

FACTS Controllers in Electric Power Systems and Effects of STATCOM Controller

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Abstract—In recent years, rapid developments in industry and industry have increased the demand for electricity. In order to meet these increasing demands, new transmission networks must be established; or to reduce losses in existing networks and to increase the active power delivered. Reactive power compensation is used to increase the efficiency of existing networks. With the help of the reactive power compensation, the transmitted power is increased, line losses are reduced and the amplitude of the voltage at the end of the line is stabilized. Especially with the help of developing semiconductor technologies, control of the energy system has created an efficient, fast and reliable technology known as FACTS (Flexible AC Transmission Systems). FACTS devices provide reactive power compensation, phase angle control, current and voltage control in AC transmission systems. FACTS devices are more powerful than mechanical controllers because they are power electronics based. Until now, many power flow controllers have been proposed under the name of FACTS. The latest developed FACTS controllers are converter based controllers that operate according to the principle of synchronous voltage supply. The most commonly used are STATCOM, static synchronous serial compensator (SSSC), static compensator (SVC) and combined power flow controller (UPFC).

Keywords—Compensation, FACTS, STATCOM

I. INTRODUCTION

With the rapid growth of modern industry and load demand, power system voltage instability has become the primary threat to system stability. Voltage stability is very important, especially when the power system becomes too complicated for control [1]. Voltage stability can be defined as the ability of a power system to maintain acceptable voltages at all busbars in the system under normal operating conditions and after being subjected to a disruptive effect [2]. There are many factors that affect the voltage stability of the power system: These effects; insufficient reactive power, automatic warning system and its controllers connected to the generator, voltage dependent loads, load voltage regulation transformers, static var compensators placed in the transmission system to improve the voltage. Reactive power compensation is often the most effective method to improve both transmission capacity and voltage stability.

Reactive power flow control started with the application of fixed reactor and capacitor groups to provide a suitable voltage profile. The use of these devices has minimized voltage fluctuations caused by load changes and reduced losses [3]. In AC power systems, mechanically switched capacitor and reactor groups have been used for many years to overcome reactive power problems. However, controlling capacitor and reactor switching has been an important problem for power engineers. Because, due to their slow response times, such elements cannot provide the necessary compensation during transients and they can actually decrease the system stability after facing disruptive effects [4].

Recent studies show that if the reactive compensation of the transmission line is performed with power electronics based circuits, the transient and dynamic stability of the power system can be improved [5]. The idea of producing a directly controllable reactive power without inductors or capacitors with power electronics switched converter circuits was first put forward by Gyugyi in 1976 [6]. At the end of the 1980s, the FACTS concept, which aims to increase or improve the capacity of existing power systems and solve operational problems, was introduced by the Electric Power Research Institute (EPRI) as a new technological idea in parallel with the development of semiconductor power technology.

According to IEEE, FACTS is defined as follows: It is a power electronics based system and other static equipment that provides control of one or more alternating current transmission system parameters to increase controllability and power transfer capacity. Since FACTS controllers are a power electronics based application, they are faster than conventional mechanical controllers (shunt capacitor, serial capacitor, phase shifter, etc.). When these controllers are properly adjusted, they increase the stable operation limits of transmission systems. These devices provide the control of the power system through the appropriate compensation of network parameters such as the serial impedance, current, voltage and active and reactive power of the transmission line [7]. FACTS devices have two main purposes:

- a) To increase the power transfer capacity of transmission systems.
- b) Ensuring control of power flow on defined transmission routes.

Until today, many power flow controllers have been proposed under the name of FACTS and many FACTS applications have been carried out worldwide. Power electronics based controllers generally; It is possible to divide it into two as “Thyristor Based Controllers or traditional static Var compensators (SVC) and“ Converter Based Controllers or advanced static Var compensators (ASVC) ”which work on the principle of Synchronous Voltage Source. Thyristor is used as the switching element in thyristor based FACTS devices. Thyristor Controlled Static Var Compensator (TCSVC), one of the thyristor based FACTS devices, is the first FACTS device applied. TCSVC, which was developed for arc furnace compensation in the early 1970s, was used for energy transmission applications in the following years. The most recently developed FACTS controllers are converter-based controllers operating according to the synchronous voltage source principle. The most used of these are STATCOM, static synchronous serial compensator (SSSC), interline power flow control (IPFC) and unified power flow control (UPFC).

Among these devices, STATCOM (Static Synchronous Compensator) based on voltage source converter is one of the most used devices [8]. STATCOM can regulate the voltage at its location by injecting reactive current into the system or consuming it from the system.

II. FACTS TECHNOLOGY

It is possible to examine FACTS devices in two ways as traditional thyristor based controllers and advanced converter based controllers. Thyristor based controllers use conventional thyristors as the switching and regulation device. Although thyristor-based devices have circuit structures similar to conventional devices (circuit breaker switched capacitor and reactor, phase shifter, transformer tap changer, etc.) that work mechanically, they operate extremely faster than these devices.

Advanced FACTS devices, on the other hand, use switched converters operating according to the SSI (Synchronous Voltage Source) principle. These converters use self-supervising semiconductor elements such as GTO as building blocks. Converter based devices provide uniform applicability and superior performance characteristics for voltage, line impedance and phase angle control when compared to conventional thyristor based FACTS devices. The SSI approach offers the ability to directly change the active power with the AC system if the converter is connected with a sufficiently large energy storage device and provide independent, controllable reactive power compensation [9]. In this study, STATCOM, one of the converter based FACTS applications, will be focused on.

III. STATCOM

STATCOM, known as Static Var Compensator (ASVC), is a FACTS controller that is controlled to draw reactive current from the power system and is made by connecting an inverter between a dc energy storage element and the three-phase system. It is a FACTS device connected to the STATCOM transmission line as a shunt. STATCOM's main task is; It is to regulate the voltage of the transmission line at the junction by drawing a controlled reactive current from the transmission line [5]. This FACTS controller is named STATCOM because it displays the operating characteristics of a rotating synchronous compensator in steady state state.

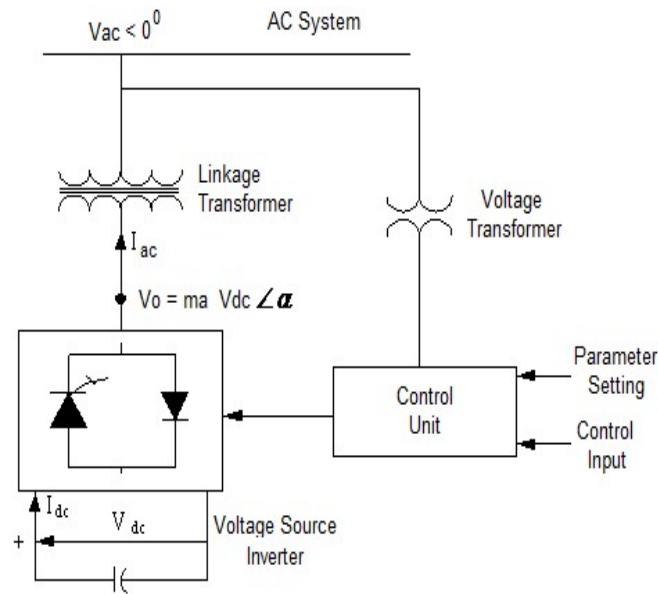


Fig 1. STATCOM circuit diagram

In the simplest form as seen in Figure 1, a STATCOM controller; It consists of a connection transformer, voltage source inverter and dc energy storage element. Since the energy storage element is a very small capacitor, it can only exchange reactive power with the STATCOM transmission system. If an accumulator or other dc voltage source is used instead of a dc capacitor, the controller can exchange active and reactive power with the transmission system by extending the operating range from two-zone operation to four-zone operation. The amplitude and phase angle of the STATCOM output voltage can be changed. For this, the amplitude and frequency of the ac output voltage of the inverter in the STATCOM circuit must be adjusted. This is done by using DGM techniques in inverters. $V_0 = m_a V_{dc}$ is controlled as the amplitude of the fundamental component of the ac output voltage of an inverter. Here m_a is the modulation index. If the dc voltage is considered constant, the amplitude of the fundamental component of the ac output voltage of the inverter can be adjusted by increasing or decreasing the m_a DGM technique used.

By changing the amplitude of the inverter's 3-phase output voltage, the STATCOM's reactive power generation or draw can be controlled. If the output voltage (V_0) of the inverter is greater than the AC system voltage (V_{ac}) then AC current (I_{ac}) flows through the transformer reactance into the ac system that produces reactive power from the inverter. In this case, the inverter generates capacitive current for the AC system at an angle beyond its voltage. If the amplitude of the inverter's output voltage is smaller than the ac system voltage, AC current flows from the AC system to the inverter from the voltage source. In this case, it draws an inductive current at an angle behind the inverter voltage, that is, it consumes inductive reactive power. If the output voltage of the inverter and the amplitudes of the AC system voltages are equal, there will be no AC current flow from the inverter to the AC system or from the AC system to the inverter. In short, the inverter will not produce or consume reactive power [10].

Assuming that the I_{ac} current flows from the inverter to the ac system, the amplitude of the ac current can be calculated by equation (1):

$$I_{ac} = \frac{V_0 - V_{ac}}{X} \quad (1)$$

Where X is the leakage reactance of the link transformer. Mutually exchanged reactive power can be expressed as in equation (2).

$$Q = \frac{V_0^2 - V_0 V_{ac} \cos \alpha}{X} \quad (2)$$

Active power exchange between inverter and ac system can be controlled by phase shifting the inverter output voltage relative to the ac system busbar voltage. If the inverter output voltage is ahead of the ac system voltage, the inverter will provide active power from the dc capacitor to the ac system. If the inverter output voltage is lower than the ac system voltage, the inverter will draw active power from the ac system. The amount of active power delivered and received in the steady state is usually small. Active power exchange between the voltage source inverter and the ac system can be calculated using equation (3).

$$P = \frac{V_{ac} V_0 \sin \alpha}{X} \quad (3)$$

1.1 Control of STATCOM

Only two methods are used for control in STATCOM applications in power systems. These are the traditional phase control technique and pulse width modulation control technique (DGM-STATCOM). In both methods, the basic circuit structure of STATCOM is exactly the same. The main difference between the two control approaches is due to the control method used.

In this study, only DGM-STATCOM technique will be mentioned. In this control technique, it is more advantageous than the conventional phase control technique as the active and reactive components of the output current of the inverter are controlled independently from each other [11]. In DGM-STATCOM, unlike the conventional phase control technique, it is accepted that the dc voltage does not change. The basic STATCOM circuit using the DGM control technique is shown in Figure 2.

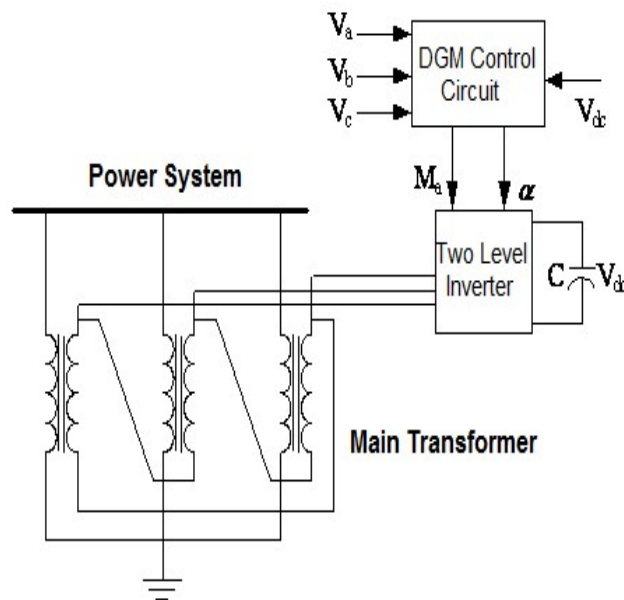


Fig 2. DGM controlled STATCOM circuit

DGM controlled inverters are used in DGM control technique. In DGM controlled inverters, it is possible to control the duty period of the switches in a wide range. This means that the switching frequency for the inverter can be increased. Increasing the switching frequency allows less harmonic output from the inverter. The internal structure of the DGM control circuit in Figure 2 is shown in Figure 3. As seen in Figure 3, DGM control circuit has three sub-control loops. These are loops that provide ac voltage control, dc voltage control and synchronization. The AC voltage controller loop determines the reactive power exchange between the power system and the inverter.

DC voltage controller loop; It ensures that the capacitor voltage remains at the desired reference value and determines the active power exchange between the ac system and the inverter. The synchronization loop determines the phase angle, frequency and angular velocity of the voltage belonging to one phase of the busbar to which the STATCOM is connected [12].

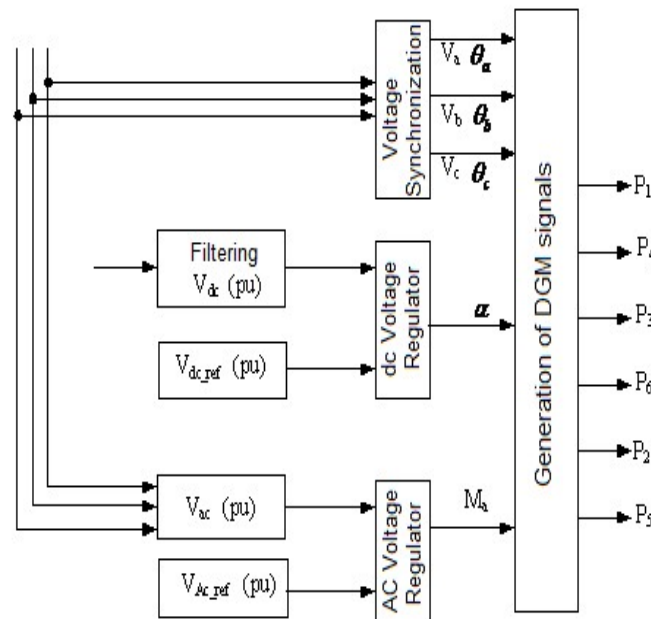


Figure 3. Internal structure of the DGM control circuit.

IV. CONCLUSIONS

Electricity companies show great interest in FACTS technology due to many reasons such as the disadvantages of conventional compensation devices, increasing energy demand, restrictions in the construction of new lines. The costs of FACTS devices are considerably higher than conventional compensation devices. However, the benefits to be obtained with the installation of these devices may be equivalent to the benefits obtained by installing new lines. Therefore, the installation of these devices may potentially delay the construction of new lines. Therefore, in-depth system analysis is required to solve transmission system problems in the most cost-effective and coordinated manner.

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