POWER ELECTRONICS IN TRANSMISSION AND DISTRIBUTION SYSTEMS

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Contents

Summary

This chapter presents an overview of the ways and areas where power electronics has been used in power systems. Virtually every aspect of the operation of a modern power system has been impacted by power electronics. This is particularly prevalent in transmission and distribution systems. Significant improvements in the performance and stability of power systems have been obtained by introducing power electronic equipment with rapid and precise controllability.

The chapter presents power electronic applications in ac transmission systems, where they have been used for such purposes as reactive power compensation, voltage profile enhancement, power factor correction, active and reactive power flow control and stability enhancement, among other things. Modern high-voltage dc transmission systems, which are entirely enabled by power electronics, are also presented. The chapter also presents power electronics in distribution systems and what is commonly referred to as custom power.

Proper representation of power electronic converters in power systems simulation tools calls for specialized techniques that ensure high accuracy with suitable computational intensity. Modeling aspects of power electronic converters, particularly for electromagnetic transient (EMT) simulation, conclude the chapter.

1. Introduction

Since the demonstration of lighting the World’s Fair in Chicago in 1893 with electricity generated from Niagara Falls, Nikola Tesla’s concept of electric power generation in one location and its transmission for use at other locations has been a worldwide reality. Generation of electricity in modern electric power systems has customarily been done at a practically feasible high voltage. For transmission over long distances, the voltages are stepped up to high levels using power transformers that allow low-current and low-loss transmission. Finally, they are stepped down to lower voltages, again using transformers, for distribution over relatively short distances to reach various loads.

In an interconnected transmission system the electric power from the source flows to the loads through the paths of least impedance. This somewhat arbitrary flow of electricity may operate the electric transmission system in an inefficient way for the following reasons.

- Transmission lines carry useful active power and less desirable reactive power. Although these two components are required by the load, the latter causes undesirable line losses, and hence lower efficiency.
- Due to free flow of power, a number of lines may reach their power rating limits before the rest of the system. This may require tripping the overloaded lines.
- When an overloaded line trips, some previously under-loaded lines will have to pick up the load and, in the process, may become overloaded. The newly overloaded lines may also trip, leading to a cascaded failure and a possible blackout.

Fortunately, the flow of electricity in a particular transmission line can be controlled with the use of a power flow controller (PFC), which regulates the parameters that affect the flow of power, namely magnitude and phase angle of the line voltage and the line reactance. Solutions based on power electronics have given system operators the ability to influence these parameters effectively, rapidly and with precision, thereby allowing them to control and designate power flow throughout the network.

The demand for electrical energy around the world is increasing continuously and the construction of new transmission lines is, at the same time, becoming increasingly difficult because of various reasons, such as regulatory and environmental constraints, and public policies, as well as their escalating cost. The power industry is in constant search for the most economic ways to transfer bulk power along a desired path. The ever-growing need for electricity transmission can also be met, for the time being, by using the existing lines in a more efficient way to carry maximum active power at a minimal reactive power.

Power electronics is an exciting field of research and development that has been able to provide answers to some of the most difficult challenges faced by the power systems industry. Power electronics has enabled development of advanced compensators that can rapidly and precisely control the flow of active and reactive powers, control the voltage profile of the network, and offer additional benefits such as improved network stability. As a result, conventional ac transmission systems have become more efficient, more responsive, and more capable of carrying additional load.

Power electronics has also played a key role in the transmission of electricity. Ac transmission has been the dominant form in most electric power systems. Alternatively, one can transmit electric power by converting the generated ac power to dc for transmission at high dc voltages, and back to ac at the end of the line for distribution. In the so-called high-voltage dc (HVDC) scheme the dc line needs to carry only the active power and no reactive power, thereby eliminating line losses due to reactive power flow and increasing line utilization when compared with an ac transmission system.

For this concept to be economically viable, however, the line needs to be of a minimum length, since the two stages of conversion – ac-dc and dc-ac – cost significantly more when compared with an ac transmission system where no such conversions are required. Early day’s HVDC systems involved the use of mercury-arc valves for both ac-dc and dc-ac conversions.

Another area in which power electronics has played enabling and crucial roles is interfacing renewable energy sources, such as wind and solar, into the grid. This has also enabled micro-grids and has gained power electronics a footing in distribution systems and what is termed as the custom power. Figure 1 shows a schematic diagram of the major areas where power electronics is used in power systems.

Advances in semiconductor technology and modern control techniques have made it possible to implement the above concepts with currently available devices. Development continues for faster switches with higher ratings, their control techniques, and their temperature control and packaging techniques, leading to a well-established field of power electronic applications in power systems.

1.1. An overview of power electronic applications in power systems

Control of the power flow in an electric power system involves control of the magnitude and phase angle of the voltage at certain points in the system. This was, for example, accomplished in the past by using a synchronous condenser, which connects the back emf of a synchronous motor in shunt with the transmission line. This is done via a tie inductor, which is composed of the machine reactance and the leakage reactance of the coupling transformer. By adjusting the field of the machine its terminal voltage is controlled, which in turn allows control of the reactive power or voltage at the point of common coupling with the transmission line.

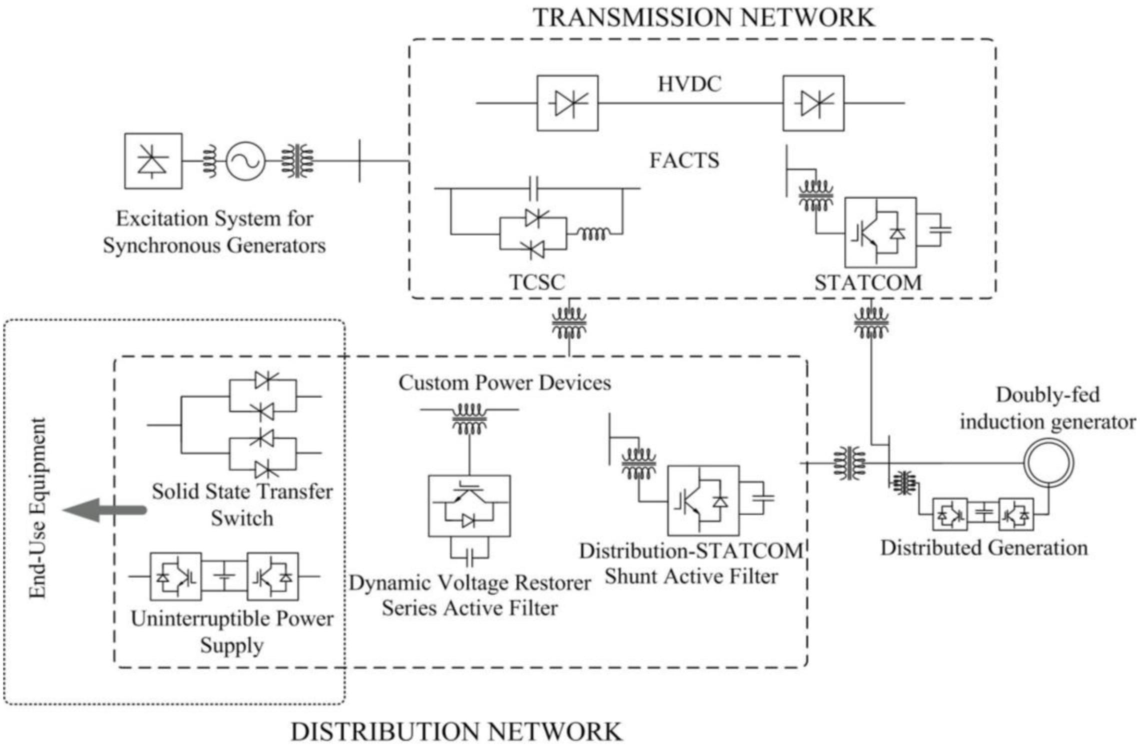

Figure 1. Power electronics in power systems.

It was known for a long time that using highly controllable voltage sources affords the same benefit. Power electronics has been the enabling technology that has replaced the bulky, slow, and high maintenance compensators of the past with compact, fast, and high-performance compensators of the today. For instance, the concept of a synchronous condenser has been extended with the use of a voltage-sourced converter (VSC)-based static synchronous compensator (STATCOM) that connects an electronically-generated sinusoidal voltage (with some harmonic components) in shunt with the transmission line through a tie inductor. The VSC used in a STATCOM is the controllable voltage source that enables such an undertaking. In 1995, Westinghouse installed a ±100 MVA-rated STATCOM at the Tennessee Valley Authority Sullivan substation in the state of Tennessee, USA. This STATCOM can respond to a 100 Mvar step-change in reference input in only a few milliseconds. Whether the utility needs such a fast (sub-cycle) response remains a debatable point. However, this virtue of a STATCOM has proven to be useful in compensating fast-acting random loads, such as electric arc furnaces, stone crushers, and so on.

The VSC-based concepts (Kundur, 1994; Hingorani & Gyugyi, 2000; Sen & Sen, 2009) were further developed to include static synchronous series compensator (SSSC), unified power flow controller (UPFC), back-to-back STATCOMs, also known as VSC-based high voltage direct current (VSC-HVDC), and back-to-back SSSCs, also known as the interline power flow controller (IPFC), for transmission applications. Also developed were dynamic voltage restorers (DVR) (Gyugyi, Schauder, Edwards, & Sarkozi, 1994) and distribution STATCOMs (D-STATCOM) for distribution applications. These ideas became suitable for implementation for the first time in the 1990s due the availability of high power semiconductor switches, such as 4500 V, 4000 A-rated gate turn-off (GTO) thyristors. The semiconductor switches that are used in the implementation of a VSC are fully controllable, meaning the switches can be turned on and off at a desired time. Besides GTO thyristors, other high-power rated switches available for these applications are integrated gate commutated thyristors (IGCT), and press-pack insulated gate bipolar transistors (IGBT). A new definition, namely flexible alternating current transmission systems (FACTS), was adopted as *alternating current transmission systems incorporating power electronic based and other static controllers to enhance controllability and increased power transfer capability*.

The key to independent control of active and reactive power flows in a transmission line is to control both the magnitude and phase angle of the transmission line voltage simultaneously. This can be achieved with either shunt-series or shunt-shunt configurations. The shunt-series configuration, employed as a UPFC and shown in Figure 2, consists of two VSCs with a common dc link capacitor. The two VSCs are connected to the same transmission line through two coupling transformers: one connected in shunt and other connected in series. The transfer of active power from one line to another can be achieved with the use of the shunt-shunt configuration as shown in Figure 3, which consists of two dc-ac VSCs, each of which is connected in shunt with the transmission line through a coupling transformer. Both the VSCs are connected at their shared dc link. This configuration in electric utility applications is known as back-to-back STATCOM (BTB-STATCOM).

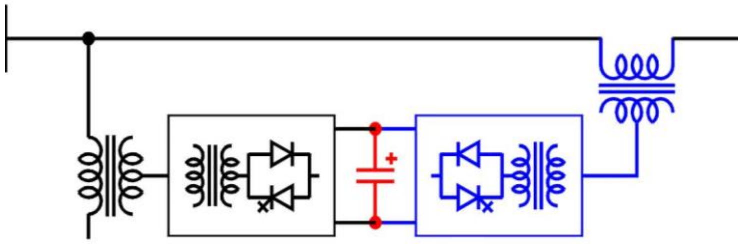

Figure 2. Shunt-series configuration (UPFC).

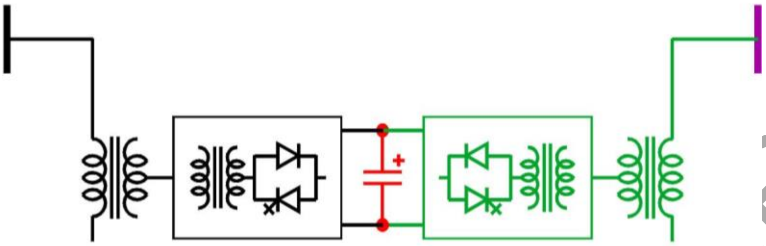

Figure 3. Shunt-shunt configuration (BTB-STATCOM).

The most important and unique feature of the shunt-series configuration is that for a given amount of transmitted power, the series compensating unit has a large ratio between its own rating and the controlled transmission line power and it needs to be rated for only *a fractional amount of transmitted power*, whereas the shunt compensating unit in the shunt-shunt configuration has no such leverage and it needs to be rated for *the full amount of transmitted power*. Because of this uniqueness, *the shunt-series connection is a preferred configuration for a power flow controller in many applications*. In certain special cases for point-to-point transfer of power between two isolated networks with different voltages, phase angles, or frequencies, the use of the shunt-shunt connection still remains the preferred configuration. In 2000, ABB installed a ±36 MVA-rated BTB-STATCOM at the American Electric Power Eagle Pass substation in the state of Texas, USA.

In 1998 Westinghouse installed a ±160 MVA-rated FACTS controller at the American Electric Power Inez substation in the state of Kentucky, USA (Renz et al, 1999). This installation can be reconfigured into nine different modes of operation, namely various combinations of STATCOM, SSSC, and UPFC. This UPFC demonstrated for the first time that active and reactive power flows in a transmission line could be regulated independently while maintaining a fixed line voltage at the point of compensation. Simultaneous control of active and reactive power flows and independent control of active and reactive power flows are shown in Figures 4 and 5, respectively.

Independent control of active and reactive power flows leads to several benefits including the following:

- reduction in reactive power flow, resulting in reduction of losses in generators, transformers and transmission lines, which increases the system efficiency;

- freeing up the generators, transformers and transmission lines to carry more active power;
- power flow through the desired transmission paths that have high impedances, low power flow, and low line utilization;
- avoiding grid congestion by redirecting excess power flow from an overloaded line to under-loaded lines, instead of tripping the overloaded line when power is needed the most;
- delaying the building of new, expensive, high-voltage electric transmission lines.

Within 5 years of its first installation, two more UPFCs were built (Fardanesh et al, 1998; Choo et al. 2002), using Westinghouse's technology. The selected VSC topology was based on multi-pulse harmonic neutralization (MPHN) techniques. The power loss in a VSC is defined as the total power consumed by various components of a VSC while carrying the rated current at rated voltage.

A MPHN-VSC with GTO devices switching once per cycle has about 1.5% power loss under rated condition. That means, for a UPFC that consists of two VSCs, the power loss is about 3%. The power loss in a single PWM-operated VSC is about 4%. Therefore, for a UPFC that is made out of two PWM-operated VSCs, the power loss is about 8%. This makes the operating cost of a VSC-based UPFC to be the highest among the available power flow solutions.

In addition to high installation and operating costs, high losses due to switching of power semiconductor devices has been a major obstacle in wide-spread adoption of power electronics-based compensators particularly, when the converters are expected to carry large amount of power. Improved waveform-synthesis techniques and novel converter topologies have been pursued as solutions. Development in both areas continues as power electronics opens up new horizons of application in power systems.

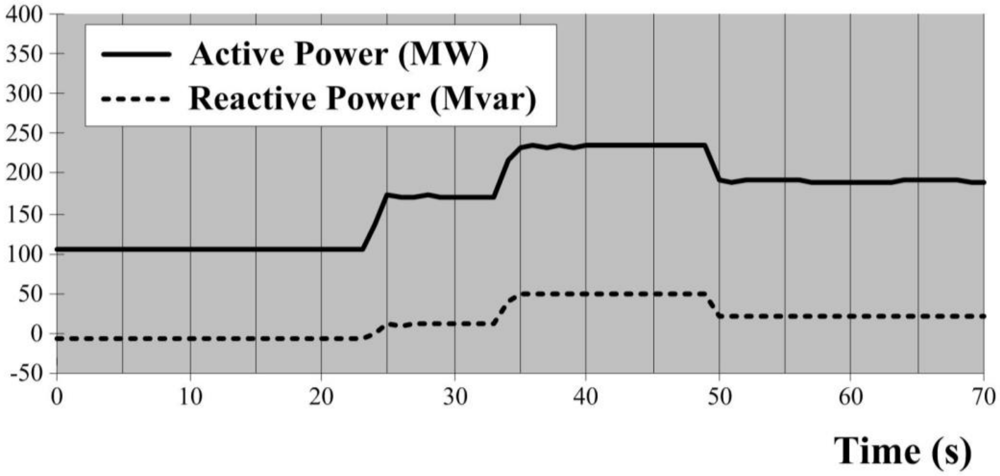

Figure 4. Simultaneous power flow control by changing only one control parameter.

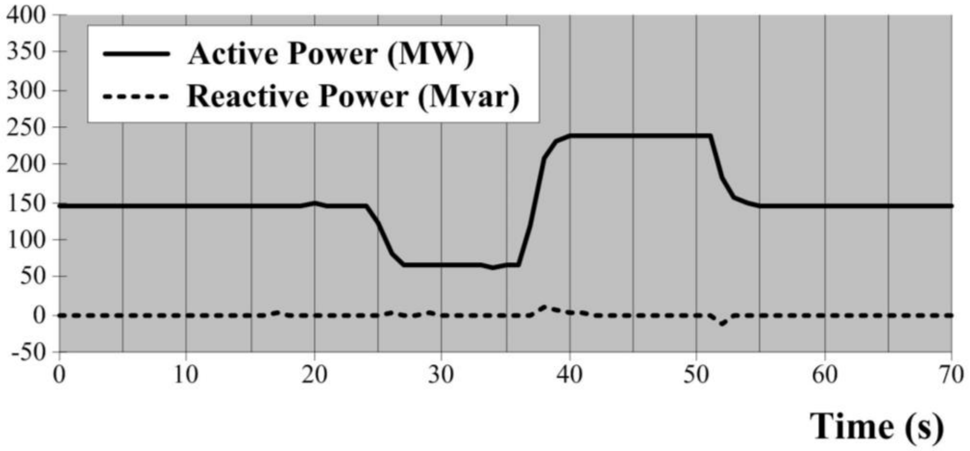

Figure 5. Independent power flow control by changing both control parameters (voltage magnitude and phase angle).

One of the great features of a VSC is its fast (sub-cycle) response time. Figures 4 and 5 show that the response time of actual equipment is in the order of seconds. Since the utility most likely does not need the sub-cycle response, the FACTS controllers are marginally designed to lower their cost (Sen & Sen, 2003b), which is already an order of magnitude higher than the comparable transformer/tap changer-type solution, namely Sen Transformer (ST) that is at just right cost to fulfill the utility power flow requirement (Sen & Sen, 2003a), see Figure 6. Since the power flow control needs change with time, a PFC may be designed with portability in mind for easy relocation to wherever it is needed the most. Once installed, it is practically impossible to relocate a VSC-based FACTS controller.

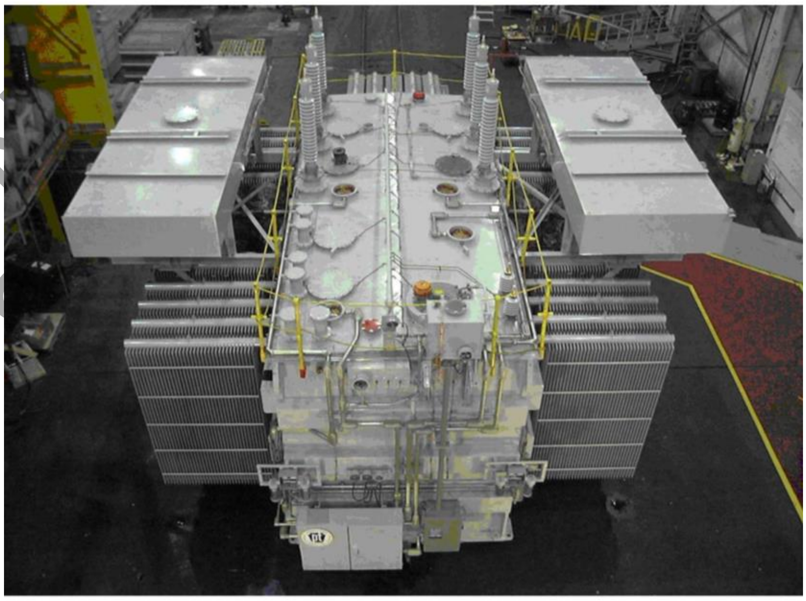

Figure 6. Sen transformer.

Just like any other evolving technology, power electronic compensators are facing their own challenges. For example, VSCs are considered to have operating life spans of 25 to 50 years. However, within the first decade, most electronic components became obsolete, reducing the expected life-time greatly. Their high installation and operating cost and typically high losses are also major factors that need to be resolved.

1.2. Evolution from thyristor-based compensators to fully-controlled VSC-based systems

Transmission of power in a single line with a sending-end voltage, $\mathbf{V}_\mathrm{s}$ (of magnitude, V_s, and angle, δ_s), and a receiving-end voltage, $\mathbf{V}_\mathrm{r}$ (of magnitude, V_r, and angle, δ_r), connected by a line reactance (X) and the related phasor diagrams are shown in Figure 7. Ignoring the line resistance, the natural voltage, $\mathbf{V}_\mathrm{Xn}$ (i.e., $\mathbf{V}_\mathrm{s} - \mathbf{V}_\mathrm{r}$), across the line reactance (X) is the difference between the sending- and receiving-end voltages. The resulting line current ($\mathbf{I}$) lags the voltage ($\mathbf{V}_\mathrm{Xn}$) by 90^o. The natural or uncompensated active and reactive power flows (P_sn and Q_sn) at the sending end and (P_rn and Q_rn) at the receiving end are:

$$P_\mathrm{sn} = P_\mathrm{rn} = A_\mathrm{n} \sin\delta \tag{1}$$

$$Q_\mathrm{sn} = A_\mathrm{n}\left[\left(V_\mathrm{s}/V_\mathrm{r}\right) - \cos\delta\right] \tag{2a}$$

$$Q_\mathrm{rn} = A_\mathrm{n}\left[\cos\delta - \left(V_\mathrm{r}/V_\mathrm{s}\right)\right] \tag{2b}$$

where $A_\mathrm{n} = V_\mathrm{s}V_\mathrm{r}/X$ and $\delta = \delta_\mathrm{s} - \delta_\mathrm{r}$.

The power flow control parameters are transmission line voltage magnitudes (V_s and V_r) at its sending- and receiving-ends, their phase angles' difference (δ), and line reactance (X). Any of these parameters can be controlled individually with the use of the following, now considered conventional, equipment:

- *Voltage regulation*: voltage regulating transformer (VRT), shunt or parallel-connected switched inductor/capacitor, static var compensator (SVC), or static synchronous compensator (STATCOM) as shown in Figure 8.
- *Phase-angle regulation*: phase angle regulator (PAR) or phase shifting transformer (PST) as shown in Figure 9.
- *Line reactance regulation*: thyristor-controlled series capacitor (TCSC) as shown in Figure 10.

For more than a century, the transmission line voltage has been regulated with transformers and tap changers. They are referred to as the VRT in the form of a two-winding transformer with isolated windings or an autotransformer with electrical connection between the windings. In both cases, the magnitude of the line voltage is regulated. The secondary voltage is varied with the use of load tap changers (LTCs)

(Faruque & Dinavahi, 2007). A LTC can step up/down the voltage without interruption of the load current. Both primary and secondary windings in the two-winding transformer carry the full transmitted power. Both primary and secondary windings in the autotransformer carry only a fraction of the full transmitted power.

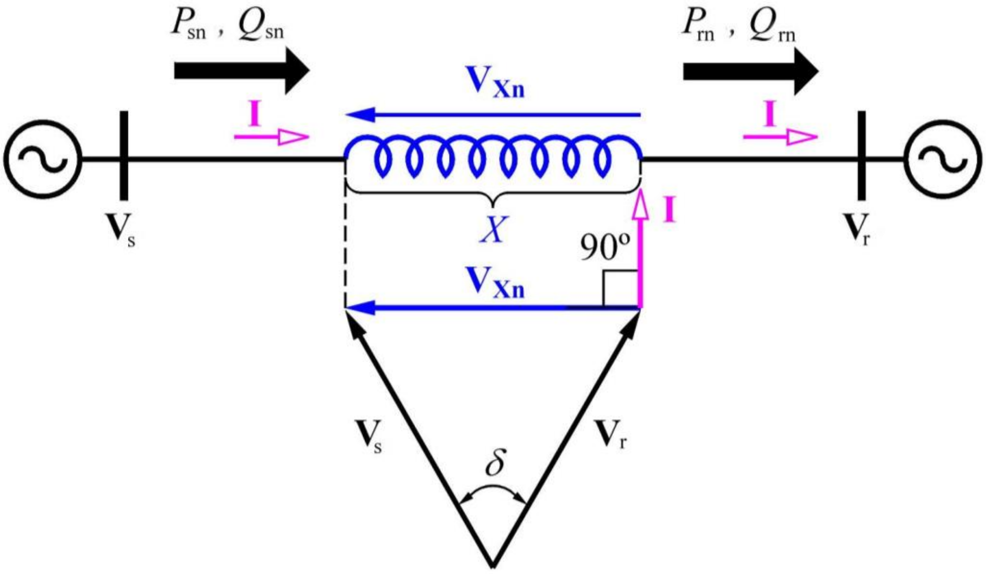

Figure 7. Simple power transmission system and the related phasor diagram.

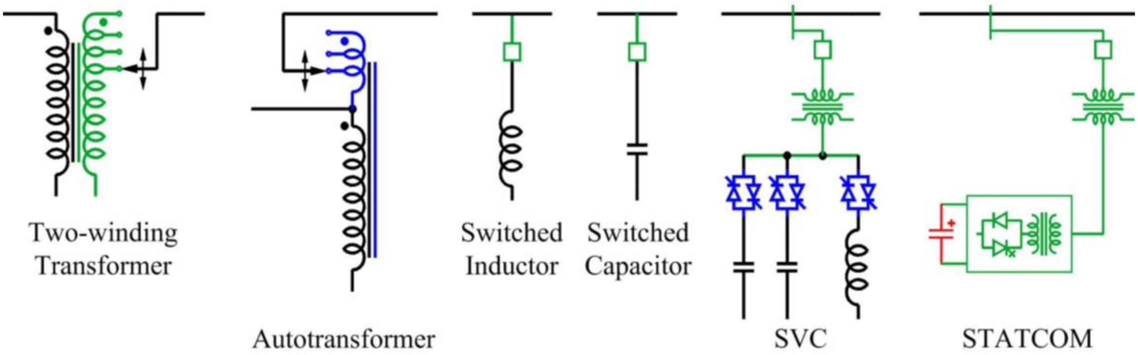

Figure 8. Transmission line voltage regulators.

An indirect way to regulate the line voltage is to connect an inductor or a capacitor in shunt with the transmission line. A shunt-connected inductor absorbs reactive power from the line and lowers the line voltage, whereas a shunt-connected capacitor raises the line voltage with its generated reactive power. The static var compensator (SVC) connects fixed capacitors in a step-wise manner in shunt with the line through thyristor switches and also connects an inductor in shunt with the line through thyristor switches whose duty cycle can be varied, thereby making it function as a variable inductor. In an SVC the reactive power is generated by the ac (controlled) inductors and (switched) capacitors. The reactive power capability of a SVC is therefore impacted by not only the size of these reactive components but also the magnitude of the ac voltage at their terminals. An alternative way to compensate reactive power is to use a VSC-based STATCOM that connects an electronically-generated sinusoidal voltage (with some harmonic components) in shunt with the transmission line through a tie inductor. This rids the system from inductive reactive power from ac reactive components and relies on the crafted voltage to supply or absorb reactive power.

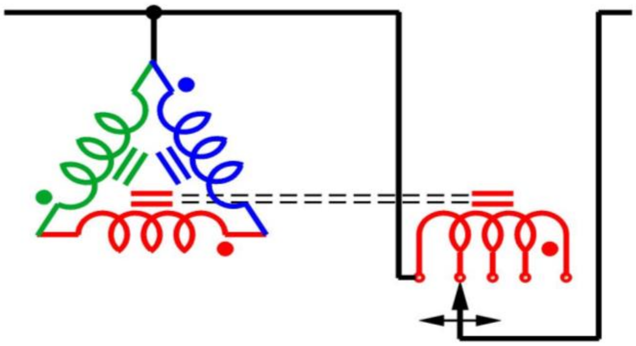

Figure 9. Transmission line voltage phase angle regulator.

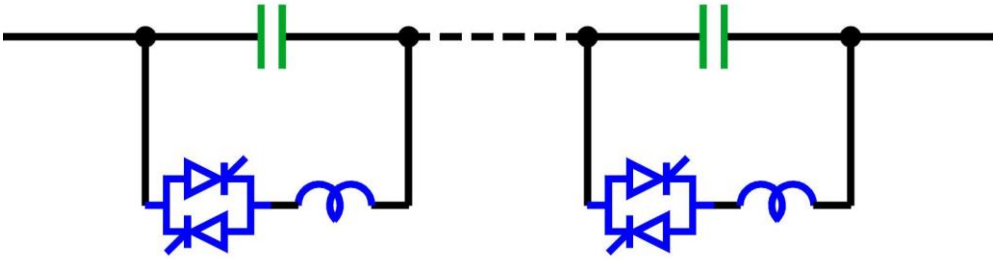

Figure 10. Thyristor-controlled series capacitor for transmission line reactance regulation.

The power flow in a transmission line has also been regulated with the use of the PAR. The line voltage is applied to the primary windings and the induced secondary voltage that is varied with the use of LTCs is connected in series with the line. Through the use of the TCSC, a series-connected variable capacitor or a variable inductor can be implemented. As a result, both the magnitude and the phase angle of the line voltage are varied simultaneously.

An ideal power flow controller controls the above-mentioned power flow control parameters simultaneously to regulate the magnitude and the phase angle of the line voltage independently. As a result, the active and reactive powers in the line can be controlled independently. This is accomplished by adding a series-connected compensating voltage to the original voltage with the use of the shunt-series configuration as shown in Figure 11. The series-connected compensating voltage is of variable magnitude and phase angle; it is also at any phase angle with the prevailing line current. Therefore, it exchanges active and reactive powers with the line. When VSCs are used, only the exchanged active power (P_{exch}) flows bi-directionally through the shared link to and from the same transmission line under compensation; both shunt- and series-connected VSCs can also provide independent reactive power compensation at their respective ac terminals.

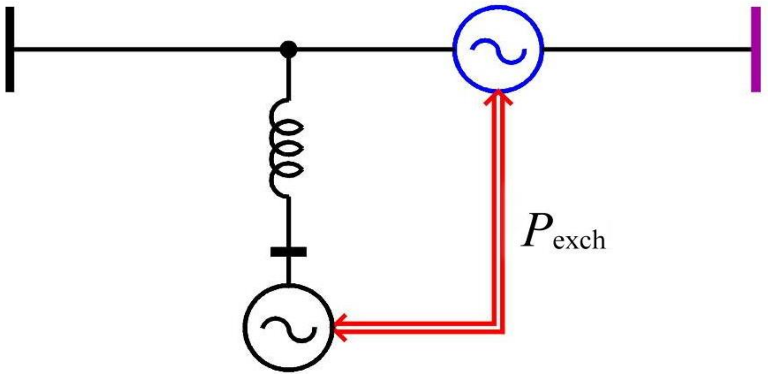

Figure 11. Independent active and reactive power flow controller using a shunt-series configuration.

The concept of a shared dc link between a shunt-connected VSC and a series-connected VSC was first introduced in the active power line conditioner (APLC) for distribution power level applications (Stacey & Brennen, 1987; Brennen & Banerjee, 1994). Realization of Figure 11 by shunt-series-connected VSCs (UPFC) was implemented in the UPFC for transmission power level applications as shown in Figure 2. The series-connected VSC that is rated for a fraction of the line voltage carries the full line current. The shunt-connected VSC that is rated for the full line voltage carries only a fraction of the line current. Therefore, each VSC carries only a fraction of the full transmitted power. For example, a shunt-series configuration with a series-connected compensating voltage of 0.1 pu (max.), delivering a line current of 1 pu, requires the series-connected compensating voltage to be rated at 0.1 pu voltage and 1 pu current; the shunt-connected exciting voltage is rated at 1 pu voltage and 0.1 pu current. Therefore, the combined power rating of the two voltage sources is 0.2 pu. As a special case, when the dc link capacitors of the two VSCs are not connected together, both the shunt-connected VSC (STATCOM) and the series-connected VSC (SSSC) provide independent reactive power compensation at their respective ac terminals and there is no exchange of active power between them.

The concept of the shunt-series configuration can be further extended to include the use of a shared magnetic link in which the compensating voltage is generated from either an electrical machine or a transformer with LTCs. In this case, both the exchanged active power (P_{exch}) and reactive power (Q_{exch}) flow bidirectionally through the shared magnetic link. All shunt-series configurations are electrically connected to the same power system network; therefore, both the shunt and series units operate at the same frequency.

The compensating voltage in an autotransformer is in phase (0°) or out of phase (180°) with the line voltage and, therefore, regulates the magnitude of the transmission line voltage. The compensating voltage in the PAR is in quadrature (+90° or –90°) with the line voltage and, therefore, regulates the phase angle of the transmission line voltage. The Sen transformer (ST), as shown in Figure 12, creates a series compensating voltage that is variable in magnitude and phase angle and can control the transmission line voltage in both magnitude and phase angle in order to achieve independent control of active and reactive power flows in the line. This compensating voltage may be thought of as two orthogonal compensating voltages of a separate autotransformer and a PAR. Therefore in the ST, the functions of the autotransformer and the PAR are combined in a single unit that results in a reduced amount of hardware from what is required for a separate autotransformer and a PAR.

The VSC-based technology has the capability of providing fast (sub-cycle) dynamic response for a given transmission line impedance, although in a PFC the dynamic response of at least a few line cycles is necessary to operate safely under contingencies. Most utility applications in the ac system allow regulation of the power flow in the line(s) in a "slow" manner as permitted by the mechanical contacts in the LTCs. If faster response is needed, the mechanical LTCs can be replaced with faster LTC switches (EPRI Report, 2000).

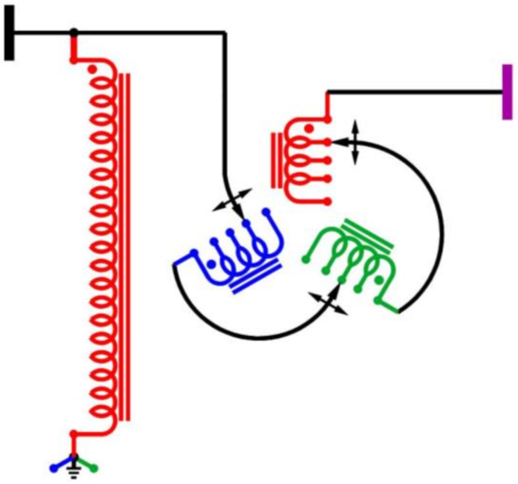

Figure 12. Realization of Figure 11 by transformer/tap changers (Sen transformer).

The magnitude and phase angle of the transmission line voltage can also be controlled independently by a shunt-connected compensating voltage, using the shunt-shunt configuration as shown in Figure 13. This concept dates back to the time when rectifiers and inverters were introduced to convert ac power from one voltage and frequency level to another with active power (P_{exch}) transfer through a dc link. The most frequently used topology is an ac-dc rectifier followed by a dc-ac inverter for variable speed motor drives and, if combined with local energy storage, an uninterruptible ac power supply. To improve the power quality at the rectifier's ac terminal and to accomplish bidirectional power flow, two dc-ac inverters are connected back to back via their shared dc links as shown in the Figure 3.

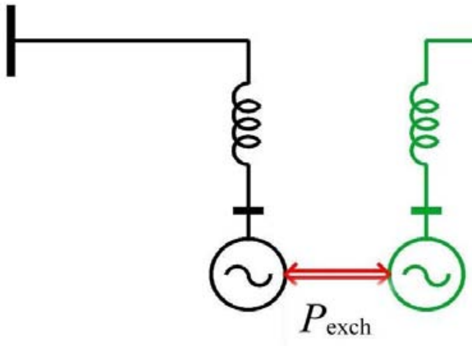

Figure 13. Point-to-point transfer of power with local reactive power compensation using a shunt-shunt configuration.

The shunt-connected compensating voltage is of variable magnitude and phase angle; it is also at any phase angle with the prevailing line current. Therefore, it exchanges active and reactive powers with the line. When VSCs are used, only the exchanged active power (P_{exch}) flows bidirectionally through the shared link; each shunt-connected VSC can also provide independent reactive power compensation at its ac terminal and, as a result, regulate the voltage of the transmission line at the point of compensation. Each shunt-connected VSC is rated for the full line voltage and carries the full line current and, therefore, is rated for its full transmitted power. Considering the previous example, a shunt-shunt configuration with a shunt-connected compensating voltage of 1.1 pu, delivering a line current of 1 pu, requires the shunt-connected compensating voltage to be rated at 1.1 pu voltage and 1 pu current; the shunt-connected exciting voltage is rated at 1 pu voltage and 1.1 pu current. Therefore, the combined power rating of the two voltage sources is 2.2 pu, which is 11 times the power rating of the shunt-series configuration. As a special case, when the dc link capacitors of the two VSCs are not connected together, both the shunt-connected VSCs (STATCOM) provide independent reactive power compensation at their respective ac terminals and there is no exchange of active power between them.

The concept of the shunt-shunt configuration can be further extended to include the use of a shared magnetic link in which the compensating voltage is generated from either an electrical machine or a transformer with LTCs. In this case, both the exchanged active power (P_{exch}) and reactive power (Q_{exch}) flow bi-directionally through the shared magnetic link. The point-to-point transfer of power from one line to another with different voltages, phase angles, or frequencies can be accomplished with the use of shunt-shunt-connected electrical machines. The ST can also generate a shunt-connected compensating voltage for the interconnection of two nearby transmission lines with different voltages and phase angles, but of the same frequency.

Equations (1) and (2) show that the expressions for active power and reactive power are sine and cosine functions, respectively. The variation of active power as a function of reactive power is shown in Figure 14. Power angle (δ) in the second, also third and fourth (not shown in the figure), quadrants are not used. If the fourth-quadrant operation of a shunt-shunt configuration is needed for power flow reversal, note that the shunt-series configuration can also be used for this purpose.

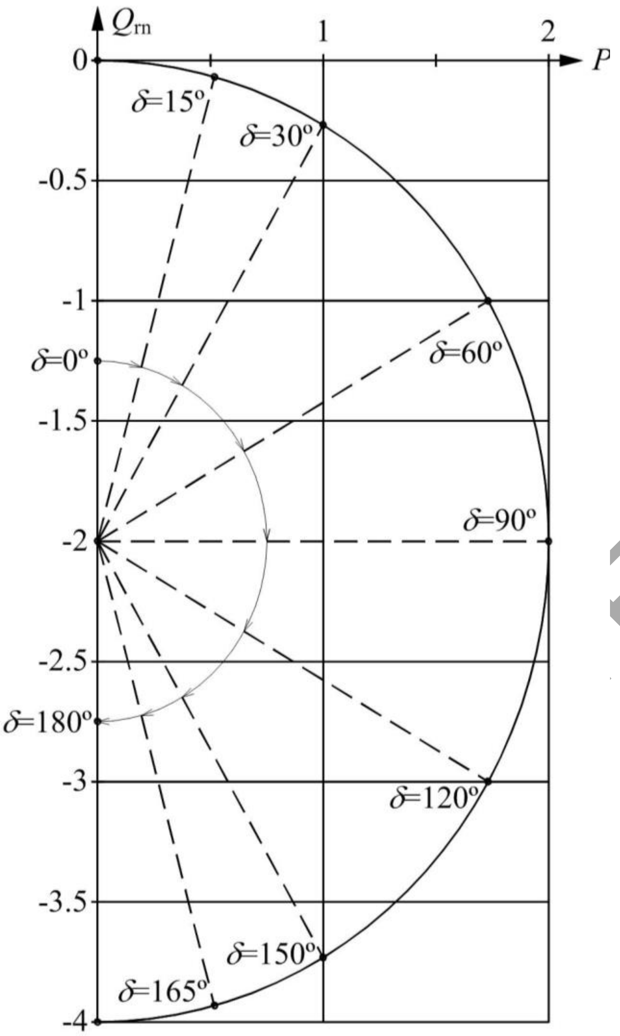

Figure 14. Q_{rn} vs P_{rn} at the receiving end of the transmission line for the range of power angle δ (i.e., $\delta_s - \delta_r$) from 0° to 180° when $V_s - V_r = 1$, and $X = 0.5$, and $R = 0$ ($X / R = \infty$).

The shunt-shunt power configuration is capable of controlling the power angle (the phase angle between the voltage at the point of compensation and the voltage at the far end of the transmission line) over its full 360° range. The maximum transfer of active power along a lossless transmission line (with quality factor $Q = X / R = \infty$) between the sending and receiving ends takes place at the 90° power angle. At the same time, the actual power angle is significantly lower and depends on the line length, system characteristics, and load flows. A transmission line with the natural (uncompensated) power angle in the range of 15° to 20° may have a possible range of compensation of additional 5° to 10°. Therefore, the shunt-shunt configuration is severely restricted to operate within the first quadrant when used as a PFC. In contrast, the shunt-series configuration requires only a fraction of the power rating of the shunt-shunt power configuration and makes the most use of its rating when used as a PFC.

Both the ST and UPFC are suitable for independent control of active and reactive power flows in a single transmission line in which they are installed. However, several transmission lines in close proximity may be connected to a shared voltage bus. Therefore, any change in the power flow in one line will affect the power flows in the other lines as well. Thus, the excessive power from one specific line cannot be transferred directly to another specific line. In a multiline transmission network, it would be advantageous to be able to transfer power from an overloaded to an under-loaded line with minimum undesirable impact on the power flows in the other uncompensated lines.

The shared dc link concept can be extended for power exchange between transmission lines with series-series-connected VSCs. The BTB-SSSC, shown in Figure 15, consists of at least two VSCs, each of which is connected in series with a transmission line. All the VSCs are connected at their shared dc link. The BTB-SSSC transfers active power from one or more transmission lines, referred to as “master” lines, to the others, referred to as “slave” lines, and provides independent series reactive power compensation in each line. A BTB-SSSC selectively controls the active and reactive power flows in each line in a multiline transmission system and provides a power flow management for the transmission system by decreasing the power flow in an overloaded line and increasing the power flow in an under-loaded line. The multiline Sen transformer (MST), shown in the figure, provides the same functionality.

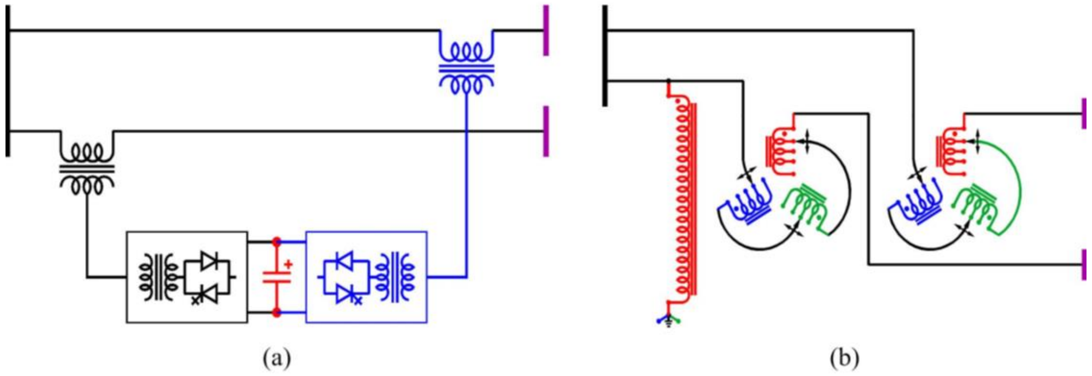

Figure 15. Multiline power flow concepts: (a) Back-to-Back SSSC; (b) Multiline Sen Transformer.

The summary of choices for transmission line power flow control equipment is shown in Figure 16 in chronological order of their introduction.

In summary, mechanically- or electronically-switched static compensators are used as FACTS controllers. If any of these compensators regulate only one power flow control parameter, active and reactive power flows in the transmission line are controlled simultaneously. The power industry’s present need requires the use of FACTS controllers that can independently control the active and reactive power flows in a transmission line, decrease the power flow in an overloaded line, and increase it in an under-loaded line, while at the same time keeping the system voltage within the allowable limits.

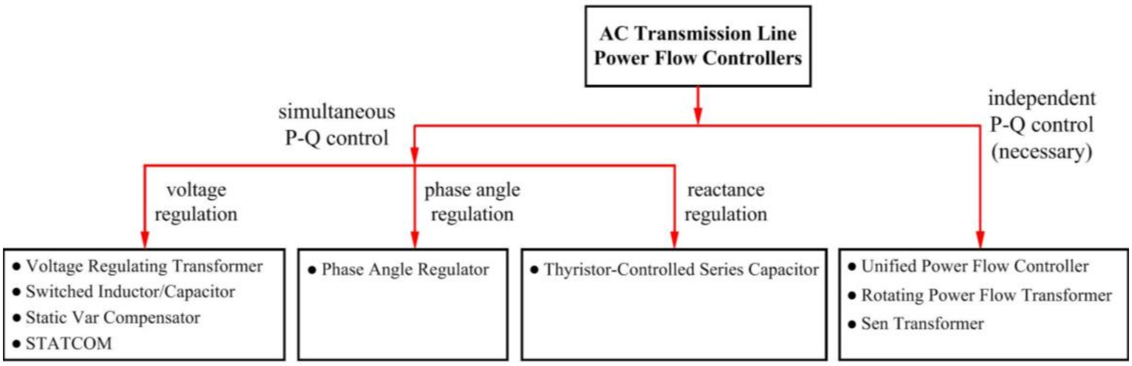

Figure 16. Choices for transmission line control equipment.

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