Comparison of PSS, SVC and STATCOM controllers for damping power system oscillation', IEEE Trans. Power Syst., 18 (2003), 786-792.
- [3] L. J. Cai, I. Erlich, G. Stamtsis, "Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms," 2004 IEEE/PES Power Systems Conference and Exposition, vol. 1, Oct. 2004, pp. 201 - 207.
- [4] P. Bhasaputra, W. Ongsakul, "Optimal power flow with multi-type of FACTS devices by hybrid TS/SA approach," 2002 IEEE International Conference on Industrial Technology, vol. 1, De 2002, pp. 285 – 290.
- [5] Larsen EV, Sanchez-Gasca J J, Chow J H. Concept for Design of FACTS Controller to Damp Power Swings IEEE Trans on PWRs, 1995, 10(2):948-956.
- [6] Iswaran Sothandara Kumar, « flexible alternating current transmission systems: static synchronous compensator (statcom) » thèse Bachelors. Novembre 2005, Curtin University of Technology, Western Austrlie.
- [7] Ricardo Dávalos Marín « Detailed analysis of a multi-pulse STATCOM » thèse Pre- doctoral, Guadalajara, Jalisco, Mexique. Mai 2003.
- [8] Edvina Uzunovic « EMTF, Transient Stability and Power Flow Models and Control of VSC Based Facts controllers ». Université de Waterloo, Waterloo Ontario, Canada Thèse PHD , 2001.
- [9] M.S. El-Moursi. A.M. Sharaf « Novel reactive power controllers for the STATCOM and SSSC », IEEE Department of Electrical and Computer Engineering, University of New Brunswick, P.O. Box 4400-UNB, Fredericton, NB, Canada, revue Electric Power system research , p 228-241 ,2006.
- [10]Emmanuelle CATZ« Evolution technique du système FACTS ». Journées Electrotechnique du Club EEA Supelec, le 15 mars 2006.
- [11]Eskandar Gholipour Shahraki « Apport de l'UPFC à l'amélioration de la stabilité transitoire des réseaux électriques » thèse pour l'obtention du titre de Docteur de l'Université Henri Poincaré, Nancy-I en Génie Electrique Soutenue publiquement le 13 Octobre 2003.
- [12] Krishnat V. Patii « *Dynamic compensation of electrical power systems using a new BVSI statcom* » thèse pour l'obtention de Doctor of Philosophy. Faculty of Graduate Studies the University of Western Ontario London, Ontario Mars 1999.