

Modeling and Simulation of Static VAR Compensator Controller for Improvement of Voltage Level in Transmission Lines

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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 control the voltage level at a specific bus with the possibility of adding additional damping control. These can effectively dampening oscillations in the power system such as sub synchronous resonances (SSR), inter-area oscillations and power oscillations. 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.

Keywords: Static VAR compensator (SVC), thyristor controlled reactor (TCR), automatic voltage regulator (AVR), voltage regulation, Simulink.

1. INTRODUCTION

The Static VAR Compensator (SVC) is today considered a very mature technology. It has been used for reactive power compensation since the 1970s [13, 29, 30]. There are multiple applications within power systems, e.g. to increase power transfers across limited interfaces, to dampen power oscillations and to improve the voltage stability margins.

An SVC is a shunt connected FACTS device whose output can be adjusted to exchange either capacitive or inductive currents to the connected system. This current is controlled to regulate specific parameters of the electrical power system (typically bus voltage). The thyristor has been an integral part in realizing the SVC and to enable control of its reactive power. It is used either as a switch or as a continuously controlled valve by controlling the firing angle. It should be noted that the SVC current will contain some harmonic content, something that needs attention in the design process. SVC are used at a large number of installations around the world and is still considered an attractive component to improve the performance of AC power systems. Examples of modern SVC installations can be found in e.g. Finland and Norway. These installations were commissioned to dampen inter-area oscillations and to enable a power transfer increase across a limited device interface, 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.

2. STATIC VAR COMPENSATOR

a) SVC:

Static VAR compensator is shown in Fig. 1 schematic diagram. The compensator in general includes thyristor-switched capacitors (TSCs), harmonic filters and thyristor controlled reactor (TCR).Mechanically switched shunt capacitors

(MSCs) may also be included and then the term static VAR system is used. At fundamental frequency the harmonic filters are capacitive. It is used for the harmonics generated by TCR. The TSC block is typically smaller than TCR so that continuous control is grasped. Other possibilities are thyristor switched reactors (TSRs) and fixed capacitors (FCs). Typically at medium voltage, a dedicated transformer is used with the compensator equipment.

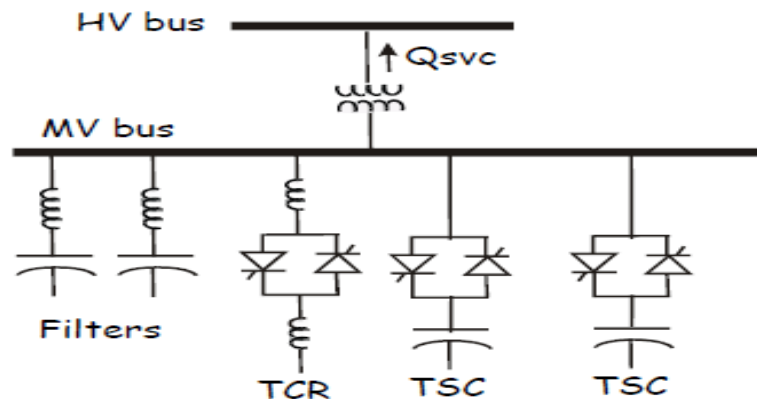


Fig. Schematic diagram of an SVC

The SVC rating can be optimized to meet up the required demand. With respect to inductive and capacitive reactive power the rating can be symmetric or asymmetric. For example, the rating can be 200 Mvar capacitive and 200 Mvar inductive or 200 Mvar capacitive and 100 Mvar inductive. SVCs are well known to improve power system properties such as steady state stability limits, voltage regulation and VAR compensation, dynamic over voltage and under voltage control, counteracting sub synchronous resonance, and damping power oscillations.

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 voltage. For this reason they are often operated at close to their zero-point in order to maximize the reactive power correction. 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.

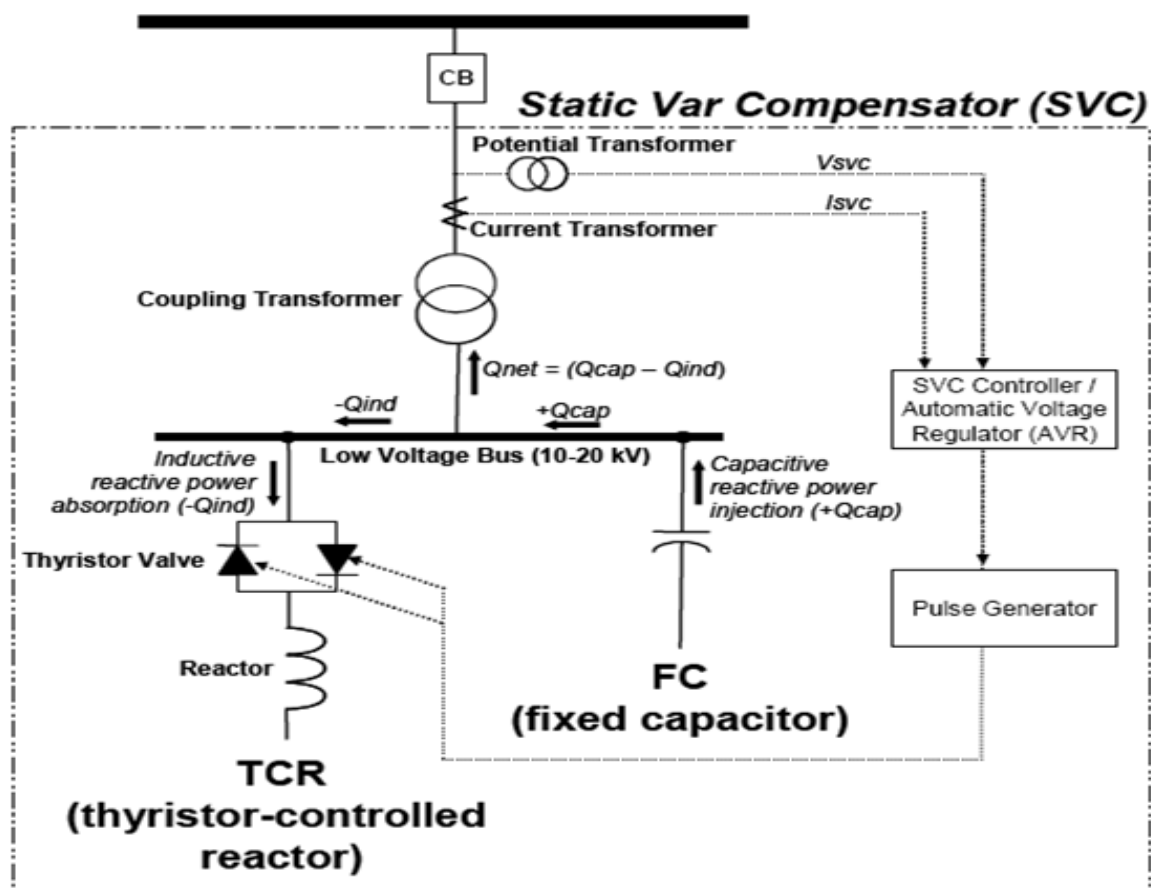
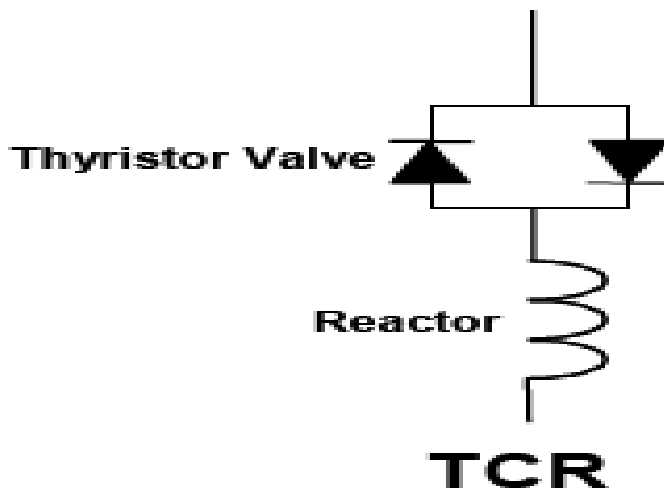


Fig.1: SVC with control concept.

The Thyristor Controlled Reactor:

The thyristor controlled reactor (TCR) can be represented by the same one-line diagram as for the previously mentioned TSR, shown in figure.1a. By enforcing partial conduction of the thyristor valve, the effective reactance of the inductor may be varied in a continuous manner. This is achieved by controlling the firing angle of the thyristor valve, thus controlling the TCR susceptance and its ability to absorb reactive power. As the firing angle can be varied continuously from zero to full conduction, the field of operation of the TCR is much greater compared to the discretely switched TSR. The operation range of the firing angle lies between 90° and 180° , which respectively corresponds to full conduction and no conduction. Operating within the firing angle interval, $0^\circ < 90^\circ$, introduces a DC offset to the reactor current which disturbs the thyristor valve. Thus, this interval should be avoided.



Fig; 2 Elementary thyristor-controlled reactors (TCR)

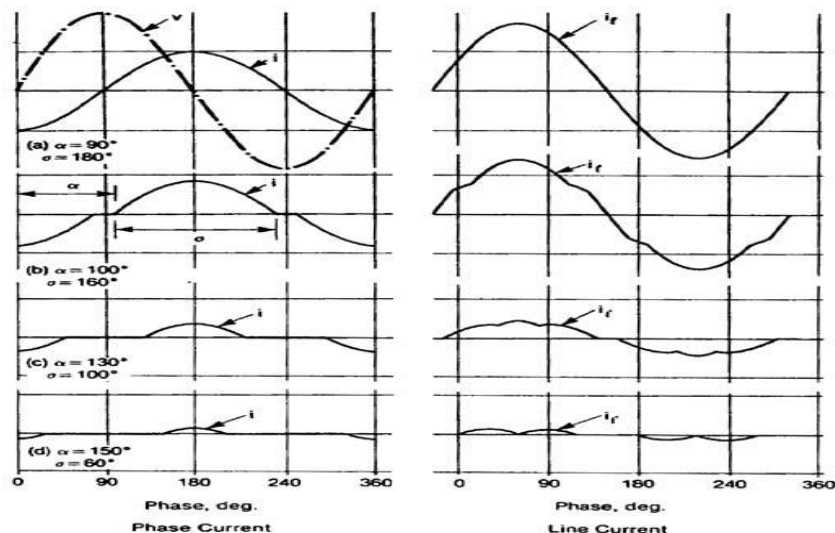


Fig.3 Phase and line current waveforms in delta connected TCR

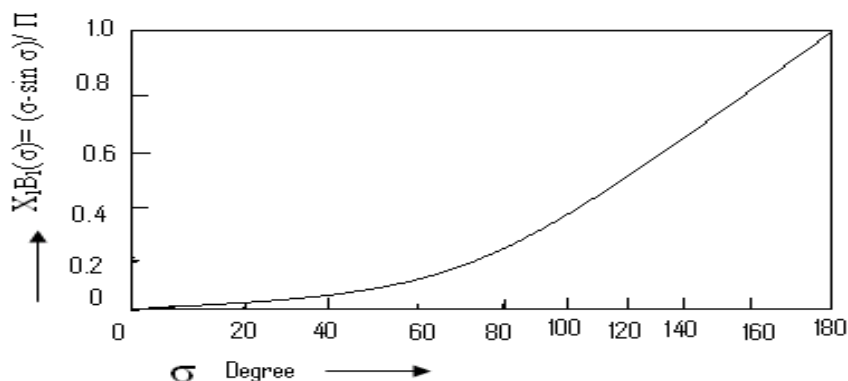


Fig. 4 : Control law of elementary TCR

Control application and modelling:

Before we can focus on the simulation study we need to address how to properly represent the SVC in computer simulations. Models must be determined for both static and dynamic power system simulations. In this section we will present both general models and how the SVC can be represented in PSSTME. A few assumptions have been made that should be kept in mind when considering the models presented in the succeeding sections. These assumptions are valid unless stated otherwise:

- i. The devices are considered lossless.
- ii. Harmonics are being neglected, only the fundamental component is considered.
- iii. Balanced operation is assumed, i.e. only the positive sequence component is considered.

4. PERFORMANCE ANALYSIS OF SVC CONTROLLER

a) Modelling for Dynamic Performance Analysis with SVC Applications: When studying system dynamic performance and voltage control, system modelling 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 modelling “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 modelling aspect is the “load” model. For short-term stability analysis, are modelled with both static (e.g. real power, reactive power) and dynamic characteristics. 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. 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

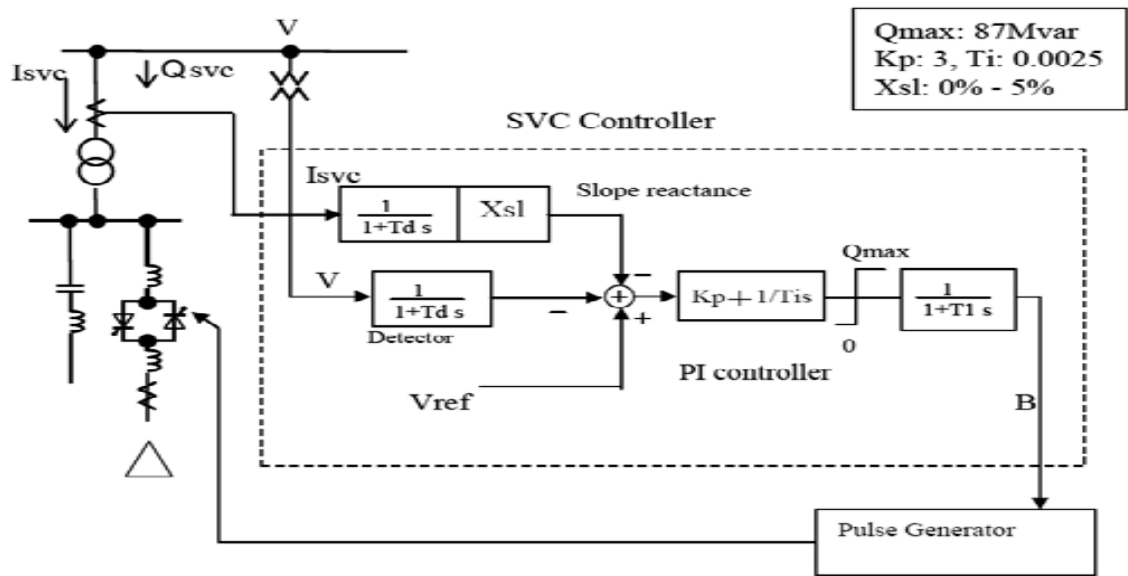


Fig.5: Detailed SVC block diagram.

$V_{error} = V_{ref} - V - (I_{svc} X_{sl})$ (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.

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. The Simulink block diagram of SVC controller is given in Fig. The SVCs steady-state response will follow the voltage-current (V-I) characteristic curve shown in Fig. 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: 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

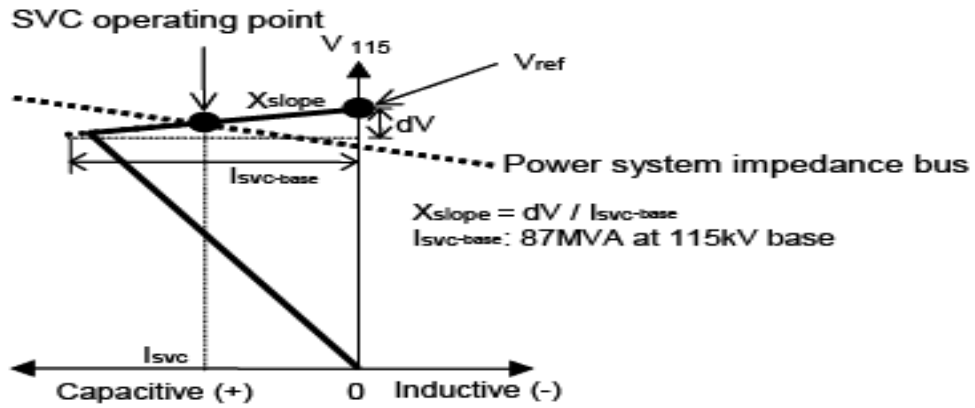
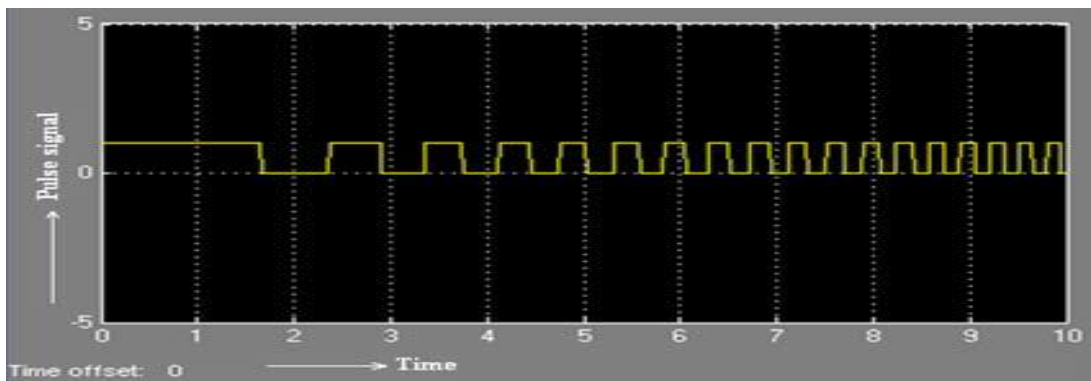
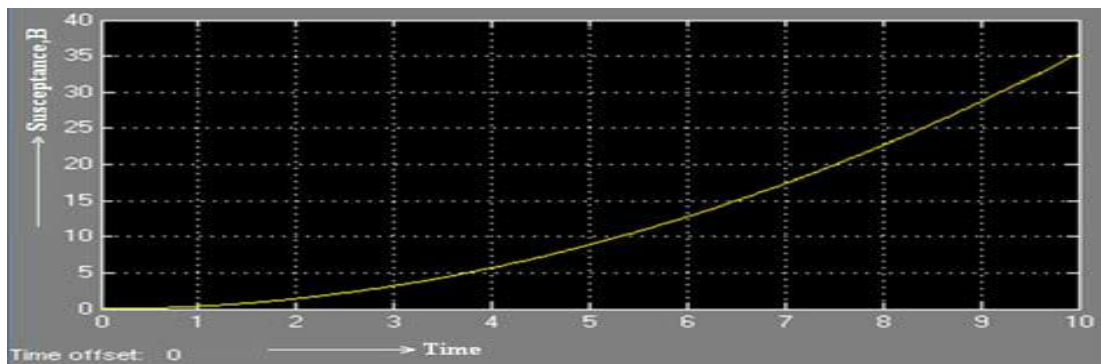


Fig.6: Steady state volt-current (V-I) characteristic of a SVC.

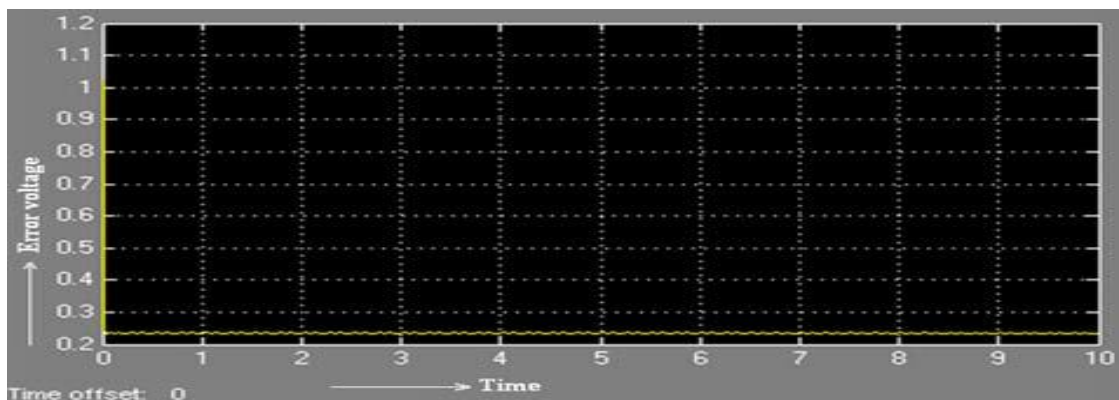
Scope: The required pulse



Scope1: The susceptance which is increased due to drop of the bus voltage:



Scope2: The voltage error signal:



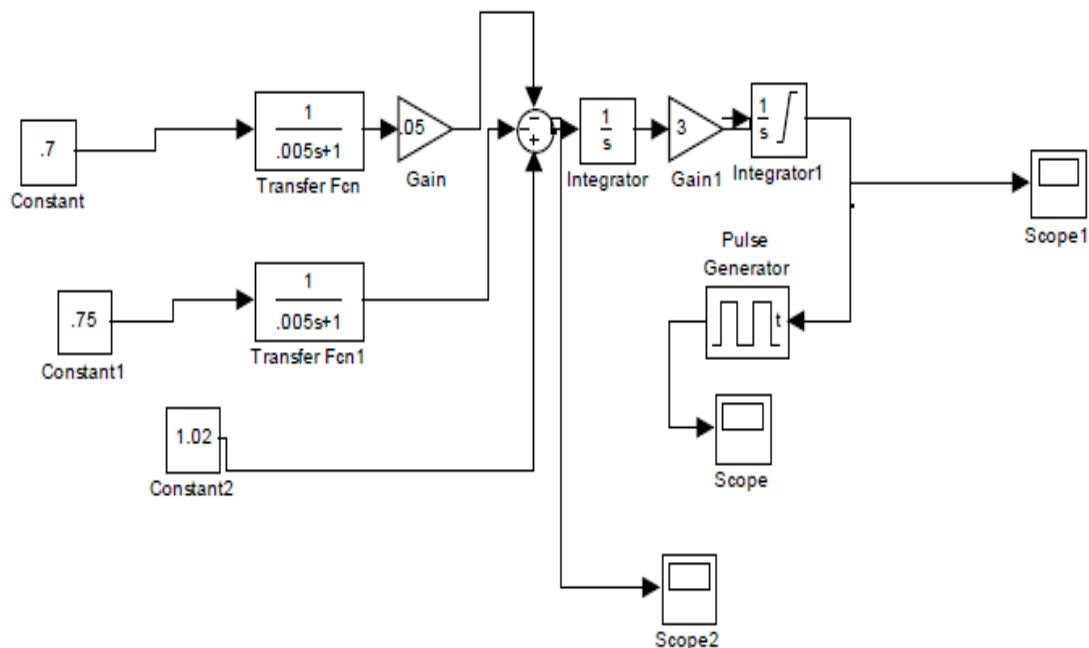


Fig. 7: Simulink block diagram of SVC controller.

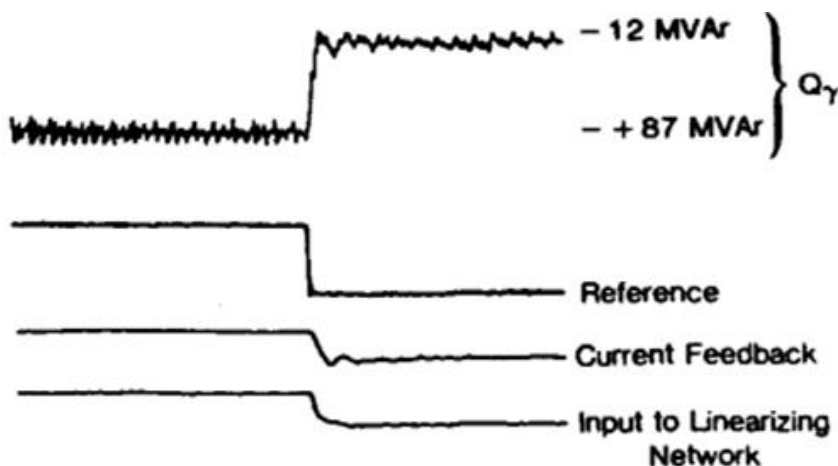
5. MODERN STATIC VAR COMPENSATOR

In modern thyristor-controlled static compensator, the Rimouski compensator is installed on the transmission network of Hydro Quebec at 230 KV. 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. One of these was installed near Rimouski, Quebec, on the 230-KV system of the Gaspé region. It was commissioned in 1978 and serves as a representative example of a transmission system compensator.

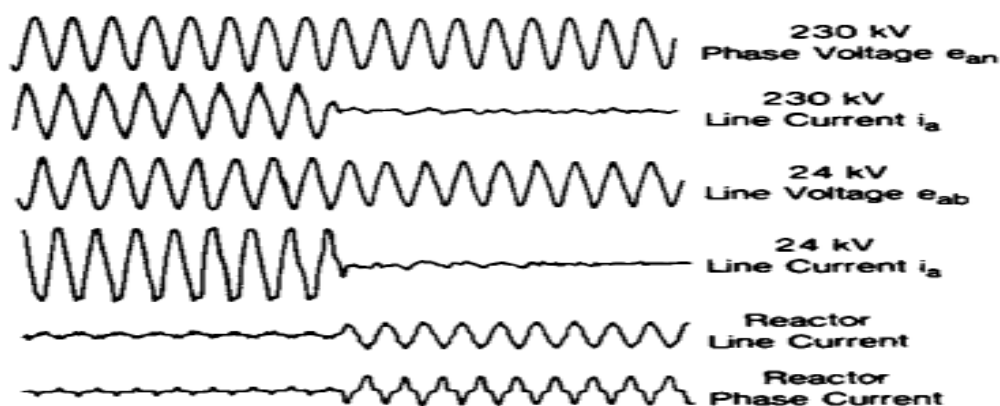
a) Performance Testing:

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

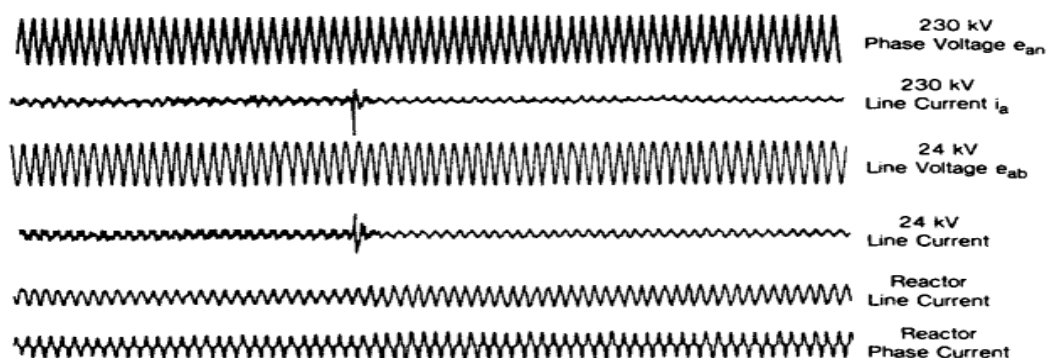
Case-1: Sudden change of -99MVAR in Response to a step change in reference signal as shown in Fig (a).



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



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



6. CONCLUSION

This thesis 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 Swedish power system 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.

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