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# DYNAMIC STABILITY IMPROVEMENT AND REAL POWER LOSSES REDUCTION OF A MULTI MACHINE POWER SYSTEM USING UNIFIED POWER FLOW CONTROLLER

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**Abstract**— This paper focuses on three key issues of the power system that is stability enhancement, minimization of real power losses, and improving voltage profile of the buses by placing the Unified Power Flow Controller (UPFC) to the best location in WSCC 3 machine 9 bus system. The comparison between with and without UPFC is carried out to prove that UPFC enhances the stability of the multi machine power system. In this paper the best location of the UPFC is recognized by Power Flow Analysis. Eigen Value Analysis and Continuation Power Flow (CPF) is employed to show the performance of UPFC for stability enhancement. The analysis is carried out using Power System Analysis Toolbox (PSAT) software.

**Keywords**- Stability; UPFC; PSAT; Losses, CPF

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## I. INTRODUCTION

The rapid development of Power Electronics technology provides exciting opportunities to develop new power system equipment for the betterment of the existing systems. In last two decades number of power devices have been proposed and implemented and put under the term Flexible AC Transmission System (FACTS). FACTS devices can be effectively used for power flow control, voltage regulation, improvement of power system stability, minimization of losses, and reduction of harmonics. There are two main objectives of FACTS devices which are increasing the power transfer capability of transmission system and restricting power flow over designated lines. In current power market, control of active and reactive power flow in a transmission line becomes a necessity aspect. Entry of more power generation companies has increased the need for enhanced secured operation of power systems, which are facing the threat of voltage instability leading to voltage collapse and also for minimization of active power loss leading to reduction in electricity cost. Also the stable operation of the power system networks revolves around improving voltage profile, minimizing power transmission loss. Power system operators ensure the quality and reliability of supply to the customers by employing system compensation and load side compensation for maintaining the load bus voltages in their permissible limits. Any changes to the system configuration or in power demands can result in higher or lower voltages in the system.

FACTS devices can be effectively used for the control of power flows, providing the possibility of operating the transmission grid with increased flexibility and efficiency. The comprehensive devices that originate from the FACTS technology are Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM) and Unified Power Flow

Controller (UPFC). This paper uses PSAT tool in MATLAB to analyze the best suitable location of UPFC for stability enhancement, minimization of losses and voltage improvement.

To achieve good performance of UPFC, proper placement of the FACTS device becomes vital task. There are several methods for finding the locations of UPFC in vertically integrated systems but they involve numerous complexities. However, a simple and effective method based on power flow analysis has been employed to locate the weak buses in the system for effective compensation.

In this paper, the selection of the best possible location for installation of UPFC is carried out with an objective of Stability Enhancement, reducing the losses and improving the voltage profile of the bus in WSCC 3 machine 9 bus system using PSAT (Power System Analysis Toolbox) software.

## II. PRINCIPLE OF OPERATION OF UNIFIED POWER FLOW CONTROLLER (UPFC)

Unified Power Flow Controller (UPFC) is a combination of static synchronous compensator (STATCOM) and 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 shunt output terminals of STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, the real and reactive power flow in the line. The UPFC is the most versatile FACTS controller developed so far, with all encompassing capabilities of voltage regulation, series compensation, and phase

shifting. It is build up by two voltage source converter (VSC), one connected in series with line through transformer and other connected in shunt through shunt transformer as shown in Figure 1.

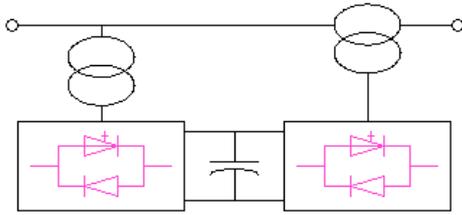


Figure 1. Basic block diagram of UPFC

### III. VOLTAGE STABILITY

#### A. Basic Concept

Voltage stability is the ability of a power system to maintain steady acceptable voltage at all the buses in a power system under normal operating conditions and after being subjected to a disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable drop in voltage. The main factor causing instability is the inability of a power system to meet the demand for the reactive power. The heart of the problem is usually the voltage drop that occurs when active power and reactive power flow through inductive reactances associated with the transmission network.

A criterion for the voltage instability is that, at a given operating condition for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased. A system is voltage unstable if, for at least one bus in the system, the bus voltage magnitude ( $V$ ) decreases as the reactive power injection ( $Q$ ) at the same bus is increased. In other words, a system is voltage unstable if  $V$ - $Q$  sensitivity is negative for at least one bus. Relation between active power ( $P$ ) and voltage ( $V$ ) is also an important interest for the voltage stability. Voltage stability, in fact, depends on the relationship between  $P$ ,  $Q$ , and  $V$ .

Voltage instability is essentially a local phenomenon; however, its consequences may have a widespread impact. Voltage collapse is more complex than the simple voltage instability leading to low-voltage profile in a significant part of the power system.

#### B. Classification of Voltage Stability

The voltage stability is classify into the following two subclasses:

- a) Large-disturbance voltage stability
- b) Small-disturbance voltage stability

Large-disturbance voltage stability is concerned with a system's ability to control voltages following

large disturbances such as system faults, loss of generation, or circuit contingencies.

Small- disturbance voltage stability is concerned with a system's ability to control voltages following small perturbations such as incremental changes in system load.

### IV. CASE STUDY

A Western System Coordinating Council (WSCC) 3 Machine 9 Bus is considered for analysis of best location of UPFC so as to enhance the stability and minimize the real losses in the system. The system is modeled in PSAT shown in Figure 2 and Figure 3 shows the network visualization.

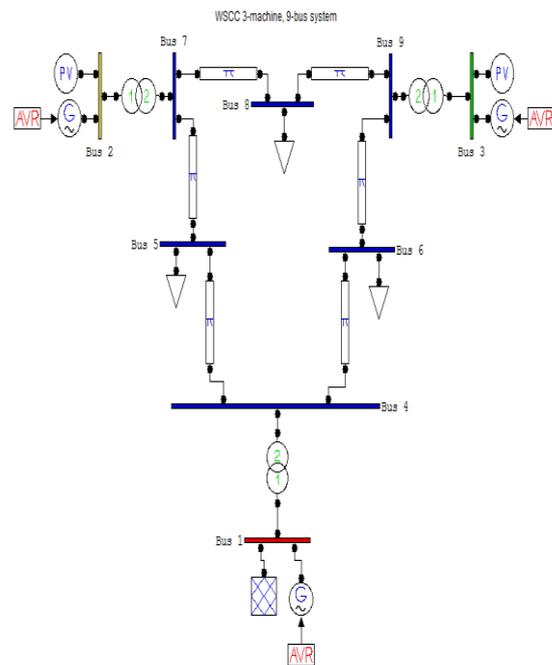


Figure 2. Single line diagram of WSCC 3 machine 9 bus system

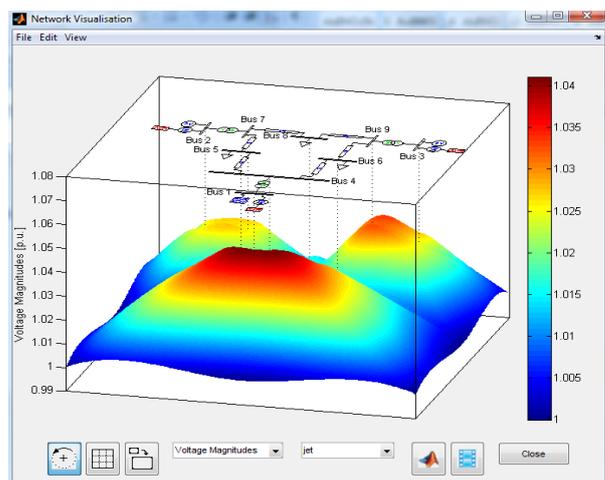


Figure 3. Network Visualization

## V. SIMULATION RESULTS

### C. Case 1. Power Flow Analysis

The fault is created at bus 7 in WSCC 3 machine 9 bus system and the power flow is done in a PSAT. It is found that the real power loss is 0.02914 p.u. UPFC is incorporated in different transmission lines to obtain the best location to analyze the reduction in real power losses. Table 1 shows the UPFC placement at different transmission lines and it's correspond real power loss.

TABLE 1: REAL POWER LOSSES WITH UPFC AT DIFFERENT LOCATIONS

UPFC POSITION (b/w Bus No.)	TOTAL GENERATION (p.u.)		TOTAL LOAD (p.u.)		TOTAL REAL POWER LOSSES (p.u.)
	REAL	REACTIVE	REAL	REACTIVE	
9-8 1	3.174	0.40578	3.1	1.15	0.02409
7-8 1	3.178	0.35185	3.1	1.15	0.02807
9-6 1	3.178	0.58796	3.1	1.15	0.02807
7-5 8	3.178	0.52908	3.1	1.15	0.02881
5-4 5	3.166	0.1243	3.1	1.15	<b>0.01636</b>
6-4 8	3.170	0.35169	3.1	1.15	0.02077

With UPFC the real power loss reduces to 0.01636 p.u. Table 2 shows the real power loss reduction comparison with and without UPFC.

TABLE 2: TOTAL REAL POWER LOSSES WITH AND WITHOUT UPFC

	Without UPFC	With UPFC
TOTAL REAL POWER LOSSES (P.U.)	0.02914	0.01636

Hence by all analysis it can be concluded that for reduction in losses UPFC should be placed between Bus 4 and 5.

### D. Case 2. Continuation Power Flow for Voltage Stability

For the voltage stability analysis, continuation power flow is carried out with and without UPFC in a WSCC 9 bus system and it is found that the UPFC increases the voltage stability of all the buses of the system. Figure 3 and 4 shows the graph between voltage and loading parameter (in p.u.) of buses 1 and 2 respectively without using UPFC and Figure 5 and 6 shows the result with UPFC.

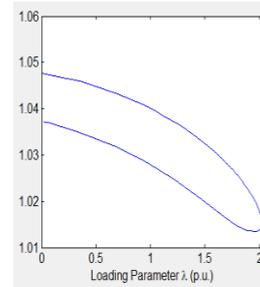


Figure 3. V-P curve of Bus 1 without UPFC

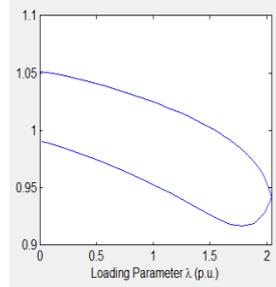


Figure 4. V-P curve of Bus 2 without UPFC

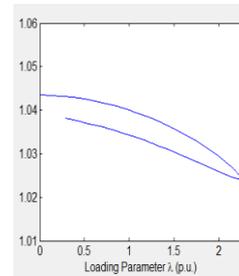


Figure 5. V-P curve of Bus 1 with UPFC

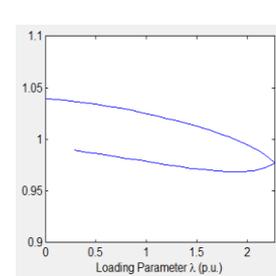


Figure 6. V-P curve of Bus 2 with UPFC

It is found that the UPFC increases the critical voltage point of the bus and also the range of the loading parameter. Hence the stability of the multi machine power system get enhanced.

### E. Case 3. Eigen Value Analysis

The eigen value analysis is carried out with and without UPFC device. Figure 7 shows the graph of eigen value analysis of WSCC 9 bus system without the UPFC.

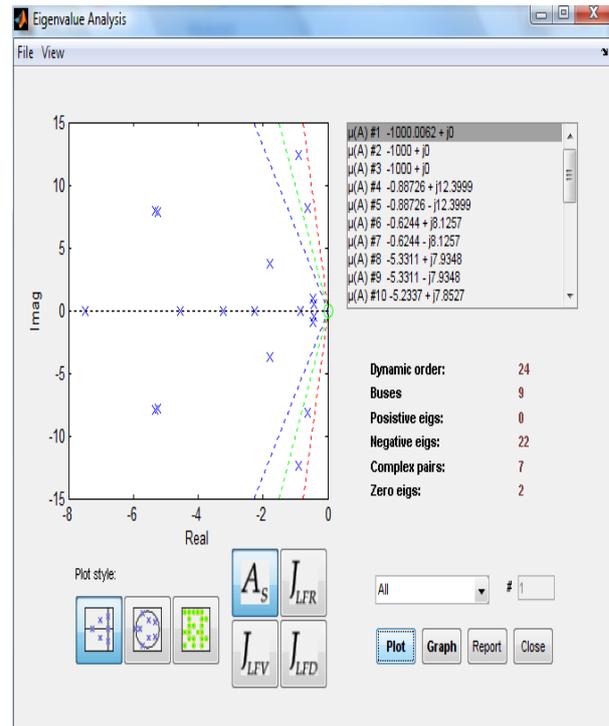


Figure 7: Eigen value analysis without UPFC

Table 5 shows the eigen value analysis with UPFC between the different buses and Table 6 shows the comparison of the eigen value analysis with and without UPFC.

TABLE 5: EIGEN VALUE ANALYSIS OF UPFC BETWEEN DIFFERENT BUSES

STATISTIC S	UPFC POSITION BETWEEN BUS NO.					
	9-8	7-8	9-6	7-5	5-4	6-4
Dynamic Order	27	27	27	27	27	27
Negative Eigen	25	25	25	25	25	25
Positive Eigen	0	0	0	0	0	0
Complex Pair	7	7	7	7	7	7
Zero Eigens	2	2	2	2	2	2

TABLE 6: EIGEN VALUES WITH AND WITHOUT UPFC

Associated States	WITHOUT UPFC	WITH UPFC
$\Delta 3, \omega 3$	$-0.88726 \pm 12.3999$	$-0.9041 \pm 12.3995$
$\Delta 2, \omega 2$	$-0.6244 \pm 8.1257$	$-0.61727 \pm 8.1026$
vr1_Exc_1, vf_Exc_1	$-5.2337 \pm 7.8527$	$-5.2581 \pm 7.8844$
vr1_Exc_3, vf_Exc_3	$-5.3311 \pm 7.9348$	$-5.338 \pm 7.9381$
vf_Exc_2, e1q_Syn_2	$-1.7763 \pm 3.7703$	$-1.9822 \pm 3.6006$
e1q_Syn_1, vr2_Exc_1	$-0.4661 \pm 0.91672$	$-0.44196 \pm 0.82105$
e1q_Syn_3, vr2_Exc_3	$-0.43857 \pm 0.55511$	$-0.44036 \pm 0.55188$

Table 6 shows the eigen values with and without UPFC. The real eigen values with UPFC increased in negative side that depicts an increase in stability of the system. It can be noticed from Table 7 that the dynamic order of the system increases when UPFC is introduced in the system. The UPFC increases more dynamic order as compared to the system without UPFC. UPFC also increases the negative eigen values of the system, hence enhancing the stability of the system.

TABLE 7: EIGEN VALUE ANALYSIS REPORT WITH AND WITHOUT UPFC

STATISTICS	WITHOUT UPFC	WITH UPFC
Dynamic Order	24	27
Negative Eigen	22	25
Positive Eigen	0	0
Real Eigen	10	13
Complex Pair	7	7
Zero Eigen	2	2

## VI. CONCLUSION

The analysis of WSCC 3 machine 9 bus system is done using PSAT (Power System Analysis Toolbox) software. The best location of UPFC is investigated using Power Flow Analysis to minimize real power losses. The stability of the WSCC 3 machine 9 bus system is studied by using continuation power flow (CPF) and Eigen Value Analysis. This paper has a vital scope for future studies. Artificial Intelligence Methods like neural network and genetic algorithm or Particle Swam Optimization (PSO) can be used to find out the optimal location of the FACTS devices.

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