IMPACT OF UPFC ON SWING, VOLTAGE STABILITY AND POWER TRANSFER CAPABILITY IN TRANSMISSION SYSTEM

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Abstract: Power flow control, in an existing long transmission line, plays a vital role in Power System area. This paper employs the unified power flow controller (UPFC) i.e. shunt-series connected compensation based FACTS device for the control of swings, voltage and the power flow in long distance transmission line. The proposed device is used in different locations such as sending end of the transmission line, middle and receiving end of the transmission line. Here also deals with determination of the optimal location of flexible a.c. transmission system (FACTS) devices for a long transmission line for damping-out swings, voltage and power transfer improvement. Here the concept of mid-point compensation is presenting for optimal location of FACTS. The results also show that optimal location depends upon voltage magnitude and the line loading and system initial operating conditions. In this paper the two area 4-machine test system were simulated using MATLAB Simulink environment.

Keywords: Stability, Power transfer, Flexible a.c. transmission system (FACTS), Unified power flow controller (UPFC).

1. INTRODUCTION

The flexible AC transmission system (FACTS) has received much attention in the last two decades. It uses high-current power electronic devices to control the voltage, power flow, stability etc. of a transmission system. Some forms of FACTS devices are already available for prototype installation [3] and others are still under development. FACTS devices can be connected to a transmission line in various ways, such as in series, shunt or a combination of series and shunt [1, 18]. For example, the static VAr compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt; static synchronous series compensator (SSSC) and thyristor-controlled series capacitor (TCSC) are connected in series; thyristor controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) are connected in a series and shunt combination. The terms and definitions of various FACTS devices are described in a recent IEEE article [4]. FACTS devices are very effective and capable of increasing the power transfer capability of a line, if the thermal limit permits, while maintaining the same degree of stability [5-8].

This paper investigates the effects of considering the actual line model on the power transfer capability and stability when a shunt FACTS device is connected to the line. Today's power systems are widely interconnected to take advantage of diversity of loads, availability of resources and fuel prices, in order to supply electricity to the loads at minimum cost with a required reliability. FACTS devices control the interrelated parameters that govern the operation of a transmission system, thus enabling the line to carry power close to its thermal rating [2].

During steady-state operation of a power system, all the synchronous machines operate in parallel and together supply the total demand plus losses so that there is equilibrium between these two. If a large disturbance occurs, this equilibrium is disturbed and the machines start 'swinging' with respect to each other [3]. Transient stability is the ability of the power system to maintain synchronism when subjected to a severe disturbance, such as a short circuit on a transmission line [4]. Reactive power compensation is an important issue in electrical power systems and series-shunt combine FACTS devices play an important role in controlling the reactive power flow in the power network, which in turn affects the system voltage fluctuations and swing stability [5]. The UPFC are members of the FACTS family that are connected in series and shunt combination with the system with the system and are highly effective in improving the voltage and swing stability [6].

It has been observed that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line [7]. The proof of maximum increase in power transfer capability is based on a simplified model of the line that neglects the resistance and capacitance, which is a reasonable assumption for short transmission lines. However, for long transmission lines, when the accurate model of the line is considered, the results may deviate significantly from those found for the simplified model especially with respect to transient swing stability improvement [8], [9]. It has been observed that the first swing stability of the system is greatly influenced by the choice of different models of the transmission line [10].
This paper gives the comparison of various results found for the different conditions of a FACTS (UPFC) device in a

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long transmission line, considering the actual (accurate) model of the line for a swing and voltage stability study. It is shown that for the exact line model with a predefined direction of real power flow, a FACTS device needs to be located slightly off-centre towards the sending end. It is also noticed that the optimal location of a shunt FACTS device for swing and voltage stability improvement depends on the line loading and the initial operating conditions.

In this work, the phasor models of UPFC are used to investigate the mid-point locations in a two-area system. The computer simulations under a severe disturbance condition (namely, a three-phase fault) for short duration. Comparison of these results shows the effectiveness of mid-point location of FACTS devices in improving swing and voltage stability with the power transfer capability.

2. POWER SYSTEM STABILITY AND TRANSFER CAPABILITY

A. Definition of stability of a System

The stability of a system is defined as the tendency and ability of the power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium [1]. Let a system be in some equilibrium state. If upon an occurrence of a disturbance and the system is still able to achieve the equilibrium position, it is considered to be stable [11].

B. Need for power system stability and classification

The power system industry is a field where there are constant changes. Power industries are restructured to cater to more users at lower prices and better power efficiency. Load demand also increases linearly with the increase in users. Since stability phenomena limits the transfer capability of the system, there is a need to ensure stability and reliability of the power system due to economic reasons.

Different types of power system stability have been classified into rotor angle stability, frequency stability and voltage stability [11]. Figure 1 shows the classification of power system stability [1].

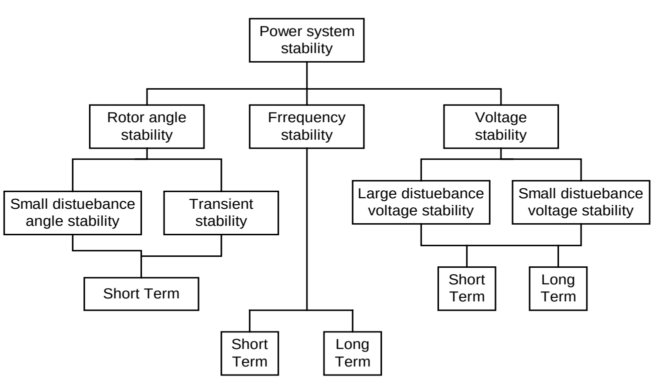

Fig. 1 Classification of power system stability

C. First swing stable

Power systems are becoming more complex because of the i ncrease inter-connection for economic operation, better reliability and strategic coverage against catastrophic outages. The transmission networks are now under more stress than ever before to avoid the capital cost involved in reinforcement and environmental objections.

Definition: A power system is said to be first-swing stable if the post-halt angle, in Thecentre of inertia (COI) reference frame, of all severely di sturbed machines (SDM) initially increases (or decreases) until a peak value is reached where the angle starts returning to the stable equilibrium point [13].

The first swing stability of a machine can also be checked by observing the variation of machine speed and accelerati ng power Pa in the post-fault period. A stable machine reaches the peak angle (or zero speed) in the post-fault period while it's accelerating power, and hence acceleration, is still negative:

$\tilde{\omega} = 0$ (1)

$P_a < 0$ (2)

The critical situation of a machine is characterized by the si multaneousoccurrence of zero speed and accelerating power in the post-fault period:

$\tilde{\omega} = 0$ (3)

$P_a = 0$ (4)

Thus determination of the degree of stability/ instability of a machine requires the machine speeds and accelerating powers in the post-fault period [13-15].

D. First Swing Stability

Faults (short circuits) in the power system cause very fast c hanges in the electrical conditions. The changed electrical state influences electrical power output from generators, changes in power flows and in load demand. The Rotor Angle swings are shown in Figure 2.

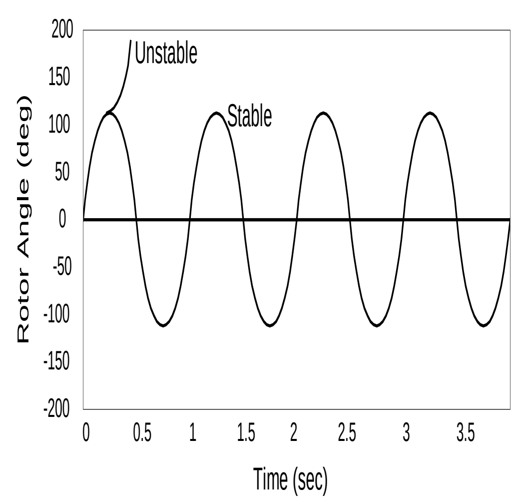

Fig. 2 Rotor Angle swings

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Generators will receive almost the same mechanical input through the shaft during the fault as before the fault. Therefore, when the fault is cleared (after roughly 0.1 s) the power system has to be restored to sufficiently small angle deviations between the generator rotors again. After the first swing we require damping of the oscillations [13,14].

E. Rotor Angle Stability (Electromechanical Oscillations)

All sudden changes in a power system are associated with a number of phenomena with different timeframes involved. The power flows in the grid changes accordingly. In the second phase the unbalance between mechanical input and electrical output of each generator are causing a change of generator mechanical speed. The individual rate of change in speed is decided by the power deviation and the rotor inertia. When generators are changing speed with different rates will the rotor angles of each generator start to deviate from the pre-disturbance value [17, 18]. They operate with different speeds depending on what they control. The voltage regulators tries to restore voltage and turbine governors adjust mechanical input to generators so we return to balance between consumption and production again. These transitions are oscillatory in its nature and very lightly damped [13-15].

F. Transmission transfer capability concepts

The key basic concepts of transmission transfer capability are described below. Numerous other terms related to transfer capability are explored in detail in NERC's May 1995 Transmission Transfer Capability reference document. The concepts and terms in that document are still applicable in an open transmission environment [16].

G. Transfer capability

Transfer capability is the measure of the ability of interconnected electric systems to reliably move or transfer power from one area to another over all transmission lines (or paths) between those areas under specified system conditions. The units of transfer capability are in terms of electric power, generally expressed in megawatts (MW). In this context, "area" may be an individual electric system, power pool, control area, sub-region, or NERC Region, or a portion of any of these. Transfer capability is also directional in nature [16, 17].

3. FACTS DEVICES IN POWER SYSTEMS

FACTS controllers may be based on thyristor devices with no gate turn-off or power devices with gate turn-off capability. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. The basic principles of the following FACTS controllers, which are used in the two-area power system under study, are discussed briefly [1-4, 18].

A. Unified power Flow controller (UPFC)

The Unified Power Flow Controller (UPFC) is the most versatile member of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids [2]. The UPFC uses a combination of a shunt controller (STATCOM) and a series controller (SSSC) interconnected through a common DC bus as shown on the figure below.

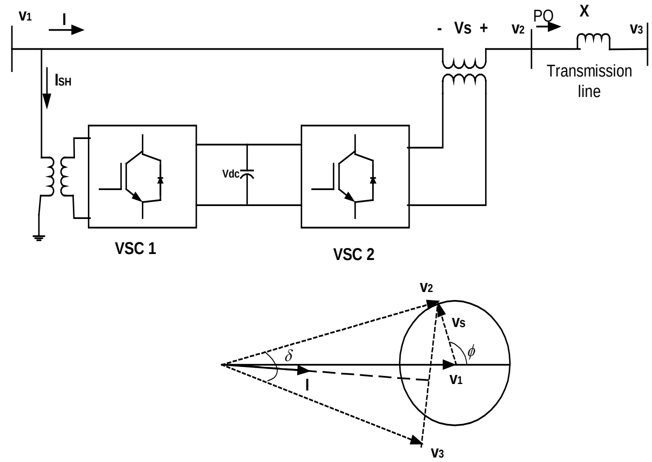

Fig. 3 Single-line Diagram of a UPFC and Phasor Diagram of Voltages and Currents

$$P = \frac{V_2 V_3 \sin\delta}{X} \quad (5)$$

$$Q = \frac{V_2 (V_2 - V_3 \cos\delta)}{X} \quad (6)$$

This FACTS topology provides much more flexibility than the SSSC for controlling the line active and reactive power because active power can now be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with respect to line current. If the magnitude of injected voltage Vs is kept constant and if its phase angle ϕ with respect to V1 is varied from 0 to 360 degrees, the locus described by the end of vector V2 (V2=V1+Vs) is a circle as shown on the phasor diagram. As ϕ is varying, the phase shift δ between voltages V2 and V3 at the two line ends also varies. It follows that both the active power P and the reactive power Q transmitted at one line end can be controlled [2, 17].

The UPFC (Phasor Type) block models an IGBT-based UPFC. However, as details of the inverter and harmonics are not represented, it can be also used to model a GTO-based UPFC in transient stability studies [2, 17].

4. LOCATION OF SHUNT FACTS DEVICES IN TWO-AREA POWER SYSTEM

Previous works on the topic prove that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line. The proof of maximum increase in stability and power transfer capability is based on the simplified model of the line neglecting line resistance and capacitance. Based on the

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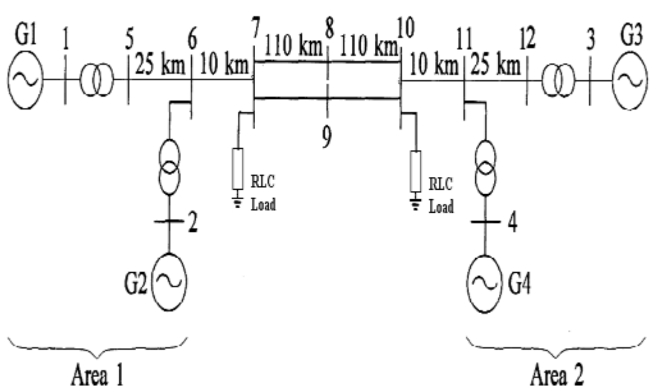
simplified line model it has been proved that the centre or midpoint of a transmission line is the optimal location for combined shunt-series FACTS devices. When the actual model of the line is considered, it is found that the FACTS device needs to be placed slightly off-centre to get the highest possible benefit [3].

The mid-point sitting is most effective in reactive power control. The transmission line must be operating below the thermal limit and the transient stability limit. Tan, Y.L suggested a novel method for the analysis of the effectiveness of an SVC and a STATCOM of the same KVar rating for first-swing stability enhancement .The analysis shows that the STATCOM is superior to the SVC for first-swing stability enhancement [5]. Siddhartha Panda, Ramnarayan N. Patel [10] investigated about the Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid -point of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. This paper deals also with the location of a shunt FACTS device to improve transient stability in a long transmission line with predefined direction of real power flow. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location.

5. TWO-AREA TEST SYSTEM

A. Introduction

The test system described in this section illustrates modeling of a simple transmission system containing two power plants as shown in fig 4. The FACT device (UPFC) and power system stabilizers (PSS) are used to improve voltages stability, power transfer and power oscillation damping of the system. The power system illustrated in this work is two area four machines system. However, the phasor simulation method allows simulating more complex power grids.



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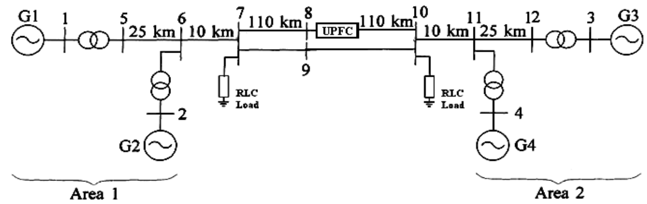


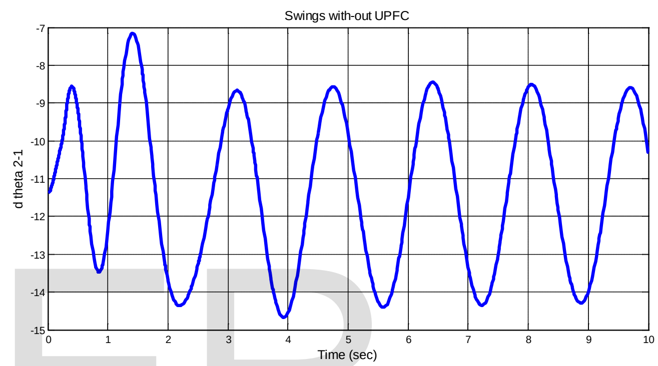
(b)

Fig.4 The single line diagram of 2-area, 4-machine test system, (a) With-out UPFC, (b) With UPFC.

VI. SIMULATION AND RESULTS

A. System analysis with-out UPFC

The simulation results for test system with-out UPFC are given below. The data for different parameters are given in table 1.



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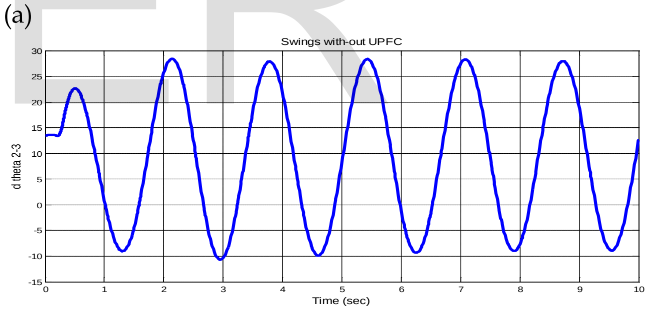

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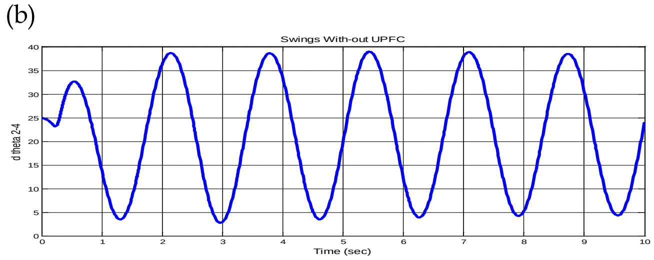

(c)

Fig.5 Waveforms for rotor angle difference with-out UPFC (a) d_theta2-1, (b) d_theta2-3, (c) d_theta2-4.

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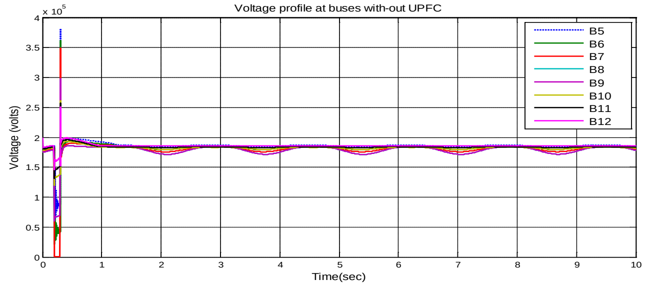
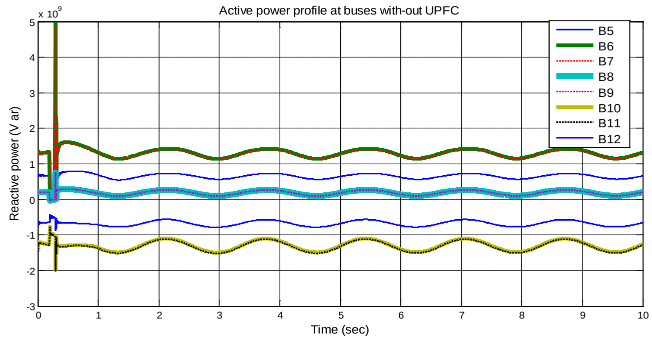


(a)



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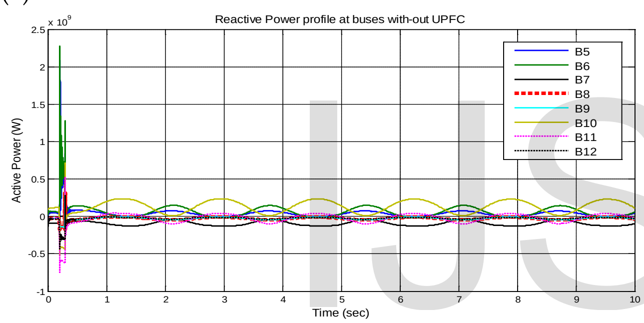


(c)

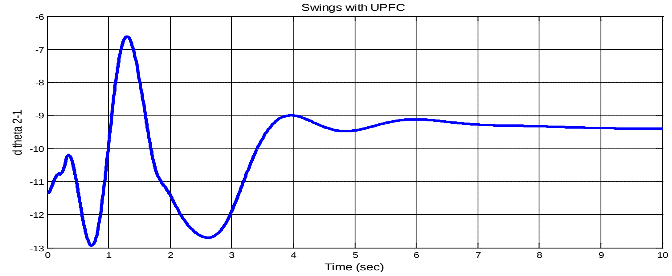
Fig.6 Profiles at buses with-out UPFC Device, (a) Voltage, (b) Active Power, (c) Reactive Power.

Table-1 Active, Reactive power & voltages with-out UPFC

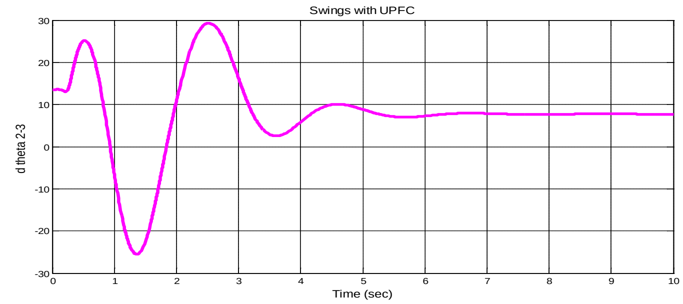
Bus	P (MW)	Q (Mvar)	S (MVA)	V (k volts)
B5	660.8	39.22	661.96	184.7
B6	1319	57.99	1320.27	181.8
B7	1301	95.78	1304.52	179.5
B8	203.3	31.04	205.66	178.1
B9	203.3	31.04	205.66	178.1
B10	1260	116.8	1265.4	181.8
B11	1277	24.23	1277.2	183.5
B12	652.5	23.98	652.94	185.8

B. System analysis with UPFC

Here observe the impact of the UPFC for stabilizing the network during a severe contingency. The data for different parameters are given in table 2.



(a)



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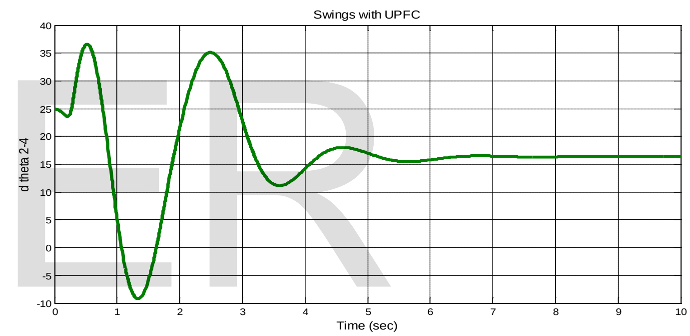
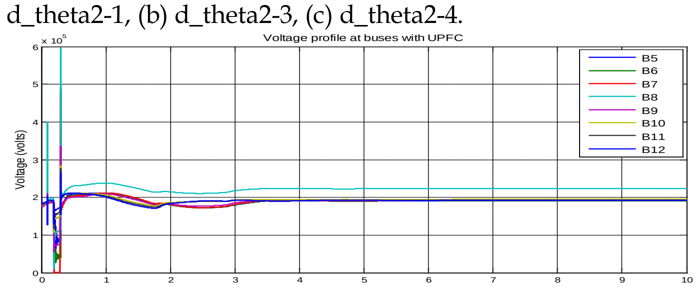
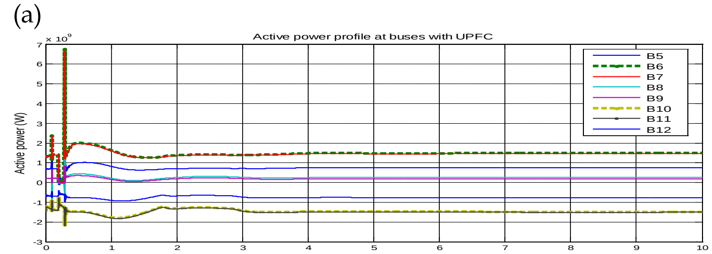


(c)

Fig.7 Waveforms for rotor angle difference with UPFC (a) d_theta2-1, (b) d_theta2-3, (c) d_theta2-4.



(a)



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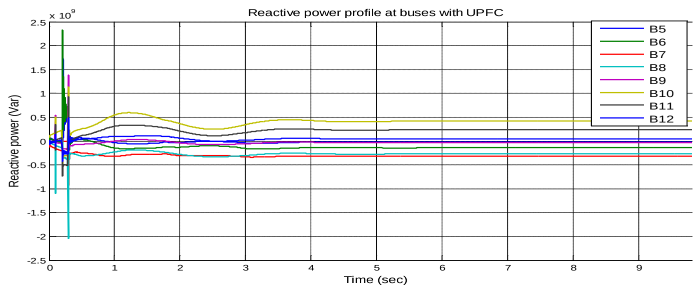
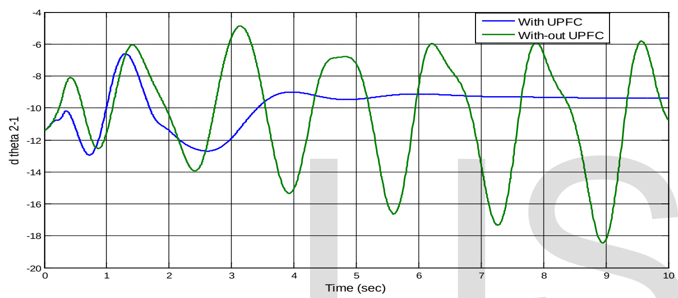


(c)

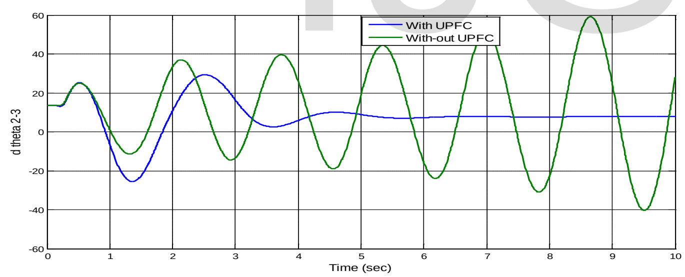
Fig. 8 Profiles at buses with UPFC, (a) Voltage, (b) Active Power, (c) Reactive Power.

C. Comparison of FACTS

Here describe the comparison of UPFC devices are including with UPFC and with-out UPFC performances for the same test system. The simulation results for comparison of UPFC are given below. The data for different parameters are given in table 3.



(a)



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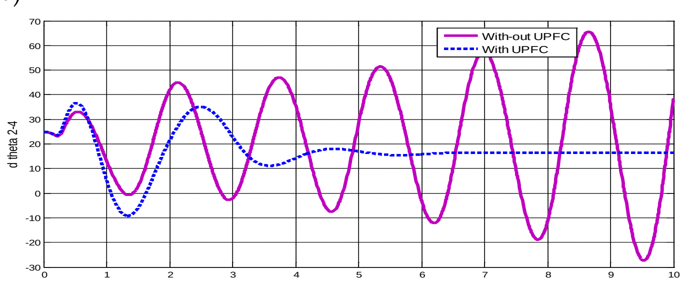
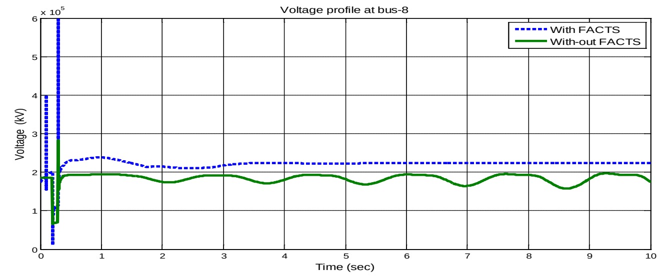
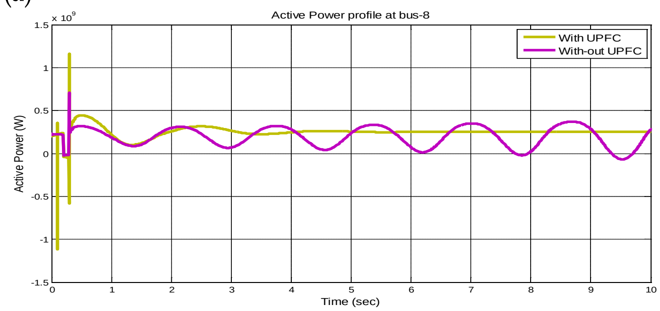


(c)

Fig. 9 Waveforms for comparison of rotor angle difference (a) d_theta2-1, (b) d_theta2-3, (c) d_theta2-4.



(a)



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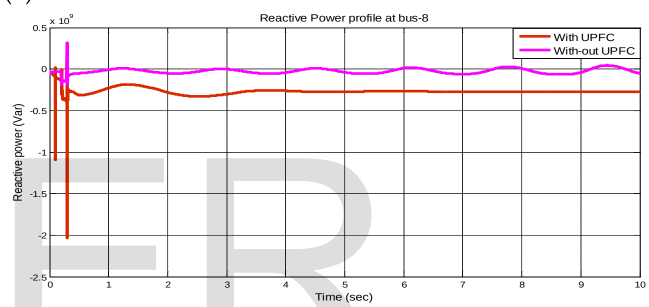


(c)

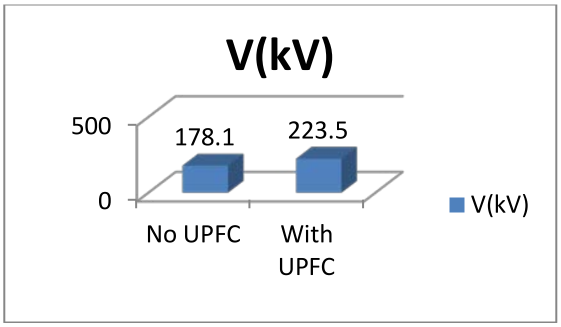
Fig. 10 Comparison of profiles at buses, (a) Voltage, (b) Active Power, (c) Reactive Power.

The simulation study has been divided into various sections for the sake of clarity. At first the optimal location of shunt FACTS devices was determined for a given operating condition, which is mid-point location or low voltage bus. Unlike previous works in this area, we have considered the actual line model, which affects the optimal location for a long line. The next section discusses how the UPFC effect the performances with the four generators while keeping the line flow for test system. Finally, the effect of different line flows, swings and voltage stability for test system is studied, while keeping the generator loadings in for test system constant and dynamically changes.

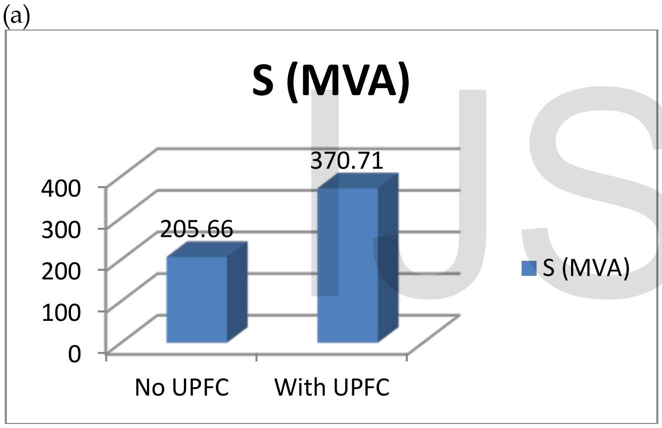
Table-2 Active, Reactive power & Voltages with UPFC

Table-3 Active, Reactive power & voltages comparison at bus 8 (B-8)

System Data comparison at bus 8 (B8)				UPFC Data	
Device	Q (Mvar)	V (k volts)	S (MVA)	V (pu)	Q (pu)
No UPFC	31.04	178.1	205.66	---	---
With UPFC	270.4	223.5	370.71	1.1	0.49



(a)



(b)

Fig. 11 (a) Comparison of voltage at bus-8, (b) Comparison of total power flow at bus-8

6. CONCLUSION

This work deals with applications of the UPFC. The models are applicable for swing, voltage stability analysis, and cover broader range of power transfer capability. The effects of UPFC installed in power transmission path are analyzed in this work, and the conclusions are as follow:

(1) The UPFC can improve swing and voltage stability limit observably, and UPFC give better performance for power transfer capability for test system transmission capacity increased 205.66 MVA (no UPFC) and 223.5 MVA (with UPFC), it's already discussed in section 6, table no. 1 and 2.

(2) The power losses in system with-out FACT is more as compared when used FACTS devices. The loading capacity with UPFC is increased, the reactive power compensated form 31.04 MVAR (no UPFC) to 270.4 MVAR (with UPFC), and voltage injected from 178.1 (no UPFC) to 223.5 kv (with UPFC) at bus-8 for test system, its already discussed in section 6, table no. 1 and 2.

Bus	P (MW)	Q (Mvar)	S (MVA)	V (k volts)	UPFC Data	
					V(pu)	Q(pu)
B5	750.7	23.33	751.06	191.4	---	---
B6	1487	141.1	1493.67	191	---	---
B7	1465	319.3	1499.39	191.8	---	---
B8	253.6	270.4	370.71	223.5	1.1	0.49
B9	187.7	32.66	190.52	192.2	---	---
B10	1482	415.9	1539.25	195.1	---	---
B11	1504	234.5	1522.17	192.9	---	---
B12	768.6	51.46	770.32	192.3	---	---

(3) Similarly the performance enhancement of test system can be analyses for compensate reactive power, voltage injected and increased power transfer capability, it's already discussed in section 6.

(4) As has been discussed above (1)-(4) it has been observed system performance improved by introducing the UPFC, which compensate reactive power (MVAR), voltage injected (kV) and increased power transfer capability (MVA). It's concluded that by introducing UPFC device system performance, voltage stability and transmission capability improves considerably.

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