

Modelling and Control Design of Unified Power Flow Controller for Various Control Strategies

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Abstract:

Unified Power Flow Controller (UPFC) is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. This controller offers advantages in terms of static and dynamic operation of the power system. It also brings in new challenges in power electronics and power system design. The basic structure of the UPFC consists of two voltage source inverter (VSI); where one converter is connected in parallel to the transmission line while the other is in series with the transmission line. The aim of the paper is to develop a control strategy for UPFC, modeling UPFC using MATLAB/SIMULINK and to analyze the control strategy to use the series voltage injection and shunt current injection for UPFC control. To simplify the design procedure we carry out the design for the series and shunt branches separately. In each case, a simple equivalent circuit represents the external system. The design has to be validated when the various subsystems are integrated.

Keywords: Unified power Flow Controller (UPFC), Control circuit Design, Modelling of UPFC.

1. INTRODUCTION

Using the advanced solid state technology FACTS Controllers offer flexibility of system operation through fast and reliable control. They enable better utilization of existing power generation and transmission facilities without compromising system availability and security. The system planner has to select a controller out of the set of FACTS Controllers, for improving the system operation, based on cost benefit analysis.

Gyugyi [1] proposed the Unified Power Flow Controller (UPFC) concept in 1991. The UPFC was devised for the real time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the delivery industry. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (i.e., voltage, impedance and phase angle), and this unique capability is signified by the adjective “unified” in its name. Alternatively, it can independently control both the real and reactive power flows in the line. The UPFC not only performs the functions of the STATCOM, TCSC, and the phase angle regulator but also provides additional flexibility by combining some of the functions of these controllers.

The Unified Power Flow Controller (UPFC) consists of two voltage sourced converters using power switches, which operate from a common DC circuit of a DC-storage capacitor. This arrangement functions as an ideal ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of the two converters and each converter can independently generate (or absorb) reactive power at its own ac output terminal[1].

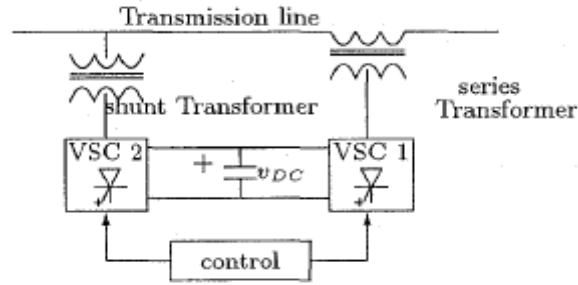


Fig.1(a): Structure of UPFC

A UPFC control strategy, in general, should preferably have the following attributes:

- Steady state objectives (i.e. real and reactive power flows) should be readily achievable by setting the references of the controllers.
- Dynamic and transient stability improvement by appropriate modulation of controller references.

2. OPERATION OF UPFC

Inverter 2 provides the main function of the UPFC by injecting an ac voltage V_{pq} with controllable magnitude V_{pq} ($0 \leq V_{pq} \leq V_{pqmax}$) and phase angle ρ ($0 \leq \rho \leq 360$), at the power frequency, in series with the line via an insertion transformer. The injected voltage is considered essentially as a synchronous voltage source. The transmission line current flows through this voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal (i.e., at the terminal of insertion transformer) is converted by the inverter into dc power that appears at the dc link as positive or negative real power demanded. The reactive power exchanged at the ac terminal is generated internally by the inverter.

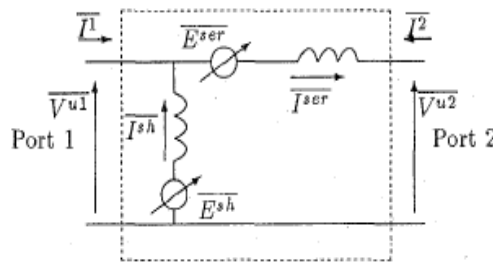


Fig. 1(b): UPFC as 2-port Device

The basic function of Inverter 1 is to supply or absorb the real power demanded by Inverter 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. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and there by it can provide independent shunt reactive compensation for the line[2]. It is important to note that where as there is a closed "direct" path for the *real power* negotiated by the action of series voltage injection through Inverters 1 and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by inverter 2 and therefore it does not flow through the line. Thus, inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by the by the Inverter 2. This means there is no continuous reactive power flow through UPFC.

2.1 Vector Representation of Instantaneous 3Φ Quantities

The notion of the real and reactive power is well known in the phasor sense. However, to study and control the dynamics of the UPFC within sub cycle frame and subject to line distortions, disturbances and unbalance, we need a broader definition of reactive power which is valid on an instantaneous basis. The instantaneous real power at a point on the line is given by $P = V_a I_a + V_b I_b + V_c I_c$. We can define instantaneous reactive voltages conceptually as a part of the three-phase voltage set that could be eliminated at any instant without altering p . The definition of instantaneous reactive voltage is obtained by vector interpretation of the instantaneous values of the circuit variables.

A set of three instantaneous phase variables that sum to zero can be uniquely represented by a single point in a plane, as illustrated in Fig.3.1. By definition, the vector drawn from the origin to this point has a vertical projection onto each of the three symmetrically disposed phase axis, which corresponds to the instantaneous value of the associated phase variable. This transformation of phase variables to instantaneous vectors can be applied to voltages as well as currents. As the values of phase variables change, the associated vector moves around the plane describing various trajectories. The vector contains all the information on the three-phase set, including steady-state unbalance, harmonic waveform distortions, and transient components.

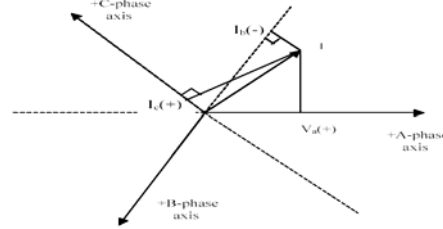


Fig. 1(c) : Vector representation of instantaneous 3-Φ variables

2.2 3-Φ to D-Q Transformation

In Fig.2, the vector representation is extended by introducing an orthogonal co-ordinate system in which each vector is described by means of its ds- and qs- components. The transformation of phase variables to ds and qs co-ordinates is as follows.

If V_a, V_b, V_c are balanced set of voltages

$$V_a = \sqrt{2} V_{rms} \sin \omega t,$$

$$V_b = \sqrt{2} V_{rms} \sin(\omega t - 120^\circ), V_c = \sqrt{2} V_{rms} \sin(\omega t - 240^\circ)$$

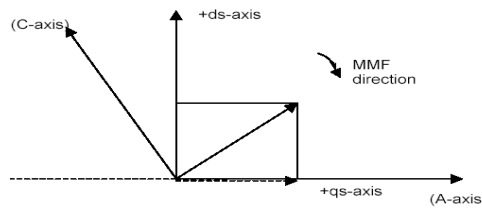


Fig.2: Definition of orthogonal co-ordinates

$$[C_1]^{-1} = \frac{2}{3\sqrt{2}} \begin{bmatrix} 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (3.1)$$

then by using the above transformation matrix, the ds and qs axis coordinates are given by

$$\begin{aligned} V_{ds} &= V_{rms} \cos \omega t \\ V_{qs} &= -V_{rms} \sin \omega t \end{aligned} \quad (3.2)$$

The per unit values represent rms quantities.

The constants are derived based on power Invariance principle $\Rightarrow V_a I_a + V_b I_b + V_c I_c = V_{ds} I_{ds} + V_{qs} I_{qs}$

The inverse transformation matrix is given by $V_{old} = C_1 V_{new}$

$$[C_1] = \sqrt{2} \begin{bmatrix} 0 & 1 & \frac{1}{\sqrt{2}} \\ -\frac{\sqrt{3}}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{\sqrt{3}}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (3.3)$$

Single phase per-unit system is used and the per-unit values represent rms quantities.

Fig.3 shows how further manipulation of vector coordinate frame leads to a useful separation of variables for power control purposes. The d-axis voltage component V_d , accounts for real component and q-axis voltage V_q , is the instantaneous reactive component.

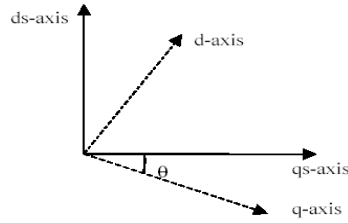


Fig.3: Transformation in rotating reference frame

The d and q axes are not stationary in the plane. They follow the trajectory of the voltage vector, and the d and q co-ordinates within this synchronously reference frame are given by the following timevarying transformation:

The transformation matrix in synchronously revolving reference frame is given by

$$[C_2] = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \quad (3.4)$$

For balanced set of phase voltages $V_a = \sqrt{2} V_{rms} \sin(\omega t - \theta)$, $V_b = \sqrt{2} V_{rms} \sin(\omega t - 120^\circ - \theta)$, $V_c = \sqrt{2} V_{rms} \sin(\omega t - 240^\circ - \theta)$ and $\theta = \omega t$. the d and q axis components are given by

$$V_d = V_{rms} \cos\theta$$

$$V_q = -V_{rms} \sin\theta$$

Under balanced steady-state conditions, the co-ordinates of the voltage and current vectors in synchronous reference frame are constant quantities. The inverse transformation in synchronous reference frame is $[C]^{-1} = [C]^T$

The d-q axis real power component is $P = V_d I_d + V_q I_q$ and the reactive power is given by $Q = -V_q I_d + V_d I_q$. These represent power in single-phase quantities. This can be summarized this way, defining complex vectors in d-q plane is

$$\hat{V} = V_d + j V_q, \hat{I} = I_d + j I_q$$

$$P + jQ = \hat{V} \hat{I}^* = (V_d I_d + V_q I_q) + j(V_q I_d - V_d I_q)$$

2.3 Transformation of Impedance Matrix

The transformation is explained by considering a simple three-phase system as shown in Fig 4

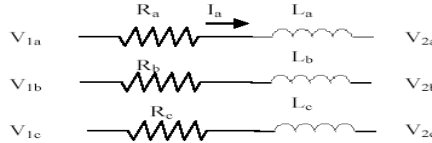


Fig.4: Simple balanced system

The balanced three-phase system can be transformed into a synchronously rotating orthogonal system.

$$\begin{bmatrix} V_{1a} - V_{2a} \\ V_{1b} - V_{2b} \\ V_{1c} - V_{2c} \end{bmatrix} = \begin{bmatrix} R + PL & 0 & 0 \\ 0 & R + PL & 0 \\ 0 & 0 & R + PL \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3.5)$$

$$Z_{new} = C^T Z_{old} C$$

in the ds- qs plane the impedance matrix transformed into

$$Z_{new} = \begin{bmatrix} R + PL & 0 \\ 0 & R + PL \end{bmatrix} \quad (3.6)$$

Now in the synchronously revolving reference frame (d-q transformation) the impedance matrix is transformed into

$$Z'_{new} = \begin{bmatrix} R + PL & -\omega L \\ \omega L & R + PL \end{bmatrix} \quad (3.7)$$

Where $P = d/dt$, the voltage equations after d-q transformation is given by the above equation can be written as

$$\begin{bmatrix} V_{d1} - V_{d2} \\ V_{q1} - V_{q2} \end{bmatrix} = \begin{bmatrix} R + PL & -\omega L \\ \omega L & R + PL \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (3.8)$$

$$\frac{di_d}{dt} = -\frac{R}{L}i_d + \omega i_q + \frac{V_{d1} - V_{d2}}{L} \quad (3.9)$$

$$\frac{di_q}{dt} = -\frac{R}{L}i_q - \omega i_d + \frac{V_{q1} - V_{q2}}{L} \quad (3.10)$$

per-unit system is adopted according to the following definitions:

$$\begin{aligned} i'_x &= \frac{i_x}{i_B} & ; & & v'_x &= \frac{v_x}{v_B} & ; & & e'_x &= \frac{e_x}{v_B} \\ z'_x &= \frac{z_x}{z_B} & ; & & x' &= \frac{\omega_B L}{z_B} & ; & & R' &= \frac{R}{z_B} \end{aligned}$$

$x = a, b, c$

by using the per unit system the above equations rewritten as

Where ω_b = base frequency

$$\frac{di'_d}{dt} = -\frac{\omega_b R'}{x'} i'_d + \omega i'_q + \frac{\omega_b (V_{d1} - V_{d2})}{x'} \quad (3.11)$$

$$\frac{di'_q}{dt} = -\frac{\omega_b R'}{x'} i'_q - \omega i'_d + \frac{\omega_b (V_{q1} - V_{q2})}{x'} \quad (3.12)$$

ω = synchronously rotating system frequency

The significance of the transformation summarized as follows:

- The physical significance of the phase transformation C1 is therefore to replace the actual three phase system by an equivalent two phase system.
- The original circuit produced in Fig 4 gave rise to an impedance matrix Z with nine non-zero terms. The transformed impedance matrix Z' has only four terms.

3. CONTROLLER DESIGN OF UPFC

A control strategy, in general, should preferably have the following attributes [8]:

- Steady state objectives (i.e. real and reactive power flows) should be readily achievable by setting the references of the controllers.
- Dynamic and transient stability improvement by appropriate modulation of controller references

To simplify the design procedure we carry out the design of the series and shunt branches separately. In each case, the external system is represented by a simple equivalent. The design has to be validated when the various sub systems are integrated [7].

3.1 Series Injected Voltage Controller

3.1.1 Power Flow Control

In this section we consider the control of real power using series voltage injection. We carry out analysis on the simplified system shown below in Fig.3.5. The differential equations for the current at port 2 in the D-Q (synchronously rotating at system frequency ω_0) frame of reference are given by:

$$\frac{di_{Dse}}{dt} = -\frac{r_{se}\omega_b}{x_{se}} i_{Dse} + \omega i_{Qse} + \frac{\omega_b}{x_{se}} (v_{2D} - v_{RD}) \quad (3.13)$$

$$\frac{di_{Qse}}{dt} = -\frac{r_{se}\omega_b}{x_{se}} i_{Qse} - \omega i_{Dse} + \frac{\omega_b}{x_{se}} (v_{2Q} - v_{RQ}) \quad (3.14)$$

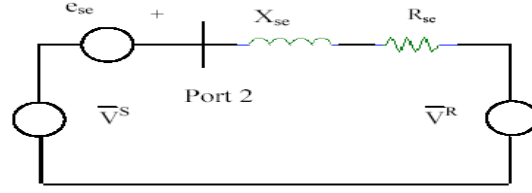


Fig.5: Simplified system UPFC

where,

$$\begin{aligned} v_{2D} &= v_{1D} + e_{Dse} \\ v_{2Q} &= v_{1Q} + e_{Qse} \end{aligned}$$

The subscripts 'D' and 'Q' denote the variables in D-Q reference frame.

v_{SD}, v_{SQ} = D – Q components of voltages at the sending end bus.

v_{RD}, v_{RQ} = D – Q components of voltages at the receiving end bus.

v_{1D}, v_{1Q} = D – Q components of voltages at UPFC port 1.

v_{2D}, v_{2Q} = D – Q components of voltages at UPFC port 2.

Power at the receiving end bus P^R is approximately equal to that at port 2 (P^{u2}) of the UPFC in the study state ; therefore we control the power at port 2 since the feedback signal is readily available.

$$P_2 = v_{2D} i_{Dse} + v_{2Q} i_{Qse} \quad (3.15)$$

Power delivered by the series converter is

From the above equations we will get the actual D-Q currents flowing in the line. References for D-Q currents are set by the required real power flow and the port 2 voltage.

$$p_{se} = e_D^{se} i_D^{se} + e_Q^{se} i_Q^{se} \quad (3.16)$$

Advanced Control Scheme :-

$$\dot{i}_{Dse} = \frac{1}{3} \frac{P_{2Ref}}{V_1} \quad \dot{i}_{Qse} = \frac{1}{3} \frac{Q_{2Ref}}{V_1} \quad (3.17)$$

The reference voltage vector for the series device e_{se}^* is generalized as follows:

$$\begin{bmatrix} e_{Dse}^* \\ e_{Qse}^* \end{bmatrix} = \begin{bmatrix} K_r & -K_q \\ K_p & K_r \end{bmatrix} \begin{bmatrix} \dot{i}_D^* - i_{Dse} \\ \dot{i}_Q^* - i_{Qse} \end{bmatrix} \quad (3.18)$$

From the above differential equations we can calculate the K_r, K_p, K_q values. The values are given by $K_p = K_q = -X_{se}$ and K_r acts as the damping resistor

Note that the control scheme comprehends both phase angle and cross coupling control schemes, so that it can be considered a generalized control scheme for UPFC. This scheme has two additional terms with identical gain K_r . A voltage vector produced by the two terms is in phase with a current phasor vector of $i^* - i$, paying attention to the polarity of these.

The above mentioned control strategy assumes that all quantities are referred to the synchronously revolving reference frame at bus 1. Hence the actual d-q currents (referred to receiving end bus) are transformed based on V_1 reference as above before they are used in the above control equation. Similarly the control references are transformed back into the synchronously revolving reference frame at receiving end bus..

$$\begin{aligned} X_D' &= i_{Dse} \cos \delta + i_{Qse} \sin \delta \\ X_Q' &= -i_{Dse} \sin \delta + i_{Qse} \cos \delta \\ \delta &= \tan^{-1} \left(\frac{V_{1Q}}{V_{1D}} \right) \end{aligned} \quad (3.19)$$

The assumption here for transient analysis is the series device is assumed to be an ideal and instantaneously controllable voltage source. Therefore, the output voltage vector is equal to its reference e_{se}^* .

$$\begin{aligned} e_{Rsh} &= e_{Dsh} \cos(\theta) - e_{Qsh}^s \sin(\theta) \\ e_{psh} &= e_{Dsh} \sin(\theta) + e_{Qsh}^s \cos(\theta) \end{aligned} \quad (3.25)$$

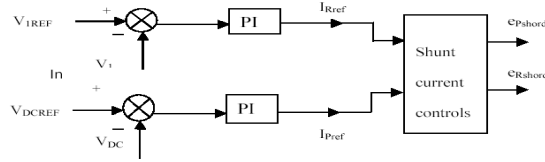


Fig.8: Shunt current controller

Shunt current control block we are calculating the shunt converter output voltages through the drop calculator block by using Idref and Iqref.

The differential equations used in drop calculator are

$$e_{Rsh} = -R_{sh} i_{dshref} - \frac{X_{sh}}{\omega_b} \frac{d i_{dshref}}{dt} + X_{sh} i_{qshref} + V_{1d} \quad (3.26)$$

$$e_{psh} = -R_{sh} i_{qshref} - \frac{X_{sh}}{\omega_b} \frac{d i_{qshref}}{dt} - X_{sh} i_{dshref} + V_{1q} \quad (3.27)$$

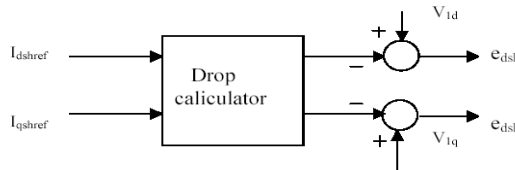


Fig.9: Converter voltage calculator

Port 1 voltages are calculated by adding shunt and series currents and from the given sending end voltage. The differential equations for port 1 voltage calculation is

$$V_{1D} = -R_{se} i_{dl} - \frac{X_{se}}{\omega_b} \frac{d i_{dl}}{dt} + X_{se} i_{ql} + V_{SD} \quad (3.28)$$

$$V_{1Q} = -R_{se} i_{ql} - \frac{X_{se}}{\omega_b} \frac{d i_{ql}}{dt} - X_{se} i_{dl} + V_{SQ} \quad (3.29)$$

The dynamical equation for the capacitor is given by

$$\frac{d V_{DC}}{dt} = -\frac{g_{cap} \omega_b}{b_{cap}} V_{DC} + \frac{\omega_b}{b_{cap}} (i_{dsh} - i_{dse}) \quad (3.30)$$

Any real power drawn / supplied by the series branch or by shunt branch (due to real current injection I_{psh}) manifests as DC side currents IDC^{ser} and IDC^{sh} respectively. Since we allow variable series voltage injection, and due to losses, the capacitor voltage tends change. To compensate this by IDC^{sh} , we set the real current reference (I_{pshref}) as the output of a PI type capacitor voltage regulator.

4. MODELING OF UPFC

4.1 Shunt Current Control Model

Shunt converter was modeled to inject currents into the port1. Inputs for the shunt converter block are V_{u1Ref} , V_{dcRef} . In these two PI control blocks are used. The PI parameters are tuned accordingly to get required output[3]. The PI values used in port1 voltage control loop are $K_P=3$, $K_I=3000$. Large value of integrator gain parameter was set to obtain rapid attainment of steady state without unacceptable oscillations. The PI values used in DC control loop are $K_P=3$, $K_I=0$. Normally integral gain in the capacitor loop set zero to avoid very low frequency oscillations in voltage across capacitor which take a long time to die down. Rate limiters are used in I_{dsh} and I_{qsh} loops [7]. The reason is only limited voltage available from the inverter to drive current through L_{sh} of inverter. The limits used are $[+2000, -2000]$.

4.2 Transmission Line 1 Model

The transmission line 1 model was used to calculate the port1 voltage and the real and reactive power flows (P1 and Q1) from the sending end at port1. Inputs to this block are sending end voltages (d-q quantities). In port1 voltage calculator block imperfect differentiators are used to represent line reactance because transmission line are generally made up of aluminium conductor steel reinforced (A.S.C.R) . So the eddy current losses are taken into account and hence the h.f gain is limited [1].

Sensing delays are used to sense d-q components of the port1 voltage. Normally voltages are sensed by potential transformers, it has delay in measurement. The delay time constant set at a representative value of 1ms. These delays also serve to break the Simulink algebraic loops Small value (0.00001) is used as a input to the sum block in calculating V1rms to avoid division by zero or NaN in simulation.

4.3 Transmission Line 2 Model

Transmission line 2 was modelled to calculate the series current flowing in the line from port 2 to the receiving end bus. D-Q power calculator block calculates the real and reactive power flow from port2 to receiving end. Inputs to this block are receiving end voltages (d-q quantities).

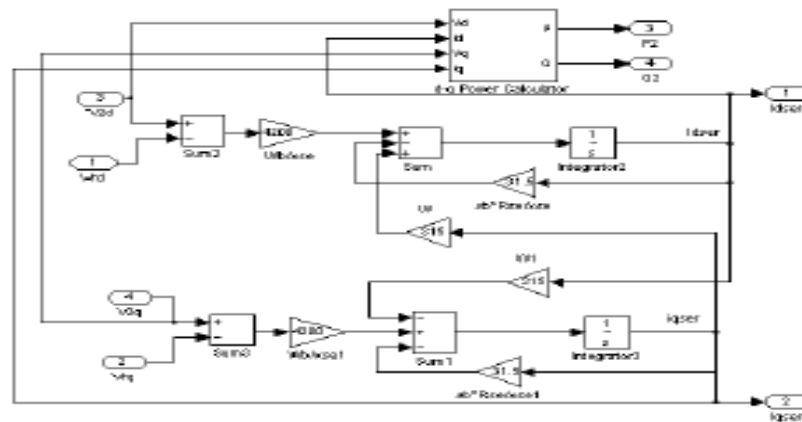


Fig.10: Transmission Line 2 Model

4.4 Inverter DC side Model

The capacitor voltage is sensed using the power balance theory, according to which the power at the AC side of the inverter is equal to the power at the DC capacitor side of the inverter, when the switching losses in the inverter switches are neglected. Inverter dc side control model was used to find the shunt converter output voltages and its RMS value. Power calculator block is used to calculate real and reactive shunt powers.

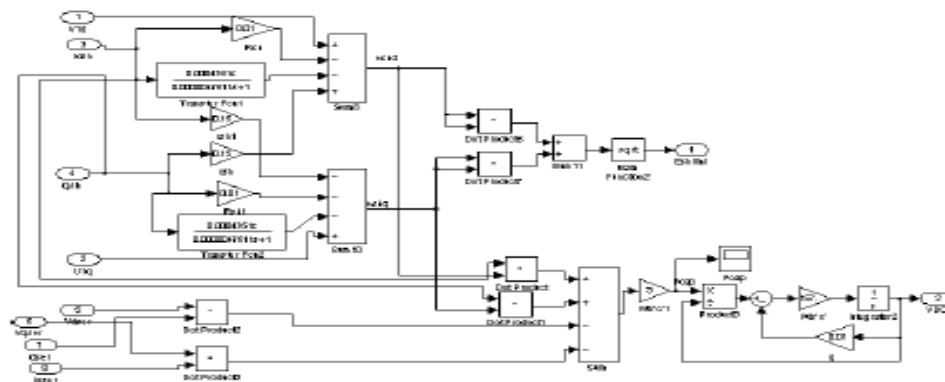


Fig.11: Inverter DC side Control Model

4.5 Load Modeling

Load was connected at the port1 of the UPFC. The real and reactive currents drawn by the load are transformed to calculate the its d-q components. The inputs to the load model are real and reactive power references. Currents in load will be delayed in practice by reactive energy storage elements. A delay time constant of 10ms is employed to take this into account.

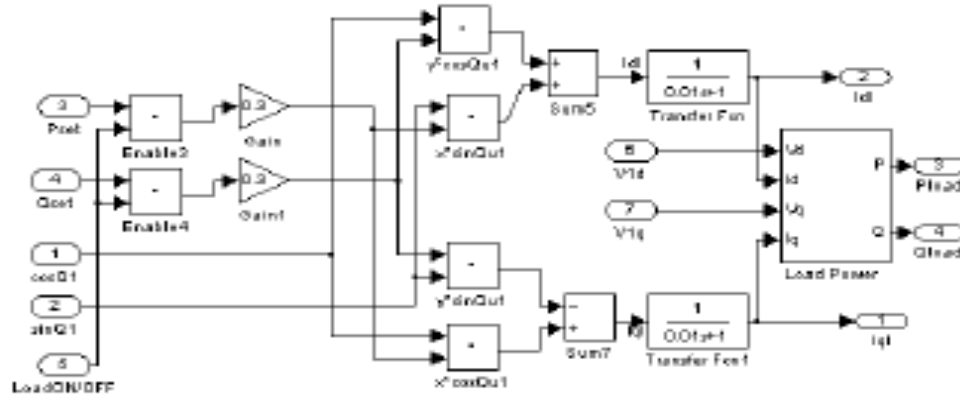


Fig.12: Load modeling

4.6 Series Inverter Control Modelling

To achieve real power and port 2 control we need to inject series voltage of appropriate magnitude and angle. The blocks are modelled using the product, trigonometric and mathematical functions available from nonlinear library.

VSI Inverter Modeling: The PWM-voltage source inverter was assumed to be instantaneous and infinitely fast to track the voltage reference template set by the control strategy, so it was implemented as a voltage amplifier with unity gain.

Inputs to this block are PRef and Vu2Ref. In these two PI controllers was used to get the real and reactive power references at the port1. PI parameters used in real power reference loop are $K_p=1$, $K_I=500$, $K_D=0.001$. Derivative control used to limit the initial peak overshoot. PI parameters used in voltage control loop are $K_p=20$, $K_I=7500$.

Power calculator Block:

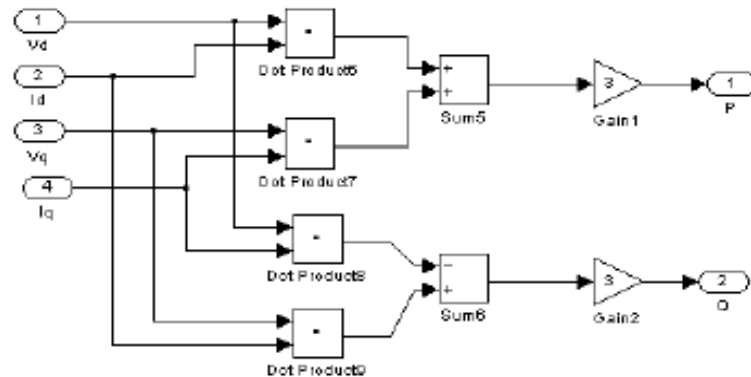


Fig.13: Power calculator block

5. TEST SYSTEM

The test system taken for simulation study of UPFC as shown below:

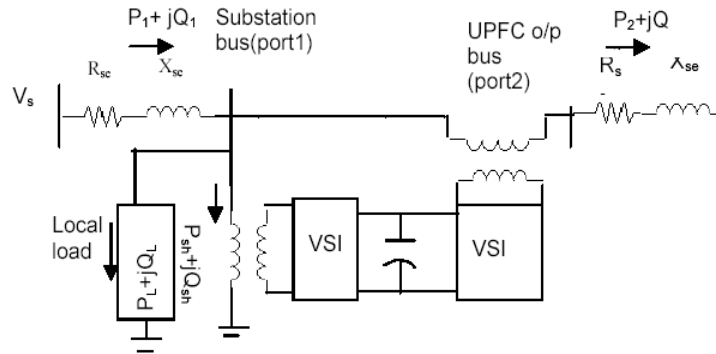


Fig.14: Test system

Specifications of the system taken for testing the simulation study are:

$$X_{se} = 0.075 \quad R_{se} = 0.0075$$

$$X_{sh} = 0.15 \quad R_{sh} = 0.01 \quad VDC_{ref} = 3.4 \text{ p.u}$$

$$g_{cap} = 0.02 \quad b_{cap} = 2$$

$$V_r = 1 \angle 0, \text{ Laod } 3 \text{ p.u with power factor } 0.8 (\text{lag}).$$

All the above quantities are on the UPFC MVA base (33.33 MVA), which is assumed to be 1/3rd of the transmission line MVA base.

6. RESULTS

After the simulation the various parameters of the UPFC are as follows:

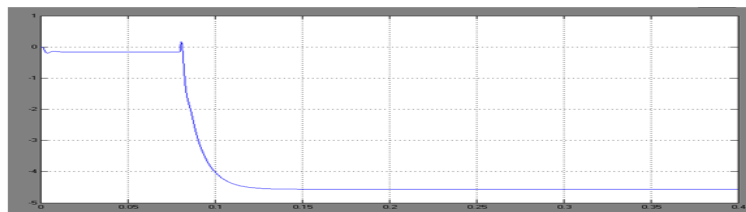


Fig.15: V1-A=Port1 phase-A voltage

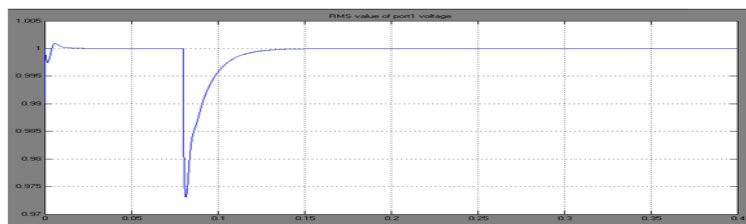


Fig.16: V1rms = RMS value of port 1 voltage

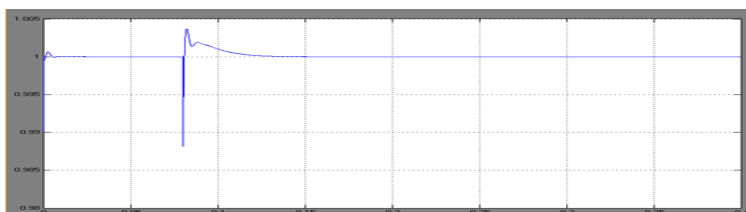


Fig.17: V2-A= Port 2 phase-A voltage.

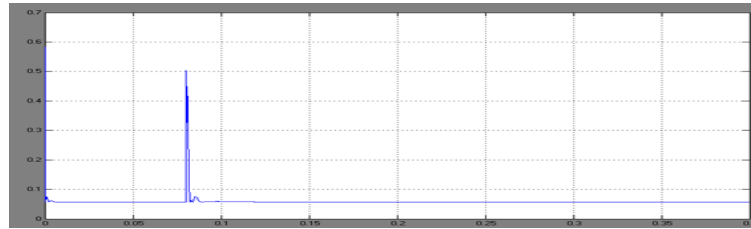


Fig.18: V2rms= RMS value of port2 voltage



Fig.19: Eserms= RMS value of series converter output voltage

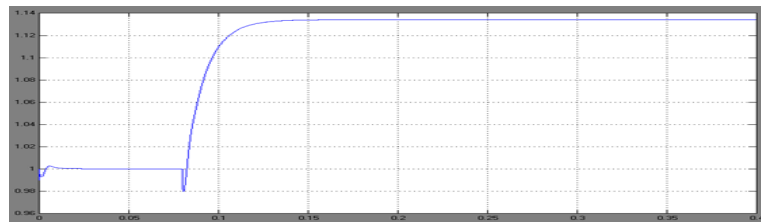


Fig.20: Eshrms= RMS value of shunt converter output voltage

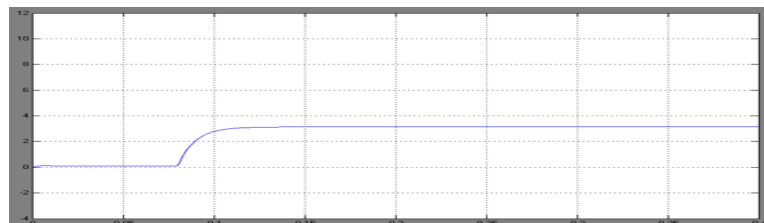


Fig.21: P1= Real power flow from sending end to port1 Measured at port1

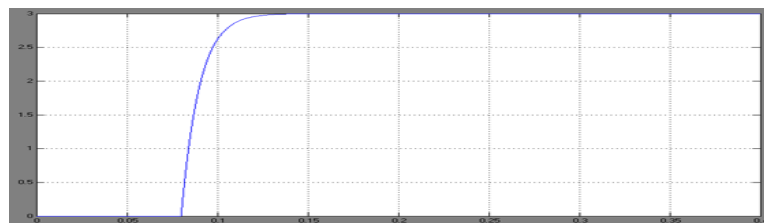


Fig.22: PL =Real power flow from port1 to load Measured at port 1.

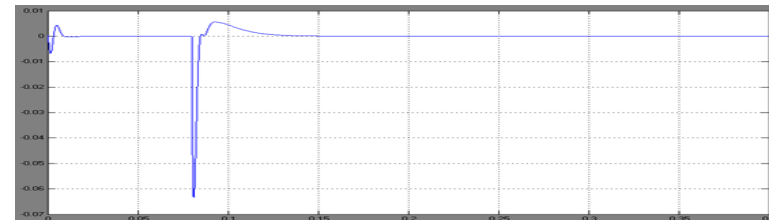


Fig.23: P2= Real power flow from port2 to receiving end Bus measured at port2

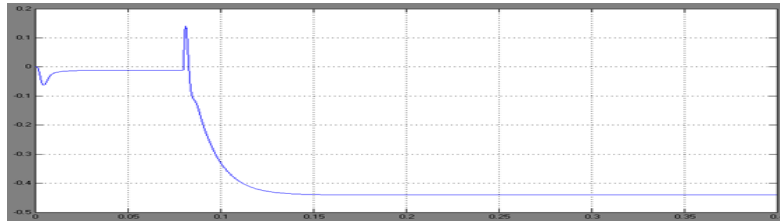


Fig.24: Q1=Reactive power flow from sending end to Port1 measured at port1

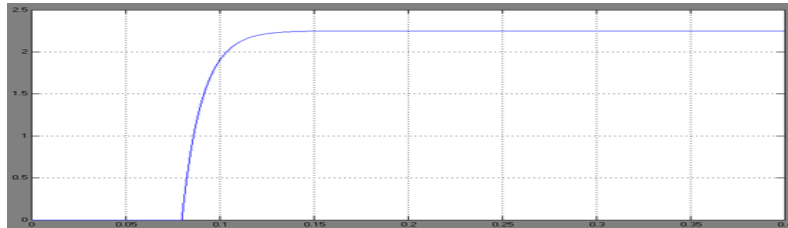


Fig.25: QL=Reactive power flow from port1 to load measured at port1

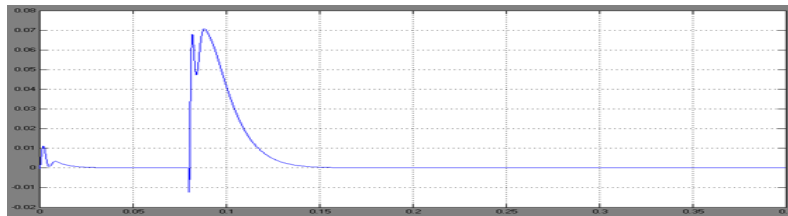


Fig.26: Q2=Reactive power flow from port2 to receiving end measured at port 2.



Fig.27: Idsh = Direct component of shunt current

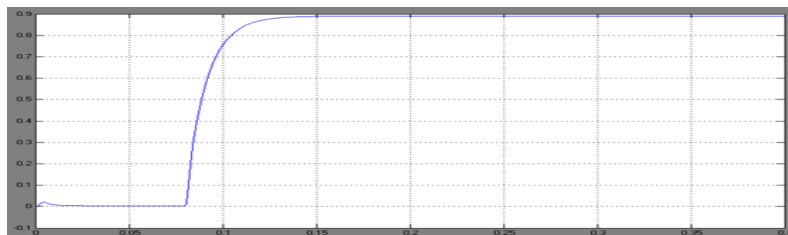


Fig.28: Iqsh = Quadrature component of shunt current

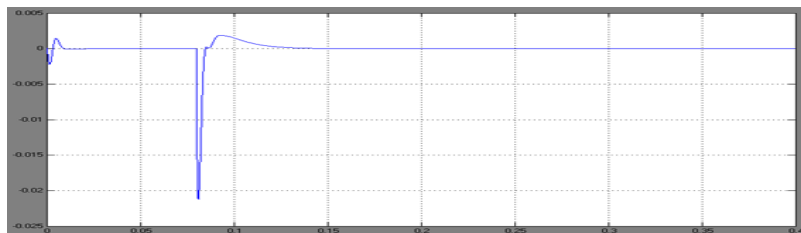


Fig.29: Idser = Direct component of series current.

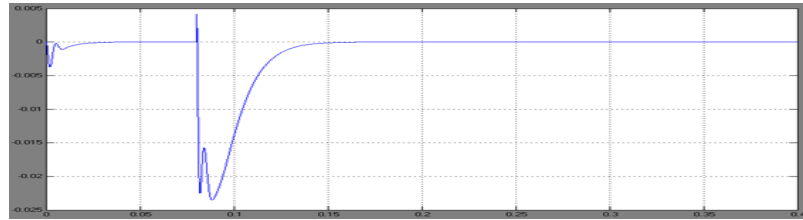


Fig.30: I_{qser} = Quadrature component of series current.

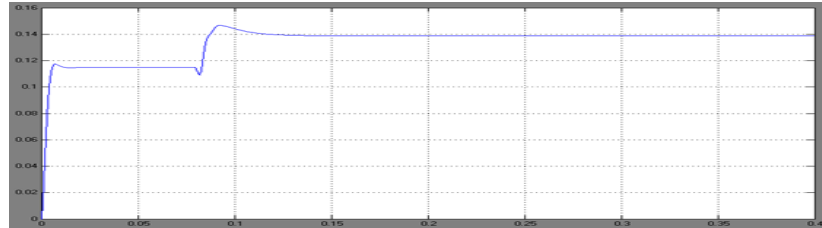


Fig.31: P_{sh} = Real power flow from port1 to shunt converter measured at port1

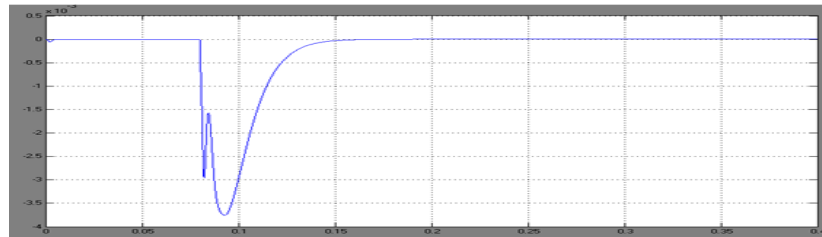


Fig.32: P_{inv} = Real power flow of the Inverter

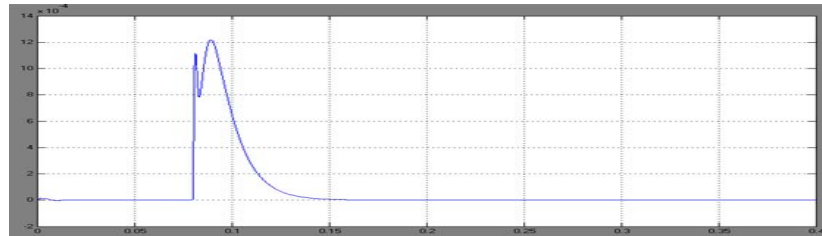


Fig.33: Q_{inv} = Reactive power flow of the Inverter

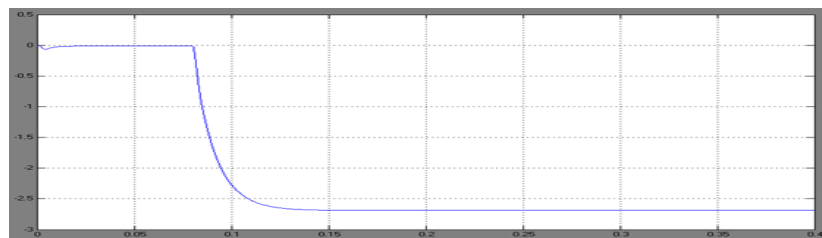


Fig.34: Q_{sh} = Reactive power flow from port1 to shunt converter measured at port1

7. CONCLUSION

A MATLAB-SIMULINK model was developed in this work for design and validation of UPFC control strategy for a UPFC located at a load substation using local measurements only. With this control approach, UPFC can perform independent control of transmittable real and reactive power at series output while regulating the shunt input voltage and maintaining the D.C. link capacitor voltage constant. The developed SIMULINK model was used to arrive at satisfactory control gain settings in various parts of the UPFC controller. Detailed simulation of UPFC system with bus voltage, UPFC second port voltage and line power flow control was carried out using the developed SIMULINK model for various cases involving load switching, step change in voltage reference and power flow references.

References

- [1] L.Gyugyi, C.D. Schauder, S.L. Williams, T.R.Rietman, D.R.Torgerson, A.Edris.,The Unified Power Flow Controller: A New Approach to Power Transmission Control., IEEE Trans .on Power Delivery, Vol.10, No.2 April 1995, pp.1085- 1097.
- [2] L.Gyugyi, . Unified Power Flow Concept for Flexible Ac Transmission Systems. IEEE Proc-C, Vol.139, No.4, July1992, pp.323-332.
- [3] Sanbao Zheng And Yoke Lin Tan . Dynamic Character Study of UPFC Based on Detailed Simulation Model .IEEE Power Conference 2000.
- [4] C.Schauder and H.Metha, . Vector Analysis and Control of Advanced Static Var Compensator. IEE Proc-C , Vol. 140, No.4, July 1993., pp. 299-306.
- [5] H.Fujita,Y.Watanabe, H. Akagi., .Control and Analysis of a Unified Power Flow Controller. IEEE Trans.on Power electronics Vol.14 No.6.Nov 1999.
- [6] I.Papic, P.Zunko, D.Povh, M.Weinhold,. Basic Control of Unified Power Flow Controller. IEEE Transactions On Power Systems, Vol.12, No.4.November 1997.
- [7] K.R.Padiyar, K.Uma Rao . Modeling and Control Of Unified Power Flow Controller for Transient Stability. A Journal on Electrical Power and Energy Systems Vol.No.21 (1999) 1-11.
- [8] Padiyar, K.R., Kulakarni, A.M., .Control Design and Simulation of Unified Power Flow Controller. IEEE Tans. on Power Delivery, Vol.13, No.4, October 1998, pp.1348-1354.

Books:

1. Understanding FACTS - L.Gyugyi & G. Hingorani (IEEE Press)

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