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STUDY AND SIMULATION OF THE UNIFIED POWER FLOW CONTROLLER (UPFC) IN POWER SYSTEM

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Abstract

The main objectives of Flexible AC Transmission Systems (FACTS) devices are to increase the transmission capacity of lines and to control the power flow over designated transmission system. FACTS devices can perform all objectives of reactive power control and voltage control required for transmission and lines. Several schemes of flexible AC transmission systems FACTS are in use today. One of the most important FACTS devices is the Unified Power Flow Controller (UPFC), which is used for series voltage injection in desired phase as shown in Fig 1. The UPFC is a combination of a static Compensator (STATCOM) and a static synchronous series compensator (SSSC), which are coupled via a common DC link.

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Introduction

The UPFC is a device, which can control simultaneously all the three parameters of line power flow which are line impedance, voltage and phase angle. The UPFC improves terminal voltage regulation, series capacitor compensation and transmission angle regulation. This paper explains the control scheme and comprehensive analysis of a unified power flow controller (UPFC). A MATLAB program using SIMULINK/SIMPOWER SYSTEMS toolboxes is developed for simulation of UPFC. This developed simulation technique is found to be very effective and it enables us to study and investigate how the UPFC can affect the transmission system using the series voltage and shunt current injection. It is possible to demonstrate with this simulation that the UPFC can improve the system characteristics and give the best transient and dynamic stability. It also improves the power factor. Some cases are investigated and studied such as the application of the UPFC to control voltage and power flow. These cases are tested for a power system with varying active and reactive power requirements of load. In all cases, the performance of the system was analyzed, tested and studied to indicate voltages, currents and power performance and shown to be satisfactory.

Unified Power Flow Controller (UPFC) is a generalized Synchronous Voltage Source(SVS), represented at the fundamental (power system) frequency by voltage phasor Vpq as shown in fig 2 with controllable

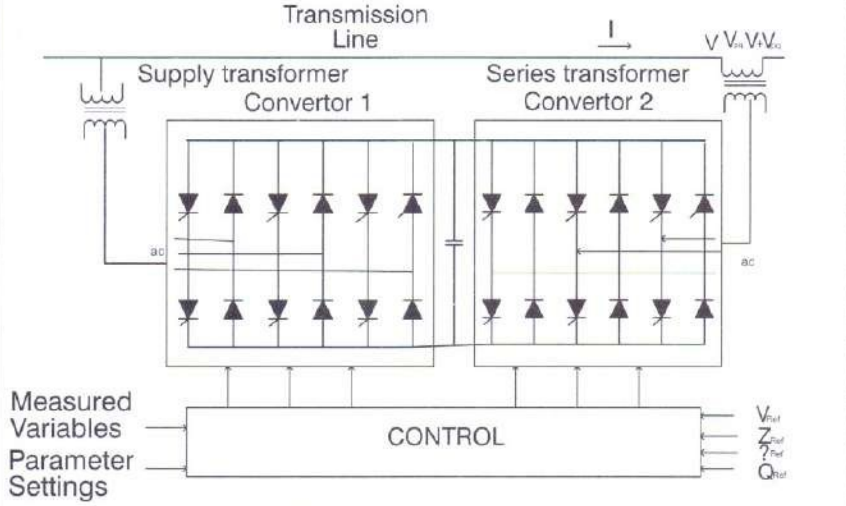


Fig 1.Implementation of UPFC by two back **-to-back voltage** *source convertors*

magnitude Vpq ($0 \leq Vpq \leq Vpqmax$) and angle 2π, in series with the transmission line, as illustrated for the usual elementary two-machine system (or for two independent systems with a transmission link intertie). In the UPFC, the real power exchanged is provided by one of the end buses(e.g.,the sending-end bus), as indicated in Fig. 1

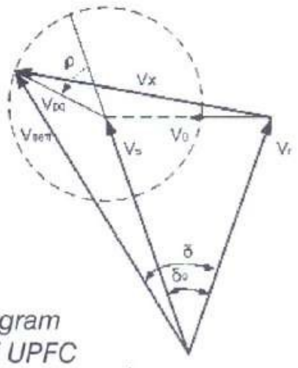


Fig 2. Phasor diagram representation of UPFC

II. Unified power flow controller

The proposed implementation of the unified flow controller, using two voltage source inverters operated from a common DC link capacitor, is shown schematically in Fig. 1. This arrangement is actually a practical realization of an AC to AC power converter which independently controls input and output parameters. Converter 2 injects an AC voltage Vpq with magnitude and angle, via an insertion transformer. The real power at the AC terminal of the insertion transformer is converted by the shunt inverter into DC power that appears at the DC link [1]. The reactive power exchanged at the AC of converter 2 terminal is generated internally by the inverter [2]. Converter 1 supplies or absorbs the real power demanded by converter 2 at the common DC link. This DC link power is converted back to AC and coupled to the transmission line via a shunt connected transformer. Converter 1 can also generate or absorb controllable reactive power and can provide independent shunt reactive compensation for the liner (voltage control). Converter 2 controls the magnitude and the angle of Vpq which controls voltage at the receiving end and the power flow. The basic functions of the UPFC are terminal voltage regulation, series capacitor compensation and transmission angle regulation.

The UPFC is an extremely powerful and versatile device for power flow control. The capability of changing all transmission parameters affecting power flow simultaneously by UPFC and equation pertaining to Real f(P) and Reactive (Qr) are as follows:

$$P - jQ_r = V_r \left(\frac{V_s + V_{pq} - V_r}{jX} \right)^*$$

If Vpq=0

$$P - jQ_r = V_r \left(\frac{V_s - V_r}{jX} \right)^*$$

With Vpq $\neq$ 0

$$P - jQ_r = V_r \left(\frac{V_s - V_r}{jX} \right)^* + \frac{V V_{pq}^*}{-jX}$$

Substituting

$$V_s = Ve^{j\delta/2} = V\left(\cos\frac{\delta}{2} - j\sin\frac{\delta}{2} \right)$$

$$V_r = Ve^{-j\delta/2} = V\left(\cos\frac{\delta}{2} - j\sin\frac{\delta}{2}\right)$$

and

$$V_{pq} = V_{pq}^{\ j(\delta/2\times\rho)} = V_{pq}\left\{\cos\left(\frac{\delta}{2}+\rho\right) + j\sin\left(\frac{\delta}{2}+\rho\right)\right\}$$

$$P(\delta,\rho) = P_o(\delta) + P_{pq}(\rho) = \frac{V^2}{X}\sin\delta - \frac{VV_{pq}}{X}\cos\left(\frac{\delta}{2}+\rho\right)$$

and

$$Q_r(\delta,\rho) = Q_{or}(\delta) + Q_{pq}(\rho) = \frac{V^2}{X}(1-\cos\delta) - \frac{VV_{pq}}{X}\sin\left(\frac{\delta}{2}+\rho\right)$$

where

$$P_o(\delta) = \frac{V^2}{X}\sin\delta$$

and $$Q_{or}(\delta) = -\frac{V^2}{X}(1-\cos\delta)$$

These equations can be used to show the variation P and Qr for different values of Vpq and δ=0°, δ=30°, δ=60°& δ=90° is

respectively.

III. Control modes of UPFC

Basically, the three modes of control are STATCOM, SSSC and UPFC

- **Unified power flow controller (UPFC) mode**

When the shunt and series converters are interconnected through the DC bus and when the switches between the DC buses of the shunt and series converter are opened, two additional modes are available:

- Shunt converter operating as a **Static**

Synchronous Compensator STATCOM

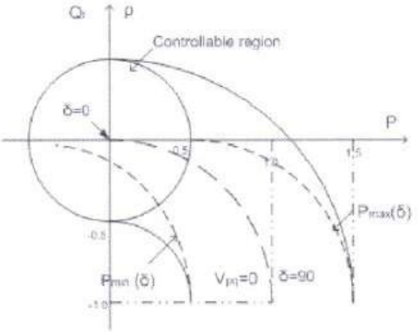
controlling voltage :

A static synchronous generator operated as shunt-connected static var compensator whose capacitive and inductive output current can be controlled independent of the ac system voltage

- Series converter operating as a **Static**

Synchronous Series Capacitor (SSSC)

controlling injected voltage, while keeping injected voltage in quadrature with current. The SSSC is one of the most recent FACTS devices for power transmission series compensation. It can be considered as a synchronous voltage source as it can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle, in series with a transmission line.



(a) δ= 0'

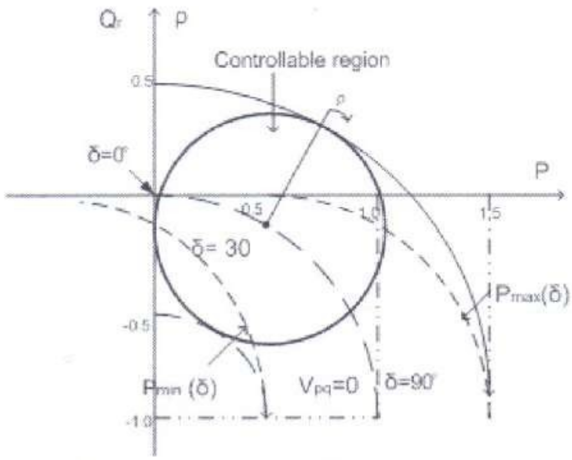
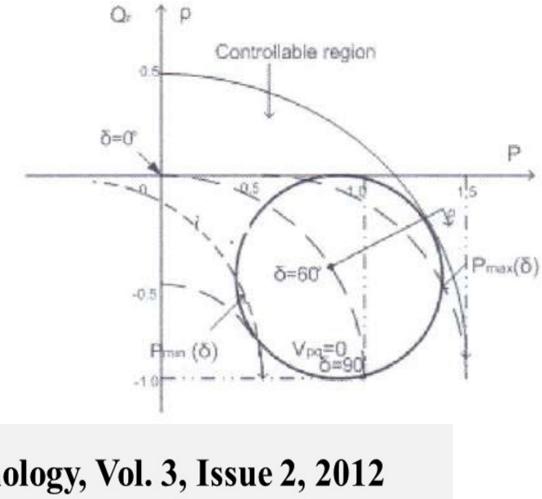


Fig3:Control region of the power P and Qr with UPFC



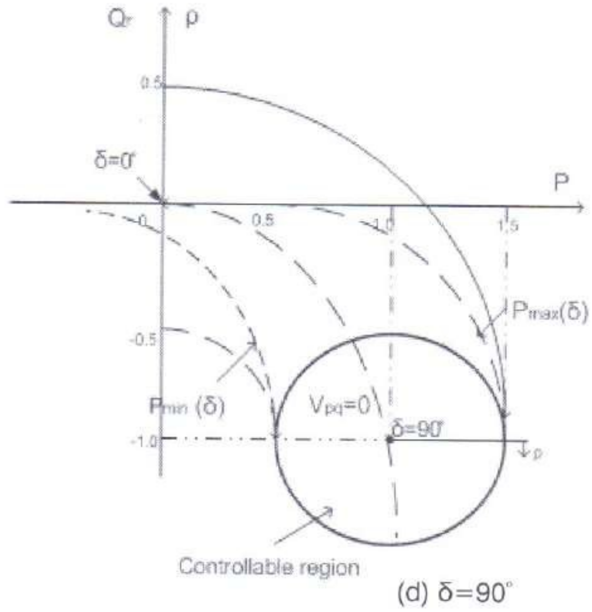
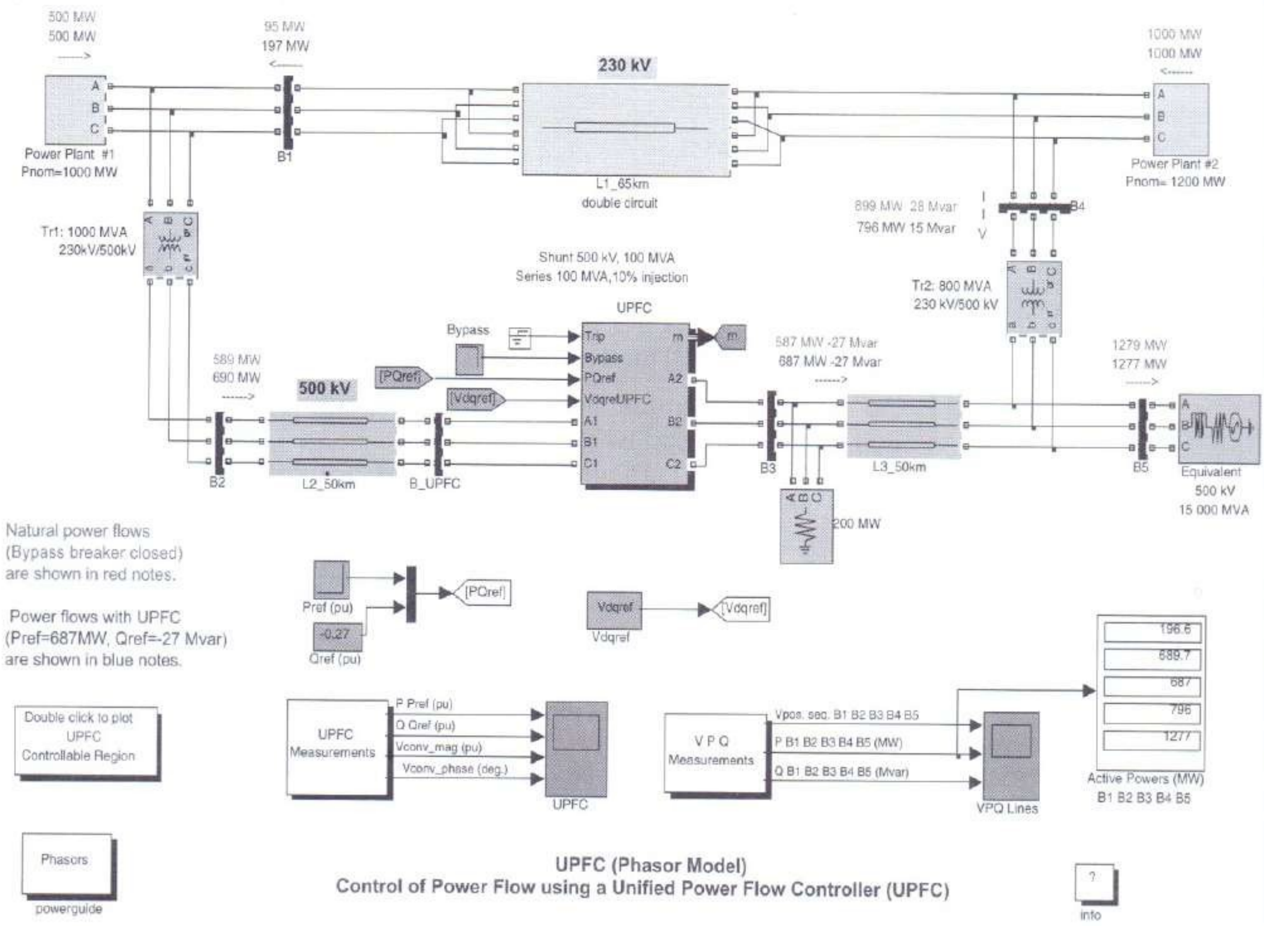


Fig3:Control region of the power P and Qr with UPFC

V. SIMULATION OF UPFC

A UPFC is used to control the power flow in a 500 kV /230 kV transmission system as shown by Fig.4. The system, connected in a loop configuration, consists essentially of five buses (B1 to B5) interconnected through three transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kV, 15000 MVA equivalent and to a 200 MW load connected at bus B3. Each plant model includes a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1200 MW generation capacity of power plant #2 is exported to the 500 kV equivalent through two 400 MVA transformers connected between buses B4 and B5. For this demo we are considering a contingency case where only two transformers out of three are available (Tr2= 2*400 MVA = 800 MVA). The load flow shows that most of the power generated by plant #2 is transmitted through the 800 MVA transformer



bank (899 MW out of 1000 MW) and that 96 MW is circulating in the loop. Transformer Tr2 is therefore overloaded by 99 MVA. The example illustrates the capability of UPFC to relieve this power congestion. The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500 kV bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based, converters (one shunt converter and one series converter interconnected through a DC bus). The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2.

V. Results and discussions

In this control mode as shown in Fig 5 the voltage generated by the series inverter is controlled by two external signals V_d, V_q multiplexed at the "V_{dqref}" input and generated in the V_{dqref} magenta block. For the first five seconds, the Bypass breaker stays closed, so that the PQ trajectory stays at the (- 27Mvar, 587 MW) point. Then when the breaker opens, the magnitude of the injected series voltage is ramped, from 0.0094 to 0.1 pu. At 10 s, the angle of the injected voltage starts varying at a rate of 45 deg./s. The voltage profile with UPFC is shown by Fig 6

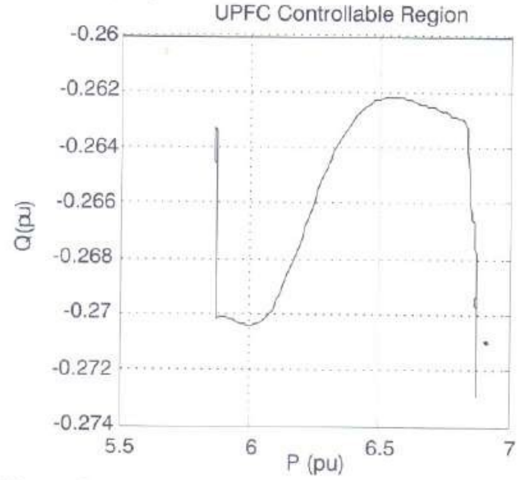
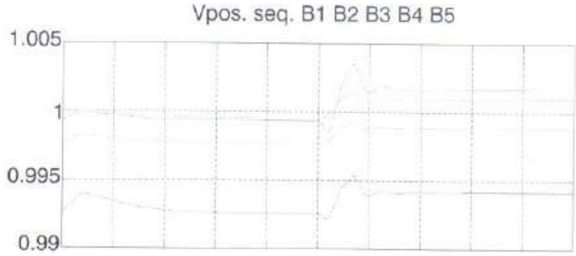


Fig 5: Controllable region



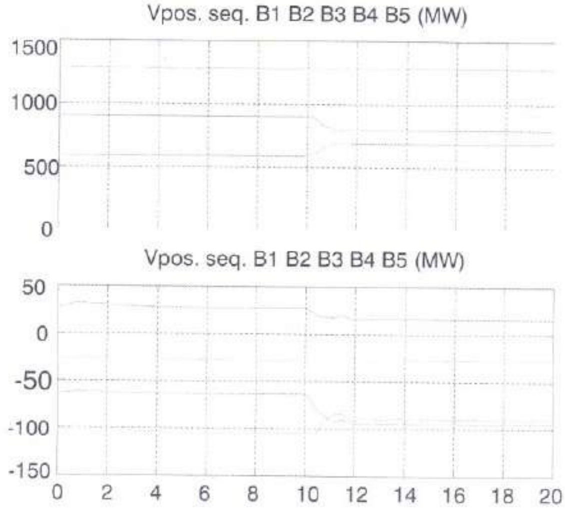


Fig. 6: Voltage profile with UPFC

VI. Conclusions

The present paper deals with the study of steady-state behaviour of electrical networks equipped with UPFC. Compared to simplified models, the model considered for the UPFC represents improvement in system performance. The simulation results are close to the real behaviour of such a system. This model has permitted us to investigate the power quality and the performances of the UPFC. The interaction between the UPFC and the transmission line is analyzed and carried out on the model of power system.

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References

1. N. G. Hingorani and L. Gyugyi, Understanding FACTS, Concepts and Technology of Flexible AC Transmission Systems. Piscataway, NJ: IEEE Press, 2000

2. Gyuygi L.,"Unified power flow controller Concept for Flexible AC Transmission Systems", IEEE Proceeding, vol.-139, no.-4, pp.323-331, July 1992.

3. Keri A.J.F., Mehraban A.S., Elriachy A., Lombard X. and Edris A. , "A Unified Power Flow Controller (UPFC): Modelling and Analysis", IEEE Transactions on Power Delivery, vol.-14, no.-2, pp. 648-654, April

4. Sun G.,Wei Z., "Power system state estimation with unified power flow controller", Third

International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp.775 -778, April 2008.

5. Schoder K., Hasanovic A., Feliachi A. and Azra H., "Load-Flow and Dynamic Model of UPFC within the Power System Toolbox (PST)", 43rd IEEE Midwest Symposium on Circuits and Systems, vol. 2, pp. 634-637, August 2002,

6. Guo J., Crow M.L., Sarangapani J., "An Improved UPFC Control for Oscillation Damping", IEEE Transactions on Power Systems, vol.-24, no.-1, pp.288-296, Feb. 2009.

7. Zarghami M., Crow M.L.,Sarangapani J., Atcitty S., "A Novel Approach to Interarea Oscillation Damping by Unified Power Flow Controllers Utilizing Ultracapacitors", IEEE Transactions on Power Systems, vol.-25, no.-1, pp.404-412, Feb 2010.

8. Papic I., Zunko P. and Povh D, "Basic Control of Unified Power Flow Controller", IEEE Transactions on Power Systems, vol.-12, no.-4, pp.1734-1739, August 1997.

9. Mihalic R., Povh D. and Zunko P, "Improvement of Transient Stability using UPFC", IEEE Transactions on power delivery, vol.-11, no.-1, pp. 485-492, August 1996.

10. Padiyar K.R. and Kulkarni A.M.,"Control Design and Simulation of UPFC", IEEE Transactions on Power Delivery, vol.-13, no.-4, pp. 1348-1354, Oct. 1998.

11. L. Gyugyi, "Dynamic compensation of ac transmission lines by solid-state synchronous voltage sources," IEEE Trans. Power Del., vol. 9, no. 2, pp. 904-911, Apr. 1994.

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