COMPARISON OF THE FACTS EQUIPMENT OPERATION IN TRANSMISSION AND DISTRIBUTION SYSTEMS

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SUMMARY

This paper describes the power electronic devices and technical review in various power engineering levels. In energy transmission systems, effective equipments on power control are generally known as Flexible AC Transmission System (FACTS). In addition, the power electronics-based equipment, which are called power conditioners are used to solve power quality problems. Since the topologies of these equipments are similar to those used in FACTS equipment, power conditioners are also called Distribution FACTS (DFACTS). The principal operating modes and applications whichever one of equipment in transmission and distribution system (such as STATCOM, SSSC, UPFC, DSTATCOM, DVR and UPQC) will be discussed and compared.

Keywords: Power electronic, Power quality, FACTS, DFACTS, PWM Converter, Power conditioner, HVDC Light

INTRODUCTION

Electrical energy is the most important component in the modern industrial society, and its yearly consumption is of the most importance rate in a nation’s welfare evaluation. A great amount of this energy is generated by hydro, thermal and nuclear power plants. Power electronic applies a big deal of this energy for industrial, commercial, home, space and military applications in today’s industrial society.

As a consequence of the advances in power electronic technologies over the last two decades, power electronic applications have quickly spread to all voltage levels, from EHV transmission to low voltage circuits in the end user facilities.

Commonly observed, power electronic applications include HVDC terminals, various static Var compensation (SVC) systems, high power ac to dc converter for dc arc furnaces, static phase shifters, isolation switches, load transfer switches, converter/inverter based drive technologies, active line conditioning, energy storage and instantaneous backup power systems, renewable energy integration, and numerous others covered under subjects of Flexible AC Transmission Systems (FACTS) and Custom Power Systems (CPS).

Power flow control in an interconnected transmission network, is one of the existing problems in designing and operating. The factors in power flow problems in an interconnected network are such as a need for interconnected networks, unforeseen increasing of load demands, limitations on power plant installation in suitable places and limitations on building new transmission lines. The factors that necessitate the use of FACTS devices in transmission lines are such as over loaded transmission lines in special paths, flow of power in unwished paths, and non-optimal operation of line capacity.

Power quality is of increasing importance in world-wide distribution systems. Consumers such as industrial plants run more automated processes and may experience substantial economic losses, if the line voltage differs from the expected characteristic (quality) due to voltage sags or flicker for example. Therefore consumers demand proper quality attached to the line voltage at the point of common coupling. In more and more cases this quality can not be achieved with conventional equipment.

The improvement of power quality has been therefore one of the most important subjects in the development of distribution and low voltage systems in the last decade. The fast development of new devices like IGBTs (Insulated Gate Bipolar Transistors) have made it possible to build PWM converters which are widely used for adjustable speed drives and are mass-produced for power ratings in the MVA range.

These converters, combined with conventional equipment and using new developed control algorithms are used for mitigation of power quality problems. Such equipment are widely known as power conditioners. Since the topologies are similar to those used in FACTS equipment intended for transmission systems, such as UPFC and STATCOM, power conditioners are also called Distribution FACTS (DFACTS).

The power electronic devices and FACTS equipment in transmission and distribution systems will be discussed and compared in this paper.

FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

Considering the increasing load demand, energy transmission systems are faced with power transmission limitation crisis. These limitations, bring up merely because of maintaining stability and supplying the allowed level of voltage. Therefore practical operation capacity is much less than their real capacity which is as their thermal limit. This will lead to non-optimal operation of energy transmission systems. One of the approaches in increasing power transmission capacity, although not very easy with some problems, is building new lines. Developing industry semiconductor and their usage in power systems, the FACTS concept was offered, to use the real capacity of transmission lines without making any new lines. The main failure in thyristor switches is that they can’t be controlled for turn-off capability. So, in a cycle it’s not
possible to use switching more than once. But due to inventing semiconductor parts in the power and voltage of power system which can be turned off too, such as IGBT and GTO, another development occurred in energy transmission systems field, which the most important of all is using VSCs. The main feature of which is generating and absorbing the reactive power without using generating and or absorbing devices reactive power such as capacitor or reactor. All FACTS equipment designed by VSCs are called FACTS new generation devices. The reason for this is their significant characteristics in proportion to other equipment working with thyristor. FACTS devices are now a reality and will soon change the way engineers plan and operate power systems. These equipment can be applied in series, shunt or shunt-series in transmission line, and controls operation parameters in transmission systems in steady state and system dynamic behaviour in transient state. Now, each device will be described in details.

**Static Synchronous Compensator (STATCOM)**

STATCOM is applied in shunt in transmission lines and can adjust the required reactive power dynamically and within the capability of the converter (Fig.1). Converter, draws a controlled current that its active component automatically is used for balancing required active power in DC link capacitor, and its reactive current component is used for desired reference level. STATCOM operation modes are as follows [1]:

- **Reactive power (Var) control mode.** In reactive power control mode the reference input is an inductive or capacitive reactive power request. The converter control transfers the Var reference into a corresponding current request and adjusts the gating of the converter to establish the desired current.

- **Automatic voltage control mode.** In voltage control mode (which is normally used in practical applications), the converter reactive current is automatically regulated to maintain the transmission line voltage to a reference value at the point of connection.

**Static Synchronous Series Compensator (SSSC)**

The SSSC is settled in transmission line in series and injects a voltage with controlled magnitude and angle into it (Fig.1). This injected voltage is, directly or indirectly, always used to control the flowing power on the line. However, this injected voltage is dependent on the operating mode selected for the SSSC to control power flow. The principal operating modes are as follows [1]:

- **Line impedance compensation mode.** When the injected voltage is kept in quadrature with respect to the line current, so that the series insertion emulates an impedance when viewed from the line, to emulate purely reactive (inductive or capacitive) compensation. This mode can be selected to match existing series capacitive line compensation in the system.

**Automatic power flow control mode.** The magnitude and angle of the injected voltage is controlled so as to force such a line current that results in the desired real and reactive power flow in the line. In automatic power flow control mode, the series injected voltage is determined automatically and continuously by a closed-loop control system to ensure that the desired real and reactive power flow are maintained despite power system changes.

**Unified Power Flow Controller (UPFC)**

UPFC is one of the unique equipment in FACTS which is used in series and shunt on the transmission line (Fig.1). UPFC is consisted of two VSC and a DC link capacitor. One converter operates in series, the other in shunt. Shunt converter, in addition to the real power need of series converter, they also can have STATCOM operation modes. Furthermore series converter through injecting voltage in series to the transmission line can operate not only in SSSC operation modes, but in following modes as [1]:

- **Direct voltage injection mode.** The series converter can simply generate a voltage with the magnitude and phase angle requested by the reference input. This operating mode may be advantageous when a separate system optimization control coordinates the operation of the UPFC and other FACTS controllers employed in the transmission system. Special functional cases of direct voltage injection include those having dedicated control objectives, for example, when the injected voltage is kept in phase with the system voltage for voltage magnitude control, or in quadrature with it for controlled “quadrature boosting”, or in quadrature with the line current to provide controllable reactive series compensation.

- **Bus voltage regulation and control mode.** The injected voltage is kept in phase with the input bus voltage and its magnitude is controlled to maintain the magnitude output bus voltage at the given reference value.

- **Phase angle regulation (phase shifter) mode.** The injected voltage is controlled with respect to the input bus voltage (V_b) so that the output bus voltage (V_o) is phase shifted, without any magnitude change, relative to V_b by an angle specified by the reference input. One special case of phase shifting occurs when injected voltage is kept in quadrature with V_b to emulate as the “quadrature booster”.

The UPFC circuit structure offers the possibility of operating
the shunt and series converters independently of each other by disconnecting their common dc terminals and splitting the capacitor bank. In this case, the shunt converter operates as a stand-alone STATCOM, and the series converter as a stand-alone SSSC. In the stand-alone mode, of course, neither converter is capable of absorbing or generating real power so that operation is only possible in the reactive power domain. In this case, the series converter has a considerable limitations available with control modes.

POWER CONDITIONER

Provisions for a reliable electric power supply with tight waveform tolerances is becoming more important to ensure customer satisfaction in the increasingly competitive electric utility industry. Power quality problems such as voltage sags, voltage swells, voltage spikes, and short term outages that causes incorrect information processing by the computers have been estimated to cost the US economy $26 billion annually[2]. On the other hand, a large amount of new equipment in industry and at private consumers is based on power electronics being nonlinear loads and therefore producing voltage fluctuations, flicker, harmonics and unsymmetries in the voltage. The number of such equipment applied in the systems will increase in the future.

Power conditioners are typically based on IGBT PWM converters and connected to low and medium voltage distribution systems in shunt, series or both at the same time. Choosing a kind of equipment to improve the power quality depends on the source of the problem. The power conditioner types will be presented in this section.

Distribution Statcom (DSTATCOM)

The coupling of DSTATCOM is three phase, in parallel to network and load. DSTATCOM injects currents into the point of common coupling (Fig.1). The injected current compensates undesirable components of the load current. There are two possible modes of operation: standard mode and flicker mode [3].

Standard mode. This mode features four distinct control tasks. A list of priorities can be specified by the customer, defining the most important control tasks for the application at hand. In standard mode, DSTATCOM can perform the following four tasks simultaneously:

Active harmonic filtering. The current, flowing from the load into the network, is measured, and separated into fundamental and harmonic components. DSTATCOM injects currents such that unwanted harmonic currents are exclusively exchanged between DSTATCOM and the load and therefore do not flow into the network. Rather than a broadband elimination, DSTATCOM filters certain discrete harmonics (e.g. 5th and 7th). Up to four discrete harmonics at a time can be eliminated. The highest harmonic which can be filtered in this manner by the standard equipment is the 13th. As only problematic harmonics are filtered, based on the DSTATCOM power and economical survey.

Reactive power compensation. DSTATCOM can dynamically supply step-less reactive power, in both capacitive and inductive modes. Power factor control (cos $\phi$ -control) is also possible in this mode.

Dynamic load balancing. DSTATCOM can inject both, positive and negative sequence currents into the point of common coupling. It is thus possible to eliminate negative sequence currents associated with unbalanced loads, thereby performing dynamic load balancing.

Active power transfer. Energy storage devices such as chemical batteries or flywheel systems connected to the dc link capacitor allow energy to be transferred in to the network.

Flicker mode. In general, to reduce the negative impact of flicker producing loads on the network voltage, a highly dynamic means of compensating for varying load currents must be available. The flicker controller features a current control with a response time of less than half a cycle, thus offering the capability of reducing variations in load current with a high dynamic performance.

In case of a short disconnection of the network power supply due to an outage, shunt equipment using energy storage can be used to deliver energy during the outage. In this application the power conditioner acts like a UPS for the duration of the outage. For undisturbed continuous load operation the supply must be disconnected immediately by an electronic switch for example and the shunt connected power conditioner must work like a generator. When the supply is fault free again, the power conditioner re-synchronizes back to the system and the electronic switch is closed.

Dynamic Voltage Restorer (DVR)

DVR injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side (Fig.1). Control response is on the order of 3msec, ensuring a secure voltage supply under transient network conditions. Voltage injection of arbitrary phase with respect to the load current implies active power transfer capability. This active power is transferred via the dc link, and is supplied either by a diode bridge connected to the ac network, a shunt connected PWM converter or by an energy storage device.
Unified Power Quality Controller (UPQC)

The best protect for sensitive loads from voltage sources with inadequate quality, is shunt-series connection power conditioner (UPQC) (Fig.1) in which the shunt part supplies the required power of the series part in the condition of voltage sags. UPQC is consisted of two PWM converters and a dc link capacitor. Shunt converters in spite of supplying the required active power by in series converters, they also can have applying DSTATCOM modes. Series converter inject a series voltage to the supply voltage and can posses DVR advantages.

COMPARING FACTS AND DFACTS EQUIPMENT

As it can be observed in Fig.1, both STATCOM with DSTATCOM, SSSC with DVR and UPFC with UPQC have similar surface structure and as mentioned before, because of special demands on transmission and distribution we can observe different features from these two components. Because power electronic devices like IGBT are expensive, their manufacturing expense is too high. For instance, a UPFC costs 100 \( \text{US} \) \( \text{KVA} \) for ranges of several 100 MVA. So, for the optimum design and the best solving method, we can use computer simulators, and evaluate their performance in the worst conditions just before making them.

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<th>Name</th>
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<th>Topology</th>
<th>Preferred Tasks</th>
<th>Transmission</th>
<th>Distribution</th>
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<td>DSTATCOM (Distribution STATCOM)</td>
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<td>SSSC (Static Synchronous Series Compensator)</td>
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<td>DVR (Dynamic Voltage Restorer)</td>
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<td>UPFC (Unified Power Flow Controller)</td>
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<td>• DSTATCOM and DVR advantages</td>
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<td>Direct Current Transmission &amp; HVDC Light System</td>
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<td>• coupling of remote loads or remote energy sources</td>
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<td>• optimization of energy cost through coupling of bus bars or system parts</td>
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If shunt converter act merely as a supply of series converter (like a diode bridge), then UPQC will be the same as series connection power conditioner based on operation and is called DVR.

Fig.1: FACTS Equipment in Transmission and Distribution Systems.
advantages are that they do not require reactive power and the current distortion is quite low.

HVDC Light is a transmission system with converters and cables coordinated in one delivery. HVDC Light is particularly well suited for long distance cables where AC cables may be impossible or uneconomic to use because of the capacitive charging current and the system impedance. As indicated in Fig.1 converters may contain energy storage system, such as capacitor banks, flywheel systems, Super conducting Magnetic Energy Storage (SMES) or chemical batteries. These energy storage systems must be connected to the dc capacitor of the PWM converter (Fig.1).

CONCLUSION

This paper generally reviews the technology industry and new attachments on power components, various topologies of the power components and power and voltage controllers. The most famous FACTS and DFACTS were discussed and their operating modes were modified.

For resolve of problems in transmission system it can be use FACTS equipment. Power conditioners offer opportunities on the one hand for utilities to provide adequate voltage quality and supply reliability for customers, and on the other hand customers can establish independently proper power quality inside their plant.

The ongoing deregulation in electrical energy transmission and distribution pushes the development and the application of these new technologies.

REFERENCES

