Analysis of the Response of a Static Reactive Power Compensator to Instability and Failure in Electrical grids

Víctor Manuel Maridueña¹, Edwin Arnaldo Castro¹, and Nelson Layedra¹
¹ Universidad Politécnica Salesiana /Electrical Department, Guayaquil, Ecuador

Email: vmariduena@est.ups.edu.ec

Abstract. The reliability of electrical power systems has led to the implementation of new equipment with reliable technology to solve transient failures, in recent decades flexible AC transmission systems (FACTS) have been implemented in power grids, resulting in high levels of stability and control. One of the elements used is static VAR compensators (SVC), however there is very little information about the dynamic response of the device to network instability and electrical failures, for which Simulink analyses the response of the SVC. The device consists of a 47.1 MVar reactive power compensator and a 97.6 MVar inductive reactivator compensator, implemented in a three-phase 500 kV system. The results indicate the effectiveness of response against network instability while maintaining the stable voltage of the network, but against electrical failures the type and time of failure must be considered. In the case of phase-phase faults, the response of the SVC is limited with drops of 0.52 pu.

1. Introduction
Your goal is to simulate the usual appearance of papers in the. We are requesting that you follow these guidelines as closely as possible. The development of populations is directly linked to the reliable supply of electricity, in recent years power electrical systems have had an accelerated change in the rate and growth of demand due to the change in consumer habits, therefore several inconveniences in the operation and quality of service are generated due to the approach to stable operating limits, so it is necessary to incorporate new technologies to maintain the quality of supply. New technologies seek to improve the transmission and flexibility of electrical power systems. Flexible Transmission Systems in Alternating Current (FACTS) are devices with the ability to control various network parameters seeking to meet two objectives, the first is to increase the transfer capacity of the power system and maintain the operating conditions of the power system by flowing the network paths. The operation of FACTS improves, controls and makes the operation of PMI [1]–[3] improved, controlled and more flexible.

One of the widely used devices in the FACTS family is static reagent compensator (SVC), its main function is to provide control of the magnitude of the bus voltage, regulates the bus voltage to compensate when you have reactive power changes, keeping voltage profiles within the permitted ranges, in case of failures or transient phenomena the voltage is stabilized through a rapid supply of reactive power with which the entire system is stabilized and does not allow a general failure. Currently commercially there are several SVC models, used to solve load flow problems including PV node and PQ models of variable susceptance based on system voltage another higher precision model uses a variable susceptance which is controlled by the firing angle of the thyristors improving the range of the nodal voltage value according to the values of the selected regulations [4].
One of the devices to reduce the inconveniences due to power quality issues are SVCs mainly in metallurgy industries, in the reference [5] the authors propose the use of a fuzzy logic controller to improve the voltage profile by reducing the capacitance of the device, the proposed method manages to reduce the harmonic currents with which it can compensate the effect of power oscillations, improving the quality of the energy, the novel method has a better performance compared to traditional mathematical methods.

Chan et al. [5] present the simulation of a hybrid model of power systems with a static VAR compensator, where dynamic phasor theory is applied, transient models are used for the AC subsystem, researchers first derive the model and use a connection algorithm between the phasor model and the subsystem. The model is tested on 39 buses located in New England, resulting in high model accuracy compared to the transient electromagnetic model, allowing the analysis of the dynamic response of electrical power systems containing SVC.

Zhigun et al. [6] using a new method they perform the simulation of an electrical power system with SVC where they apply the theory of single-phase dynamic phasors, transient models are used for the AC subsystem. An interface algorithm is used to join the dynamic phasor model of the SVC and the AC subsystem, the simulation results show that var’s static compensator single-phase dynamic phasor model has greater accuracy than the transient electromagnetic model, with the simulation of the new hybrid method achieving a new vision for dynamic simulation of large power systems with SVC.

In this work, a power system connected to a var static compensation phasor model is simulated to regulate system voltage by generating reactive or capacitive power according to the voltage threshold to be controlled and analysing the system’s response for instability or electrical failures, the results of the investigation are described in the document [7].

2. Dynamic phasor model of the SVC

2.1 Model concept

The SVC connected in the electrical power systems operate equivalent to a capacitor, by means of which they can control the voltage and reactive power in the bars or terminals near the connection, in an ideal state without loss of active power (w) or reactive (var) provided instantaneous responses to the system, manages to maintain the constant voltage, among the goodness of the device is the unlimited ability to absorb or generate reactive power [7].

The phasor dynamic model is also the same method of averaging in the state space, it is developed based on the theorem of the Fourier series with variations in time coefficients. It is assumed that the waveform in the time domain can be represented by a time interval $t = \in (t - T, t)$ applied in the Fourier series and can be calculated using the following equation:

$$x(t) = \sum_{k=-\infty}^{\infty} X_K(t) e^{jk\omega_s t}$$  \hspace{1cm} (1)

$$\omega_s = \frac{2\pi}{T}$$

Where, $\omega_s = 2\pi/T$, and is the dynamic time $X_K(t)$ phasor along with the variable coefficients in time of the Fourier series, the dynamic k-th phasor at time t is calculated using equation 2.

$$X_k(t) = \frac{c}{T} \int_{t-T}^{t} X(t) e^{-jk\omega_s t} dt = (X)_K(t)$$  \hspace{1cm} (2)

Where, c s 1 for k s 0 and c s 2 for k> 0.

Two properties are used for the development of the SVC dynamic model. The first property refers to the difference of the dynamic k-th and is described by the following equation.
\[
\frac{dX_k}{dt}(t) = \left(\frac{dx}{dt}\right)_k(t) - jk\omega_s x_k(t) \tag{3}
\]

Property 2 is the product of two dynamic phasors, where the dynamic k-th phasor of the product of two time domains with the waveform in \(x(t)\) and \(y(t)\), can be calculated using equation 4.

\[
(xy_k) = \sum_{l=\infty}^{\infty} (x)_{k-1} (y)_l \tag{4}
\]

The waveform in the time domain \(x(t)\) can be calculated from dynamic phasors using the following equation:

\[
X(t) = Re\left(X_k(t)e^{jk\omega_0t}\right) = X_{-K}(t)e^{-jk\omega_0t} + X_{-(K-1)}(t)e^{-j(k-1)\omega_0t} + \ldots
\]

\[
X_{K-1}(t)e^{j(k-1)\omega_0t} + X_k(t)e^{j\omega_0t} \tag{5}
\]

\(x(t)\) is a real function according to a time-time int, it is easy to conclude that, \(X_{-K} = X_k^*\) where * indicates that you are working with a complex variable.

### 2.2 TCR thyristor-controlled reactor

The advances presented in power electronics have allowed the development of thyristor-based SVC devices, the thyristor-controlled reactor (TCR) is one of the characteristic elements, the element combining fixed capacitors or switched by thyristors, whose main mission is to provide a fast and continuous control of the reactive power consumed by a coil.

The diagram of a TCR is made up of an inductive resistive coil together with an alternating current to alternating current converter formed by 2 antiparallel placed thyristors, the control is carried out by phase, where the value of the current through the inductance is regulated, the current that circulates is a transient sequence on the whole of the coil RL. For the analysis of the behaviour of thyristor-controlled reactor thyristors behave in an ideal way, the pure sinusoidal potential differential can be calculated by means of equation 6.

\[
e(t) = \sqrt{2}E\text{sen}\omega t \tag{6}
\]

### 2.3 TSR thyristor-switched reactor

TSRs are defined as a thyristor-switched inductor, effective reactance is presented in a staggered way due to complete thyristor conduction or zero conduction management if the thyristor valve is open.

Thyristor-switched reactors are bypass compensators, which can produce or generate reactive power. TSRs have a simple principle of operation mentor, consist of a half cycle delay and have the peculiarity of non-harmonics [8].

The thyristors are connected in parallel; they are built by different inductors and they are switched to the operating state or through the switching of thyristors without controlling the firing angle, achieving lower costs and losses, however it does not have continuous control.

### 2.4 TCR Dynamic Phasor Model

The single-phase TCR circuit, the thyristors are connected in parallel but inverted with the aim of firing symmetrically in positive and negative with respect to the semi cycle of the voltage, in this connection only the current of harmonics of odd order occurs.
To prevent or eliminate the circulation of triple-order harmonics the delta connection of three single-phase TCR is used, research conducted shows that harmonics of more than the seventh order have fewer effects on dynamic characteristics of the TCR. In many cases considers the fundamental and fifth harmonic for the dynamic phasor model of the TCR [9], for the calculation of voltage and current of the single-phase circuit the following equation is used.

\[
\begin{align*}
\frac{dy}{dx} &= i_l - i \\
L \frac{di}{dt} &= SV
\end{align*}
\]

(7)

where, the variable \( S \) is there presentation of as witching function defined by \( S=1 \), when one of the two thyristors is energized and driving, when \( S=0 \) the thyristors are in an open state.

2.5 Dynamic phasor model of filter circuits

The RLC filters are made up of resistors, inductances and capacitors connected in series, these elements are connected to the SVC bus to eliminate high-order harmonics. Applying the differential property in equation 8 is derived in e circuit resistive, inductive, separates the real and imaginary parts in equation 8 and 9, infers the model of the circuit is the \( V_1(t) \) voltage, the same procedure is applied for the current.

\[
V_1(t) = L \frac{dI_1(t)}{dt} + Ri(t)
\]

(8)

the dynamic phasors are calculated:

\[
L \frac{dI_k}{dt} = V_{1,k} - jk\omega L I_k - R I_k
\]

(9)

2.6 Var static compensator block

Simulink in the library presents the block the phasor model of the three-phase static compensator of var, in the connection terminals regulates the voltage by controlling the amount of reactive power generated (capacitive SVC) when the voltage is low and absorbs reactive power (inductive SVC) when the voltage is high. Switching three-phase capacitor banks and secondary inductors installed in a coupling transformer varies the reactive power of the device.

The compensators are turned on and off by means of three thyristor switches (TSC), while thyristor-controlled (TSR) or phase-controlled (TCR) reactors are turned on and off. Figure 1 shows the one-line diagram of the SVC next to the simplified block diagram of the control system [10].

![Diagram of a line of an SVC and its control system block]

Figure 1. Diagram of a line of an SVC and its control system block
In the control system the positive sequence voltage to be controlled is measured, the measurement system is based on Fourier, using the moving average of a cycle, the voltage regulator uses the difference known as error between the measured voltage and the reference voltage to calculate the B susceptance of the compensator to maintain the constant voltage.

The SVC block (phasor type) is a phasor model, which has to be used with the phasor simulation method, it includes elements such as synchronous, various dynamic loads to carry out the analysis and study of transient stability and observe the impact of the static compensator on the power system.

In control parameters the block is configured in voltage regulation mode, it is necessary to parameterize the reference voltage in pu, the signals are processed in the signal processing block, where the characteristics of the sampled information are extracted, analysed in a uniform way and not uniform.

The mentioned block can contain filters for resampling and smoothing to extract the characteristics of change point, patterns etc. Additionally, it can analyse several signals simultaneously in time and frequency domains.

3. Power system modelling

The system is modelled in Matlab Simulink, the goal is to analyse the response of the behaviour of the SVC against instability and network failures, the SEP is connected to a voltage of 500 kV, 60 hz, when the system voltage is under the compensator generates capacitive reactive power by means of the TSC (thyristor controlled capacitors) with a capacity of 47.1 MVar.

While when the voltage is high it absorbs the inductive reactive power by means of TCR (thyristor-controller inductors) with a capacity of 97.6 MVar, the SVC block used is of phasor type, pre-work is referenced [11] electrical failures the three phase fault block is used, the opening and closing times can be controlled from an internal timer, additional can be scheduled phase-by-phase failures, phase-to-ground failures, the block is commanded by the Three-Phase Breaker block. The figure 2 shows the plant used for simulation, with each of the blocks used to achieve the simulation of the power system.

![Figure 2](image)

**Figure 2.** Block diagram used in Simulink

3.1. Response from the SVC system

The first simulation is to analyse the dynamic response of the SVC versus instability is in the network, for which the three-phase voltage source is programmed, at the beginning the source generates the rated voltage, after $t=0.1\text{s}$ the voltage is reduced to 0.97 pu, after $t=0.4\text{s}$ the voltage increases to 1.03 pu, at the end of the simulation at $t=0.7\text{s}$ the voltage returns to a nominal value.
Figure 3 shows the dynamic response of the system, the black curve represents the positive sequence voltage of the actual system, while the blue curve is the voltage measurement with SVC response.

![Figure 3. Dynamic response of the SVC to network instability](image)

The actual voltage drop is 0.03 pu at that time the current of the device is fully capacitive for such a reason from \(t=0.2\) to \(t=0.4\) the voltage approaches 1 pu, while when the voltage increases to 1.03 pu by \(t=0.4\) the current is inductive in order to reduce the actual voltage of the system.

On the other hand, the figure 4 shows the behavior of the curve, the voltage drop reaches 0.69 pu, however despite the performance of the SVC is not able to maintain stable voltage.

The following analysis corresponds to an electrical fault in one of the ground phases, to perform the simulation at the voltage source the types of variation are canceled either by amplitude, phase or frequency, the procedure is to close the fault breaker and program the electrical fault for a switching time(s) [20/60 30/60].

![Figure 4. Dynamic SVC response to phase-to-ground failure](image)

On the other hand when a phase-phase failure occurs the voltage drop reaches 0.52 pu, similar to the previous case you have an SVC response but due to the type of failure is not able to maintain the voltage, without clutch when you have the transient fault clearing in \(t=0.5\) the voltage damping is displayed due to the performance of the inductive capacity of the SVC. The system response is shown in figure 5.
4. Conclusions

One of the devices used to control the voltage level in the SEP is the SVC, in this document an electrical system is simulated for three scenarios in Simulink, despite the difficulty of presenting the exact conditions of the system, in the first scenario presents an unbalance of the voltage level as well as drop and overvoltage, the device manages to mitigate the problem with which the network is stabilized with an acceptable response reaching up to 1.05 pu.

The second scenario is due to a phase-earth fault, in which the static compensation device is not capable of solving the problem with a voltage drop up to 0.69 pu, but it does collaborate to stabilize the problem in less time when the fault is cleared. In the third scenario with a phase-phase failure is similar to the second, the only difference is in the depth of the voltage drop with a drop of 0.52 pu. In the following research works, other factors must be included and different values of the integral gain of the SVC must be placed to improve the dynamic response.

5. References

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