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MODELING AND CONTROL OF FACTS DEVICES FOR REAL & REACTIVE POWER ENHANCEMENT

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Abstract – 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). The reactive power transfer is occurring at reactive power coordination of IPFC The basic control for the IPFC is such that the series converter of the IPFC controls the transmission line real/reactive power flow and the shunt converter of the IPFC controls the IPFC bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the shunt converter of the IPFC supplies the real power demand of the series converter. The interline power flow controller (IPFC) is one of the latest generation flexible AC transmission systems (FACTS) controller used to control power flows of multiple transmission lines To avoid instability/loss of DC link capacitor voltage during transient conditions, a new real power coordination controller has been designed.

Index Terms *- Power System modeling, power flow control, Reactive Power Compensation, FACTS, Voltage Source Converter, Matlab Software*

I. INTRODUCTION

With the ongoing expansion and growth of the electric utility industry, including deregulation in many countries, numerous changes are continuously being introduced to a once predictable business. Although electricity is a highly engineered product, it is increasingly being considered and handled as a commodity. Now, more than ever, advanced technologies are paramount for the reliable and secure operation of power systems. To achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission system infrastructure is required. Improved utilization of the existing power system is provided through the application of advanced control technologies. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of n advanced solutions as cost-effective alternatives to new transmission line construction. The potential benefits of FACTS equipment are now widely recognized by the power systems engineering and T&D communities. With respect to FACTS equipment, voltage sourced converter (VSC) technology, which utilizes self-commutated thyristors/transistors, has been successfully applied in a number of installations world-wide.

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

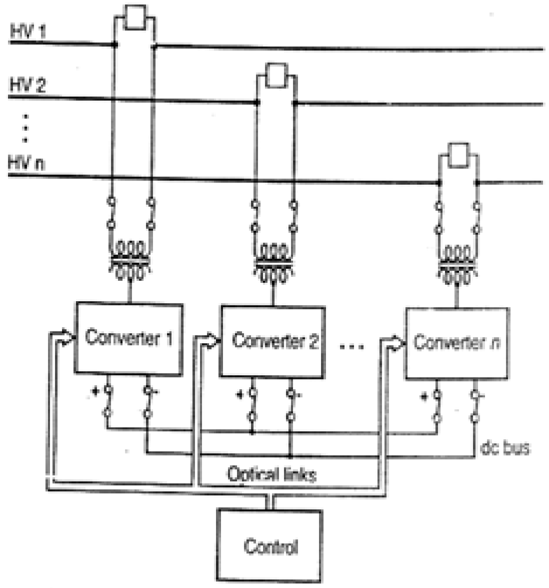


Fig. 1. General schematic of IPFC transmission line.

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.

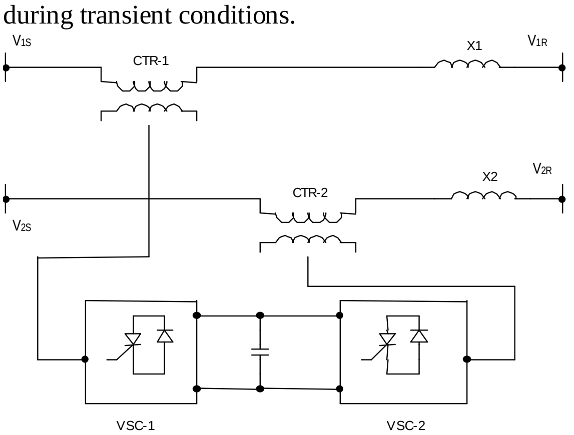


Fig:2 IPFC with two VSC's

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 $(0 \le V1pq \le V1pqmax)$ and angle $(0 \le \rho 1 \le 360°)$ 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.

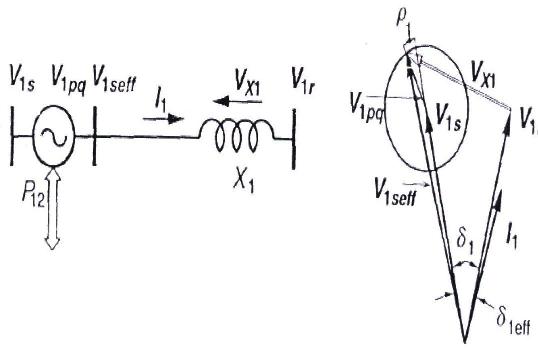


Fig. 3. Phasor representation of IPFC

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 / l VIPFC bus l (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.

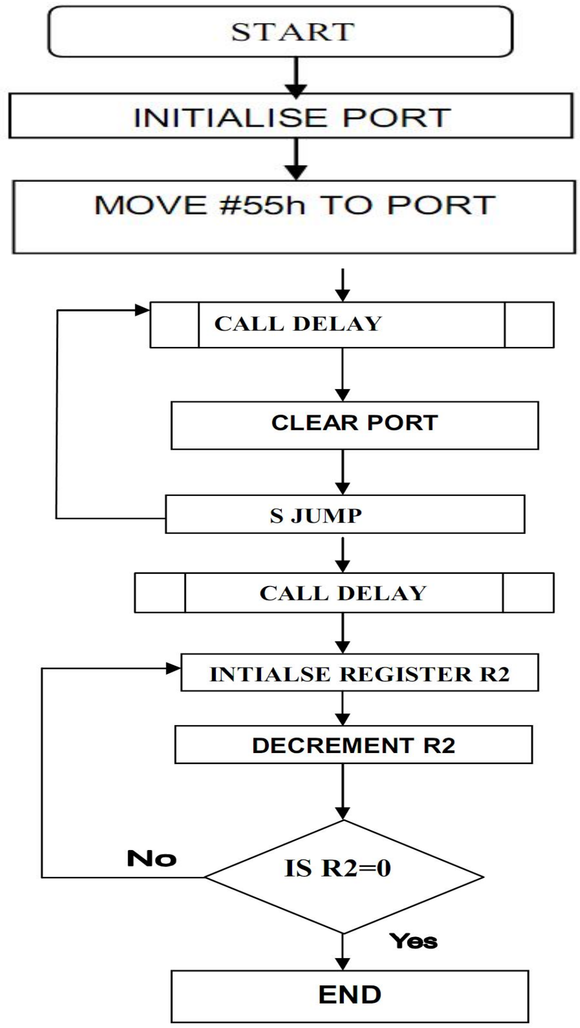
The mechanism by which the request for transmission line reactive power flow is supplied by the shunt converter is as follows. Increase in transmission line reactive power reference causes a decrease in IPFC bus voltage. Decrease in IPFC bus voltage is sensed by the shunt converter IPFC bus voltage controller 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.IMPLEMENTATION OF THE PROJECT



V. BASIC INTERLINE POWER FLOW CONTROLLER CIRCUIT

Upper line and lower line referred to as Line-1 and Line-2 respectively. Line-1 and Line-2 are connected by coupling transformers at the sending end (Lines leaving the sub-station). Diode bridge, capacitor and VSC form the dc link permitting the real power transfer between lines in this case from Line-1 to Line-2 due to unidirectional nature of dc link (actual dc link bi-directional with two VSC's). For our study consider Line-1 is overloaded and Line-2 under-loaded. Till the overloaded/under-loaded condition is detected that is during normal operating condition Line-1 and Line-2 is decoupled with the isolation of the coupling transformers from the lines.

Under overloaded/ under-loaded conditions Line-1 and Line-2 are linked by the dc link via respective coupling transformers. Line-1 being overloaded will

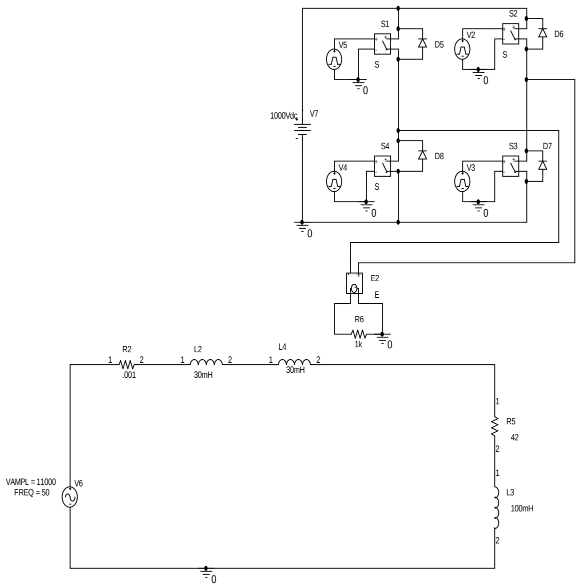


Fig 4 Modeling of 11KV line terminating at the sub-station.

setup dc link voltage depending on the extent of overload. VSC converts the dc to ac of required magnitude and phase angle due to self commutating nature of the power devices. Injected voltage modifies the sending end voltage to correct the under-loaded condition of the Line-2.

Mathematical expressions of IPFC

For uncompensated line

$$V_R=V_S-V_X \quad (1)$$

$$I=V_S/(X+X_L+R_L) \quad (2)$$

For compensated line

$$V_R=V_S+V_{pq}-V_X \quad (3)$$

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. IPFC IN SHUNT COMPENSATION IN MODE.

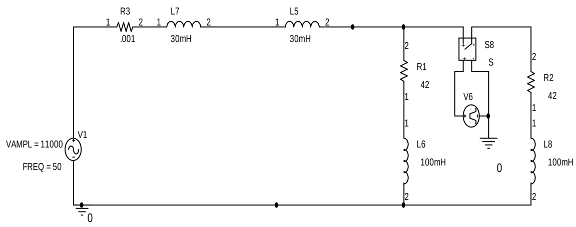


Fig 5: CASE_4_11KV_UNCOMP

Modeling and Simulation of 11KV line with change in load condition. Load change (increase) is effected at t=0.5s.

VII. SIMULATION RESULTS & WAVEFORMS

V_S KV	Without Comp V_R KV	DC link voltage KV	V_R KV ρ=-90°	V_R KV ρ=-180°	V_R KV ρ=-270°	V_R KV ρ=0°
11	8	1	8.5	7.5	8.5	9
11	8	2	9	7	10	10.5
11	8	3	10	6	11	11.5

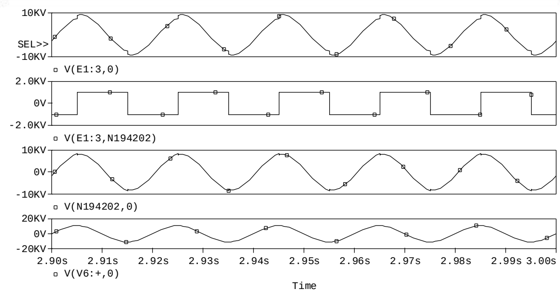


Fig 6 : V_{DC}=8KV, V_S, V_R, V_{COMP}, V_{IPFC}

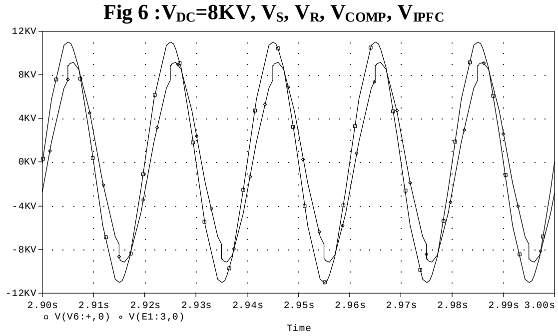


Fig 7. V_{DC}=1KV, ρ=-90° V_S, V_{Reff}

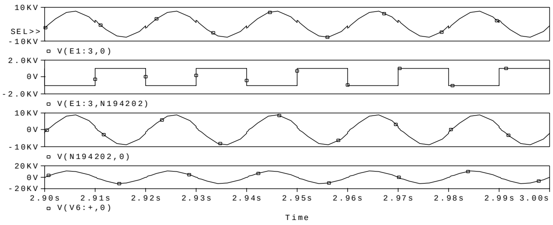


Fig 8 : V_{DC}=1KV, ρ=-180° V_S, V_R, V_{pq}, V_{Reff}

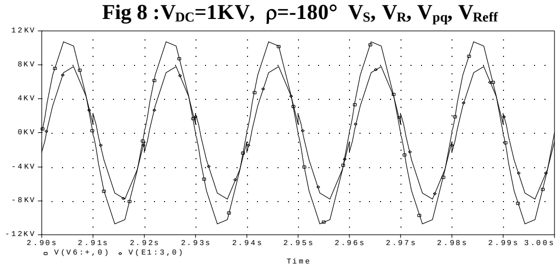


Fig 9: V_{DC}=1KV, ρ=-180° V_S, V_{Reff}

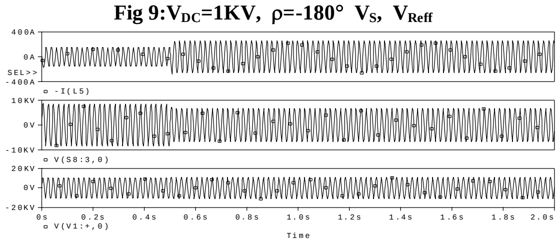


Fig10: V_S, V_R, I (2 sec)

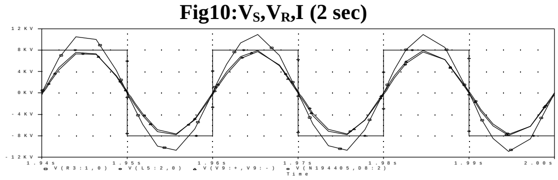


Fig: V_{DC}=8KV, V_S, V_R, V_{COMP}, V_{IPFC}

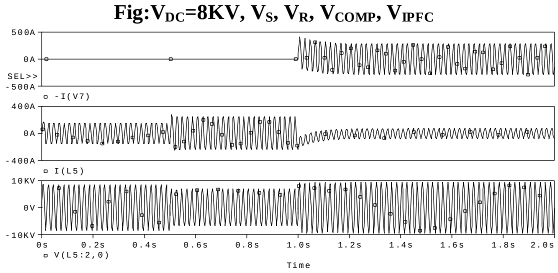


Fig 11: V_{DC}=10KV, V_R, I_{LINE}, I_{COMP}

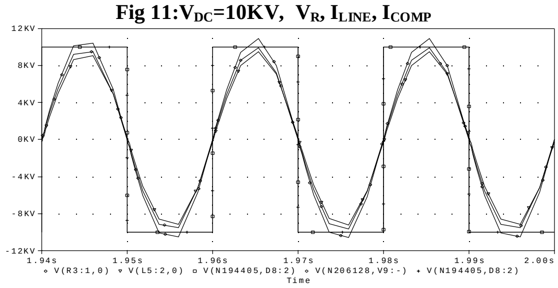


Fig 12: V_{DC}=10KV, V_S, V_R, V_{COMP}, V_{IPFC}

V_S KV	COMP. Voltage KV	V_R at normal load KV	V_R after load increase (t=0.5s) KV	V_R after load increase (t=1.0s) KV
11	Without	9	7	7
11	8	9	7	8
11	9	9	7	9
11	10	9	7	10

VIII.CONCLUSION

In this project, AC Transmission systems to achieve both operational reliability and financial profitability by more efficient utilization and control of the existing transmission system infrastructure. In this project IPFC capability to balance the power in a overloaded line and a under-loaded line modeled and simulated for two cases (1) Identical lines (2) Non-identical lines. Simulation results demonstrate the power transfer capability of IPFC between two or more lines through dc link.

Numerical results on the test system have shown the convergence and the effectiveness of the IPFC model .It shows that the incoming of IPFC can increase the bus voltage to which IPFC converters are connected and there is a significant change in the system voltage profile at the neighboring buses, increase in active power flow and decrease in reactive power flow through the lines Also, the effect of IPFC parameters on active and reactive power flows through the lines in which IPFC is placed has been investigated.

IPFC being a powerful FACTS controller to become standard equipment at every sub-station future an attempt is made to enlarge its scope of utilization. In this project proposed IPFC modeled and simulated to perform the receiving end voltage regulation for lines which terminate at the given sub-station to feed the distribution network. Two options considered namely series compensation and shunt compensation modes. Simulation results are highly encouraging.

In other words the proposed model of IPFC increases the real power transfer and improves the voltage profile.

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X. 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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