Priyank Srivastava, Rashmi Pardhi / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 3, May-Jun 2013, pp.879-883

A Review on Power System Stability and Applications of FACT Devices

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Abstract

stability is one of the major concerns related to power system. The instability causes the fluctuations in different parameters of power system but the voltage and frequency are most importantly considered because may cause great damage and even cause complete shutdown of power system. This paper presents brief overview of different types of instabilities in power system and the techniques used to overcome it. The paper also compares the applicability of different techniques on the basis of performance.

Keywords: *power system stability, FACT devices.*

1. Introduction

The stability of the power system is defined as "the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact" [1]. According to above definition it is clear that if system fails to get operating equilibrium then it will be called instable. There are many kind of instabilities exists in the modern power systems (such as voltage, frequency etc.) and accordingly the different stabilization methods are used. The stabilization processes basically works by compensation of the causing the instability in past this is done by connecting and disconnecting the capacitor, inductors or combination of both after that synchronous condenser, saturated reactor, thyristor controlled reactor, fixed capacitor thyristor controlled reactor, thyristor switched capacitor were used; but in present days this is performed by more advanced devices like STATCOM, VSC, TCSC etc. these devices evolves the intelligent controlling and fast switching power devices like MOSFET and IGBT the capability of fast switching makes them feasible for providing precise and smooth controlling. The intelligent controlling is performed by the complex calculations which are done by either analog circuits or microprocessors. Although analog devices performed well but in recent past developments in the semiconductor technology makes the digital controllers as first choice because of their capabilities and lower cost.

2. Types of Instabilities in Power System

The classification to be introduced here is based on the physical mechanism being the main driving force in the development of the associated instability.

Power System Stability (PSS) problems may be classified as [2]:

- Angle Stability
- Voltage Stability
- Frequency (Mid- and Long-Term) Stability

Each category can be divided to [2]:

- Small-Signal (Dynamic) Stability: Determines if system remains in synchronism following a small disturbance (e.g., small load and/or generation variations).
- Transient Stability: Determines if system remains in synchronism following a major disturbance (e.g., transmission fault, sudden load change, loss of generation, line switching). The transient stability can further be divided into two classes.
- First-Swing Stability: for 1st second after a system fault (simple generator model & no control model).
- Multi Swing Stability: system analysis over long period of time (more sophisticated machine model).

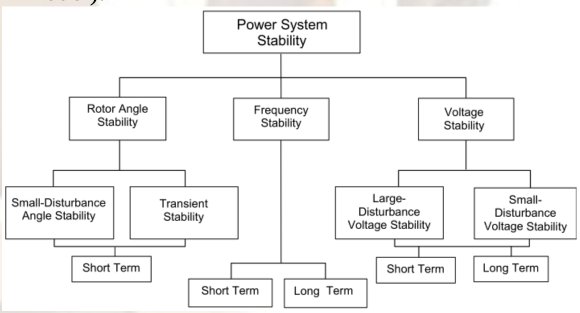

Figure 1: Classification of power system stability [3].

2.1 Rotor Angular or Synchronous Stability

The rotor angle stability problem involves the study of the electromechanical oscillations inherent in power systems. A fundamental factor in this problem is the manner in which the power outputs of synchronous machines vary as their rotor angles change. The mechanism by which interconnected synchronous machines maintain synchronism with one another is through restoring forces, which act whenever there are forces tending to accelerate or decelerate one or more machines with respect to other machines. Under steady-state conditions, there is equilibrium between the input mechanical torque and the output electrical torque of each machine, and the speed remains constant. If the system is perturbed, this equilibrium is upset, resulting in acceleration or deceleration of the rotors of the machines according to the laws of motion of a rotating body. If one generator temporarily runs faster than another, the angular position of its rotor relative to that of the slower machine will advance. The resulting angular difference transfers part of the load from the slow machine to the fast machine, depending on the power angle relationship. This tends to reduce the speed difference and hence the angular separation. The power angle relationship, as discussed above, is highly nonlinear. Beyond a certain limit, an increase in angular separation is accompanied by a decrease in power transfer; this increases the angular separation further and leads to instability. For any given situation, the stability of the system depends on whether or not the deviations in angular positions of the rotors result in sufficient restoring torques. It should be noted that loss of synchronism can occur between one machine and the rest of the system, or between groups of machines, possibly with synchronism maintained within each group after separating from each other [3].

2.2 Voltage Stability

When it comes to reactive power balance the situation is not as clear and simple as concerning active power. There is always a balance between "produced" and "consumed" reactive power in every node of a network. This is in fact a direct consequence of Kirchoff's first current law. When one talks about imbalance in this context we mean that the injected reactive power is such, normally too small, that the voltage in the node cannot be kept to acceptable values. (At low load the injected reactive power could be high resulting in a too high voltage, possibly higher than the equipment might be designed for. This is of course not desirable but it could usually be controlled in such a way that no instabilities develop.) When we talk about imbalance in this case we thus mean that the injected reactive power differs from the desired injected reactive power, needed to keep the desired voltage. If this imbalance gets too high, the voltages exceed the acceptable range [1].

2.3 Frequency Stability

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads. Severe system upsets generally result in large excursions of frequency, power flows, voltage, and other system variables, thereby invoking the actions of processes, controls, and protections that are not modeled in conventional transient stability or voltage stability studies. These processes may be very slow, such as boiler dynamics, or only triggered for extreme system conditions, such as volts/Hertz protection tripping generators. In large interconnected power systems, this type of situation is most commonly associated with conditions following splitting of systems into islands. Stability in this case is a question of whether or not each island will reach a state of operating equilibrium with minimal unintentional loss of load. It is determined by the overall response of the island as evidenced by its mean frequency, rather than relative motion of machines. Generally, frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection equipment, or insufficient generation reserve.

3. Device used for Enhancement of the Stability of Power System

The conventional control devices like synchronous condenser, saturated reactor, thyristor controlled reactor, fixed capacitor thyristor controlled reactor, thyristor switched capacitor having less system stability limit, less enhancement of system damping, less voltage flicker control when compared to emerging facts devices like TCSC, STATCOM and UPFC [7]. This Section investigates only FACT devices for system stability.

3.1. Static VAR Compensator (SVC)

Static VAR systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends. Static VAR Compensators are shunt connected static generators / absorbers whose outputs are varied so as to control voltage of the electric power systems. The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated.

Typically, an SVC comprises one or more banks of fixed or switched shunt capacitors or reactors, of which at least one bank is switched by thyristors (figure 1). Elements which may be used to make an SVC typically include:

- Thyristor controlled reactor (TCR), where the reactor may be air- or iron-cored.
- Thyristor switched capacitor (TSC).
- Harmonic filter(s).

- Mechanically switched capacitors or reactors (switched by a circuit breaker).

The firing angle can be controlled through a PI (Proportional + Integral) controller in such a way that the voltage of the bus, where the SVC is connected, is maintained at the reference value.

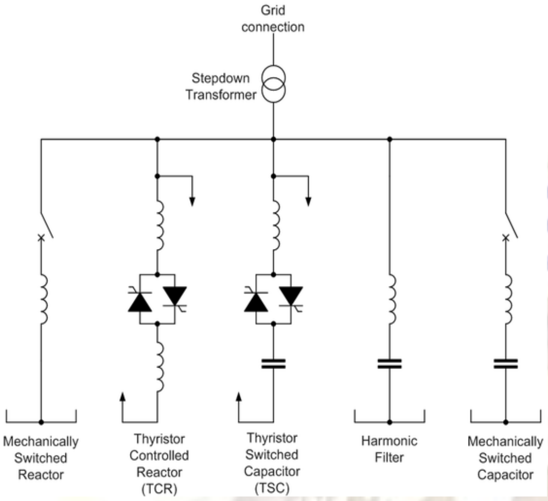

Figure 1: Typical SVC configuration

3.2 Thyristor Controlled Series Compensator (TCSC)

TCSC is one of the most important and best known FACTS devices, which has been in use for many years to increase line power transfer as well as to enhance system stability. The main circuit of a TCSC is shown in Figure. 1. The TCSC consists of three main components: capacitor bank C, bypass inductor L and bidirectional thyristors SCR_1 (T1) and SCR_2 (T2). The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to some system parameter variations. According to the variation of the thyristor firing angle or conduction angle, this process can be modeled as a fast switch between corresponding reactance offered to the power system.

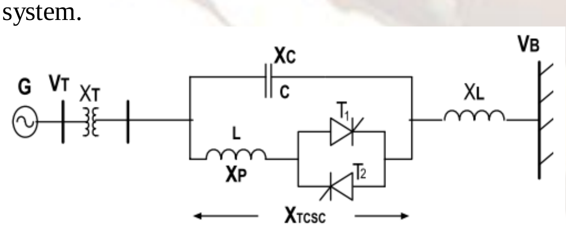

Figure 2: Single machine infinite bus power system with TCSC

3.3 Static Compensator (STATCOM)

It is a device connected in derivation, basically composed of a coupling transformer, that serves of link between the electrical power system (EPS) and the voltage synchronous controller (VSC), that generates the voltage wave comparing it to the one of the electric system to realize the exchange of reactive power. The control system of the STATCOM adjusts at each moment the inverse voltage so that the current injected in the network is in quadrature to the network voltage, in these conditions P=0 and Q=0.

In its most general way, the STATCOM can be modeled as a regulated voltage source Vi connected to a voltage bar Vs through a transformer.

The STATCOM uses a VSC interfaced in shunt to a transmission line. In most cases the DC voltage support for the VSC will be provided by the DC capacitor of relatively small energy storage capability hence, in steady state operation, active power exchanged with the line has to be maintained at zero, as shown symbolically in the Figure 3.

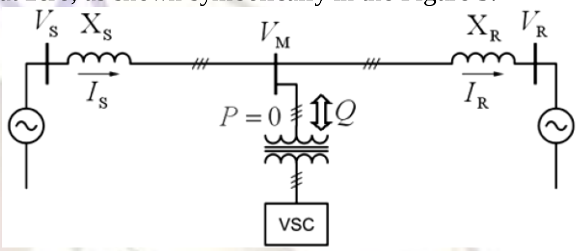

Figure 3: STATCOM Connections.

With the active power constraint imposed, the control of the STATCOM is reduced to one degree of freedom, which is used to control the amount of reactive power exchanged with the line. Accordingly, a STATCOM is operated as a functional equivalent of a static VAR compensator; it provides faster control than an SVC and improved control range.

3.4 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.

The Static Synchronous Series Compensator (SSSC) uses a VSC interfaced in series to a transmission line, as shown in the Figure 4.

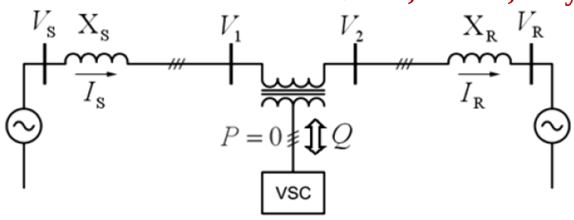

Figure 3: SSSC Connections.

Again, the active power exchanged with the line has to be maintained at zero hence, in steady state operation, SSSC is a functional equivalent of an infinitely variable series connected capacitor. The SSSC offers fast control and it is inherently neutral to sub-synchronous resonance.

3.5 Unified Power Flow Controller (UPFC)

A unified power flow controller (UPFC) is the most promising device in the FACTS concept. The UPFC can provide simultaneous control of all basic power system parameters (transmission voltage, impedance and phase angle). The controller can fulfill functions of reactive shunt compensation, series compensation and phase shifting meeting multiple control objectives. From a functional perspective, the objectives are met by applying a boosting transformer injected voltage and an exciting transformer reactive current. The injected voltage is inserted by a series transformer. Besides transformers, the general structure of UPFC contains also a" back to back" AC to DC voltage source converters operated from a common DC link capacitor, Figure 1. First converter (CONV1) is connected in shunt and the second one (CONV2) in series with the line. The shunt converter is primarily used to provide active power demand of the series converter through a common DC link. Converter 1 can also generate or absorb reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line. Converter 2 provides the main function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via a voltage source (Figure 5)

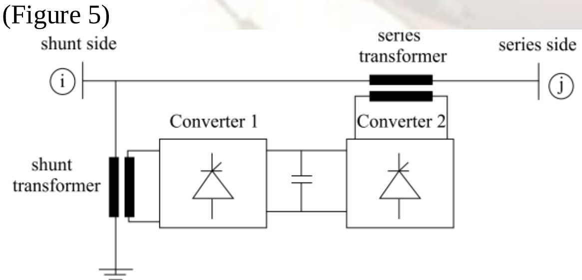

Figure 5: Implementation of the UPFC by back-to-back voltage source converters

4. Comparison of performance of different fact devices for specific conditions

Conditions Vs FACT Devices Comparison	SVC	TCSC	STATCOM	SSSC	UPFC
Reactive Power Generation/Absorption	G	A	E	E	E
Voltage control	G	A	E	A	E
Voltage stability improvement	G	G	E	E	E
Power flow control	A	A	G	E	E
Rotor angle stability improvement	A	G	A	E	E
Flicker mitigation	G	D	E	D	E
Harmonics reduction	D	D	G	G	E
Frequency stability improvement	A	A	G	A	G

Where A = Average, G = Good, E = Excellent and D = Depends upon Conditions.

5. Conclusion

The paper discussed the various types of instability issues involved in power system it also discussed the FACT devices, their working, Structure and placement in power system. Finally a comparison tablet is presented for comparison of the performance of FACT devices for different system conditions. The comparison results shows that the UPFC shows the best performance followed by the STATCOM while SSSC comes at the third position and the devices TCSC and VAR gets the last position in the table this is because of lower controllability of the thyristors. Finally it can be said that the paper provides a non mathematical explanation and a fair comparison of different FACT devices.

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