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Comparative Study of Reactive Power Compensator Methods for Integration of Renewable Energy Sources

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Abstract. The integration of renewable energy sources with power system network brought a number of challenges. One of them is imperfect power quality. The power quality is the primary goal of an electrical power distribution system network. The assessment of demand for reactive power, required for inductive loads, limits the quality of power. In the past, many inductive power compensating techniques were used to control the inductive loads. A flexible alternating current transmission system (FACTS) devices like static synchronous compensator (STATCOM) and voltage source converter (SVC) are the state-of-the-art and the most modern reactive power compensators in order to deal with renewable energy sources. The current paper presents the study of the olden times of reactive power control methods used in the past and state-of-the-art reactive power control method through STATCOM & SVC. This paper also discusses effects of STATCOM and SVC on power system to progress the power quality .i.e. improvement in the power transfer capability of the transmission system and voltage stability for the distribution system.

Introduction

The emerging trend of renewable energy sources into power system network has brought many new challenges for power system operation, control and planning. The intermittent nature of renewable energy sources has made the power system uncertain and imperfect. The quality of power system network parameter is an essential factor. The voltage quality is a fundamental parameter among other methods. The emerging power quality problems and state-of-the-art solutions are presented in [1-3].

Most of the electrical power issues are related to the adequate control and monitoring of reactive power [4-7]. The supervision of reactive power can enhance the performance of AC electrical power system network [8]. The FACT devices SVC and STATCOM can deliver reactive power control in the transmission and distribution systems for voltage stability improvement [9]. There are two significant benefits of reactive power control. One is the compensation of inductive load, and other is voltage support. The primary goals of compensation of load are power factor improvement, the stability of real power drawn from AC supply, voltage regulation and to get rid of the current harmonics created by the massive industrial inductive load. The voltage support is necessary to decrease voltage variations at any node of an electric power system, network.

The transmission and distribution losses are considered normal if loss value is below 8% [10]. The functionality of modern electronic devices plays a vital rule for improvement of power quality, such

as a programmable logic controller (PLC) [11]. It is the responsibility of energy providers to deliver high-quality power to the consumers according to the specified standard voltage, magnitude, frequency and without any interruption. In this paper, olden to the state-of-the-art techniques are presented with corresponding advantage and disadvantages in order to control and monitor the reactive power in transmission and distribution power systems. The rest of the paper is organized as: Section 2, describe the different techniques for improvement of power system network voltage quality. Section 3, concludes the paper.

Comparison of Reactive Power Control Techniques

Fixed Capacitor Banks

The fixed capacitor banks were introduced first time in 1914 in order to improve the system power factor. Here the leading current of fixed capacitor bank compensates the current drained by the inductive load. The use of such type of compensators is limited to the smooth loads.

Switched Capacitors

For dynamic loads, switched capacitors are employed according to the requirement of the load. If the load is high, more capacitors are added. On the other hand, if the load is low, the capacitors are switched out with the help of relays and mechanical switches. The disadvantage of such type of compensators is that they make high inrush currents and necessitate routine maintenance.

Synchronous Condensers

Synchronous machines may also use as variable VAR compensators. They played a vital role for more than 50 years to control the reactive power. When the synchronous machine is overexcited, it produces reactive power which can be delivered to the high inductive load. On the other hand, when the synchronous machine is under excited, it has the ability to absorb reactive power. They can be used for both transmission and distribution systems. However, they are rarely used now a day because of the requirement of high cost on substation foundation and protective equipment. Also, their losses are very high as compared to static compensators.

Fixed Capacitors/self-saturated Reactor

Reactors have a predominant inductive coil. This is why they are said to belong to transformer family. They can be divided into two types.

Series Reactors. The purpose of these reactors is to limit the fault current in the distribution system, and they are connected in series.

Shunt Reactors. The purpose of shunt reactor is to compensate the reactive power, and they are connected in parallel. It is a fixed voltage device that delivers definite voltage. It consists of a variable reactor L and a variable capacitor C. The reactive power of the system is controlled by changing the values of L and C according to the requirement of the load and a fixed voltage is delivered to the load. In this scheme, switching losses are very high.

Static Compensators

With the invention of thyristor, fast control on the reactive power is possible. The response time of the thyristor is very small and static compensators are very popular for high dynamic industrial loads. They have the ability to switch into or switch out the inductor or capacitor banks according to the necessity of the load. The response time of static compensators is very fast and it became possible with the advent of thyristors. SVC and STATCOM are the shunt connected controllers as they are connected in parallel of the transmission line or inductive load. The configuration, working, advantages/disadvantages of STATCOM and SVC is discussed below.

Static Var Compensator. Static var compensators is a shunt connected device and practically, SVC can be divided into two basic groups, thyristor switch capacitor (TSC) and thyristor control rector (TCR).

(a) TSC basic principle and configuration: TSC type SVC configuration is shown in below Fig.1 (a) and it was first announced by ASEA in 1971. Here, shunt capacitor bank is switched in or switched out, according to the requirement of the load, with the help of bidirectional thyristors valve. There is a capacitor *C*, the thyristor switches SW_1 and SW_2 and a current limiting reactor (*L)* can be used in each phase. The basic function of *L* is to limit the current through switches SW_1 and SW_2.

(b) TCR basic principle and configuration: TCR type static compensator configuration is shown in Fig. 1(b), and in most of the cases TCR also contains fixed capacitor and filter to remove the low order harmonics. There is an inductor *L* and switches Sw_1 and Sw_2 in each branch of TCR. Reactors can be controlled by controlling the phase angle of the switches. When thyristors are fired at 90 degrees, full conduction is achieved and when thyristors are fired between 90 degrees and 180 degrees, a part of conduction is achieved as shown in Fig. 2(a).

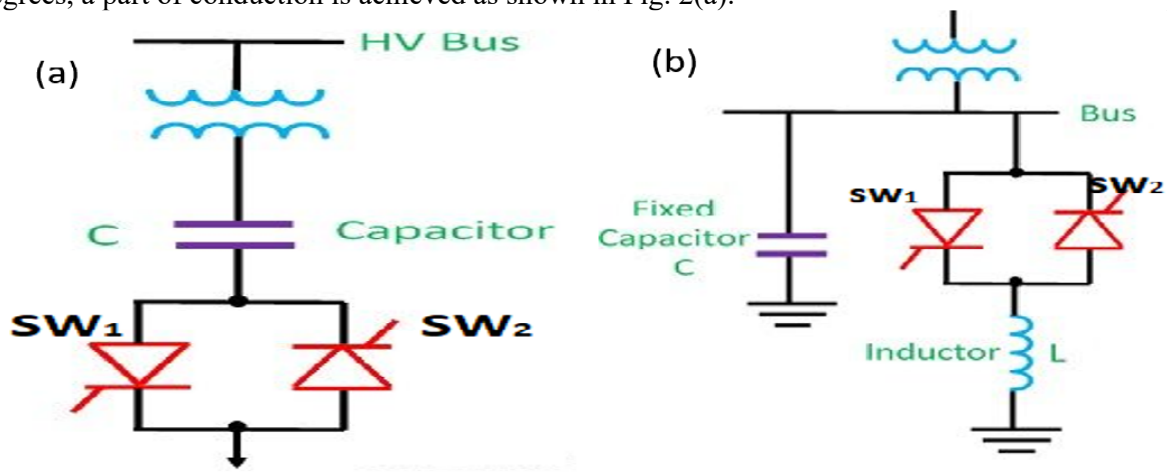


Figure 1. Basic configuration of (a) thyristor switch capacitor (b) thyristor control rector.

SVC basically is a combination of TSC and TCR and the combined TCR and TSC configuration is shown in Fig. 2(b). The SVC stables the voltage level at the weak points of the power network. In a transmission system, SVC can be installed at the start or the mid or at the end of a transmission line. However, it is noted that voltages are more stable and maintained when it was installed at the mid of the transmission system. The SVC stables the system voltages by controlling and monitoring the amount of reactive power and it inserts or absorbs the VARS. When system voltage is a smaller amount than the specified value, SVC produces the reactive power and the behavior of SVC is capacitive. As system voltage is high than the specified value, it absorbs the reactive power and SVC behavior is inductive.

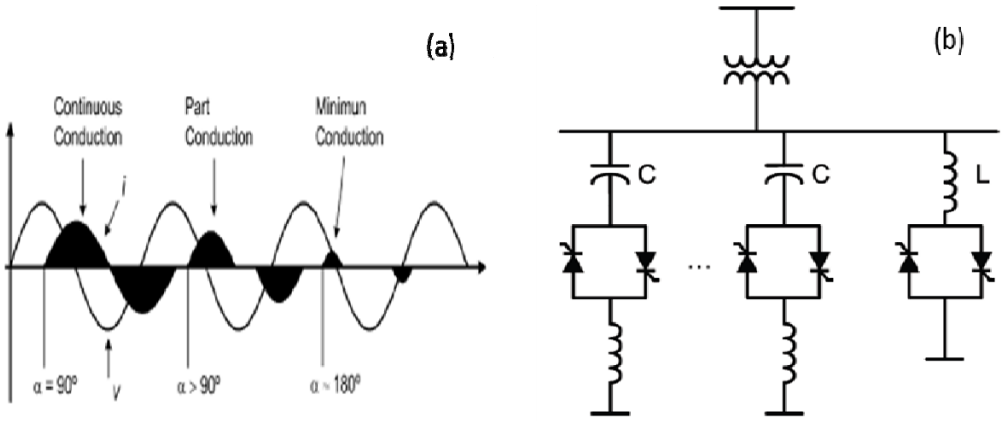


Figure 2. (a) Voltage and current waveforms with TCR for different phase angles (b) Combined TSC & TCR.

In heavy industries, where the load behavior is very dynamic, SVC has the advantage to control the transients in voltages. For example, in Hot Rolling Steel Mills, load pattern is very dynamic. It changes with the variation in rolling temperature of consecutive steps, the composition of the material, rolling method and according to load nature. For such type of loads, fixed capacitors are not able to compensate the reactive power. SVC is the solution to control such type of transient loads.

Advantages of SVC:

- Its cost is less as compared to STATCOM.
- As this device is based on capacitors and inductors, so it controls the reactive power more precisely at the time of fault as compared to STATCOM.

Static Synchronous Compensator-STATCOM

It is also a shunt connected compensator and here VSC is used rather than reactors and switched capacitors.

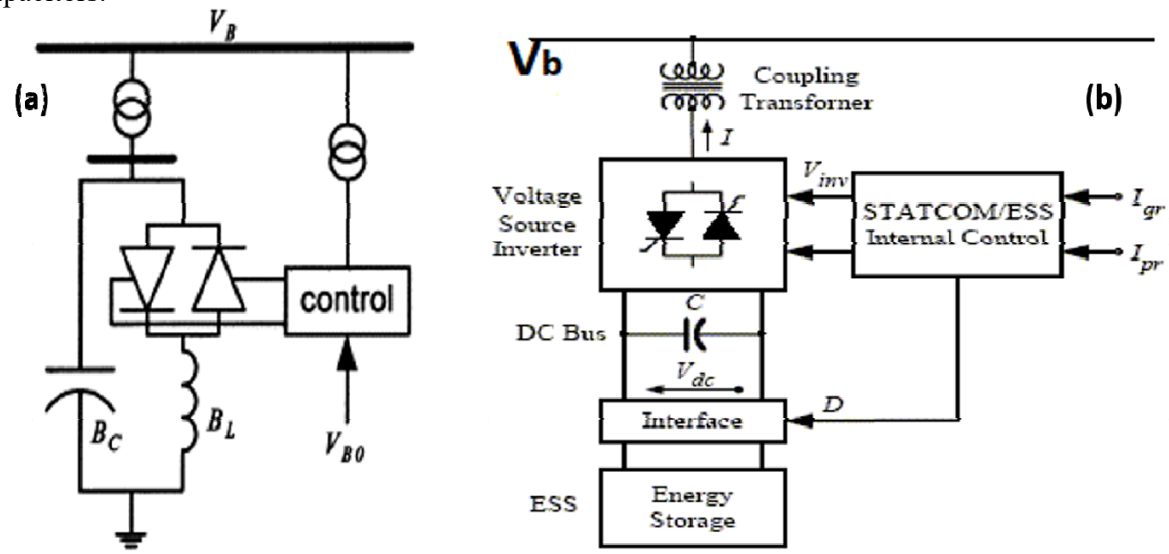


Figure 3. Configuration of STATCOM with (a) Basic control, (b) Integrated with Energy Storage.

Fig. 3(a) shows the most straightforward configuration of a STATCOM with control circuity. Its basic components are the DC voltage source, voltage source inverter and a coupling transformer. There are two controls in the STATCOM. One is, inside the STATCOM, DC voltage control and other is the AC voltage regulation at the bus bar or the location where the STATCOM is installed. The regulation of AC voltage is made by monitoring the reactive power interchange between the STATCOM and power system. The PWM (Pulse Width Modulation) technique is used in VSC. DC voltage across the capacitor must be kept constant for PWM algorithm. Basically, by converting DC input voltage into AC output voltage, STATCOM monitors the active and reactive power of the system. The AC output voltage can be controlled in phase and magnitude and the active power can also be exchanged by adding the energy source on DC side. Fig. 3(b) shows the STATCOM with integrated energy storage.

Figure 4 shows another way of the configuration of STATCOM. *E* is the STATCOM inverter voltage, X_{tie} is the tie reactance connected to an AC system with voltage source *Vth* and *Xth* is the Thevenin reactance. For higher converter voltage, STATCOM operates in the capacitive mode as it senses inductive reactance at its terminal. In this situation, the device produces reactive power and the current flows from the STATCOM to the AC system. There is a 90 degree lead of the capacitor current supposing zero converter loss.

Advantages of STATCOM over VSC:

- Its response time is very high as compared to SVC.
- It provides more reactive power other than the fault conditions.

- It needs less space as huge passive elements such as reactors are excluded.
- Its performance is very high during system low voltage conditions.
- Interfacing is possible with real power sources such as a battery, fuel cell or SMES.

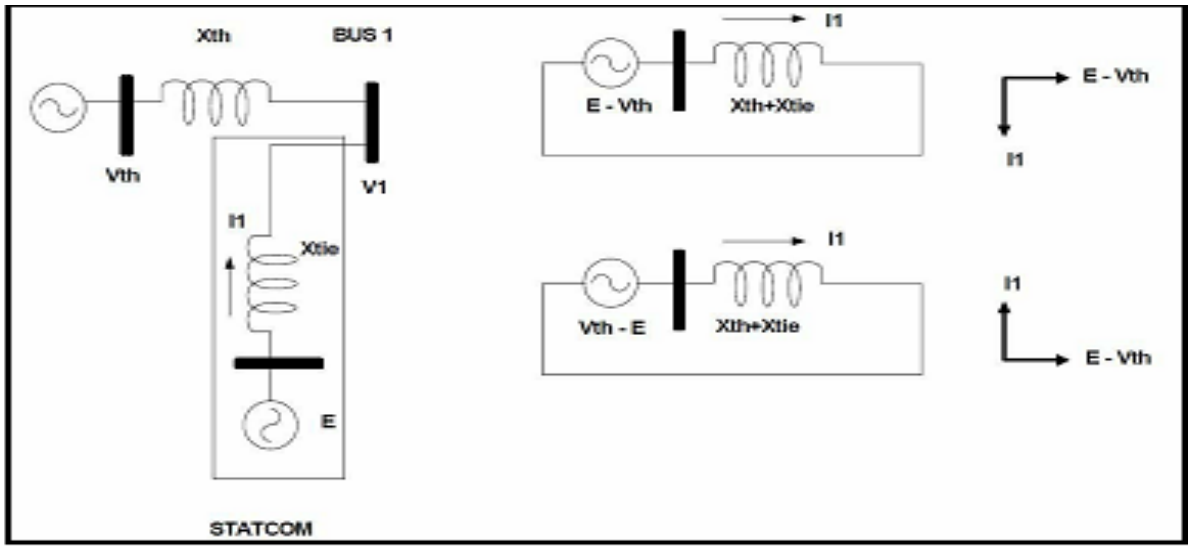


Figure 4. STATCOM operation in capacitive & Inductive Mode.

Conclusion

This paper has been discussed the history of reactive power compensators and basic configuration, working, applications, advantages and disadvantages by comparing the state-of-the-art reactive power compensators like SVC and STATCOM. The comparative technical study shows that SVC or STATCOM are the shunt devices and can be used for the transmission line in order to increase the power transfer ability of the transmission network. These devices can also be installed at the load points where the nature of the load is very dynamic in order to stabilize the voltages at the terminals where these devices are connected. Additional, response of static devices for improvement of power system quality in the presence of renewable energy sources, especially for reactive power regulation is tremendous.

Acknowledgements

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Conflicts of Interest

The authors declare no conflict of interest.

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