Enhancement of Power System Stability by using Power System Stabilizer and UPFC

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***Abstract*—Among different FACTS devices, UPFC is the most superior one. Though the primary objective of UPFC is to provide powerful control of active and reactive powers, it can also be modulated effectively to improve transient performance of a system and to damp power system oscillations. In the same way, power system stabilizer (PSS) is also explained. The basic operation of PSS is to apply signal to the excitation system that creates damping torque which is in phase with the rotor oscillation. This paper presents the idea of improvement of transient stability and voltage stability of power system by utilizing the combination of UPFC and PSS. When there is a severe fault on the transmission line, real and reactive power get disturbed. A test model of power system is considered and comparison is shown between the two cases i.e. UPFC connected and without UPFC connected to the power system. Simulations are performed in Matlab/Simulink environment**.

Keywords—damping; PSS; transient stability; UPFC; voltage stability

I. INTRODUCTION

Transmission grids of present power systems are becoming increasingly distressed because of growing demand and constraints on building new lines. Due to such a stressed system there is a danger of losing stability following a disturbance. The instability normally emerges from imbalance of voltage, rotor angle etc. Voltage control and reactive power control are interrelated [1]. There should not be any mismatch in reactive power balance which would otherwise affect the bus voltage magnitudes. The design of a reactive power coordination controller has been explained in [2].

In general, power systems are subjected to wide ranges of transient and dynamic instability. The transient stability limit of a synchronous machine has been significantly improved by using fast acting excitation systems with high gain; however the same resulted into deterioration of dynamic stability. The dynamic instability is improved by using the power system stabilizer (PSS).The PSS, a supplementary excitation control, provides additional damping torque to the rotor angle oscillation of synchronous machine which would otherwise limit the power transfer capability. An introduction to PSS and methods of PSS design are explained briefly in [3][4]. General concepts and their practical considerations about PSS are very well presented in [5][6]. The art and science of employing PSS has progressed considerably over past few decades since the first widespread application to Western system of the United States.

With the development of FACTS (Flexible AC Transmission System) technology, its been possible to control the power flow along the transmission line smoothly. FACTS devices such as STATCON, TCSC, TCPR, UPFC can be used to regulate bus voltage, line impedance, phase angle in the power system rapidly and flexibly. Thus FACTS speed up the power flow control, improve the power transfer capability, minimize generation cost, and enhance security and stability of the power system. References [7] and [8] throw some light on comparison of FACTS devices for power system stability improvement. The Unified Power Flow Controller (UPFC) is a new device in FACTS family which comprises of shunt and series connected converters. Reference [9] analyses control strategy for each function of UPFC. The impact of UPFC on the power swing characteristics is investigated in [10] and [11] inspects impact of UPFC on power system reliability examining its cyber vulnerability. Transient stability and power flow on the transmission line can be efficiently controlled by introducing UPFC in power system [12]-[18].

In this paper, transient stability and voltage stability of a test power system is improved by the application of UPFC and PSS in the power system. For the sake of simplicity, paper is categorized into number of sections. Section II introduces the 'power system stability' concept. Section III throws some light on the power system stabilizer and its different input signals. In section IV, operating principle of unified power flow controller is explained and its steady state model along with power flow control range is derived which assists in understanding the significance of UPFC in power system. Section V displays all the simulated results performed on the test model of power system which are simulated in the Matlab/Simulink environment. Section VI and VII presents the conclusion and referred study material respectively.

II. POWER SYSTEM STABILITY

"Power system stability is the ability of electrical power system, for given operating condition, to regain its state of operating equilibrium after being subjected to a physical disturbance, with the power system variables bounded, so that the entire system remains uninterrupted". Traditionally, stability problem is concerned with maintaining synchronous operation i.e. synchronous machines should remain "in step". This aspect of stability is influenced by the dynamics of generator rotor angles and power angle relationship. There are different kinds of stabilities e.g. small signal stability, transient stability, voltage stability, frequency stability etc. However, this paper is restricted to transient and voltage stability.

A. *Transient stability*

Transient stability of power system is the ability to maintain synchronism when subjected to severe transient disturbance. The resulting system response involves large excursions of generator rotor angles and is affected by nonlinear power angle relationship. Stability depends on both the initial operating state of the system and severity of the disturbance. Transient instability is caused due to different types of short circuits: phase to ground, phase to phase to ground, or three phase. The real and reactive power flow of the power system get disturbed after the disturbance.

B. *Voltage stability*

It is the ability of power system to maintain steady acceptable voltages at all buses in the system under normal operating condition and after being subjected to a disturbance. A system gets in a state of voltage instability when a disturbance, e.g. changes in system conditions, causes a growing and irresistible drop in voltage. The major factor causing voltage (V) instability is the inability of power system to meet the demand of reactive power (Q). The system is voltage stable if V-Q sensitivity is positive for every bus and voltage unstable if V-Q sensitivity is negative for at least one bus [1].

Voltage collapse is more complicated than plain voltage instability and is usually the outcome of a sequence of events accompanying voltage instability leading to a low-profile in a significant part of the power system.

III. POWER SYSTEM STABILIZER

The excitation system provides direct current to field winding of synchronous generator. Additionally it controls the voltage and reactive power, thus enhances the stability limit. Usually, it consists of autonomic voltage regulator (AVR), exciter and measuring elements. Exciter is governed by AVR which has better effect during steady state operation but in some cases of sudden disturbance it may cause adverse impact on the damping of power swings. By introduction of auxiliary control loop, the power system stabilizer (PSS), this adverse impact may be eradicated.

The basic function of PSS includes widening of stability limits by modulating generator excitation to provide damping to the oscillations of synchronous machine rotors (0.2- 2.5 Hz) with respective to one another inadequate damping of which may restrict the ability to transmit power. This is achieved by modulating the generator excitation so as to develop a component of electrical torque in phase with rotor speed deviation.

The basic structure and performance of PSS is illustrated by considering a thyristor excitation system as shown in figure (1). It shows the block diagram of excitation system including Automatic Voltage regulator (AVR) and PSS. The PSS representation in the figure (1) consists of three blocks: A phase compensation block, a signal washout block and a gain block.

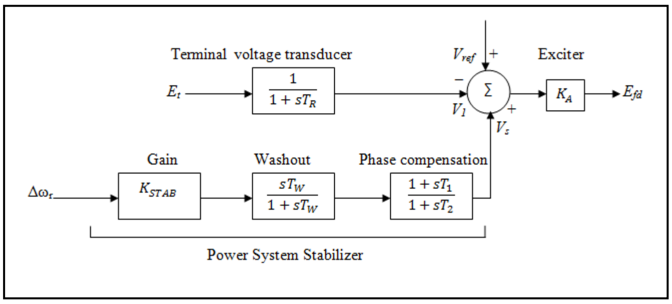

Fig.1 Thyristor excitation system AVR and PSS

The phase compensation block provides the appropriate phase-lead characteristic to compensate for phase lag between the exciter input and the generator electrical torque. The signal washout block serves as a high-pass filter, with the time constant T_w high enough to allow signals associated with oscillations in ω_r to pass unchanged. Steady changes in speed would modify the terminal voltage without it. It allows the PSS to respond only to changes in speed. T_w may be in the range of 1-20 seconds. The stabilizer gain K_{STAB} determines the amount of damping introduced by the PSS. Ideally, the gain should be set at a value corresponding to maximum damping; however it is often limited by other considerations. In applying the PSS, care should be taken that not only the small signal stability but also the overall stability is enhanced.

Shaft speed, integral of power and terminal frequency are among the commonly used input signals to PSS. Implementation details differ according to the input.

A. *Speed input*

Since the main action of the PSS is to handle the rotor oscillations, the input signal of rotor speed has been the most frequently advocated in the literature. Controllers based on speed deviation would ideally use a differential-type of regulation and a high gain. Since this is unrealistic, the lead-lag structure is commonly used. However, one of the constraints of the speed input PSS is that it may excite torsional oscillatory modes.

B. *Power input*

A power input PSS design was proposed as a solution to the torsional interaction problem suffered by the speed-input PSS. The power signal used is the generator electrical power, which has high torsional attenuation. Due to this, the gain of the PSS may be increased without the resultant loss of stability, which leads to greater oscillation damping.

C. *Frequency input*

In case of frequency input stabilizer it has been found that frequency is highly sensitive to the strength of the transmission system, i.e. more sensitive when the system is weaker, which may offset the controller action on the electrical torque of the machine. Other limitations include the presence of sudden phase shifts following rapid transients and large signal noise induced by industrial loads. On the other hand, the frequency signal is more sensitive to inter-area oscillations than the speed signal, and may contribute to better oscillation attenuation.

IV. UNIFIED POWER FLOW CONTROLLER

A. *Operating Principle*

UPFC consist of two 3-phase switching converters employing GTO's. The key function of converters is to change a dc input voltage to a symmetrical ac output voltage of desired magnitude, frequency and phase shift. These converters are processed from a common dc link provided by a dc storage capacitor.

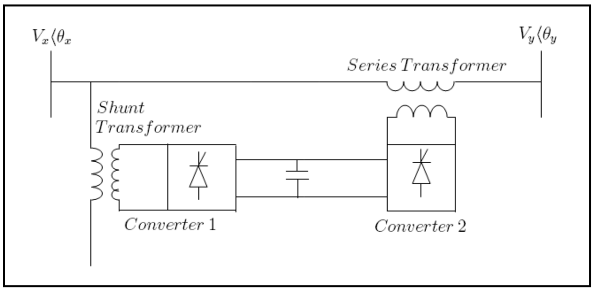

Fig.2 Circuit arrangement of UPFC

Series converter (converter 2) inserts a voltage of controllable magnitude and phase angle in series with the transmission line via series-connected transformer, thereby provides the control of real and reactive power flow on the transmission line. Transmission line current I_L flows through the series transformer resulting in real and reactive power flow between UPFC and power system. Phase angle of converter 2, γ, can be chosen independently of the phase angle of I_L i.e. ϕ_{I_L} which means that output voltage of series branch can be independently controlled without any restriction. This enables free flowing of real power in either direction between ac terminals of the two converters. UPFC has the operational flexibility to be used for terminal voltage regulation, series compensation and transmission angle regulation. The basic function of shunt converter (converter 1) is to supply or absorb the real power demand by converter 2 at the common dc link. It is realized that converter 2 must be able to internally generate or absorb all the reactive power demanded in all operating modes of UPFC at its ac terminals.

B. *Steady state model and power flow control range*

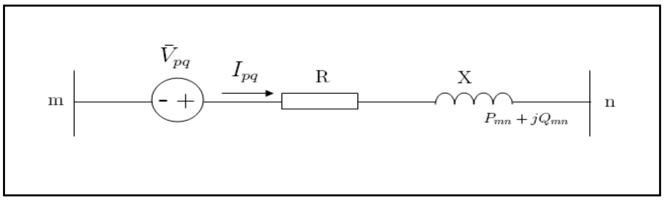

Fig.3 Model of Transmission lime m-n installed with UPFC

As shown in the figure (3), series voltage source V_{pq} is used to represent the series control. To be simple, it is assumed that $\vec{V}_m = V_m\angle 0$, $\vec{V}_n = V_n\angle -\theta$. Suppose line has impedance $Z = R + jX$, for such uncompensated line power flow is given as

$$\vec{S}_{mn} = P_{mn} + jQ_{mn} = V_n\left[\frac{\vec{V}_m+\vec{V}_{pq}-\vec{V}_n}{Z}\right]^* \qquad (1)$$

If $\vec{V}_{pq} = 0$, the line is uncompensated and power flow on it is

$$\vec{S}_{mn} = \vec{S}^o_{mn} = P^o_{mn} + jQ^o_{mn} = \left[\frac{\vec{V}_m-\vec{V}_n}{Z}\right]^* \qquad (2)$$

From (1) and (2), it is found that

$$\vec{S}_{mn} = V_n\left[\frac{\vec{V}_m-\vec{V}_n}{Z}\right]^* + \vec{V}_n\frac{\vec{V}^*_{pq}}{Z^*} = \vec{S}^o_{mn} + \vec{S}^{UPFC}_{mn} \qquad (3)$$

In UPFC, a voltage of variable magnitude and phase can be introduced by series voltage source; practically, $\vec{V}_{pq}\angle\gamma$ where $0 \le \gamma \le 360^o$, $0 \le V_{pq} \le V_{pq\max}$. Equation (3) presents a circle with the center at $\vec{S}^o_{mn}$ (initial power flow on uncompensated line) and a radius of $\left[\vec{V}_n\frac{\vec{V}^*_{pq}}{Z^*}\right]$. The allowable operation point for this UPFC is anywhere within the circle.

V. SIMULATIONS

A UPFC and PSS combination is utilized to control the power flow in a 500 kV /230 kV transmission system. The system which is connected in a loop configuration, consists of five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks T1 and T2. Two power plants located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 200-MW load connected at bus B3. The plant models encompass a speed regulator, an excitation system as well as a power system stabilizer (PSS).

A three phase fault is applied on the line L1. The UPFC situated at the right end of line L2 is used not only to control the active and reactive powers at the bus B3 but also the voltage at bus B_UPFC. It is made up of a phasor models of IGBT-based, two 100-MVA converters (one connected in shunt and one connected in series and both interconnected through a DC bus on the DC side and to the AC power system, via coupling transformers).

Two cases are considered under the influence of fault. Each case is simulated in Matlab/Simulink environment.

A. *Case 1: Without UPFC and PSS connected in the system*

The simulink model of the power system described above without inclusion of UPFC and PSS is given below. The output waveforms of the voltage, active and reactive power variations are also provided.

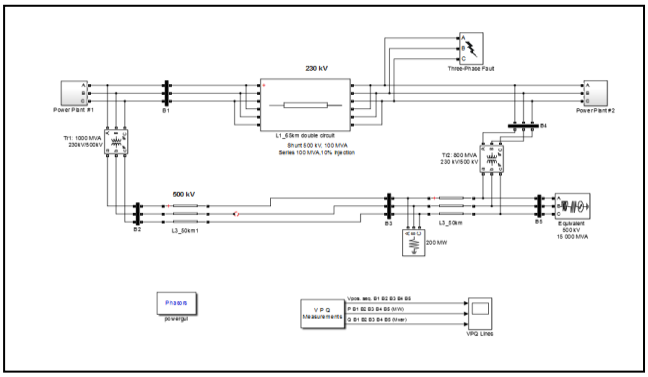

Fig.4 Simulink model for case 1

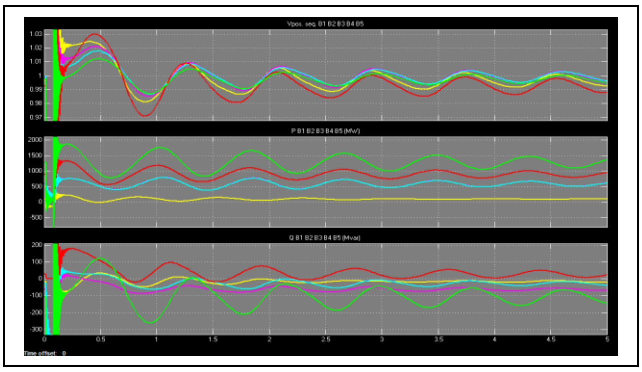

Fig.5 Output waveforms of V, P and Q for case 1

B. *Case 2: With UPFC and PSS connected in the system*

As above, Simulink model for the power system including UPFC and PSS is presented below with the corresponding output waveforms of the voltage, active and reactive power variations.

The simulations of both the cases are run for 5 seconds.

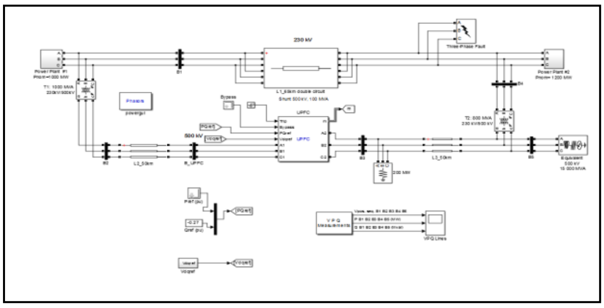

Fig.6 Simulink model for case 2

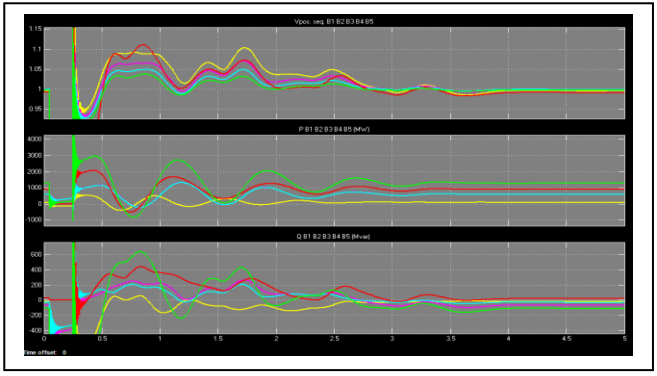

Fig.7 Output wavefo of V, P and Q for case 2

VI. CONCLUSION

A brief introduction to the power system stabilizer (PSS) and unified power flow controller (UPFC) is presented in this paper. PSS can be provided with three input signals, out of which power is given as an input to PSS in the power system considered in the simulation section. Along with operating principle of UPFC, its steady state model is also derived which conveys the power flow control range of UPFC.

A power system model is considered which is connected in loop configuration, consist of five buses interconnected through transmission lines (L1,L2,L3) and three phase fault is applied on line L1. The output waveforms indicate that damping time of voltage and power variations is considerably reduced by the introduction of UPFC and PSS into the power system.

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