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Application of Sensitivity Approach for Congestion Management By UPFC

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Abstract: The properties of both shunt and series compensations are integrated in the Unified Power Flow Controller (UPFC) and can effectively alter power system parameters in a way that increases loadability and enhances the voltage profile. In this paper Voltage deviation based sensitivity index (VDSI) and Total Active Power Loss Deviation Based Sensitivity index (PLDS) have been proposed for the optimal location and operating range of UPFC device to enhance voltage profile and loading margin in the unbalanced power system and so the congestion management problem can be solved. So ultimately, a more energy efficient transmission system is possible. Its efficiency was proved through the application in IEEE14 bus test system.

Index Terms: UPFC placement, Sensitivity indexes, loadability, voltage profile, congestion management.

1. INTRODUCTION

Because of the limitation of energy resources and, also, a number of economic constraints increasingly pressurise the present pace of de-regulated power system to operate near its loadability and stability margins. In order to use the maximum capacity of power transmission lines while avoiding overloaded lines, utilities have expensive and time consuming solutions such as building new lines [1]. Hence, there is a better usage of power system available capacities by installing new devices such as flexible ac transmission systems (FACTS) in the existing power system. FACTS devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability [2], low system loss, improved voltage stability and minimization of congestion management problem in the network. FACTS device provide a better choice to have the change in operational conditions and improve the utility of existing installations.

The unified power flow controller (UPFC) is one of the most technically promising devices in the flexible ac transmission systems (FACTS) family [3]. It has the capability to regulate voltage magnitude and phase angle and can also independently provide reactive power injections. Therefore, the UPFC can provide voltage support, control of real power flow, and other functions such as improves the available transfer capability and reduces the congestion management problem. Because of high capital and installation cost, the UPFC can’t be installed in every possible transmission line. Thus, the optimal location to install the UPFC is very important. However, the benefits of these devices are extremely dependent on their type, size, number and location in the transmission system [4]. Many research projects and studies have been conducted in the area of FACTS device placement to improve power system operations.

Congestion in a transmission system cannot be given space except for a very short duration, for fear of cascade outages with uncontrolled loss of load. Generally, FACTS devices are able to relieve congestions and decrease power losses as well as to reduce load shedding [5], [6] and generation re-scheduling [7], which may significantly contribute to a more energy efficient transmission system.

A method based on the Voltage deviation based sensitivity index and Total Active Power Loss Deviation Based Sensitivity indexes (VDSI and PLDS) has been used in this paper for the optimal placement of UPFC to enhance voltage profile, to solve the transmission congestion management problem and loading margin and IEEE 14-bus test system is used to verify the effectiveness of proposed method.

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2. MODELLING OF UPFC

Unified Power Flow Controller (UPFC) was devised for real time control and dynamic compensation of ac transmissions system. Basically, the UPFC has two voltage source converters sharing a common dc storage capacitor on their DC side and a unified control system. The simultaneous control of active and reactive power flows, and voltage magnitude at the UPFC terminals is possible by UPFC. Alternatively, the controller may be set to control one or more of these parameters in any combination or to control none of them. Converter 1 is primarily used to provide the real power demand of converter 2 at the common dc link terminal from the ac power system. The schematic representation of the UPFC is shown in Figure 1. Converter 1 can also generate or absorb reactive power at its ac terminal, which is independent of the active power transfer to (or from) the dc terminal. Converter 2 is used to generate a voltage source at the fundamental frequency with variable amplitude ($0 \le V_T \le V_{TMAX}$) and phase angle ($0 \le \varnothing T \le 2\pi$), which is added to the ac transmission line by the series-connected boosting transformer.

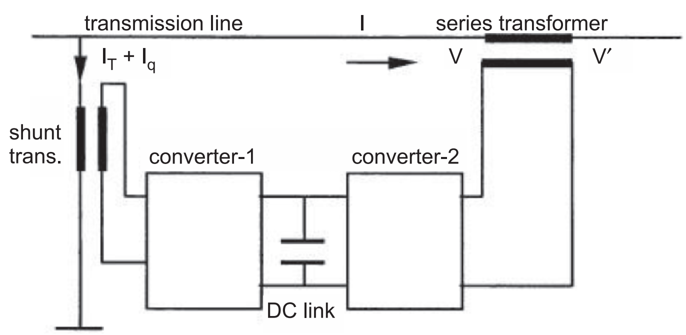

Figure 1: The UPFC basic Circuit Arrangement

The inverter output voltage injected in series with line can be used for direct voltage control, series compensation, phase shifter, and their combinations. The placement of UPFC in a transmission line between node *i* and node *j* is as shown in Figure 2.

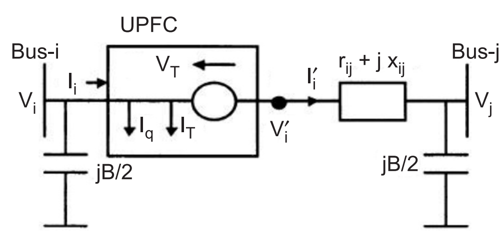

Figure 2: The UPFC Placed Between Bus-*i* And Bus-*j*

$$P_{is} = V_T^2 g_{ij} - 2V_i V_T g_{ij} \cos \varnothing_T - \delta_i + V_j V_T [g_{ij} \cos \varnothing_T - \delta_i + b_{ij} \sin \varnothing_T - \delta_i] \quad (1)$$

$$P_{js} = V_j V_T [g_{ij} \cos \varnothing_T - \delta_i - b_{ij} \sin \varnothing_T - \delta_i] \quad (2)$$

$$Q_{is} = V_i I_q + V_i V_T [g_{ij} \sin \varnothing_T - \delta_i + (b_{ij} + B/2) \cos \varnothing_T - \delta_i] \quad (3)$$

$$Q_{js} = -V_j V_T [g_{ij} \sin \varnothing_T - \delta_i + b_{ij} \cos \varnothing_T - \delta_i] \quad (4)$$

Where,

V_T = The magnitude and the angle of inserted voltage.

$\varnothing_T$ = The angle of inserted voltage.

I_Q = The magnitude of the current.

P_{is} = The injected active power at bus-*i*.

P_{js} = The injected active power at bus-*j*.

Q_{is} = The injected reactive power at bus-*i*.

Q_{js} = The injected reactive power at bus-*j*.

3. CONGESTION MANAGEMENT

In deregulated electricity market transmission congestion occurs when there is insufficient transmission capacity to simultaneously accommodate all constraints for transmission of a line. Congestion should be alleviated as fast as possible since it may lead to tripping of overloaded lines, consequential tripping of other lines, and in some cases to voltage stability problem. Managing transmission congestion in an unbundled electric power system poses a challenge to an Independent System Operator (ISO). In practice, it may not be possible to deliver all bilateral and multilateral contracts in full and to supply all pool demand at least cost due to violation of operating constraints such as voltage limits and line over-loads (congestion)[8]. One of the major issues is the transmission line congestion in deregulated power industry. Congestion management in is not simple in the non-regulated power environment. Flexible Alternative Transmission System (FACTS) devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network [9] and reduced cost of production by controlling the power in the network. The location of FACTS devices is very important for congestion management by controlling the device parameters [10].

4. VOLTAGE STABILITY

Maintaining steady acceptable voltages at all buses in the system is known as voltage stability. A system enters state of voltage instability when disturbances like sudden change in load demand. A power system at a given operating state and subjected to a given disturbance is voltage stable if voltages near the loads approach post disturbance equilibrium values. Power system voltage stability is characterized as being capable of maintaining load voltage magnitudes within specified operating limits under steady state conditions [11]. Reduction of voltage in a significant portion of a power system leads to voltage collapse. The tripping of transmission or generating equipment often triggers voltage collapse [12] and is the major sources of power system insecurity. In general Voltage stability problems occur more frequently in a heavily loaded system. The cause of voltage instability could be numerous. The control of voltage levels can be accomplished using Flexible Ac Transmission System Controllers [13]. Because of voltage instability in the power system, there is a possibility of transmission congestion management problem. So by the optimal placement of UPFC voltage instability problem will be reduced and so the congestion management problem.

5. PROBLEM FORMULATION

A. Proposed Index for Optimal Placement of UPFC

(i) **Placement of Shunt Converter:** Voltage deviation based sensitivity index (VDSI) has been used in this work to find the optimal place for shunt converter i.e., to identify the critical bus in the system. After that according to reactive power support we have chosen the rating of the shunt converter.

$$VDSI = (V_{BC} - V_{AC})/V_{BC} \tag{5}$$

(ii) **Placement of Series Converter:** Total Real power loss deviation based sensitivity index have been used in this work to optimally place series converter to reduce the overflows in the transmission lines which results in an increased loadability of the power system and so the maximum relief of congestion management problem is achieved. The optimal location of series converter has been decided by the Total Real Power Loss Deviation Based Sensitivity index (PLDS) computed for each transmission line is defined as follows (with suitable compensation i.e., 10% to 70%). Total Real Power Loss Sensitivity Index,

$$PLDS = (P_{Lb} - P_{La})/P_{La} \tag{6}$$

Where

P_{La} is real power loss after compensation.

P_{Lb} is real power loss before compensation.

Ranking for the transmission lines is given according to PLDS index. So finally we identified the top ten transmission lines for the placement of TCSC.

6. SYSTEM STUDIES

The proposed method is tested using IEEE 14 bus system. The proposed fitness function tries to find an optimal solution for the location of UPFC by minimizing the Branch loading and improving voltage stabilization. To study the proposed technique, congestion is created in the lines by uniformly over loading without changing the initial power factor with a scaling factor of 4.1.

Based on VDSI index the most critical buses are identified and are tabulated in Table 1.

Table 1
Voltage deviation based sensitivity index (VDSI)

Bus no	*VDSI*	*RANK*
4	0.29098	1
5	0.301357	2
10	0.318786	3
9	0.332389	4
14	0.368979	5

According to the above ranking bus 4 is considered as the suitable bus to place shunt converter.

Based on the PLDS index the top five ranks for the transmission lines are shown in Table 2.

Table 2
Total Real Power Loss Deviation Sensitivity Index (PLDS)

LINE	*PLDS*	*RANK*
2-4	0.005757	1
3-4	0.001966	2
4-5	0.000281	3
4-7	0.00014	4
4-9	0.00014	5

According to the above ranking line 2-4 is considered as the suitable line to place series converter. The voltages at the most critical buses with and without UPFC is tabulated in Table 3 and the graphical representation in Figure 3.

Table 3
Voltages at the critical buses

Bus no	*Bus voltages without UPFC*	*Bus voltages with UPFC*
4	0.731	0.883
5	0.721	0.846
10	0.718	0.803
9	0.707	0.804
14	0.655	0.734

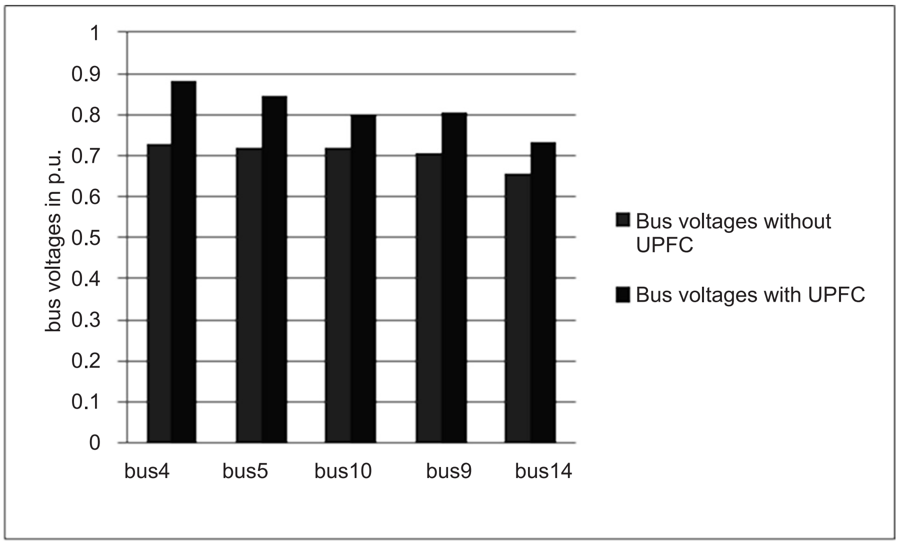

Figure 3

The power flows in the most critical lines with and without UPFC is tabulated in Table 4 and the graphical representation in Figure 4.

Table 4
Power flows in the congested lines

Line	*Power flow without UPFC*	*Power flow with UPFC*
2-4	256.976	260.356
3-4	-41.414	-73.822
4-5	-179.985	-197.031
4-7	83.534	85.236
4-9	48.636	52.806

Based on VDSI and PLDS index the optimal location for UPFC is chosen at bus 4 and line 2-4.

7. CONCLUSION

In this paper, a new indexes, called Voltage deviation based sensitivity index (VDSI) and Real power loss deviation based sensitivity index has been proposed for the optimal placement of UPFC in the power system. Further FACTS devices have seen to be one of the most important tools for the system operator in the changing utility environment. FACTS devices, namely UPFC have been proven to provide the most reliable and efficient solution in relieving the congestion management. The proposed method is tested on IEEE14 bus test system. The test results demonstrate the effectiveness of the proposed method in terms

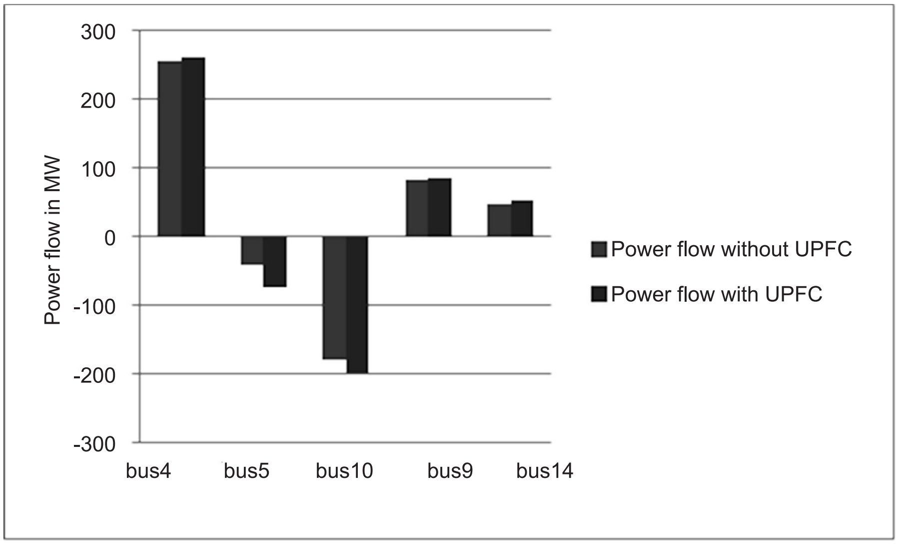

Figure 4

of reducing the voltage instability problem, improves the loading margin considerably in the unbalanced power system and so the congestion management problem. The proposed method of optimal placement of UPFC can be applicable to any type of FACTS devices in the power system.

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