

Uses of FACTS Devices in Modern Power System

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Abstract: With development in power systems there is a need for controlling the power flow along the transmission line. This document describes the concept, types and components in a Flexible AC Transmission System (FACTS). FACTS is economic and plays a vital role in the power transmission. This was designed to overcome the mechanically controlled AC power transmission systems. This uses thyristor switching devices. A frequently occurring situation is transmission of more power in a line than what it was originally designed for. FACTS can be used there. FACTS reduces the losses and the structural limitation of power system.

Keywords: Reactive power, SVC, STATCOM, Thyristor Controlled Reactors (TCR), series compensation, shunt compensation.

I. INTRODUCTION

A flexible alternating current transmission system (FACTS) is a system composed of static equipment used for AC transmission. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics based system. FACTS is defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability." FACTS is a device used to control the governing parameters of the transmission line

Requirements of FACTS

1. Rapid dynamic response
2. Ability for frequent variations in output
3. Smoothly adjustable output

Application of FACTS

1. Power transmission
2. Power quality
3. Railway grid connection
4. Wind power grid connection
5. Cable systems

Due to voltage and transient stability limits the lines operate at low thermal ratings. But FACTS increases the loading capacity of the line without compromising the reliability. There is a demand for power, hence the network should be able to deliver the power to consumer from the supplier without considering the geographical area between them. Hence we need a huge network to supply the required power but due to cost and environmental problems the size of the network is restricted. FACTS was started to solve this emerging problem.

The main objectives of FACTS is to improve the power transferring capacity of the line and to have a control over the power flow in a line. If these objectives are fulfilled, then the

power can be transferred in a transmission line with less requirements. The major problem in a transmission line is blackouts caused by the reactive power. FACTS reduces the reactive power. Consider that the consumer turn on a light at the home then it should be fluctuation-free and free from harmonics so that there won't be any intensity fluctuation. This is an important task of FACTS. The residence area should not be near the industrial plants because the industries causes' huge disturbance that spread through electrical grids.

II. REACTIVE POWER AND FACTS

We all know that reactive power is not a useful power but it can't be totally eliminated it. Consider the example of sending a paper in postal. You can't send the paper alone, you need an envelope to post the paper. But the paper is of no use to us. We need it to post the paper. Here the paper is active power and envelop is the reactive power. Reactive power appears in all electric power systems, due to the laws of nature. Contrary to active power, which is what we really want to transmit over our power system, and which performs real work, such as keeping a lamp lit or a motor running, reactive power does not perform any such work. If reactive power is not enough then Voltage sag would occur. In case of excess reactive power then there would be too high voltage in the line. The magnitude of the reactive power depends on the power factor (cosine angle between the active power and apparent power). If reactive power is high then current required will be high hence the reactive power should be compensated by increasing the power factor. If we can minimize the flow of reactive power over the transmission system, we can make the system more efficient and put it to better and more economical use. Here the FACTS act as a capacitor bank. It would produce a reactive power to oppose the reactive power of the line. A reactive power compensator needs to be fast, i.e. fast response is a key characteristic of the device. This is particularly crucial in situations where some fault appears in the grid. In such a situation, it will often be a matter of milliseconds for the Reactive Power Compensator, the FACTS device, to go into action and help restore the stability, and the voltage of the grid, in order to prevent, or mitigate, a voltage collapse.

In certain cases there would be deficient reactive power, hence reactive power should be added to meet the required reactive power factor. In such a case FACTS is the solution where it as an inductive circuit.

Much reactive power flowing in the grid also gives rise to losses, and losses cost money. To prevent such losses, it is important that reactive power is not permitted to flow over long distances, because losses grow with the distance that the reactive power is flowing over. Instead, reactive power should be inserted where it is needed, i.e. close to large cities and/or large industry enterprises. This too is a task for FACTS.

A. Types of FACTS devices

Rapid development in FACTS devices are taking place. The FACTS devices are focused on power flow modulation and control, stability enhancement and oscillation damping

Whatever may be the FACTS device it can be classified in to four types namely,

1. Shunt compensation
2. Series compensation
3. Shunt-series compensation
4. Back to back compensation

In shunt compensation, the controller (variable impedance or variable voltage source or combination of both) is parallel to the system. FACTS works as a controllable current source. Here FACTS act as a reactive power compensator.

It has two types namely

1. Shunt capacitive
2. Shunt inductive

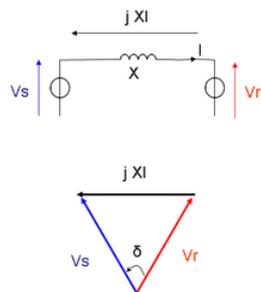


Fig. 1. Transmission on no loss line

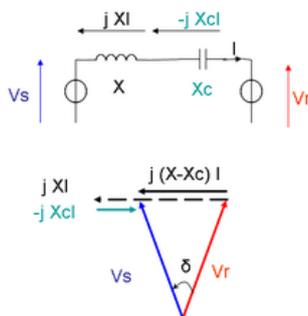


Fig. 2. Shunt compensation

1. Shunt capacitive compensation

This method is used to improve the power factor. When there is an inductive circuit there is a lagging current. Due to this, the losses and poor efficiency occur. Hence when a capacitor is added it will produce a leading current, compensating the lagging current.

2. Shunt inductive compensation

This is used in two cases

- a) When charging the transmission line.
- b) When there is very low load at the receiving end.

As a result very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification (Ferranti Effect). The receiving end voltage may

become double the sending end voltage. To compensate, shunt inductors are connected across the transmission line.

Advantages of shunt compensation

- Compensate the reactive power and hence reduce the losses
- Improvement in static and transient stability
- Improvement in power quality
- Compensation of thyristor converters

Examples of shunt compensation

B. Static synchronous compensator (STATCOM)

Static synchronous compensator is a regulating device used on AC transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network.

I_q is the converter output current and is perpendicular to the converter voltage V_i . The magnitude of the converter voltage and thus the reactive output of the converter (Q) is controllable. If $V_i > V_t$, the STATCOM supplies reactive power to the ac system. If $V_i < V_t$, the STATCOM absorbs reactive power.

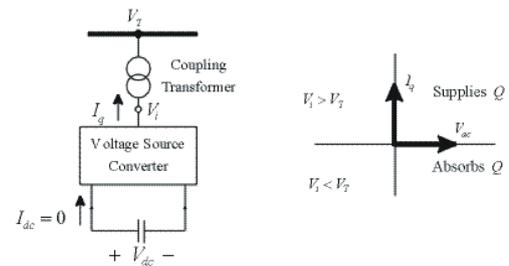


Fig. 3. Static synchronous compensator

State of the art for STATCOM is by the use of IGBT (Insulated Gate Bipolar Transistors). By use of high frequency Pulse Width Modulation (PWM), it has become possible to use a single converter connected to a standard power transformer via air-core phase reactors. The core parts of the plant are located inside a prefabricated building. The outdoor equipment is limited to heat exchangers, phase reactors and the power transformer. For extended range of operation, additional fixed capacitors, thyristor switched capacitors or an assembly of more than one converter may be used. The semiconductor valves in a STATCOM respond almost instantaneously to a switching order. Therefore the limiting factor for the complete plant speed of response is determined by the time needed for voltage measurements and the control system data processing. A high gain controller can be used and a response time shorter than a quarter of a cycle is obtained. The high switching frequency used in the IGBT based STATCOM concept results in an inherent capability to produce voltages at frequencies well above the fundamental one. This property can be used for active filtering of harmonics already present in the network. The STATCOM then injects harmonic currents into the network with proper phase and amplitude to counteract the harmonic voltages. By adding storage capacity to the DC side of STATCOM, it becomes possible not only to control reactive power, but also active power.

C. Static VAR Compensator (or SVC)

SVC is an electrical device for providing fast-acting reactive power on high voltage electricity transmission networks.

An SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or Fixed Capacitors (FC) tuned to Filters. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, epoxy resin impregnated.

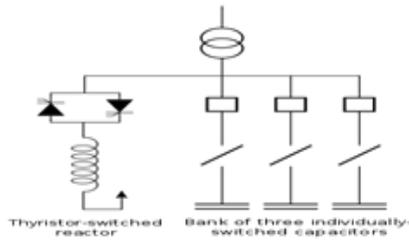


Fig. 4. Static VAR Compensator

The main advantage of SVCs over simple mechanically-switched compensation schemes is their near-instantaneous response to changes in the system voltage. For this reason they are often operated at close to their zero-point in order to maximize the reactive power correction they can rapidly provide when required.

They are in general cheaper, higher-capacity, faster, and more reliable than dynamic compensation schemes such as synchronous condensers.

D. Series compensation

In a series compensation, the controller (variable impedance or variable voltage source or combination of both) is in series to the system. FACTS works as a controllable voltage source.

Series inductance occurs in long transmission lines, and when a large current flow causes a large voltage drop. To compensate, series capacitors are connected.

Advantages of series compensation:

1. Reduction of series voltage drop
2. Reduction of voltage fluctuation
3. Improvement of system damping
4. Limitation of short circuit current

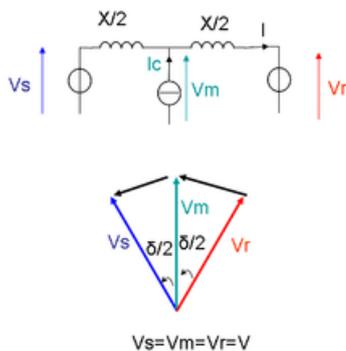


Fig. 5. Series compensation

E. Static Synchronous Series Compensator (SSSC)

It is static synchronous generator operated without an external electric energy source as a series compensator. It is

independent of the line current for changing the overall reactive voltage drop. It has energy absorbing devices to increase the dynamic behavior of the system by adding real power to momentarily change in real voltage drop in the line. SSSC can inject a voltage lagging or leading the current.

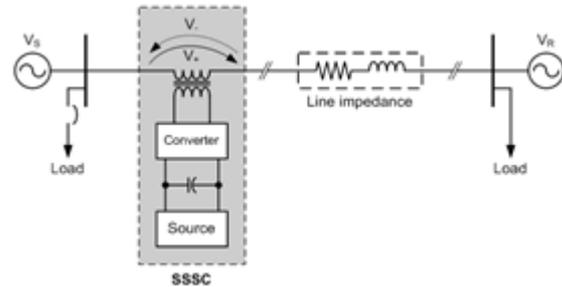


Fig. 6. Static Synchronous Series Compensator (SSSC)

F. Thyristor Controlled Series Capacitor (TCSC)

It is a series capacitor bank shunted with thyristor controlled reactor (TCR) to provide variable capacitive reactance. TCSC is a thyristor without gate turn off capability. If the firing angle is 180° then the TCR becomes non-conducting. But when the angle is 90° impedance become purely inductive. TCSC at 90° is used to limit the fault current.

G. Thyristor Switched Series Capacitance (TSSC)

Similar to that of a TCSC but it provides step wise control of the reactance. The TSR will conduct fully or zero conduction.

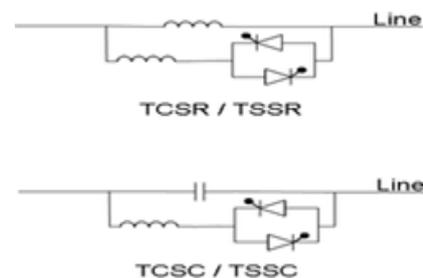


Fig. 7. Thyristor Switched Series Capacitance (TSSC)

H. Thyristor Controlled Series Reactor (TCSR)

TCSR consist of a reactor (inductance) in parallel with the TCR to provide variable inductive reactance. Since the circuit is purely inductive at 180° this won't conduct but when it slowly shift from 180° to 90° it will start conducting. And there would be full conduction will take place at 90°.

I. Thyristor Switched Series Reactor (TSSR)

Similar to a TCSR it also works but it will provide step wise control of the series reactance. It can fully conduct else no conduction.

J. Back-to-back devices

A back to back device provide a full power flow controllability and power flow limitation.

Overload in these devices are not possible.

They can resist cascading outages which occur due to line outages when one line after the other is over loaded.

Uses of back to back device

1. Coupling of electricity mains of different
2. Frequency coupling two networks of the same nominal frequency but no fixed phase relationship

K. Series shunt controllers

This could be the combination of both shunt and series controllers, which are controlled in a coordinate manner. Combined series and shunt controller would inject current with the shunt part and voltage in series. There is a real power exchange in this system. There are various application of this device.

1. Dynamic Flow Controller (DFC)
2. Unified Power Flow Controller (UPFC)
3. Interline Power Flow controller (IPFC)
4. Generalized Unified Power Flow Controller (GUPFC)

1. Dynamic Flow Controller (DFC)

The controller, Dynamic Flow Controller (DFC) is a hybrid compensator that provides series and/or shunt compensation. In comparison with Unified Power Flow Controller (UPFC). DFC has some salient features like cost effectiveness, simplicity, maturity and ruggedness of the technologies of its subsystems, potentially lower losses and thus higher efficiency, which makes it alternative to the UPFC, Structurally, a DFC unit is composed of a Mechanically - switched phase shifting transformer (PST), a mechanically switched shunt capacitor (MSC), and multi-module, thyristor-switched series capacitor (TSSC) and inductors (TSSR).

2. Unified Power Flow Controller (UPFC)

UPFC is a combination of Static synchronous compensator (STATCOM) and Static Synchronous Series Compensator (SSSC) which are coupled via a common dc link to allow bi-directional power flow between the series output of the SSSC and the shunt output of the STATCOM.

The UPFC can be used to control the flow of active and reactive power through the line and to control the amount of reactive power supplied to the line at the point of installation.

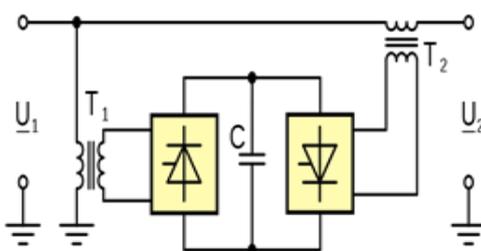


Fig. 8. Unified Power Flow Controller (UPFC)

For efficient operation transmission systems need distributed reactive power support. This is commonly accomplished by installing banks of capacitance at strategic locations within the system, and by switching these banks in and out as needed. The UPFC can make limited use of such hardware; by definition it

uses the shunt converter to supply the active power coupled by the series converter, and once the shunt converter is in place it is also used to supply all of the needed reactive power.

3. Interline Power Flow controller (IPFC)

The major purpose of the parallel filter is to keep voltage on the source element on constant value. The series filter has to inject controllable (with angle and magnitude) voltage and in this way control power flow. One of the disadvantages of this solution is need to equip every transmission line with independent

This solution is not attractive from economical point of view. This problem can be solved by using so called Interline Power Flow Controllers (IPFC). Those systems are the classical series or series-parallel filters applied to given number of independent lines, with common for all lines, DC element. If IPFC system consists only from back-to-back dc to ac series inverter, there is danger that power flow control in one line will degrade power quality in others. This is happening because series connected inverters cannot internally generate voltage in phase with line current. This problem can be solved by adding one, common for all series inverters, parallel back-to-back inverter. Its major purpose is supplying DC element with real power (meet demands on active power of the series inverters).

L. Impact of FACTS in interconnected networks

We all know the benefits of interconnected network.

1. Optimization of power generation.
2. Utilization of differences in load profiles and pooling of reserve capacity.

Not only technical and economic benefits, but also environmental. The energy generated by the renewable sources can be transmitted to a long distance efficiently. This can reduce the power generation using fossil fuel. For interconnections to serve their purpose, however, available transmission links must be powerful enough to safely transmit the amounts of power intended. Else the solution is by building additional lines in parallel with the existing, or by up rating the existing system(s) to a higher voltage.

M. FACTS for minimizing grid investments

It has been mentioned that an important reason for considering FACTS in grid planning is its being an economically as well as environmentally attractive alternative to larger, more costly and more time-consuming investments in extended transmission networks, i.e. basically more lines. Thus, for instance, it can be shown that the cost of installing series capacitors as means for improving the power transmission capacity of existing lines amounts to only a fraction of the cost for installing one or several new lines. This is valid for all existing transmission voltages and for all transmission distances where series compensation comes into consideration.

By considering series compensation from the very beginning, power transmission between regions can be planned with a minimum of transmission circuits, thereby minimizing costs as well as environmental impact from the start.

III. CONCLUSION

Power Transmission system is undergoing dramatic. This new environment puts growing demands for flexibility and power quality into focus. Also, trade of electric power between countries is gaining momentum, to the benefit of all involved. This calls for the right solutions as far as power transmission facilities between countries as well as between regions within countries are concerned. Properly utilized, this offers benefits to users of a variety of kinds.

Existing lines and substations FACTS brings about:

1. An increase in synchronous stability
2. Increased power transmission capability

3. Increased voltage stability in the grid
4. Improved load sharing capability
5. Decreased system transmission losses
6. Improved power quality in grids.

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