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Incorporating Voltage Stability Index and the "-" Transformation Theory into the Design of Multi-Machine Power Systems

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Abstract

When it comes to FACTS devices, the Unified Power Flow Controller (UPFC) has emerged as one of the most flexible. Based on this research, the Unified Power Flow Controller (UPFC) is developed and tested. A 3-phase system (abc) is reduced to a 2-axis system (-) here, allowing the power profile to be individually regulated while simultaneously managing the local bus voltage. Implementation and analysis of an integrated power flow controller for varying loads are discussed in this paper's 3 machine 9 bus standard (WSCC) implementation and analysis. A UPFC placement study is also included in this work, which aims to establish the best location and operating parameters for a power system's voltage profile improvement. The Voltage Stability Index (VSI) or L-index approach is used to determine the placement of the UPFC under various loading scenarios. Matlab/Simulink12a is used for all simulations, and the results demonstrate that the controller improves the system's power profile and voltage profile.

Voltage Stability Index, L-index approach, UPFC, power flow control, - theory Voltage Stability Index

INTRODUCTION

Improved power quality is required in today's increasingly complicated power system to meet rising demand. Improved power quality is required because modern technologies are being employed to enhance power system security, resiliency, and profitability. In order to do this, the transmission network's stability and power profile must be improved. When the system is faulty, excessively loaded, or reactive power demand spikes unexpectedly, the voltage collapse happens in the power system due to new transmission line networks and power stations, a variety of loads, and transformers. Due to the increasing load on long transmission lines and the inability of the system to fulfil reactive power demands caused by voltage variations, the power system becomes unstable and unbalanced.

Power electronics controllers, also known as Flexible AC Transmission Systems (FACTS) controllers, were made possible due to the introduction of semiconductor devices such as the thyristor switch FACTS devices are semiconductor devices that may either inject or absorb reactive power in a system, and they are one of the most significant reactive power sources. Third generation FACTS controller, Unified Power Flow Controller (UPFC).

UPFC power and voltage profiles are studied in this article under various loading circumstances using the - control theory. Using the Voltage Stability Index (VSI) or L-index approach, the best position of UPFC in the power system is also described in this work. To determine the best position for the UPFC, it was put through its paces on a 9-Bus test system, which will be the subject of this study.

UNIFIED POWER FLOW CONTROLLER

Unified power flow controller (UPFC) is seen in Fig.1. Two voltage source converters, a series and a shunt, are linked to each other through a shared dc link capacitor, which permits bidirectional flow of actual power between the SSSC and STATCOM. Figure 1 illustrates how these converters are connected to shunt and series transformers using an ac voltage bus. In series with the line, the SSSC and STATCOM (Static Synchronous Compensator) add regulated voltage magnitude and phase angle; the STATCOM (Static Synchronous Compensator) shunt converter provides reactive power for the ac system and the dc power necessary for both VSC. This is where the dc capacitor or energy storage capacity is often minimal, therefore the active power consumed by the shunt converter should match the active power provided by the series converter. The reactive power in the shunt or series converter may be selected individually, allowing for more flexibility in power flow regulation.

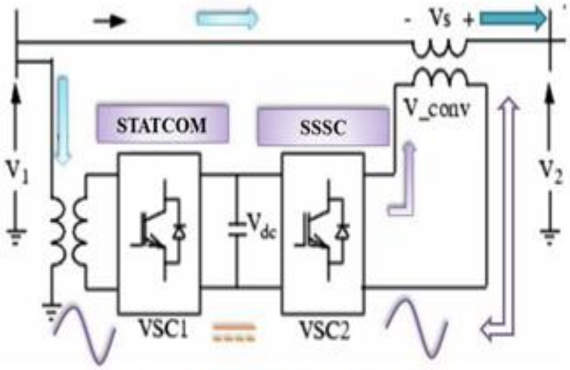

Fig. 1 Basic structure of UPFC

It's capable of adjusting things like terminal voltage, line impedance, and phase angle in power systems. Aside from controlling power flow, it may also be employed as a stabilising control mechanism. Real and reactive power flows may be directed by unified power flow controllers, which can also regulate the system voltage by compensating for reactive power losses.

INSTANTANEOUS REACTIVE POWER THEORY

The - or Clark transformation theory is another name for the instantaneous reactive power theory. As seen in figure 2, UPFC uses the - theory for basic control. Reference data like AC voltage, DC link voltage, real and reactive powers over the line and load current may be tracked using this - axis control system. This kind of controller allows for a reasonably rapid reaction time and reduces the interplay between actual and reactive power flow by using an axis controller.

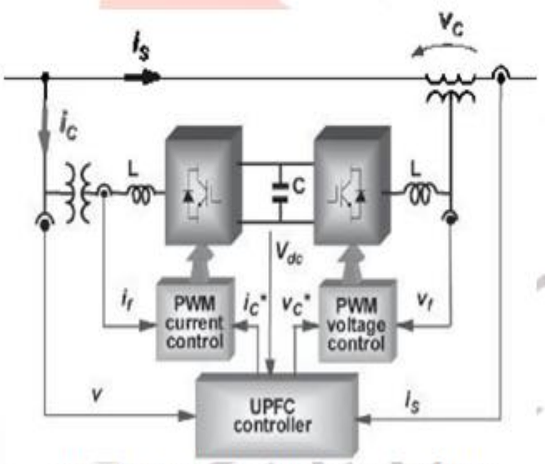

Fig. 2 Basic Controlling block diagram of UPFC

Modeling of shunt VSC

The Basic Controlling block diagram of shunt VSC using α-β axis controller is shown in fig. 3.

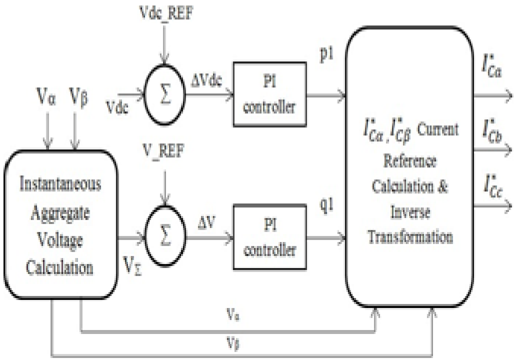

Fig. 3 Basic Controlling block diagram of shunt VSC

Here α-β or Clark transformation is given by Eq. 1 and inverse transformation is given by Eq. 2 in general form for both voltage and current.

$$\begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} \qquad \text{.... Eq. 1}$$

$$\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} \qquad \text{.... Eq. 2}$$

Here instantaneous aggregate voltage calculation is given by Eq. 3 and current reference calculation is given by Eq.4.

$$V_\Sigma = \sqrt{V_\alpha^2 + V_\beta^2} \quad \text{.... Eq. 3}$$

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} P_l \\ q_l \end{bmatrix} \quad \text{.... Eq. 4}$$

Here DC voltage reference and source voltage reference is given for generating error value which is controlled by PI controller asshown in fig. 3.

Modeling of series VSC

The Basic Controlling block diagram of series VSC using α-β axis controller is shown in fig. 4.Here power calculation is given byEq. 5 & voltage reference calculation is given by Eq. 6.

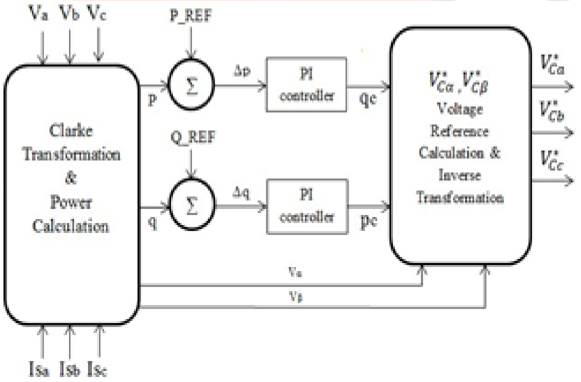

Fig. 4 Basic Controlling block diagram of series VSC

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \quad \text{.... Eq. 5}$$

$$\begin{bmatrix} V^*_{c\alpha} \\ V^*_{c\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} P_c \\ q_c \end{bmatrix} \quad \text{.... Eq. 6}$$

Here power profile reference is given for generating error value from controlled bus which is controlled by PI controller as shownin fig. 4.

SIMULATION OF 3-MACHINE 9-BUS STANDARD (WSCC) SYSTEM

The Basic Controlling block diagram of this system is shown in fig. 5. & the system parameters are specified in [2].

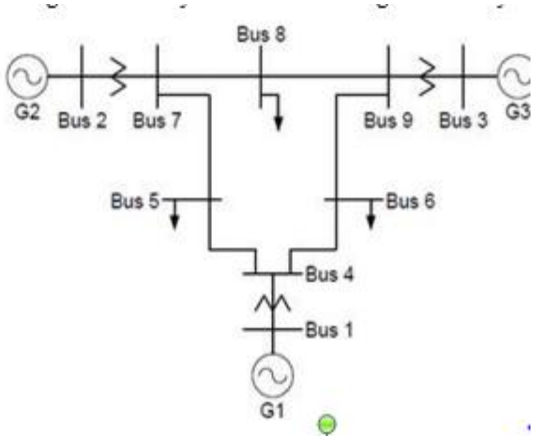

Fig. 5 Basic Controlling Block Diagram of 3-Machine 9-Bus Standard (WSCC) System

The MATLAB simulation circuit of 3-Machine 9-Bus Standard (WSCC) System is shown in Fig. 6. The simulation results areshown in results and comparisons.

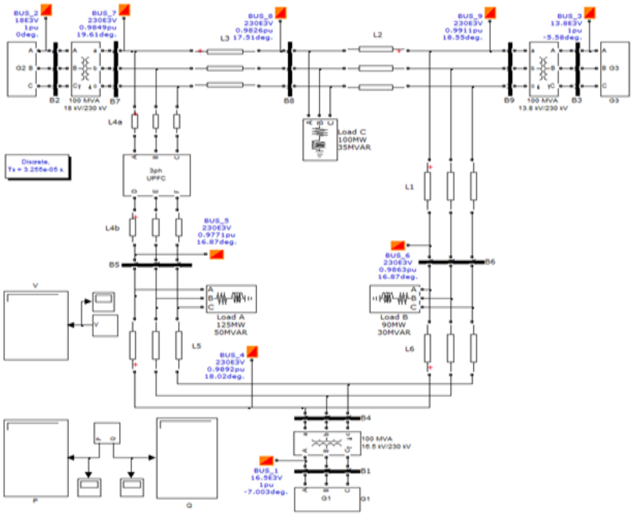

Fig. 6 MATLAB simulation of 3-Machine 9-Bus Standard (WSCC) System

SIMULATION OF UNIFIED POWER FLOW CONTROLLER

The MATLAB simulation of UPFC is shown in fig. 7.

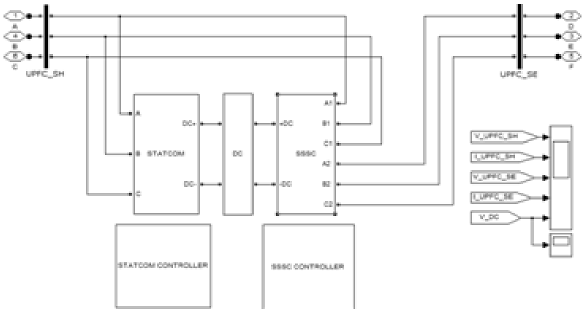

Fig. 7 MATLAB simulation of UPFC

Here both shunt and series VSCs are simulated by 24-puls converter, comprising 4 set of 6-pulse converter with 4 set of Zig-Zeg transformer for achieving phase difference of 15° in each set.

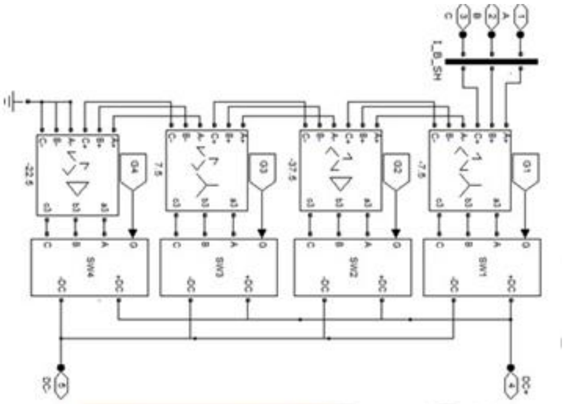

Fig. 8 MATLAB simulation of shunt VSC

This will generate ±7.5° phase sifted wave forms, combining which compensating voltage and current can be generated. Fig. 8 shows simulation of shunt VSC and Fig. 9 shows simulation of series VSC. The details of modeling circuits are specified in [1].

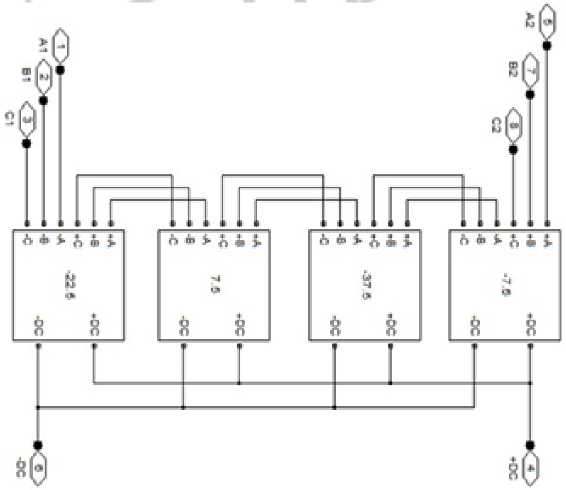

Fig. 9 MATLAB simulation of series VSC

OPTIMAL PLACEMENT OF UNIFIED POWER FLOW CONTROLLER

Impedance, voltage, and phase angle may all be adjusted using FACTS devices, which are power electronic devices. Controlling the power flows in the network is also a benefit, resulting in higher loadability, low system loss, better stability of the network and lower costs of production, as well as fulfilling contractual requirements. In order to do this, the software must be installed correctly in the system and the relevant parameter settings must be made.

Today's power systems face a growing number of challenges when it comes to voltage stability. Voltage instability is primarily seen as a result of poor reactive power support or active power transmission capabilities, or both, in the network. Analysis and improvement of steady-state voltage stability based on L-index is the primary focus of this paper The L-Index [3] is a measure of how near a system is to its instability threshold.

The stability index equation may be expressed as, [3].

$$L_{(p.u.)} = 4\left\{\left|\left(\frac{PX - RQ}{V_s^2}\right)\right| + \left|\left(\frac{RP - XQ}{V_s^2}\right)\right|\right\} \quad \text{.... Eq. 7}$$

Where L = stability index
For stable system, L<1

When a load bus reaches a steady state voltage collapse scenario, the L-index approaches the numerical value 1.0. There must thus be a lower-than-unity value for the overall system voltage stability index at any of the buses. As a result, the index value L indicates the system's vulnerability to voltage collapse [3].

WSCC System 3-Machine 9-Bus Standard (WSCC) System L-Index Calculation

Table No. 1 L-index calculation

Line	P (PU)	Q (PU)	V (PU)	L-Index
1	0.52	0.0701	0.991	0.021796
2	0.3249	0.1402	0.991	0.01713
3	0.6421	0.0238	0.985	0.024826
4	0.8361	0.122	0.985	0.035772
5	0.3595	0.2034	0.989	0.021193
6	0.3564	0.0384	0.989	0.014777

Line 7-5 has a higher Voltage Stability Index (L-Index) rating, indicating that system security is a greater concern. As a result, bus 5 is a better place for the UPFC to enhance the security and stability of the power system. For WSCC 9 bus test system without and with UPFC, the analysis of voltage magnitudes is presented in the results and analysis.

On the WSCC9 bus system, the simulation of a unified power flow controller is shown in Figure 10.

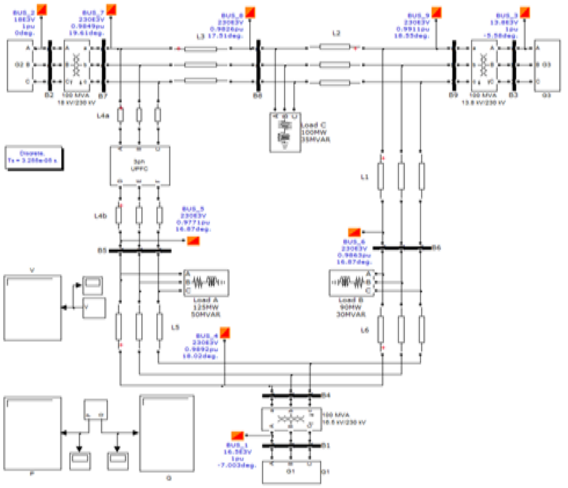

Fig. 10 Implementation of unified power flow controller on WSCC9 bus system

RESULTS & ANALYSIS

With L-index analysis being used in every example, all of the various loading conditions are examined in this section (i.e. 92%, 100%, 108/116).

Figures 11 and 12 illustrate the power and voltage profiles with and without UPFC for a 92 percent load scenario with an L-index of 0.031424 for L4.

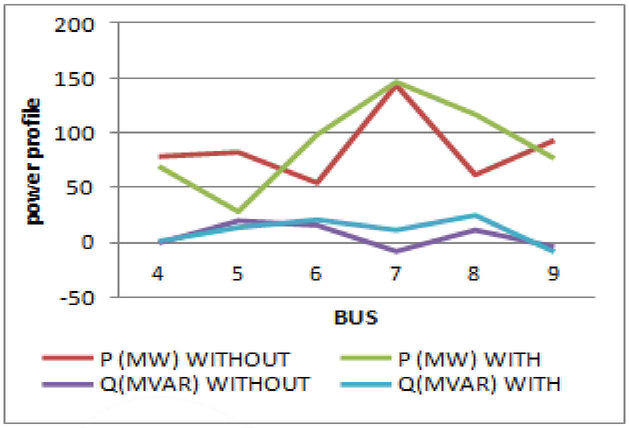

Fig. 11 Power Profile on 92% loading

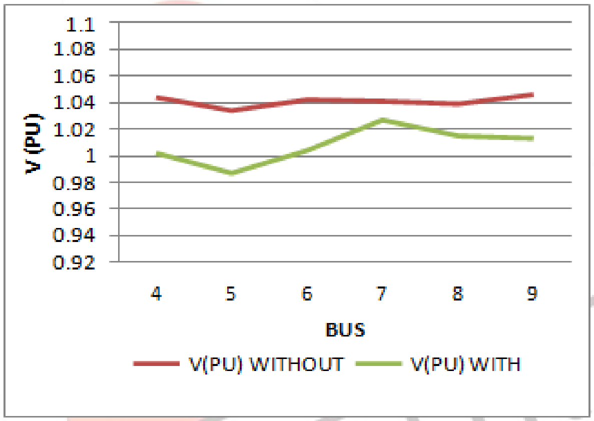

Fig. 12 Voltage profile on 92% loading

For 100% of loading condition with L-index of 0.035772 for L4, power profile in Fig. 13 and voltage profile in Fig. 14 with andwithout UPFC are shown below.

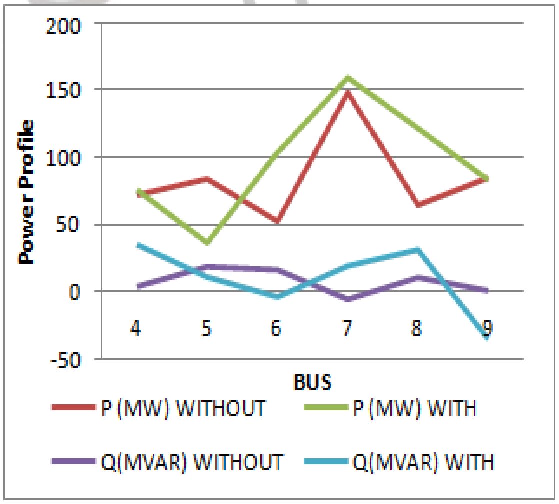

Fig. 13 Power Profile on 100% loading

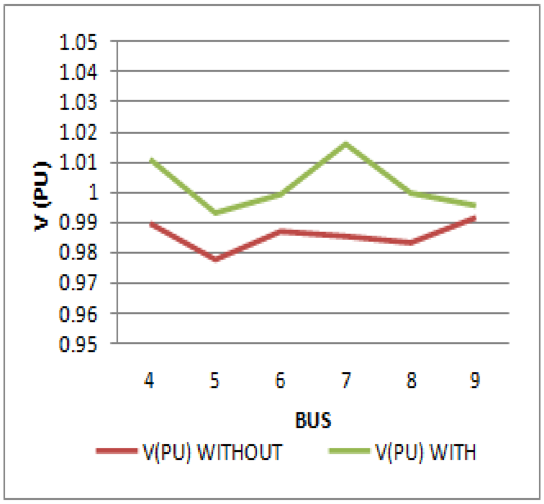

Fig. 14 Voltage Profile on 100% loading

For 108% of loading condition with L-index of 0.039998 for L4, power profile in Fig. 15 and voltage profile in Fig. 16 with and without UPFC are shown below.

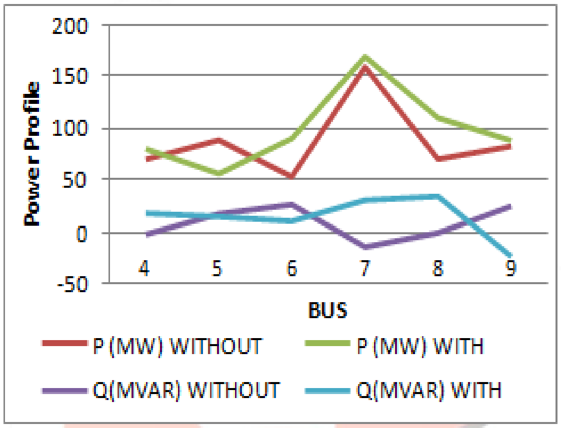

Fig. 15 Power Profile on 108% loading

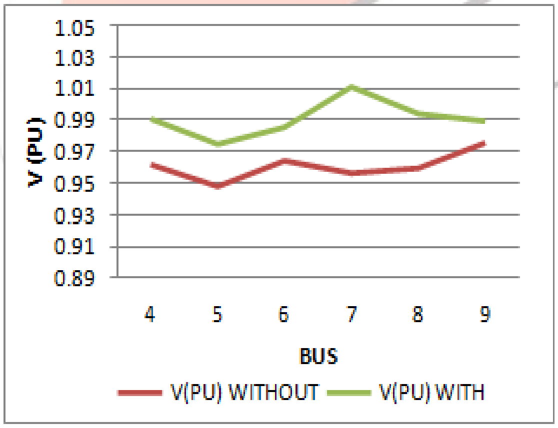

Fig. 16 Voltage Profile on 108% loading

For 116% of loading condition with L-index of 0.0438623 for L4, power profile in Fig. 17 and voltage profile in Fig. 18 with and without UPFC are shown below.

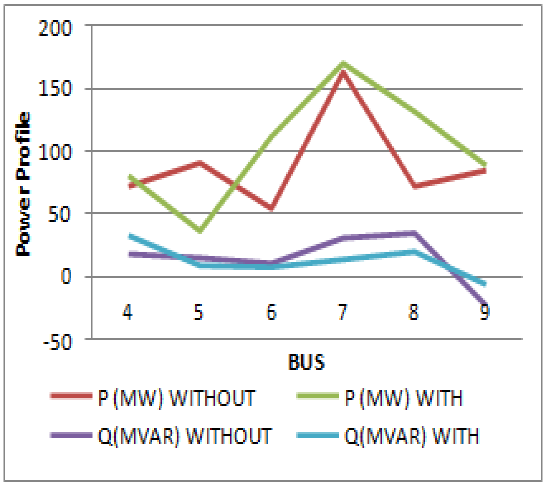

Fig. 17 Power Profile on 116% loading

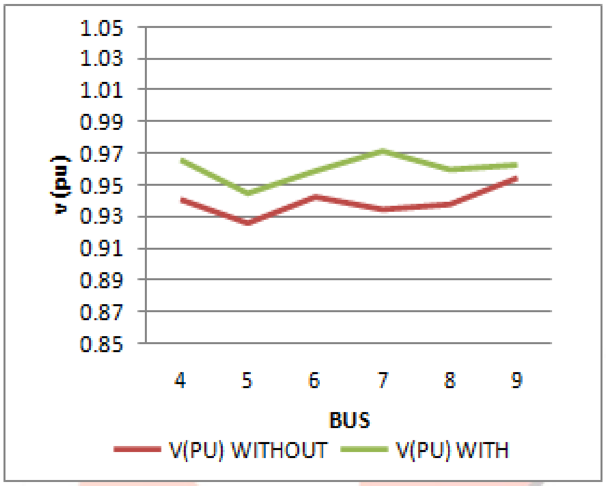

Fig. 18 Voltage Profile on 116% loading

As can be shown in Figures [11- 18], the UPFC has a significant impact on the WSCC 9 bus system under various load circumstances.

When using UPFC, results reveal that the voltage profile rises over 1 PU in 92 percent of loading cases. To demonstrate how well UPFC regulates power flow, a corresponding correction to the power profile is also made.
The same effects may be seen when the system is fully loaded, with significant increases in both active and reactive power.

The voltage profile is far below 1 PU in both the 108 percent and the 116 percent of loading circumstances. It is proven that UPFC improves both situations compared to those without UPFC after installation. In both cases, the overall voltage and power flow management is shown by the improved power profile at the bus.

CONCLUSIONS

A transmission line's actual and reactive power may be swiftly controlled by a UPFC. Simulations are used to examine the UPFC's performance under various loading circumstances while using the "−" axis theory, also known as the "instantaneous reactive power theory." UPFC's two converters may benefit from the - axis theory, which allows for a faster reaction time and less interference between the actual and reactive power flows. Fast power flow management and improved transmission system stability are also possible benefits of the - control system.
In order to improve the voltage profile in a power system, a strategy for optimally placing and adjusting UPFC parameters was examined in this article. An properly located UPFC, as shown in simulations run on the test system, keeps the voltage profile constant while also enhancing stability and boosting the overall efficiency of the power system.

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