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Compensation Of Transmission Line By Advance FACTS Devices

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Abstract—

During the past two decades, the increase in electrical energy demand has presented higher requirements from the power industry. More power plants, substations, and transmission lines need to be constructed. However, the most commonly used devices in present power grid are the mechanically-controlled circuit breakers. The long switching periods and discrete operation make them difficult to handle the frequently changed loads smoothly and damp out the transient oscillations quickly. The demands of lower power losses, faster response to system parameter change, and higher stability of system have stimulated the development of the Flexible AC Transmission systems (FACTS) .

Keywords— FACTS controllers, FACTS, power electronic equipment, STATCOM

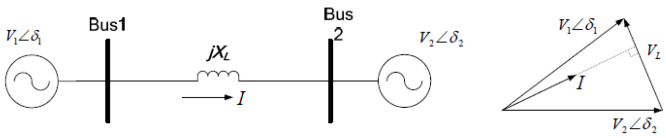
I INTRODUCTION

In general, the problem of reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation the objectives are to increase the value of the system power factor, to balance the real power drawn from the ac supply, compensate voltage regulation and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line. Reactive power compensation in transmission systems also improves the stability of the ac system by increasing the maximum active power that can be transmitted. Series and shunt VAR compensation are used to modify the natural electrical characteristics of ac power systems. Series compensation modifies the transmission or distribution system parameters, while shunt compensation changes the equivalent impedance of the load.

Based on the use of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies, Flexible AC Transmission Systems, also known as FACTS, have been developed and represent a new concept for the operation of power ransmission systems.

II Basic principal of power compensation in transmission system.

Figure 1(a) shows the simplified model of a power transmission system. Two power grids are connected by a transmission line which is assumed lossless and represented by the reactance X_L. $V_1\angle\delta_1$ and $V_2\angle\delta_2$ represent the voltage phasors of the two power grid buses with angle $\delta = \delta1 - \delta2$ between the two. The corresponding phasor diagram is shown in Figure 1(b).



(a) (b)

Fig.1 Power transmission system: (a) simplified model; (b) phase diagram.

The magnitude of the current in the transmission line is given by:

$$I = \frac{V_L}{X_L} = \frac{|V_1\angle\delta_1 - V_2\angle\delta_2|}{X_L} \quad \text{--------} \qquad (1)$$

The active and reactive components of the current flow at bus 1 are given by:

$$I_{d1} = \frac{V_2 \sin\delta}{X_L}, \qquad I_{q1} = \frac{V_1 - V_2\cos\delta}{X_L} \quad \text{-------} \qquad (2)$$

The active power and reactive power at bus 1 are given by:

$$P_1 = \frac{V_1 V_2 \sin\delta}{X_L}, \qquad Q_1 = \frac{V_1(V_1 - V_2\cos\delta)}{X_L} \quad \text{----} \qquad (3)$$

Similarly, the active and reactive components of the current flow at bus 2 can be given by:

$$I_{d2} = \frac{V_1 \sin\delta}{X_L}, \qquad I_{q2} = \frac{V_2 - V_1\cos\delta}{X_L} \quad \text{-----} \qquad (4)$$

The active power and reactive power at bus 2 are given by:

$$P_2 = \frac{V_1 V_2 \sin\delta}{X_L}, \qquad Q_2 = \frac{V_2(V_2 - V_1\cos\delta)}{X_L} \quad \text{----} \qquad (5)$$

Equations (1) through (5) indicate that the active and reactive power/current flow can be regulated by controlling the voltages, phase angles and line impedance of the transmission system. The active power flow will reach the maximum when the phase angle δ is 90º. In practice, a small angle is used to keep the system stable from the transient and dynamic oscillations.

A Shunt Compensation.

Figure 2 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac system, which comprises a source V1, a power line and a typical inductive load. Figure 2-(a) shows the system without compensation, and its associated pharos diagram. In the pharos diagram, the phase angle of the current has been related to the load side, which means that the active current IP is in phase with the load voltage V2. Since the load is assumed inductive, it requires reactive power for proper operation and hence, the source must supply it, increasing the current from the generator and through power lines. If reactive power is supplied near the load, the line current can be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals. This can be done in three ways: a) with a capacitor, b) with a voltage source, or c) with a current source. In Fig. 2-(b), a current source device is being used to compensate the reactive component of the load current (IQ). As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated.

If the load needs leading compensation, then an inductor would be required. Also a current source or a voltage source can be used for inductive shunt compensation. The main advantages of using voltage or current source VAR generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection.

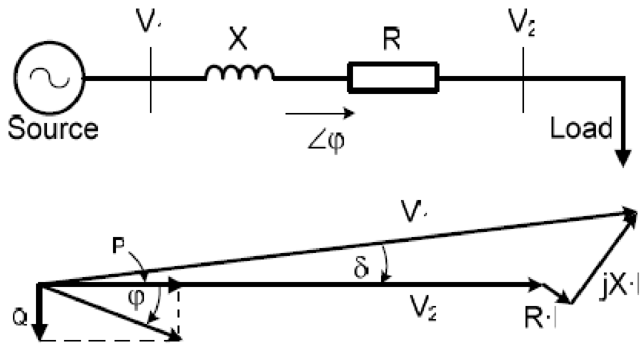


Fig. 2.(a) Principles of shunt compensation in a radial ac system. Without reactive compensation.

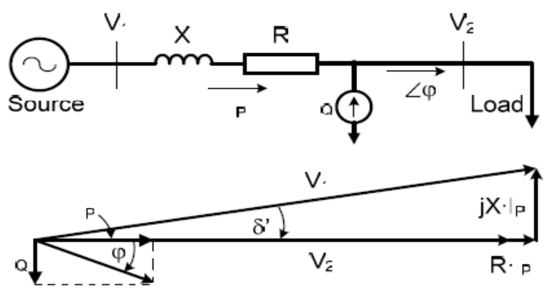


Fig. 2.(b) Principles of shunt compensation in a radial ac system. Shunt compensation with a current source.

B Series Compensation

Like shunt compensation, series compensation may also be implemented with current or voltage source devices, as shown in Fig. 3. Figure 3-a) shows the same power system of figure 1-a), also with the reference angle in V2, and Fig. 3-b) the results obtained with the series compensation through a voltage source, which has been adjusted again to have unity power factor operation at V2. However, the compensation strategy is different when compared with shunt compensation. In this case, voltage VCOMP has been added between the line and the load to change the angle of V2’, which is now the voltage at the load side. With the appropriate magnitude adjustment of VCOMP, unity power factor can again be reached at V2. As can be seen from the pharos diagram of Fig. 3-b), VCOMP generates a voltage with opposite direction to the voltage drop in the line inductance because it lags the current IP.

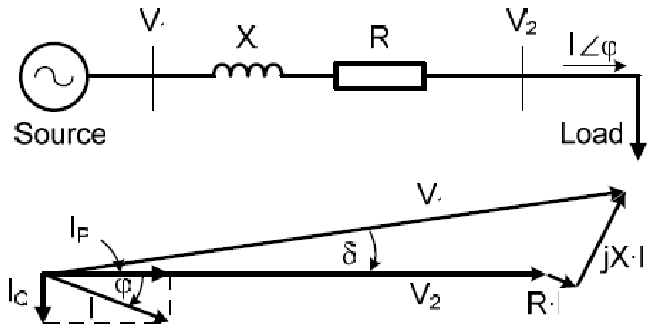


Fig. 3..(a) Principles of series compensation, without compensation.

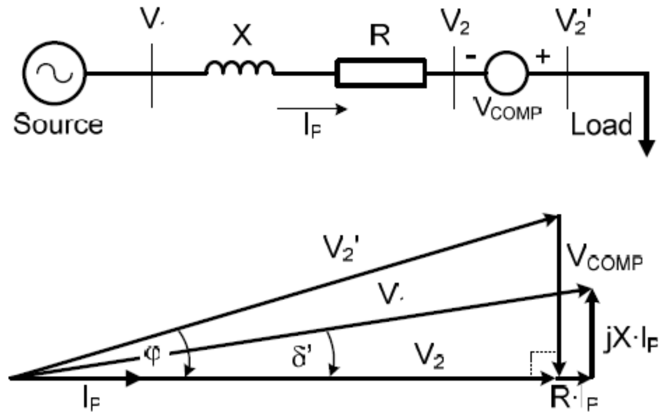


Fig. 3.(b) Principles of series compensation, with a voltage source.

III Flexible AC Transmission System (FACTS)

The history of FACTS controllers can be traced back to 1970s when Hingorani presented the idea of power electronic applications in power system compensation. From then on, various researches were conducted on the application of high power semiconductors in transmission systems. The shunt-connected Static VAR compensator (SVC) using solid-state switches and the series-connected controllers were proposed in AC transmission system application. In 1988, Hingorani defined the FACTS concept and described the wide prospects of the application in .

As new technology for power transmission system, FACTS and FACTS controllers not only provide the same benefits as conventional compensators with mechanically-controlled switches in steady state but also improve the dynamic and transient performance of the power system.

A Shunt-connected controllers

FACTS controllers can be impedance type, based on thyristors without gate turn-off capability, which are called Static Var Compensator (SVC) for shunt-connected application. Another type of FACTS controllers is converter-based which is usually in the form of a Static Synchronous Compensator (STATCOM).

a Static Var Compensator (SVC)

Static Var Compensator is “a shunt-connected static Var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage)” . SVC is based on thyristors without gate turn-off capability. The operating principal and characteristics of thyristors realize SVC variable reactive impedance. SVC includes twomain components and their combination: (1) Thyristor-controlled and Thyristor-switched Reactor (TCR and TSR); and (2) Thyristor-switched capacitor (TSC). In Figure 1.4 shows the diagram of SVC.

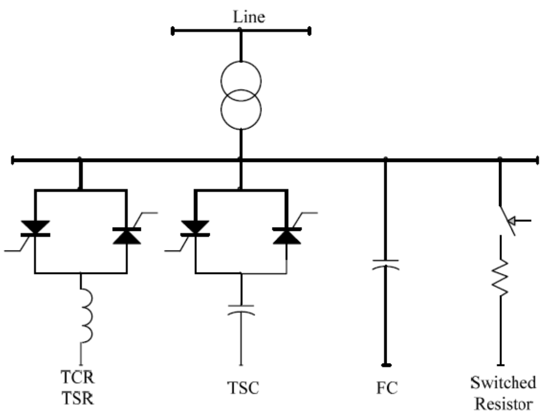


Fig. 4. Static VAR Compensators (SVC): TCR/TSR, TSC, FC and Mechanically Switched Resistor.

TCR and TSR are both composed of a shunt-connected reactor controlled by two parallel, reverse-connected thyristors. TCR is controlled with proper firing angle input to operate in a continuous manner, while TSR is controlled without firing angle control which results in a step change in reactance.

TSC shares similar composition and same operational mode as TSR, but the reactor is replaced by a capacitor. The reactance can only be either fully connected or fully disconnected zero due to the characteristic of capacitor. TSC shares similar composition and same operational mode as TSR, but the reactor is replaced by a capacitor. The reactance can only be either fully connected or fully disconnected zero due to the characteristic of capacitor.

b Converter-based Compensator

Static Synchronous Compensator (STATCOM) is one of the key Converter-based Compensators which are usually based on the voltage source inverter (VSI) or current source inverter (CSI), as shown in Figure 5(a). Unlike SVC, STATCOM controls the output current independently of the AC system voltage, while the DC side voltage is automatically maintained to serve as a voltage source. Mostly, STATCOM is designed based on the VSI.

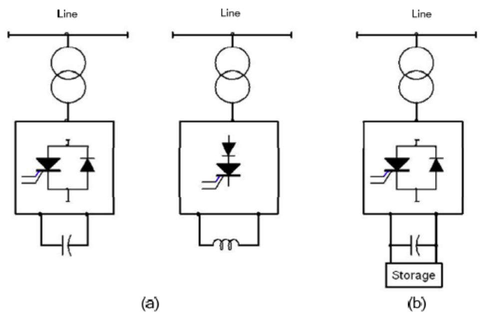


Fig. 5. STATCOM topologies: (a) STATCOM based on VSI and CSI (b) STATCOM with storage.

Compared with SVC, the topology of a STATCOM is more complicated. The switching device of a VSI is usually a gate turn-off device paralleled by a reverse diode; this function endows the VSI advanced controllability. Various combinations of the switching devices and appropriate topology make it possible for a STATCOM to vary the AC output voltage in both magnitude and phase. Also, the combination of STATCOM with a different storage device or power source as shown in Figure 5(b) endows the STATCOM the ability to control the real power output.

STATCOM has much better dynamic performance than conventional reactive power compensators like SVC. 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 a SVC. This advantage also brings higher reliability and larger operating range. Figure 6 shows the V-I characteristics of STATCOM and SVC.

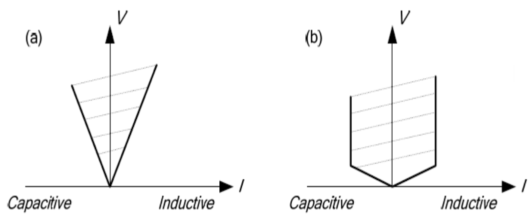


Fig.. 6 V-I characteristics of SVC and STATCOM: (a) SVC; (b) STATCOM

B Series-connected controllers

As shunt-connected controllers, series-connected FACTS controllers can also be divided into either impedance type or converter type. The former includes Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Capacitor (TCSC), Thyristor-Switched Series Reactor, and Thyristor-Controlled Series Reactor. The latter, based on VSI, is usually in the form of a Static Synchronous Series Compensator (SSSC). The composition and operation of different types are similar to the operation of the shunt-connected peers.

Figure 7 shows the diagrams of various series-connected controllers.

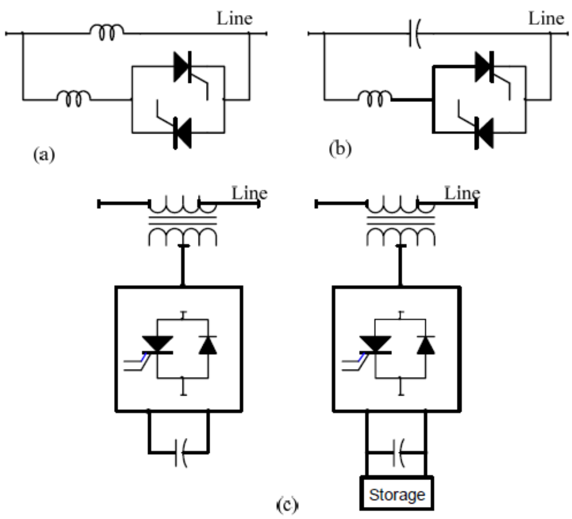


Fig. 7. Series-connected FACTS controllers: (a) TCSR and TSSR; (b) TSSC; (b) SSC

C Static Synchronous Compensator (STATCOM)

As discussed in the previous section, STATCOM is a very popular FACTS controller application effective in transmission system voltage control. Since 1980 when the first STATCOM (rated at 20 Mvar) using force-commutated thyristor inverters was put into operation in Japan , many examples have been installed and the ratings have been increased considerably. In 1991, KEPCO and Mitsubish Motors installed a ±80MVar STATCOM at Inuyama Switching Station [11]. In 1996, TVA, EPRI and estinghouse installed a ±100Mvar STATCOM at Sullivan 500 kV Substation . In 2001, EPRI and Siemens developed a ±200Mvar STATCOM at Marcy 345kV substation . It is expected that more STATCOMs will be installed due to the advances in technology and commercial success.

STATCOM could have many topologies, but in most practical applications it employs the DC to AC converter, which can also be called a Voltage Source Inverter (VSI) in 3-phase configuration as the primary block. The basic theory of VSI is to produce a set of controllable 3-phase output voltages/ currents at the fundamental frequency of the AC bus voltage from a DC input voltage source such as a charged capacitor or a DC energy supply device. By varying the magnitude and phase angle of the output voltage and current, the system can exchange active/reactive power between the DC and AC buses, and regulate the AC bus voltage.

IV Conclusion

In this paper transmission line series and shunt compensation basic is discussed. Based on the use of reliable high-speed power electronics, powerful analytical tools, advanced control and microcomputer technologies, Flexible AC Transmission Systems, also known as FACTS, have been developed and represent a new concept for the operation of power transmission systems.

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