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VOLTAGE LEVEL IMPROVING BY USING STATIC VAR COMPENSATOR SVC

Strictly as per the compliance and regulations of:

Voltage Level Improving by Using Static VAR Compensator (SVC)

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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. Again, the static VAR compensators are being increasingly applied in electric transmission systems economically to improve the post-disturbance recovery voltages that can lead to system instability. A SVC performs such system improvements and benefits by controlling shunt reactive power sources, both capacitive and inductive, with high-tech power electronic switching devices. This work is presented to solve the problems of poor dynamic performance and voltage regulation in an 115KV and 230KV transmission system using SVC.

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I. INTRODUCTION

Day by day, demands on the transmission network are increasing because of the increasing number of non utility generators and heightened competition among utilities themselves. Increased demand on transmission system, absence of long term planning and the necessity to provide open access to power generating companies and customers; all together have created tendencies toward a reduction of security and decreased quality of supply.

The AC power transmission system has diverse limits, classified as static limits and dynamic limits [1]-[3]. These inherent limits restrict the power transaction, which lead to the under utilization of the existing transmission resources. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to solve much of these problems. However, there are some restrictions as to the use of these conventional devices. Desired performance was being unable to achieve effectively. Wear and tear in the mechanical components and slow response were the major problems. As a result, it was needed for the alternative technology made of solid state electronic devices with fast response characteristics. The requirement was further fuelled by worldwide restructuring of electric utilities, increasing environmental and efficiency regulations and difficulty in getting permit and right of way for the construction of overhead power transmission lines [4]. This, together with the invention of semiconductor thyristor switch, opened the door for the development of FACTS controllers.

The path from historical thyristor based FACTS controllers to modern technologically advanced voltage source converters based FACTS controllers, was made possible due to rapid progress in high power semiconductors switching devices [1]-[3]. 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, in improving the quality performances of the electric services. A SVC is one of FACTS controllers, which can control one or more variables in a power system [5]. The dynamic nature of the SVC lies in the use of thyristor devices (e.g. GTO, IGCT) [4]. The thyristor, usually located indoors in a “valve house”, can switch capacitors or inductors in and out of the circuit on a per-cycle basis, allowing for very rapid superior control of system voltage.

The compensator studied in the present work is made up of a fixed reactance connected in series to a thyristor controlled reactor (TRC) based on bi-directional valves- and a fixed bank of capacitors in parallel with the combination reactance-TRC. The thyristors are turned on by a suitable control that regulates the magnitude of the current.

II. STATIC VAR COMPENSATOR

a) *Configuration of SVC*

SVC provides an excellent source of rapidly controllable reactive shunt compensation for dynamic voltage control through its utilization of high-speed thyristor switching/controlled devices [6]. A SVC is typically made up of coupling transformer, thyristor valves, reactors, capacitance (often tuned for harmonic filtering).

b) *Advantages of SVC*

The main advantage of SVCs over simple mechanically switched compensation schemes is their near-instantaneous response to change in the system

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voltage. For this reason they are often operated at close to their zero-point in order to maximize the reactive power correction [7]-[10]. They are in general cheaper, higher-capacity, faster, and more reliable than dynamic compensation schemes such as synchronous compensators (condensers). In a word:

1) Improved system steady-state stability.
2) Improved system transient stability.
3) Better load division on parallel circuits.
4) Reduced voltage drops in load areas during severe disturbances.
5) Reduced transmission losses.
6) Better adjustment of line loadings.

c) Control Concept of SVC

An SVC is a controlled shunt susceptance (B) as defined by control settings that injects reactive power (Q) into the system based on the square of its terminal voltage. Fig. 1 illustrates a TCR SVC, including the operational concept. The control objective of the SVC is to maintain a desired voltage at the high-voltage bus. In the steady-state, the SVC will provide some steady-state control of the voltage to maintain it the high-voltage bus at a pre-defined level.

If the high-voltage bus begins to fall below its set point range, the SVC will inject reactive power (Q_{net}) Into thereby increasing the bus voltage back to its net desired voltage level. If bus voltage increases, the SVC will inject less (or TCR will absorb more) reactive power, and the result will be to achieve the desired bus voltage. From Fig. 1, $+Q_{cap}$ is a fixed capacitance value, therefore the magnitude of reactive power injected into the system, Q_{net}, is controlled by the magnitude of $-Q_{ind}$ reactive power absorbed by the TCR. The fundamental operation of the thyristor valve that controls the TCR is described here. The thyristor is self commutates at every current zero, therefore the current through the reactor is achieved by gating or firing the thyristor at a desired conduction or firing angle with respect to the voltage waveform [11].

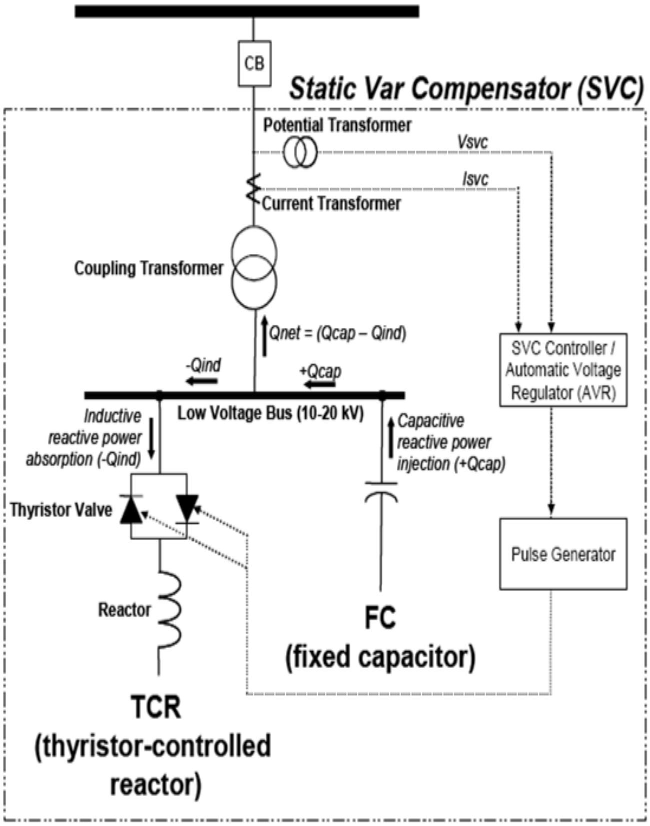


Fig.1 : SVC with control concept.

III. THE THYRISTOR CONTROLLED REACTOR

The basis of the thyristor-controlled reactor (TCR) is shown in Fig. 2. The controlling element is the thyristor controller, shown here as two oppositely poled thyristors which conduct on alternate half-cycles of the supply frequency. If the thyristors are gated into conduction precisely at the peaks of the supply voltage, full conduction results in the reactor, and the current is the same as though the thyristor controller were short-circuited.

a) Principle of Operation

The current is essentially reactive, lagging the voltage by nearly 90^0. It contains a small in-phase component due to the power losses in the reactor, which may be of the order of 0.5-2% of the reactive power. Full conduction is shown by the current waveform in Fig. 3(a). If the gating is delayed by equal amounts on both thyristors, a series of current waveforms is obtained, such as those in Fig. 3(a) through 3(d). Each of these corresponds to a particular value of the gating angle α, which is measured from a zero-crossing of the voltage. Full conduction is obtained with a gating angle of 90^0. Partial conduction is obtained with gating angles between 90^0 and 180^0. The effect of increasing the gating angle is to reduce the fundamental harmonic component of the current. This is equivalent to an increase in the inductance of the reactor, reducing its reactive power as well as its current. So far as the fundamental component of current

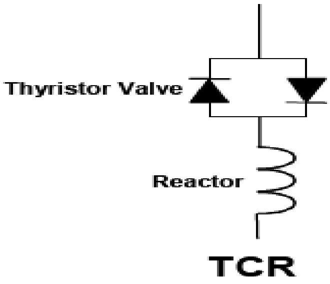


Fig. 2 : Elementary thyristor-controlled reactor (TCR).

is concerned, the thyristor-controlled reactor is a controllable susceptance, and can therefore be applied as a static compensator.

The instantaneous current *i* is given by,

$$i = \frac{\sqrt{2}\,V}{X_L}(\cos\alpha - \cos\omega t) \qquad \alpha < \omega t < \alpha + \sigma$$
$$= 0 \qquad \alpha + \sigma < \omega t < \alpha + \pi \qquad (1)$$

Where V is the rms voltage, $X_L = \omega L$ is the fundamental-frequency reactance of the reactor (in ohms), $\omega = 2\pi f$, and α is the gating delay angle. The time origin is chosen to coincide with a positive-going zero-crossing of the voltage. The fundamental component is found by Furier analysis and is given by,

$$I_1 = \frac{\sigma - \sin\sigma}{\pi X_L} V \qquad (2)$$

Where, σ is the conduction angle, and $\alpha + \sigma/2 = \pi$. We can write (2) as,

$$I_1 = B_L(\sigma) V \qquad (3)$$

Where $B_L(\sigma)$ represents an adjustable fundamental-frequency susceptance, which is controlled by the conduction angle according to the law,

$$B_L(\sigma) = \frac{\sigma - \sin\sigma}{\pi XL} \qquad (4)$$

This control law is shown in Fig. 4. For the full conduction in the thyristor controller that is with $\sigma = \pi$ or 180^0, the maximum value of B_L is obtained as $1/X_L$. The minimum value is obtained with $\sigma = 0$ ($\alpha = 180^0$) as zero. This control principle is called phase control.

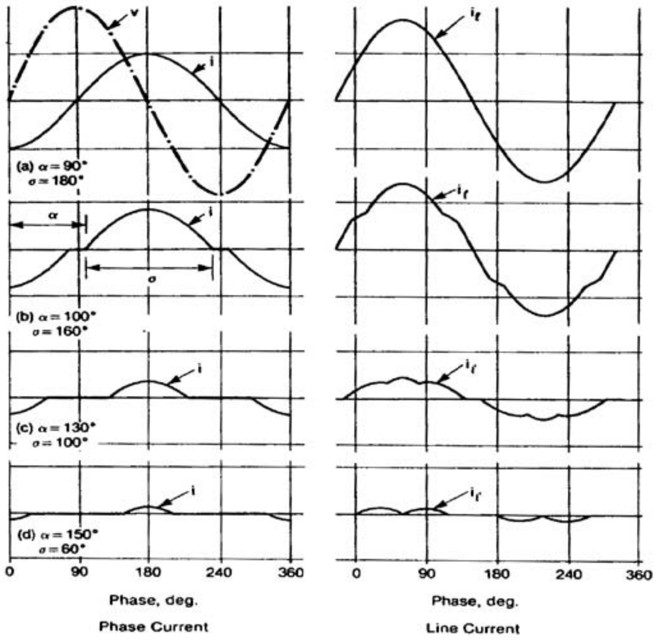


Fig.3 : Phase and line current waveforms in delta-connected TCR.

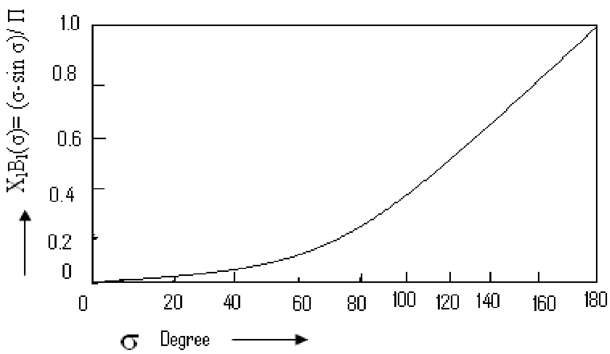


Fig. 4 : Control law of elementary TCR.

IV. PERFORMANCE ANALYSIS OF SVC CONTROLLER

a) Modeling for Dynamic Performance Analysis with SVC Applications

When studying system dynamic performance and voltage control, system modeling is an important aspect especially in and around the specific area of study. It is typical for many electric utilities to share large system models made up of thousands of buses representing the interconnected system. Details on modeling "system" elements such as transformers, generators, transmission lines, and shunt reactive devices (i.e. capacitors, reactors), etc., for short-term stability analysis are discussed. A significant and continually debated modeling aspect is the "load" model. For short-term stability analysis, loads are modeled with both static (e.g. real power, reactive power) and dynamic characteristics [12]. The automatic voltage regulator (AVR) control block is an important part of SVC models that operates on a voltage error signal. The generic AVR control block is defined by the transfer function as shown in Fig. 5.

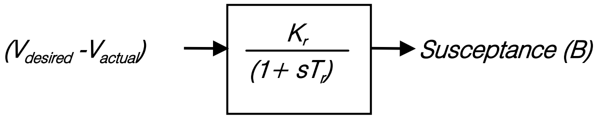


Fig. 5 : Transfer function of AVR control block.

Where K_r and T_r denotes the gain and time constant, respectively. The slope setting, maximum and minimum susceptance limits, thyristor firing transport lag, voltage measurement lag, etc are the additional commonly used control block functions of SVC dynamic models.

b) Controller Design Analysis

The SVC is operated as a shunt device to provide capacitance for voltage support or inductance to reduce the bus voltage. The fixed capacitors are tuned to absorb the harmonics which are generated by the TCR operation. Although the SVC is capable of providing support for short-term stability and power oscillation damping, its major function is to provide voltage support and dynamic reactive power. A SVC in principal is a controlled shunt susceptance (+/-B) as defined by the SVC control settings that injects reactive power (+Q) or removes reactive power (-Q) based on the square of its terminal voltage. The block diagram is shown in Fig. 6.

In this application $Q=B\times V^2$, and L and C are components which are sized such that $Q\geq 0$ is the only operating range. The AVR in the form of proportional and integral control, operates on a voltage error signal

$$V_{error} = V_{ref} - V - (I_{svc}X_{sl}) \tag{5}$$

There are also measurement lags (T_d) and thyristor firing transport lag (T_1). The output B of this control block diagram feeds into the pulse generator controller that generates the required thyristor firing signal for the light-triggered TCR.

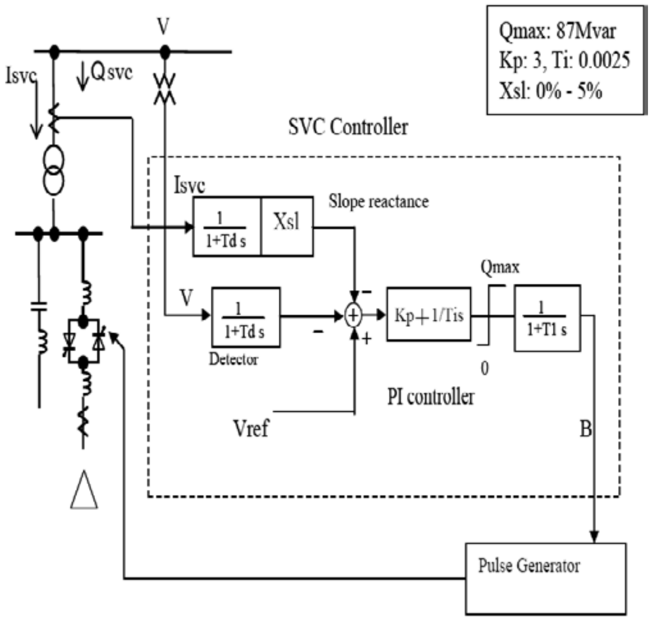


Fig. 6 : Detailed SVC block diagram.

c) Performance Criteria of SVC Operation

The control objective is to maintain the system voltage at 115 kV bus at 1.01 p.u. voltage. If the bus begins to fall below 1.01 p.u., the SVC will inject reactive power (Q) into the system (within its controlled limits), thereby increasing the bus voltage back to its desired 1.01 p.u. voltage according to its slope setting, X_{sl}. On the contrary, if bus voltage increases, the SVC will inject less (or TCR will absorb more) reactive power (within its controlled limits), and the result will be the desired bus voltage at bus [9]-[10]. The Simulink block diagram of SVC controller is given in Fig. 7.

The SVCs steady-state response will follow the voltage-current (V-I) characteristic curve shown in Fig. 8. The VI characteristic is used to illustrate the SVC rating and steady-state performance with the typical steady-state operating region being based primarily on the V_{ref}, X_{sl} setting, and the impedance of the system.

d) Typical Parameters of SVC

Table I : Typical parameters for SVC model

Parameter	Definition	Typical value
T_d	Time constant	.001-.005
T_1	Firing delay	.003-.006
X_{sl}	Slope reactance	.01-.05 pu

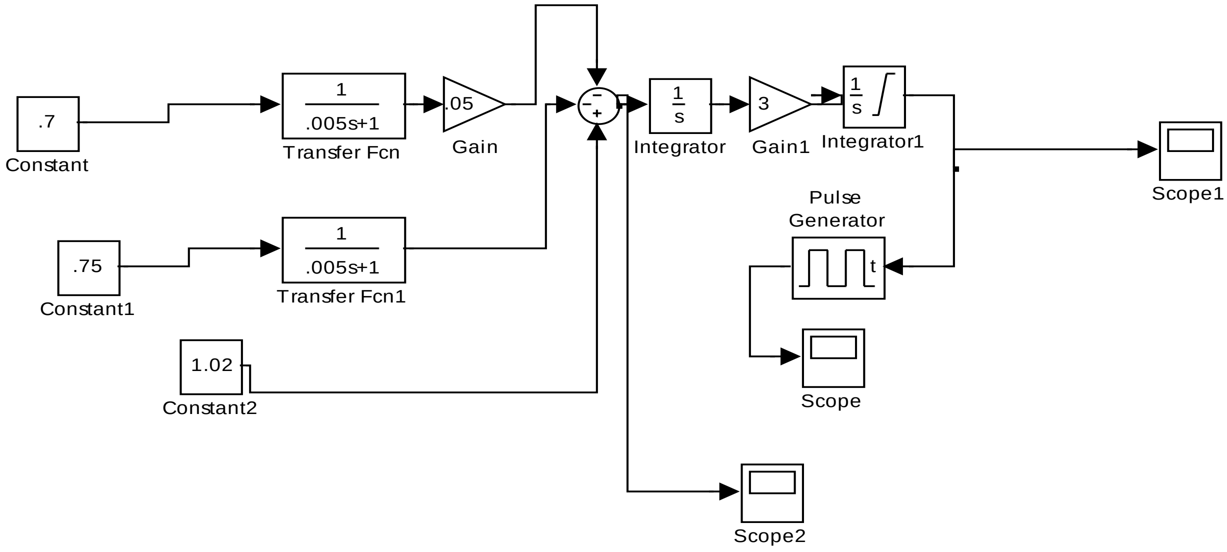


Fig. 7 : Simulink block diagram of SVC controller.

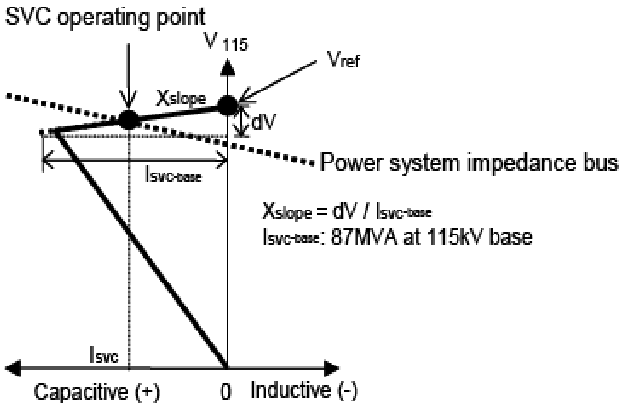
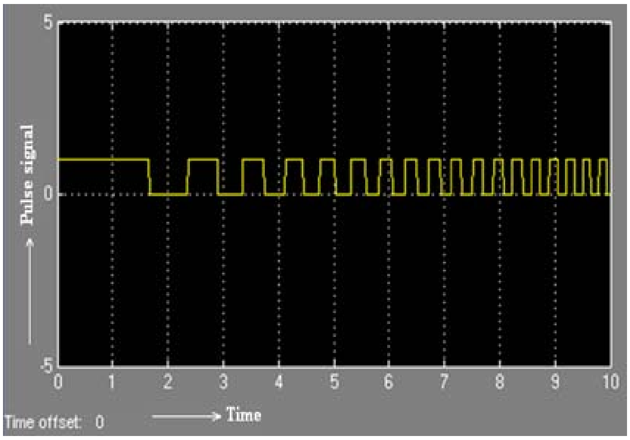
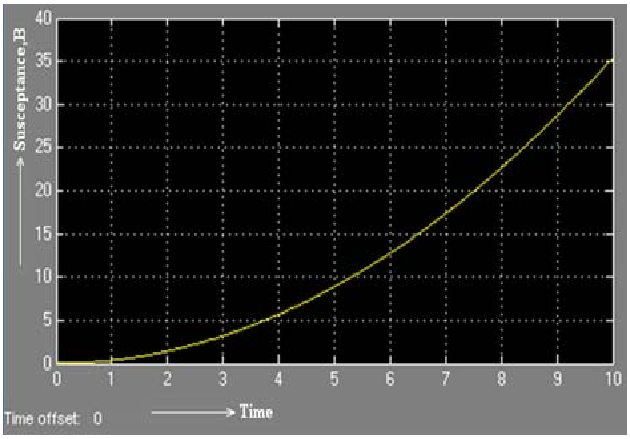


Fig. 8 : Steady state volt-current (V-I) characteristic of a SVC.

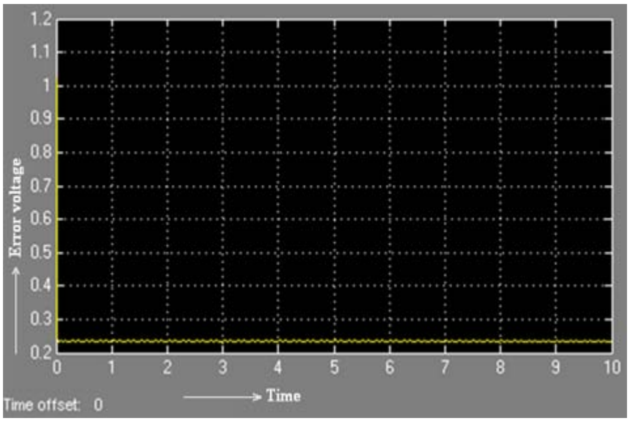
Scope : The required pulse.



Scope 1 : The susceptance which is increased due to drop of the bus voltage.



Scope 2 : The voltage error signal.



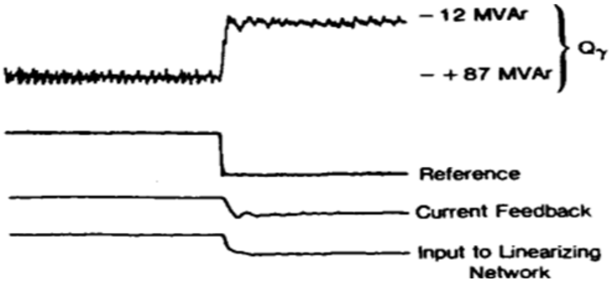
V. MODERN STATIC VAR COMPENSATOR

In modern thyristor-controll edstatic compensator, the Rimouski compensator is installed on the transmission network of Hydro Quebec at 230 KV [6]-[7]. 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 Hydro Quebec system has many long distance, high voltage transmission lines. Prior to 1978 synchronous condensers were installed to provide reactive compensation. Planning studies, which considered various alternative forms of compensation, led to the decision to install two static compensators for performance evaluation, at locations not on the Baie James system [13]. One of these was installed near Rimouski, Quebec, on the 230-KV system of the Gaspe region. It was commissioned in 1978 and serves as a representative example of a transmission system compensator.

a) Performance Testing

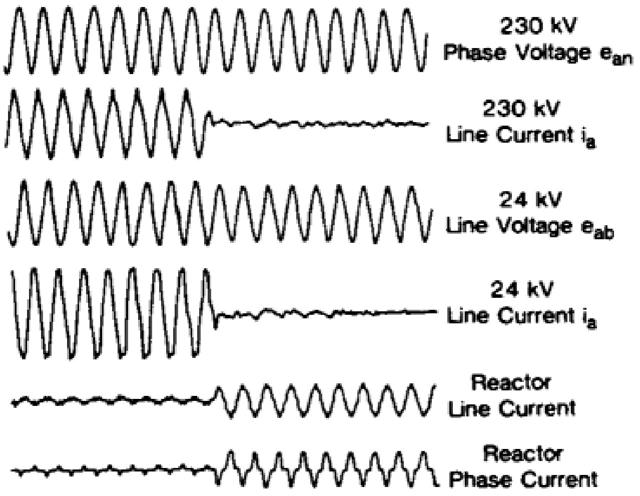
An extensive series of tests was made during and after commissioning to check the performance of the compensator. These tests included measurements of regular transfer function. The performance results are given below:

Case-1: Sudden change of -99MVAR in response to a step change in reference signal as shown in Fig 9(a).



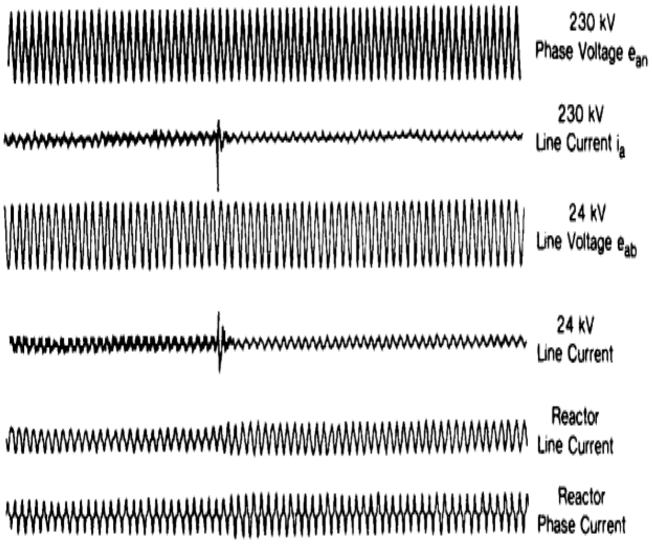
(a)

Case-2: Voltage and current waveforms as shown in Fig. 9(b).



(b)

Case-3: Energizing the capacitor bank producing a sudden change of MVAR as shown in Fig. 9(c).



(c)

Fig. 9 : Compensator performances for different cases.

VI. CONCLUSION

This research demonstrated that modern transmission static VAR compensator can be effectively applied in power transmission systems to solve the problems of poor dynamic performance and voltage regulation in a 115 KV and 230 KV transmission systems. Transmission SVCs and other FACTS controller will continue to be applied with more frequency as their benefits make the network "flexible" and directed towards an "open access" structure. Since SVC is a proven FACTS controller, it is likely that utilities will continue to use the SVC's ability to resolve voltage regulation and voltage stability problems. 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 modeling and device modeling will further ensure that proposed solutions are received by upper management with firm confidence.

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