Voltage Control and Dynamic Performance of Power Transmission System Using Static Var Compensator

Nang Sabai, Hnin Nandar Maung, and Thida Win

Abstract**—**This paper will discuss and demonstrate how Static Var Compensator (SVC) has successfully been applied to control transmission systems dynamic performance for system disturbance and effectively regulate system voltage. SVC is basically a shunt connected static var generator whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power variable; tyipically, the control variable is the SVC bus voltage. One of the major reason for installing a SVC is to improve dynamic voltage control and thus increase system loadability There are the mainly accomplishes work to construct an effective for SVC. Firstly, to design a controller for SVC devices on transmission lines, a Single Machine Infinite Bus (SMIB) system is modeled. A stated-space mathematical model is constructed which considers both electromechanical oscillations and reactive current of the SVC at the installation site.

The installation site for this paper is Hlawkar generation station in Myanmar. And datas will also be taken from this station. Simulation results will be provided by using MATLAB programming. The SVC is more effectively enhance the transient stability and increase transmission capacity.

Keywords**—**Voltage control, static var compensator, FACTs, dynamic performance, transient stability.

I. Introduction

THE focus of this paper and research is the application of Static Var Compensator to solve voltage regulation and system dynamic performance deficiencies. SVC is thyristor based controller that provides rapid voltage control to support electric power transmission voltages during immediately after major disturbances. Since the advent of dereguralation and the separation of generation and transmission systems in electric industry, voltage stability and reactive power-related system restrictions have become an increasing growing concern for electric utilites. When voltage security or congestion problems are observed during the planning study process, cost effective solution must be considered for such problems.

One approach to solving this problem is the application of "Flexible AC Transmission System" (FACTs) technologies, such as the Static Var Compensator (SVC). In an ideal ac power system, the voltage and frequency at every supply point would be constant and free from harmonics, the power factor would be unity.

There are two types of voltage stability: transient voltage stability and longer-term voltage stability. Longer-term voltage stability involving loads that are inherently voltage sensitive has been of greatest interest in recent years. Voltage stability involves the load, transmission, and generation-sub systems of large power systems. Three keys aspects of voltage stability are:

1. the load characteristic as seen from bulk power network;
2. the available means for voltage control at generators and in the network; and
3. the ability of the network to transfer power, particularly reactive power, from the point of production to point of consumption.

II. Modeling of the SVC

A. TCR/FC SVC

The SVC provides an excellent source of rapidly controllable reactive shunt compensation for dynamic voltage control through its utilization of high-speed thyristor switching/controlled reactive devices.

An SVC is typically made up of the following major components:

1. Coupling transformer
2. Thyristor valves
3. Reactors
4. Capacitors (often tuned for harmonic filtering)

In general, the two thyristor valve controlled/switched concepts used with SVCs are the thyristor-controlled reactor (TCR) and the thyristor-switched capacitor (TSC). The TSC provides a "stepped" response and the TCR provides a "smooth" or continuously variable susceptance.

Fig. 1 illustrates a TCR/FC including the operating process concept. The control objective of SVC is to maintain the desired voltage at a high voltage bus. In steady- state , the SVC will provide some steady- state control of the voltage to maintain it the highest voltage bus at the pre-defined level. If the voltage bus begins fall below its setpoint range, the SVC will inject reactive power (Q_{net}) into the system (within its control limits), thereby increasing the bus voltage back to its

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desired voltage level. If bus voltage increases, the SVC will inject less (or TCR will absorb more) reactive power (within its control limits), and the result will be to achieve the desired bus voltage. From Fig. 1, $+Qc_{ap}$ is a fixed value, therefore the magnitudes of reactive power injected into the system, Q_{net} is controlled by the magnitude of $-Q_{ind}$ reactive power absobed by the TCR.

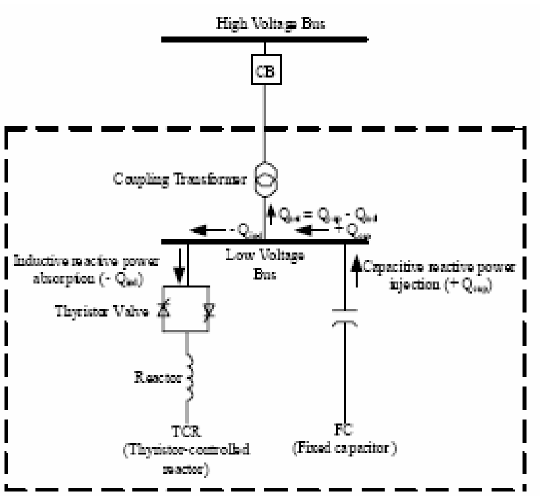

Fig. 1 Block diagram of a TCR-FC SVC

B. Basic Arrangement

The compensator is a thyristor-controlled reactor (TCR) with the fixed capacitor. Figure.2 is a simplified one line diagram of the main components. The compensator is connected to the system through 3× 47.5 MVA, 33 kV step-up transformer. On the secondary side, a three-phase wye-connected capacitor bank rated 50 Mvar is paralleled with the delta-connected TCR. The rating of the reactor bank may be variable. Moreover, 50 Mvar of reactor bank rating is the most suitable for Hlawga generating station.

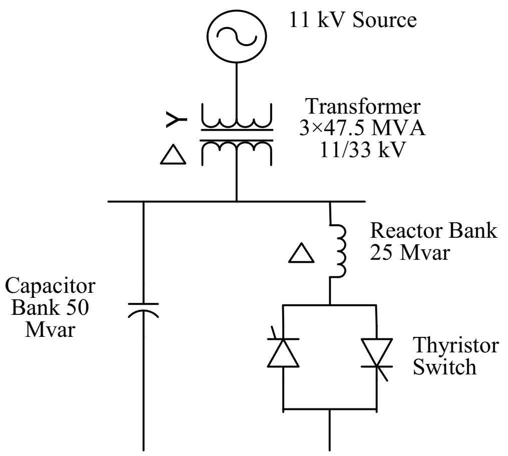

Fig. 2 Basic Circuit of Compensator

A static var compensator (SVC) is used to regulate voltage on a 33 kV, 3×47.5 MVA system at Hlawga generation station in Myanmar. When system voltage is low the SVC generates reactive power (SVC capacitive). When system voltage is high it absorbs reactive power (SVC inductive). The SVC is rated +50 Mvar capacitive and 25 Mvar inductive. The Static Var Compensator block is a phasor model representing the SVC static and dynamic characteristics at the system fundamental frequency. The SVC is set in voltage regulation mode with a reference voltage $V_{ref} = 1.0$ pu. The voltage droop is 0.03 pu, 50MVA, so that the voltage varies from 0.97 pu to 1.015 pu when the SVC current goes from fully capacitive to fully inductive. By simulating the SVC V-I characteristic curve is obtained. Then, the actual SVC positive-sequence voltage (V_1) and susceptance (B_1) can be measured.

C. Dynamic Response of the SVC

The three-phase programmable voltage source is used to vary the system voltage and observe the SVC performance. Initially, the source is generating nominal voltage. Then, voltage is successively decreased (0.97 pu at t = 0.1 s), increased (1.03 pu at t = 0.4 s) and finally returned to nominal voltage (1 pu at t = 0.7 s). Start the simulation and observe the SVC dynamic response to voltage steps on the Scope. Trace 1 shows the actual positive-sequence susceptance B_1 and control signal output B of the voltage regulator. Trace 2 shows the actual system positive-sequence voltage V_1 and output V_m of the SVC measurement system. The SVC response speed depends on the voltage regulator integral gain K_i (Proportional gain K_P is set to zero), system strength (reactance X_n) and droop (reactance X_s). If the voltage measurement time constant and average time delays T_d due to valve firing are neglected, the system can be approximated by a first order system having a closed loop time constant

$T_c= 1/(K_i (X_n+X_s))$

With system parameters

$K_i = 200$

$X_n = 0.0667$ pu/50 MVA

$X_s = 0.03$ pu/50 MVA

T=0.0345s

And the short circuit level is 500 MVA, which is the largest fault before the last several years period at Hlawga station.

D. Description of Static Var Compensator

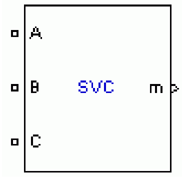

Fig. 3 SVC Block

The static var compensator (SVC) is a shunt device of the flexible AC transmission systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The SVC regulates voltage at its terminals 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 banks 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).

E. 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 Fourier-based measurement system using a one-cycle running average is used.

-A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage V_{ref}) 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 using a phase-locked loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors. This is shown in Fig. 4.

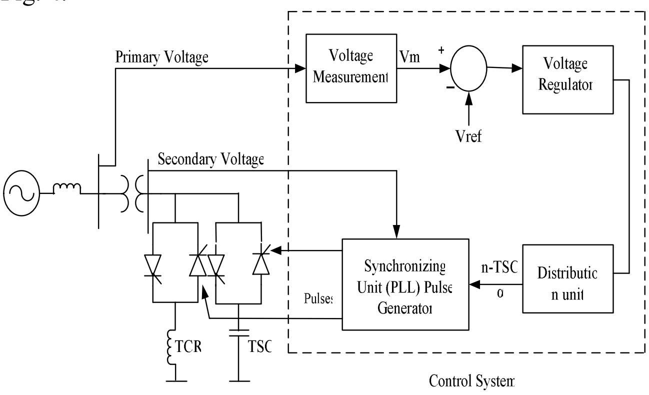

Fig. 4 The Control System of SVC

F. SVC V-I Characteristic

The SVC can be operated in two different modes: In voltage regulation mode 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 characteristic. As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (B_{cmax}) and reactor banks (B_{lmax}), the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the Figure.5. The V-I characteristic is described by the following three equations:

SVC is in regulation range ($-B_{max} < B < B_{Lmax}$)

$$V = V_{ref} + X_s \cdot I$$

SVC is fully capacitive ($B=B_{cmax}$)

$$V = \frac{I}{Bc_{max}}$$

$$V = \frac{I}{Bl_{max}}$$

SVC is fully inductive ($B=B_{Lmax}$)

Where,
V = Positive sequence voltage (p.u.)
I = Reactive current (p.u./P_{base}) (I > 0 indicates an inductive current)
X_s = Slope or droop reactance (p.u./P_{base})
B_{Cmax} = Maximum capacitive susceptance (p.u./P_{base}) with all TSCs in service, no TSR or TCR
B_{Lmax} = Maximum inductive susceptance (p.u./P_{base}) with all TSRs in service or TCRs at full conduction, no TSC
P_{base} = Three-phase base power

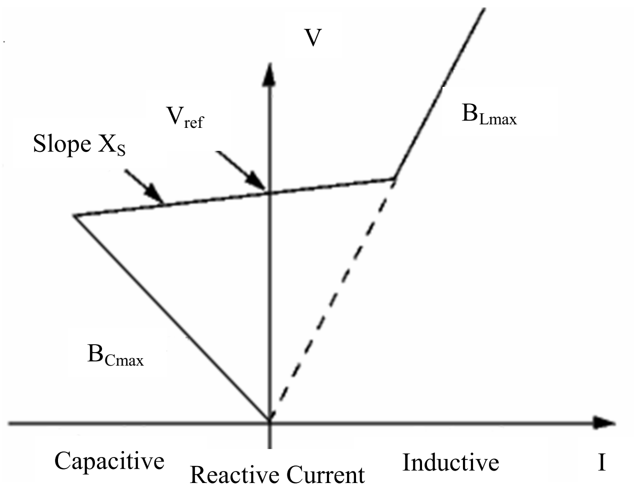

Fig. 5 The V-I Characteristic Curve of SVC

G. SVC Dynamic Response

When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains (proportional gain Kp and integral gain K_i), the droop reactance X_s, and the system strength (short-circuit level). For an integral-type voltage regulator ($K_p = 0$), if the voltage measurement time constant T_m and the average time delay T_d due to valve firing are neglected, the closed-loop system consisting of the SVC and the power system can be approximated by a first-order system having the following closed-loop time constant:

$$T_c = \frac{I}{K_i \cdot (X_s + X_n)}$$

where
T_c = Closed loop time constant

K_i = Proportional gain of the voltage regulator (p.u._B/p.u._V/s)

X_s = Slope reactance p.u./Pbase

X_n = Equivalent power system reactance (p.u./Pbase)

Start the simulation and observe the SVC dynamic response to voltage steps on the scope. Waveforms are reproduced on the Fig. 7 below. Trace 1 shows the actual positive-sequence susceptance B1 and control signal output B of the voltage regulator. Trace 2 shows the actual system positive-sequence voltage V_1 and output V_m of the SVC measurement system.

The voltage/current characteristic of the compensator at the 33 kV bus is shown in Fig. 8. The slope of the control range is nominally 3%. This means that a voltage change of -3% produces the rated capacitive reactive power of 50 MVar. For a linear voltage-current characteristic, a voltage changes of +3% produces an inductive reactive power of 50 MVar in Fig. 8. This slope was chosen as a result of system studies.

III. Control System of Thyristor Controller

The control system consists basically of a voltage regulator, a current- limit, and thyristor gating circuit. The block diagram is as follow,

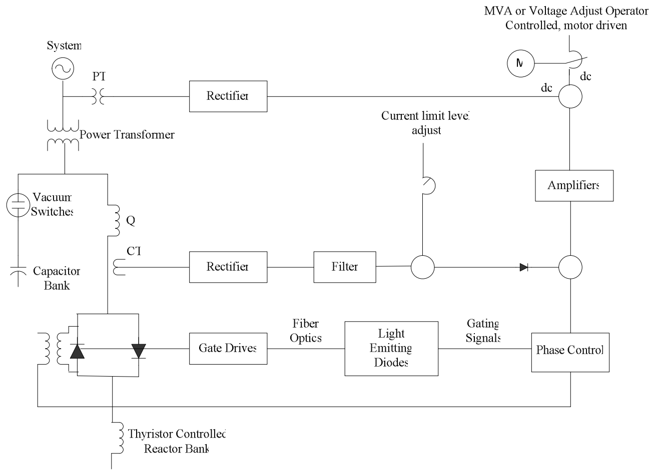

Fig. 6 Control Blocked Diagram

IV. Simulation Results

These simulation curves are results of this paper and location is Hlawga Generation Station (Gas Turbine), Yangon Division in Myanmar.

A. Simulation Curves for B_{actual} and V_{actual}

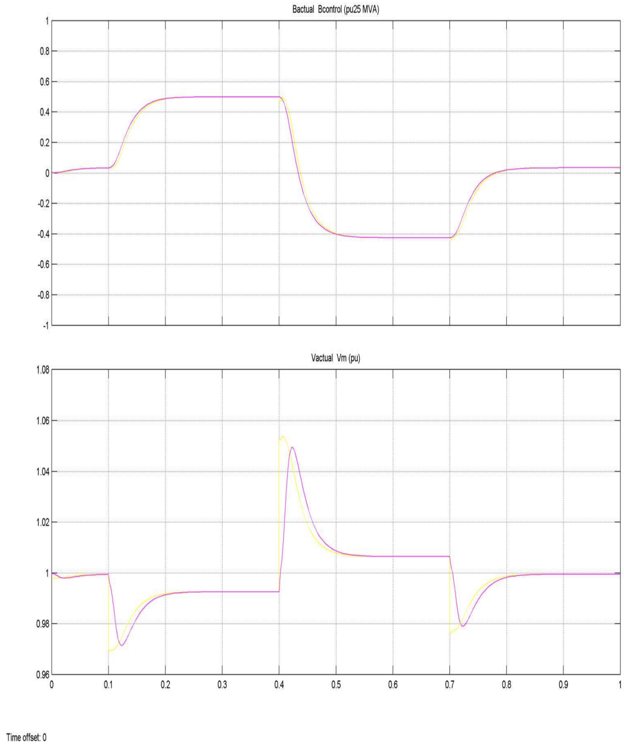

Fig. 7 The SVC Dynamic Response to Voltage Steps Waveforms

B. SVC V-I Characteristic Curves

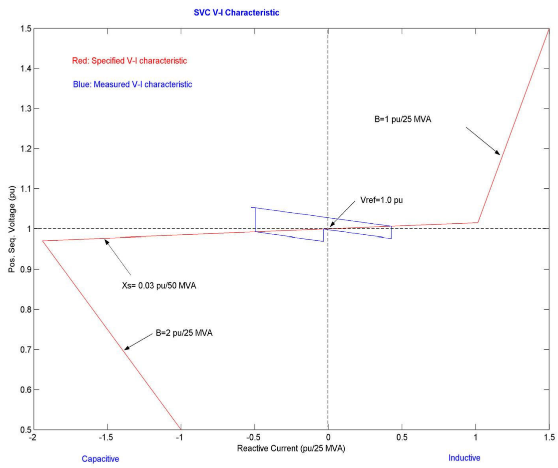

Fig. 8 Voltage-Current Characteristic

V. Conclusion

This paper provides a detailed description of a modern, thyristor- controlled static compensator installed on the transmission network of 33 kV lines at Hlawga Gas Turbine Generation Station, Yangon Division in Myanmar. The compensator is typical of many such installations on high-voltage transmission systems, but many of its design features are reproduced in load compensators also, particularly in supplies to electric arc furnaces. The thyristor controllers, reactor and capacitor are essentially the same in both cases. The main differences are in the control strategy and the system voltage.

Although the SVC is a controller for voltage regulation, that is, for maintaining constant voltage at a bus, a finite slope is incorporated in the SVC's dynamic characteristic and provides the following advantages despite a slight deregulation of the bus voltage.

1.substantially reduces the reactive-power rating of the SVC for achieving nearly the same control objectives;

2.prevents the SVC from reaching its reactive-power limits too frequently; and

3.Facilitates the sharing of reactive power among multiple compensators operating in parallel.

Static var compensators (SVCs) are used primarily in power system for voltage control as either an end in itself or a means of achieving other objectives, such as system stabilization. This paper presents a detailed overview of the voltage-control characteristics of SVC and the principles of design of the SVC voltage regulator. The performance of SVC voltage control is critically dependent on several factors, including the influence of network resonances, transformer saturation, geomagnetic effects, and voltage distortion. When SVCs are applied in series-compensated networks, a different kind of resonance between series capacitors and shunt inductors becomes decisive in the selection of control parameters and filters used in measurement circuits.

This will also demonstrate the advantages of using MATLAB Simulink system for analyzing steady state power system stability including control behavior. This paper mentioned only the author's research and approaching of her studies in MATLAB software.

VI. Future Work

Future work related to the study and analysis of voltage regulation and voltage stability should be focused in the area of load modeling. In particular, the static load characteristics and percentage of dynamic motor load needs to more accurately reflect what is in the "real system" under study. The load model has significant influence on the system's response to disturbances, and therefore significantly influences the rating of any proposed solution.

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