OPTIMALLY LOCATED SVC FOR TRANSMISSION OF RENEWABLE ENERGY IN LARGE POWER SYSTEM

M.LAXMI DEVI[1], SK.SHAKEER AHAMMAD[2] & G.SRINIVASULU REDDY[3]

[1](M.Tech) EEE Department, P.G Scholar @ NEC, Nellore, Andhra Pradesh
[2](M.Tech), EEE Department, Assistant Professor @ MRRITS, Udayagiri, Andhrapradesh
[3](M.Tech), Ph.d, EEE Department, Assosiate Professor @ NEC, Nellore, Andhrapradesh
Email: m.laxmidevi@yahoo.com, ssamerits@gmail.com, gsmeghana@gmail.com

Abstract- Shunt FACTS devices provide the possibility to control voltages and therefore to improve the security of the system. In order to use this possibility, the optimal location and the set values of the FACTS controllers have to be selected correctly. The singular analysis of the power system Jacobian matrix are applied to identify the optimal location of shunt FACTS devices in large power systems. Furthermore the application of Optimal Power Flow control is a possible method for choosing set values. In this paper a sensitivity index for the detection of sensor nodes is defined. Sensitivity analysis is used to determine the area on which the FACTS device has significant influence. And then only this limited area is included in the Optimal Power Flow control, because it is very difficult to include the entire system into the optimization process. Matlab code is written to find the optimal location of Shunt Facts device i.e., SVC. Furthermore the objective function of Optimal Power Flow control is analyzed. This function consists of three components. A certain type of FACTS is not able to influence all these components.

Index terms*—FACTS controllers, Optimal power flow, Jacobian matrix, Sensitivity analysis,*

(1) M.Laxmidevi (M.Tech)
m.laxmidevi@yahoo.com, 9493913676
(2) G.Srinivasulu Reddy M.Tech,PhD
gsmeghana@gmail.com

Nomenclature:-

β- phase angle of current flowing in a branch;
I - magnitude of current flowing in a branch;
I_r - shunt injected reactive current;
V- bus voltage magnitude;
P_{sh}- shunt injected real power;
P_f - real power flow in a branch;
Q_{sh}- shunt injected reactive power;
X_{br}-inductive compensating reactance in a branch considered.

1. INTRODUCTION:

Flexible A.C. Transmission System (FACTS)

The main objectives of a FACTS controller are as follows:

1. Regulation of power flows in prescribed transmission routes.
2. Secure loading of lines near their thermal limits.
3. Prevention of cascading outages by contributing to emergency control.
4. Damping of oscillations which can threaten security or limit the usable line capacity.
5. Prevention of voltage collapse by providing reactive power support.

Flexible a.c. transmission system (FACTS) technology opens up new opportunities for controlling power flow and enhancing the usable capacity of present transmission lines. FACTS devices control the interrelated parameters that govern the operation of a transmission system, thus enabling the line to carry power close to its thermal rating.

1. During steady-state operation of a power system, all the synchronous machines operate in parallel and together supply the total demand plus losses so that there is equilibrium between these two. If a large disturbance occurs, this equilibrium is disturbed and the machines start 'swinging' with respect to each other.
2. Transient stability is the ability of the power system to maintain synchronism when subjected to a severe disturbance, such as a short circuit on a transmission line.
3. FACTS devices are capable of controlling the network condition in a very fast manner and this unique feature of FACTS devices can be exploited to improve the transient stability of a power system. Reactive power compensation is an important issue in electrical power systems and shunt FACTS devices play an important role in controlling the reactive power flow in the power network, which in turn affects the system voltage fluctuations and transient stability.
4. The SVC and STATCOM are members of the FACTS family that are connected in shunt with the

system and are highly effective in improving the transient stability.
5. It has been observed that shunt FACTS devices give maximum benefit from their stabilised voltage support when sited at the mid-point of the transmission line.
6. The proof of maximum increase in power transfer capability is based on a simplified model of the line that neglects the resistance and capacitance, which is a reasonable assumption for short transmission lines.

This paper is organized as follows. In Section II optimal placement of SVC is discussed. In Section III the effectiveness of the SVC, in terms of load curtailment minimization, has been observed at increased load conditions. In Section IV the OPF problem is run for the market scenarios In Section V case study, test system, results conclusion and the scope for future research in this area is given.

II. OPTIMAL PLACEMENT OF SVC

SVC is a shunt connected static Var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variable. Typically, the power system control variable is the terminal bus voltage. There are two popular configurations of SVC. One is a fixed capacitor (FC) and thyristor controlled reactor (TCR) configuration and the other one is a thyristor switched capacitor (TSC) and TCR configuration. In the limit of minimum or maximum susceptance, SVC behaves like a fixed capacitor or an inductor. Choosing appropriate size is one of the important issues in SVC applications in voltage stability enhancement.

A possible structure of the SVC is given in Fig1

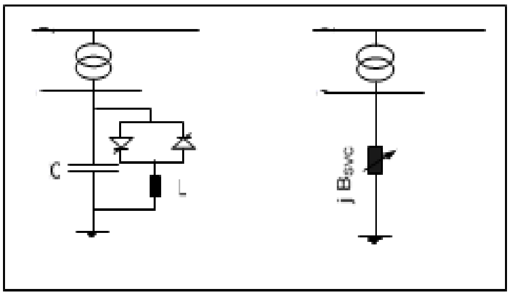

Fig.1. a) Structure of a SVC and b) model of a SVC

The detection of sensor and weak nodes plays an important role for the optimal placement of shunt FACTS devices, which can be eliminated by analysis of network Jacobian matrix. This paper illustrates the significance of determining the minimum eigenvalue of the Jacobin matrix for evaluation of weak nodes und the interrelation between the minimum eigenvalue and the voltage. The static voltage stability analysis is based on the modal analysis of the power flow Jacobian matrix, It is meaningful to use the decomposed form of the Jacobian matrix.

$$J = W\Lambda V^T = \sum_{i=1}^{n} w_i \lambda_i v_i^T$$

$$J^{-1} = V\Lambda^{-1}W^T = \sum_{i=1}^{n} \frac{v_i w_i^T}{\lambda_i}$$

III. EFFECTIVENESS OF THE SVC, IN TERMS OF LOAD CURTAILMENT MINIMIZATION:

Utilities offer the load curtailment programs to commercial and industrial building owners with an agreement to curtail energy use at the request of the utility in exchange with reduced electrical rates. Curtailing loads should be as minimal as possible since it is detrimental to both system reliability and customer satisfaction. The only technical aspect of load curtailment has been taken into account in this thesis. The cost aspect of the load curtailment has not been taken into account; hence how much amount of load curtailed can be minimized by placing a FACTS device in the system has been studied in this thesis.SVC is used as the FACTS device over a conventional capacitor bank. A capacitor bank is enough for the under voltage problem which caused load curtailment. But for over voltage problem capacitor is insufficient and an inductor is required to absorb the reactive power to reduce the voltage. Hence, SVC is preferred over capacitor bank as it can generate or absorb the reactive power as per the requirement. Moreover FACTS devices are controlled by power electronics which enable faster response of the device. In present day scenario of power system, faster switching is essential for stability purpose. Only one SVC has been connected at a time.

IV.THE OPF PROBLEM:

Power Flow Optimization process. The area of influence is defined as an area for which the sensitivity is larger than a certain level. The sensitivity of a variable *y* with respect to a control variable *u* is a measure for the impact of changes in *u* on the variable y. The sensitivity value is higher, if the control variable affects more on the considered system variable.

U-Q sensitivity analysis calculates the relation between voltage change and reactive power change:

$$\Delta U = J_R^{-1} . \Delta Q$$

The elements of the inverse of the reduced Jacobian matrix are the *U-Q* sensitivities. The diagonal components are the self sensitivities and the nondiagonal elements are the mutual sensitivities and are defined as SVC sensitivity factor *KSVC* for the determination of the influence area of SVC.

The aim of the OPF problem is to determine control setting of FACTS such that an objective function is minimized. for a given system situation, for the optimal setting of FACTS the objective function can be defined as following:

$$f(x)=a\sum_i (U_i-U_{i,ref})^2+b\sum_j (I_j-I_{j,\lim})^2+c\sum_j P_{j,loss}$$

V. CASE STUDY:

Case studies are presented for IEEE 57 bus systems to validate the method.

Test System: It consist of 57 nodes, 81 transmission lines and 7 generators connected at the nodes 1, 2, 3, 6, 8, 9 and 12. The generator connected at node 1 is assumed as a slack node**.**

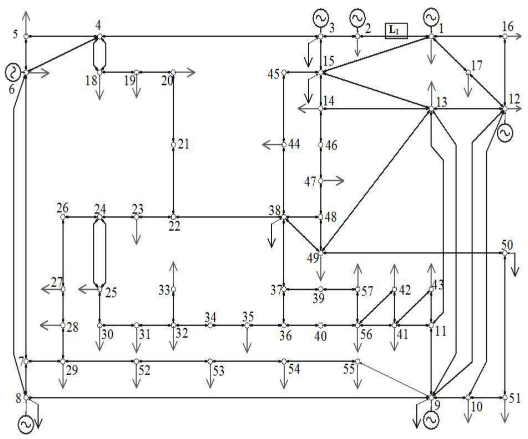

Fig 2. Scheme of the test system

Critical area in the test system without FACTS devices: This is a critical network situation with 21 under voltages The bus that is more sensitive regarding to voltage magnitude or reactive power injection plays a decisive role for static stability analysis.

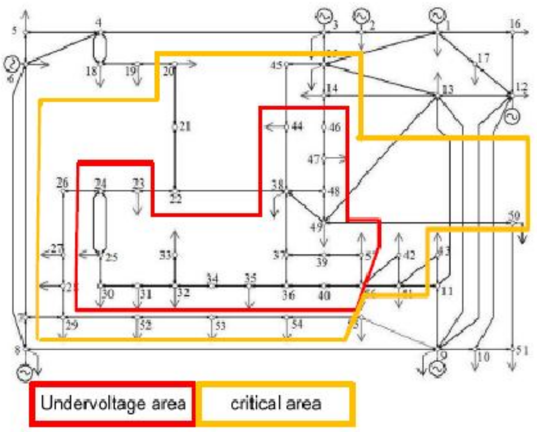

Fig 3.Critical area in the test system without FACTS devices

VI. RESULTS

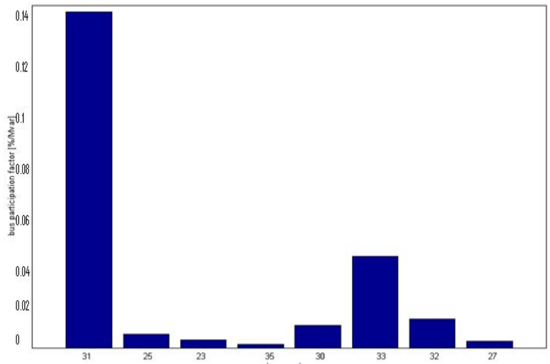

Fig 4 Calculated bus participation factors

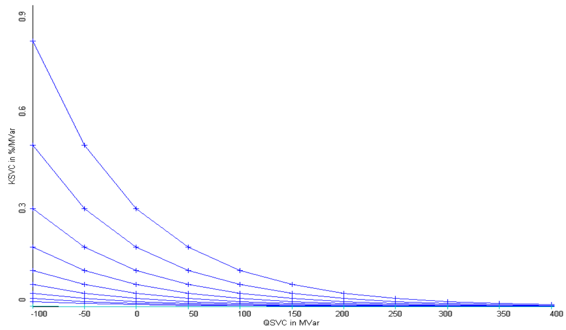

Fig 5. Sensitivity of the other buses vs the changing of Q_{svc} at bus 31

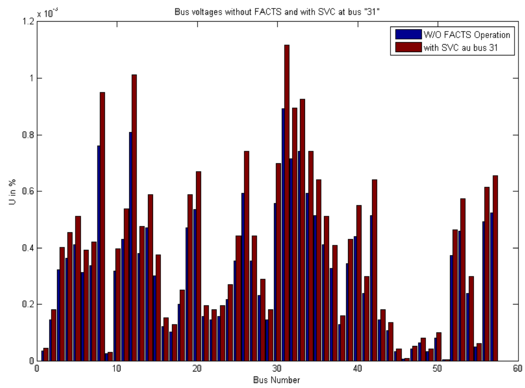

Fig 6. Bus voltages without FACTS and with SVC at bus " 31"

VII. CONCLUSION

FACTS devices are a powerful technology that can solve many problems in power systems. They can influence power flows and voltages and therefore enhance the system security [16]. Voltage stability plays a major role in power systems. Static var compensator is a shunt connected FACTS device which is able to control the voltage profile in a system. It have been shown that for the determination of the optimal placement of shunt FACTS good results can be reached by analysis of the network Jacobian matrix. This fact is visible on the basis of a test system. The test system has a critical condition (21 undervoltages). The voltage profiles became more balanced with only one SVC in the test system. For an optimal voltage control the set values of the FACTS controllers have to be selected correctly. Thus a method for the determination of the optimal set value based on optimal power flow has be introduced in this paper.

SCOPE FOR FUTURE RESEARCH:

The simultaneous use of several FACTS devices will be the subject for future studies. Additionally, the coordinated control of several FACTS devices will be studied for the German 380kV grid in order to investigate the performance in a more practical environment.

REFERENCES

[1] A. Danesh Shakib and G. Balzer, "Optimal location of shunt FACTS devices in a power system with high wind feeding," *in Proc. 8th international workshop on large-scale intergation of wind power into power systems as well as on transmission networks for offshore wind farms*, 2009, paper 56, p.641.

[2] G. Glanzmann and G. Andersson, "Coordinated control of FACTS devices based on optimal power flow," power symposium, 2005, *in Proc. The 37th annual north american*, 23-25 October, 2005, p. 141-148.

[3] B. Gao, G. K. Morison, and P. Kundur, "Voltage stability evaluation using modal analysis," *IEEE Trans. Power Systems*, vol. 7, pp. 1529-1542, Nov. 1992.

[4] S. Gerbex, R. Cherkaoui, and A. J. Germond, "Optimal location of FACTS devices to enhance power system security," presented at the *PowerTech Conference*, Bologna, Italy, 2003.

[5] S. Gerbex, R. Cherkaoui, and A. Germond, "Optimal location of multi- Type FACTS devices in a power system by mean of genetic algorithms," *IEEE Trans. Power Systems*, vol. 16, pp. 537-544, Aug.2001.

[6] Cigre, working group C1.04, "Application and required developments of dynamic models to support practical planning," final report, pp. 141-143, Feb. 2007.

[7] X.-P.Zhang, C. Rehtanz, and B. Pal, *Flexible AC Transmission Modeling and Control*,Germany:Springer, 006,p.11.

[8] P. Moore an[d P. Ashomble, "Flexible AC Transmission System FACTS controllers," *power engineering journal*, pp. 177- 183,

[9] H. Marashi shoushtari, "Optimale Platzierung von FACTS-Elementen in elektrischen Netzen anhand von Eigenwertanalyse," seminar paper, institute of electrical power & energy, Technische Univ. Darmstadt, Germany, 2008.

[10] L.-J. Cai, and I. Erlich, "Power system voltage stability analysis considering all active and reactive power controls- singular value approach," presented at the *PowerTech conference*, Lausanne, Switzerland, 2007.

[11] A.Z. Gamm, I. I. Golub, A. Bachry, and Z.A. Stryczynski,"Solving several problems of power systems using spectral and singular analyses," *IEEE Transactions on Power Systems*, vol 20, pp. 138-148, Feb. 2005.

[12] P. Kundur, *Power System Stability and Control*," Palo Alto:McGraw- Hill, 1993, pp.27-33.

[13] I. Elgerd, *Control systems theory*, Kogakusha: McGraw Hill,Tokyo,1976

[14] G. Glanzmann, and G. Andersson, "Coordinate control of FACTS devices in power systems for security enhancement," presented at *BULK power dynamics an control- VII conference*, Charleston, south California, USA, 2005.

[15] Y. Wang, "OPF-Analyse zur Regelung von FACTS-Geräten in großen Netzen,"seminar paper, institut of Electrical Power & Energy, Darmstadt, Germany, Sep. 2009.

[16] N.G. Hingorani and L. Gyugyi, "Understanding FACTS concepts and technology of flexible AC transmission systems," *IEEE press*, New York, 2000.