A Survey of SVC Device; its Principle of Operation, Advantages and Limitations

ABSTRACT

This work centers on the survey of the Static Var Compensator (SVC) device principle of operation, advantages and limitations. There has been persistent problems of sudden blackout and brownout of the power supply in Nigeria and some other developing nation as a result of high level of instability existing in the power lines. Due to the increase in the population, expansion of the power line network and also load increase, there has been tremendous level of disturbances being introduced into the power lines. These disturbances can cause low frequency oscillation which may last long and result to instability in the lines if not adequately damped or compensated. SVC is an electrical device and a type of Flexible Alternating Current Transmission Systems (FACTS) device introduced for providing fast-acting reactive power compensation on high voltage electricity transmission networks for voltage regulation and stabilization. However, the SVC device has no revolutionary parts, for the implementation of surge impedance compensation, and it was identified that the device is not suitable to be employed for the regulation of voltage up and downs because it has limited overload capability. The device was designed for power supply line with lesser load and simple network. Therefore, SVC device cannot provide adequate compensation to the present power supply line because of the huge, complex load and disturbance in the system. This work recommends that the SVC device must be improved or replaced with newer compensation devices in order to achieve better power supply improvement.

Keywords: Power Supply, Transmission Line, SVC, FACTS Devices, Power Stability

1. INTRODUCTION

The generating plant output is usually decided by the turbine mechanical torque, which could be altered by excitation value transiently. This alteration is associated with some disturbances in the form of power swing/oscillations that are usually unwanted. In interconnected large electric power systems, there have been always unwanted spontaneous system oscillations at very low frequencies in order of 0.2-2.0Hz (Kundur, 1994). There is need to damp the unwanted power swing by changing output power, controlling the excitation value and reducing the power oscillation in order to have a stable

system. The stability of electrical power can most simply be explained as the system ability to continue in a stable or equilibrium operation after the occurrence of some disturbances.
The advent of power electronics gave rise to the development of FACTS devices that effectively damp oscillations by circuits combined with the control strategies prominent in the modern control systems. FACTS devices have been designed to have a significant impact on the improvement of overall power systems performance and stability. Shunt FACTS controllers, such as Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM), are capable of effectively damping power swing mode oscillation especially in a low load condition.
SVC is the most common and major compensation method used in most developing nations such as Nigeria. However, despite the use of the SVC, there has been significant evidence of inefficiency in the power compensation due to the continuous presence of power fluctuation, brown-out, power surge and sudden blackout as a result of instability in the system. SVC consists of a set of shunt-connected capacitor and reactor banks with fast control action by means of thyristor switching; and it can be considered as a variable shunt reactance, which is adjusted in response to power system operative conditions in order to control specific parameters of the network. Depending on the equivalent SVC's reactance which is capacitive or inductive; the SVC is capable of drawing capacitive or inductive current from the electric power system at the coupling point (Barrios-Martínez E. and Ángeles-Camacho, 2017). SVC model may include a combination of both mechanically and thyristor-controlled shunt capacitors and reactors; however, the most popular configurations for continuously controlled SVCs are the combination of either fixed capacitor-thyristor controlled reactor (FC-TCR) or thyristor switched capacitor-thyristor controlled reactor (TSC-TCR) (Fuerte-Esquivel, 1997). It has some limitation as presented in (Elprocus, 2021).
Due to the increasing demand for steady and stable power supply and its need for economic growth and general development in the country, it has become very important to study the existing power compensation method in order to understand its principles and limitation and hence deduce the root of the power instability problem. This will help to provide a better solution than the usual load analysis and shading research that are more common.

2. LITERATURE REVIEW

In the quest to enhance power system damping, especially by utilizing and improving on the existing resources brought about the introduction of power electronics. The theory and improvements in the power electronics area led to a new advance introduced by the Electric Power Research Institute in the late 1980 and named FACTS. It was an answer for a more efficient use of already existing resources in present power systems while maintaining and even improving power system security (Eslami et al., 2012). This method appeared to be cheap and more convenient in implementation. In 1988, (Hingorani, 1995) the concept of FACTS devices have been initiated and their application. Edris et al. (1997) proposed terms and definitions for different FACTS controllers. As stated in (Eslami et al., 2012), there are two groups for recognition of power electronics-based FACTS controllers: the first group occupies conventional thyristor-switched capacitors and reactors, and quadrature tap-changing transformers, the second group occupies gate turn-off (GTO) thyristor-switched converters as voltage source converters (VSCs). The first group has produced in the Thyristor- Controlled Series Capacitor (TCSC), the Static VAR Compensator (SVC), and the Thyristor-Controlled Phase Shifter (TCPS). The second group has produced in the Unified Power Flow Controller (UPFC), the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) and the Interline Power Flow Controller (IPFC).
The AC transmission system has various limits classified as static limits and dynamic limits (Hingorani et al, 1999; Song et al, 1999). These inherent power system limits restrict the power transaction, which lead to the underutilization 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 the problem. However, there are restrictions as to the use of these conventional devices. Desired performance was not being able to be achieved effectively. Wear and tear in the mechanical components and slow response were the heart of the problems. Acharya et al (2004) stated that there was greater need for the alternative technology made of solid-state devices with fast response characteristics. The need 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 transmission lines (Paserba, 2004). This, together with the invention of Thyristor switch (semiconductor device), opened the door for the development of power electronics devices known as Flexible AC Transmission Systems (FACTS) controllers. The path from historical Thyristor based FACTS controllers to modern state-of-the-art voltage source converters-based FACTS controllers, was made possible due to rapid advances in high power semiconductors devices (Hingorani et al, 1999; Song et al, 1999). FACTS controllers have been in use in utilities around the world since 1970s, when the first utility demonstration of first family of FACTS named as Static Var Compensator (SVC) was accomplished. Since then the large effort was put in research and development of FACTS controllers (Acharya et al, 2004). The FACTS devices have recorded a trend of development from the first and traditional method to the recent advancement.
The use of Flexible Alternating Current Transmission System (FACTS) Controllers with fast responses and no major alterations to the system layout are increasingly replacing electromechanical devices (Adepoju et al., 2017). FACTS devices are power electronic devices or other static controllers incorporated in AC transmission systems to enhance controllability and increase power transfer capability (Hingorani and Gyugyi, 2000).

2.1. Static VAR Compensator

SVC is an electrical device for providing fast-acting reactive power compensation on high voltage electricity transmission networks (Eslami et, 2012). They are considered as part of the FACTS device family, regulating voltage and stabilizing the system. Static VAR Compensator is the most primitive and first generation of FACTS controllers (Acharya et al, 2004). Electric Power Research Institute (EPRI) brought this technology to the market three decade ago. This compensator consists of a fast thyristor switch controlling a reactor and/or shunt capacitor bank, to provide dynamic shunt compensation. More than 800 SVCs are being installed worldwide, both for utility and industrial (especially in electric arc furnace and rolling mills) application. Even the utilities in developing countries took the benefit of SVCs since its invention. ABB remains the pioneer in deployment of SVC and has supplied 55% of the total installation of which 13% were being installed in Asian countries (Acharya et al, 2004). The world’s first demonstration of SVC for utility application was installed in 1974, which was commercialized by General Electric (GE) (Hingorani and Gyugyi, 1999).

Thyristor controlled reactors and capacitors, termed as static var compensators 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 subsynchronous resonance, and damp power oscillations (Rahim and Al-Baiyat, 2003; Hosseini and Mirshekhar, 2001). Voltage controlled SVC, as such, does not provide any damping to the power system (Oliviera, 1994). However, it can be used to increase power system damping by introducing supplemental signals to the voltage set point (So and Yu, 2000).

From the review, it is known that the SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system (Eslami et al., 2011; Robak, 2009; Gu et al., 2007; Qun et al., 2003; Lo et al., 2003; Benabid et al., 2009; Li et al., 2009). The low frequency oscillation damping enhancement using SVC has been studied in the following works (Eslami et al., 2011). Self-tuning and model reference adaptive stabilizers for SVC control have been proposed and designed (Parniani and Iravani, 1998). Robust SVC controllers based on H∞, structured singular value μ, and quantitative feedback theory QFT has been presented to enhance system damping (Robak, 2009; Gu et al., 2007). Robustness control analysis was presented in Agbaraji (2015). Genetic algorithms and fuzzy logic-based approaches have been proposed for SVC control (Qun et al., 2003; Lo et al., 2003). Optimal location of SVC was investigated in many researches (Benabid et al., 2009; Haque, 2007). Messina and Barocio (2003) studied the nonlinear modal interaction in stressed power systems with multiple SVC voltage support. A robust nonlinear coordinated generator excitation and SVC controller was proposed to enhance the transient stability of power systems (Ruan et al., 2005; Wang et al, 2000). In (Li et al., 2009), a sensitivity model for var dispatch was proposed to restore the var reserve of SVC while keeping desirable voltage profile and the control capability of SVCs was defined by the available control margin, the slopes, the reference voltage, the static voltage characteristic of the system.

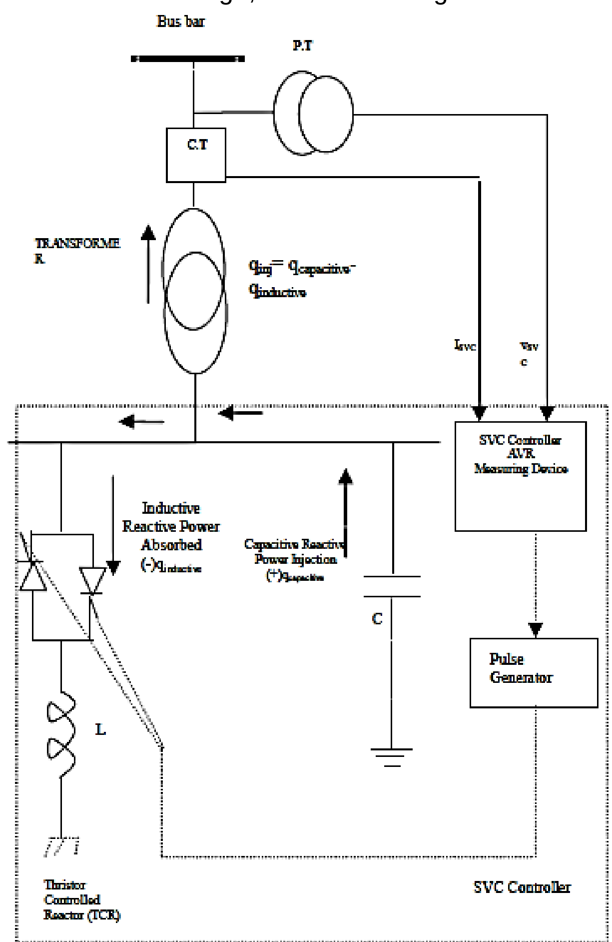

Figure 1: Basic Diagram of SVC Control (Rahim and Al-Baiyat, 2003)

An SVC can also be described as a controlled shunt suceptance which injects or absorbs reactive power into the system thereby mitigate the power system oscillations and improve the transient stability of the system. It can also be used to improve the steady state stability and voltage stability. Figure 1 shows the basic diagram of SVC Control.

3. SVC PRINCIPLE OF OPERATION

3.1 **SVC Function**

The SVC system is applied to the power line through direct connection or through a coupling transformer to the transmission lines. This is illustrated in figure 2 and figure 3 respectively. Though, most SVC devices cannot be operated at the line voltage levels, some transformers are required to step down the transmission voltage levels. This approach decreases the equipment and the size of the device necessary for the compensator even though the conductors be required to manage the extended levels of currents related to the minimum voltage. However, in some of the static VAR compensators used in commercial purposes like electric furnaces, prevailing mid-range of bus bars are present. In such case, a static VAR compensator will have a direct connection in order to conserve the transformer cost.

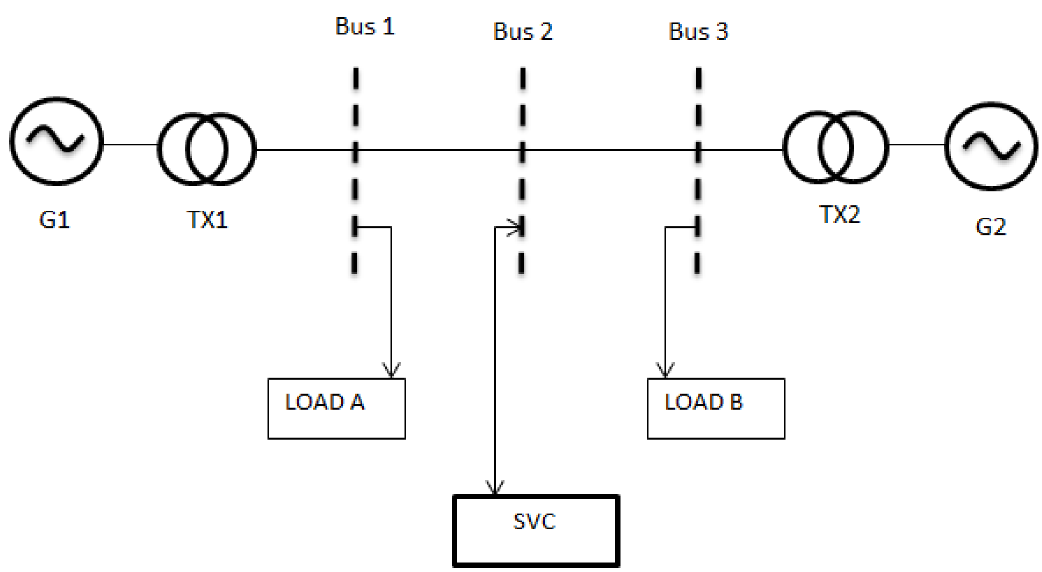

Figure 2: SVC direct connection to the power line

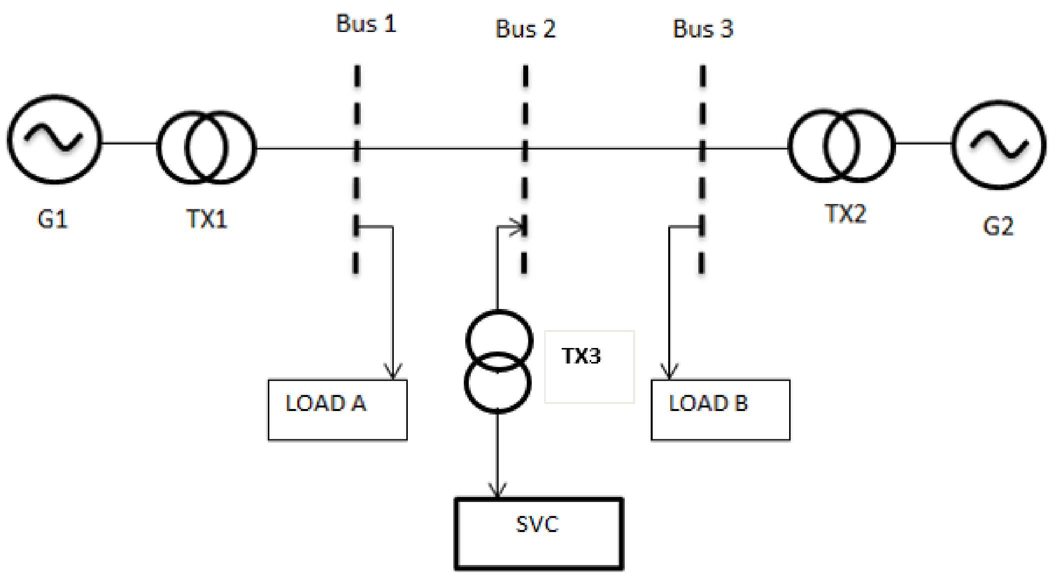

Figure 3: SVC connection to the power line through a coupling transformer

SVC systems can be classified into three types (Esteban, 2020)

i. Industrial SVCs are installed for example in steel mills, mines, oil & gas facilities and railway electrification systems. They are mainly used to improve power factor, reduce voltage fluctuations, increase production efficiency, reduce harmonic distortion, load balancing and improve installations' voltage profile.
ii. Renewables SVCs are installed for example in wind farms and solar power plants. They are mainly used to control reactive power and maintain the voltage level at the point of common coupling, and to reduce the voltage fluctuation caused by power variation during generation, stabilizing the electric power system.
iii. Transmission and distribution (or utility) SVCs are installed by electric utilities. They are large size SVCs, up to 1000 kV and hundreds of Mvar, mainly used to improve grid availability and the available active power, improve power factor, suppress voltage fluctuations, control voltage unbalance and reduce the loss of reactive power.

3.2 Components of SVC

The components of an SVC can be divided into the ones forming the passive part of the device and the ones forming the active part of the device (Esteban, 2020):

Passive Parts: The main components of the passive part are:

i. Step-up transformer: It enables the use of medium voltage thyristor valves by connecting the medium voltage and the high voltage electric power system.

ii. TCR reactors: They provide inductive reactive power by point-on-wave control (smooth adjustable output) from minimum current to full rated current. They absorb reactive power to decrease system voltage.
iii. MSC banks: They are usually tuned filter capacitor banks. They provide capacitive reactive power at fundamental frequency and they absorb the harmonic currents generated by the equipment and the TCR reactors.
iv. TSC banks: They provide capacitive reactive power by fast ON/OFF switching (output in blocks, no current or full rated current). They generate reactive power to increase system voltage.
v. Switchgear: Circuit breakers, contactors, earthing switches and disconnectors allow connection and maintenance of TCRs, MSCs and TSCs. CTs and VTs are used for the measurement of currents and voltages. Surge arresters protect medium voltage components.

Active Part: The main components of the active part are:

i. Thyristor valves: High-performance valves built on multilevel valve topology using modular light-triggered thyristors (LTTs) take care of switching the TCR reactors and TSC banks.
ii. Cooling system: De-ionized water system used for cooling the thyristor valves.
iii. Control system: Real-time operation control of the SVC ensuring response to system's requirements.
iv. Protection system: Real-time protection detecting system faults and abnormalities and disconnecting the SVC from the rest of the electric power system.
v. HMI: Monitors SVC condition and communicates with customers' SCADA system. It can also provide remote monitoring and analysis capability by IIoT.

3.3 Advantages and Limitations of SCV

Few of the **advantages of static VAR compensator** are (Elprocus, 2021):

- The power transmission ability for the transmission lines can be enhanced through these SVC devices
- The system's transient strength can also be increased through the implementation of SVC's
- In the case of a high range of voltages and for controlling steady states, SVC is generally used which is one of the foremost advantages
- SVC increases the load power rating and so the line losses will be decreased and system efficiency enhances.

The **limitations of the static VAR compensator** are (Elprocus, 2021):

i. As the device has no revolutionary parts, for the implementation of surge impedance compensation, additional equipment is needed.
ii. The size of the device is heavy
iii. Deliberate dynamic response
iv. The device is not suitable to employ for the regulation of voltage up and downs because of furnace loads
v. Limited overload capability

4. CONCLUSION

SVC is an electrical device and a type of the FACTS devices introduced for providing fast-acting reactive power compensation on high voltage electricity transmission networks for voltage regulation and stabilization. It consists of a fast thyristor switch controlling a reactor and/or shunt capacitor bank, to provide dynamic shunt compensation. However, the SVC device has no revolutionary parts, for the implementation of surge impedance compensation, thus additional compensation equipment is needed which may be very expensive. From the review, it was identified that the device is not suitable to be employed for the regulation of voltage up and downs because it has limited overload capability. Despite these limitations, the SVC has been the main compensation technique used in most transmission lines in Nigeria and some other developing nations. This has contributed to the power supply problems being faced in Nigeria which has affected the economic and social growth. Huge amount of money has been spent in the power supply system in order to improve the supply and quality of the supplied power, but issues such as sudden black out and brown out still exist as a result of instability in the lines which shows that the SVC is no longer efficient.
This work recommends that the SVC devices should be improved or replaced with newer compensation devices in order to achieve better power supply improvement.

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