Reactive Power Flow Control Using Static VAR Compensator to Improve Voltage Stability in Transmission System

Brij Sunder Joshi
Apex Institute of Engineering & Technology, Jaipur, India
brijyit@gmail.com

Om Prakash Mahela
Indian Institute of Technology Jodhpur, India
opmahela@gmail.com

Sheesh Ram Ola
Apex Institute of Engineering & Technology, Jaipur, India
sheeshola@gmail.com

Abstract— **Power systems are complex systems consisting of large number of generating units and interconnected network of transmission lines. The voltage stability is an issue of prime importance in this complex power system network since the demand for electric power is increasing drastically. The control of reactive power in the transmission lines will enhance the voltage stability of the power system network. This paper presents the design and implementation of the Static VAR Compensator (SVC) in the transmission network for reactive power flow control to improve the voltage stability. The proposed method detects automatically the optimal number of SVCs required for the control of reactive power. The detailed simulation study has been carried out in MATLAB/Simulink environment.**

Keywords—Power system network; reactive power; static VAR compensator; transmission line; voltage stability.

I. INTRODUCTION

The power systems are complex systems consisting of large number of generating units and interconnected network of transmission and distribution lines. The power demand is increasing at an alarming rate day by day, as a result of which the utilities are being compelled to operate their generating units and transmission lines at their maximum capacity [1]. This degrades the stability of the power system network in terms of voltage. The use of flexible AC transmission system (FACTS) devices in the transmission system increases the voltage stability as well as also controls the flow of active and reactive powers in the network. The transmission system parameters and variables such as line series and shunt line impedances, lines power flow, magnitudes and angles of bus voltage can be controlled with the help of FACTS devices. The use of FACT devices in the transmission system has the merits such as improvement in the system dynamic, reliability and voltage profile and controllability of lines power flow [2].

In the literature, the articles have been reported on the design and implementation of FACTS devices to control the parameters of transmission system. The utilization of interline power flow controller (IPFC), implemented on a test system, consisting of 6-machine and 22-buses to solve overload problem using optimal power flow (OPF) control method has been reported in [3]. This paper also details the OPF control method to obtain the solution with minimum cost and the entire power flow balance. In [4], authors presented an efficient modeling of IPFC using the 12-pulse, three-level converters to investigate the sub-synchronous resonance (SSR) characteristics for different operating modes of the IPFC. The analysis of SSR is carried out based on Eigen value analysis and transient simulation of the detailed system. Reza *et al.* [5], presented a Line Flow Based (LFB) equation which uses variables such as square of the bus voltages and line power flow. In [6], authors presented that the application of FACTS devices increases the ability of the transmission lines to double the power transfer of the uncompensated line. The mid-point sitting also helps in the independent control of reactive power at both ends of the transmission line. In [7], authors presented the performance of SVC and STATCOM connected in parallel to each other. These devices have been examined in terms of their ability to provide damping to a power system network. In [8], authors presented the use of an Unified Power Flow Controller (UPFC) improves the voltage profiles of power system networks. The same has been implemented based on the mathematical model of the UPFC. This uses a load flow algorithm and the L-index for the different values of the control parameters. The location of the UPFC in the network has been changed to minimize the sum of squares of the L-indices at all load buses. The results obtained are quite encouraging as compared to the other techniques used to identify the optimal location of the UPFC. The merits of an analytical method used to determine the optimal location as well as amount of the series compensation which helps to increase the steady state power transfer capability in the power system specifically applied on cascading line overload consideration has been reported in [9]. In [10], authors presented a method for the optimal locations of FACTS devices. This method also determines the best optimal location in order to reduce the production and device costs. In [11], authors presented the basics of thyristor controlled series compensator (TCSC) device utilized to analyze the impedance characteristics along with the associated single & multi resonance conditions. In [12], authors presented determination of the area on which the FACTS device has considerable influence based on the sensitivity analysis. This limited area is included in the Optimal Power Flow control method. In [13], authors

[978-1-5090-2807-8/16/$31.00 ©2016 IEEE]

presented the a method based on the genetic algorithm used for the optimal choice and allocation of FACTS devices in multi-machine power systems. In [14], authors presented the use of FACTS devices in the control of disturbed power systems. The Unified Power Flow Controller (UPFC) is chosen for a specific application to investigate the effect of UPFC on the voltage of the related bus. In [15], authors presented a method used for the optimal placement of FACTS controllers in a multi machine power system using Genetic Algorithm (GA). In [16], authors presented a new methodology for placement of the UPFC in a classical power system for the control of transient stability.

This paper presents a design and implementation of the static VAR compensator (SVC) for improvement of the voltage stability of the power system network based on phase locked loop (PLL) based control. The voltage stability has been achieved by the control of reactive power in the network. The study has been carried out using MATLAB simulations.

This paper is organized into four Sections. Starting with an introduction in the Section I, the Section II describes the proposed test system with the details of proposed SVC. The simulation results and their discussions are presented in the Section IV. Finally, the conclusions are detailed in the Section V.

II. Proposed Test System

The proposed study has been carried out using the test system shown in Fig. 1. This system consists of a conventional generator (G1) rated at 735 kV. There are four buses in the system designated as B1 to B4. The two loads L1 and L2 are connected on the buses B1 and B4 respectively as shown in Fig. 1. The loading status of these loads is given in Table 1. The data of transformer TRF is provided in Table 2. Thyristor switched capacitor (TSC) is connected to the bus B3. The static VAR compensator (SVC) is consists of the one unit of thyristor controlled reactor (TCR) and three units of TSC. The TCSR consists of a bidirectional thyristor switch fixed with reactor a inductance L. The available power thyristors can block voltage up to 4000 to 9000 V and conduct current up to 3000 to 6000 A. Hence, in a practical valve the many thyristors (ranging from 10 to 20) are connected in series to meet the required blocking voltage capability at a given power rating. A thyristor switch can be brought into conduction by simultaneous application of a gate pulse to all thyristors of the same polarity. The thyristor switch automatically blocks immediately after the ac current crosses zero, unless the gate signal is re-applied. The TCR inductance is $18.7e^{-3}$ henry and quality factor is 50. The thyristor snubber resistance and capacitance are respectively 500 ohm and 250e-9 F. The TCS consists of three parallel units each of capacity 94 MVAR. It consists of a fixed capacitor of capacitance C, and a bidirectional thyristor switch. The TSC capacitance in each unit is 308.4e-6 F. Thyristor snubber resistance and capacitance are respectively 500 ohm and $250e^{-9}$ F. The phase locked loop based control of the TSC and TCR are used in this study for reactive power flow control.

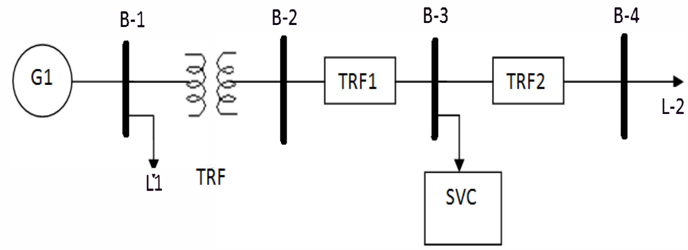

Fig. 1. Single line diagram of the proposed test system.

TABLE 1. Load Data

S. No.	Load	Voltage (kV)	MW rating	kVAr rating
1	L1	735	200	0
2	L2	16	1	1

TABLE 2. Transformer Data

Transformer	MVA	kV-High	kV-Low	HV winding		LV winding	
				R(pu)	L(pu)	R (pu)	X(pu)
TRF	333	735	16	0.0025	1.05	0.0025	1.05

III. Simulation Results and Discussion

The voltage stability of the power system network has been achieved by the control of reactive power using the SVC. The voltage stability during the power system operational events such as voltage variations and switching of the loads has been investigated. The study has been carried out using the MATLAB simulations. The study has been carried out with the help of test system shown in Fig. 1. Bus B-1 is selected as the test point and voltage and current signals are captured at this bus. The various case studies are detailed in the following subsections. The results have been plotted for 1 second.

A. Healthy Condition

The proposed test system with SVC has been simulated without any disturbance in the network and all parameters are observed. The voltage signal on the test bus is shown in Fig. 2 (a). There is no disturbance in the voltage and it is maintained at the constant value at all the times. The current drawn by the network is shown in the Fig. 2 (b). The reactive power flow is shown in the Fig. 2 (c). Initially the reactive power drawn by the network is quite high due to the starting transients in the network. Only one thyristor switched capacitor is utilized during the healthy conditions.

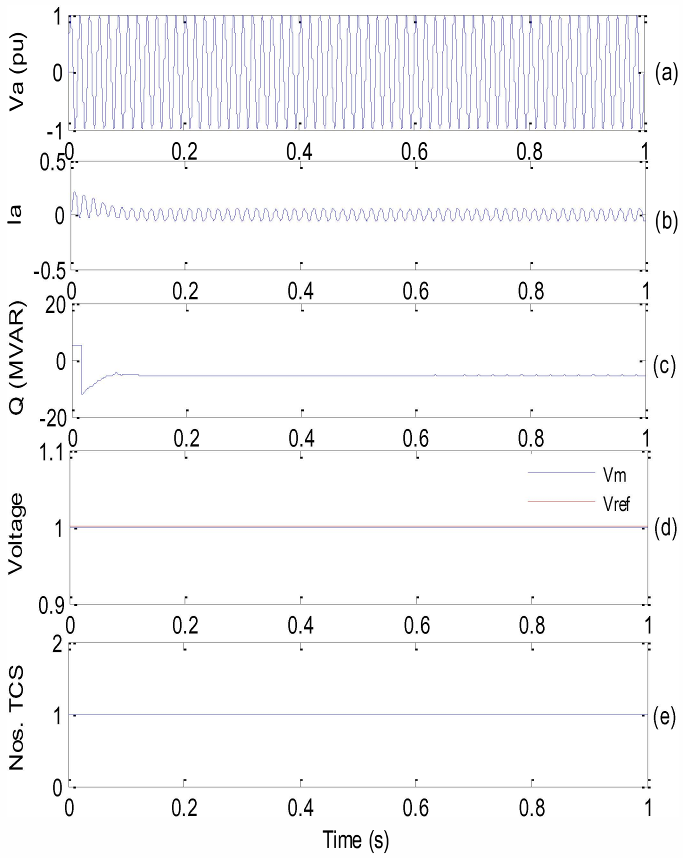

Fig. 2. Healthy condition (a) voltage (b) current (c) reactive power (d) measured voltage and reference voltage (e) number of TCS utilized.

B. Variations in Amplitude of All the Phases

The magnitude of voltage of all the phases has been changed in the sequence (1.0 1.025 0.93 1.0) at the time intervals (0 0.1 0.4 0.7). Hence, there are three transitions in the amplitude of generator voltage. All related plots are shown in Fig. 3. It is observed from the Fig. 3 (b) that current varies due to the variations in the voltage. The reactive power flow has been changed according to compensate the variations in the voltage as shown in Fig. 3 (c). The reference voltage is kept at 1 per unit (pu) whereas the system voltage tracks the reference voltage and finally it attains the value as the reference value by utilizing the additional reactive power supplied by the SVC as shown in Fig. 3 (d). The numbers of TCSs utilized are shown in Fig. 3 (e). It is observed that the TCSs in circuit changes to supply reactive power in order to maintain the voltage constant.

C. Variations in Amplitude of Phase-A

The magnitude of the voltage of phase-A has been changed in the sequence (1.0 1.025 0.93 1.0) at the time intervals (0 0.1 0.4 0.7). Hence, there are three transitions in the amplitude of generator voltage of phase-A. All related plots are shown in Fig. 4. It has been observed from the Fig. 4 (b) that current of phase-A varies due to variations in the voltage of phase-A. The reactive power flow has been changed accordingly to compensate the variations in voltage as shown in Fig. 4 (c). The reference voltage is kept at 1 per unit (pu) whereas the system voltage tracks the reference voltage and finally it attains the value as the reference value by utilizing the additional reactive power supplied by the SVC as shown in the Fig. 4 (d). The small magnitude variations in the measured voltage are observed. However, the measured voltage finally tracks the reference voltage. The numbers of TCSs utilized are shown in Fig. 4 (e). The durations of the TCS used is also shown clearly. This duration is different as used with the variation in the amplitude of all the phases. It is observed that the TCSs in circuit changes to supply reactive power in order to maintain the voltage constant.

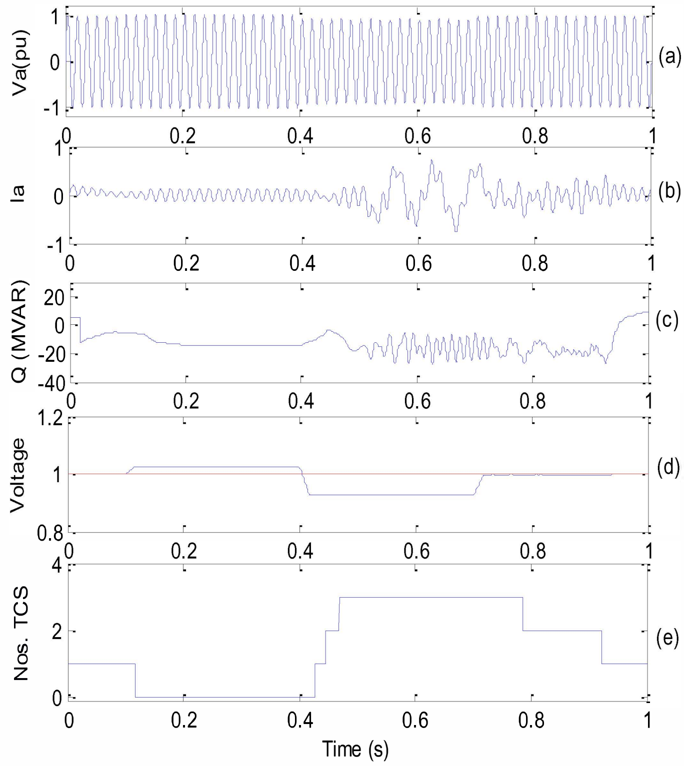

Fig. 3. Variations in amplitude of all the phases (a) voltage (b) current (c) reactive power (d) measured voltage and reference voltage (e) number of TCS utilized.

D. Switching of Load L2

The load L2 is switched off at 20[th] cycle and reclosed at 30[th] cycle to check the suitability of proposed SVC for the control of reactive power to improve the voltage stability. All related plots are shown in Fig. 5. It has been observed from the Fig. 5 (b) that current of phase-A decreases during the time interval the load is switched off the again regains the original value when load is again switched on. The reactive power flow has been increased for this duration to control the voltage variations as shown in Fig. 5 (c). The reference voltage is kept at 1 per unit (pu) whereas the system voltage tracks the reference voltage as shown in the Fig. 5 (d). In this case of study, only one TCS is utilized at all the time as shown in Fig. 5 (e).

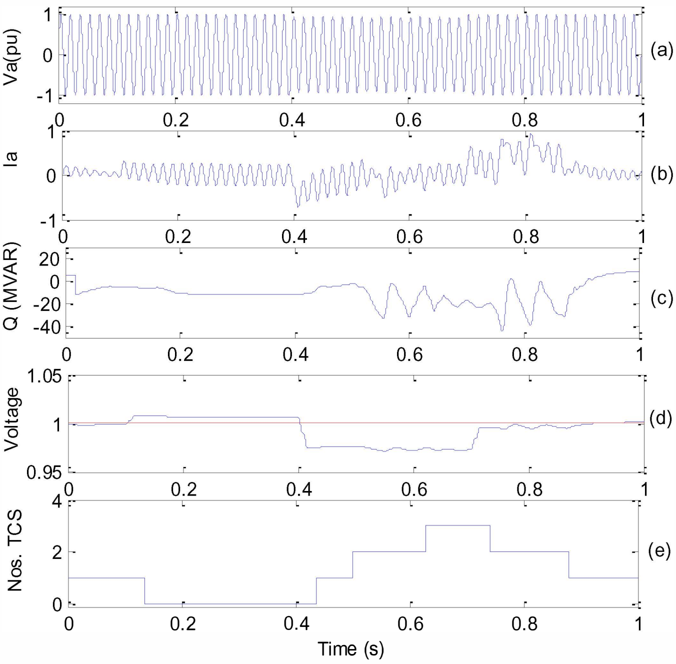

Fig. 4. Variations in amplitude of phase-A (a) voltage (b) current (c) reactive power (d) measured voltage and reference voltage (e) number of TCS utilized.

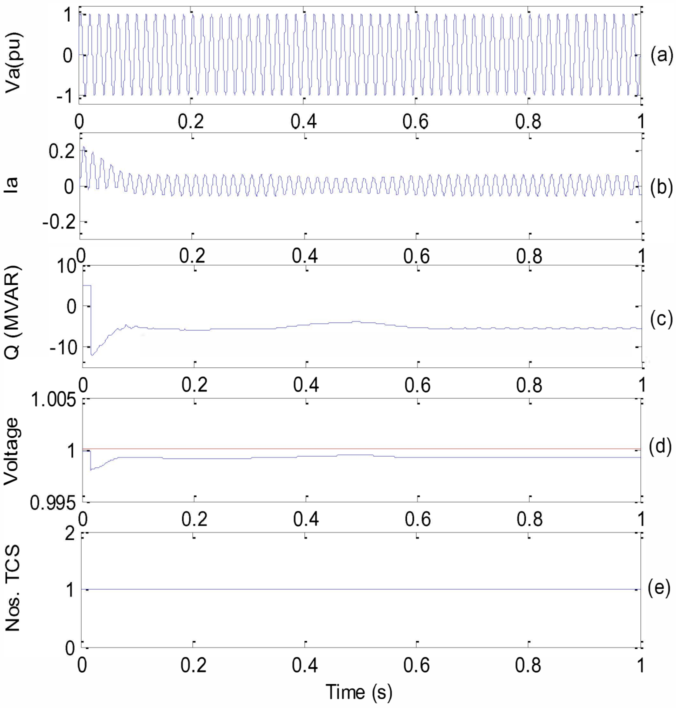

Fig. 5. Switching of the load L2 (a) voltage (b) current (c) reactive power (d) measured voltage and reference voltage (e) number of TCS utilized.

E. Switching Load L1

The load L1 is switched off at 20th cycle and reclosed at 30th cycle to check the suitability of the proposed SVC for the control of reactive power during switching of lage loads to improve the voltage stability. All related plots are shown in Fig. 6. It has been observed from the Fig. 6 (b) that current of phase-A decreases during the time interval the load is switched off and again regains the original value when load is again switched on. The reactive power flow has been increased for this duration to control the voltage variations as shown in Fig. 6 (c). The reference voltage is kept at 1 per unit (pu) whereas the system voltage tracks the reference voltage as shown in the Fig. 6 (d).

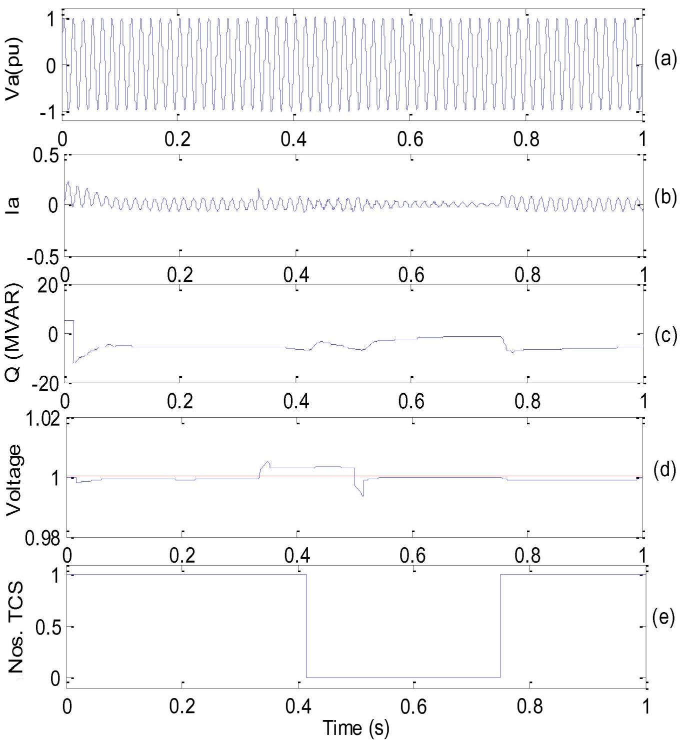

Fig. 6. Switching of the load L1 (a) voltage (b) current (c) reactive power (d) measured voltage and reference voltage (e) number of TCS utilized.

IV. CONCLUSIONS

In this paper, a SVC has been proposed for the improvement of voltage stability in the transmission network of the power system based on the reactive power flow control using the phase locked loop based control. Proposed SVC is capable to control the voltage variations in the power system events such as variations in the amplitude of voltage, switching of the large and small loads etc. The proposed SVC is capable to control the reactive power as per requirement of the system by automatically switching on the number of TSC in the circuit. The results have been validated in MATLAB/Simulink environment.

REFERENCES

[1] Hridya K. R., Mini V., R. Visakhan, Asha Anu Kurian, "Analysis of voltage stability enhancement of a grid and loss reduction using series FACTS controllers," *2015 IEEE International Conference on Power, Instrumentation, Control and Computing (PICC)*, 2015, pp. 1-5.

[2] Reza Etemad, Reza Navabi, and Heidar Ali Shayanfar, "Optimal placement of SVC based on line flow base equation using mixed integer nonlinear programming" *IEEE Power and Energy Engineering Conference*, 2010, pp. 1-5.

[3] S. Teerathana, Yokoyama, Y. Nakachi, and M. Yasumatsu, "An optimal power flow control method of power system by interline power flow controller (IPFC)," *IEEE Transaction on Power System Delivery*, pp. 1-6.

[4] K. R. Padiya and Nagesh Prabhu, "Analysis of SSR with three-level twelve pulse VSC based interline power flow controller," *IEEE Transaction on Power System Delivery*, vol. 22 pp. 1688-1695, July 2007.

[5] Reza Etemad and Reza Navabi and Heidar Ali Shayanfar, "Optimal placement of SVC based on line flow base equation using mixed integer nonlinear programming," *IEEE Transaction on Power System Delivery*, 2010.

[6] B. T. Ooi, M. Kazerani, R. Marceau, Z. Wolanski, F. D. Galiana, D. McGillis, and G. Joos, "Mid-point siting of FACTS devices in transmission lines," *IEEE Transactions on Power Delivery*, Vol. 12 pp.1717-1722 , October 1997.

[7] A. H. M. A. Rahim, S. A. Al-Baiyat and M. F. Kandlawala, "Parallel FACTS devices for improving power system stability." *IEEE Transactions on Power Delivery*.

[8] M. Kowsalya, K. K. Ray, Udai Shipurkar and Saranathan, "*Voltage stability enhancement by optimal placement of UPFC*," IEEE Transactions on Power Delivery, Vol. 4, No. 3, pp. 310-314, 2009.

[9] Rajesh Rajaraman, Fernando Alvarado, Arthur Maniaci, Robert Camfield, and Sasan Jalali, "Determination of location and amount of series compensation to increase power transfer capability," *IEEE Transactions on Power Systems*, Vol. 13, No. 2, pp. 294-294, May 1998.

[10] S. N. Singh and A. K. David, " Placement of FACTS device in open power market," *IEEE Transactions on Power Delivery*, pp. 173-177, Oct. 2000.

[11] S. Meikandasivam, Rajesh Kumar Nema and Shailendra Kumar Jain, "Behavioral study of TCSC device: a MATLAB Simulink implementation," *IEEE Transactions on Power Systems*, pp. 694-699, 2008.

[12] Gabriela Hug-Glanzmann and Goran Andersson, "Coordinated control of FACTS devices in power systems for security enhancement," *IEEE Transactions on Power Systems*, pp. 1-10, 19 August 2007.

[13] LJ. Cai, I. Erlich, and G.Stamtsis, "Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms," *IEEE Transactions on Power Systems*, pp. 1-10, August 2007.

[14] Salim. Haddad, A. Haddouche, and H. Bouyeda, "The use of FACTS devices in disturbed power systems-modeling, interface, and case study," *IEEE Transactions on Power Systems*, Vol. 1, No. 1, pp. 56-59,April 2009.

[15] K. Vijayakumar, and R. P. Kumudinidevi, "A new method for optimal location of FACTS controllers using genetic algorithm," *IEEE Transactions on Power Systems,* pp.1-6, 2007.

[16] Natália M. R. Santos, Vítor M. F. Pires, Rui M. G. Castro and J. Fernando Silva, "Incorporating a unified power flow controller in a conventional transient stability model," *IEEE Transactions on Power Delivery*, pp. 283-288, 20-23 June 2011.