IMPROVEMENT OF VOLTAGE STABILITY AND POWER SYSTEM SECURITY BY FACTS DEVICES

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Abstract— In this pepper we are working to improve the Improvement of voltage stability and power system security by facts devices throw by last two decades, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Flexible AC transmission systems controllers have been mainly used for solving various power system steady state control problems. Flexible AC transmission systems or FACTS are devices which allow the flexible and dynamic control of power systems. Enhancement of system stability using FACTS controllers has been investigated. This paper is aimed towards the benefits of utilizing FACTS devices with the purpose of improving the operation of an electrical power system. Performance comparison of different FACTS controllers has been discussed. In addition, some of the utility experience and semiconductor technology development have been reviewed and summarized. Applications of FACTS to power system studies have also been discussed.

Index Terms— SVC, STATCOM, SSSC, TCSC, TCPS, FACTS, IPFC, PSS, UPFC.

1 INTRODUSCTIO

The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents. Flexible Alternating Current Transmission System (FACTS) is a static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability. It is generally a power electronics based device. The FACTS devices can be divided in three groups, dependent on their switching technology: mechanically switched (such as phase shifting transformers), thyristor switched or fast switched, using IGBTs. While some types of FACTS, such as the phase shifting transformer (PST) and the static VAR ompensator (SVC) are already well known and used in power systems, new developments in power electronics and control have extended the application range of FACTS. Furthermore, intermittent renewable energy sources and increasing international power flows provide new applications for FACTS. The additional flexibility and controllability of FACTS allow to mitigate the problems associated with the unreliable of supply issues of renewable. SVCs and STATCOM devices are well suited to provide ancillary services (such as voltage control) to the grid and fault rid through capabilities which standard wind farms cannot provide Furthermore, FACTS reduce oscillations in the grid, which is especially interesting when dealing with the stochastic behavior of renewable.

2. POSSIBLE BENEFITS FROM FACTS TECHNOLOGY

Within the basic system security guidelines, the FACTS devices enable the transmission system to obtain one or more of the following benefits: Control of

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power flow as ordered. This is the main function of FACTS devices. The use of power flow control may be to follow a contract, meet the utilities' own needs, ensure optimum power flow, ride through emergency conditions, or a combination of them. One of the principal reasons for transmission interconnections is to utilize the lowest cost generation. When this cannot be done, it follows that there is not enough cost-effective transmission capacity. Cost-effective enhancement of capacity will therefore allow increased use of lowest cost generation. DS enhancement. This FACTS additional function includes the TS improvement, POD and VS control. Increase the loading capability of lines to their thermal capabilities, including short term and seasonal demands. Increased system reliability. Elimination or deferral of the need for new transmission lines. Added flexibility in siting new generation Provide secure tie-line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.

3.CONTROL OF POWER SYSTEMS

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

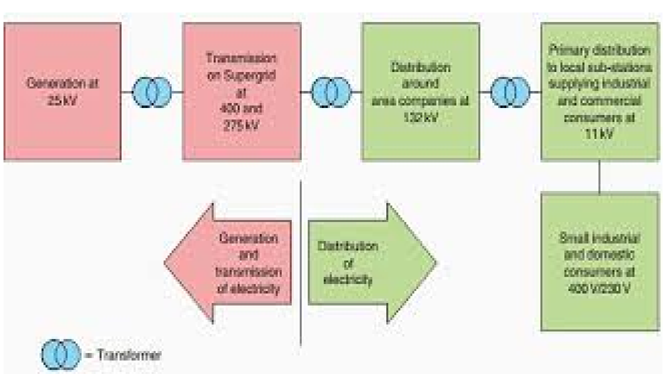

Fig – 1Block diagram of generation, transmission & distribution

Although power electronic based equipment is prevalent in each of these three areas, such as with static excitation systems for generators and Custom Power equipment in distribution systems [8], the focus of this paper and accompanying presentation is on transmission, i.e, moving the power from where it is generated to where it is utilized. 2.2. Power System Constraints As noted in the introduction, transmission systems are being pushed closer to their stability and thermal limits while the focus on the quality of power delivered is greater than ever. The limitations of the transmission system can take many forms and may involve power transfer between areas or within a single area or region and may include one or more of 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

Each transmission bottleneck or regional constraint may have one or more of these system-level problems. The key to solving these problems in the most cost-effective and coordinated manner is by thorough systems engineering analysis. 2.3. Controllability of Power Systems To illustrate that the power system only has certain variables that can be impacted by control, we have considered here the power-angle curve, shown in Figure 2. Although this is a steady-state curve and the implementation of FACTS is primarily for dynamic issues, this illustration demonstrates the point that there are primarily three main variables that can be directly controlled in the power system to impact its performance. These are: • Voltage • Angle • Impedance

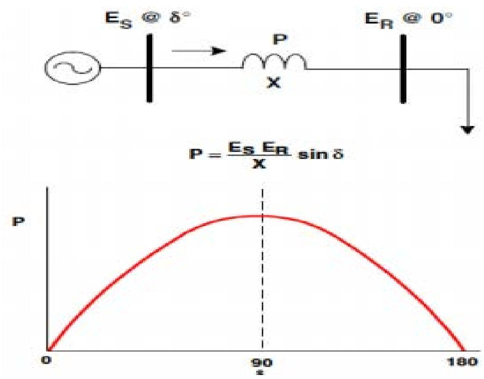

Fig – 2. Illustration of controllability of power systems

We can also infer the point that direct control of power is a fourth variable of controllability in power systems. With the establishment of "what" variables can be controlled in a power system, the next question is "how" these variables can be controlled. The answer is presented in two parts: namely conventional equipment and FACTS controllers. Examples of Conventional Equipment For Enhancing Power System Control • Series Capacitor -Controls 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 include direct control of power • Others (When Thermal Limits are Involved) - Can included reconductoring, raising conductors, dynamic line monitoring, adding new lines, etc. Example of FACTS Controllers for Enhancing Power System Control • Static Synchronous Compensator (STATCOM) -Controls voltage • Static VAR Compensator (SVC) -Controls voltage • Unified Power Flow Controller (UPFC) • Convertible Series Compensator (CSC) • Inter-phase Power Flow Controller (IPFC) • Static Synchronous Series Controller (SSSC)

Each of the above mentioned controllers have impact on voltage, impedance, and/or angle (and power) • 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 Benefits of Control of Power Systems Once power system constraints are identified and through system studies viable solutions options are identified, the benefits of the added power system control must be determined. The following offers a list of such benefits: • 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 for New Transmission Lines

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows [1]:

•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 •Environmental benefits Better utilization of existing transmission system assets 2.6. Classification There are different classifications for the FACTS devices: Depending on the type of connection to the network FACTS devices can differentiate four categories • serial controllers

• derivation controllers

• serial to serial controllers

• serial-derivation controllers Depending on technological features, the FACTS devices can be divided into two generations

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

• second generation: semiconductors with ignition and extinction controlled by These two classifications are independent, existing for example, devices of a group of the first classification that can belong to various groups of the

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second classification. The main difference between first and second generation devices is the capacity to generate reactive power and to interchange active power. The first generation FACTS devices work like passive elements using impedance or tap changer transformers controlled by thyristors. The second generation FACTS devices work like angle and module controlled voltage sources and without inertia, based in 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

4. FIRST GENERATION OF FACTS

4.1. Static VAR Compensator (SVC) A static VAR compensator (or SVC) is an electrical device for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage and stabilising the system. The term "static" refers to the fact that the SVC has no moving parts (other than circuit breakers and disconnects, which do not move under normal SVC operation). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. If the power system's reactive load is capacitive (leading), the SVC will use reactors (usually in the form of Thyristor-Controlled Reactors) to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. They also may be placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage. It is known that the SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system . It is observed that SVC controls can significantly influence nonlinear system behavior especially under high-stress operating conditions and increased SVC gains.

4.2. Thyristor-Based FACTS Controllers Developments in the field of high voltage power electronics have made possible the practical realization of FACTS controllers. By the 1970s, the voltage and current rating of GTOs had been increased significantly making them suitable for applications in high voltage power systems [2]. This made construction of modern Static Var Compensators (SVCs), Thyristor Controlled Series Capacitors (TCSCs), Thyristor Controlled Phase Angle Regulators (TCPARs), and many other FACTS controllers possible. A fundamental feature of the thyristor based switching controllers is that the speed of response of passive power system components such as a capacitor or a reactor is enhanced, but their compensation capacity is still solely determined by the size of the reactive component. For example, a SVC requires fully rated reactors and capacitors to absorb or generate reactive power, and a thyristor based electronic circuit rated for the sum of the maximum inductive and capacitive currents and voltages to control voltage magnitude in a power system. This arrangement has speeded up the response of the controller to approximately 1 cycle but the SVC still shows behavior similar to that shown by mechanically switched capacitor and reactor banks, as the reactive power generation changes with the change of the line voltage [3, 4, 5].

Series capacitors are connected in series with transmission lines to compensate for the inductive reactance of the line, increasing the maximum transmittable power and reducing the effective reactive power loss. Power transfer control can be done continuously and rather fast using, for example, the Thyristor Controlled Series Capacitors (TCSCs), making it very useful to dynamically control power oscillations in power systems [6]. However, the problem with these devices is that

that it can form a series resonant circuit in series with the reactance of the transmission line, thus limiting the rating of the TCSC to a range of 20 to 70 % the line reactance. It has been also noted that since the line current is a function of the impedance and phase angle, the compensating voltage is also a function of these parameters, making the reactive power demand of the transmission line a direct function of the transmitted active power.

4.3 Thyristor-Controlled Series Capacitor (TCSC) TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank. The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bidirectional thyristor pairs conduct continuously and insert an inductive reactance into the line. TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line. A TCSC is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. The functioning of TCSC can be comprehended by analyzing the behavior of a variable inductor connected in series with a fixed capacitor

4.4 GTO-Based FACTS A normal thyristor, which is basically a one-way switch, can block high voltages in the off-state and carry large currents in the on-state with only small on-state voltage drop [10]. The thyristor, having no current interruption capability, changes from onstate to off-state when the current drops below the holding current and, therefore, has a serious deficiency that prevents its use in switched mode applications. With the development of the high voltage, high current Gate Turn-Off thyristors (GTOs), it became possible to overcome this deficiency. Like the normal thyristor, a gate current pulse can turn on the GTO thyristor, while to turn it off, a negative gate-cathode voltage can be applied at any time. This feature and the improved ratings of GTOs made possible the use of Voltage-Sourced Converters (VSC) in power system applications [11].

4.5. Thyristor-Controlled Phase Shifter (TCPS) In a TCPS control technique the phase shift angle is determined as a nonlinear function of rotor angle and speed. However, in real-life power system with a large number of generators, the rotor angle of a single generator measured with respect to the system reference will not be very meaningful. 4. SECOND GENERATION OF FACTS 4.1. Static Compensator (STATCOM) The emergence of FACTS devices and in particular GTO thyristor-based STATCOM has enabled such technology to be proposed as serious competitive alternatives to conventional SVC [10] A static synchronous compensator (STATCOM) is a regulating device used on alternating current electricity 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. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability.

From the power system dynamic stability viewpoint, the STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system. Static Synchronous Series Compensator (SSSC) This device work the same way as the STATCOM. It has a voltage source converter serially connected to a transmission line through a transformer. It is necessary an energy source to provide a continuous voltage through a condenser and to compensate the losses of the VSC. A SSSC is able to exchange active and reactive power with the transmission system. But if our only aim is to balance the reactive power, the energy source could be quite small. The injected voltage can be controlled in phase and magnitude if we have an energy source that is big enough for the purpose. With reactive power compensation only the voltage is controllable, because the voltage vector forms 90º degrees with the line intensity. In this case the serial injected voltage can delay or advanced the line current. This means that the SSSC can be uniformly controlled in any value, in the VSC working slot. Unified Power Flow Controller (UPFC) A unified power flow controller (UPFC) is the most promising device in the FACTS concept. It has the ability to adjust the three control parameters, i.e. the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage, and shunt compensation. The UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission systems. It offers major potential advantages for the static and dynamic operation of transmission lines. The UPFC was devised for the real-time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the power industry. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line. Alternatively, it can independently control both the real and reactive power flow in the line unlike all other controllers.

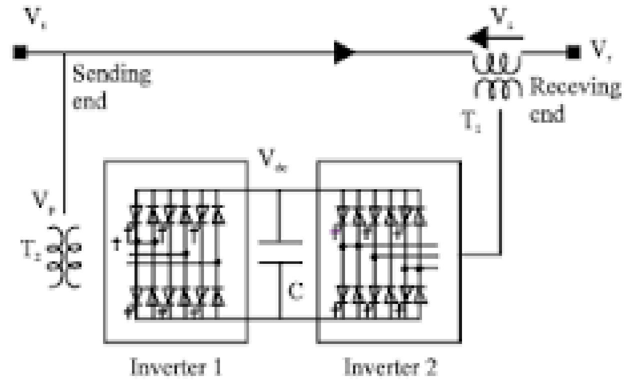

Fig – 3. Unified Power Flow Controller

5. TYPES OF NETWORK CONNECTION

5.1. Serial controllers. It can consist of a variable impedance as a condenser, coil, etc or a variable electronics based source at a fundamental frequency. The principle of operation of all serial controllers is to inject a serial tension to the line. A variable impedance multiplied by the current that flows through it represents the serial tension. While the tension is in quadrature with the line current the serial controller only consumes reactive power; any other phase angle represents management of active power. A typical controller is Serial Synchronous Static Compensator (SSSC). 5.2. Controllers in derivation. As it happens with the serial controller, the controller in derivation can consist of a variable impedance, variable source or a combination of both. The operation principle of all controllers in derivation is to inject current to the system in the point of connection. A variable impedance connected to the line tension causes variable current flow, representing an injection of current to the line. While the injected current is in quadrature with the line tension, the controller in derivation only consumes reactive power; any other phase angle represents management of active power. A typical controller is Synchronous Static Compensator (STATCOM).

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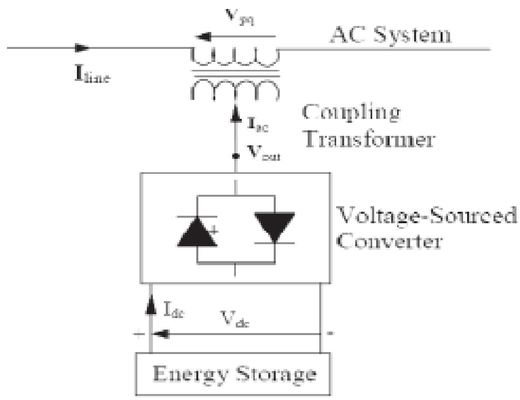


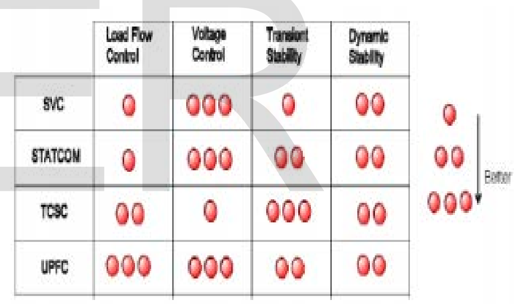
5.3. Serial-serial Controllers. This type of controllers can be a combination of coordinated serial controllers in a multiline transmission system. Or can also be an unified controller in which the serial controllers provide serial reactive compensation for each line also transferring active power between lines through the link of power. The active power transmission capacity, that present a unified serial controller or line

6. FACTS APPLICATIONS TO STEADY STATE POWER SYSTEM PROBLEMS

For the sake of completeness of this review, a brief overview of the FACTS devices applications to different steady state power system problems is presented in this section. Specifically, applications of FACTS in optimal power flow and deregulated electricity market will be reviewed. 6.1. FACTS Applications to Optimal Power Flow In the last two decades, researchers developed new algorithms for solving the optimal power flow problem incorporating various FACTS devices [11]. Generally in power flow studies, the thyristor controlled FACTS devices, such as SVC and TCSC, are usually modeled as controllable impedance [12]. However, VSC-based FACTS devices, including IPFC and SSSC, shunt devices like STATCOM, and combined devices like UPFC, are more complex and usually modeled as controllable sources [13]. The Interline Power Flow Controller (IPFC) is one of the voltage source converter(VSC) based FACTS Controllers which can effectively manage the power flow via multi-line Transmission System. [14].

7. TECHNICAL BENEFITS OF FACTS AND ITS APPLICATIONS

The technical benefits of the principal for dynamic applications of FACTS in addressing problems in transient stability, dampening, post contingency voltage control and voltage stability are summarized in Table-1. FACTS devices are required when there is a need to respond to dynamic (fast-changing) network conditions. The conventional solutions are normally less expensive than FACTS devices, but limited in their dynamic behavior. It is the task of the planners to identify the most economic solution.



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

Table 1. Technical benefits of the main FACTS devices

8. CONCLUSION

FACTS controllers are in power system environments for enhancement of performance parameters of systems as RP support, minimize the AP losses, improvement in VP of systems, improvement in damping ratio of PSs, flexible operation and control of systems, etc. the application of FACTS controllers in PSs for enhancement of performance parameters of systems. The essential features of FACTS controllers and their potential to improve system stability is the prime concern for effective & economic operation of the power system. The location and feedback signals used for design of FACTS-based damping controllers were discussed. The coordination problem among different

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control schemes was also considered. Performance comparison of different FACTS controllers has been reviewed. The likely future direction of FACTS technology, was discussed. In addition, utility experience and major real-world installations and semiconductor technology development have been summarized. A brief review of FACTS applications to optimal power flow and deregulated electricity market has been presented.

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