Enhancement of Transient Stability Performance Using UPFC with PSS in Large Power Network

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Abstract: The ever-increasing load demand in today massive power networks has made operation planning essential. A relatively new transmission technology called Flexible AC Transmission systems is widely utilized to improve power grid stability, maintain bus voltage levels and decrease flows on heavily laden lines. This study looks into how UPFC can improve the operation of major power networks. The performance of the power network is enhance by the Unified Power Flow Controller, which regulates the power tide across the network. Additionally, the Power System Stabilizer (PSS) is an excitation controller that supplements damping. In order to handle voltage fluctuations and transient stability concerns, the study focuses on integrating the UPFC into the power system model and using its PI controller. MATLAB/SIMULINK was used to design and test the system. Using the UPFC the suggested system may minimize rotor speed deviation ($\Delta\omega$), stability rotor speed (ωn) and swiftly dampen out oscillations caused by defects. Additionally, it improves the system real power, reactive power and node voltage profile more efficiently than a system without a UPFC and PSS. The outcome show notable gains in oscillation damping capabilities and power system performance.

1 INTRODUCTION

The increasing capacity of interconnected power networks in contemporary transmission line systems is driving up the demand for electricity. The power system must run efficiently and dependably to guarantee a steady supply of electricity to satisfy the expanding needs of contemporary civilization. Advanced technologies are becoming more and more necessary to improve system performance as power grids get more complicated and linked. The usage of Flexible AC Transmission Systems devices, such as the Unified Power Flow Controller has been made possible by recent developments in power electronic devices. These devices improve controllability and boost the electrical networks capacity to transport power. Additionally, electro-mechanical oscillations are dampened by the Power System Stabilizer (PSS), a supplemental excitation controller. A power system stabilizer is a control system that lessens oscillations in the generator rotor angle hence increasing power system stability. Transient stability is crucial for power system design and operation in the face of noteworthy interruptions like faults and switching lines. Transient stability mentions to the system capacity to quickly revert to a stable condition when the load changes. The regulation of real and reactive power flow, rotor speed, rotor speed deviation and voltage at system buses within transmission power system networks areas just a few of the topics that have been the subject of current UPFC simulation studies utilizing MATLAB software. A survey of important articles in this field is provided below, with references.

In a study published in 2006 (Chandrakar, Kothari, et al. , 2006), Chandrakar et al. examine the

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Radial Basis Function Network controller in conjunction with damping schemes such as Power System Stabilizer and Power Oscillation Damping for VSC based various FACTS devices in order to enhance the line power conduct capability, improve transient stability and reduce oscillation in the power system. Both SMIB and multi-machine systems are used to test the developed controller. A 4-bus system that was modelled in MATLAB software was used by Singh et al. (2023) (Singh, Jha, et al. , 2023) to analyze the UPFC controller. According to their research, the UPFC improves system stability by guaranteeing that the DC link capacitor voltage stays relatively constant during load variations sustaining a voltage profile at 1 per unit and preserving a smooth real and reactive power flow. In order to improve the power system transient stability and dynamic stability, Jagtap et al. (2021) (Jagtap, Vinod, et al. , 2021) conducted a comparative analysis of the system and found that UPFC with a fuzzy logic controller performed better than UPFC with a PI controller. Joshi et al. (2016) (Joshi, Chandrakar, et al. , 2016) suggested that the first peak, oscillation damping and critical clearing time may all be improved by integrating superconducting magnetic energy storage (SMES) with the DC link of Unified Power Flow Controller. In mandate to increase control capacity and power system stability and dependability, Khaleel 2024 (Khaleel, 2024)looks at the use of UPFC operation to alleviate power mobbing on a 500/230KV grid. An Artificial Neural Network-based STATCOM for power system dampening was created by Chandrakar et al. 2008 (Chandrakar and Kothari, 2008) in order to enhance the transient stability of a SMIB system and multi machine system. The power system stabilizer (PSS) and power oscillation damping (POD) control worked in tandem with the RBFN controller-based STATCOM to boost the power system dynamic performance. By comparisons of power system factors, like rotor speed deviation to a reference value and generating operational beats for the voltage source converter in the UPFC system, Hameed et al. (Hameed and Nourl, 2023) are creating a smart support-based UPFC device with a fuzzy logic controller (FLC) to recover the stability and dependability of the electrical grid in a MATLAB environment. Et al. Jagtap (2024) The PI controller with UPFC was compared to a fuzzy logic controller (FLC) in this research (Jagtap and Vinod, 2023), (Jagtap and Vinod, 2024) and the PI controller outperformed the UPFC, FLC and ANN controllers in terms of rotor angle stability and oscillations as well as transient stability performance in a multi-machine power system (MMPS) with LG fault in MATLAB simulation. (Joshi and Chandrakar, 2017) Joshi et al. (2017) studying the impact of energy storage particularly ultra-capacitors on improving power oscillation damping on different FACTS controllers with 48 pulse configuration is the focal goal of this paper. The study of an SSSC controller based on a radial basis function network was the main focus of Kothari et al. (2007) (Chandrakar and Kothari, 2007). This controller is intended to synchronize two control inputs in phase voltage and the quadrature voltage of the SSSC is trained using the real power and injection bus voltage with power oscillation damping control and power system stabilizer. The system dynamic performance is evaluated to enhance the line power conduct capacity, transient stability and oscillation damping of SMIB and multi-machine systems. The multi-machine power system with and without an Interline Power Flow Controller (IPFC) is shown in More et al. (2016) (More and Chandrakar, 2016) in order to increase transient stability of the system in MATLAB simulation dampen power oscillations and control power flow. Insights into developments in UPFC design and simulation methods with MATLAB SIMULINK software are offered by these publications taken together. They investigate applications and ways to increase performance across a range of interconnected transmission lines. This study examines how the PSS function interacts with the UPFC device in a large power system during a disturbance. Few researchers have examined the PSS function. In addition to lowering the settling time the UPFC_PI controllers are made to minimize the first peak and oscillation frequency. In the MATLAB environment, the suggested UPFC performances are verified.

2 UPFC ARCHETYPAL

The Unified Power Flow Controller one of the most multipurpose FACTS devices is used in this work to introduce a novel control method. A multipurpose tool for dynamic reimbursement and real-time control of AC transmission networks is the UPFC. It provides multifunctional flexibility to tackle a number of the issues that the electricity delivery sector faces.

The UPFC has the ability to regulate all of the factors such as voltage, phase angle and impedance that impact power tide in a power system network either collectively or separately. This special capacity is what makes the phrase “Unified”. One of the main factors contributing to the UPFC broad use is its capacity to control power flow in both directions while preserving a steady alternating current transmission line voltage. With transmission lines the UPFC functions as a synchronous voltage source that trade active and reactive power. Figure 1 shows a schematic diagram of a unified power flow controller and its phasor diagram.

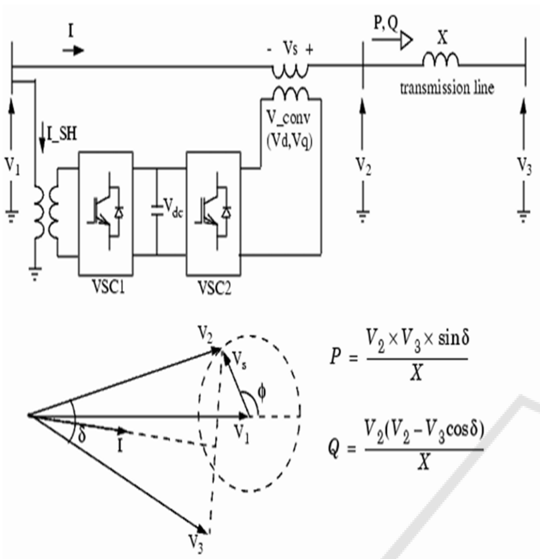

Figure 1: Solo line diagram of UPFC and phasor diagram.

An insulated gate bipolar transistor (IGBT) is used to connect the two voltage source converters in UPFC back-to-back via a shared DC link. One utilized a shunt transformer to link to the transmission line in parallel while the other used a series transformer to link to the transmission line in series. By using a DC link capacitor the shunt converter delivers the actual power that the series converter requires. The AC voltage with a regulated magnitude and phase angle is inoculated into the transmission line by the series converter. The phasor diagram offers a standard way to depict the liaison between the system voltage and current. Phasors are used to depict the voltages V1, V2 and V3 with V2 being impacted by the series-injected voltage Vconv. The angle is essential for figuring out the power flow since it shows the phase difference between V2 and V3. Using the following formulas real power P and reactive power Q can be articulated.

$$\mathrm{P} = \frac{\mathrm{V2*V3*Sin}\,\partial}{\mathrm{X}} \qquad \text{--------(1)}$$

$$\mathrm{Q} = \frac{\mathrm{V2(V2-V3\ Cos}\,\partial)}{\mathrm{X}}\text{-} \qquad \text{----------(2)}$$

Where the transmission line reactance is denoted as X. By altering the amplitude and phase angle of the injected voltage Vconv, these equations show how the UPFC controls the power flow.

3 POWER SYSTEM STABILIZER

A Power System Stabilizer (PSS) is an additional excitation controller that mitigates system irregularities by giving generators a damping torque component. Maintaining the system transient stability and controlling power generating system instability are made easier with the use of a power system stabilizer controller.

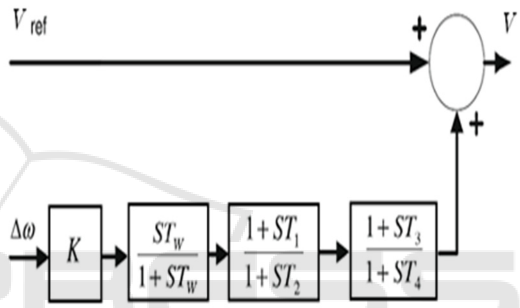

Figure 2: Block diagram of PSS Controller.

Gain block, signal washout block (Tw), a high pass filter and phase compensator of Lead-Lag block comprise the Power System Stabilizer controller block diagram seen in Figure 2. Equation (3) is the transfer function T(s) of the Power System Stabilizer controller, where K_{pss} is the PSS gain.

$$T(s) = \frac{Kpss(1+ST_1)(1+ST_3)}{(1+ST_2)(1+ST_4)} \qquad \text{----------(3)}$$

4 SIMULATION AND METHODOLOGY

One of the most popular FACTS devices is the UPFC. In this work, the solo-line diagram of the modelled power system is displayed in Figure 3, which represents a test system model. FACTS devices are used to standardise the power flow and improve the transmission capacity of the power system.

This system uses a UPFC to standardize the power flow. The system is comprised of two 500KV/230KV transformer banks (Tr1 and Tr2) and five node (B1 to B5) coupled in a loop arrangement via transmission lines (L1, L2, L3). The 1500 MW generated by two power plants on the 230 KV system is sent to a 200 MW load connected at node B3 and a 500 KV, 15,000 MVA equivalent.

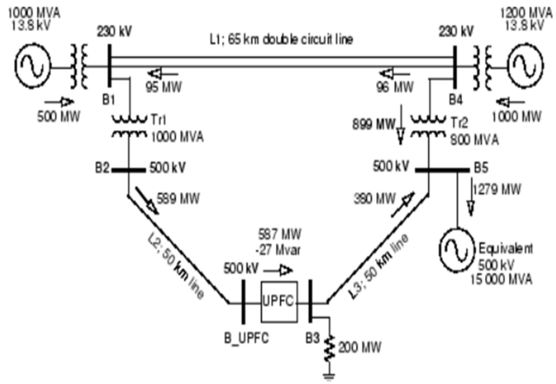

Figure 3: Test System Models.

The 500 KV node B3 active and reactive power as well as the voltage at node B are managed by the UPFC which is situated at the right end of line L2. One shunt converter and one series converter both 100 MVA IGBT-based are coupled via a DC bus to form the UPFC. In successions with line L2 the series converter can inoculate up to 10% of the minimal line-to-ground voltage (28.87 KV).

The test system is a transmission system without the UPFC device that has a problem. Transmission line L1 between the system buses B1 and B4 is where the fault is formed. Near bus B1, a three-phase-to-ground failure happens. There is symmetry in the three-phase-to-ground (LLLG) fault. In a test system model transmission system power flow is controlled by the UPFC under fault conditions. At the 500kV node B3 the UPFC device which is sited at the right end of L2 regulates the voltage at node B_UPFC and the active and reactive power at node B3. The system transmission line L1 which connects buses B1 and B4 is where the LLLG fault is formed.

5 SIMULATION AND RESULTS

In the MATLAB domain, a test system model transmission system was used to simulate both with UPFC and without UPFC related faults. A three-phase to ground fault is induced for 0.4 seconds next to bus B1 in order to analyze the system performance. A number of measures including rotor speed, rotor speed deviation, terminal voltage, active power and reactive power are used to test the power system enhancement. Compared to PI-based controllers the UPFC with PSS is far more effective at dampening out system oscillations.

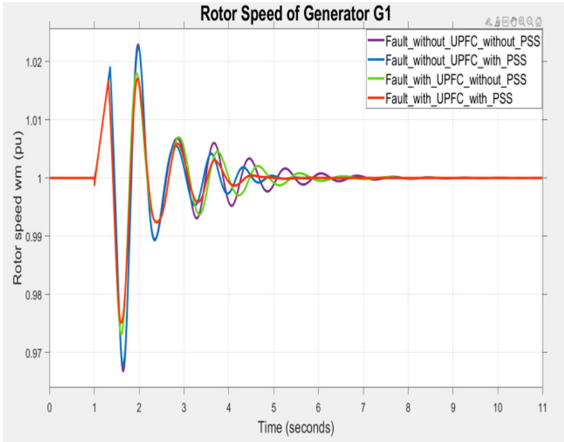

Figure 4: Rotor speed of generator G1.

Fig.4 illustrates how the rotor speed of generator G1 is examined following the fault resolution. The rotor speed oscillates for a longer period of time without UPFC and PSS controller than when these devices are used. Under unusual circumstances the UPFC with PSS controller performs far better than the PI controller. UPFC with PSS improves transient stability by reducing the first peak magnitude and setting time considerably according to the results.

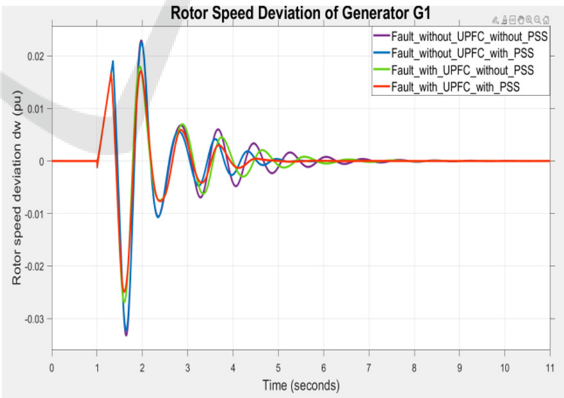

Figure 5: Rotor speed deviation of generator G1.

Fig.5 displays the generator G1 rotor speed deviation both with and without PSS and UPFC. Compared to a PI controller, a UPFC with PSS controller reduces rotor speed deviation oscillations, first peak and settling time once the problem is fixed. Rotor angle stability has improved.

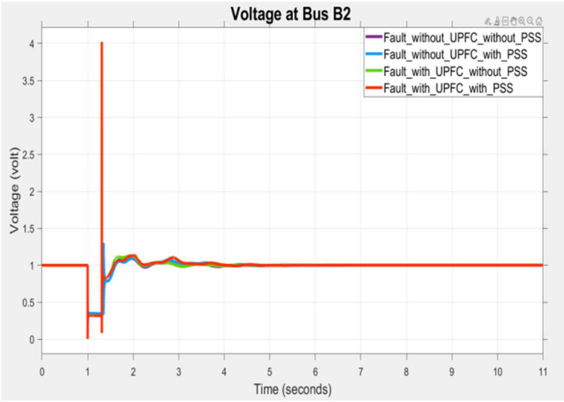

Figure 6: Voltage at bus B2.

Fig. 6 shows bus B2 terminal voltage both with and without UPFC and PSS conditions. According to the results UPFC with PSS stabilizes the system and works well following a post-fault condition.

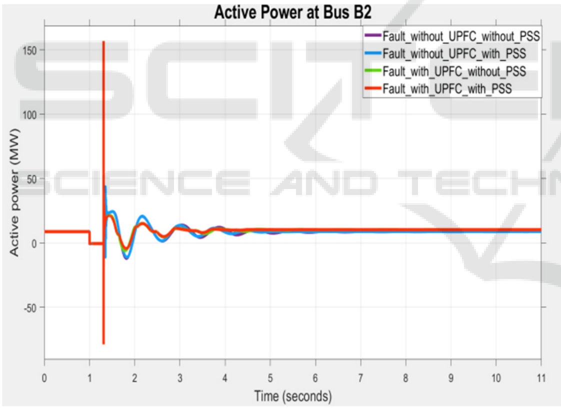

Figure 7: Active power at bus B2.

Fig.7 talks about real power at bus B2 during a 0.4 s fault period both with and without UPFC and PSS. After the fault has been unfurnished the active power with UPFC with PSS increases demonstrating the power control capacity of UPFC with PSS which further improves transmission line system performance by reducing oscillation and managing power flow.

Fig. 8 shows the reactive power at node B2 with and without PSS and UPFC over a 0.4 second fault period. The rise in reactive power with UPFC and PSS following fault defrayal shows that reactive power is supported by maintaining the UPFC and PSS voltage profile to improve power system performance.

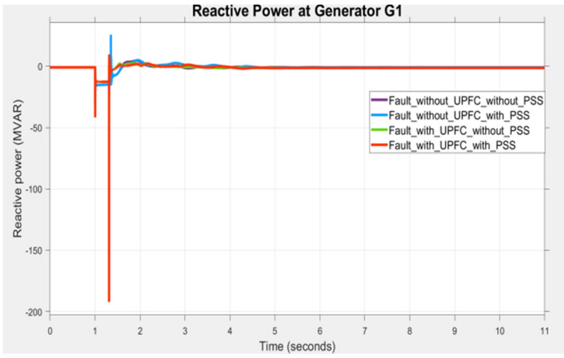

Figure 8: Reactive power at node B2.

Table 1: System response during LLLG fault without PSS.

Without Power System Stabilizer					
Sr. No.	Parameters	Controller	First Peak	Setting Time (sec)	No. of Oscillation
1	Rotor speed of generator G1	Without UPFC	1.019	9.4	8
		With UPFC	1.017	8.8	6
2	Rotor speed deviation of G1	Without UPFC	0.019	9.2	8
		With UPFC	0.017	8.5	6
3	Voltage at node B2	Without UPFC	1.29	6.5	4
		With UPFC	4.0	5.5	2
4	Active power at node B2	Without UPFC	44	8.1	8
		With UPFC	159	5.5	4
5	Reactive power at node B2	Without UPFC	25	6.5	4
		With UPFC	10	5.2	2

Table 1 above shows that the system cannot react as fast to changes in power system oscillation and voltage without a Power System Stabilizer (PSS) as it can with one. Instability will result from the oscillation increasing.

Table 2: System response during LLLG fault with PSS.

With Power System Stabilizer					
Sr. No.	Parameters	Controller	First Peak	Setting Time (sec)	No. of Oscillation
1	Rotor speed of generator G1	Without UPFC	1.019	6.1	5
		With UPFC	1.017	5.5	4
2	Rotor speed deviation of G1	Without UPFC	0.019	6.1	5
		With UPFC	0.017	5.5	4
3	Voltage at node B2	Without UPFC	1.29	6	4
		With UPFC	4.0	4.9	2
4	Active power at node B2	Without UPFC	44	5.6	6
		With UPFC	159	4.5	4
5	Reactive power at node B2	Without UPFC	25	5.5	4
		With UPFC	10	4.8	2

A system with Power System Stabilizers will provide better transient stability and dynamic stability of the large power network. Table 2 above shows that the number of oscillations the value of the first peak and the settling time for the various strictures such as rotor speed and rotor speed deviation of G1, voltage, real and reactive power at node B2 of the transmission system are all lower when UPFC is used than when it is not.

6 CONCLUSIONS

According to the simulation results, the UPFC is essential for improving the power system performance when there is a problem. The outcomes unequivocally demonstrate how well the UPFC system is able to stabilize voltage, rotor speed and rotor speed deviation during the abrupt significant disturbance as well as maintain active and reactive power via the line. Comparing the suggested system with UPFC to the traditional system with a PI controller the former is noticeably better. The combination of UPFC and PSS also improves the transient stability of the power system with PSS playing a major role. The transient enactment of the power system is greatly enhanced by the combination of the UPFC and PSS.

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