MODELING AND SIMULATION STUDY OF THE USE OF STATIC VAR COMPENSATOR (SVC) FOR VOLTAGE CONTROL IN NIGERIA TRANSMISSION NETWORK

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ABSTRACT

Flexible AC Transmission System (FACTS) controllers, such as the Static Var Compensator (SVC), employ latest technology power electronic switching devices in electric power transmission systems to control voltage and power flow, and improve voltage regulation. There is increase in demand for electricity globally to feed the technology driven economy. Given a profit-driven, deregulated electric power industry coupled with increased load growth, the power transmission infrastructure is being stressed to its upper operating limits to achieve maximum economic returns to both generation and transmissions system owners. In such an environment, system stability problems such as inadequate voltage control and regulation must be resolved in the most cost-effective manner to improve overall grid security and reliability. Static Var Compensators are being increasingly applied in electric transmission systems to economically improve voltage control and post-disturbance recovery voltages that can lead to system instability. An SVC provides such system improvements and benefits by controlling shunt reactive power sources, both capacitive and inductive, with state-of-the-art power electronic switching devices.

Keywords: Voltage Stability, PSAT, Simulink, SVC, Power Transmission.

1. INTRODUCTION

The electric power system has grown in size and complexity with a huge number of interconnections to meet the increase in the electric power demand. Moreover, the role of long distance and large power transmission lines become more important. Due to this today’s changing electric power systems create a growing need for flexibility, reliability, fast response and accuracy in the fields of electric power generation, transmission, distribution and consumption. Static Var Compensators (SVC) devices are used to improve voltage and reactive power conditions in AC systems. It also increases damping. The effectiveness of this controller depends on its optimal location and proper signal selection in the power system network [1]. SVC has the ability to improve stability and damping by dynamically controlling it’s reactive power output.

2. REVIEW OF RELATED LITERATURE

Nowadays, voltage collapse, due to the voltage instability, is a major problem in power system. Research work is going on to find new ways of minimizing voltage collapse by increasing voltage stability (Transient stability, Steady state stability). There are many analytical methods for determining voltage stability of power system. In [2], finding of optimal location of SVC and TCSC, saddle node bifurcation analysis is applied and power flow is used to evaluate the effect of FACTS devices on system load ability. In [3], the ability of power system, on how to control small disturbances, for example:- change in load has been discussed. In [4], power quality improvement on how FACTS devices are used and how to improve power system operation has been studied. In [5], the effect of SVC and STATCOM on static voltage stability margin enhancement was studied. In [6], various types of FACTS controller and their performance characteristics have been described. In [7], simulation and comparison of various FACTS devices (FC-TCR, CPFC) using PSPICE software have been done. In [8], modeling and simulation of SSSC multi machine system for power system stability enhancement was studied. How to improve steady state stability by placing SVC at different places has been discussed in [9]. In [10], use of FACTS controllers for the improvement of transient stability has been studied. In [11], using MATLAB/SIMULINK software simulation was done to demonstrate the performance of the system for each of the FACTS devices for example, FC-TCR, STATCOM, TCSC, SSSC and UPFC in improving the power profile and there by voltage stability of the same.
using MATLAB/SIMULINK software performance of shunt capacitor, FC-TCR and STATCOM has been discussed. In [13], Modelling and Simulation of various FACTS devices (FC-TCR, STATCOM, TCSC and UPFC) have been done using MATLAB/SIMULINK software. [14], discuss how SVC has successfully been applied to control dynamic performance of transmission system and regulate the system voltage effectively. In this paper modeling and simulation study of the use of Static Var Compensator (SVC) for Voltage Control in Nigeria Transmission Network have been done using SIMPOWERSYSTEMS /PSAT software.

3. STATIC VAR COMPENSATOR
The Static Var Compensator (SVC) is a device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. The SVC regulates voltage at its terminal 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.

Figure 1. Single-line diagram of an SVC and its control System
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)[15],[16],[17].

Figure shows a single-line diagram of a static var compensator and its control system.
The control system consists of:
- A measurement system measuring the positive-sequence voltage to be controlled
- A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) 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 and a pulse generator that send appropriate pulses to the thyristors.

3.1 SVC V-I Characteristics
The SVC can be operated in two different modes:
- In voltage regulation mode (the voltage is regulated within limits)
- 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 characteristics [18].

Figure 2. SVC V-I characteristics
As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bc_max) and reactor banks (Bl_max), the voltage is regulated at the reference voltage Vref. However, a voltage drop is normally used (usually between 1% and 4% at maximum reactive power output). The V-I characteristic is described by the following three equations:

\[ V = V_{\text{ref}} + X_s I \quad \text{SVC is in regulation range (} -B_{\text{c max}} < B < B_{\text{l max}} \text{)} \]
\[ V = \frac{B}{B_{\text{c max}}} \quad \text{SVC is fully capacitive} \]
\[ V = \frac{I}{B_{\text{l max}}} \quad \text{SVC is fully inductive} \]
\[ V = \text{Positive sequence voltage (p.u.)} \]
I=Reactive current (p.u./Pbase)(I>0 indicates an inductive current).

3.2 MODELING OF SVC
A 300-Mvar Static Var Compensator (SVC) regulates voltage on a 6000-MVA 735-kV system. The SVC consists of a 735kV/16-kV 333-MV coupling transformer, one 109-Mvar thyristor-controlled reactor bank (TCR) and three 94-Mvar
thyristor-switched capacitor banks (TSC1, TSC2, TSC3) connected on the secondary side of the transformer. Switching the TSCs in and out allows a discrete variation of the secondary reactive power from zero to 282 Mvar capacitive (at 16 kV) by steps of 94 Mvar, whereas phase control of the TCR allows a continuous variation from zero to 109 Mvar inductive. Taking into account the leakage reactance of the transformer (15%), the SVC equivalent susceptance seen from the primary side can be varied continuously from -1.04 pu/100 MVA (fully inductive) to +3.23 pu/100 Mvar (fully capacitive). The SVC sends appropriate pulses to the 24 thyristors (6 thyristors per three-phase bank) in order to obtain the susceptance required by the voltage regulator.

Figure 3. Detailed model of SVC in SimPowerSystems/Simulink

4. SIMULATION RESULTS OF IEEE 9-BUS SYSTEM

Table 1. Network Visualisation of simulation results for IEEE 9-bus test system

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<tr>
<th></th>
<th>Without FACTS</th>
<th>With SVC</th>
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<td>Voltage</td>
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<td>Voltage</td>
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Figure 4: PSAT model of IEEE 9-bus test system
4.1 Simulation results of IEEE 14-bus System

![IEEE 14-bus test system](image)

**Figure 5. PSAT model of IEEE 14-bus test system**

IEEE 14-bus test system: Rotor angle (Angular speed) circuit breaks at 2s and closes back at 10s

4.2 Simulation results of Nigerian 31-bus 330 kV network

![Nigeria 31-bus high voltage network in PSAT](image)

**Table 3. Network Visualisation of simulation results for IEEE 14-bus test system**

<table>
<thead>
<tr>
<th>Without FACTS</th>
<th>With SVC</th>
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<td><strong>Voltage Magnitudes</strong></td>
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<td><strong>Voltage angles</strong></td>
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It can be seen from the network visualization diagram that the presence of SVC smoothes the distribution of flow in the network to achieve a more balanced and uniform power flow.

5. SUMMARY

The aim of this paper is to show, through computer modeling and simulation, that static var compensator (SVC) can be used to control voltage stability on Nigeria 31-bus 330 kV power transmission network. Its objectives includes, among other things, the modeling and simulation study of the use of svc in the Nigeria 31-bus 330 kV power transmission network, using mathematical simulation software. The modeling and simulation study were carried out in Matlab environment, using simpowersystems and PSAT. Simpowersystems was used to study the steady state and dynamic characteristics of a 330 MVAR SVC, while PSAT was used to study the time domain behavior of IEEE 9-bus and 14-bus test systems under normal and faulty condition with and without svc. Also PSAT was used to create a model of Nigeria 31-bus 330 kV power transmission network. Various simulation tests were carried out on the model to study the time domain response of the network to simulated faults with and without SVC in place. The simulation results show that the presence of SVC smoothes the dynamic response of the system to faults. The SVC, in its inductive role, also absorbs excess power from the generating stations, thus overtime the demand on the station settles to an optimum level. Once this steady state is reached the SVC regulates the network voltage by absorbing power when voltage is high and generating power, in its capacitive role, when voltage is low, thus maintain stable voltage level and constant power towards the distribution networks.

5.1 CONCLUSION

This paper has demonstrated that modern transmission static var compensators can be effectively applied in power transmission systems to solve the problems of poor dynamic performance and voltage regulation in Nigeria 31-bus 330 kV transmission system. Transmission SVCs and other FACTS controllers 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, transmissions SVC also provide an environmentally-friendly alternative to the installation of costly and often un-popular new transmission lines.
The model developed in this study offers opportunity for more fine tuning and refinement to reflect the accurate status of the Nigeria transmission network. Dynamic performance and voltage control analyses 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.

References


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Oyedojia, K.O. received is B.Eng., M.Eng., in Electrical Engineering from University of Ilorin, Nigeria, Msc in Industrial and Production Engineering from University of Ibadan, Nigeria, respectively. At present, he is with the Department of Technical Education, EACOED, Oyo, Oyo.
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Appendix 1

Figure 9. Detailed model of Nigeria 31-bus high voltage network in PSAT