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Simulation of Voltage Stability Enhancement at Primary Substation Using Static VAR Compensator

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***Abstract* — For the voltage stability enhancement of power system, the reactive power compensation is vital important. With the advancement in technology, the Flexible AC Transmission System Devices (FACTS) are widely used for stability improvement. In the primary substation, the stability is poor due to load conditions and system faults. In this research, the voltage stability enhancement for a Primary Substation using Static VAR (volt-amp reactive) compensator (SVC) is presented. SVC can be used to improve system voltage stability and addition of damping control. With the application of SVC, the voltage stability can be improved under normal condition as well as under contingency conditions. Shunt reactive power sources, including capacitive and inductive, are controlled by high power electronic switching devices in an SVC to enhance voltage stability. The goal of this attempt is to use SVC to improve the voltage stability of the 230/33 kV system. To evaluate the voltage stability improvement by SVC, a simulation model is implemented in Matlab/Simulink and performance analysis are carried out based on the simulation results.**

Keywords—MATLAB Simulation, Static VAR compensator (SVC), Thyristor controlled reactor (TCR), Thyristor Switched Capacitor (TSC), Voltage stability enhancement

I. INTRODUCTION

Power transmission system enhancements is very important for large scale system. The restrictions of the AC power transmission system can be divided into static limits and dynamic limits. Shunt and series capacitors, reactors, and synchronous generators have all been employed historically to promote similar sorts of stability augmentation. In the application of these devices, the expected performance was not successfully accomplished. An electrical device called a static VAR compensator (SVC) is used to quickly compensate for reactive power on high-voltage transmission networks. It can also help to improve the voltage profile during transient conditions, which in turn can enhance the quality and effectiveness of the electric services [1].

In most of the studies, the voltage stability enhance of primary substations are carried out based on mechanically switched compensators. Using of these devices cannot sufficiently improve the stability of primary substation voltages. Therefore, this paper presents Thyristor based SVC application for voltage stability enhancement of 230/33 kV Primary Substation. The detail design calculation for SVC rating is also described. To ensure the voltage stability enhancement by SVC, the comparisons for without SVC and with SVC are presented based on simulation results.

II. VOLTAGE STABILITY ENHANCEMENT BY REACTIVE POWER COMPENSATION

Recent widespread major power outages have been largely caused by voltage instability. It is the voltage drop or rise that occurs when active and reactive power flow through inductive reactance of the transmission network, which limits the capability of the transmission network for power transfer and voltage support. When some of the generators reach their field or armature current time-overload limits, the capacity to transfer power and support voltage is further constrained. When a disturbance raises the reactive power demand above the sustainable limit of the available reactive power resources, voltage stability is compromised. Typically, loads are what cause voltage instability. Motor slip adjustment, distribution voltage regulators, tap-changing of transformers, and thermostats all tend to restore power when there is a disturbance. By consuming more reactive power and resulting in further voltage reduction, restored loads

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put more strain on the high voltage network. When load dynamics try to recover power consumption beyond what the system is capable of, a run-down condition that results in voltage instability arises. The main causes of voltage stability problems are as follow:

- Overvoltage or Undervoltage
- Voltage Sags
- Voltage Swell
- Momentary Outage
- Faults
- Voltage Collapse [2]

Reactive power compensation is important to maintain system voltage stability. Reactive power compensation is an important topic in power systems as it is an effective means to improve voltage stability. Reactive power must be compensated to ensure efficient delivery of active power to the load, freeing up system capacity, reducing system losses, and improving system power factor and bus voltage profile. By controlling the generation, absorption and flow of reactive power at all levels in the system, Voltage/Var Control helps keep voltage profiles within acceptable limits and reduces transmission losses. Compensation can be bypassed using a compensating device in parallel with the circuit to be compensated. Compensation is most often capacitive but can be capacitive (leading) or inductive (lagging). Shunt compensation reduces the current flow in the installation area, thus successfully alleviating the problem of network voltage drop and power loss under constant load conditions. It may also be a series circuit in which the compensating device is connected in series with the circuit to be compensated. Shunt compensation reduces the current flow in the installation area, while series compensation acts directly on the series reactance of the line. It reduces the transfer reactance between the feed point and the load, thereby reducing the voltage drop. The main techniques used for voltage stability improvement in power system are as follow:

- Synchronous Condensers
- Excitation Control
- Tap-Changing Transformers
- Booster Transformer
- Phase-Shifting Transformers
- Different Type of FACTS Controller [3]

In this research, Static VAR Compensator (SVC) which is shunt connected FACTS devices is used for voltage stability enhancement of primary transmission substation.

III. STATIC VAR COMPENSATOR

Several types of FACTS devices have been developed for application in power systems. The function of these devices is primarily to control the power flow through the transmission lines and regulate the voltage level where they are installed. It is a concept that involves the application of high power electronic controllers in AC transmission networks which enable fast and reliable control of power flows and voltages [4].

The SVCs are shunt connected static generators or absorbers whose outputs are varied so as to control specific parameters of an electric power system. SVCs overcome the limitation of mechanically switched shunt capacitors or reactors. As SVCs use capacitors they suffer from the same degradation in reactive capability as voltage drops. The accuracy, availability and fast response enable SVC's to provide high performance steady state and transient voltage control compared with classical shunt compensation. SVCs can perform the duty of providing rapidly controlled Vars more appropriately and thus, by maintaining the voltage, inherently improve transient stability. They also do not have the short – term overload capability of generators and synchronous condensers. Basic types of SVCs are:

- Saturated reactor (SR),
- Thyristor - controlled reactor (TCR),
- Thyristor - switched capacitor (TSC),
- Thyristor – switched reactor (TSR),
- Thyristor – controlled transformer (TCT) and
- Self – or line – commutated converter (SCC/LCC)

In this research, the combination of TSC-TCR is used for voltage stability enhancement.

A. Thyristor Switched Capacitors & Thyristor Controlled Reactor (TSC-TCR)

For a given capacitive output range TCR-TSC usually consists of TSC branches and one TCR branch as shown in Fig. 1. The operation of TCR-TSC can be described as follows: The total capacitive output range is divided into n intervals. In the first interval, the output of the var generator is controllable from zero to QCmax/n, where QCmax is the overall score provided by all TSC branches. During this time, the capacitor bank turns on, and at the same time the TCR current is regulated by the appropriate firing angle so that the sum of TSC's var output and TCR's output equals the desired capacitance output. This scheme can be repeated many times depending on the desired output variables.

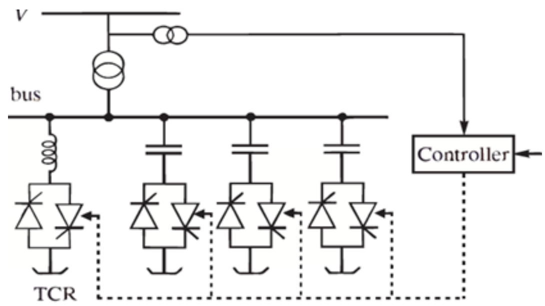

Fig. 1. TCR – TSC Scheme [4].

To prevent switching conditions from being determined at the endpoints of the interval, the TCR Var weighting should be greater than the TSC weighting to provide sufficient overlap between switching of reactive power. The TCR-TSC response depends on the number of TCR branches used. A single charged capacitor TSC has a maximum switching delay of one cycle, while TCR has a maximum switching delay of only half a cycle. However, if the TSC consists of three or more branches, it is more likely that one or more capacitor banks with the desired polarity of charge will be available.

B. SVC Controller System

The SVC Controller System Consists of Voltage Measurement System, Voltage regulator, Distribution unit and Synchronizing Pulse generator as shown in Fig. 2. The TCR and TSC control of SVC is done based on this control principle.

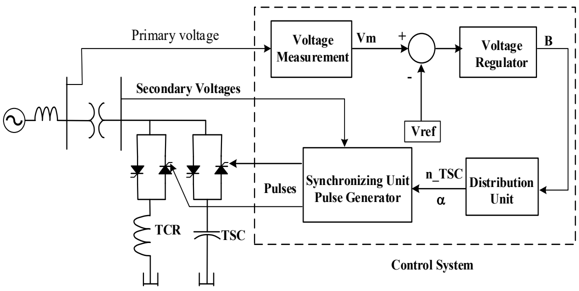

Fig. 2. SVC with control system [4].

C. SVC Rating and Formulation

SVC cannot guarantee perfect voltage regulation and perfect reactive power compensation at the same time. The requirement for the highest network quality overrides the need for perfect reactive power compensation. Therefore, for optimal voltage regulation, the SVC's variable reactive power output must not only compensate for the reactive power of the load, but also correct for voltage fluctuations. The rating of SVC can be determined by using the following equation.

$$Q_{SVC} = Q_{Load} + \frac{P_{Load}^2}{2S_{SC}} + KP_{Load} \tag{1}$$

, where Q_{load} and P_{load} are the reactive and active power of load respectively. S_{SC} is short circuit MVA and K = R/X of the system [5].

IV. FACTS AND DATA FOR THANLYIN PRIMARY SUBSTATION

For the voltage stability enhancement using SVC, the detail study is carried out at Thanlyin Primary Substation. Thanlyin Primary substation is located at Thanlyin Township of Southern Yangon District. It is operated as primary substation since July, 2009. It is connected to Tharketa, East Dagon and Thiliwa 230 kV primary substations. It is responsible to provide electricity to Southern Yangon District loads, Star City Housing and Thiliwa Special Economic Zones (SEZ). Thilawa SEZ is operating with the modernized industries and thus to maintain the voltage stability is important. Also Phayargone, Dagon Seikkan, Thonegwa, Aung Chan Thar, Myoma, Phwint Phyo Yay and Thilawa feeders are connected to Thanlyin 33 kV bus. Thus Voltage Stability by SVC is carried out at 230 kV Thanlyin Primary Substation. The substation has power transformer having capacity of 100 MVA. Incoming voltage level is 230 kV and distribution voltage level is 33 kV.

A. System Configuration for Case Study

For the modelling of 230/33kV Thanlyin Primary Substation, Matlab/Simulink software is used. In compensation, the most important one is the sizing and allocation of compensation devices in the system. To determine the sizing and allocation of SVC, the steady state load flow programme is executed with MATLAB. The Simulink model of the system without SVC is shown in Fig. 3. The important data for the system are described in Table I and Table II.

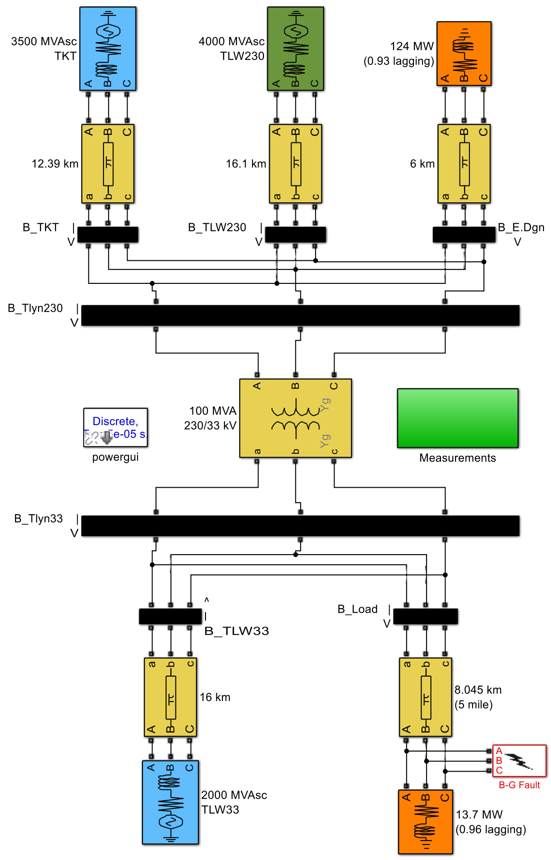

Fig. 3. Simulink Model for Without SVC.

To determine the sizing and allocation of SVC, the steady state load flow programme is executed with Matlab. Newton – Raphson method is employed for load flow analysis. The simulation model consists of 230 kV and 33 kV system. From the simulation result, Voltages, Currents, Active and Reactive Powers are measured at each load and source. To observe the voltage stability conditions of the existing system, the simulations are carried out for maximum load condition, load feeder outage conditions and single line to ground fault condition. The measurements are carried out for voltages, active powers and reactive powers at the sending and receiving ends of each load feeder.

Table I: System data of Thanlyin primary substation.

SN	Name	Pmax (MW)	Pmin (MW)	Power Factor
1	TLW	168	105	0.99
2	TKT	39.9	0.8	0.93
3	E - Dagon	124	65.7	0.93

Table II: System data of Thanlyin primary substation feeders.

SN	Name	Length (mile)	Size (mm^2)	Pmax (MW)	Pmin (MW)
1	Phayargone	0.13	120	14.9	3.3
2	Dagon Seikkan	7.6	300	22.7	10.5
3	Thilawa-1	6.5	150	3.5	2.2
4	Thone-gwa	30	150	18	7
5	Star City	6.5	150	2.3	1.2
6	Aung Chan Thar	3.5	120	0.74	0.4
7	Myo-ma	5	120	13.7	4.5
8	Phwint-Phyo-Yay	0.5	150	0.08	0.06
9	Thilawa-2	10.5	120	1	0.51
10	Thilawa-3	10.5	120	0.46	0.04

For voltage stability study, the simulations are carried out for steady state condition as well as contingency conditions. The simulation schemes are as follow:

- Normal condition at maximum load
- Single Line to Ground Fault at Myoma Feeder.

B. Simulation Results for Existing System

After simulation without SVC, the voltages, currents, active powers and reactive powers at 230 kV bus and 33 kV bus are obtained as shown in Fig. 4 through Fig. 5.

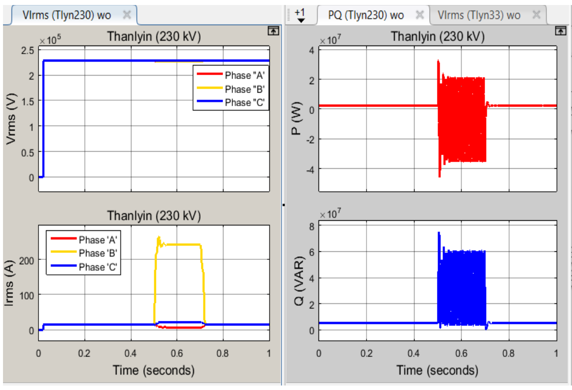

Fig. 4. Voltage, Current, Active and Reactive Powers at Thanlyin 230 kV Bus for Without SVC.

Figure 4 shows the voltage, current, active and reactive powers at Thanlyin 230 kV bus for without SVC. When single line to ground fault applied at 0.5 second, 230 kV bus voltage is maintained nearly constant. The current at faulted phase is increased and the real/reactive power is oscillating. Figure 5 illustrates the voltage, current, active and reactive powers at Thanlyin 33 kV bus for without SVC. At 33 kV bus, the voltages are significantly decreased. The current at faulted phase is increased and the real/reactive power are oscillating as shown in figure.

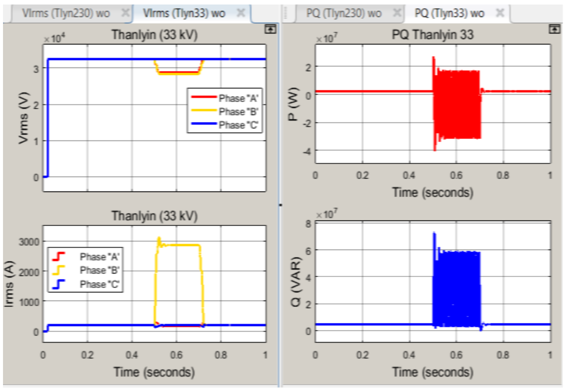

Fig. 5. Voltage, Current, Active and Reactive Powers at Thanlyin 33 kV Bus for Without SVC.

V. CALCULATION OF SVC FOR VOLTAGE STABILITY ENHANCEMENT AT THANLYIN PRIMARY SUBSTATION

An SVC cannot assure perfect voltage stabilization and perfect reactive power compensation at the same time. The requirement for highest power quality precedes the need for perfect reactive power compensation. For optimum voltage stabilization, the variable reactive power output of the SVC hence needs to compensate not only the reactive power of the load, but also correct the voltage variations. For the voltage stability enhancement of Thanlyin Primary Substation, the required minimum rating of the SVC to maintain constant voltage is calculated using equation shown in Section III.

According to the simulation result shown in above figures, the active and reactive power under steady state at 230 kV bus are as follow:

P_{load} = 48.15 MW

Q_{load} = 44.52 MVAR

From Myanmar Electric Power System parameters, the short circuit level (S_{SC}) and resistance to reactance ratio (K) at Thanlyin 230 kV bus are as follow:

S_{SC} = 3284.371 MVA

K = 0.103

Thus, the required minimum rating of the SVC to maintain constant voltage at 230 kV Thanlyin Bus is:

$$Q_{SVC} = 44.52 + \frac{48.15^2}{2 \times 3284.371} + 0.103 \times 48.15$$

$$= 49.85 \text{ MVAR}$$

Therefore, the rating of SVC for 230 kV Thanlyin bus is selected as 51 MVAR.

The SVC design is consisting of three numbers of TSC and one number of TCR since it is the commonly used configuration and suitable for SVC rating of 51 MVAR. With this arrangement, the range of SVC is 17/51 MVAR.

Q_{TCR} = 17 MVAR

Q_{TSC} = 51 MVAR (for three number)

Three phase connection is taken as delta connection for both TCR and TSC.

VI. MODELLING OF THANLYIN PRIMARY SUBSTATION FOR EXISTING SYSTEM (WITH SVC)

For the simulations of Thanlyin Primary Substation with the calculated SVC ratings, the simulation model is implemented as shown in Fig. 6. After modeling of the system with SVC, simulations are carried out for normal condition as well as contingency conditions. The conditions for contingency cases are 230 kV East Dagon load outage, 33 kV Dagon Seikkan load outage and single line to ground fault at Myoma Feeder. The conditions and data are set as in without SVC case so that comparison can be executed. The measurements are done for voltages, real power, real power losses, reactive power, and reactive power losses for each line and feeder. The main aim of SVC is to inject the required reactive power and to improve the bus voltages so that the voltage stability of the system can be improved.

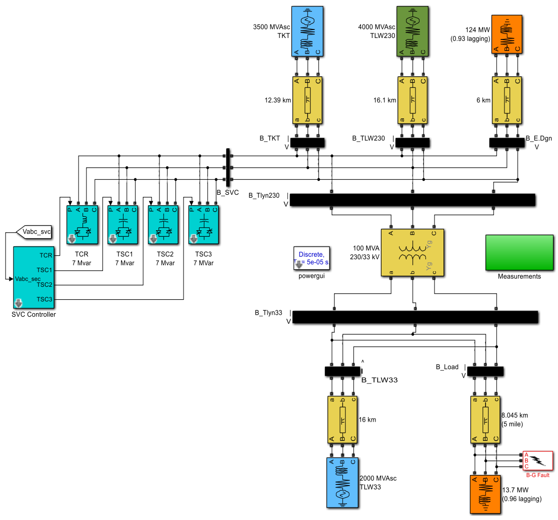

Fig. 6. Simulink Model for with SVC.

The simulation results for bus voltages at 230 kV and 33 kV buses of Thanlyin Primary Substation are shown in Fig. 7 and Fig. 8. The other simulation results for various conditions are tabulated as shown in Table III through Table IV.

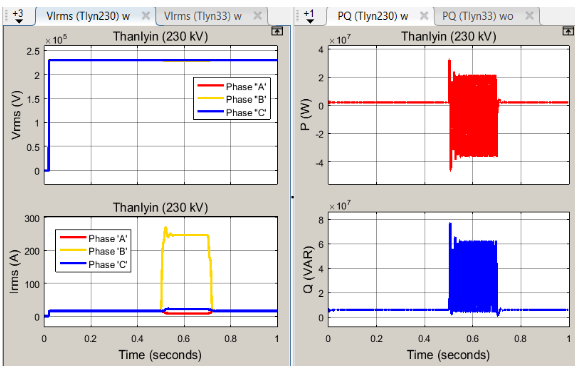

Fig. 7. Voltage, Current, Active and Reactive Powers at Thanlyin 230 kV Bus for with SVC.

Figure 7 shows the voltage, current, active and reactive powers at Thanlyin 230 kV bus for with SVC. The parameters at 230 kV buses are nearly the same as in without SVC case.

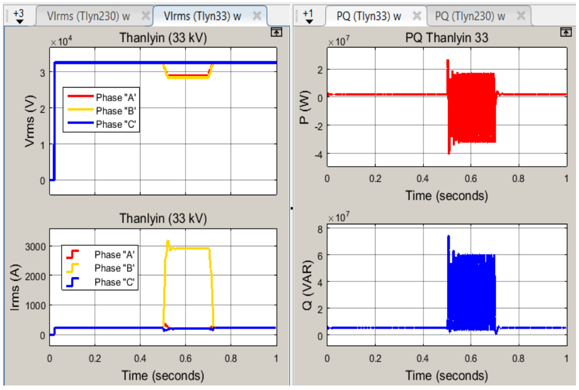

Fig. 8. Voltage, Current, Active and Reactive Powers at Thanlyin 33 kV Bus for with SVC.

Figure 8 shows the voltage, current, active and reactive powers at Thanlyin 33 kV bus for with SVC. With the application of SVC, the voltages at 33 kV bus are improved compared to without SVC case.

Table III: Normal Condition of Thanlyin Primary Substation (With SVC).

Feeder	V_S (kV)	V_R (kV)	P_S (MW)	P_R (MW)	P_{Loss} (MW)	Q_S (MVar)	Q_R (MVar)	Q_{loss} (MVar)
E.dgn	229	228.8	122.90	122.90	0.0388	25.80	25.15	0.6449
TKT	229	228.7	39.53	39.52	0.0111	10.41	10.15	0.2602
PYG	32.4	30.94	12.63	12.62	0.0094	7.68	7.49	0.1921
D.SKN	32.4	29.85	17.15	16.92	0.2240	11.98	11.68	0.2994
TLW1	32.4	31.9	2.92	2.91	0.0106	1.80	1.75	0.0449
TGWA	32.4	23.4	10.30	9.59	0.7118	8.28	8.07	0.2069
SCTY	32.4	32.07	1.93	1.93	0.0046	1.18	1.15	0.0295
ACT	32.4	32.33	0.63	0.63	0.0003	0.39	0.38	0.0097
MMA	32.4	30.78	10.97	10.83	0.1418	6.95	6.77	0.1737
PPY	32.4	32.4	0.0714	0.0702	0.0011	0.04	0.04	0.0010
TLW2	32.4	32.14	0.84	0.84	0.0017	0.52	0.50	0.0129
TLW3	32.4	32.28	0.39	0.39	0.0004	0.23	0.23	0.0059

Table IV: Output Data of all Load Buses at Myoma 33 kV Feeder Single Line to Ground Fault Condition.

Feeder	V_S (kV)	V_R (kV)	P_S (MW)	P_R (MW)	P_{Loss} (MW)	Q_S (MVar)	Q_R (MVar)	Q_{loss} (MVar)
E.dgn	224.7	224.6	122.40	122.00	0.4834	25.61	24.97	0.6402
TKT	224.2	224.1	39.38	39.22	0.1641	10.32	10.06	0.2580
PYG	22.46	21.46	10.06	9.87	0.1877	6.23	6.07	0.1557
D.SKN	22.46	21.33	13.56	13.19	0.3659	9.70	9.45	0.2424
TLW1	22.46	22.2	2.32	2.36	-0.0342	1.46	1.42	0.0364
TGWA	22.46	17.33	8.08	6.38	1.7029	6.70	6.53	0.1674
SCTY	22.46	22.29	1.58	1.57	0.0147	0.96	0.93	0.0239
ACT	22.46	22.43	0.50	0.51	-0.0129	0.31	0.31	0.0078
MMA	22.45	0.03823	30.48	9.35	21.13	51.72	50.42	1.2930
PPY	22.46	22.46	0.06	0.06	0.0012	0.03	0.03	0.0008
TLW2	22.46	22.32	0.67	0.68	-0.0138	0.42	0.41	0.0105
TLW3	22.46	22.4	0.31	0.32	-0.0074	0.19	0.19	0.0048

VII. COMPARISON FOR IMPROVEMENT OF THE SYSTEM USING SVC

For the analysis of voltage stability improvement by SVC, the comparison for without and with SVC are carried out for each case based on the simulation results shown in above tables.

A. Comparison for Normal Condition

Under normal condition, 230 kV Thanlyin Bus voltage is about 219.5 kV for without SVC and it is about 229 kV for with SVC case. At 33 kV Thanlyin Bus, it is about 27.35 kV and 32. 4 kV for without and with SVC case respectively. Thanlyin Bus voltages and hence all sending end bus voltages are improved for with SVC case.

As the sending end bus voltages are increased with SVC, the receiving end bus voltages are also increased. Without SVC, the receiving end bus voltages are small especially at 33 kV feeders, some of these bus voltages are below the lower regulation limits. With SVC, the receiving end bus voltages at 33 kV feeders are improved and most of these bus voltages are within the voltage regulation limits except at Thonegwa feeder. Due to long length and large load, the voltage drop on Thonegwa feeder is large and its voltage stability improvement should be carried out by reconductoring of the feeder.

Due to reactive power injection from SVC at 230 kV bus, the reactive power flows on 230 kV lines are reduced. These 230 kV lines are composed of twin bundle 605 MCM conductors and thus capacitive reactive power production of these lines are large on these lines. But the reactive power consumptions of 33 kV loads are increased as the receiving end bus voltage increased. Thus, the reactive power flows on 33 kV feeders are increased.

In power losses comparison, the active power loss of the system without SVC is about 2.51 MW and with SVC is about 1.16 MW. Similarly, the reactive power loss of the system without SVC is about 4.41 MVAR and with SVC is about 1.88 MVAR. The power losses are reduced with SVC application and thus the system efficiency is improved.

B. Comparison for Single Line to Ground Fault at Myoma Feeder

Among the various 230 kV lines and 33 kV feeders, the fault occurrence on Myoma feeder is more frequent compared to others. The commonly fault type is single line to ground fault. Thus, the single line to ground fault is applied to Myoma feeder and simulations are carried out. Due to the fault, the excessive current flow on the system for both without and with SVC cases. These excessive current flows cause the large voltage drop. Thus, all bus voltages are decreased compared to other case. But the application of SVC can improve the system voltages. In 230 kV sending buses, it is improved from 211.7 kV to 224.7 kV in 33 kV sending end buses, it is improved from 19.12 kV to 22. 46 kV with SVC application. During fault condition, the power oscillations occurs and some power losses become negative values.

C. Analysis on the Simulation Results

As mention above, the application of SVC can improve the system voltage stability under all possible conditions. In SVC application, the correct SVC rating is important. With the calculated SVC presented in this paper, the system efficiency can also improve by reducing the real and reactive power losses in the system.

VIII. CONCLUSION

The use of Static Var Compensators as TCR-TSC configuration for reactive power compensation, voltage stability enhancement and loss reduction is carried out in this paper. The improvements in power system with using SVCs are investigated and implemented on Thanlyin primary substation. According to design calculation results, the combination of 17 MVAR TCR with 51 MVAR TSC is recommended for the selected system. The application of SVC can improve system voltage stability and performance under normal as well as contingency conditions. Under normal condition, 230 kV bus voltage is improved from 219.5 kV to 229 kV with SVC application. Similarly, in 33 kV bus, it is improved from 27.35 kV to 32.4 kV. As the sending end bus voltage improves, the receiving end bus voltages are also increased. The application of SVC can also reduce system losses. According to simulation results, the real power losses are reduced from 2.51 MW to 1.16 MW. Similarly, the reactive power losses are reduced from 4.41 MVR to 1.18 MVAR. The results show that the number of load buses with voltages that recovered to within acceptable limit between 0.95 pu and 1.05pu. For further study, the cost benefit analysis of voltage stability enhancement using SVCs should be proceeding.

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