Flexible Alternating Current Transmission Systems (FACTS), Volume II

An Online Continuing Education Course for Engineers

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Flexible Alternating Current Transmission Systems (FACTS), Volume II

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Introduction

The first volume is this series provided a basic description of power flow and voltage supply concepts and outlined the types of *Flexible Alternating Current Transmission System* (FACTS) devices. The operation of one of the earliest FACTS devices, a Static Var Compensator (SVC) was explained.

Static VAR Compensator (SVC), described in Volume I, is a first-generation FACTS device that can control voltage at the required bus thereby improving the voltage profile of the system. The primary task of an SVC is to maintain the voltage at a particular bus by means of reactive power compensation. SVCs have been installed in lieu of traditional shunt compensation to dampen power swings, improve transient stability, and reduce system losses by optimized reactive power control.

This volume builds on the basics of volume I and describes the following FACTS devices,

- Static Synchronous Compensator (STATCOM),
- Distribution STATCOM,
- Series Static Synchronous Compensator (SSSC),
- Thyristor Controlled Series Capacitor (TCSC), and
- Unified Power Flow Controller (UPFC).

FACTS devices use power electronic components and conventional equipment in different configurations for switching or controlling reactive power for active power conversion or control. Many of the devices in this volume focus on voltage source converter (VSC) technology. FACTS controllers based on VSC have several advantages over the variable impedance type. For example, a STATCOM is a solid-state shunt compensation device using a voltage source converter. A STATCOM injects an almost sinusoidal current, of variable magnitude, at the point of connection. This injected current is almost in quadrature with the line voltage, thereby emulating an inductive or a capacitive reactance at the point of connection with the transmission line. A STATCOM is much more compact than an SVC for a similar rating and is technically superior. It can supply the required reactive current even at low values of the bus voltage and can be designed to have built-in short-term overload capability. Also, a STATCOM can supply active power if it has an energy source or large energy storage at its DC terminals.

The only drawback with VSC-based controllers is the requirement for self-commutating power semiconductor devices such as Gate Turnoff (GTO) thyristors and Insulated Gate Bipolar Transistors (IGBT). Thyristors do not have this capability and cannot be used although they are available in higher voltage ratings and tend to be cheaper with reduced losses. However, the technical advantages with

VSC-based controllers coupled will emerging power semiconductor devices using silicon carbide technology are expected to lead to the widespread use of VSC-based controllers in the future.

The use of FACTS technology increases the value of the transmission system by facilitating a greater utilization of the system's existing assets. FACTS controllers can control the network condition in a very fast manner and this feature of FACTS can be exploited to improve the voltage stability, steady-state, and transient stabilities of a complex power system. This allows increased utilization of the existing network closer to its thermal loading capacity, thus avoiding the need to construct new transmission lines.

Course Structure

This series is divided into two volumes. It is recommended that the courses be taken in sequence.

Volume I

Volume I is an introduction to FACTS devices and an explanation of the design and application of one of the earliest FACTS devices – a Static Var Compensator (SVC). Chapter One of introduces the family of FACTS controllers and their respective applications. Chapter Two provides technical insight into how FACTS device help control power flow in a transmission system. Chapter Three discusses Static Var Compensators in detail.

Volume II

Volume II explains other prominent FACTS devices such as STATCOMS, SSSR, TCSC, and UPFC devices. Chapter One describes the design and application of a STATCOM. Chapter Two explains a variant of the STATCOM, which is a distribution STATCOM (DSTATCOM). Chapters Three, Four, and Five describe the design and application of Thyristor Controlled Series Capacitor (TCSC), Series Static Synchronous Compensator (SSSC), and Unified Power Flow Controller (UPFC) respectively.

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Chapter 1: Static Synchronous Compensator (STATCOM)

Like an SVC, a Static Synchronous Compensator (STATCOM) is a shunt-connected reactive-power compensation device that can generate and/or absorb reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals.

Photo of an Operating STATCOM System

A STATCOM is a converter-based compensator and uses either a *voltage source inverter* (VSI) or a *current source inverter* (CSI) though STATCOMs are mostly based on VSI technology. The output can be varied to control the specific parameters of an electric power system. These *voltage source converters* (VSCs) use require self-commutated power semiconductor devices such as either *Gate Turn Off Thyristors* (GTOs) or *Insulated Gate Bipolar Transistors* (IGBTs). A direct current (DC) voltage source is used to generate a set of three-phase AC output voltages.

STATCOM has several advantages over SVC's though they are costlier and exhibit higher losses. The response time of a STATCOM is shorter than that of an SVC, mainly due to the faster switching times provided by the IGBTs of the voltage source converter. As a result, the reaction time of a STATCOM is one to two cycles vs. two to three cycles for an SVC.

The technical advantages of a STATCOM over an SVC include:

- Faster response times,
- Require less space,
- Does not require reactors,
- Inherently modular, and
- Can be interfaced with real power sources such as batteries.

STATCOMs appear as an adjustable voltage source behind a reactance, and as such do not require capacitor or reactor banks to generate/absorb reactive power. Figure 1 is a schematic of a STATCOM.

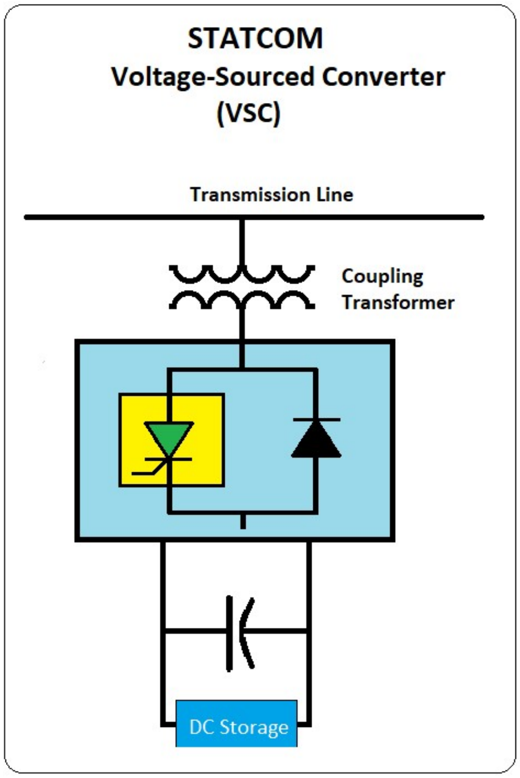

Figure 1

The primary components of a STATCOM include a Voltage Source Converter (VSC), DC storage system, coupling transformer, and commonly a harmonic filter, and are described below,

- The voltage-source converter is used to convert the DC input voltage to an AC output voltage. This is accomplished with either square-wave inverters such as Gate Turn-Off Thyristors (GTOs) or Pulse Width Modulation inverters which use Insulated Gate Bipolar Transistors (IGBT). GTO inverters control the AC output voltage by changing the DC capacitor input voltage since the fundamental component of the converter output voltage is proportional to the DC voltage. IGBT inverters use PWM technology to create a sinusoidal waveform from a DC voltage source with a typical chopping frequency of a few kHz. In contrast to the GTO-based type, the IGBT-based VSC utilizes a fixed DC voltage and varies its output AC voltage by changing the modulation index of the PWM modulator.

- The DC storage system uses DC capacitors to supply constant DC voltage to the voltage source converter, VSC. The coupling transformer is connected between the output of the VSC and the HVAC transmission system. In addition to stepping voltage up to the HVAC transmission voltage, it can also neutralize some of the harmonics contained in the square waves produced by VSC.

- The harmonic filter attenuates the harmonics and other high-frequency components due to the VSC.

STATCOM controls the output current independently of the AC system voltage, while the DC voltage is automatically maintained to serve as a voltage source. A STATCOM has superior performance during low voltage conditions as the reactive current can be maintained and, in some cases, reactive current can be increased in a STATCOM during transient conditions. This is because the reactive power from a STATCOM decreases linearly with the AC voltage, as opposed to power being a function of a square of voltage as with an SVC. The SVC is not used in severe undervoltage conditions of less than 0.6 per unit (p.u.), since leaving the capacitors on can worsen the transient overvoltage once the fault is cleared, while STATCOM can operate down to about 0.15 to 0.2 p.u.

STATCOM has much better dynamic performance than conventional reactive power compensators like SVCs. The gate turn-off ability shortens the dynamic response time from several utility period cycles to a portion of a period cycle. STATCOM is also much faster in improving the transient response than an SVC. This advantage also brings higher reliability and a larger operating range. Figure 2 is a comparison of the V-I characteristics of an SVC and a STATCOM.

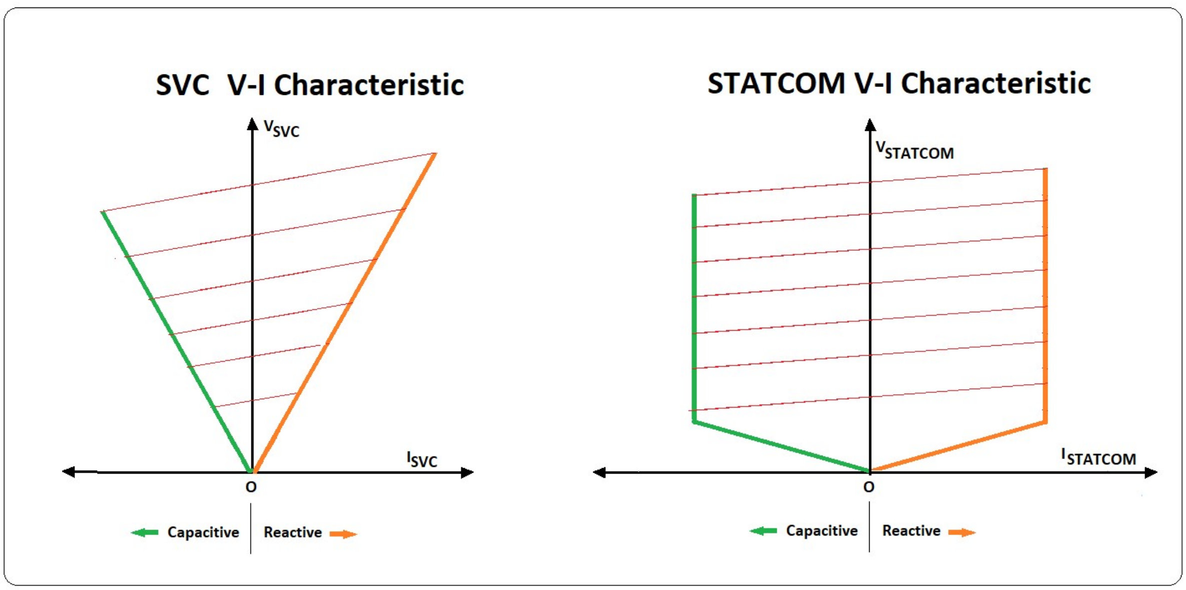

Figure 2

STATCOMs generate harmonics because of power electronic switching. To resolve these undesired effects, STATCOMs can employ filters. In addition, their robust switching capability also enables them to employ strategies to mitigate harmonic production.

Summary Comparison of SVC versus STATCOM Characteristics

A summary of the characteristics of SVCs versus STATCOMs is provided in Table 1.

Table 1
Comparison of SVC and STATCOM

Issue	SVC	STATCOM
V/I characteristic	Good over-voltage perf... Impeda...	Good ... ge performance
Control rang...		...lutions
Modularity		...e for various
Redundancy		
Response time		
Transient behavio...		
Space requirement...		
Availability		
Investment costs		...c

Operation of a STATC...

STATCOM is a controlled reactive power source. It provides the desired reactive power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC). A STATCOM is seen as an adjustable voltage source behind a reactance, meaning that capacitor banks and shunt reactors are unnecessary for reactive power generation and absorption. This results in a compact design, or small footprint, as well as low noise impact.

Although STATCOM devices provide a measure of capability beyond SVCs, the fundamental intent of these devices is to provide voltage control, via reactive power support, to the transmission system.

The exchange of reactive power between the converter and the AC system can be controlled by varying the amplitude STATCOM output voltage. If the amplitude of the STATCOM voltage is increased above that of the system voltage, then current flows into the transmission system and the STATCOM generates capacitive-reactive power for the system. If the amplitude of the STATCOM voltage is decreased below