A NEW APPROACH FOR VOLTAGE CONTROL OF IPFC AND UPFC FOR POWER FLOW MANAGEMENT

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Abstract – The interline power flow controller (IPFC & UPFC) is one of the latest generation flexible AC transmission systems (FACTS) controller used to control power flows of multiple transmission lines. The main objective of this paper is detailed study about a new real and reactive power coordination controller for a interline power flow controller (IPFC & UPFC). The basic control for the IPFC is such that the series converter of the UPFC controls the transmission line real/reactive power flow and the shunt converter of the (IPFC & UPFC) controls the bus voltage/shunt reactive power and the DC link capacitor voltage. Because of the common link, any inverter within the (IPFC & UPFC) is able to transfer real power to any other and thereby facilitate real power transfer among the lines of the transmission system. Since each inverter is able to provide reactive compensation, the (IPFC & UPFC) is able to carry out an overall real and reactive power compensation of the total transmission system. This capability makes it possible to equalize both real and reactive power flow between the lines, transfer power from overloaded to under loaded lines, compensate against reactive voltage drops and corresponding reactive line power and to increase the effectiveness of the compensating system against dynamic disturbances. A simulation in MATLAB has been done in order to extend conventional algorithm based on this model.

Index Terms --- Power System modeling, FACTS Controllers, UPFC, IPFC, power flow, Small Signal Stability, Voltage Source Converter, Matlab Software

I. INTRODUCTION

Power system stability has been recognized as an important problem for its secure operation since 1920s [1, 2]. Result of the first laboratory tests on miniature systems were reported in 1924 [3]; the first field tests on the stability on a practical power system were conducted in 1925.Traditionally, the problem of stability has been one of maintaining the synchronous operation of generators operating in parallel, known as rotor angle stability. The problem of rotor angle stability is well understood and presented in literatures. With continuous increase in power demand, and due to limited expansion of transmission systems, modern power system networks are being operated under highly stressed conditions. This has been imposed the threat of maintaining the required bus voltage, and thus the systems have been facing voltage instability problem [4]-[5].

Due to increase in power demand, modern power system networks are being operated under highly stressed conditions. This has resulted into the difficulty in meeting reactive power requirement, especially under contingencies, and hence maintaining the bus voltage within acceptable limits. Voltage instability in the system, generally, occurs in the form of a progressive decay in tripping of a transmission line, load shedding and under load tap changer action

II. SCOPE OF THE PRESENT EXPLORATION

Objective of Interline Power Flow Controller (IPFC) is to provide a comprehensive power flow control scheme for a multi-line transmission system, in which two or more lines employ a SSSC for series compensation. A multi-line IPFC comprises of number of ‘n’ SSSC’s, one for each line of the transmission system to be controlled, with a common dc bus as illustrated schematically by a block diagram as shown in Fig:1. The IPFC scheme has the capability to transfer real power between the compensated lines in addition to executing the independent and controllable reactive power compensation of each line. This capability makes it possible to equalize both real and reactive power flow between the lines, to transfer power demand from overloaded to under-loaded lines to compensate against resistive line voltage drops and the corresponding reactive line power and to increase the effectiveness of the compensating system for dynamic disturbance like transient stability and power oscillation. Consider a IPFC scheme shown in Fig: 2 consisting of two back-to-back dc to ac inverter each compensating a transmission line by series voltage injection.

This arrangement has two synchronous voltage sources with phasors V_1pq and V_{2pq} in series with transmission Lines 1 and 2, represent the two back to back dc to ac inverters. The common dc link is represented by a bidirectional link ($P_{12}=P_{1pq}=P_{2pq}$) for real power exchange between the two voltage sources. Transmission Line-1, represented by reactance X_1, has a sending end bus with voltage phasor V_{1S} and a receiving end bus with voltage phasor V_{1R}. The sending end voltage phasor of Line-2 represented by reactance X_2 is V_{2S} and the receiving end voltage phasor is V_{2R}.

The real power coordination discussed in this project is based on the known fact that the shunt converter should provide the real power demand of the series converter. In this case, the series converter provides the shunt converter control system an equivalent shunt converter real power reference that includes the error due to change in dc link capacitor Voltage and the series converter real power demand. The control system designed for the shunt converter in cause's excessive delay in relaying the series converter real power demand information to the shunt converter. This could lead to improper coordination of the overall IPFC control system and subsequent collapse of dc link capacitor voltage under transient conditions. In this project, a new real power coordination controller has been developed to avoid instability/excessive loss of dc link capacitor voltage during transient conditions.

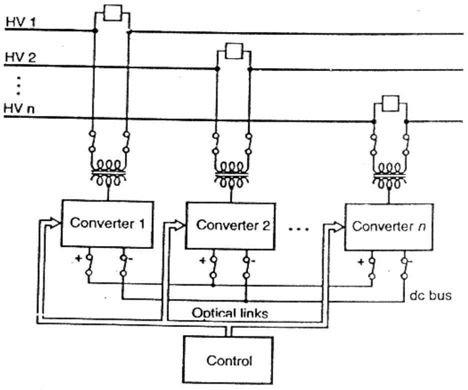


Fig. 1. General schematic of IPFC transmission line.

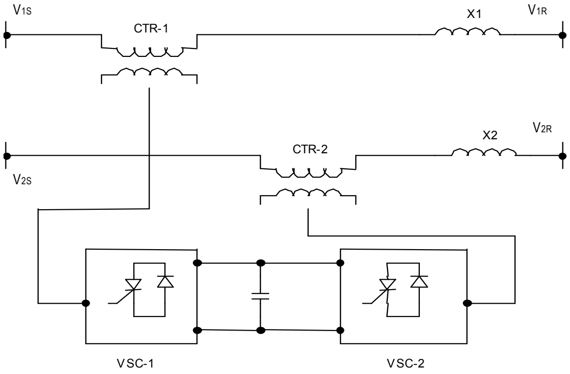


Fig:2 IPFC with two VSC's

Transmission relationship between the two systems, system 1 selected to be the prime system for which free controllability of both real and reactive line power flow is stipulated. A phasor diagram of system 1, defining the relationship between V1S, V1R, VX1 (the voltage phasor across X1) and the inserted voltage phasor V1pq with controllable magnitude (0≤V1pq≤V1pqmax) and angle (0≤ρ1≤360°) is shown in Fig:3. The inserted voltage phasor V1pq is added to the fixed sending end voltage phasor V1s to produce the effective sending end voltage V1Seff=V1S+V1pq. The difference V1Seff-V1R provides the compensated voltage phasor, VX1 across X1. As angle ρ1 is varied over its full 360° range, the end of phase V1pq moves along a circle with center located at the end of phasor V1S. The area within this circle obtained with V1pqmax define the operating range of phase V1pq and thereby the achievable compensation of Line-1. The rotation of phasor V1pq with angle ρ1 modulates the magnitude and the angle of phase VX1 and therefore both the transmitted real power P1R and the reactive power Q1R vary with ρ1 in a sinusoidal manner. This process requires the voltage source representing Inverter 1 (V1pq) to supply and absorb both reactive and real power, Q1pq and P1pq which are sinusoidal function of angle.

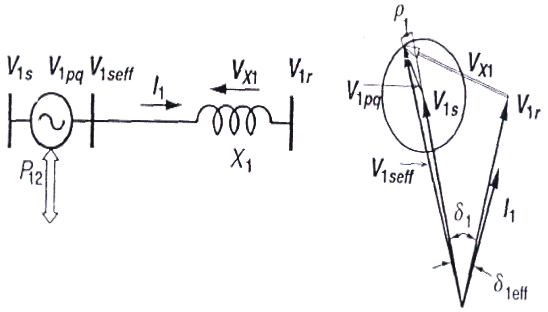


Fig. 3. Phasor representation of IPFC

III. IPFC IN SERIES COMPENSATION MODE

A Real Power Coordination Controller

To understand the design of a real power coordination controller for a IPFC, consider a IPFC connected to a transmission line as shown in Fig. 3. The interaction between the series injected voltage (Vse) and the transmission line current (Ise) leads to exchange of real power between the series converter and the transmission line. The real power (Pse) demand of the series converter (Pse) causes the dc link capacitor voltage (Vdc) to either increase or decrease depending on the direction of the real power flow from the series converter. This decrease/increase in dc link capacitor voltage (Vdc) is sensed by the shunt converter controller that controls the dc link capacitor voltage (Vdc) and acts to increase/decrease the shunt converter real power flow to bring the dc link capacitor voltage (Vdc) back to its scheduled value. Alternatively, the real power demand of the series converter is recognized by the shunt converter controller only by the decrease/increase of the dc link capacitor voltage (Vdc). Thus, the shunt and the series converter operation are in a way separated from each other. To provide for proper coordination between the shunt and the series converter control system, a feedback from the series converter is provided to the shunt converter control system. The feedback signal used is the real power demand of the series converter (Pse). The real power demand of the series converter (Pse) is converted into an equivalent D-axis current for the shunt converter (iDse).

$$iDse = Pse / | VIPFC\ bus | \quad (1)$$

The real power demand of the series converter (Pse) is the real part of product of the series converter injected voltage (Vse) and the transmission line current (Ise). VIPFC bus, iDse represent the voltage of the bus to which the shunt converter is connected and the equivalent additional D-axis current that should flow through the shunt converter to supply the real power demand of the series converter. The equivalent D-axis additional current signal (iDse) is fed to the inner control system, thereby increasing the effectiveness of the coordination controller. Further, the inner control system loops are fast acting PI controllers and ensure fast supply of the series converter real power demand (Pse) by the shunt converter.

B. Reactive Power Coordination Controller

The in-phase component (VseD) of the series injected voltage which has the same phase as that of the IPFC bus voltage, has considerable effect on the transmission line reactive power (Qline) and the shunt converter reactive power (Qsh). Any increase/decrease in the transmission line reactive power (Qline) due to in-phase component (VseD) of the series injected voltage causes an equal increase/decrease in the shunt converter reactive power (Qsh). In short, the shunt converter supplies increase/decrease in transmission line reactive power. Increase/decrease in the transmission line reactive power also has considerable effect on the IPFC bus voltage.

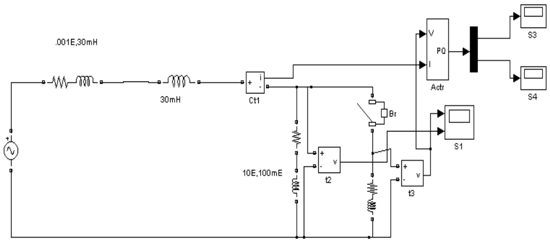
The mechanism by which the request for transmission line reactive power flow is supplied by the shunt converter is as follows. Increase in transmission line reactive power reference causes a decrease in IPFC bus voltage. Decrease in IPFC bus voltage is sensed by the shunt converter IPFC bus voltage controller which causes the shunt converter to increase its reactive power output to boost the voltage to its reference value. The increase in shunt converter reactive power output is exactly equal to the increase requested by the transmission line reactive power flow controller (neglecting the series transformer reactive power loss). Similarly, for a decrease in transmission line reactive power, the IPFC bus voltage increases momentarily. The increase in IPFC bus voltage causes the shunt converter to consume reactive power and bring the IPFC bus voltage back to its reference value. The decrease in the shunt converter reactive power is exactly equal to the decrease in transmission line reactive power flow (neglecting the reactive power absorbed by the series transformer). In this process, the IPFC bus voltage experiences excessive voltage excursions. To reduce the IPFC bus voltage excursions, a reactive power flow coordination controller has been designed.

The input to the reactive power coordination controller is the transmission line reactive power reference. The shunt converter Q-axis control system with the reactive power coordination controller is shown. The washout circuit represents the reactive power coordination controller. The gain of the washout circuit has been chosen to be 1.0. This is because, any increase/decrease in the transmission line reactive power flow due to change in its reference is supplied by the shunt converter. The washout time constant is designed based on the response of the power system to step changes in transmission line reactive power flow without the reactive power coordination controller.

C. Power Factor Corrector

In transmission line, the power factor is controlled by means of injecting a voltage across it. The transmission line consists of lumped R and L parameters. Without an injecting of voltage, the power factor is lagging in RL circuit. By injecting additional voltage across it, the angle between V and I is reduced and the power factor is improved. By appropriately selecting the value of injecting voltage, the power factor can be made to unity.

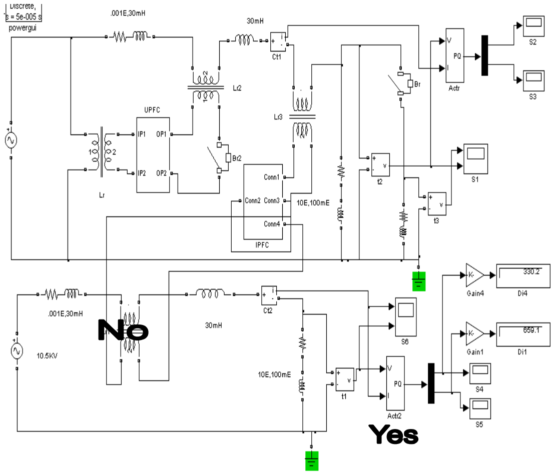
IV. LINE MODEL WITHOUT COMPENSATION CIRCUIT



A UPFC can be represented in the steady state by two voltage sources representing fundamental components of output voltage waveforms of the two converters and impedances being leakage reactance of the two coupling transformers. The below Fig:3 depicts a two voltage-source model of compensation.

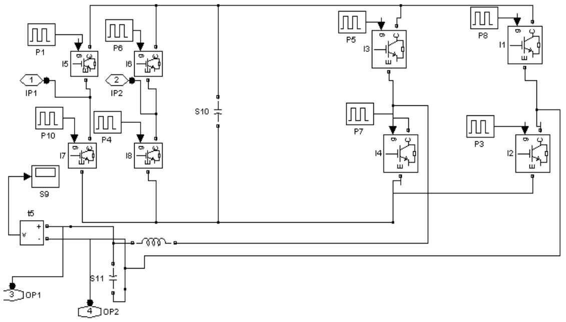
V.LINE MODEL WITH COMPENSATION CIRCUIT

The UPFC is the most versatile FACTS controller developed so far, with all encompassing capabilities of voltage regulation, series compensation, and phase shifting. It can independently and very rapidly control both real- and reactive-power flows in a transmission line. It is configured as shown in Fig. and comprises two VSCs coupled through a common dc terminal.



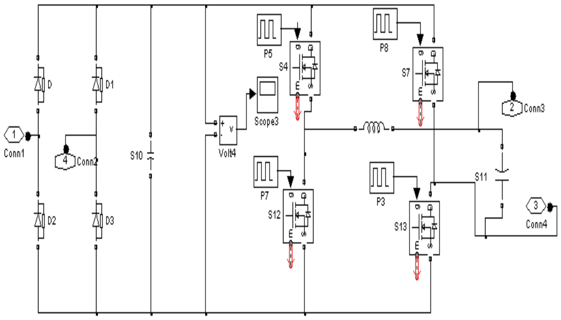
One VSC—converter1—is connected in shunt with the line through a coupling transformer; the other VSC—converter2—is inserted in series with the transmission line through an interface transformer. The dc voltage for both converters is provided by a common capacitor bank. The series converter is controlled to inject a voltage phasor, Vpq, in series with the line, which can be varied from0toVpqmax.

Moreover, the phase angle of Vpq can be independently varied from 0 to 360 . In this process, the series converter exchanges both real and reactive power with the transmission line. Although the reactive power is internally generated /absorbed by the series converter, the real-power generation/absorption is made feasible by the dc-energy–storage device—that is, the capacitor transmission line.



Upfc circuit model

The shunt-connected converter1 is used mainly to supply the real-power demand of converter2, which it derives from the transmission line itself. The shunt converter maintains constant voltage of the dc bus. Thus the net real power drawn from the ac system is equal to the losses of the two converters and their coupling transformers. In addition, the shunt converter functions like a STATCOM and independently regulate the terminal voltage of the interconnected bus by generating/ absorbing a requisite amount of reactive power.



Ipfc circuit model

Mathematical expressions of UPFC & IPFC

For uncompensated line

$$V_R=V_S-V_X \tag{1}$$

$$I=V_S/(X+X_L+R_L) \tag{2}$$

For compensated line

$$V_R=V_S+V_{pq}-V_X \tag{3}$$

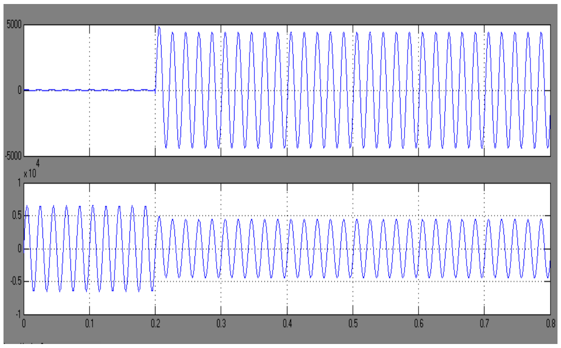
V_R - Receiving end voltage
V_S - Sending end voltage
V_X - Voltage across the line reactance
I - Line current
V_{pq} - Injected compensating voltage
X - Line reactance
X_L Load reactance
R_L Load resistance

Line-1 and Line-2 operating at 11KV and 10KV respectively. Operating status of Line-1 overloaded and Line-2 under-loaded. Line-1 & 2 terminates on identical loads.

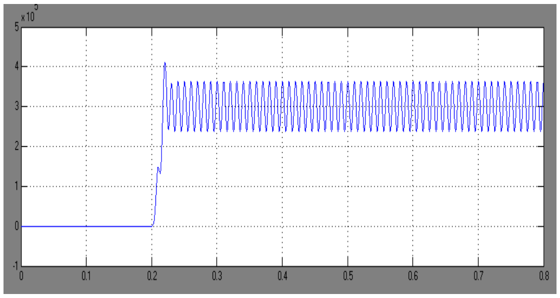
Both are identical lines. For uncompensated condition IPFC disabled with the coupling transformers disconnected from the lines.

VI. SIMULATION RESULTS & WAVEFORMS

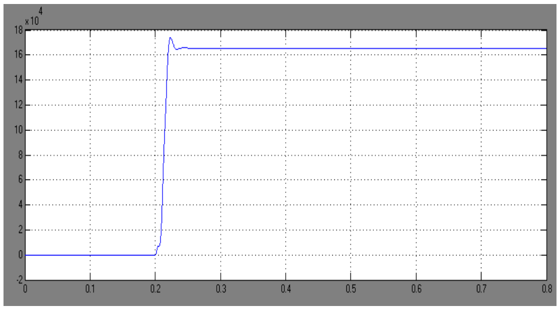
a) LINE MODEL WITHOUT COMPENSATION CIRCUIT



VOLTAGE ACROSS LOAD -2 AND LOAD-1



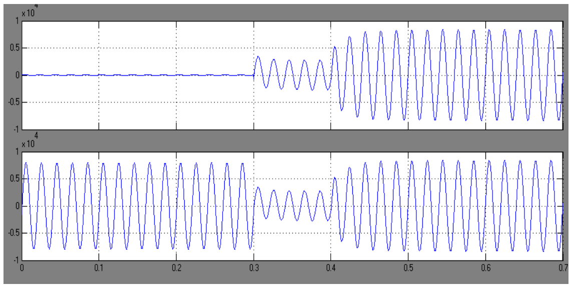
Real power



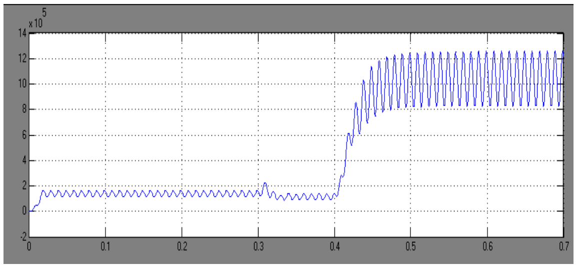
Reactive power

b) LINE MODEL WITH COMPENSATION CIRCUIT

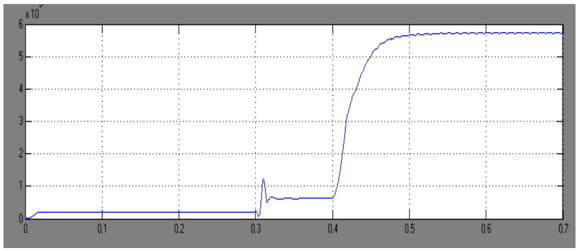
UPFC Circuit Model



VOLTAGE ACROSS LOAD -2 AND LOAD-1

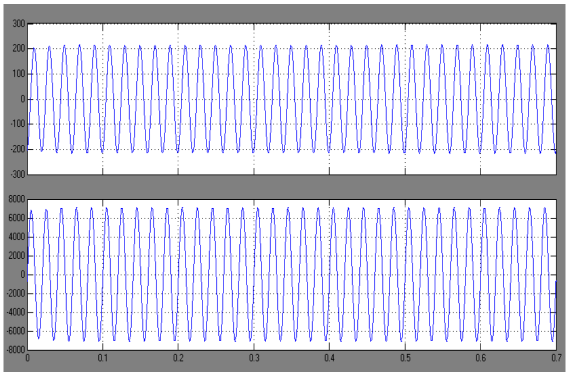


Real power

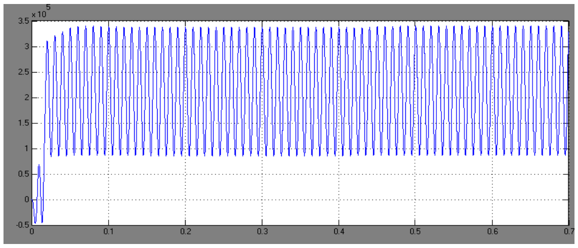


Reactive power

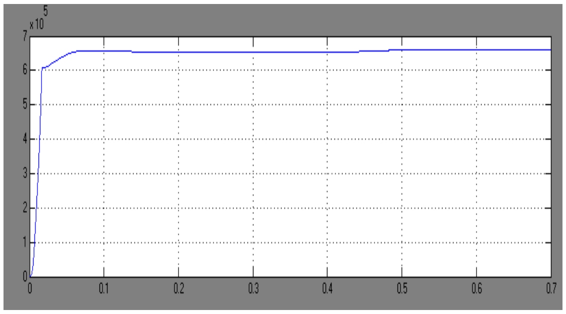
IPFC Circuit Model



CURRENT AND VOLTAGE WAVE FORM



REAL POWER WAVE FORM



REACTIVE POWER WAVE FORM

VII.CONCLUSION

In this study, the MATLAB environment using phasor model of UPFC connected to a three phase-three wire transmission system. This paper presents control and performance of UPFC intended for installation on a transmission line. Simulation results show the effectiveness of UPFC in controlling real and reactive power through the line.

Also, with UPFC in transmission line, results in improvement of transient stability of the system, which is an added advantage along with the power flow control [5], improved Plant Utilization Factor, better Voltage Profile.

A simple efficient technique has been carried out for solving the IEEE bus system. It is observed that the method has fast convergence characteristics. The work has been carried out by placing the Multiple FACTS devices is placed in suitable places to minimize the power losses in IEEE bus system and to improve the voltage profile, reduction in power losses. By placing various FACTS devices with multiple compensation techniques is used in the specified lines for increased power flows, and is implemented for an IEEE bus system

The referred analysis was based upon the shunt and series real power balance, when the converters' losses are neglected. The model developed can also be adapted, by doing some minor changes, to the case of an IPFC and UPFC device. The simulations performed showed the IPFC and UPFC capabilities and advantages for controlling simultaneously both active and reactive power flow.

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IX. BIOGRAPHY

Murugan A. was born in Tamilnadu, India, on June 6, 1986. He received the B.E in Electrical and Electronics Engineering from Ranippettai Engineering College, Anna University, in 2007. He was worked as a lecturer in Electrical Engineering department at Sri Balaji Chokkalingam Engineering College, Arni, and Tamilnadu for a period of eight months He completed his M.E degree in Power Systems at College of Engineering Guindy, Anna University in 2010, and he is working as a lecturer in AdhiParasakthi College of Engineering at kalavai.

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