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# Power system stability improvement using FACTS devices

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## ABSTRACT

***Due to limited resources and environmental restrictions, the power generation and transmission has been severely limited even though the power demand has increased substantially in the last two decades. The consequence being some of the transmission lines are heavily loaded and the system stability becomes a power transfer limiting factor. To solve various power system steady state control problems, FACTS (Flexible ac transmission system) controllers have been used. Flexible and dynamic control of power systems are allowed through Flexible AC transmission system or FACTS. The investigation of FACTS devices for the enhancement of system stability has been done. To improve the operation of electrical power system by utilizing FACTS devices is the main aim of this paper. This paper also discussed the performance comparison of different FACTS controllers. Reviews and summaries of some of the utility experience and semiconductor technology development have also been taken into consideration.in this paper, the discussion of applications of FACTS to power system studies has also been done.***

**Keywords:** AC, FACTS, IPFC, PSS, SVC, STATCOM, SSSC, TCSC, TCPS, UPFC.

## 1. INTRODUCTION

A great opportunity is offered by FACTS controllers to regulate the transmission of alternating current (AC), increase or decrease the power flow in specific lines and responding to the stability problems instantaneously. The possibility of controlling the route of power flow and the ability of connecting networks that are not adequately interconnected as well as providing the possibility of trading energy between distant agents is the potential of this technology. The AC transmission of electrical energy is done with the help of a static equipment called Flexible Alternating Current Transmission Line (FACTS). Power transfer capability and controllability is enhanced by using FACTS devices, which is generally power electronic based device. These devices can be divided into three groups depending on their switching technology: mechanically switched (such as phase shifting transformers), thyristor switched or fast switched, using IGBTs. New developments in power electronics and control have extended the application range of FACTS irrespective of the fact that we are already aware of some types of FACTS, such as phase shifting transformer (PST) and static VAR compensator (SVC) in power system. Further, new applications of FACTS are provided by intermittent renewable energy sources and increasing international power flow. The mitigation of problems associated with the unreliable supply issues of the renewable are also allowed through the additional flexibility and controllability of FACTS. SVC and STATCOM provide ancillary services (like voltage control) to the grid and fault rid through capabilities which cannot be provided by standard wind farms. Moreover, oscillations are reduced in the grid with the help of FACTS which seems especially interesting while dealing with the stochastic behaviour of renewable.

## 2. CONTROL OF POWER SYSTEM

### A. Generation, Transmission and Distribution

The creation, transmission and utilization of electrical power can be separated into three areas in any power system which traditionally determined the way in which electric utility companies had been organized.

- Generation
- Transmission
- Distribution

 

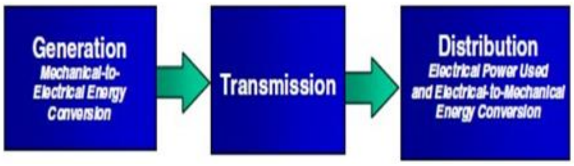


**Fig.1. Block diagram of generation, transmission and distribution**

Though in each of these three areas, power electronic based equipment is prevalent yet the focus of this paper is on transmission, i.e. moving the power from where it is generated to where it is utilized.

**B. Power System Constraints**

As the introduction specifies, transmission systems are being pushed closer to their stability and thermal limits whereas, the complete focus is headed towards the quality of power delivered to be greater than ever. The transmission system's limitations can take many forms and power transfer between areas or within a single area or region may be involved along with the following characteristics:

• Steady state power transfer limit

• Voltage stability limit

• Dynamic voltage limit

• Transient stability limit

• Power system oscillation damping limit

• Inadvertent loop flow limit

• Thermal limit

• Short circuit current limit

• Others

One or more of these system level problems may be incorporated in each transmission bottleneck or regional constraint. By thorough system engineering analysis, these problems can be solved in the most cost effective and coordinated manner.

**C. Controllability of Power System**

In fig.2. Power-angle curve is shown, which is considered to illustrate that the power system only has certain variables that can be impacted by control. Despite of being a steady state curve and the implementation of FACTS is primarily for dynamic issues, this illustration demonstrates that there are three main variables that can be directly controlled to impact the performance of power system. They are:

• Voltage

• Angle

• Impedance

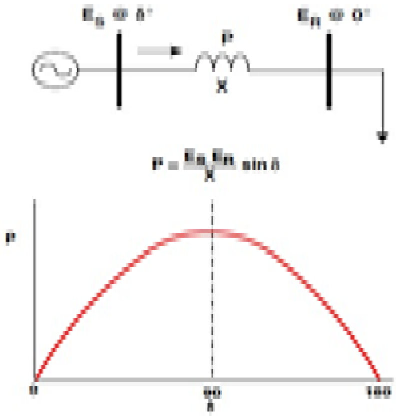

**Fig.2. illustration of controllability of power systems**

 

We can also conclude that the fourth variable of controllability in power system is the direct control of power. With the establishment of "what" and "how", the variables can be controlled in a power system. The answer to these questions is presented in two parts, namely:

• Conventional equipment

• FACTS controllers

Examples of FACTS controllers for enhancing power system control

• Static Synchronous Compensator (STATCOM)

• Static VAR Compensator (SVC)

• Unified Power Flow Controller (UPFC)

• Convertible Series Compensator (CSC)

• Interphase Power Flow Controller (IPFC)

• Static Synchronous Series Controller (SSSC)

• Thyristor Controlled Series Compensator (TCSC)- controls impedance

• Thyristor Controlled Phase Shifting Transformer (TCPST)- controls angle

• Super Conducting Magnetic Energy Storage (SMES)- controls voltage and power

Examples of conventional controllers for enhancing power system control

• Series capacitor-control impedance

• Switched Shunt-capacitor and Reactor- controls voltage

• Transformer LTC- controls voltage

• Phase Shifting Transformer- controls angle

• Synchronous condenser- controls voltage

• Special Stability Controls- focuses on voltage control but often includes direct control of power

• Others (when thermal limits are involved)- can include reconductoring, raising conductors, dynamic line monitoring, adding new lines etc.

**D. Benefits of control of power system**

Once the identification of power system constraints is done and identification of viable solution option is done through system studies, the benefits of added power system control must be determined. The benefits are offered by the following list:

• Increased loading and more effective use of transmission corridors

• Added power flow control

• Improved power system stability

• Increased system security

• Increased system reliability

• Added flexibility in starting new generation

• Elimination or deferral of the need of new transmission lines

**E. Benefits of utilizing FACTS devices**

The benefits of utilizing FACTS devices can be summarised as follows:

• Better utilization of existing transmission system assets

• Increased transmission system reliability and availability

• Increased dynamic and transient grid stability and reduction of loop flows

• Increased quality of supply for sensitive industries

 

**F. Classification**

Different classification of FACTS devices are:

1. Depending on the type of connection to the network, FACTS can be categorized into:

• Serial controllers

• Derivation controllers

• Serial to serial controllers

• Serial derivation controllers

2. Depending on the technological features, the FACTS devices are divided into two generations:

• First generation: used thyristors with ignition controlled by gate (SCR)

• Second generation: semiconductors with ignition and extinction controlled by gate (GTO's, MCT's, IGBT's, IGCT's etc.)

The capacity to generate reactive power and to interchange active power is the main difference between first and second generation devices.

By using impedance or tap change transformers that are controlled by thyristors, the first generation FACTS devices work as passive elements. The second generation FACTS device works like angle and module controlled voltage sources and that too without inertia and are based on converters, employing electronic tension sources(three phase inverters, auto switched voltage sources, synchronous voltage sources, voltage source control) fast proportioned and controllable and static synchronous voltage and current sources.

## 3. FIRST GENERATION OF FACTS

### A. Static VAR compensator (SVC)

An electrical device used for providing fast-acting reactive power on high voltage electricity transmission network is called static VAR compensator. SVC is a part of Flexible AC transmission system device family. It regulates voltage and stabilizes the system. The term "static" in SVC refer to the fact that it does not possess any moving part other than circuit breakers. The circuit breaker disconnects and does not move in any normal SVC operation. Before the use of SVC, power factor compensation was in preserves to large rotating machines like synchronous condensers. An automated impedance matching device, called SVC is designed to bring the system closer to unity power factor. The SVC uses reactors (usually in the form of thyristor-controlled reactors) to consume VAR from the system to lower the voltage of the system if the reactive load of the system is capacitive (leading) whereas if the reactive load of the system is lagging (inductive) then the capacitor banks are automatically switched in which in turn provides a higher system voltage. In order to smooth the flicker voltage, the may also be placed near high and rapidly varying loads, such as, arc furnaces. The dynamic stability of power system can be improved by the SVCs with an auxiliary injection of a suitable signal. The influenced non-linear system behaviour under high stress operating conditions and SVC gains can be controlled by SVC.

### B. Thyristor-Controlled Series Capacitor (TCSC)

Thyristor-controlled reactor is used in parallel with capacitor segments of series capacitor bank in a TCSC. TCR and capacitor combine together to allow the capacitive reactive to be controlled smoothly over a wide range and switched upon a command to a condition where there is pairing of bidirectional thyristors that conduct continuously and inductive reactance is inserted into the line.

Solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines through TCSC is an economical and effective means. The line impedance can be controlled by the first generation of FACTS, TCSC through the introduction of a thyristor controlled capacitor in series with the transmission line. A continuous control of power on the ac transmission line can be achieved over a wide range through a TCSC which is a series controlled capacitive reactance. The analysis of the behaviour of a variable inductor connected in series with a fixed capacitor can comprehend the functioning of the TCSC.

### C. Thyristor Controlled Phase Shifter (TCPS)

The phase shift angle in a TCPS is determined as a non-linear function of rotor angle and speed. However, in real life, power system with a large number of generators, the measurement of rotor angle of a single generator is done with respect to the system reference which is not that meaningful.

## 4. SECOND GENERATION FACTS

### A. Static Compensator (STATCOM)

STATCOM is a regulating device used on alternating current electricity transmission network and is based on power electronics voltage source converter. It can act as either a source or sink of reactive AC power to an electricity network. When connected to a source of power, it provides an active AC power. STATCOM is a FACTS' family of devices. Where the electricity network has a poor power factor and a poor voltage regulation, STATCOM is installed in support of it. The most common use among all uses is the voltage stability. STATCOM provides a better damping characteristic than the SVC in the viewpoint of power system dynamic stability as it is able to transiently exchange active power with the system.

 

**B. Static Synchronous Series Compensator (SSSC)**

SSSC and STATCOM work in the same fashion. SSSC has a voltage source converter connected to a transmission line serially through a transformer. A continuous voltage should be provided by an energy source and the losses of the VSC should be compensated. Exchange of active and reactive power is done with the help of SSSC. The energy source can be very small if our aim is to balance the reactive power. If the energy source is big enough then the injected voltage can be controlled in phase and magnitude. The voltage is controllable with the reactive power compensation because the voltage vector forms 90 degrees with the line intensity. SSSC can be controlled uniformly in any value, in any VSC working slot.

**C. Unified Power Flow Controller (UPFC)**

The most promising FACTS device is the Unified Power Flow Controller (UPFC). Three control parameters are adjusted by it, i.e. the bus voltage, transmission line reactance and phase angle between two buses, either simultaneously or independently. The control of in-phase voltage, quadrature voltage and shunt compensation is performed through UPFC. This device is the most versatile and complex power electronic equipment which emerges to control and optimize the power flow in electrical power transmission system. Static and dynamic operations of transmission line are the major potential advantages offered by UPFC. Real time control and dynamic compensation of ac transmission systems are done by UPFC to provide multifunctional flexibility that is required to solve many problems faced by power industry. All the parameters that affect the power flow in the transmission line is controlled by UPFC within the framework of traditional power transmission concepts simultaneously or selectively.it can independently control both real and reactive power flow in the line.

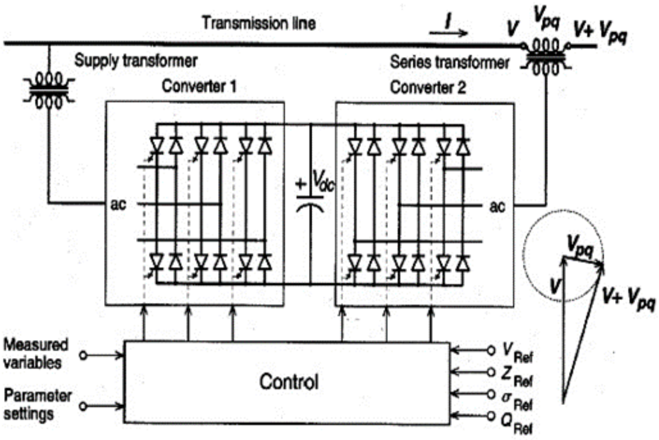


**Fig.3. Unified power flow controller**

**5. TYPES OF NETWORK CONNECTION**

**A. Serial Controllers**

A variable impedance as a condenser or a variable electronics based source at a fundamental frequency is comprised in it. Injection of a serial tension to the line is the principle of operation of all serial controllers. Serial tension is represented by a variable impedance multiplied by the current. The tension is represented in the quadrature with the line current. Reactive power is only consumed by the serial controller. Any phase angle represents the management of active power. Serial Synchronous Static Compensator (SSSC).

**B. Controllers in Derivation**

Like the serial controller, the derivation controller consists of a variable impedance, variable source or a combination of both. The injection of current to the system in the point of connection is the principle of operation of all controllers in derivation. A variable current flows due to the connection of a variable impedance to the line tension which in turn represents an injection of current to the line. The controller in the derivation only consumes reactive power while the injected current is in quadrature with the line tension. Any other phase angle would represent management of active power. Synchronous Static Compensator (STATCOM) is a typical controller.

**C. Serial-Serial Controllers**

A combination of serial controllers coordinated in a multiline transmission system is a serial-serial controller. It can also be summed up as a unified controller in which serial reactive compensation for each line is provided by the serial controllers and active power is also transferred between lines through the link of power. The active and reactive power flow balance is made possible and the use of transmission bigger with the help of the active power transmission capacity that presents a unified serial controller or line fed power controller. The word "unified" in this case means that the DC terminals of the converters of all controllers are connected to achieve a transfer of active power between each other. Interline power flow controller (IPFC) is a typical controller.

**D. Serial-Derivation Controllers**

This device is a combination of serial and derivation controllers separated, coordinate controlled or a unified power flow controller with serial and derivation elements. The injection of current to the system through the component in derivation of the controller and serial tension with the line utilizing the serial component is the principle of operation of serial-derivation controllers. When there is a unification of serial and derivation controllers then they can have an exchange of active power between them through their link. UPFC is a typical controller through which incorporating the function of a filtering and conditioning becomes a universal power line conditioner (UPLC).

## 6. APPLICATIONS AND TECHNICAL BENEFITS OF FACTS

The addressing problems in transient stability, dampening, post contingency voltage control and voltage stability in some of the technical benefits of the principal for dynamic applications of FACTS are summarized in Table-1. Whenever there is a need to respond to dynamic network conditions then FACTS devices are used. The conventional solutions are less expensive than FACTS devices but are limited in their dynamic behaviour. The task of planners is to identify the most economical solution.

**Table-1 Technical benefits of the main FACTS devices**

| | Load Flow Control | Voltage Control | Transient Stability | Dynamic Stability |
|---|---|---|---|---|
| SVC | ● | ●●● | ● | ●● |
| STATCOM | ● | ●●● | ●● | ●● |
| TCSC | ●● | ● | ●●● | ●● |
| UPFC | ●●● | ●●● | ●● | ●● |

● → ●● → ●●● Better

## 7. CONCLUSION

The prime concern for effective and economic operation of the power system is the essential feature of FACTS controllers and its potential to improve the stability of the system. The discussion of the location and feedback signals which are used for the design of FACTS based damping controllers is done. The consideration of the coordination problem among different control schemes is also done. The review of the performance comparison of different FACTS controllers has been taken. The discussion of future direction of FACTS technology is also done. In addition to that, utility experience, major real world installations and semiconductor technology development has also been summarized.

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