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A Review on Power System Stability using Different FACTS Devices

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Abstract – Now a day's power demand increases and widely expanded in the power generation and transmission and distribution system sector. But to maintain the stability and steady state operation of power system causing from disturbance or oscillation, faults and suddenly changing of the load, voltage instability, voltage sag, disturbance in frequency, stability is the most important factor regarding to power system. Due to instability, different problems come forward in power system such as fluctuation in voltage and frequency, which may cause damage or failure of power system. Flexible AC Transmission System (FACTS) devices are used to solve the problems of modern power system (generation and transmission system) which leads in improvement and development of performance of the power system. Various types of FACTS devices consist of Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Compensator (TCSC), Static Series Synchronous Compensator (SSSC), Static VAR Compensator (SVC), Unified Power Flow Controller (UPFC), Thyristor Controlled Series Reactor (TSSR), Thyristor Controlled Voltage Reactor (TCVR), Interline Power Flow Controller (IPFC) and another more devices. This paper describes the performance of study and comparison of various FATCS devices and their effect on power system stability enhancement. In addition, this paper reviews about different power system stabilizer using various FACTS devices.

Index Terms: - FACTS Devices, power system stabilizer (PSS), AVR

1 INTRODUCTION

Modern electric power system is facing many problems day by day growing in complex network and their operation and structure. In the power system, instability of the problems are arised vary frequently. There are number of stability issues that limit the transmission capability in transient stability, dynamic stability, steady state stability, frequency collapse, voltage collapse. Recently electrical power demand is continuously increasing or growing due to rapid industrial development growth. To meet this demand, it is necessary to increase the transmitted power along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident. Greater demands have been placed on the transmission network, and these demands will continue to increase because of the increasing number of non-utility generators and more competition among utilities themselves. Increased demands on transmission, absence of long-term planning, and the need to provide open access to generating companies and customers, all together have created tendencies toward less security and reduced quality of supply. As a consequence, some transmission lines are heavily loaded and the power system stability becomes a power transfer-limiting factor. Flexible AC transmission systems
(FACTS) device/ controllers have been mainly used for solving and evolving advance technology to improve the stability of transmission and various power system steady state control problems. To achieve both reliable and benefit economically, it has become clearer that more efficient utilization and control of the existing transmission system infrastructure is required. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics has developed the flexible AC transmission system (FACTS) devices which are effective and capable of increasing the power transfer capability of a line and support the power system to work with comfortable margins of stability [2]-[3]. FACTS devices are use in transmission system to control and utilize the flexibility and system performance [5].
The opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at various frequencies below the rated frequency.
FACTS devices have increased controllability and improved power transfer capability. The FACTS devices consist of three groups, dependent on their switching technology: mechanically switched (such as phase shifting transformers), thyristor switched using semiconductor device, while some types of FACTS, such as the phase shifting transformer and the static VAR compensator are already well known and used in power systems. New

developments in power electronics and control have extended the application range of FACTS [6]. The devices are used in transmission system to control and utilize the flexibility and system performance. To obtain this, the FACTS devices control the main parameters namely voltage, phase angle and impedance, which are affecting ac power transmission system.

The power system stabilizer (PSS) is mainly connected with electromechanical oscillation and improves the power system stability with the help of its additional excitation system. For maintaining the consistent generation and transmission of electric energy, the electric power systems become larger and larger, which covers a area and include all transmission lines, synchronous generators, loads and variety of controllers in more economical way. Power system stability can be improved by using dynamic controllers as excitation systems, power system stabilizers and FACTS devices, controlled islanding and HVDC [4].

2 Literature Review

Power system stability is a major challenge for engineers from many years. It is significantly noticed 1920s [2]. Where as it is tested for practical power system in 1926 [3]. Initially stability problems occurred in distant power plants feeding load hubs over expanded transmission lines which used slow exciters and non-continuously acting voltage controllers due to which power transfer capability was often restricted by steady-state as well as transient rotor angle variability due to inadequate synchronizing torque.

The power circle diagram and equal area criterion (EAC) methods are design to solve this problem and so models become superior and economical. The next significant test on the way of stability improvement was the development of network analyzer, which was proficient of power flow investigation of multi-machine power systems in 1930 [4]. This system has a drawback that the system dynamic had to explain by explaining the swing equation using step-by-step numerical integration.

After the invention of electronic analog computer in 1950 detailed modelling of the synchronous machine, excitation system and speed governor became easier. Later on with evolution in digital computers about 1956, the first digital program for power system stability investigation was return. In later decades various system for power stability were design in the Canada and United States. Now a day's most of the industries concentred on transient stability [4].

In earlier days efforts were made for optimal linear regulator design of a multi-machine power system through a computational algorithm based on the matrix sign function theory, which can give solutions without the evaluation of the system eigen values (1972). A computer program has been design to incorporate the developed computational techniques, which are based on the matrix sign function theory and can obtain the optimal controllers and the dynamic responses of the power system [18].

Later on a technique for designing variable structure controllers (VSCs) to damp out multimodal oscillations in a multi machine power system along with an approach of incorporating nonlinearities in the system operation at the design stage is proposed. V. Samarasinghe and N. Pahalawaththa show the possibility of achieving a robust design using a simple linear model of power systems. The system demonstrate the effectiveness of the VSC through a number of experiments results in showing that a VSC performs better than a conventional power system stabiliser and both types of controllers on different units in the system co-operate in a positive manner in damping oscillations [19].

After that in 2004 N. S. D. Arrifano, V. A. Oliveira, R. A. Ramos a design method, and application of fuzzy power system stabilizers for electrical power systems subject to random abrupt variations of loads are considered. Here, a control design method that uses recently developed techniques based on linear matrix inequalities with damping and control input constraints for fuzzy logic control design was proposed. The effectiveness of the control design method can be by simulation results on a single-machine infinite-bus model and compared to classical power system stabilizer [20].

In 2007 system was design for the study of dynamic behavior and transient stability of the single-machine infinite-bus (SMIB) with used eigenvalue analysis [21].

On more power, system stabilizers were added to excitation system to enhance the damping during low frequency oscillations with the help of fuzzy logic. To enhance the system stability, speed deviation ($\Delta\omega$) and acceleration ($\Delta\varpi$) of the rotor of synchronous generator of Kota Thermal were taken as the input to the fuzzy logic controller. These variables take significant effects on damping of the generator shaft mechanical oscillations [22].

An alternative approach on designing PSS for a Single Machine and Infinite Bus (SMIB) system based on optimal control (OP) techniques was proposed in later days. The simulation technique were used for analyzation of the small signal stability characteristics of the system about the steady state operating condition following the loss of a transmission line. The focus of the

system was on the control performance [23].
The Artificial Bee Colony algorithm was also used for achieving better stability of the power system as compared to the conventional techniques [24].
Research was done for designing power system stabilizer for interconnected power system. In this system, information available at the high voltage bus of the step-up transformer is used to set up a modified Heffron-Phillip's model to decide the structure of the PSS compensator and tune its parameters at each machine in the multi-machine environment, using only those signals that are available at the generating station [25].
Power system stabilizer based on the Particle Swarm Optimization (PSO) algorithm was use for tuning dual input power system stabilizer parameters to optimize a suitable objective function, optimal values for PSS controlling parameters including lead-lag compensator time constants as well as the controller gain calculation. The employed objective function is the error between the reference voltage and the signal produced from the terminal voltage (i.e. to minimize the overshoot of low-frequency oscillations). This algorithm is applied to a single machine power system and for various operating conditions [26].
Exact linearization approach of feedback linearization was use to design the nonlinear observer when the power system is fully linearized. The excitation control law was derived for the exactly linearized power system model [27].
The method had been developed obtained simplified model of the system by using different reduction technique. One research team had used the differentiation method in time & frequency domain to preserve the stability and characteristic parameters of a single machine infinite bus system (SMIB) with power system stabilizer [28].
An attempt had been made to study the application of static synchronous series compensator (SSSC) equipped with a Hybrid Fuzzy Logic Damping Controller (HFLDC) to improve the small signal stability of Single Machine Infinite Bus (SMIB) power system. This is carried out with modified Heffron-Phillips model of a single machine infinite bus (SMIB) system integrated with SSSC. This enhanced the transient stability of the power system.[29]

3 Power System Stability (PSS)

Power system stability is 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.
Stability of power systems are continues to be of major concern in system operation. In steady state means under normal conditions, the overall average electrical speed of all the generators must remain the same anywhere in the system. It is called as the synchronous operation of a system. This synchronous operation can be disturbed by any small or large disturbance. For example, there can be a suddenly changing or increase in the load or loss of generation. Another type of disturbance is the switching out of a transmission line, which may occur due to overloading or a fault [7]. The disturbance can be dividing into small and large. Disturbances can be large or small depending on their origin. The small changes in the load or generation can be termed as small disturbances. Transmission system faults, sudden load changes, loss of generating units, and line switching are examples of large disturbances [7, 8].
Power system stability is mainly classified into different phenomena's: wave, electromagnetic, electromechanical, and thermodynamic. Here electromechanical phenomenon only assume, which takes place in the windings of a synchronous machine. A disturbance in the electrical system will produce power fluctuations between the generating units and the electrical network system. And due to electromechanical phenomenon disturb the stability of the rotating parts in the power system [9]. Figure 1 shows the functional block diagram of a typical excitation control system for a large synchronous generator [10].

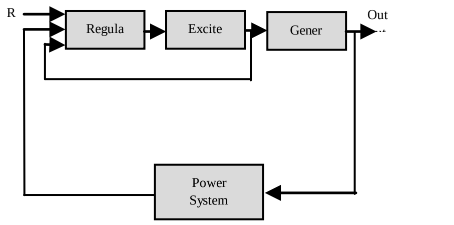

Fig. 1. Functional block diagram of a synchronous generator excitation control system

The PSS is a feedback controller, part of the control system for a synchronous generator, which provides an additional signal that is added to the input summing point at the Automatic Voltage Regulator AVR. The PSS main function is to damp generator rotor oscillations due to electromechanical dynamics and is called electromechanical oscillations. Different input signals have been used to extract the rotor oscillations. The most common input signals are the active power, the terminal frequency, and the shaft speed. To provide effective damping and ensure the stability of the system, the PSS should be carefully tuned.

Hence, stabilizing signal was needed and the Power System Stabilizer (PSS) developed.

2.1 Operating Principle of PSS-

The Power System Stabilizer (PSS) is a supplementary excitation controller used to damp generator electro-mechanical oscillations in order to protect the shaft line and stabilize the grid. The general function of power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation by using auxiliary external stabilizing signal. Based on the automatic voltage regulator (AVR) and using frequency deviation, power deviation or speed deviation as extra control signals, Power system stabilizer is designed to introduce an additional torque coaxial with the rotational speed deviation, so that it can increase low-frequency oscillation damping and increase the dynamic stability of the power system. The AVR regulates the generator terminal voltage by controlling the amount of current supplied to the generator field winding by the exciter.

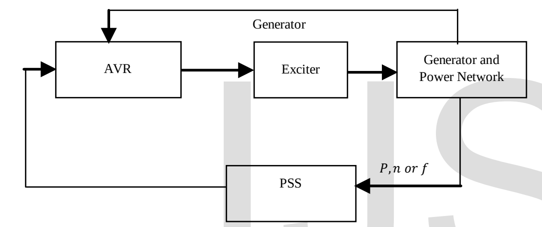

Fig. 3. The structure diagram of power system stabilizer (PSS)

4 CLASSIFICATION OF INSTABILITY IN POWER SYSTEM

The stability is most important for the power transmission, generation system. But there are the various stabilities depend on different factors of the power system. These stabilities are identify to more difficult to solve and getting improvement on this. Power system stability is understood as the ability to regain an equilibrium state after being subjected to a physical disturbance. The three quantities are important for power system operation power or load angles, frequency, voltage magnitudes. These quantities are especially important from the point of view of defining and classifying power system stability. Hence, power system stability can be divided into rotor angle stability, frequency stability, and voltage stability.

4.1 Rotor angle stability

Due to electromechanical oscillation problems, rotor angle stability disturbs. When the problem was occurring, the power output of synchronous machine varies as the rotor angle changes. The interconnected synchronous machine maintains the synchronism with another machine by restoring force when one or more machine accelerate or decelerate. The rotor angle stability means the ability of synchronous machine of an interconnected power system network to persist in synchronism subsequently been subjected to an interruption. Under the steady state condition, there is maintain or restore the equilibrium between input the mechanical torque and output the electromagnetic torque of the synchronous machine in the system and the speed remains constant. If the system is disturb the synchronism is upset causing in acceleration or deceleration of the rotors of the machines. The instability of this case produces because of the increasing angular swing of the generators or the loss of synchronism with other generators [4]. The loss of synchronism in the system happens by the non-equilibrium state between the mechanical torque and electromagnetic torque and the speed difference between the generators.

4.2 Voltage stability

Voltage stability of power system means the ability of the power system to maintain constant voltage at all the transmission lines in the system after being affected by a disturbance from initial operating condition. This stability depends on to maintain or restore equilibrium between the load demand and supply from the power system [11, 12]. The effect of instability in this case is fall or rise of voltage of transmission lines. The reason for this instability in this loss of load is tripping of transmission lines or other elements and loss of synchronism and induces voltage fluctuation occurs. When load dynamic struggle to restore power consumption, apart from the capacity of the transmission network and connected generation [13, 14]. The main circumstances contributing to voltage drop because when the active and reactive power flow through inductive reactance of the system [15]. And this happens when the generators swing their field or armature current time-overload competence limits [16]. The voltage instabilities are like voltage collapse, voltage surge etc., this all can be decreased by maintaining the condition of generators and other devices [17].

4.3 Frequency stability

Frequency stability assign to ability of a power system to maintain steady frequency severe system disconcerted resulting in a significant imbalance between load and generator. The frequency stability depends on capability to restore between system generation and load. The fluctuations that may occur in power system it ensure that uninterrupted frequency swings well known to trip of generating unit or load. Generally, frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection equipment, or insufficient generation reserve.

5 CLASSIFICATIONS

There are various types of FACTS devices and classified as according to depend on their connection like as series connected controller, shunt connected controller and combination of shunt series connected controller. The main types of FACTS devices are describe below

5.1 Static Synchronous Compensator (STATCOM)

A Static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. STATCOM is one of the key FACTS controllers. It can be based on a voltage sourced or current-sourced converter. Fig. 1 shows a simple line diagram of STATCOM based on a voltage-sourced converter and a current-sourced converter. A static synchronous compensator (STATCOM) is a regulating device used on alternating current electricity transmission networks. For the voltage-sourced converter, its ac output voltage is controlled such that it is just right for the required reactive current flow for any ac bus voltage dc capacitor voltage is automatically adjusted as required to serve as a voltage source for the converter. STATCOM can be designed to also act as an active filter to absorb system harmonics. Usually a STATCOM is installed to support that have a poor power factor and often-poor voltage regulation. There are however the most common use is for voltage stability.

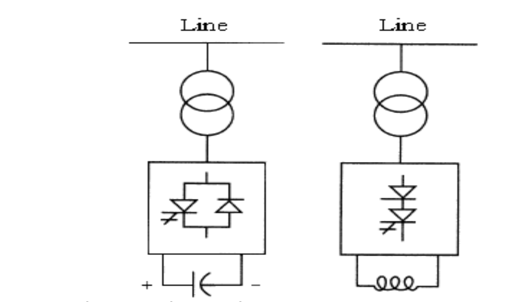

Fig.1. Static Synchronous Compensator

5.2 Static VAR Compensator (SVC)

A shunt-connected static var generator or absorber whose output is adjusts to exchange capacitive or inductive current so as maintain or control specific parameters of the electrical power system. This is a general term for a thyristor-controlled or thyristor-switched reactor, and/or thyristor-switched capacitor or combination shown in fig. 2. SVC is based on thyristors without the gate turn-off capability. It includes separate equipment for leading and lagging vars; the thyristor-controlled or thyristor-switched reactor for absorbing reactive power and thyristor-switched capacitor for supplying the reactive power. A static VAR compensator 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 stabilizing the system. Some as a lower cost alternative to STATCOM consider SVC, although this may not be the case if the comparison is made based on the required performance and not just the MVA size.

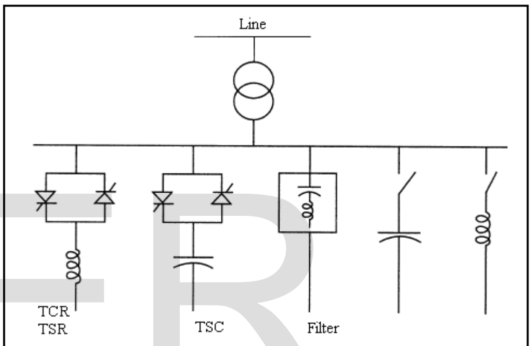

Fig.2. Static VAR Compensator

5.3 Thyristor Controlled Series Capacitor (TCSC)

A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance. The TCSC shown in fig. 3 based on thyristors without the gate turn-off capability. It is a very important FACTS Controller. A variable reactor such as a Thyristor-Controlled Reactor (TCR) is connected across a series capacitor. The main disadvantage in TCSC is not giving high voltage profile when compare to other devices. The TCSC may be a single, large unit, or may consist of several equal or different-sized smaller capacitors in order to achieve a superior performance.

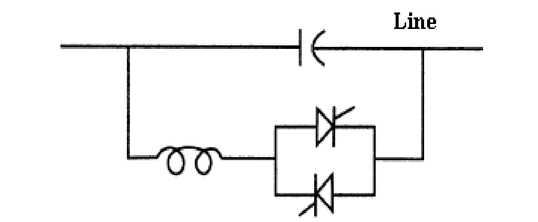

Fig.3. Thyristor Controlled Series Capacitor

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4.4 Unified Power Flow Controller (UPFC)

Fig. 4 show a combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC) which are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation. A unified power flow controller (UPFC) is the most promising device in the FACTS concept. Either it has the ability to adjust the three control parameters, i.e. the transmission line reactance and bus voltage, and phase angle between two buses, simultaneously or independently.

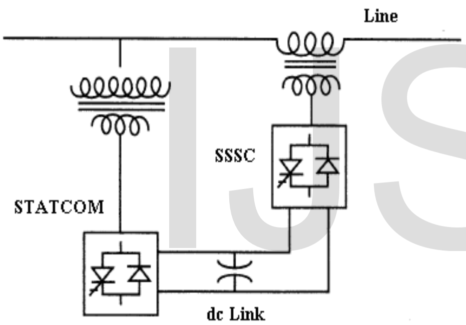

Fig. 4. Unified Power Flow Controller

5.5 Static Synchronous Series Compensator (SSSC)

A static synchronous generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real (resistive) voltage drop across the line. SSSC is one the most important FACTS Controllers. It is like a STATCOM, except that the output ac voltage is in series with the line. It can be based on a voltage sourced converter or current-sourced converter. It has a DC-AC converter and it is connected to a transmission line by series connection through a transformer. Fig. 5 shows SSSS.

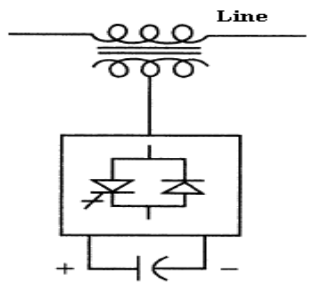

Fig. 5. Static Synchronous Series Compensator

5.6 Interline Power Flow Controller (IPFC)

The IPFC is a recently introduced Controller. A possible definition is the combination of two or more Static Synchronous Series Compensators which are coupled via a common dc link to facilitate bi-directional flow of real power between the ac terminals of the SSSCs, and are controlled to provide independent reactive compensation for the adjustment of real power flow in each line and maintain the desired distribution of reactive power flow among the lines. The IPFC may also include a STATCOM, coupled to the IFFC's common dc link, to provide shunt reactive compensation and supply or absorb the overall real power deficit of the combined SSSCs.

5.7 Thyristor-Controlled Series Reactor (TCSR)

An inductive reactance compensator, which consists of a series reactor shunted by a thyristor, controlled reactor in order to provide a smoothly variable series inductive reactance. The TCSR fig. 6 shown below.

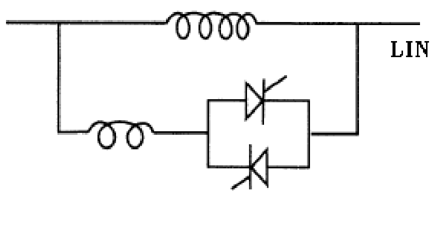

Fig.6. Thyristor Controlled Voltage Regulator

4.7 Thyristor-Contolled Voltage Regalator (TCVR)

A thyristor-controlled transformer, which can provide variable in-phase voltage with continuous control. There are two regulators, a transformer with a thyristor-controlled tap changer fig. 7a or with a thyristor-controlled ac

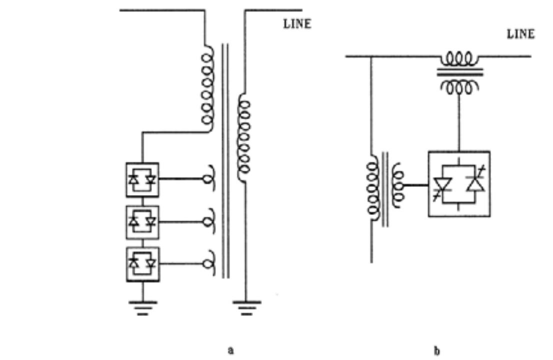

Fig.7. a) TCVR base on Tap Changing b) TCVR base on Voltage Injection

voltage converter for injection of variable ac voltage of the same phase in series with the line in fig. 7b. This is low cost controller can be very effective in controlling the flow of reactive power between two ac systems.

Advantage of FACTS devices

The advantage of utilizing FACTS devices in electrical transmission systems as follows.

1. Better utilization of existing transmission system assets.
2. Increased quality of supply for sensitive industries.
3. Environmental benefits better and Provide greater flexibility in sitting new generation.
4. Reduce reactive power flows, thus allowing the lines to carry more power that is active.
5. Improved the power system stability.
6. Increased dynamic and transient grid stability and reduce loop flows
7. Increased transmission system reliability and availability.
8. Increase the system security through raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines.

6 Conclusion

This paper focuses on FACTS devices used in transmission lines. The idea of power system stabilizer (PSS) or external excitation control system is to apply a signal through the excitation system to produce additional damping torque of the generator in a power system at all operating and system conditions. This paper concludes that in order to provide faster responses over a wide range of power system operation and improve the power system stability by using FACTS devices with PSS and to provide the optimal power flow power networks. The FACTS are economically and efficiently operation in transmission and generation system's and due application of FACTS devices to prevent the uninterrupted power supply provide to generation, transmission and distribution system. The power system stabilizer means using external excitation (AVR) controller also prevent upset output power of generation system causing various reasons.

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