International Journal of Science and Engineering Applications
Volume 8–Issue 12,498-502, 2019, ISSN:-2319–7560

Voltage Stability Enhancement for Power Transmission System using Static VAR Compensator

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Abstract: This paper presents the potential applications of flexible AC transmission system (FACTS) controllers, such as the static VAR compensator (SVC), using the latest technology of power electronic switching devices in the fields of electric power transmission systems with controlling the voltage and power flow, and improving the voltage regulation. The SVC can be used to enhance voltage stability of the system with the possibility of adding additional damping control. With the application of SVC, the voltage stability can be improved under normal condition as well as under disturbances such as faults. A SVC performs such system improvements and benefits by controlling shunt reactive power sources, both capacitive and inductive, with high power electronic switching devices. This work is presented to solve the problems of poor dynamic performance and voltage regulation in an 230KV transmission system using SVC. To evaluate the voltage stability enhancement by SVC, the simulation model is implemented using Matlab/Simulink and performance analysis is done based on simulation results.

Keywords: Static VAR compensator (SVC), Thyristor controlled reactor (TCR), Voltage regulation, MATLAB Simulink, PI ontroller

1. INTRODUCTION

Power transmission system enhancements is very important for large scale system. The AC power transmission system has diverse limits, classified as static limits and dynamic limits. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to enhance same types of stability augmentation. For many reasons desired performance was being unable to achieve effectively. A static VAR compensator (SVC) is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the voltages profile in the transient state and therefore, it can improve the quality performances of the electric services. A SVC can be controlled externally by using properly designed different types of controllers which can improve voltage stability of a large scale power system. And also designed PI controller. The dynamic nature of the SVC lies in the use of Thyristor devices. Therefore, this paper presents Thyristor based SVC with PI controller to improve the performance of multi-machine power system. In this paper, voltage stability enhancement by SVC is presented. The case study is carried out for load variation as well as application of three phase fault. Comparison is expressed for simulation results for without SVC and with SVC conditions.

2. ENHANCEMENYOFVOLTAGESTABI LITY

Transmission systems are part of the overall electrical power supply systems. Transmission system consists of conductors carried on steel towers linking generation stations to users through the distribution system. They deliver bulk power from power stations to the load centres and large industrial consumers beyond the economical service range of the regular primary distribution lines. Like many transmission systems in the world, transmission system is characterized by high technical and non-technical losses, overloading, voltage instability, radial lines having no redundancy, results of de-regularization of the electricity market and obsolete substation equipment.

Increase in population leads to increase in economic activities and hence increase in electrical energy demand, thereby causing burdens on existing transmission lines also to increase. This has caused the loading of the transmission lines beyond their design limits with consequent reduction in power quality.

A major consequence of overstretching transmission lines is voltage instability. Voltage instability is defined as the inability of a power system to maintain steady voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. Instability may result in the form of a progressive fall or rise of voltage of some buses. The possible outcome of voltage instability is loss of load in the area where voltages reach unacceptably low values or a loss of integrity of the power system. Voltage instability could be due to large disturbance or small disturbance.

The proximity of a given system to voltage instability is typically assessed by indices that measure one or a combination of:

- Sensitivity of load bus voltage to variations in active power of the load.
- Sensitivity of load bus voltage to variations in injected reactive power at the load bus.
- Sensitivity of the receiving end voltage to variations in sending end voltage.
- Sensitivity of the total reactive power generated by generators, synchronous condensers, and SVS to variations in load bus reactive power

There are various conventional methods of improving the voltage stability of power systems. Some of these are as follow.

2.1 Reactive Power Compensation

Reactive power compensation is an important issue in electric power systems being an effective measure to improve voltage stability. Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile. Through controlling the production, absorption, and flow of reactive power at all levels in the system, voltage/Var control can maintain the voltage profile within acceptable limit and reduce the transmission losses. Compensation could be shunt whereby the compensating device is connected in parallel with the circuit to be compensated. It can be capacitive (leading) or inductive (lagging) reactive power, although in most cases, compensation is capacitive. Shunt compensation is successful in reducing voltage drop and power loss problems in the network under steady load conditions as it reduces the current flow in areas of installation. It could also be series whereby the compensating device is connected in series with the circuit to be compensated. Whereas shunt compensation reduces the current flow in areas of installation, series compensation acts directly on the series reactance of the line. It reduces the transfer reactance between supply point and the load and thereby reduces the voltage drop.

2.2 Synchronous Condensers

Synchronous condenser is simply a synchronous machine without any load attached to it. Like generators, they can be over-exited or under-exited by varying their field current in order to generate or absorb reactive power. Synchronous condensers can continuously regulate reactive power to ensure steady transmission voltage, under varying load conditions. They are especially suited for emergency voltage control under loss of load, generation or transmission, because of their fast, short-time response. Synchronous condensers provide necessary reactive power even exceeding their rating for short duration, to arrest voltage collapse and to improve system stability.

2.3 Excitation Control

When the load on the supply system changes, the terminal voltage of the alternator also varies due to the changes in voltage drop in the synchronous reactance of the armature. Since the alternators have to be run at a constant speed, the induced emfs, therefore, cannot be controlled by adjustment of speed. The voltage of the alternator can be kept constant by changing the field current of the alternator in accordance with the load. The excitation control method is satisfactory only for relatively short transmission lines.

2.4 Tap-Changing Transformers

Tap-changing transformer method is a method of voltage control for long transmission lines where main transformer is necessary. The principle of regulating the secondary voltage is based on changing the number of turns on the primary or secondary i.e. on changing the ratio of transformation. Decrease in primary turns causes increase in emf per turn, and so in secondary output voltage. Secondary output voltage can also be increased by increasing secondary turns and keeping primary turns fixed. In other words, decrease in primary turns has the same effect as that of increase in secondary turns

2.5 Booster Transformer Sometimes

It is desired to control the voltage of a transmission line at a point far away from the main transformer. This can be conveniently achieved by the use of a booster transformer. The secondary of the booster transformer is connected in series with the line whose voltage is to be controlled. The primary of this transformer is supplied from a regulating transformer fitted with on-load tap-changing gear. The booster transformer is connected in such a way that its secondary injects a voltage in phase with the line

2.6 Phase-Shifting Transformers

When the load on the supply system changes, the terminal voltage of the alternator also varies due to the changes in voltage drop in the synchronous reactance of the armature. Since the alternators have to be run at a constant speed, the induced emfs, therefore, cannot be controlled by adjustment of speed. The voltage of the alternator can be kept constant by changing the field current of the alternator in accordance with the load. The excitation control method is satisfactory only for relatively short transmission lines

3. STATIC VAR COMPENSATOR

The Static Var Compensator (SVC) is a device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor bank connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR). Figure shows a single-line diagram of a static var compensator and its contr system

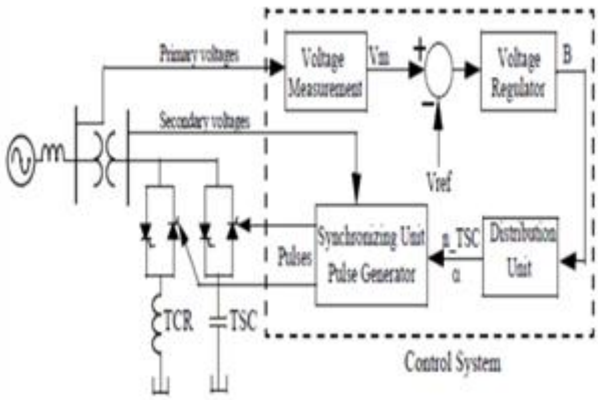

Figure 1. Single-line diagram of an SVC and its control system

The control system consists of: A measurement system measuring the positive-sequence voltage to be controlled. A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep the system voltage constant. A distribution unit that determines the TSCs (and eventually TSRs)that must be switched in and out, and computes the firing angle α of TCRs. A synchronizing system and a pulse generator that send appropriate pulses to the thyristors

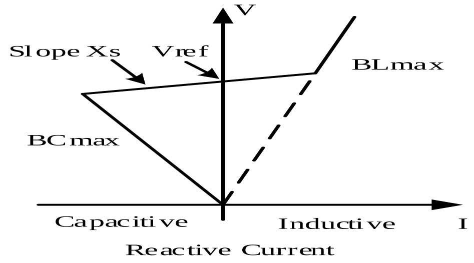

Figure.2. Steady State VI Characteristic of SVC

The SVC can be operated in two different modes: In voltage regulation mode (the voltage is regulated within limits) and In var control mode (the SVC susceptance is kept constant). When the SVC is operated in voltage regulation mode, it implements the following V-I characteristics. As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bcmax) and reactor banks (Blmax), the voltage is regulated at the reference voltage Vref. However, a voltage drop is normally used (usually between 1% and 4% at maximum reactive power output).

4. MODELING OF HIGH VOLTAGE TRANSMISSION SYSTEM

For the voltage stability enhancement by SVC, the detail study is carried out at 230 kV Thanlyin Primary substation. It is located at southern Yangon, Myanmar. The single line diagram of the selected transmission system is shown in Figure 4. The important data for the system are described in Table 1 through Table 4.)

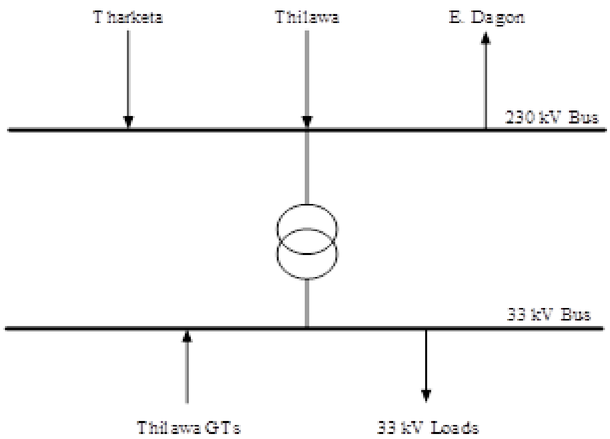

Figure.3. Single Line Diagram for Thanlyin Substation

Table 1. Source data of the system

Parameters	TKT	TLW 230	TLW GT
Phase-to-phase voltage (kV):	230	230	33
3-phase short-circuit level at base voltage (MVA):	3500	4000	2000
Base voltage (kV):	230	230	230
X/R ratio:	10.31	10	8
Generator type:	PV	Swing	PV
Active power generation P (MW)	32.6	-	37.0

Table 2. Load data of the system

Parameters	E. Dagon	33 kV
Nominal phase-to-phase voltage Vn (kV)	230	33
Active power P (MW):	102	27.3
Base voltage (kV):	230	33
Inductive reactive power QL (MVAR):	40.2	16.92

Table 3. Line data of the system

Winding 1 connection (ABC terminals)	Y
Winding 2 connection (abc terminals)	Y
Nominal power and frequency [Pn(VA) , fn(Hz)]	[100e6 50]
Winding 1 parameters [V1 Ph-Ph(Vrms) , R1(pu) , L1(pu)]	[230e3 0.013 0.13]
Winding 2 parameters [V2 Ph-Ph(Vrms) , R2(pu) , L2(pu)]	[33e3 0.013 0.13]
Magnetization resistance Rm (pu)	400
Magnetization inductance Lm (pu)	400

5. MODELING OF SYSTEM

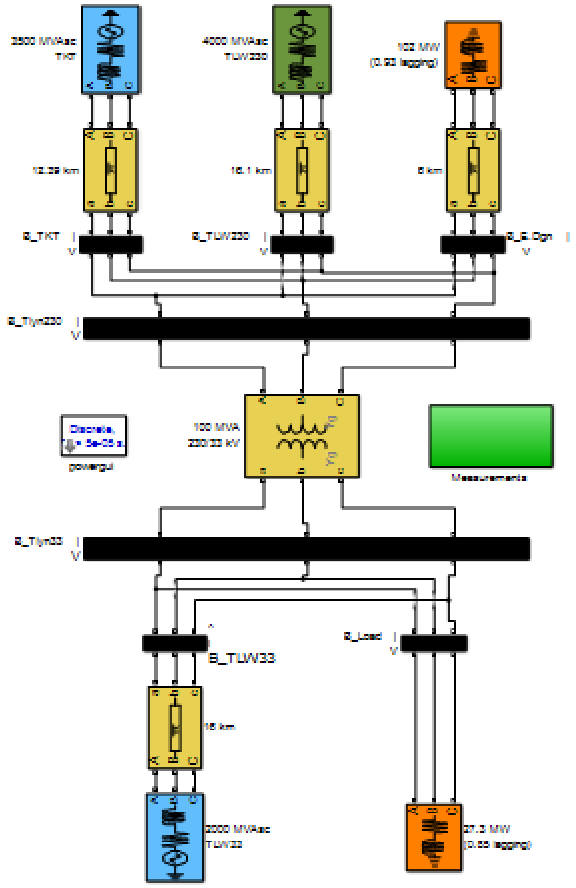

Figure 4. Simulink model of Thanlyin 230/33kV substation for Voltage Stability Study

For this study, the simulation model is implemented with Matlab software. The simulation model consists of 230 kV and 33 kV system. There are two loads, three sources, four feeders and a transformer. To study the simulation results, the voltages, currents and powers are measured at each load/source. For all the simulations, the simulation time is set as 1 second and sampling time is set as 50 μsecond. To observe the voltage stability conditions of the existing system, the simulations are carried out for maximum load condition and fault conditions the area where voltages reach unacceptably low values or a loss of integrity of the power system. Voltage instability could be due to large disturbance or small disturbance

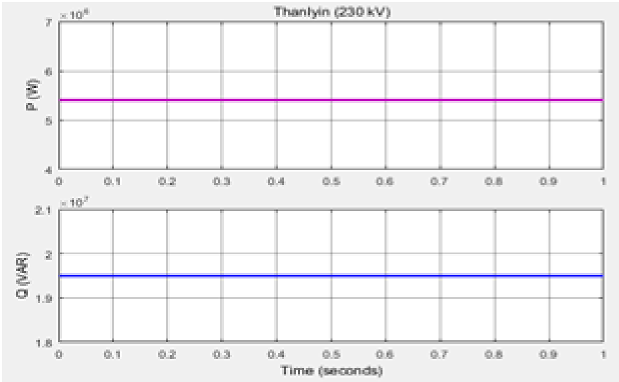

Figure 5. Active and Reactive Power at 230kV Buses under Maximum Load

The active and reactive powers under maximum load at 230kV bus and 33 kV bus are shown in Figure 6 and Figure 7 respectively. The values of the powers are nearly the same that are mentioned in the Tables. Fig. 8 shows voltages at 230/33 kV busses under maximum load. Under maximum load condition, the voltages are about 228 kV at 230 kV bus and about 31.2 kV at 33 kV bus. Fig. 9 shows voltages at 230/ 33kV busses under three phase fault. Under three phase fault condition, the voltages are about 213 kV at 230 kV bus and about 1.5 kV at 33 kV bus.

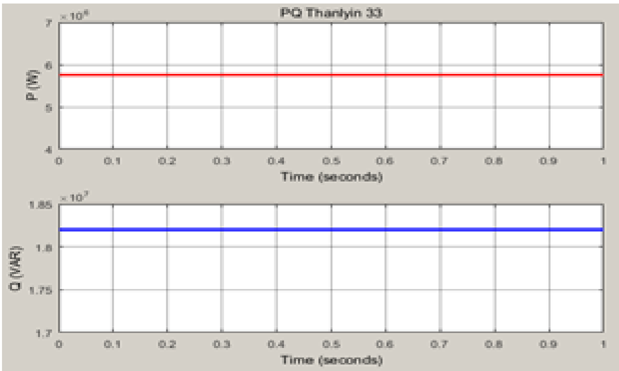

Figure 6. Active and Reactive Power at 33kV Buses under Maximum Load

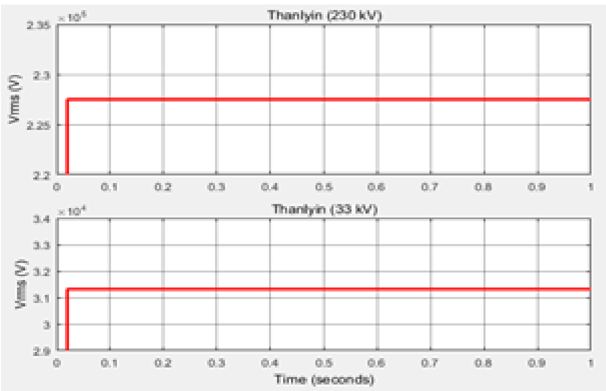

Figure.7. Voltages at 230/33 kV Busses under Maximum Load

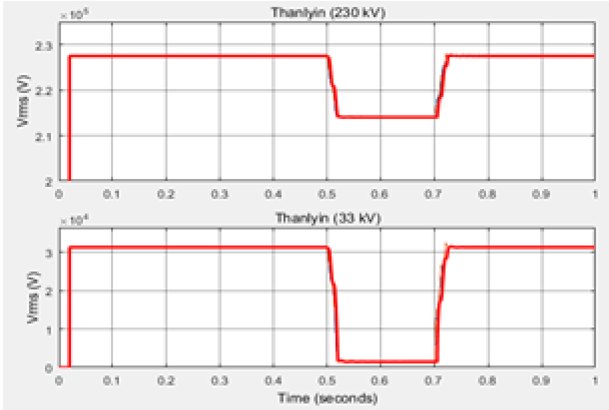

Figure.8. Voltage Stability Study at 230/ 33kV Busses (Under Three Phase Fault)

6. DESIGN CALCULATION OF TSC AND TCR

The compensated values for the capacitance and inductance are calculated based on the setting.

$$X_{SVC} = \frac{V_{bus}^2}{Q_{SVC}} = \frac{(230x10^3)^2}{21x10^6} = 2519\Omega$$

$$X_{SVC} = \frac{X_{TSC}\ X_{TCR}}{X_{TSC} + X_{TCR}},\ X_{TSC} = 3X_{TCR}$$

$$= \frac{3X_{TCR}\ X_{TCR}}{3X_{TCR} + X_{TCR}} = \frac{3X_{TCR}^2}{4X_{TCR}} = 0.75X_{TCR}$$

$$\therefore X_{SVC} = 0.75\ X_{TCR}$$

$$\therefore X_{TCR} = \frac{X_{SVC}}{0.75} = \frac{2519}{0.75} = 3358.73\Omega$$

$$\therefore X_{TSC} = 3\ x\ 3358.73 = 10076.19\Omega$$

$$X_{TCR} = 2\pi fL\ ,\ f = 50\ Hz\ ,\ X_{TSC} = \frac{1}{2\pi fc}$$

$$L = \frac{X_{TCR}}{2\pi\pi} = \frac{3358.73}{2\pi\ x\ 50} = 10.69H$$

$$C = \frac{1}{2\pi fX_{TSC}} = \frac{1}{2\pi\ 50\ x\ 10076.19} = 3.159x10^{-7}F$$

$$X_{TCR} = \frac{\pi X_L}{\sigma - Sin\sigma},\ \sigma = 2(\pi - \alpha) = 2(\pi - \frac{\pi}{2}) = \pi$$

X_L = reactance of the Linear inductor. α and σ are Thyristor conducting angle and firing angle.
At α =90, TCR conduct fully and its equivalent reactance X_{TCR} become X_L

$$X_L = \frac{X_{TCR}(\sigma - sin\sigma)}{\pi}$$

$$X_L = \frac{3358.73(\pi - sin\ (180°)}{\pi}$$

$$X_L = 3358.73\Omega$$

7. VOLTAGE STABILITY ENHANCEMENT BY SVC

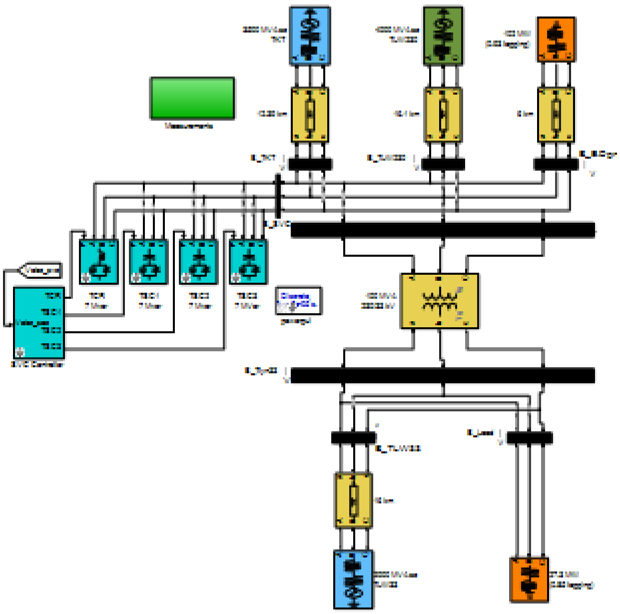

Figure.9. Simulink model of Thanlyin 230/33kV substation for Voltage Stability by SVC

In the simulation, the fault is located at 33 kV load side of transformer since most of faults are occurred at that location. To obtain the stable voltage of the complete system, SVC is located at 230 kV bus bar of Thanlyin substation. With this SVC location, the cost can be reduced and the voltage stability of the complete system can be better small disturbance.

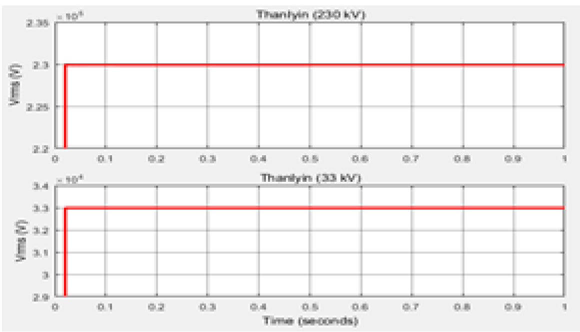

Figure.10. Voltage Stability by SVC at 230/33 buses

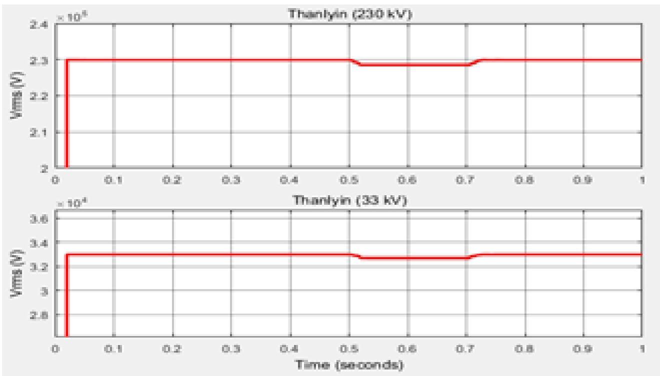

Figure.11.. Voltage Stability by SVC at 230/33 kV Buses (under Three Phase Fault)

For the simulation with fault, the total simulation time is set as 1 second. To avoid the starting transient effects, the fault is initiated at 0.5 second and cleared at 0.7 second. For three phase fault and without and with SVC simulations, the fault occurrence is the same as start at 0.5 second and end at 0.7 second. The following figures illustrate the voltages at 230 kV bus and 33 kV bus of Thanlyin substation.

Table 5. Voltage Comparison For Without And With SVC

Load Condition	230 kV Bus (kV)		33 kV Bus (kV)	
	without SVC	With SVC	without SVC	With SVC
Max Load	227.5	230.0	31.32	33.00
Fault	214.0	228.6	1.49	32.69

8. CONCLUSION

This paper has examined the concept of voltage stability and methods used to evaluate and extend the stability limits of a power system. The work has been focused on SVCs and how they could be used to stabilize the power system to avert a voltage collapse situation. Sensitivity indices have been presented and evaluated to identify areas in the Thanlyin Substation which is prone to super a voltage collapse under certain stressed conditions. In some cases, transmission SVCs also provides an environmentally-friendly alternative to the installation of costly and often unpopular new transmission lines. Dynamic performance and voltage control analysis will continue to be a very important process to identify system problems and demonstrate the effectiveness of possible solutions. Therefore, continual improvements of system modelling and device modelling will further ensure that proposed solutions are received by upper management with firm confidence..

9. ACKNOWLEDGMENTS

The authors of this technical Paper would like to express their sincere thanks to JSET journal for providing us excellent guidance, encouragement and inspiration throughout this paper. The authors wish to thank specially to Dr. Hnin Wai Hlaing, Professor , Dept. of EP, Thanlyin, she was my supervisor of this paper work & thanks to her for her innovative ideas, encouragement & observation for completing this paper.

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