ISSN2394-3777 (Print)
ISSN2394-3785 (Online)
Available online atwww.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 14, April 2018

EXTENDED BOOST THREE-PHASE MATRIX CONVERTER HAVING BUCK BOOST ABILITY

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Abstract

This project presents a PI controller for three phase matrix converter (MC) operating as a BUCK BOOST CONTROLLER (BBC). A matrix converter allows the direct ac-ac power conversion without DC energy storage links. Therefore, the MC based BBC has reduced volume, reduced cost, reduced capacitors and power losses together with higher reliability.

A simplified steady state model of matrix converter based UPFC fitted with the modified venturini high frequency pulse width modulator is first used to design the linear controller for transmission line active and reactive power.

In order to minimize the resulting cross coupling between P and Q power controller. PI controllers are synthesized using different mode control technique. Linear controller show acceptable steady state behavior and designed P and Q power controllers using Matlab for simulink simulation package.

Introduction

The main intension of the power system is, to supply the required demand and to compensate the transmission loss, voltage and frequency. Increase in the energy demand leads higher requirement from the power system industry. Additional plants, substations and transmission lines have to be constructed. Generally used devices in the current power grid are mechanically controlled circuit breaker. Due to higher switching periods and detached operation, it is difficult to handle the repeatedly changing loads and to damp the transient oscillation quickly. To overcome these drawbacks large operational limits to protect the system from faults and dynamic fluctuation. This would increase the cost, reduce the efficiency and increases the complexity of the system which leads difficulty in operation and control. The FACTS are the power electronic devices installed at the high voltage side to make the system electronically controllable. The FACTS devices are capable to provide reactive power and active power to the grid quickly. By using the FACTS device compensation these would regulate the voltage of the entire system & power flow can be controlled acceptably.

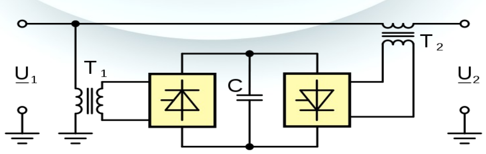

Fig1: schematic diagram of BBC

CURRENTLY, BUCK BOOST CONTROLLER (BBC). are the most adaptable and powerful flexible ac transmission system which allows a fast dynamic performance of the power transmission network, while providing reliable and precise control of both line active *P* and reactive *Q* power flow. The UPFC technology allows the operation of power transmission networks near to their maximum ratings by enforcing power flow through well-defined high voltage line corridors, without violating the transmission line thermal limits, and increasing network transient stability.

The BBC concept was proposed in the nineties by Gyugyi, consisting, two ac–dc converters, back to back connected through a common dc link using large high-voltage dc storage capacitors. The ac side of each converter is

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connected to the transmission line through a coupling transformer, with a shunt connection in one side and a series connection on the other, allowing bidirectional power flow control. The dc capacitor bank used in the UPFC topology to link the two back-to-back converters increases the UPFC weight, cost, volume and introduces extra losses. Replacing these two converters by a direct three-phase ac–ac matrix converter (MC) eliminates the dc-link capacitors, thus reducing costs, size, maintenance, while rising reliability and life. The ac–ac MC processes electrical energy directly without large storage needs, allows bidirectional power flow, guarantees close to sinusoidal input and output currents, and controls the voltages amplitude and frequency at adjustable power factor.

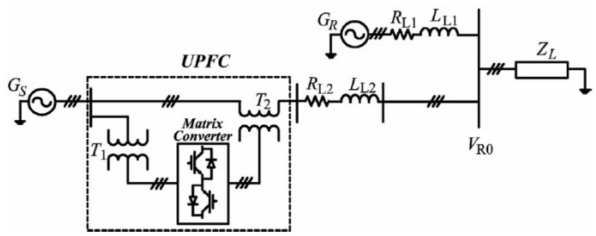

FIG 2: Transmission network with MC-BBC.

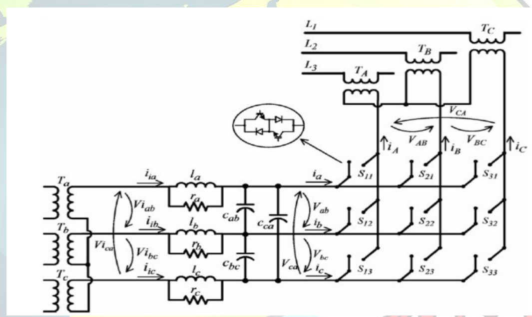

FIG3: Detailed diagram with MC-BBC.

1. METHODOLOGY

To model MC based UPFC can be effectively utilized to perform the following five important functions:

- Transfer of active power harvested from transmission line,
- Load reactive power requirement support connect different loads: resistive, Inductive and Capacitive,
- Design and control of PI linear controller
- Dynamic and steady state performance of P and Q power control techniques are evaluated and discussed using simulation
- Unbalanced reactive power can be balanced by MC.

2. Modeling of a BBC power system

A simplified model of the power transmission network using the projected MC-BBC is presented in Fig. 2, where $V_S$and V_R are the sending-end and receiving-end voltages, respectively, of $G_S$and $G_R$generators providing load Z_L. The MC is connected to transmission line 2, represented as a series inductance and resistance (L_{L2} and R_{L2}), through coupling transformers T_1 and T_2 .

A UPFC system diagram showing the connection of the MC to the transmission line is presented in Fig. 3. This diagram contains three-phase shunt input transformer (Ta, Tb , and Tc), three phase series output transformer (T_A, T_B, and T_C), and a three phase MC. The three phase LCR input low pass filter is required to bring back a voltage-source boundary to the MC input, enabling also smoother input currents.

A. Matrix converter Model

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For MC-BBC system modeling, the voltage source, the transformers, and the MC are all considered ideal. Supposing also ideal power semiconductors, each MC bidirectional switch S_{kj}(k, j ∈ {1, 2, 3}) can assume two probable states: "S_{kj}= 1" or "S_{kj}= 0," if the switch is closed or open, respectively

The nine MC switches can be represented as a 3 × 3 matrix

$$s=\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \quad (1)$$

Circuit topology restriction for k ∈ {1, 2, 3} implies that

$$\sum_{j=1}^{3} S_{kj}=1$$

Based on equation 1, the relation between load and input voltages can be expressed as follows:

$$[\, v_A v_B v_C]^T = \mathbf{S}\, [\, v_a v_b v_c]^T \quad (2)$$

The input phase currents can be related to the output phase currents (3), using the transpose of matrix **S**

$$[\, i_a i_b i_c]^T = \mathbf{S}^T [\, i_A i_B i_C]^T \quad (3)$$

From 27 probable switch patterns of three phase MCs, time variant vectors can be obtained in αβ coordinates, which are dependent on the input voltage sectors, while vectors for the remaining sectors can be obtained and αβ transformation to the relevant sector. Similarly, time-variant non rotating current vectors in αβ and dq coordinates synchronous with via input voltage can be obtained using (3) Applying dq coordinates to the input filter state variables presented in Fig. 2 & neglecting the effects of damping resistors, equation 4 can be written, where V_{id}, V_{iq} , i_{id}, and i_{iq}represent input voltages and input currents in dq components (at shunt transformer secondary) and V_d, V_q, i_d, and $i_q$are MC voltages and input currents in d and q components respectively

$$\frac{di_{id}}{dt}=\omega i_{iq}-\frac{1}{2l}V_d-\frac{1}{2\sqrt{3}l}V_q+\frac{1}{l}v_{id}$$

$$\frac{di_{iq}}{dt}=-\omega i_{id}+\frac{1}{2\sqrt{3}l}V_d-\frac{1}{2l}V_q+\frac{1}{l}v_{iq}$$

$$\frac{dV_d}{dt}=\omega V_q-\frac{1}{2\sqrt{3}C}i_{iq}+\frac{1}{2C}i_{id}-\frac{1}{2C}i_{id}+\frac{1}{2\sqrt{3}C}i_q$$

$$\frac{dV_q}{dt}=-\omega V_d+\frac{1}{2\sqrt{3}C}i_{id}+\frac{1}{2C}i_{iq}-\frac{1}{2C}i_{iq}-\frac{1}{2\sqrt{3}C}i_d$$

(4)

B. BBC Power System Steady-State Model

A BBC steady-state model can be used to design slow feedback controllers. Single phase MC equivalent circuit as a controllable voltage source (fig 2) is considered, with amplitude V_C and phase ρ, in series with line inductance L_2 ($L_2 = X_2/\omega$, $X_2 = X_{L2}+X_{L1}\|X_{ZL}$), ignoring line resistance and shunt capacitances, V_{R0} is voltage at load bus. From the sending end complex power obtained by the product of end voltage and complex conjugate of the line current, controllable parts of active and reactive powers, ΔP and ΔQ respectively.

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$$\Delta P = \frac{V_S V_C}{X_2} \sin \rho \tag{5}$$

$$\Delta Q = \frac{V_S V_C}{X_2} \cos \rho \tag{6}$$

These terms can both be controlled by changing the controllable voltage source amplitude V_C& phase ρ. However, considering an operating point near $\rho \approx \pi/2$, it can be said that amplitude $V_C$controls mainly the active power P, whereas the phase ρ can enforce the reactive power Q. Equations (5) and (6) are helpful in determining the needed maximum values of V_C, phase angle ρ, and operating gains. They will be also useful to design linear controllers.

C. BBC Power System Dynamic Model

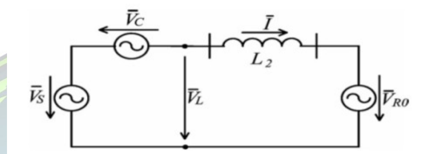

Fig4: Per phase equivalent circuit of the MC-UPFC and Transmission line

For dynamic system modeling, consider the three phase equivalent circuit of MC-UPFC transmission model based on fig 3, where the power source, the coupling transformers, and the MC are all considered ideal. Also, the Thevenin equivalent inductance and resistance are calculated, respectively, by $L_2 = X_2/\omega$ and $R_2 = R_{L2}+R_{L1}\|R_{ZL}$.

Considering a symmetrical and balanced three phase system and applying the Kirchhoff laws to the equivalent circuit gives the equations of the ac line currents in dqcoordinates

$$\frac{dI_d}{dt} = \omega I_q - \frac{R_2}{L_2} I_d + \frac{1}{L_2}\left(V_{ld} - V_{R0d}\right) \tag{7}$$

$$\frac{dI_q}{dt} = -\omega I_d - \frac{R_2}{L_2} I_q + \frac{1}{L_2}\left(V_{Lq} - V_{R0q}\right)$$

Applying the Laplace transform to system transfer function (7), (8) is obtained as follows:

$$\left(s + \frac{R_2}{L_2}\right)\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \omega \begin{bmatrix} I_q \\ -I_d \end{bmatrix} + \frac{1}{L_2}\begin{bmatrix} V_{Lq} - V_{R0q} \\ V_{Lq} - V_{R0q} \end{bmatrix} \tag{8}$$

Solving (8), line currents Id and Iq(9) are obtained as functions of voltages V_{Ld}, $V_{Lq}$and V_{R0d}, V_{R0q}in the sending and receiving end, respectively

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \frac{\frac{1}{L_2}\begin{bmatrix} s + \frac{R_2}{L_2}\omega \\ -\omega\, s + \frac{R_2}{L_2} \end{bmatrix}}{\left(s + \frac{R_2}{L_2}\right)^2 + \omega} \begin{bmatrix} V_{Lq} - V_{R0q} \\ V_{Lq} - V_{R0q} \end{bmatrix} \tag{9}$$

The active and reactive power of a sending end generator in dqcoordinates are given by

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$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_{Sd} V_{Sq} \\ V_{Sq} - V_{Sd} \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} \tag{10}$$

These dynamic equations will be used for the design of MC UPFC P and Q decoupled power controllers.

3. Synthesis of steady state model based controllers for MC-BBC

A. Design of an Active Power Controller

The synthesis of P power controller is based on a linearized model of (5). Assuming small variations near the operating point $\rho \approx \pi/2$, from (5), the incremental gain relative to V_C is

$$\frac{\Delta P_C}{\Delta V_C} \approx \frac{V_S}{X_2} \tag{11}$$

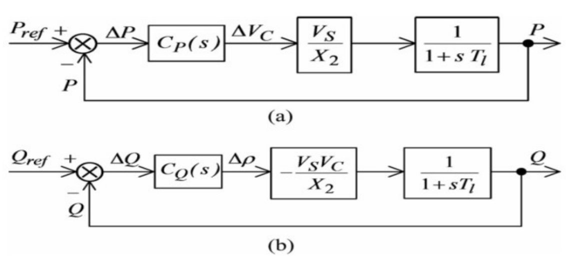

Fig 5: Block diagram for: (a) active power and (b) reactive power.

According to (5) considering the active power dynamics represented by a first-order transfer function with time constant T_l[15] and choosing a PI controller $C_P(s) = K_P[(1 + sT_{iP})/sT_{iP}]$ to guarantee zero steady state error, the block diagram from Fig. 5(a) is obtained. To determine the PI controller parameters, it is chosen to cancel the open-loop pole with the controller zero (i.e., $T_{iP} = T_l$). The closed-loop transfer function will be given by

$$\frac{P}{P_{ref}} = \frac{K_P V_S}{K_P V_s + sT_{iP} X_2} = \frac{1}{1 + s\frac{T_{iP} X_2}{K_P V_S}} = \frac{1}{1 + s\tau_{Peq}} \tag{12}$$

Its response time constant is $\tau_{Peq} = X_2 T_{iP}/K_P V_S$. The controller $C_P(s)$ proportional and integral gains are

$$k_{pP} = K_P = \frac{T_{iP} X_2}{\tau_{Peq} V_S}$$

$$k_{iP} = \frac{K_P}{T_{iP}} = \frac{X_2}{\tau_{Peq} V_S} \tag{13}$$

B. Design of a Reactive Power Controller

According to (6), for the reactive power near the operating point $\rho \approx \pi/2$, the incremental gain relative to phase ρ is

$$\frac{\Delta Q_C}{\Delta \rho} \approx -\frac{V_S V_C}{X_2} \sin\rho \approx -\frac{V_S V_C}{X_2} \tag{14}$$

The parameters of the reactive power PI controller $C_Q(s) = K_Q[(1 + sT_{iQ})/sT_{iQ}]$ [see Fig. 5(b)] can be obtained, considering the reactive power dynamics also represented by a first order transfer function with time constant T_l[15] and making $T_{iQ} = T_l$. The resulting closed-loop transfer function is

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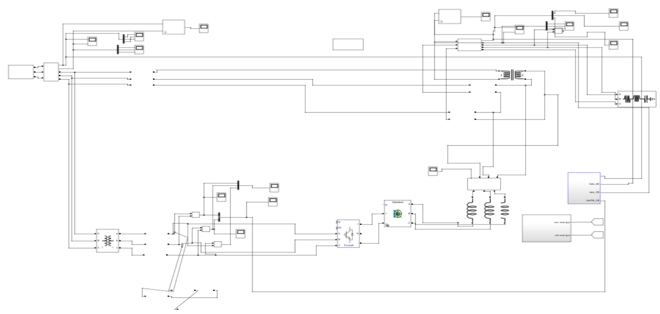
$$\frac{Q}{Q_{ref}}=\frac{V_S V_C K_Q}{V_S V_C K_Q+sT_{iQ}X_2}=\frac{1}{1+s\frac{T_{iQ}X_2}{V_S V_C K_Q}}=\frac{1}{1+s\tau_{Peq}} \quad (15)$$

Its response time constant is $\tau_{Qeq} = X_2T_{iQ}/ K_QV_SV_C$. The controller $C_Q(s)$ proportional and integral gains are

$$k_{pQ} = K_Q=\frac{T_{iQ}X_2}{\tau_{Qeq}V_S V_C}$$

$$k_{iQ} = \frac{K_Q}{T_{iQ}}=\frac{X_2}{\tau_{Qeq}V_S V_C} \quad (16)$$



The PI controllers for ΔP_C and ΔQ_C will serve to obtain simulation and experimental results, where MC switches drive signals are generated using a Venturini based high frequency PWM.

$$m_{kj}(t)=\frac{1}{3}+\left(\frac{1}{3}\right)\left\{\left(\frac{v_k v_j}{V_i^2}\right)+\left(4/3\sqrt{3}\right)q\sin\left(\omega_i t-\beta_k\right)\sin\left(3\omega_i t\right)\right\}$$

k=a,b,c. j=A,B,C. $q=V_0/V_i$ and $\beta_k=0,\frac{2\pi}{3},\frac{4\pi}{3}$ (17)

This PWM technique allows close sinusoidal output voltages with amplitude defined by the P power controller and phase is defined by the Q power controller as well as almost sinusoidal input currents with close to unity input power factor.

4. BLOCK DIAGRAM

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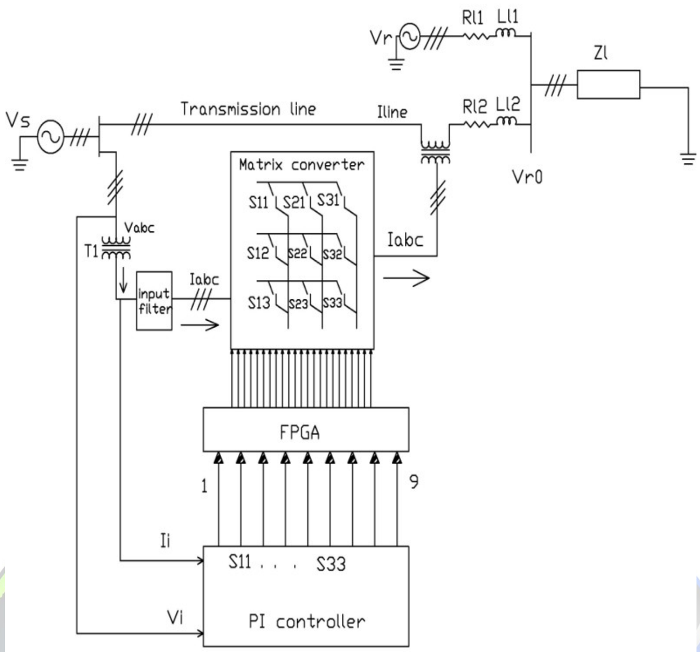
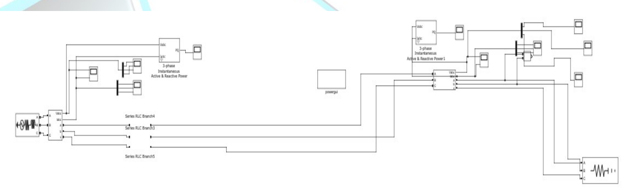


Fig 6: Control scheme for the three-phase matrix converter operating as BBC.

➢ **Matrix converter:** Among the most popular features in power frequency changers are :

i. Simple and compact power circuit.
ii. Generation of load voltage with arbitrary amplitude and frequency.
iii. Sinusoidal input and output currents.
iv. Operation with a unity power factor for any load.
v. Regeneration capability.

➢ **FPGA :** It stands for Field Programmable Gate Array. It is an integrated circuit designed to be configured after manufacturing. The FPGA configuration is usually specified using a hardware description language (HDL). FPGAs have an array of programmable logic blocks, and hierarchy of reconfigurable interconnects which allow the blocks to be "wired together". The output from the transformer T1 is fed to the FPGA through PI controller which in turn fed signal to the Matrix converter.



➢ **Transformers :** Transformers are used at two end i.e at sending end and receiving end.Since the entire system is working on very high voltage thus Step UP transformers are used for the effective working of the transformers

➢ **Filter :**In the proposed system high frequency filter placement were chosen to obtain control parameters almost independent of load and filter characteristics.

➢ **PI controller:** It stands for Proportional Integral Controller. In the proposed system Linear PI controllers are used obtained from a linear P and Q steady-state power UPFC linearized model,around an operating point, using a modified Venturini high frequency MC pulse width modulator (PWM)

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5. SIMULATION

5.1 With conventional converter

The performance of a conventional control of distribution system is evaluated using MATLAB/SIMULINK SIMPOWERSYSTEMS to represent conventional converters, transformers, sources and transmission lines, and SIMULINK blocks to simulate the control system.

Fig7: Simulation model of conventional control of distribution system.

The prototype of conventional model is built using three phase three level Neutral Point Clamped (NPC) Converter and three phase Inverter which consists of power electronic devices IGBT/diode.+
The device on state resistance, snubber resistance of three-level NPC is 0.001ohms and 1*10^6ohms.

5.2 Without converters

The performance of a distribution system without using any converters is evaluated using the MATLAB/SIMULINK SIMPOWERSYSTEMS.

Fig 8:Simulation model of distribution system without any converters

The distribution system without incorporating any converters is built using three phase source, distribution lines, three phase load and measuring devices. The input is given as 230kV, 50Hz.

5.3 With Matrix Converter based Buck Boost Converter

The performance of a proposed direct control system is evaluated with a detailed simulation model using the MATLAB/SIMULINK SIMPOWERSYSTEMS to represent a matrix converter, transformers, sources and transmission lines, and SIMULINK blocks to simulate the control system. Ideal switches are considered to simulate matrix converter semiconductors reducing simulation times.

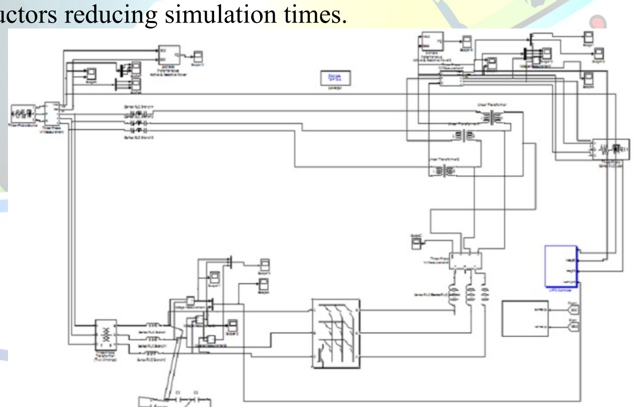

Fig9:Simulation Circuit of MC-BBC

6. RESULTS & DISCUSSION

SI.NO	CONVERTERS	INPUT RMS VOLTAGE in volts(KV)	OUTPUT RMS VOLTGE in volts (KV)	VOLTAGE TRANSFER RATIO
01.	CONVENTIONAL CONVERTER	230	165.64	72.01%
02.	WITHOUT MC-BBC CONVERTER	230	134.11	58.30%
03.	WITH MC-BBC CONVERTER	230	219.79	95.56%

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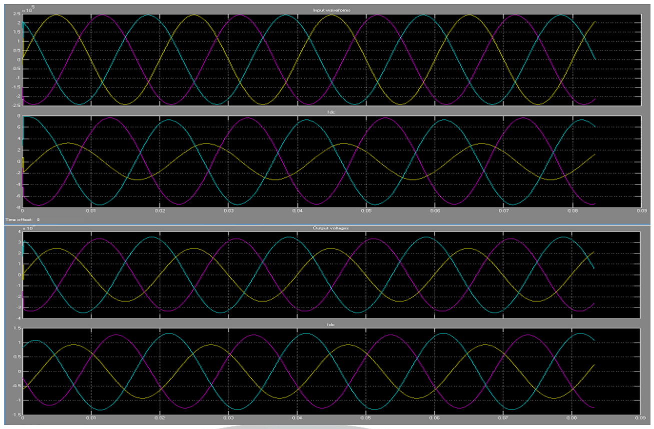
Fig 10:Input and Output Voltage-Current Waveform of MC-BBC

Difference in voltage transfer ratio in different converters

It is found from the simulation results that P and Q power flow can be controlled using MC as an UPFC controller.

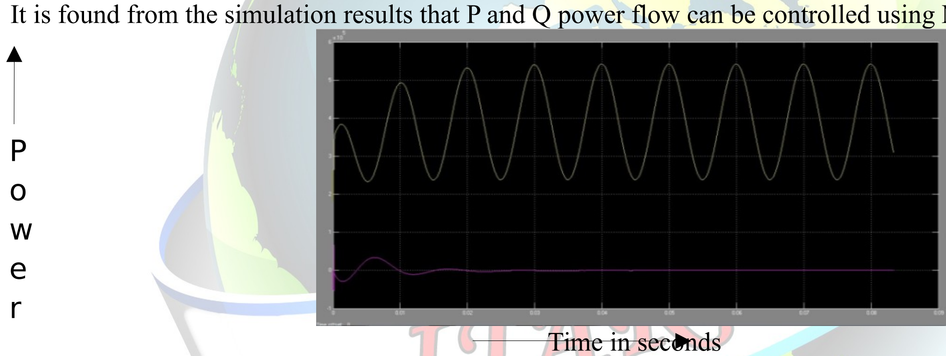

Fig 11: Output power of MC-BBC with RLC load

CONCLUSION

This project designs and PI control methods for active and reactive power flow using MCs connected to power transmission lines as UPFC: PI linear controllers and different-mode based.MC-UPFCs need almost no energy storage, which is a clear advantage in the converter sizing and design, and the proposed controllers and high frequency filter placement were chosen to obtain control parameters almost independent of load and filter characteristics.

Simulation result shows that P and Q power flow can be effectively controlled using the MC-UPFC using PI. The PI linear P and Q power controllers using a modified Venturini high-frequency PWM show a small cross coupling and slower response times.

This project worked on “Matrix converter based UPFC using PI controller method” also we can use this method for other FACTS controllers in the future and it is utilized for smart grid system.

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