COMPARISON AND ANALYSIS OF UPFC AND TRANSFORMERLESS UPFC DEVICE FOR POWER QUALITY ENHANCEMENT IN POWER SYSTEM

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Abstract

In this paper, a modulation and control method for the new transformer-less unified power flow controller (UPFC) is presented. As is well known, the conventional UPFC that consists of two back-to-back inverters requires bulky and often complicated zigzag transformers for isolation and reaching high power rating with desired voltage waveforms. To overcome this problem, a completely transformer-less UPFC based on an innovative configuration of two cascade multilevel inverters (CMIs) has been proposed. The new UPFC offers several advantages over the traditional technology, such as transformer-less, light weight, high efficiency, low cost and fast dynamic response. This paper focuses on the modulation and control for this new transformer-less UPFC, including optimized fundamental frequency modulation (FFM) for low total harmonic distortion (THD) and high efficiency, independent active and reactive power control over the transmission line, dc-link voltage balance control, etc.

Introduction

The power quality issues are so much increased in the latest time. So, for power quality improvement the use of FACTS devices is increased, and they become much popular compare to normal filtering devices. Facts devices used power electronics devices to improve power quality and providing control on voltage, current, power flow, stability, etc. of given transmission line or power system. FACTS devices can relate to the transmission line in different configurations like series with the power system (series compensation) and shunt with the power system (shunt compensation) and in some cases it will be connected in series and shunt compensation. The example of these configurations of facts devices are the static VAR compensator and static synchronous compensator (STATCOM) are connected in shunt. At the other side static synchronous series compensator (SSSC) and thyristor-controlled series capacitor (TCSC) are connected in series.

And the third one configuration example is thyristor controlled phase shifting transformer and unified power flow controller (UPFC) are connected in a series and shunt combination. In the series compensation the FACTS devices are connected in series with the power system and they will be works as a controllable voltage source. In shunt compensation power system has been connected in shunt with the FACTS devices and they will be works as a controllable current source. The effectiveness and capability of FACTS devices are very high due to that it will increasing the power transfer capability of the transmission lineand also improves the stability of the given system. In this the rating of a shunt FACT device has been selected in such a way that the receiving end voltage becomes equal to sending end voltage at which bus the shunt FACT device has been connected. A series capacitor is placed at the centre to get the maximum power transfer capability and compensation efficiency for the selected rating of the shunt FACTS device. In earlier times for power quality improvement there is active filter and passive filter based on current source and voltage source topology has been used. But they have some limitation due to which their use has been reduced in the modern times. In place of these conventional devices there are different FACTS devices has been established and used in the power system. The unified power flow controller (UPFC) is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (voltage magnitude, impedance, and phase angle) [1]. The conventional UPFC consists of two back-to-back connected voltage source inverters (VSIs) that share a common dc link. The injected series voltage from Inverter-2 can be at any angle with respect to the line current, which provides complete flexibility and controllability to control both active and reactive power flows over the transmission line. The resultant real power at the terminals of Inverter-2 is provided or absorbed by Inverter-1 through the common dc link. As a result, UPFC is the most versatile and powerful flexible ac transmission systems (FACTS) device. It can effectively reduce congestions and increase the capacity of existing transmission lines. This allows the overall system to operate at its theoretical maximum capacity.

UNIFIED POWER FLOW CONTROLLER (UPFC)

The UPFC is the most versatile FACTS-equipment and can insert a voltage in series with the line. This voltage can have any phase and magnitude referred to the line voltage. The UPFC consists of a parallel and a series branch, each consisting of a three-phase transformer and a PWM converter. Both converters are operated from a common dc link with a dc storage capacitor. The real power can freely flow in either direction between the two-ac branches. Each converter can independently generate or absorb reactive power at the ac output terminals [1]. The controller provides the gating signals to the converter valves to provide the desired series voltages and simultaneously drawing the necessary shunt currents, In order to provide the required series injected voltage, the inverter requires a dc source with regenerative capabilities. One possible solution is to use the shunt inverter to support the dc bus voltage. The pulse width modulation (PWM) technique is used to provide a high-quality output voltage, to reduce the size of the required filter, and to achieve a fast-dynamic response [1]. The harmonics generated by the inverter are attenuated by a second order filter, providing a low THD voltage to the transformer [3]. The Unified Power Flow Controller (UPFC) was proposed' for real turn-off time control and dynamic compensation of ac transmission systems, providing the necessary functional flexibility required to solve many of the problems facing the utility industry.

The Unified Power Flow Controller consists of two switching converters, which in the implementations considered are voltage sourced inverters using gate thyristor valves, as illustrated in Fig. These inverters, labelled "Inverter1" and "Inverter 2" in the figure, are operated from a common dc link provided by a dc storage capacitor. This arrangement functions as an ideal auto ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminal since the series branch of the UPFC can inject a voltage with variable magnitude and phase angle it can exchange real power with the transmission line. The UPFC is a combination of a static compensator and static series compensation. It acts as a shunt compensating and a phase shifting device simultaneously.

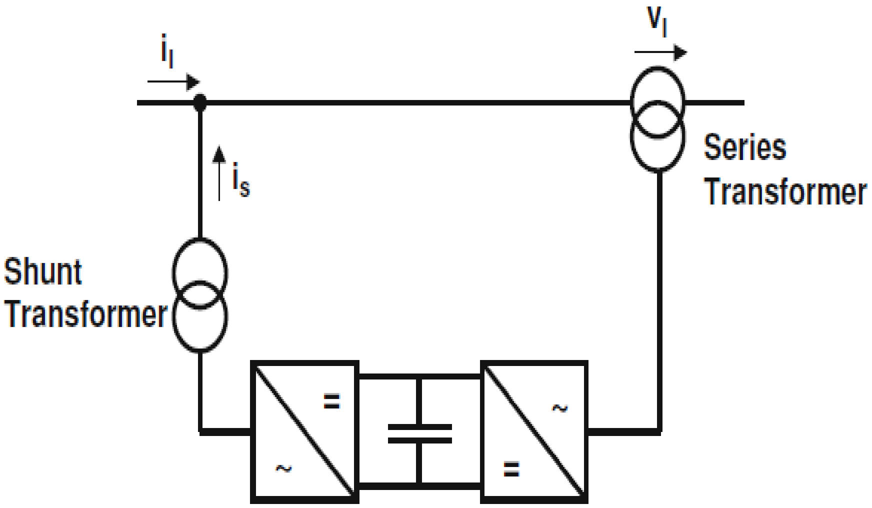


Figure Principle configuration of an UPFC

TRANSFORMERLESS UNIFIED POWER FLOW CONTROLLER (UPFC)

The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways. Direct Voltage Injection Mode: The reference inputs are directly the magnitude and phase angle of the series voltage. Phase Angle Shifter Emulation mode: The reference input is phase displacement between the sending end voltage and the receiving end voltage. Line Impedance Emulation mode: The reference input is an impedance value to insert in series with the line impedance Automatic Power Flow Control Mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes. The enabling technology of modularity, scalability makes it easy installation anywhere in the existing grid. Furthermore, the transformer-less UPFC helps maximize/optimize energy transmission over the existing grids to minimize the need for new transmission lines. Resulting increase in the transfer capability of the grid, combined with the controllability and speed of operation of the devices, will enable increased penetration of renewables and demand response programs. Finally, it will reduce transmission congestion and increasing dynamic rating of transmission assets.

With the unique configuration of the series and shunt CMIs, the transformer-less UPFC has some new features:

1. Unlike the conventional back-to-back dc link coupling, the transformer-less UPFC requires no transformer, thus it can achieve low cost, light weight, small size, high efficiency, high reliability, and fast dynamic response;

2. The shunt inverter is connected after the series inverter, which is distinctively different from the traditional UPFC. Each CMI has its own dc capacitor to support dc voltage;
3. There is no active power exchange between the two CMIs and all dc capacitors are floating;
4. The new UPFC uses modular CMIs and their inherent redundancy provides greater flexibility and higher reliability.

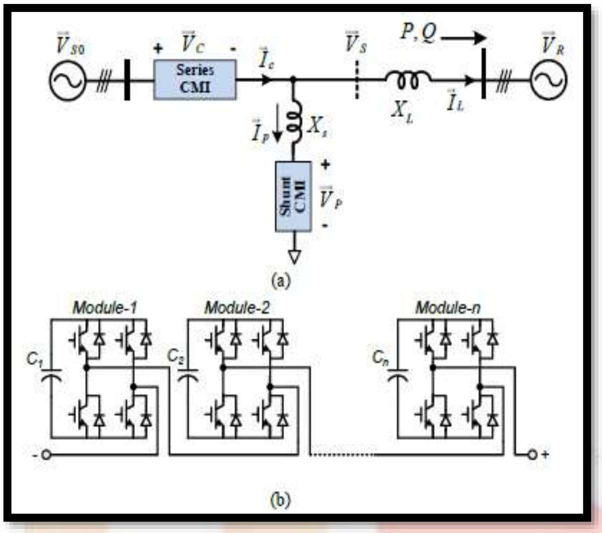


Figure New transformer-less UFPC, (a) System Configuration of Transformer-less UPFC , (b) One phase of the cascaded multilevel inverter

<u>MODELLING AND SIMULATION</u>

MATLAB DESIGN OF THREE PHASE COMPENSATED NETWORK WITHOUT UPFC

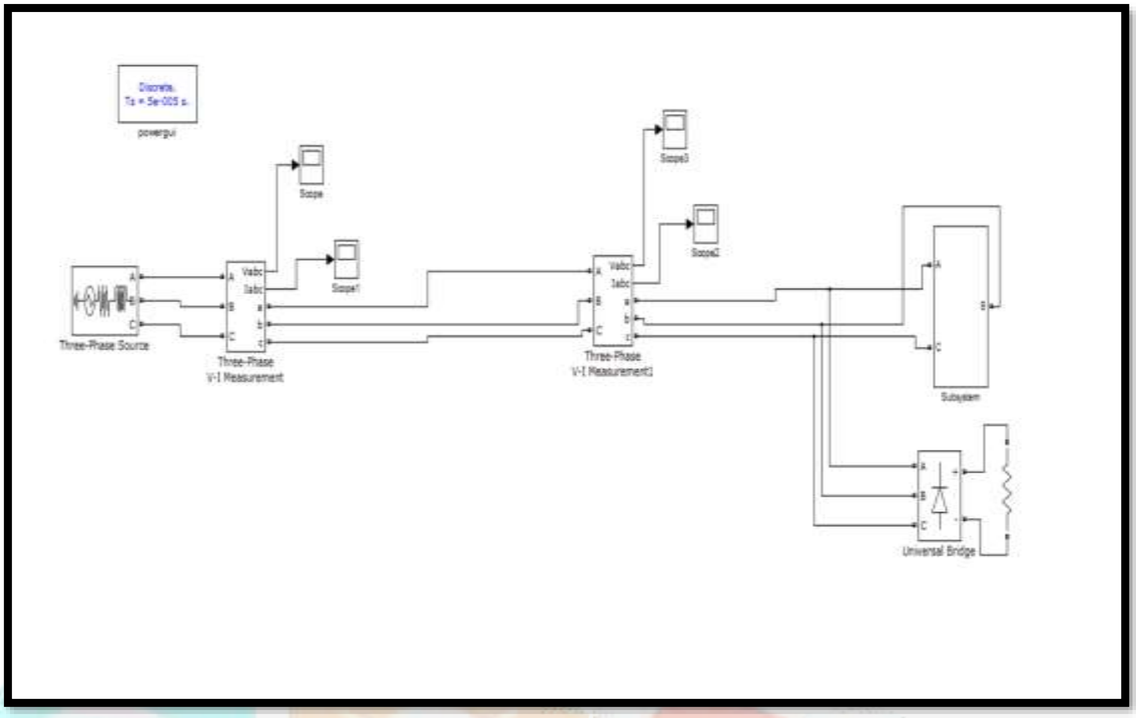


Fig-Matlab model of three phase series compensated network

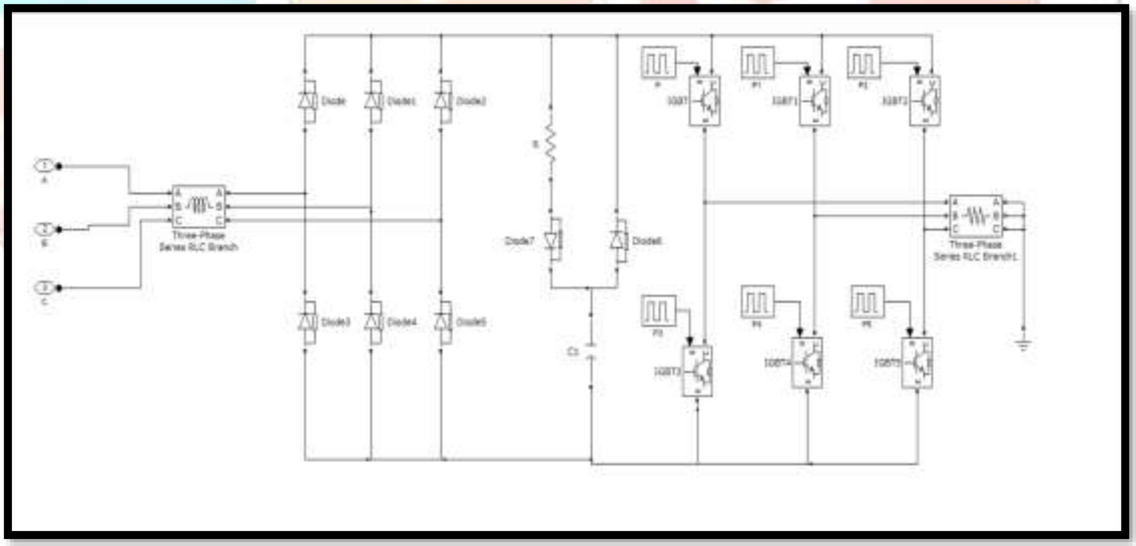


Fig- Nonlinear switching load

Simulation Results

The simulation results of Voltage and current at source side and load side are shown in fig below with effects in current due to Nonlinear switching load.

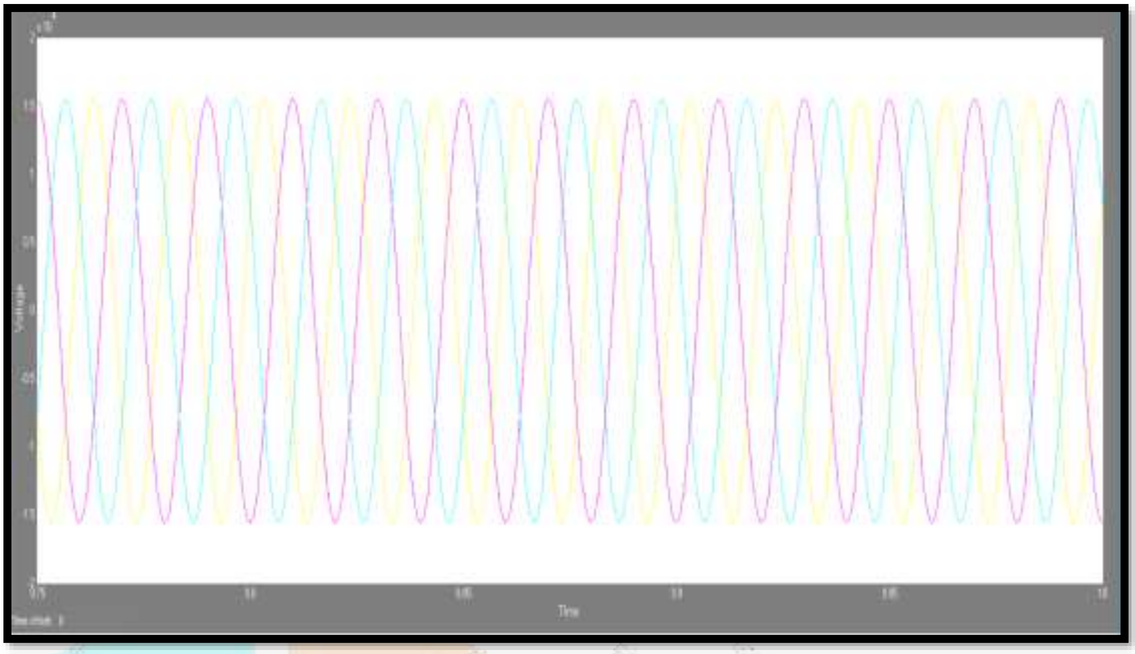


Fig Source Side Voltage

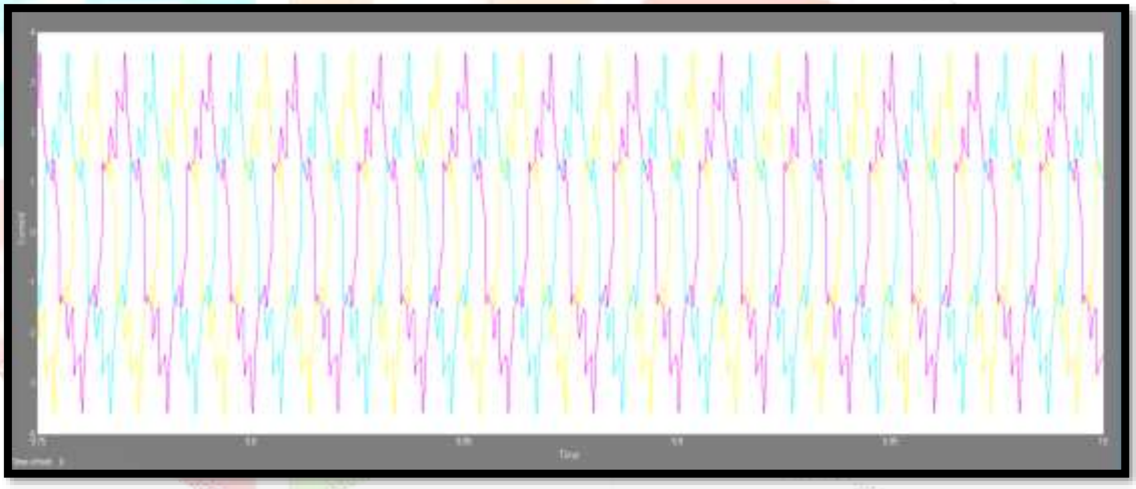


Fig Source side current

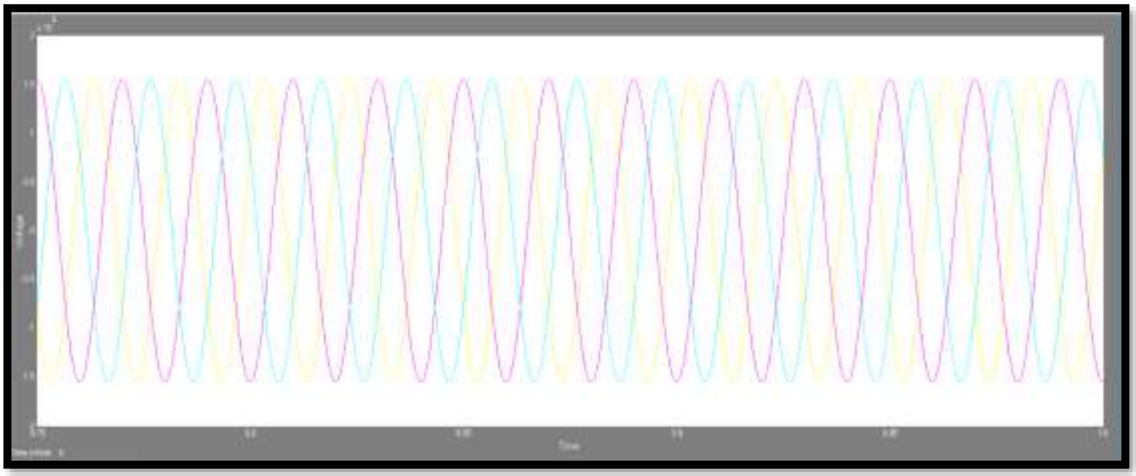


Fig Load side voltage

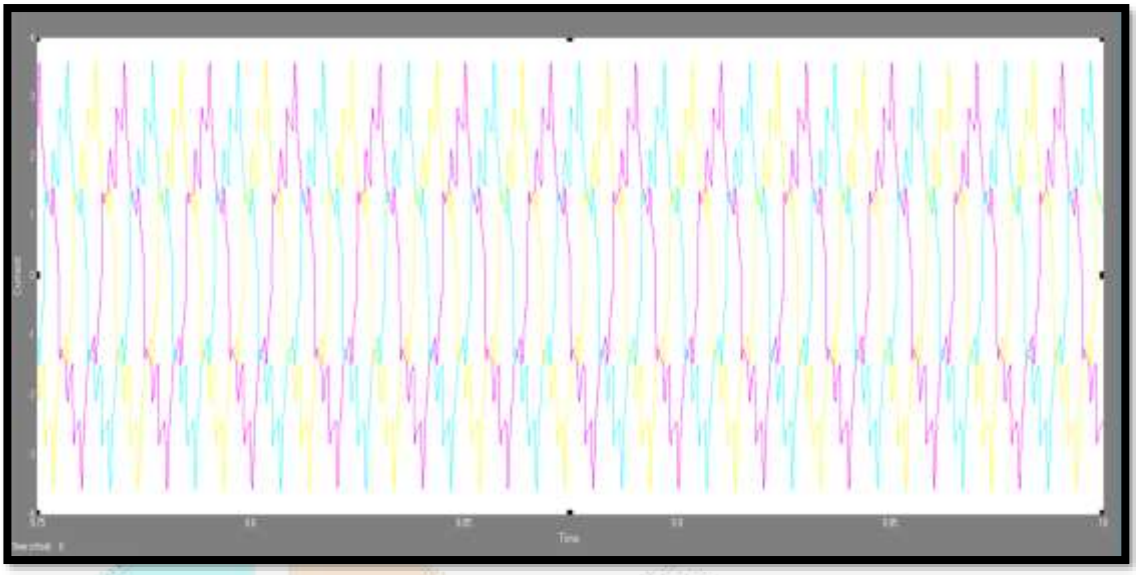


Fig load side current

MATLAB DESIGN OF UPFC AND CONNECTION WITH THREE PHASE SYSTEM

From the above simulation results we can say that the three-phase system without UPFC device generates distorted voltage, current and power. The value of these output quantities does not remain constant. So, we have to interconnect the UPFC device with this three-phase compensated network as shown in the fig below. As shown in the fig below the UPFC device is connected between source side and load side. The design of UPFC includes the VSC at input side and one VSC at output side. After the interconnection of UPFC system with three phase compensated network the output value of voltage, current and power becomes constant and pure sinusoidal.

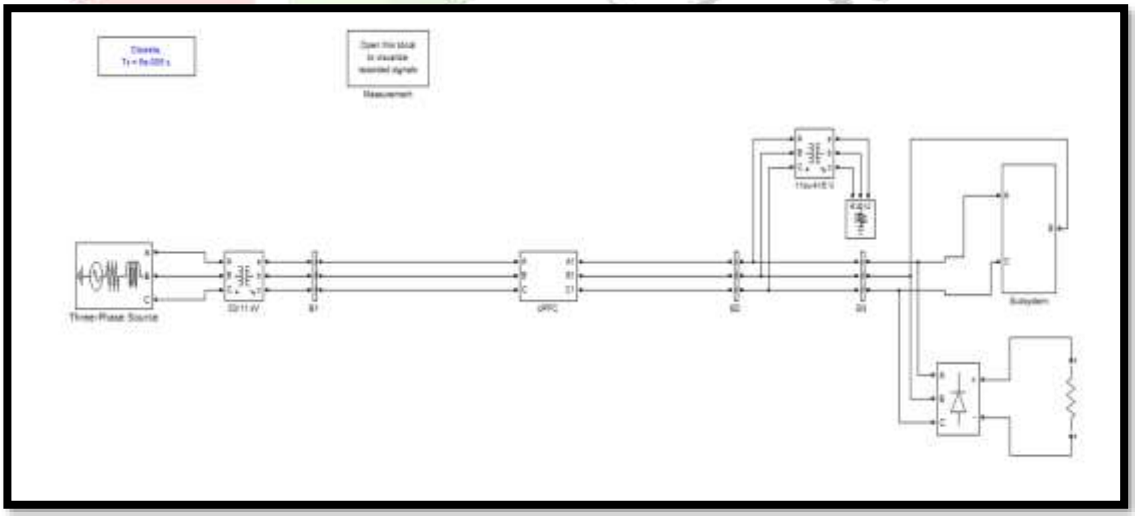


Fig Three phase compensated network connect with UPFC system

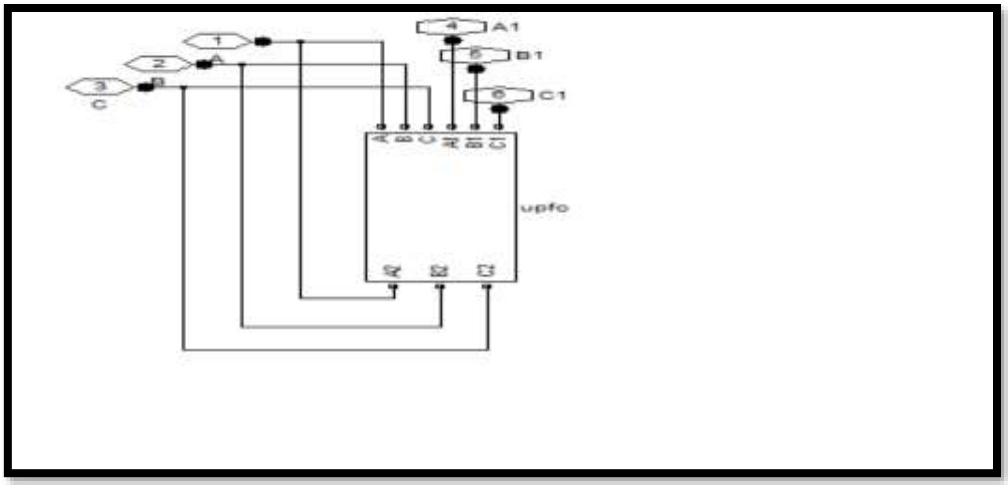


Fig UPFC Subsystem

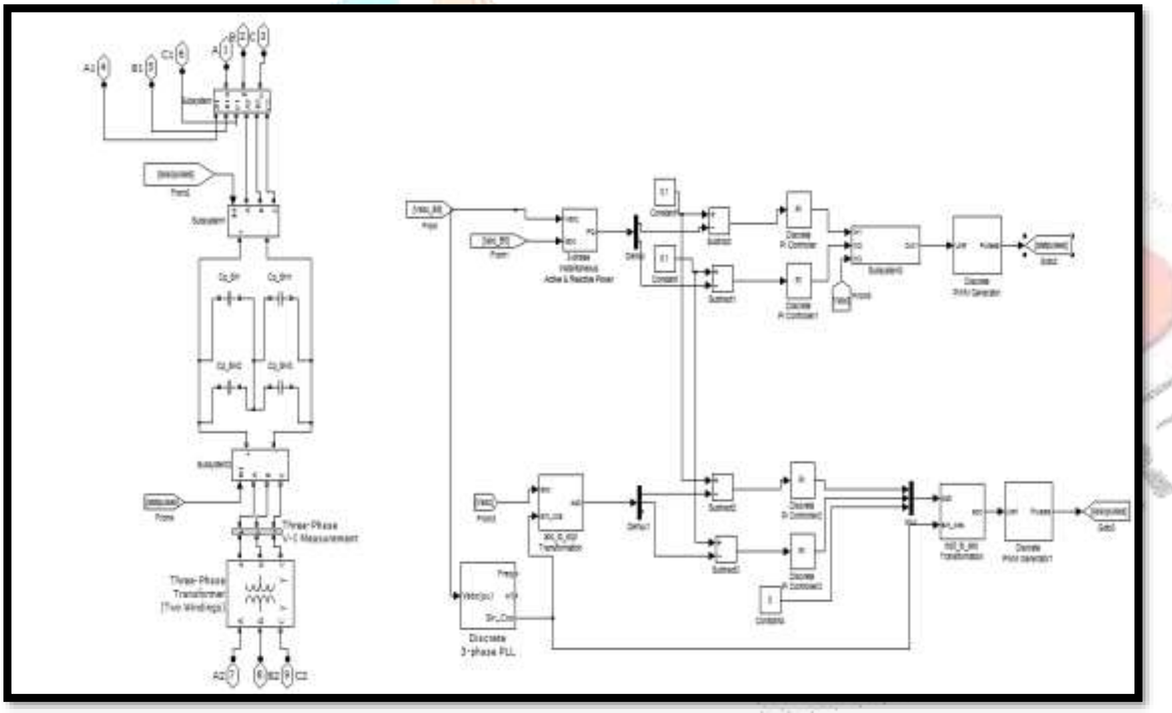


Fig Configuration of UPFC System

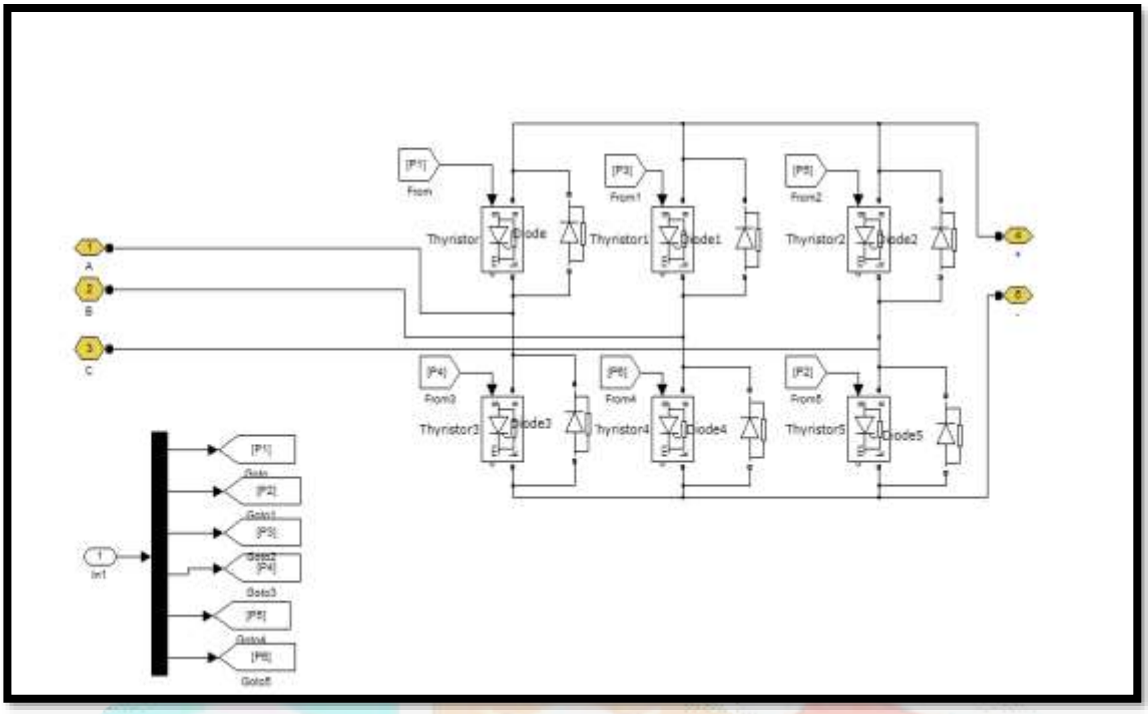


Fig VSC configuration in UPFC design

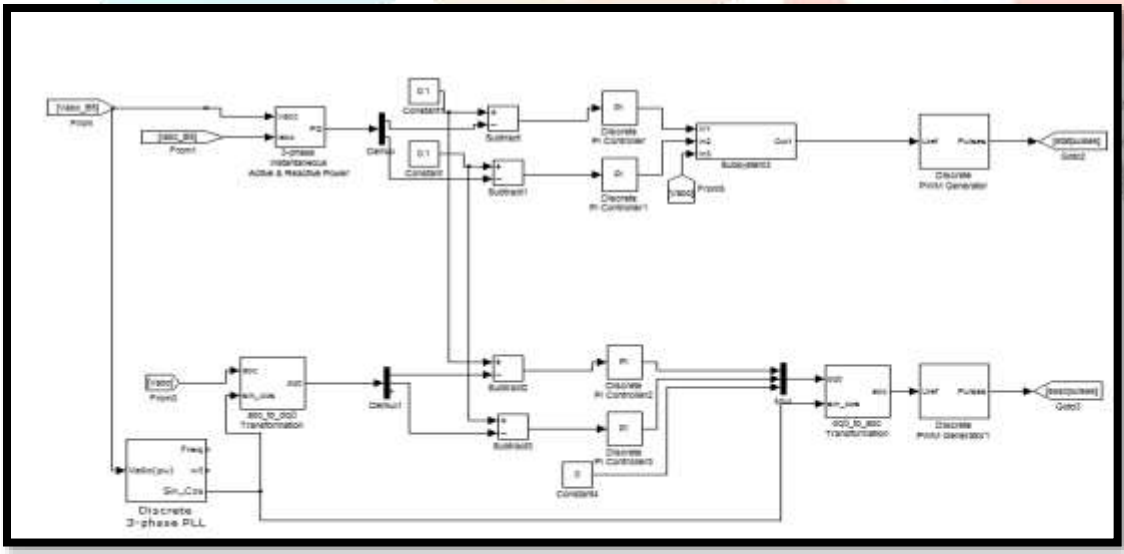


Fig Control Strategy of UPFC System

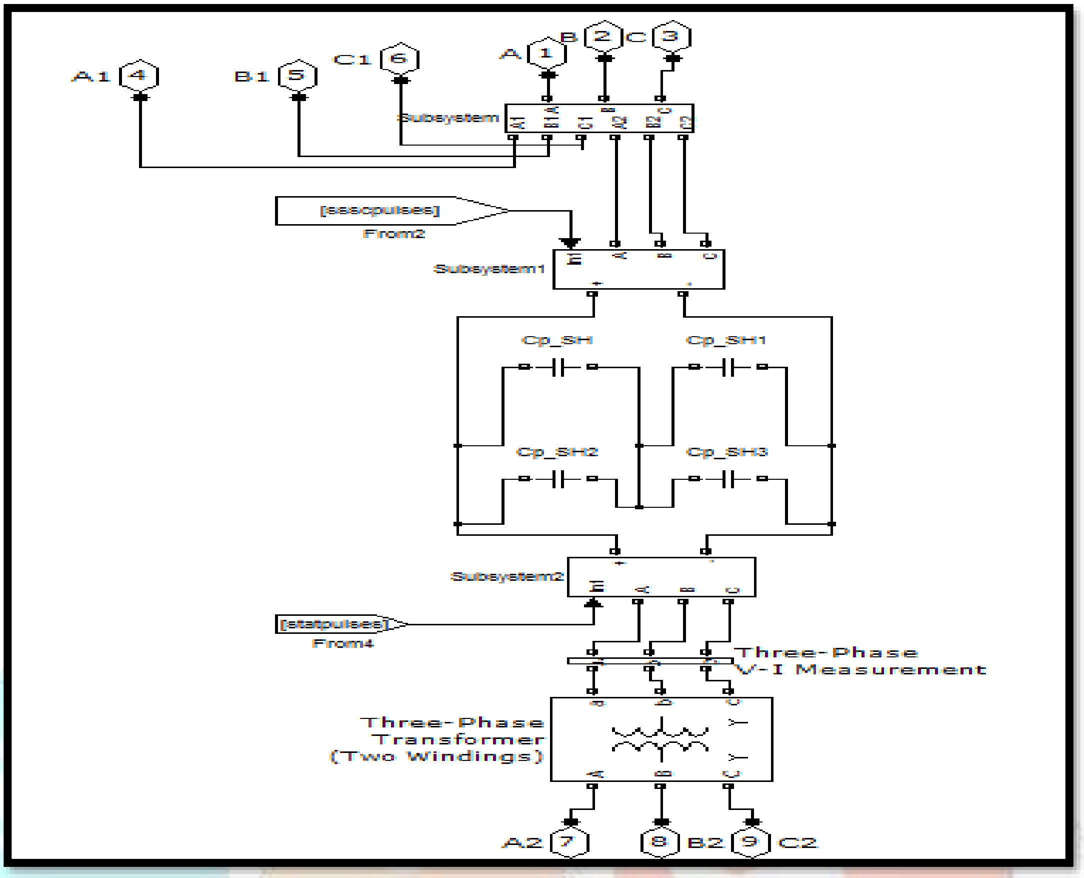


Fig Controlling Subsystem

Simulation Results: -

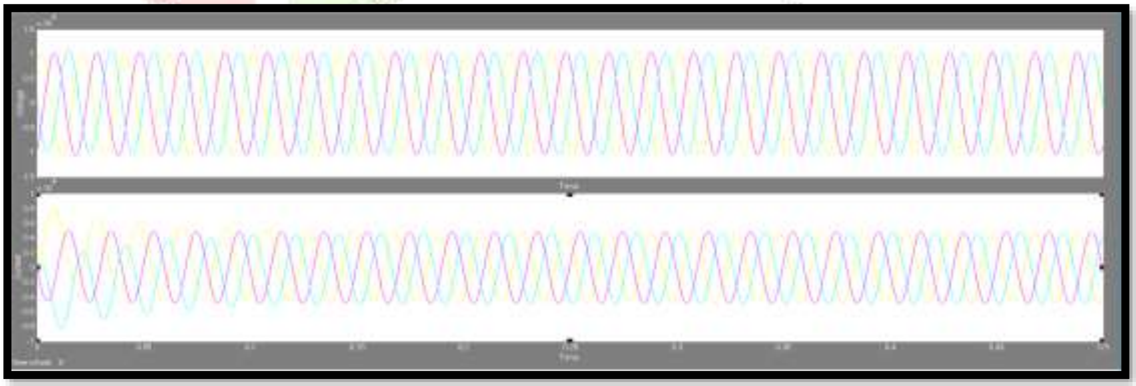


Fig Voltage and Current waveform at Source Side (B-1)

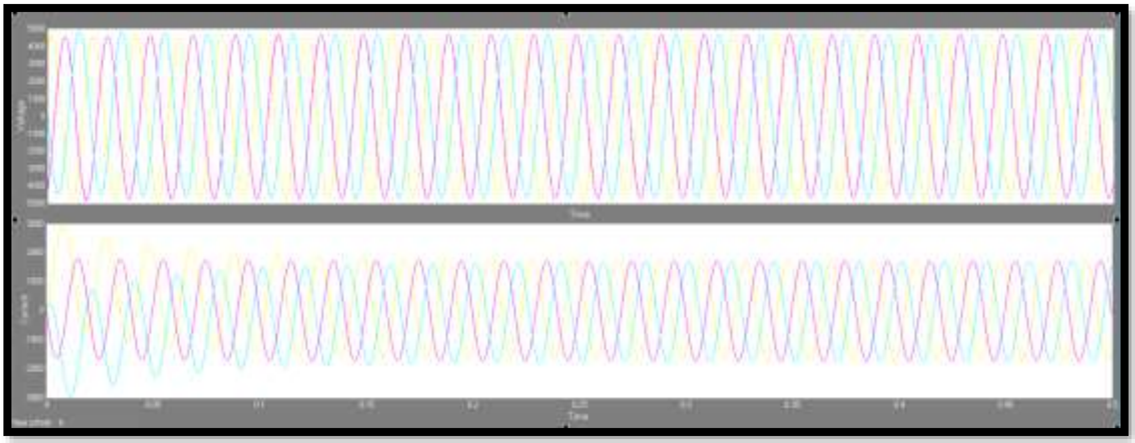


Fig Voltage and Current waveform at load Side (B-2)

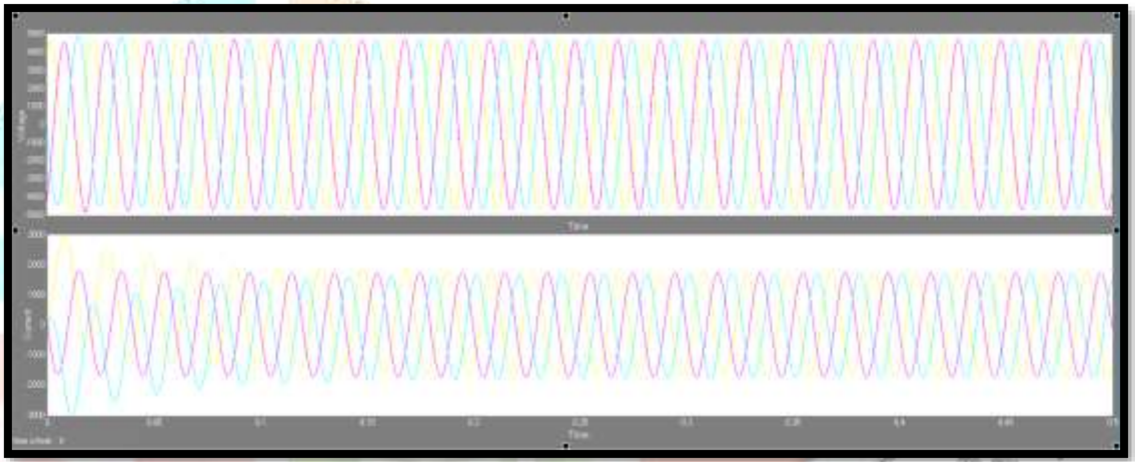


Fig Voltage and Current waveform at load Side (B-3)

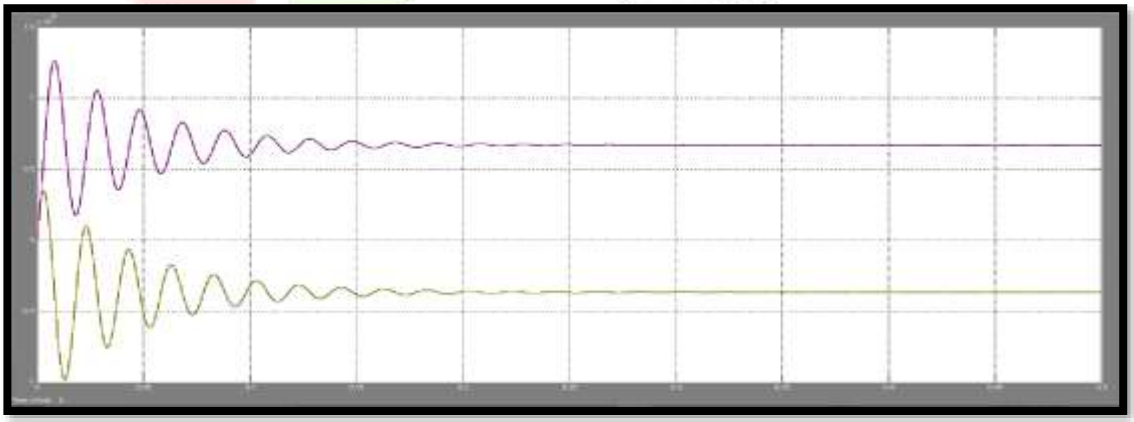


Fig 6.16- Active and Reactive Power at Source Side

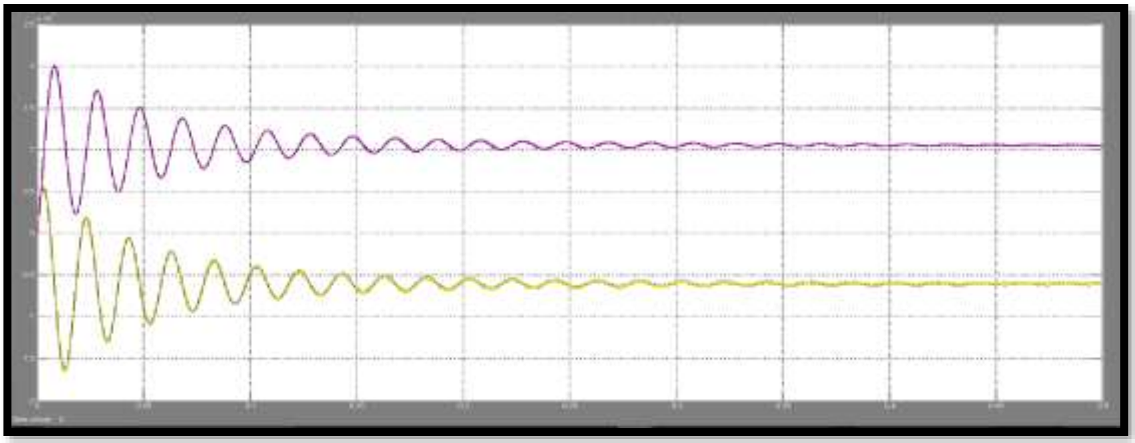
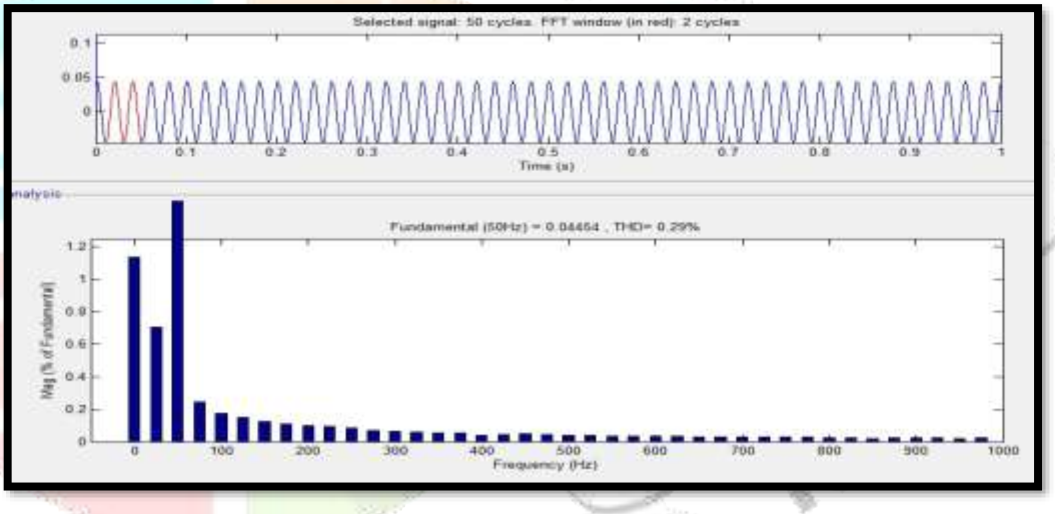
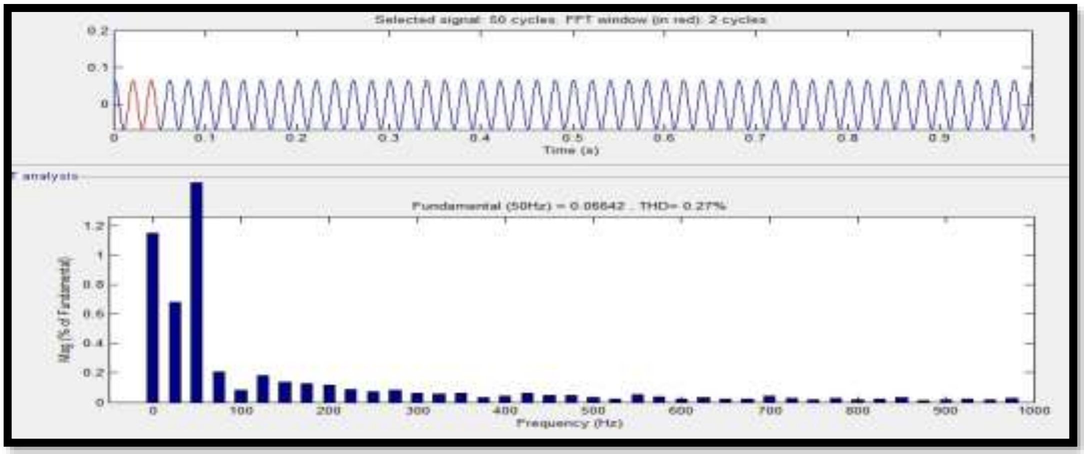
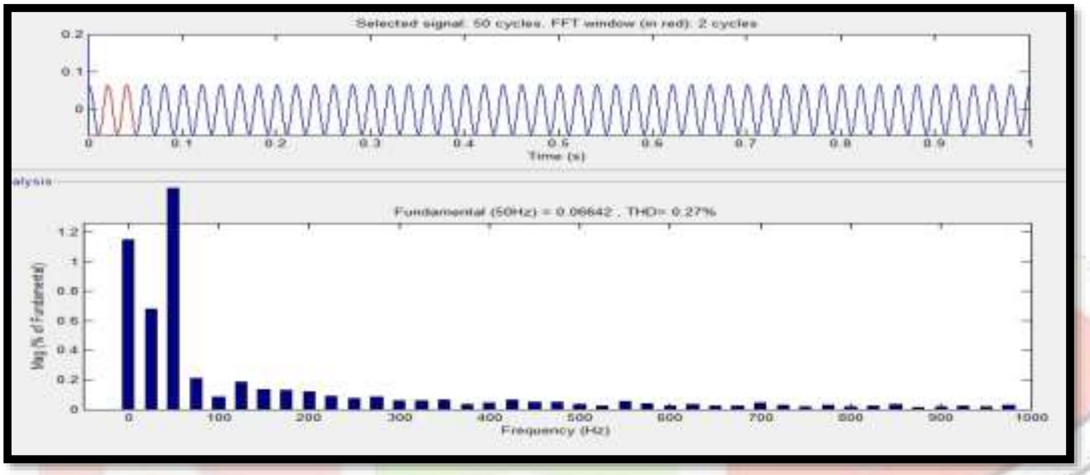


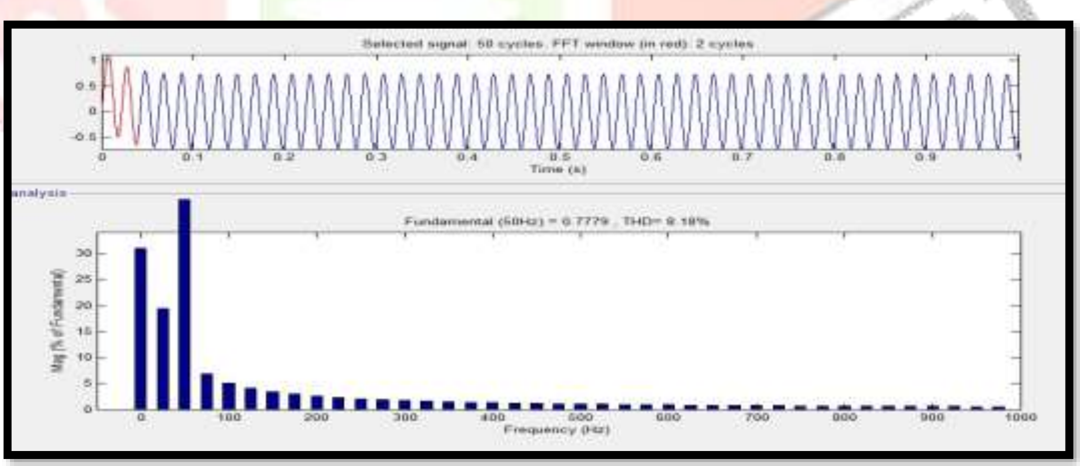
Fig 6.17- Active and Reactive Power at Load side

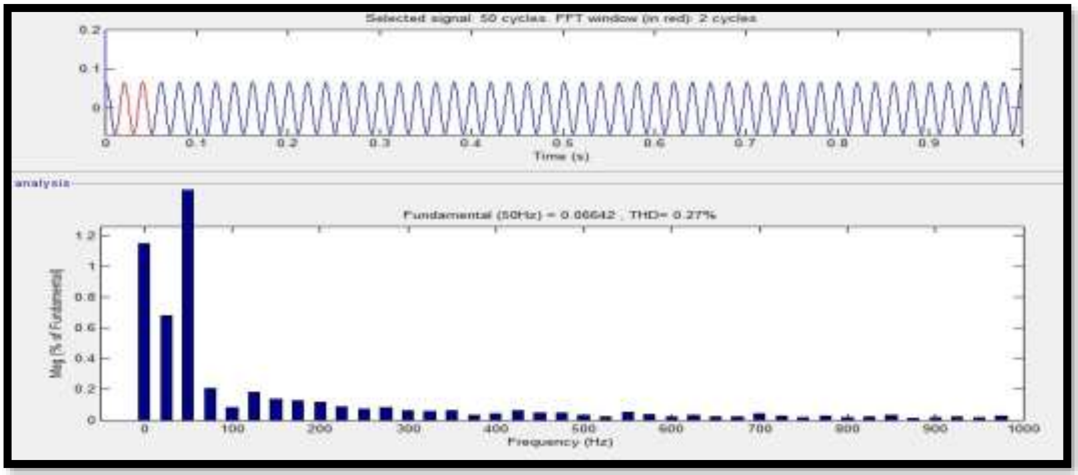
VOLTAGE THD ANALYSIS: -

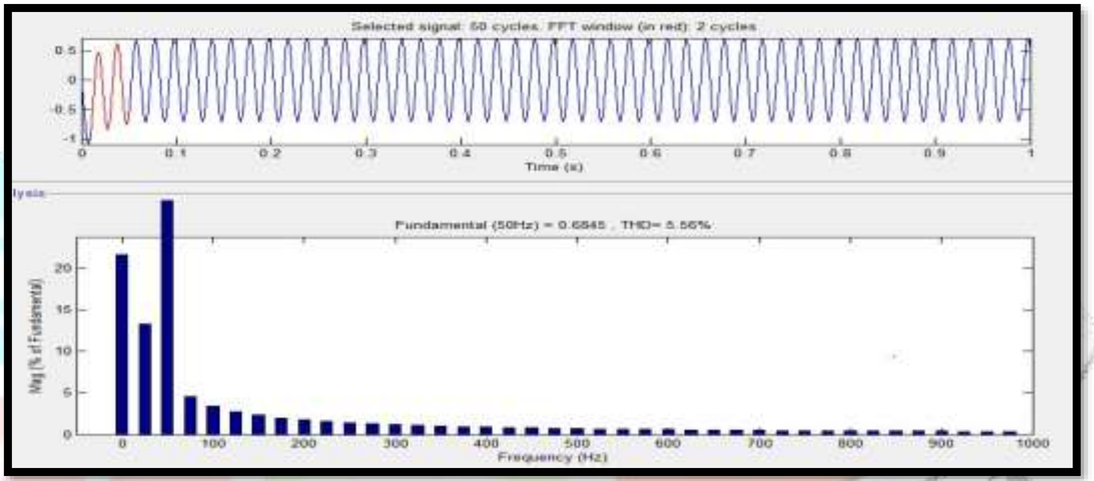



Selected signal: 50 cycles. FFT window (in red): 2 cycles
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Time (s)
T analysis
Fundamental (50Hz) = 0.06642 , THD= 0.27%
Mag (% of Fundamental)
1.2
1
0.8
0.6
0.4
0.2
0
0 100 200 300 400 500 600 700 800 900 1000
Frequency (Hz)


Selected signal: 50 cycles. FFT window (in red): 2 cycles
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Time (s)
alysis
Fundamental (50Hz) = 0.06642 , THD= 0.27%
Mag (% of Fundamental)
1.2
1
0.8
0.6
0.4
0.2
0
0 100 200 300 400 500 600 700 800 900 1000
Frequency (Hz)


Selected signal: 50 cycles. FFT window (in red): 2 cycles
1
0.5
0
-0.5
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Time (s)
analysis
Fundamental (50Hz) = 0.7779 , THD= 9.18%
Mag (% of Fundamental)
30
25
20
15
10
5
0
0 100 200 300 400 500 600 700 800 900 1000
Frequency (Hz)





POWER FLOW AND DC-LINK VOLTAGE CONTROL OF TRANSFORMER-LESS UPFC

Dynamic Models of UPFC system

The equations derived from the phasor diagram are limited to steady-state operation analysis. To design the vector-oriented control (V_{OC}) for the proposed transformer-less UPFC with considering both steady-state and dynamic performance, the dynamic modules are necessary. The models are based on synchronous (dq) reference frame. The phase angle of original sending-end voltage is obtained from a digital phase-locked loop (PLL), which is used for *abc* to *dq0* transformation. The dynamic models for the whole system shown in Fig. 6.18 (a) will be divided into several parts. Firstly, we can get the dynamic model from the new sending-end bus to receiving-end bus.

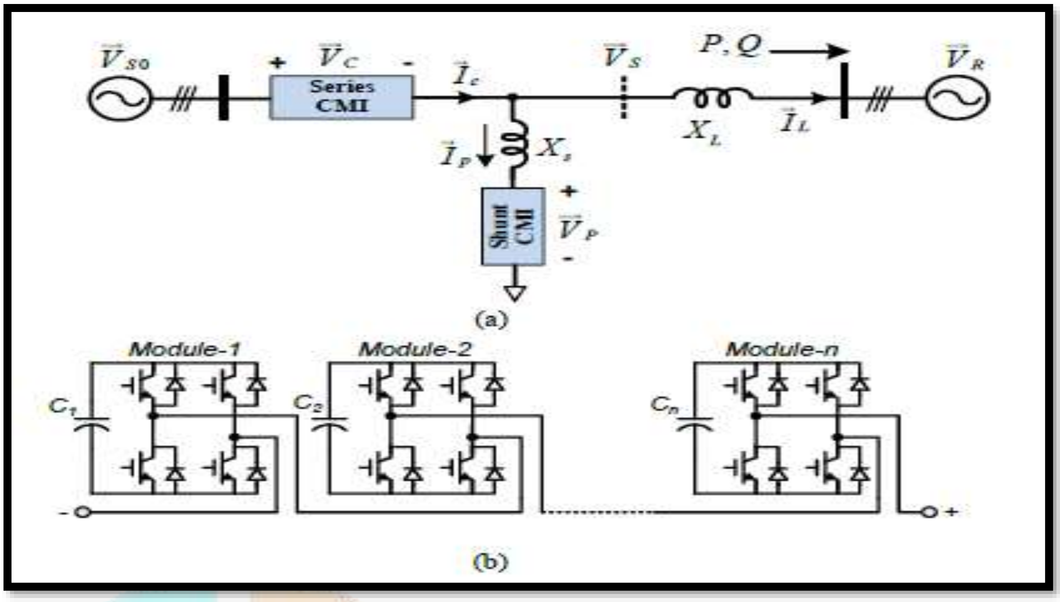


Fig. New transformer-less UFPC, (a) System Configuration of Transformer-less UPFC, (b) One phase of the cascaded multilevel inverter.

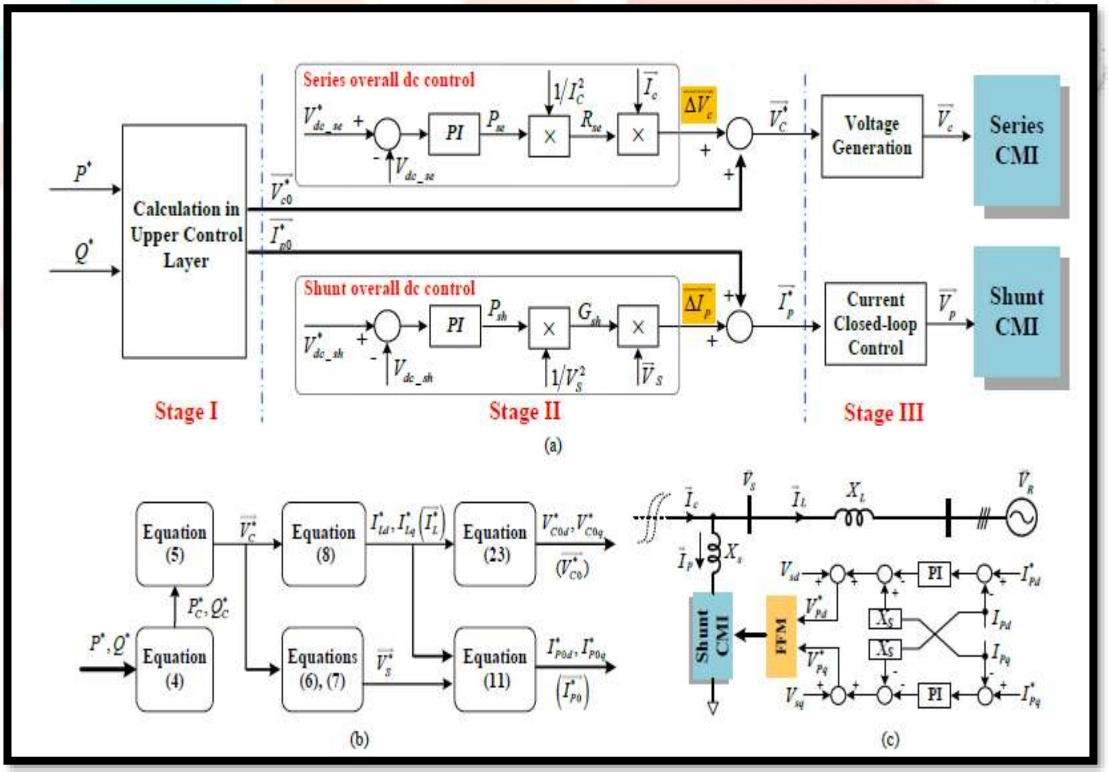


Fig. Control system for transformer-less UPFC, (a) overall control diagram for both power flow and dc capacitor voltage control, (b) detailed calculation from to and (c) current closed-loop control for shunt CMI

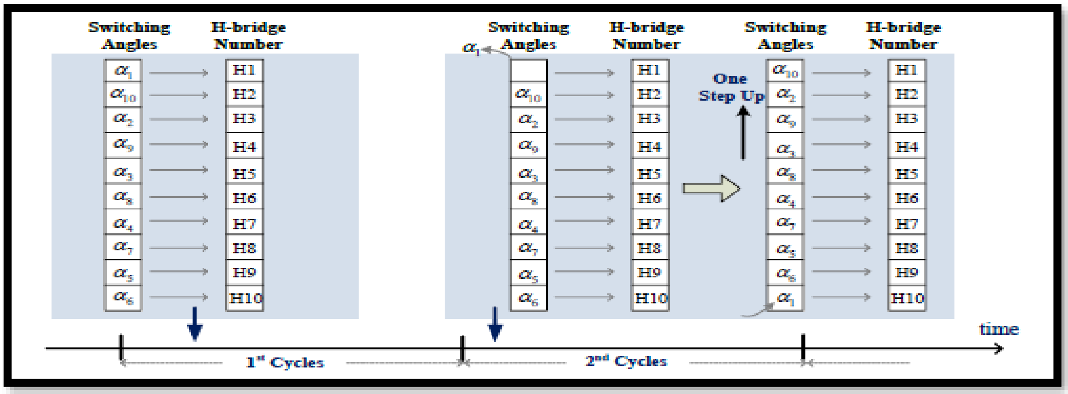


Fig. Illustration of pulse swapping from one fundamental cycle to next fundamental cycle

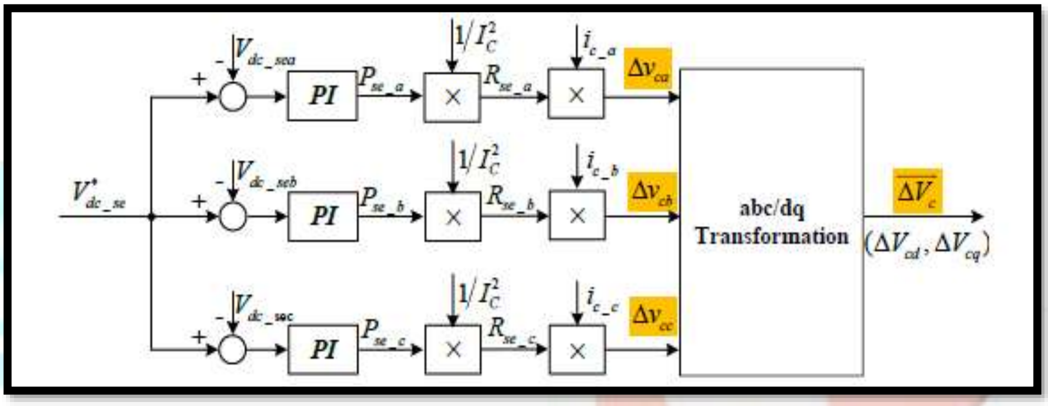


Fig. Three-phase separated overall dc voltage control for series CMI, considering capacitor-voltage unbalance between the three phase

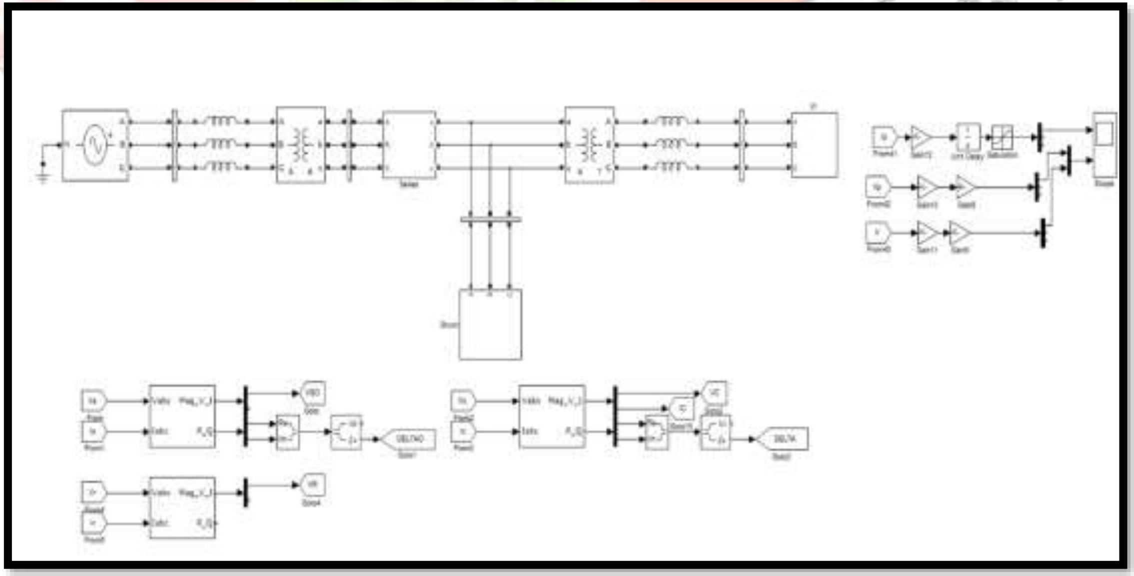


Fig Proposed System with CMI based Transformer less UPFC

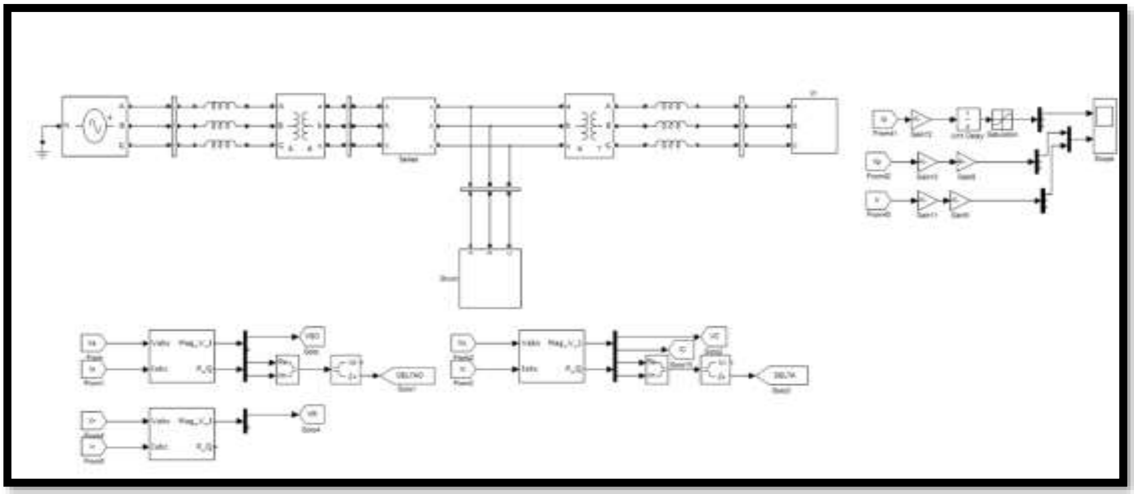


Fig Control System of CMI System

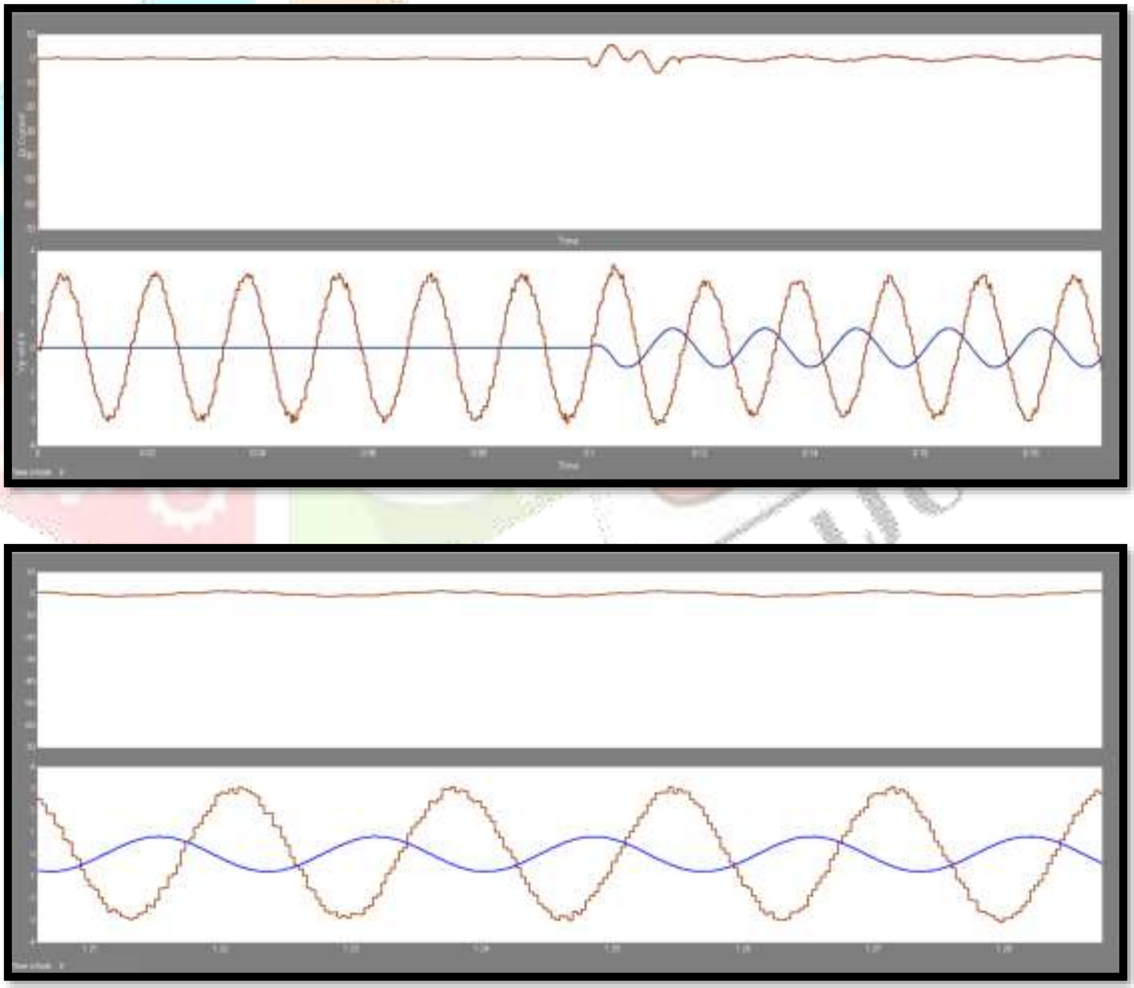
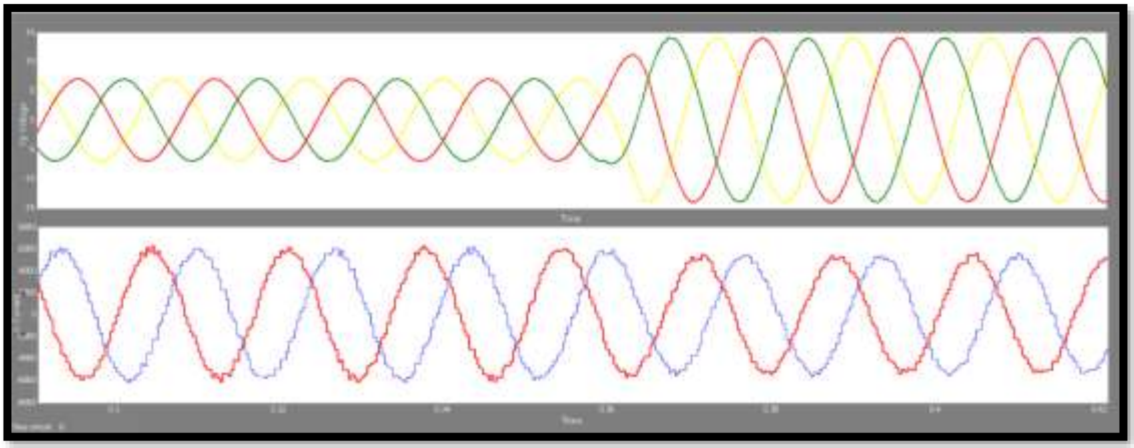


Fig. Experimental waveforms of UPFC operating from case A1 to case A2 (phase shifting 30° to 15°): (a) shunt CMI line voltage VP ab , shunt CMI phase current IP a , and line current ILa , and (b) the zoomed in waveforms



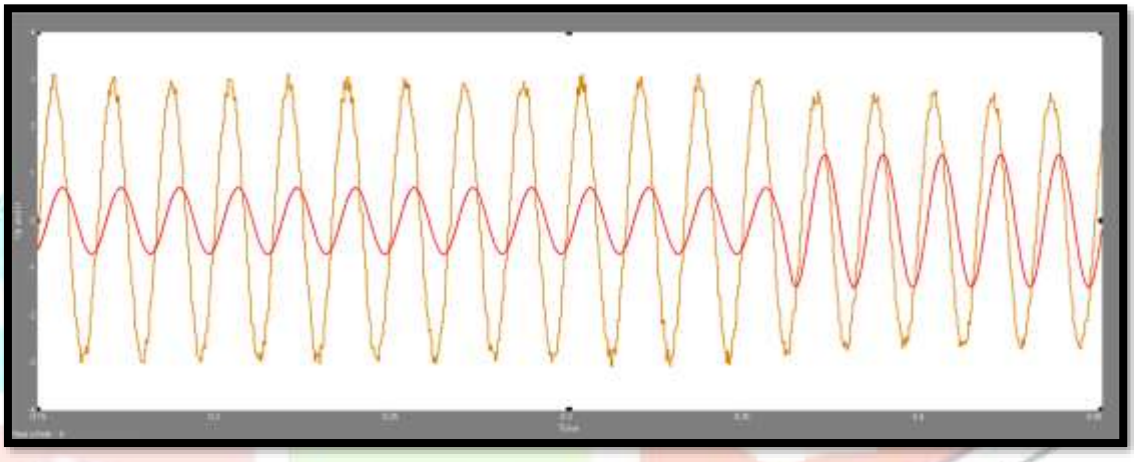


Fig.Experimental waveforms of UPFC operating from case A2 to case A3 (phase shifting 15° to 0°): (a) shunt CMI phase voltage VP a , VP b and line current ILa , ILb , ILc , and (b) line current ILa and shunt CMI line voltage VP ab .

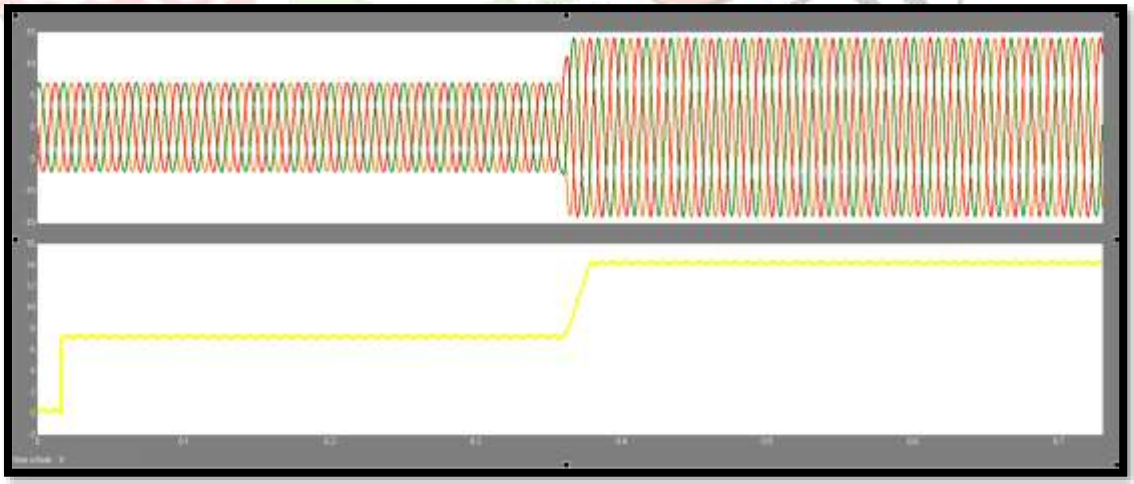


Fig. Measured dynamic response with operating point changing from case A2 to case A3 (phase shifting 15° to 0°).

Fig. Experimental results of dc capacitor voltage of series and shunt CMIs, from case A2 to case A3 (phase shifting 15° to 0°): (a) dc capacitor voltage of series CMI and (b) dc capacitor voltage of shunt CMI.

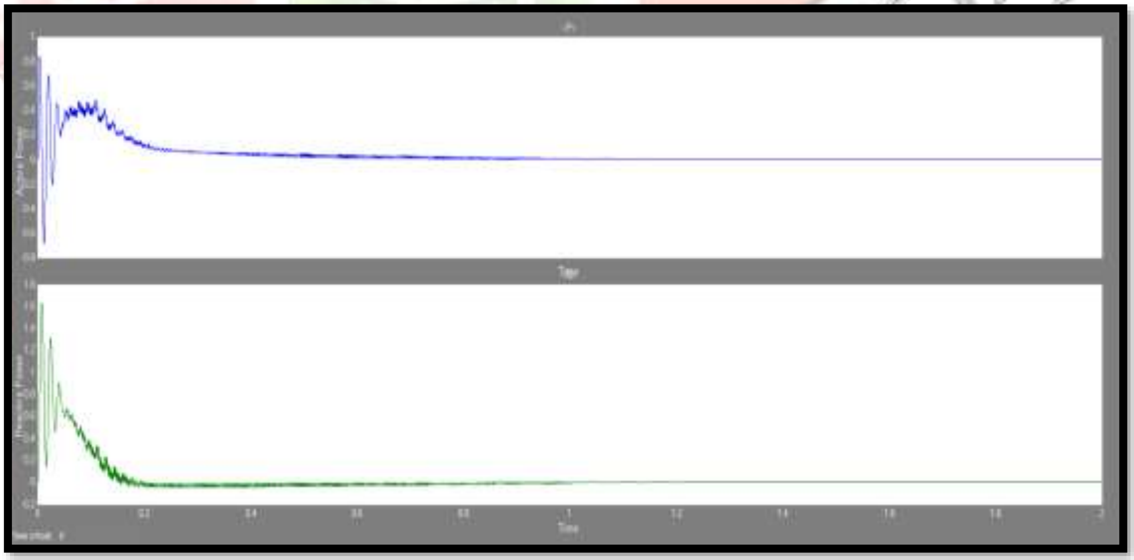


Fig Active & Reactive Power at sending end (case-I)

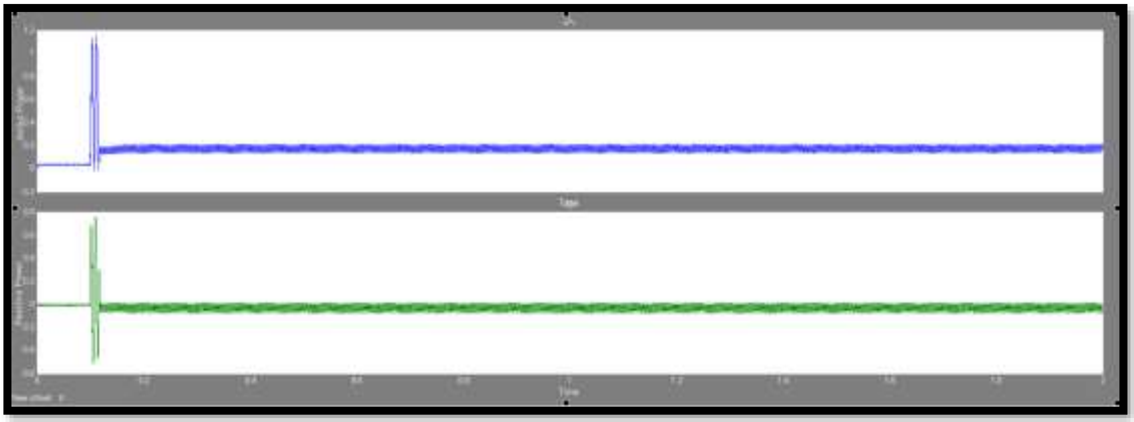


Fig Active & Reactive Power at Receiving end (case-I)

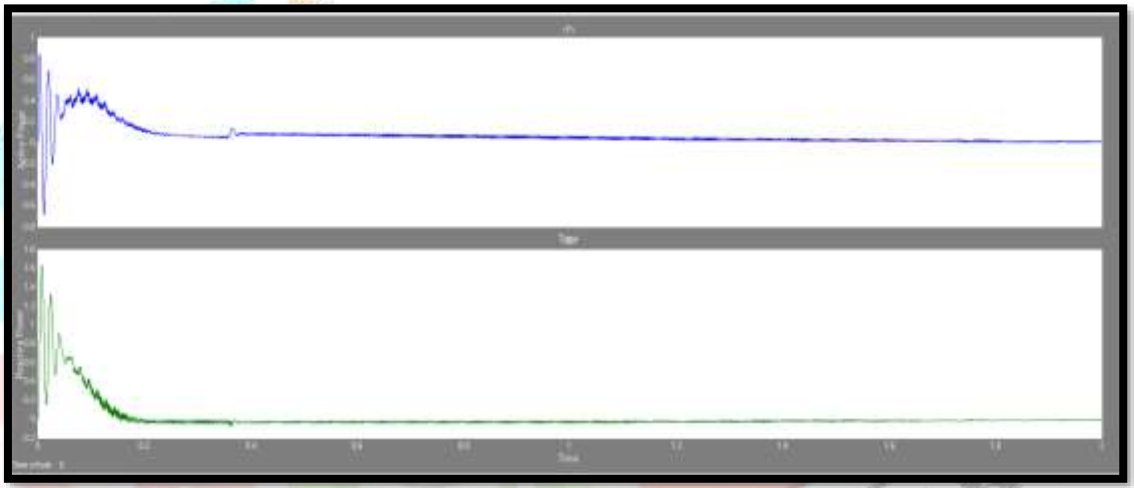


Fig Active & Reactive Power at sending end (case-II)

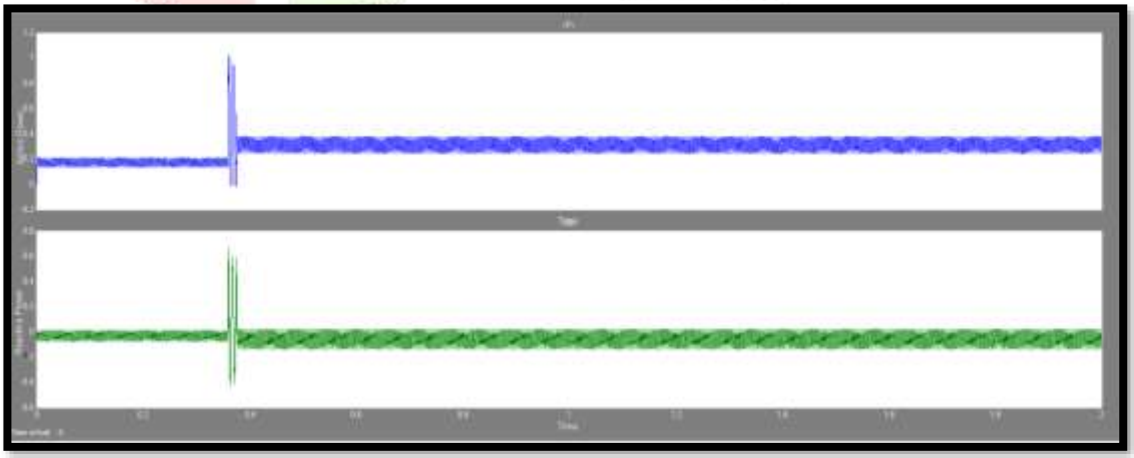


Fig Active & Reactive Power at Vp end (case-II)

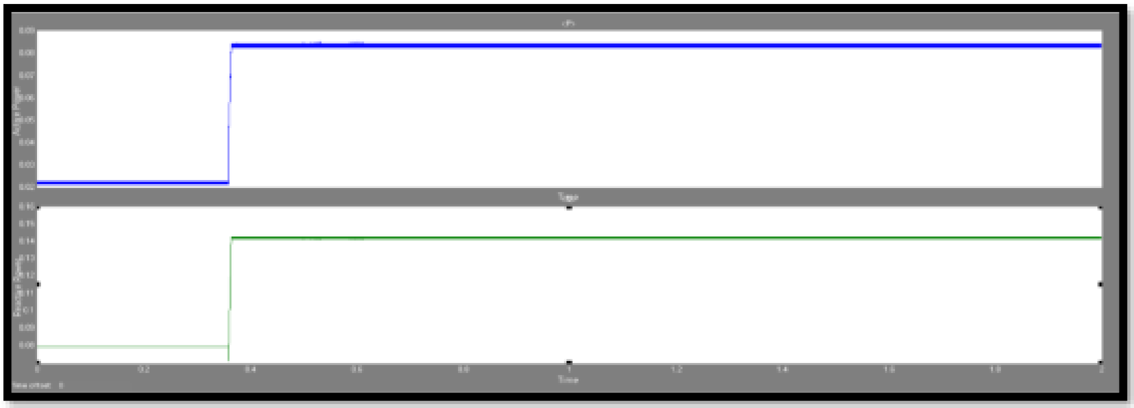


Fig Active & Reactive Power at Receiving end (case-II)

THD Analysis in Transformer less UPFC

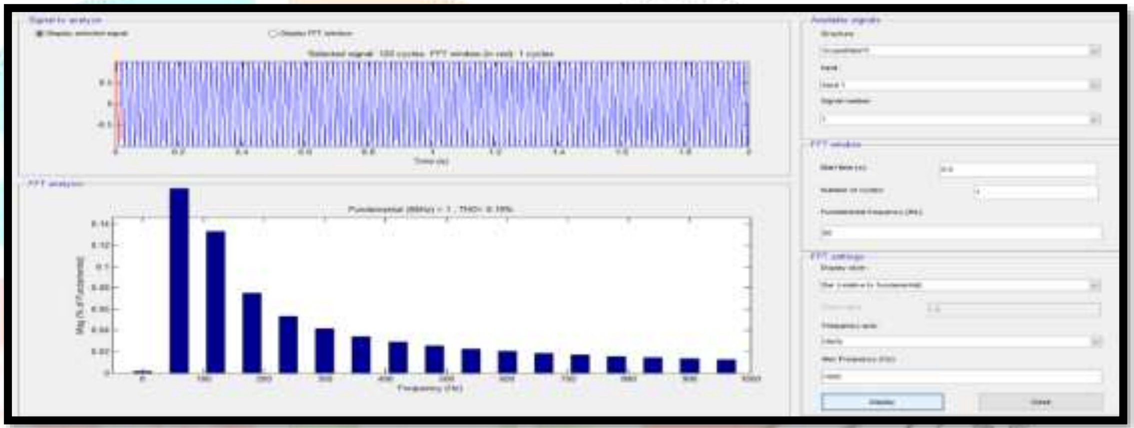


Fig THD of Load Side/ Receiving end Voltage

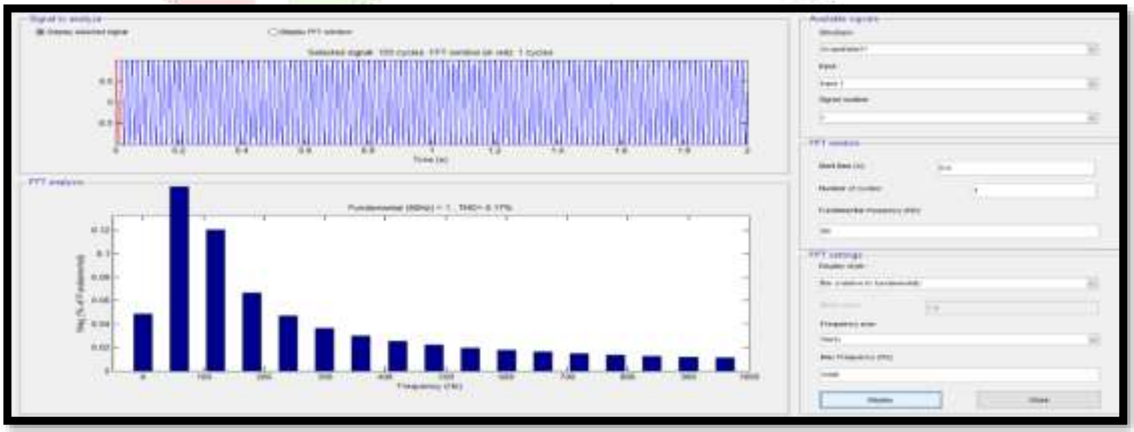


Fig THD of Source Side/ Sending end Voltage

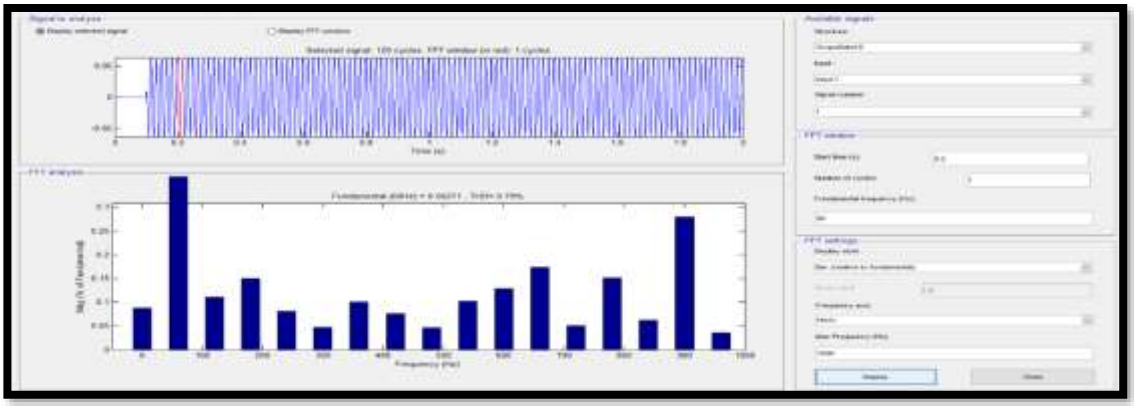


Fig THD of Load Side/ Receiving end Current

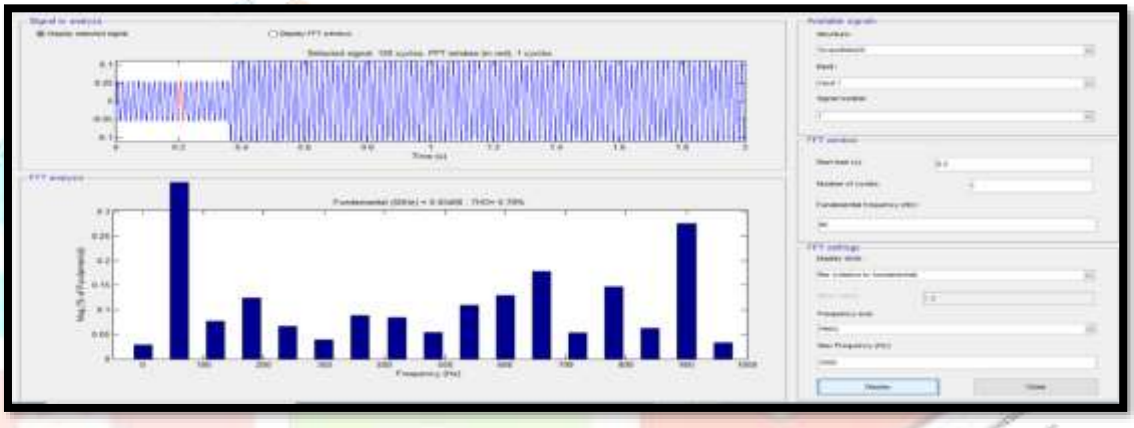


Fig THD of Ir Current

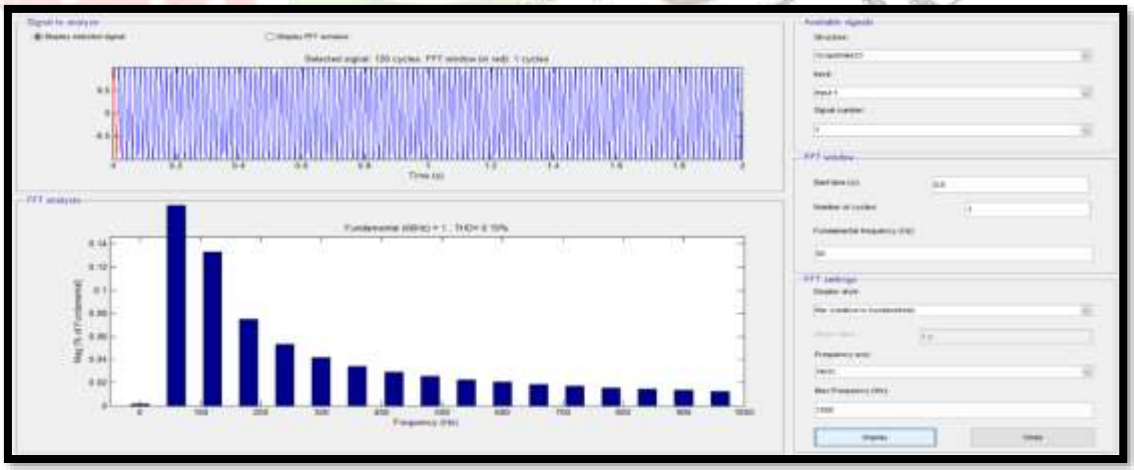


Fig THD of Vp Voltage

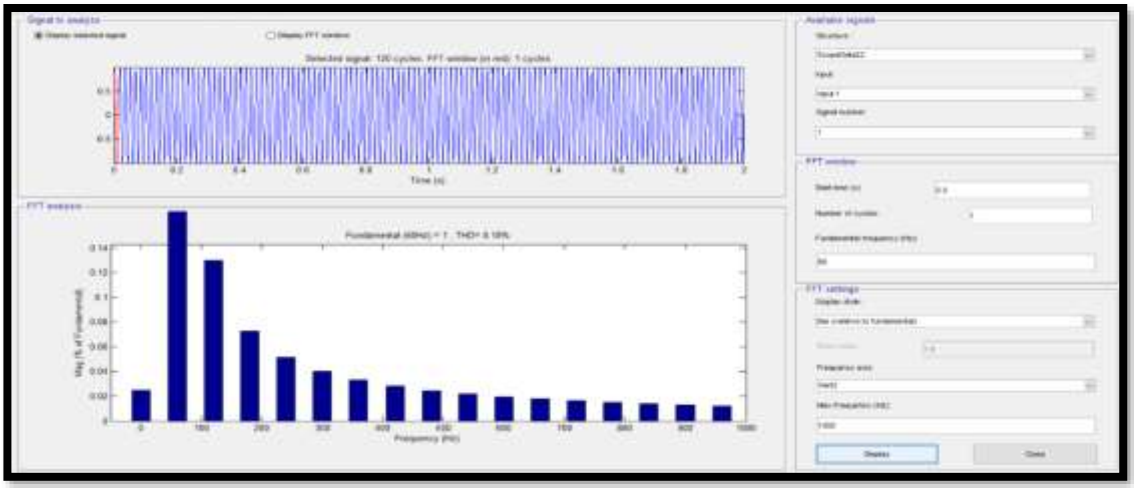


Fig THD of Vr Voltage

CONCLUSION

- From the simulation results we can say that after the application of UPFC in three phase system the distortion in voltage, current and power has been reduced.
- The power quality is improved using the control strategy of UPFC in three phase compensated system.
- The Cascaded Multilevel Inverter (CMI) based Transformer less UPFC System has been successfully developed and used for Power quality enhancement using Matlab-Simulink.

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