



Simulation of Real and Reactive Power Coordination Using CSC Based IPFC for Power Quality Issues

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ABSTRACT: FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact and implementation time compared to the construction of new transmission lines. FACTS provide the needed corrections of transmission functions in order to efficiently utilize existing transmission systems and therefore minimize the gap between the stability and the thermal level. Interline Power Flow Controller(IPFC) is a Voltage Source Converter(VSC) based FACTS controller for controlling power in multi-line system located at a substation. The main aim of the IPFC is to verify the power transfer capability between two or more lines and to establish the proposed voltage regulation function. In this paper, a current source converter topology based IPFC is proposed. In this structure, the dc-side current is regulated to a value larger than the peak value of the maximum line current. The injected voltage is controlled according to the desired reactive power compensation and management active power flow for master line. The decoupled state feedback control for the injected voltage with a separated dc current control is applied to the proposed system. The proposed IPFC has been simulated using the Matlab program.

KEYWORDS: IPFC, CSC, Linear model, non linear model

I. INTRODUCTION

Three main variables that can be directly controlled to impact its performance are voltage, angle and impedance. The power quality can be mainly affected by voltage sags, harmonics, voltage fluctuations and flicker and transients. The family of compensators and power flow controllers based on VSC are the Static Synchronous Series Compensator(STATCOM), the Static Synchronous Series Compensator(SSSC), the Unified Power Flow Controller(UPFC) and the Interline Power Flow Controller (IPFC). The FACTS controllers can be realized by either a voltage-source converter (VSC) or a Current Source Converter (CSC). But, in this paper, the choice of CSC over VSC because of the advantages such as since input current is maintained constant, the misfiring of switching devices or short circuit across source would not be a serious problem, the peak current of power devices is limited, large dc link filter acts as a current limiter making it easier to apply protective fuses. The IPFC 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 underloaded 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, harmonics and power oscillations. In this paper, IPFC based on the current source converter topology is proposed. For simplicity, we analyse the IPFC with only two CSC, in which one CSC is called Master CSC, while the other CSC is called Slave CSC, which provides appropriate power to the Master CSC so that it can only regulate one variable.

LITERATURE SURVEY

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II.SIMULATION OF REAL AND REACTIVE POWER COORDINATION OF CSC BASED IPFC

The simulation circuit diagram of a CSC based IPFC is shown in fig1. It is connected in series with the transmission lines through three single transformers. The primary side of each transformer is connected in series with the transmission line. The secondary sides of transformers are connected in Y form. The main functions of IPFC control system are dc-side current regulating and introduce proper control signals in order to exchange the required active and reactive power with AC power system.In Fig.1, transformers are modeled as a combination of an ideal transformer and R-L impedance. The series CSC injects its output voltage in the transmission line via a series coupling transformer. In this paper, we use injected voltage source model of IPFC for fundamental frequency studies in which by regulating the amplitude and angle of its output voltage it can change both the active and reactive power in the line.

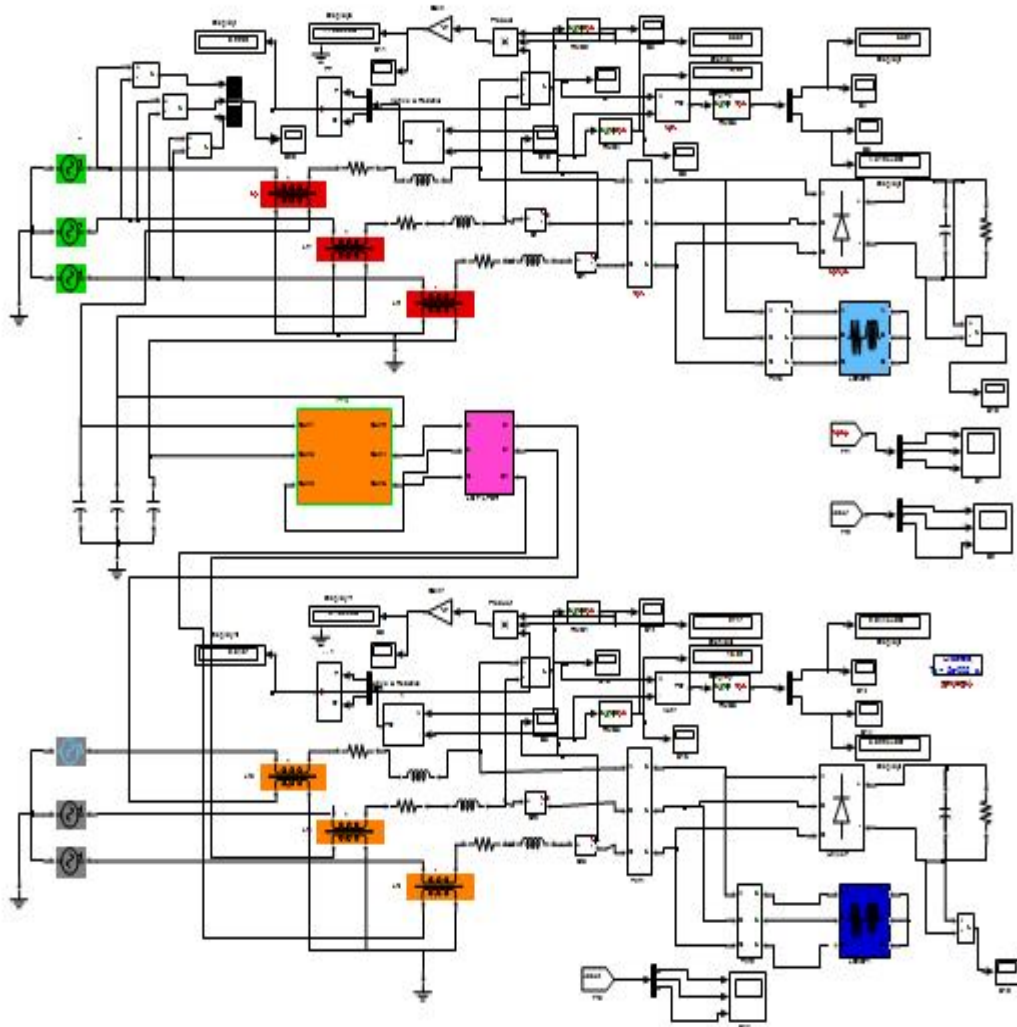


Fig1. CSC BASED IPFC



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(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

The CSC can be controlled by the tri-level SPWM technique [7] in which case it behaves as a 3-phase linear power amplifier. The CSC under tri-level SPWM control can be modeled as:

$$i_{ia1} = m_{a1}I_{dc1} \quad (1)$$

$$i_{ib1} = m_{b1}I_{dc1} \quad (2)$$

$$i_{ic1} = m_{c1}I_{dc1} \quad (3)$$

$$i_{ia2} = m_{a2}I_{dc2} \quad (4)$$

$$i_{ib2} = m_{b2}I_{dc2} \quad (5)$$

$$i_{ic2} = m_{c2}I_{dc2} \quad (6)$$

The power balance equation for the IPFC considered is:

$$P_{se1} + P_{se2} = P_{Rloss} + P_{dc} \quad (7)$$

Where Pse1 and Pse2 are three phase instantaneous AC power going into series converter 1 (Master line) and series converter 2(slave line) respectively, while PRloss represents losses in converter circuits and Pdc is the DC power at DC inductor. By neglecting transformer losses and assuming fundamental frequency balanced conditions, three phase instantaneous powers, for the series converter 1 and 2, respectively, are given as:

$$P_{se1} = 3I_{aca1}V_{inj1}\cos(\delta_1) \quad (8)$$

$$P_{se2} = 3I_{aca2}V_{inj2}\cos(\delta_2) \quad (9)$$

In equations (8),(9), Iaca1, Iaca2 are RMS values of transmission line currents; Vinj1 Vinj2 are RMS values of voltages across the primary side of series transformers; while angles δ_1 and δ_2 represent phase shift between line currents and series inserted voltages. The DC current equation can be obtained by substituting Pse1 and Pse2 by equation (7), (8) and (9):

$$I_{dc}L_{dc}d/dtI_{dc} + R_{dc}I_{dc}^2 = 3I_{ac1}V_{inj1}\cos(\delta_1) + 3I_{ac2}V_{inj2}\cos(\delta_2) \quad (10)$$

Where m_{a1} , m_{b1} , m_{c1} and m_{a2} , m_{b2} , m_{c2} are the modulation indexes of the 3 phases, normalized to the peak of the triangular carrier signal. The modulation signals can also be transformed into d-q frame. Thus, (1) to (6) can be re-written as:

$$I_{id1} = M_{d1}I_{dc1} \quad (11)$$

$$I_{iq1} = M_{q1}I_{dc1} \quad (12)$$

$$I_{id2} = M_{d2}I_{dc2} \quad (13)$$

$$I_{iq2} = M_{q2}I_{dc2} \quad (14)$$

Consider the line current of phase- a in Master line as the reference phasor for the d-q transformation for variable of the reference phasor for the d-q transformation for variables of Slave line, the dynamic equations from the converter to the secondary side of the transformer are:

$$d/dt(V_{d1}) = 1/c_1(I_{d1}) + \omega V_{q1} - 1/c_1(M_{d1}I_{dc1}) \quad (15)$$

$$d/dt(V_{q1}) = -\omega V_{d1} - 1/c_1(M_{q1}I_{dc1}) \quad (16)$$

$$d/dt(V_{d2}) = 1/c_2(I_{d2}) + \omega V_{q2} - 1/c_2(M_{d2}I_{dc2}) \quad (17)$$

$$d/dt(V_{q2}) = -\omega V_{d2} - 1/c_2(M_{q2}I_{dc2}) \quad (18)$$

The input variable, are M_{d1} , M_{q1} , M_{d2} and M_{q2} and the output variable are I_{dc} and V_{d1} , V_{q1} and V_{d2} , V_{q2} that given by equation (10), (1) to (18) which are chosen based on the control objectives of the IPFC. The above system is nonlinear. A common method to deal with the nonlinearity is to linearization the equations around an operating point. But, in this particular case, since the nonlinearity is caused by I_d and the dynamics of I_d , is slower than those of V_d and V_q , it is possible to divide the system into an inner control loop and an outer control loop, where the two loops can be deal with separately.

The inner loop is the linear part of the system. The model is:

$$d/dt(V_{d1}) = 1/c_1(I_{d1}) + \omega V_{q1} - 1/c_1(I_{id1}) \quad (19)$$

$$d/dt(V_{q1}) = -\omega V_{d1} - 1/c_1(I_{iq1}) \quad (20)$$

$$d/dt(V_{d2}) = 1/c_2(I_{d2}) + \omega V_{q2} - 1/c_2(I_{id2}) \quad (21)$$

$$d/dt(V_{q2}) = -\omega V_{d2} - 1/c_2(I_{iq2}) \quad (22)$$

In this system, I_{id1} , I_{iq1} , I_{id2} and I_{iq2} are the inputs, V_{d1} , V_{q1} , V_{d2} and V_{q2} are the state variables, as well as the outputs, (ω , C_1 and C_2 are constant values, and I_{d1} , I_{d2} is the line current). From the control view, I_{d1} , I_{d2} can be considered as a 'measurable disturbance input', since it is neither a state variable, nor an input or output. The dynamic model in the matrix form is:

$$\dot{X} = AX + BU + Fe \quad (23)$$

$$Y = CX \quad (24)$$

Where,

$$X = [V_{d1} \ V_{q1} \ V_{d2} \ V_{q2}]^T;$$

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

$$U = [I_{id1} \ I_{iq1} \ I_{id2} \ I_{iq2}]^T; \ e = [I_{d1} \ I_{q1}]^T;$$

$$Y = [V_{d1} \ V_{q1} \ V_{d2} \ V_{q2}]^T;$$

For a linear system represented by (23) and (24), it is easy to design a stable feedback controller so that the output variables follow the reference input variables and are not influenced by the disturbance input. The controller can be in the form of

$$U = -KX + TY_{ref} + Me \quad (25)$$

Where

$Y_{ref} = [V_{d1ref} \ V_{q1ref} \ V_{d2ref} \ V_{q2ref}]^T$ is the reference input.

K is a 2X2 constant state feedback matrix;

T is a 2X2 constant diagonal gain matrix; and

M is a 2X1 constant vector.

III. TEST SYSTEM AND RESULTS

The test power system (Fig.1) which has been modeled with Matlab is consist of two identical transmission systems. The simulated power system is composed of two voltage sources at the sending and receiving ends of a transmission lines. The test system parameters are given in the Appendix.

Figure 2-10 show how the system responses for Linear and non-linear loads in Master line and Slave line.

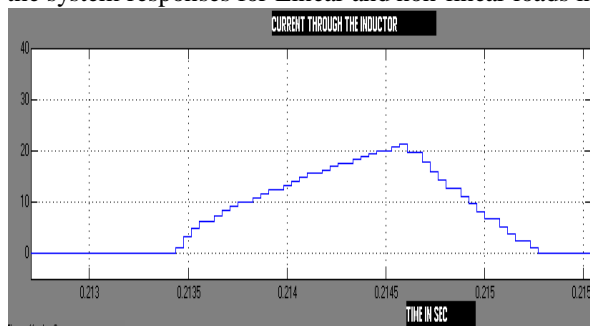


Fig. 2. Current through the Inductor

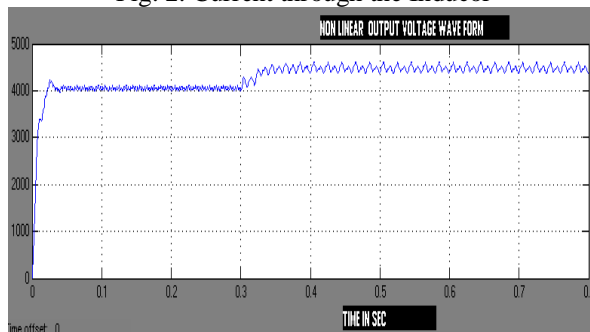


Fig.3. Non linear output voltage in Master line

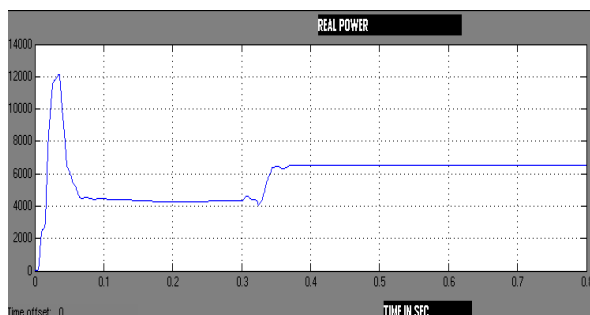


Fig. 4. Real power in Master Line

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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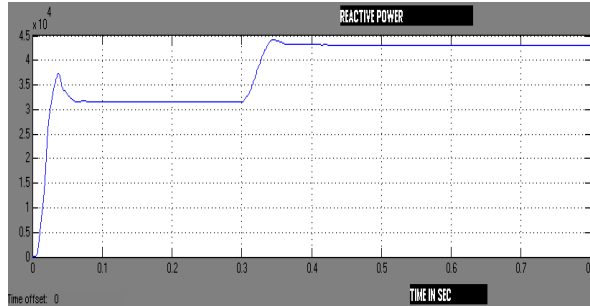


Fig. 5. Reactive power in Master Line

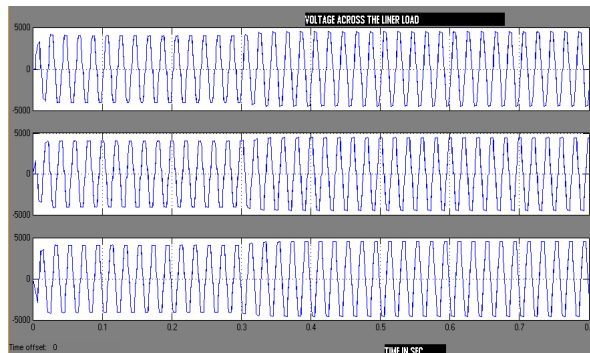


Fig. 6. Linear output voltage in Master Line

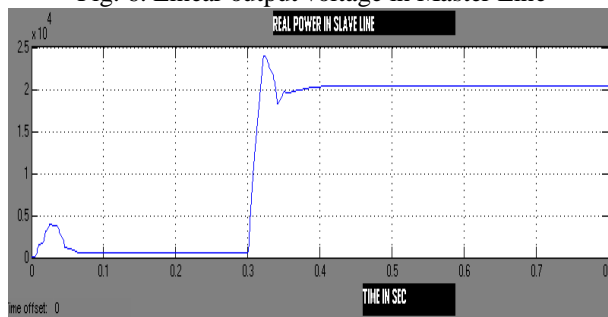


Fig. 7. Real power in Slave Line

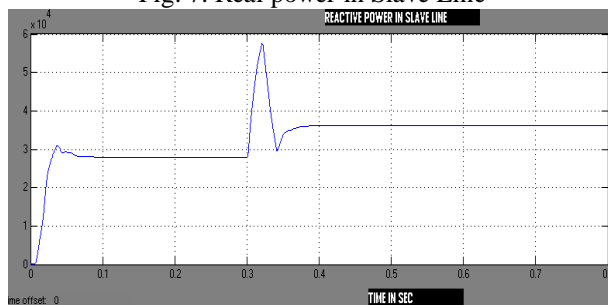


Fig. 8. Reactive power in Slave line

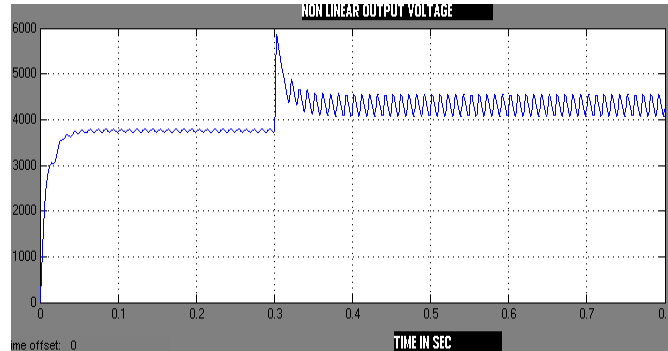


Fig. 9. Non linear output voltage in Slave Line



Fig. 10. Linear output voltage in Slave Line

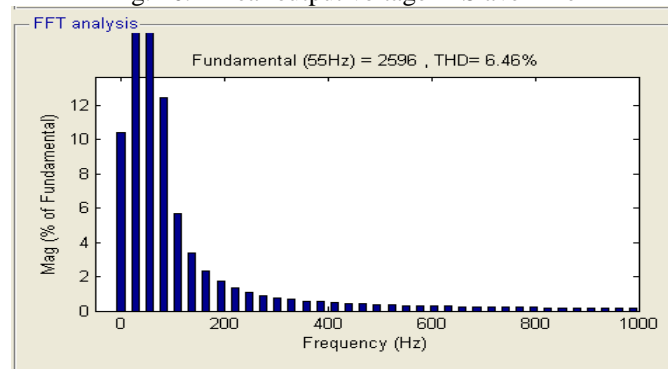


Fig. 11. Total Harmonic Distortion (THD) waveform for with IPFC

IV. CONCLUSION

In this paper, the IPFC based on the current source converter (CSC) topology is proposed. The dynamic model of the system is derived and divided into a linear part and a nonlinear part. The linear part is controlled in an inner loop by a decoupled state feedback controller. The nonlinear part is controlled in an outer loop by a PI controller which regulates the dc side current. The steady state performance of the IPFC are evaluated using the simulation results from Matlab program.

I. APPENDIX

System data is referred with $P_{base}=25MVA$, $V_{base}=3.3KV$. The value of $L_{dc}=30mh$, $f=50Hz$, $R_{L1}=R_{L2}=R_{L3}=10\Omega$, $L_{L1}=L_{L2}=L_{L3}=30mH$, R_L Load = 500Ω , $80mH$.



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