REVIEW AND OPERATION OF IPFC DEVICE FOR POWER FLOW CONTROL IN POWER SYSTEM

Nikul Bhatesara[1], Maulik Pandya[2]
[1]PG Scholar, Electrical Department, LDRP-ITR, Gandhinagar, Gujarat, India
[2]Assisatnt Professor, Electrical Department, LDRP-ITR, Gandhinagar, Gujarat, India

Abstract

This paper presents a power flow management in interline (IPFC), capable of simultaneous compensation for voltage and current in multi-bus/multi- feeder systems. In this configuration, one shunt voltage-source converter (shunt VSC) and two or more series VSCs exist. The system can be applied to adjacent feeders to compensate for supply-voltage and load current imperfections on the main feeder and full compensation of supply voltage imperfections on the other feeders. In the proposed configuration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag/swell and interruption. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations. The performance of the IPFC as well as the adopted control algorithm is illustrated by simulation.

INTRODUCTION

With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems, such as harmonics, flicker, and imbalance have become serious concerns. In addition, lightning strikes on transmission lines, switching of capacitor banks, and various network faults can also cause PQ problems, such as transients, voltage sag/swell, and interruption. On the other hand, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper load operation. To meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering.

If there are supply voltage imperfections, a series active power filter may be needed to provide full compensation. In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder. Recently, multi converter FACTS devices, such as an interline power-flow controller (IPFC) and the generalized unified power-flow controller (GUPFC) are introduced. The aim of these devices is to control the power flow of multi lines or a sub network rather than control the power flow of a single line by, for instance, a UPFC. When the power flows of two lines starting in one substation need to be controlled, an interline power flow controller (IPFC) can be used.

An IPFC consists of two series VSCs whose dc capacitors are coupled. This allows active power to circulate between the VSCs. With this configuration, two lines can be controlled simultaneously to optimize the network utilization. The GUPFC combines three or more shunt and series converters. It extends the concept of voltage and power-flow control beyond what is achievable with the known two-converter UPFC.

In this paper a power flow management in interline (IPFC), capable of simultaneous compensation for voltage and current in multi-bus/multi-feeder systems is presented. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations.

IPFC

The interline power flow controller (IPFC) is one of the latest FACTS controller used to control power flows of multiple transmission lines. Interline Power Flow Controller (IPFC) is an extension of static synchronous series compensator (SSSC). Any converters within the IPFC can transfer real power to any other and hence real power transfer among the lines may be carried out, together with independently controllable reactive series compensation of each individual line. IPFC employs several VSCs linked at the same DC terminal, each of which can provide series compensation for its own line. In this way, the power optimization of the overall system can be realized in the form of appropriate power transfer through the common DC link from overloaded lines to under-loaded lines. The power flow control design for IPFC is proposed and transfer functions are analyzed in this thesis. In its general form the interline power flow controller employs number of DC to AC inverters each providing series compensation for a different line as shown in Fig.

IPFC is designed as a power flow controller with two or more independently controllable static synchronous series compensators (SSSC) who are solid state voltage source converters injecting an almost sinusoidal voltage at variable magnitude and are linked via a common DC capacitor. SSSC is employed to increase the transferable active power on a given line and to balance the loading of a transmission network. In addition, active power can be exchanged through these series converters via the common DC link in IPFC. It is noted that the sum of the active powers outputted from VSCs to transmission lines should be zero when the losses of the converter circuits can be ignored. A combination of the series connected VSC can inject a voltage with controllable magnitude and phase angle at the fundamental frequency while DC link voltage can be maintained at a desired level. The common DC link is represented by a bidirectional link for active power exchange between voltage sources.

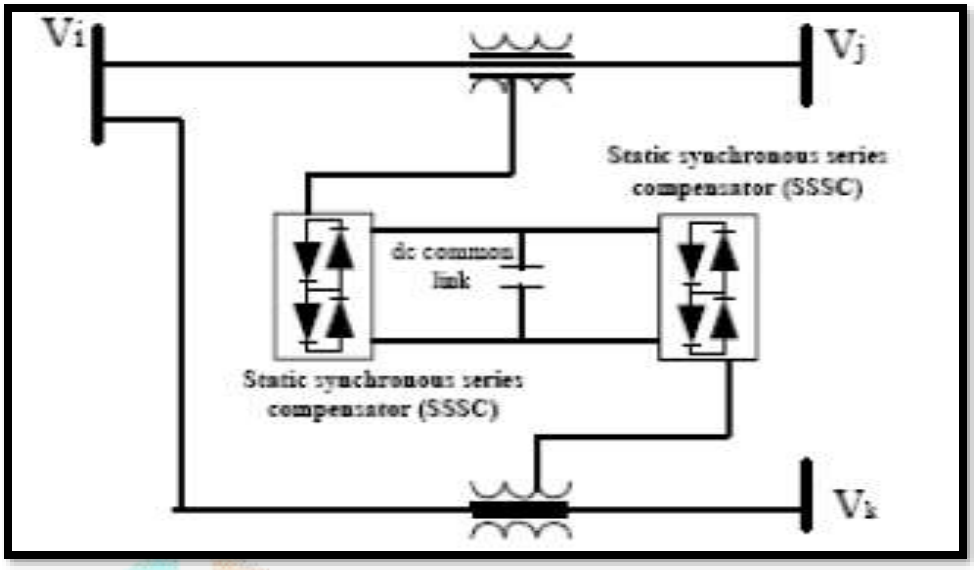

Fig Schematic representation of IPFC

Generalized Interline Power Flow Controller

There can be compensation requirements for multi-line transmission systems which would not be compatible with the basic constraint of the IPFC, stipulating that the sum of real power exchanged with all the lines must be zero. This constraint can be circumvented by a generalized IPFC arrangement, in which a shunt connected inverter, is added to the number of inverters providing series compensation as illustrated in fig.

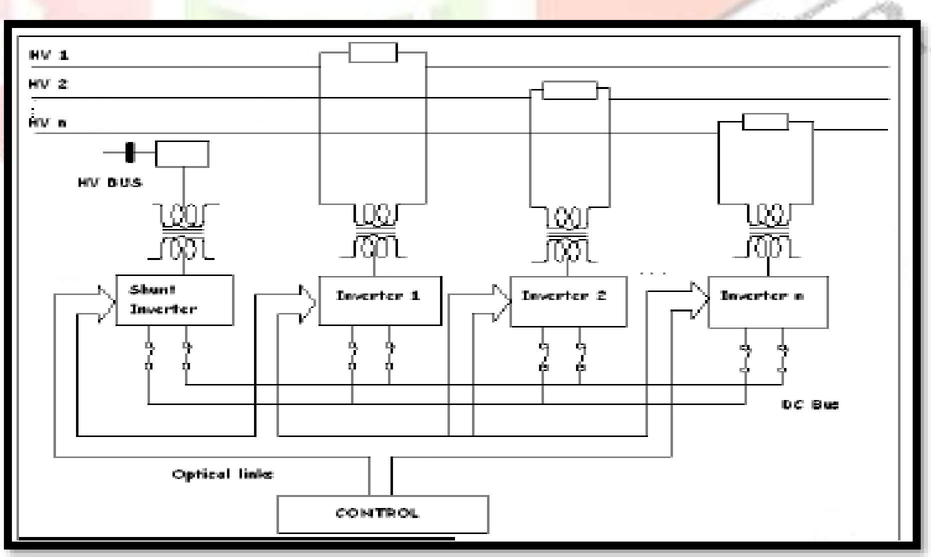

Fig-A Generalized Interline Power Flow Controller for Power Transmission Management

With this scheme the net power difference at the ac terminal is supplied or absorbed by the shunt inverter, and ultimately exchanged with the ac system at the shunt bus. This arrangement can be economically attractive, because the shunt inverter must be rated only for the maximum real power difference anticipated for the whole system. It can also facilitate relatively inexpensive shunt reactive compensation, if this is needed at the substation bus.

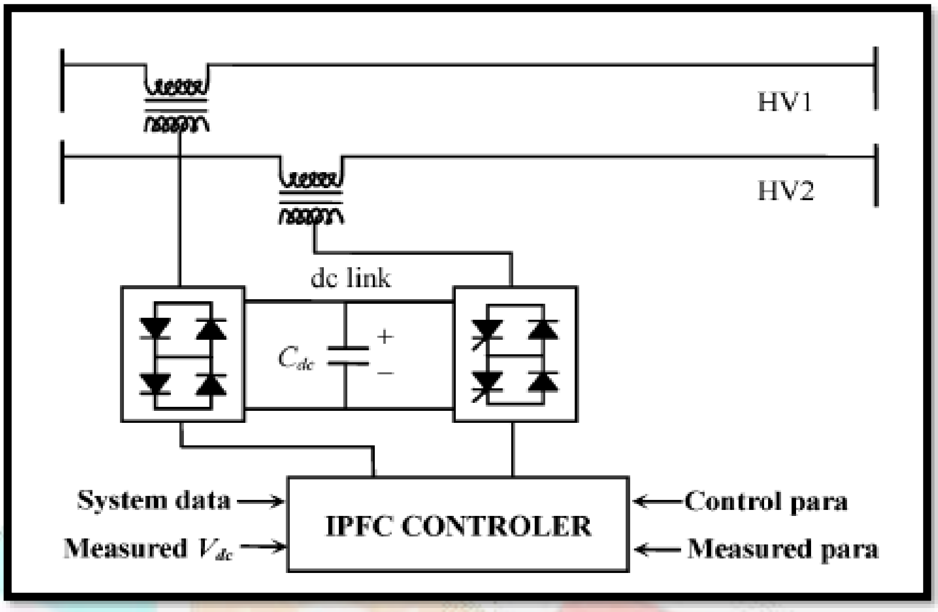

Fig Schematic diagram of two-converter IPFC

MODELLING AND SIMULATION

Three Phase System with IPFC Device

The voltage source converter topology is provided for power flow management in IPFC. There are two voltage source converters provided at input side of IPFC and one VSC is provided at output side.

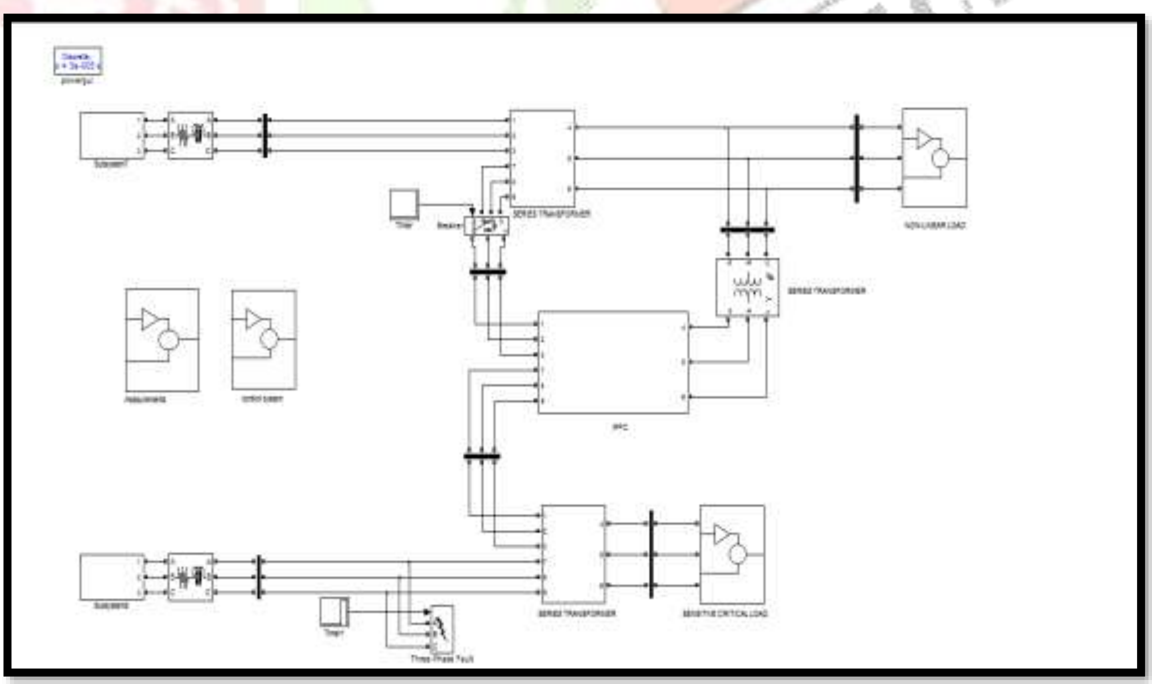

Fig Three phase system connected with IPFC device

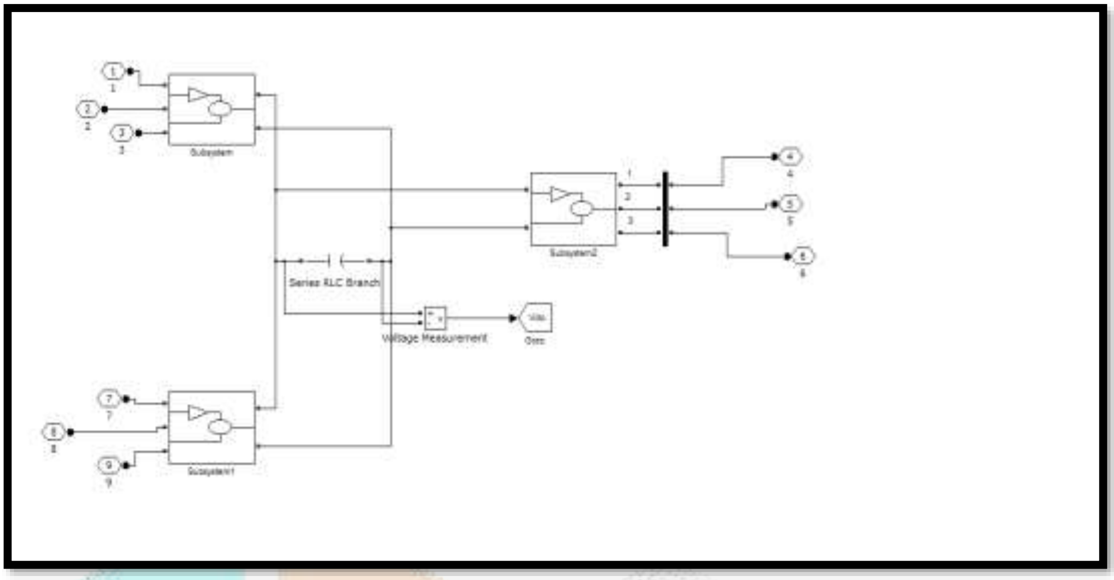

Fig IPFC device subsystem

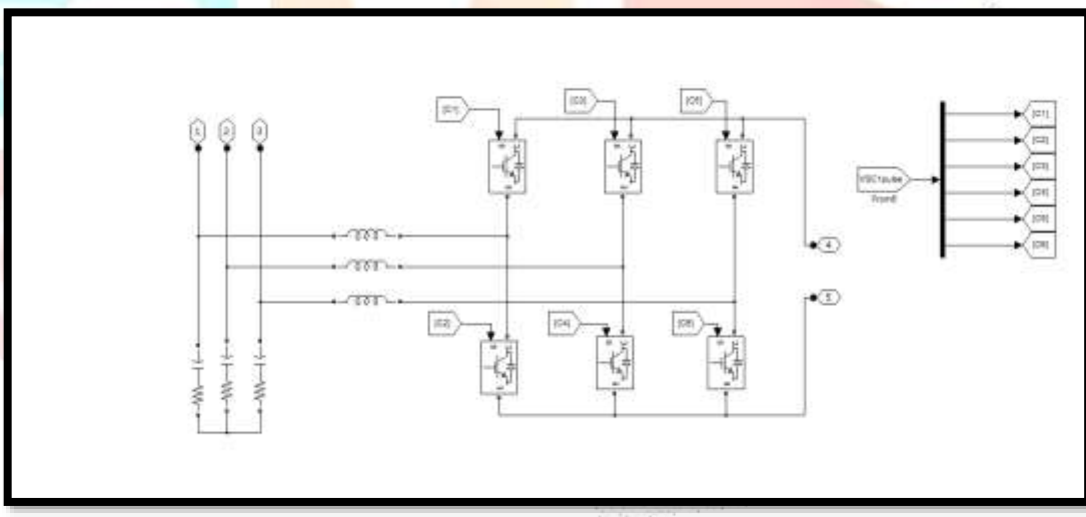

Fig VSC configuration in IPFC

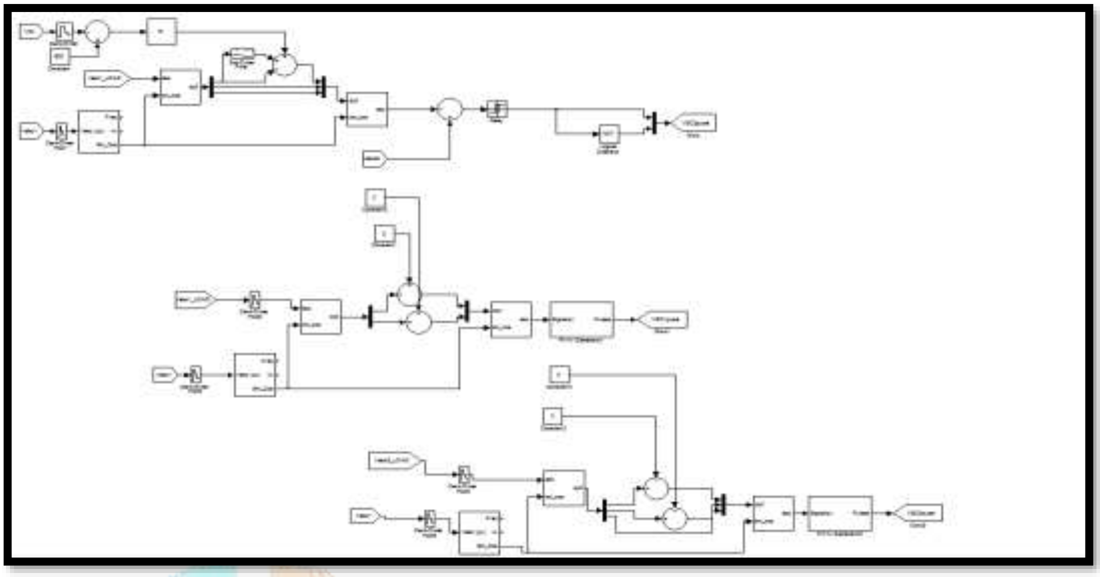

Fig control circuit for IPFC device

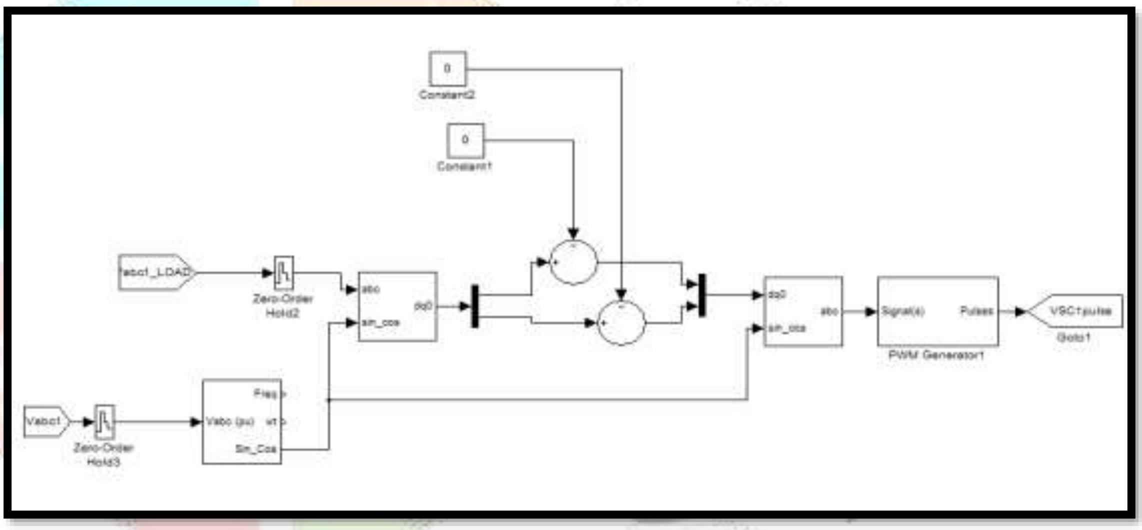

Fig Input side VSC control circuit

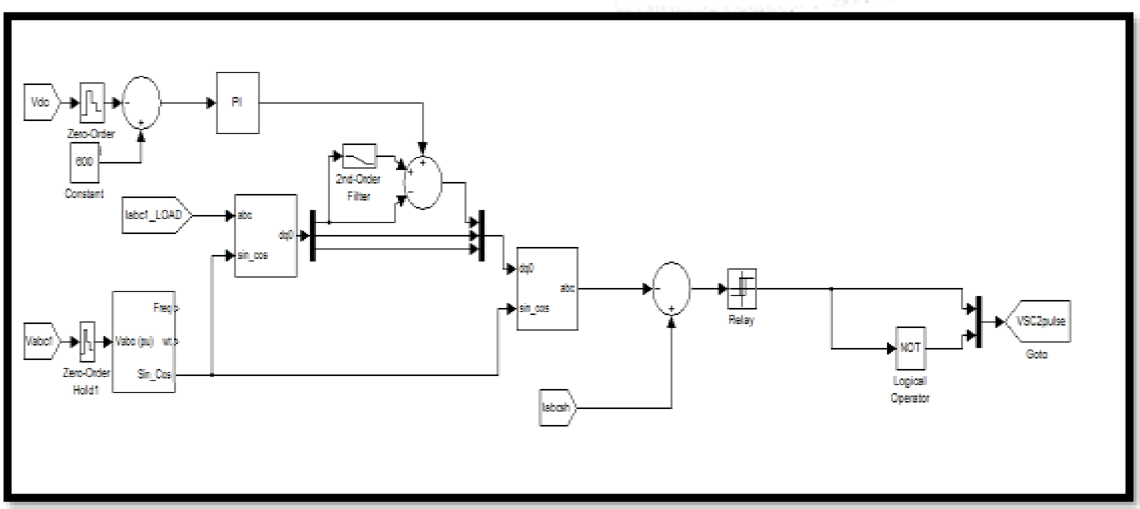

Fig Load side VSC control Circuit in IPFC

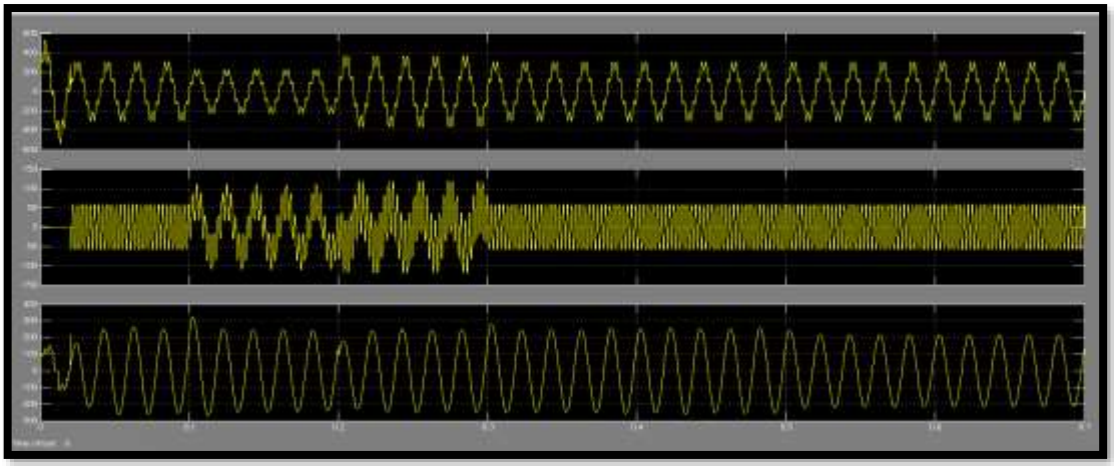

Fig (a) Vabc at input side (b) Vabc between series transformer and IPFC (c) Vabc at load side for bus-1

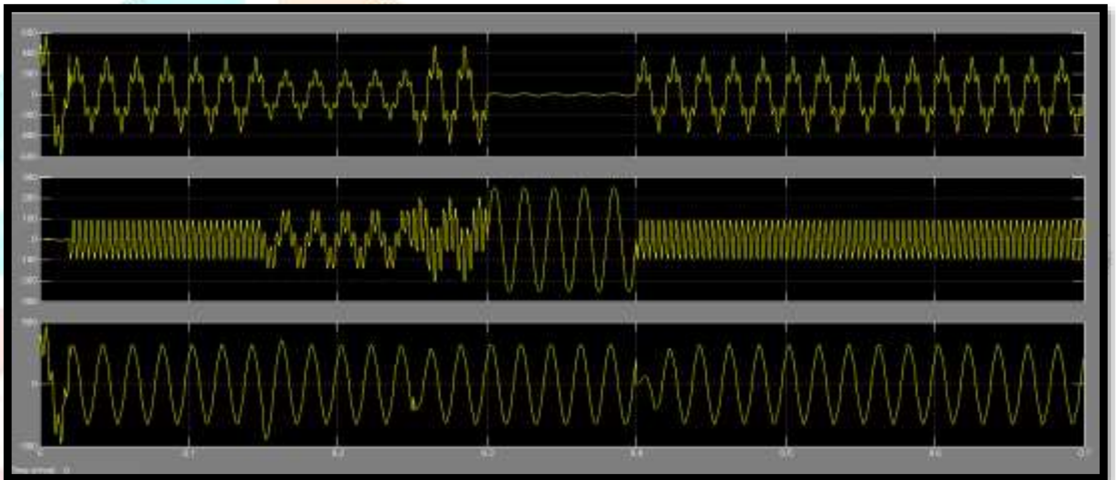

Fig (a) Vabc at input side (b) Vabc between series transformer and IPFC (c) Vabc at load side for bus-2

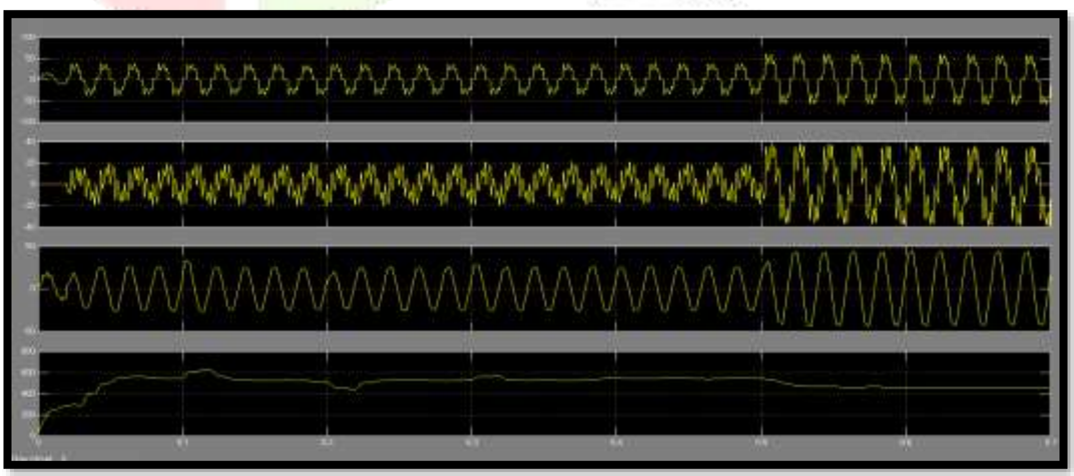

Fig (a) Iabc at input side (b) Iabc between series transformer and IPFC (c) Iabc at load side for bus-1 (d) D.C voltage at Common link D.C Capacitor

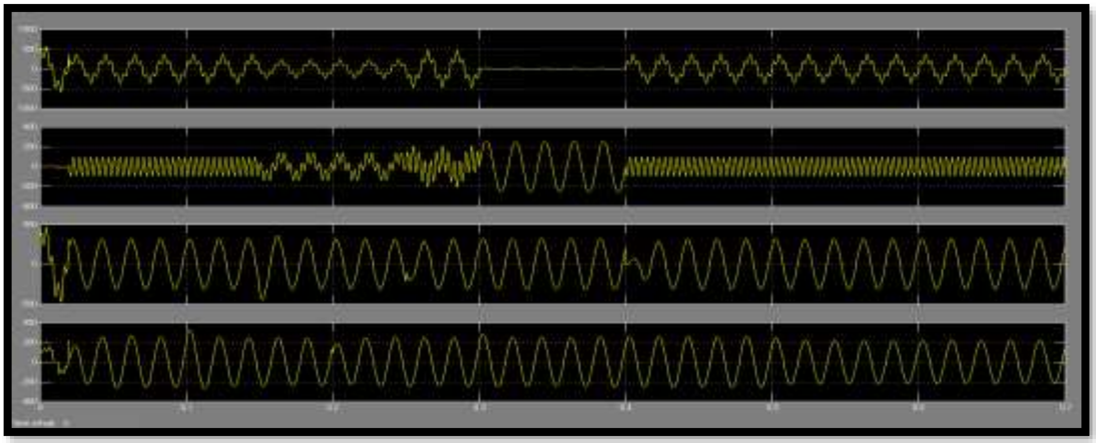

Fig (a) Vabc at input side (b) Vabc between series transformer and IPFC (c) Vabc at load side for bus-2 (d) Vabc at load side for bus-1

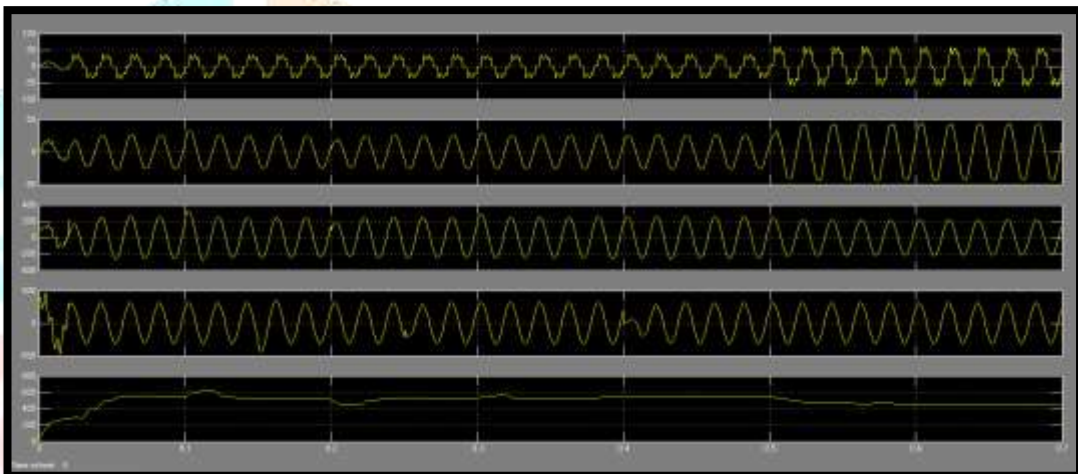

Fig load current values for bus-1 and bus-2 and D.C voltage at Common link D.C Capacitor

IPFC in Closed Loop

The MATLAB Simulink circuit model of the IPFC connected in closed loop is shown in figure 5.18. Scopes are connected to the primary load and secondary load. Real and reactive powers in the loads are measured. Voltages across primary load and secondary load are sensed and compared.

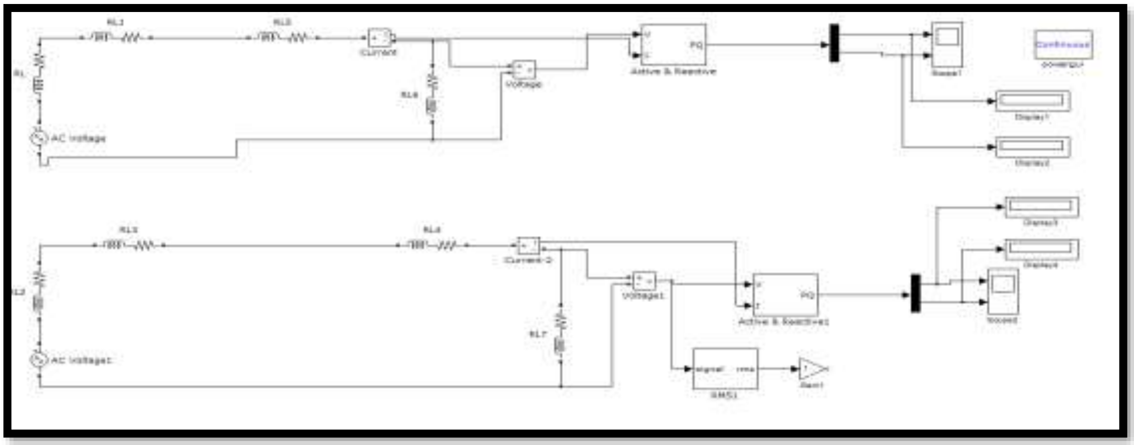

Fig MATLAB Simulation Model of Primary and Secondary Lines without IPFC

IPFC Subsystem

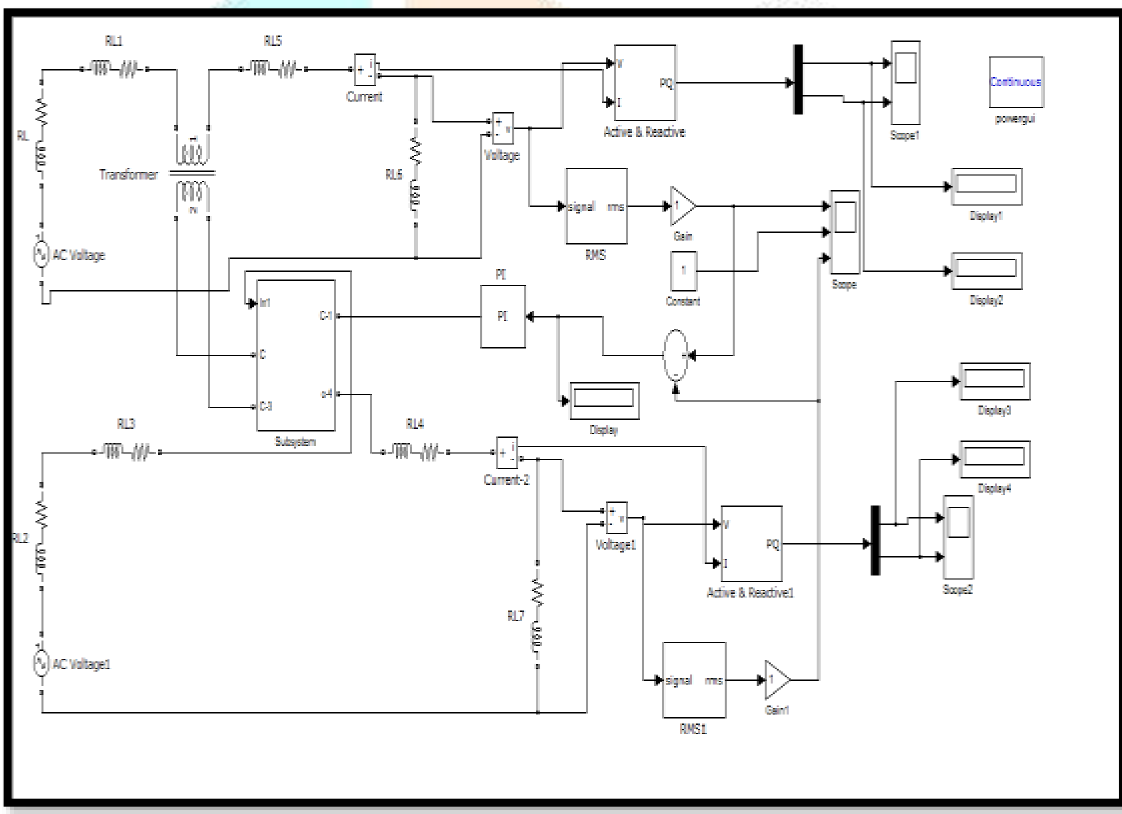

Fig Matlab Circuit Model of Closed Loop IPFC System

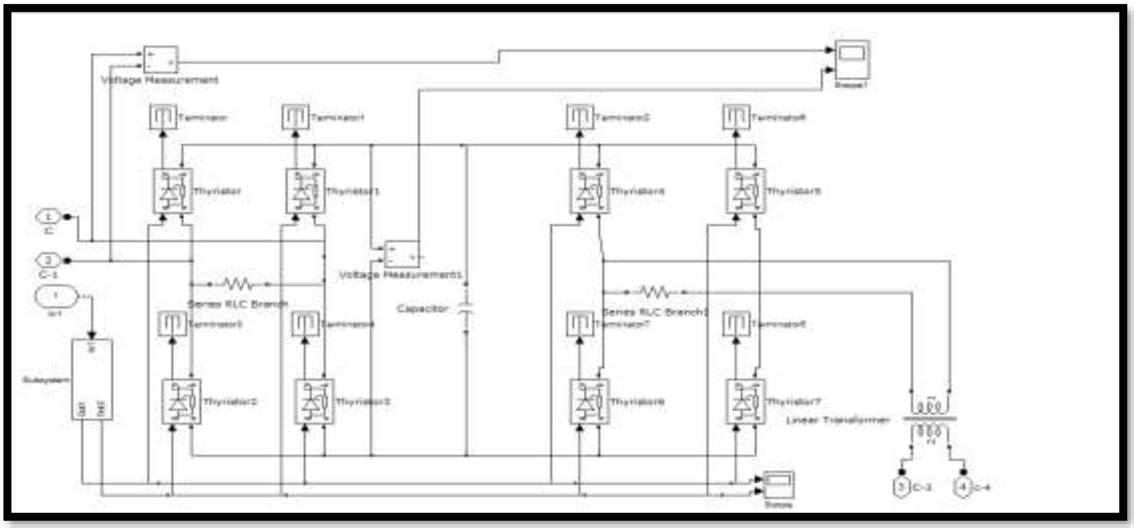

Fig-IPFC Subsystem

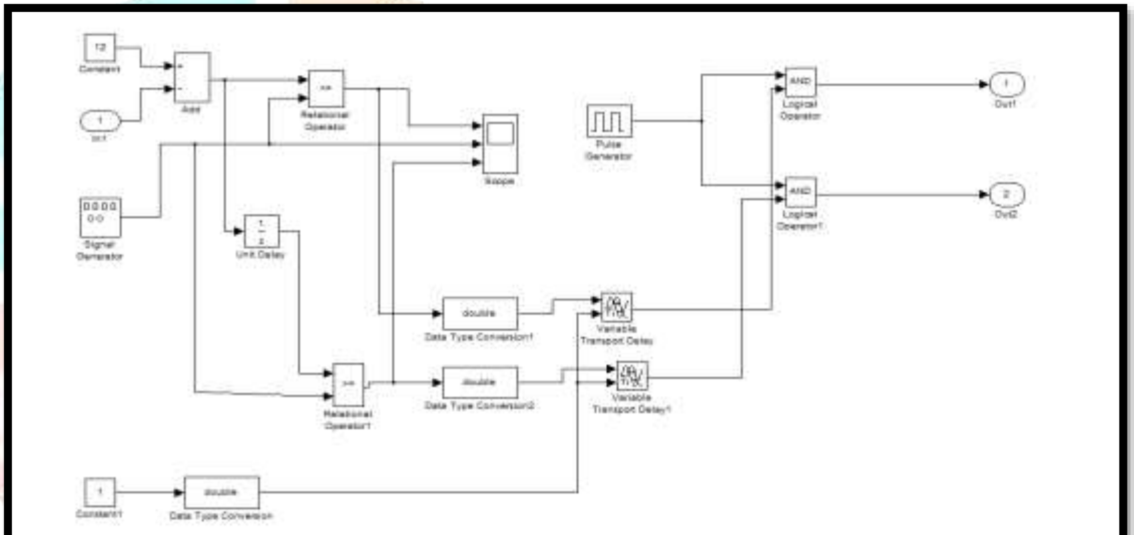

Fig Matlab Circuit model for Pulse Generation Module

Lines without IPFC	Primary Load		Secondary Load	
	Active Power (MW)	Reactive Power (MVAR)	Active Power (MW)	Reactive Power (MVAR)
	8.767	6.589	9.417	7.1

Table Real and reactive powers of primary and secondary Circuits without IPFC

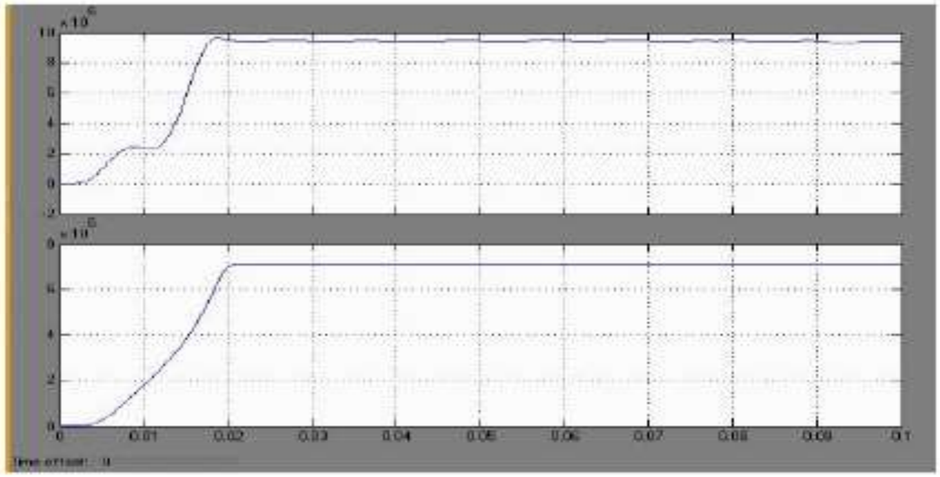

Fig Active and Reactive Power in Secondary Load without IPFC

Condition	Primary Load		Secondary Load	
	Active Power (MW)	Reactive Power (MVAR)	Active Power (MW)	Reactive Power (MVAR)
Lines without IPFC	8.780	6.570	9.464	7.088
Lines with Individual SSSC	8.781	6.578	9.467	7.092
Lines with IPFC	**8.813**	**6.601**	**9.492**	**7.110**

Table active and reactive powers with IPFC

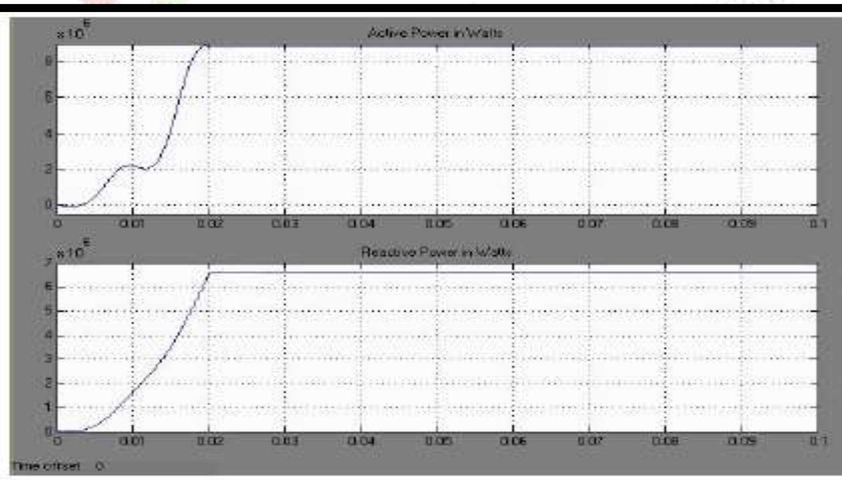

Fig Active and Reactive Power of Primary Load with IPFC in Closed Loop

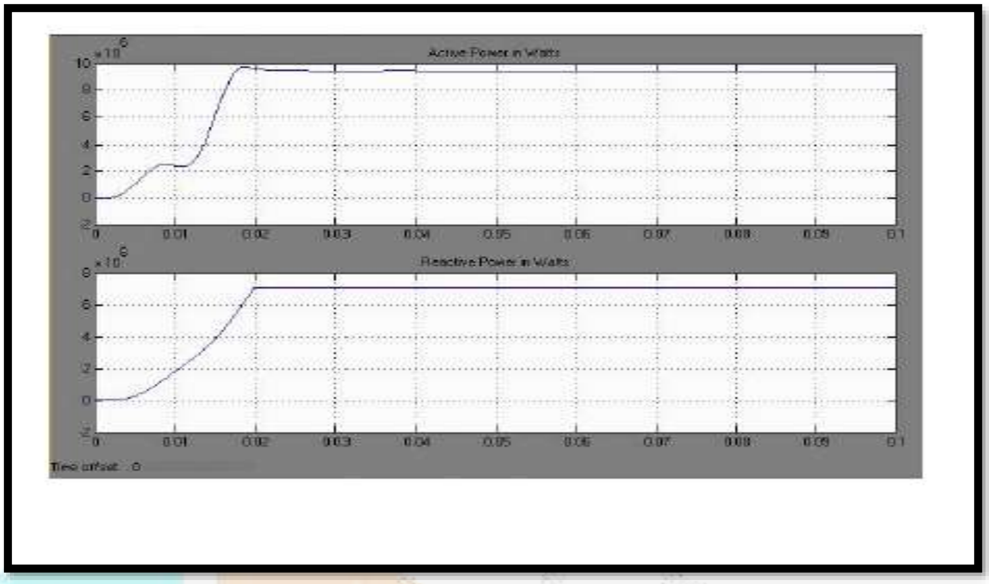

Fig Active and Reactive Power of Secondary Load with IPFC in Closed Loop

Matlab Simulation of IPFC with MMC (Modular Multi-level converter)

In this section there is one three phase source has related to three phase A.C load and Non-Linear D.C load to show the voltage and current variations for power quality issues at 4-bus which has been shown in the simulation results. The simulation results show the fluctuations in the voltage and current waveforms at different bus. For mitigating that problems and improve the power quality we connect the IPFC in interline between two transmission line.

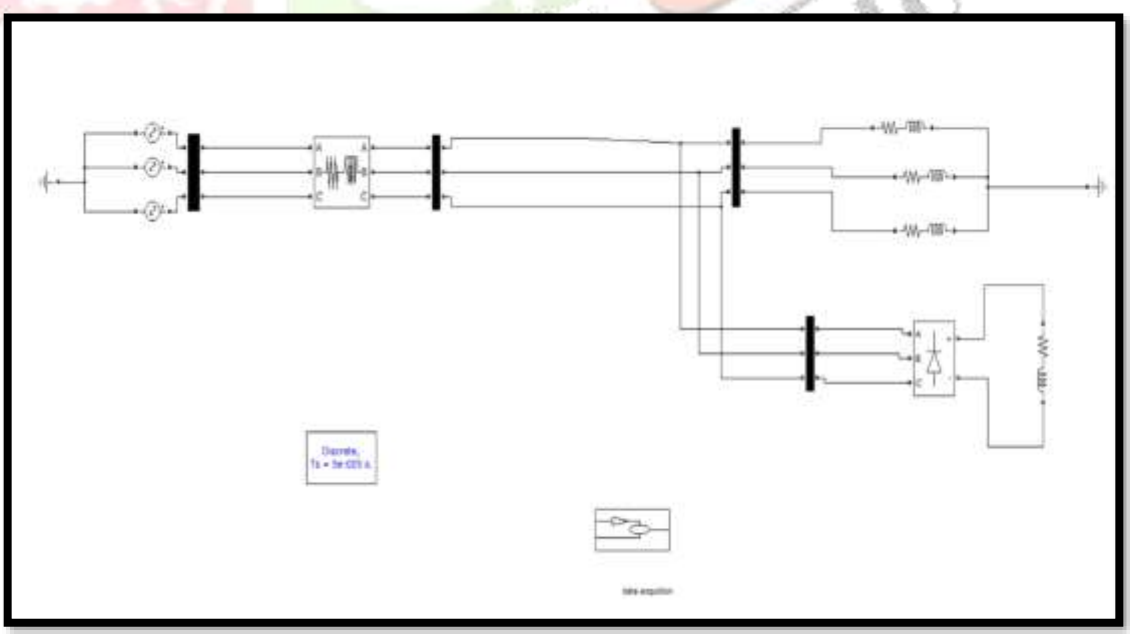

Fig Proposed System without IPFC

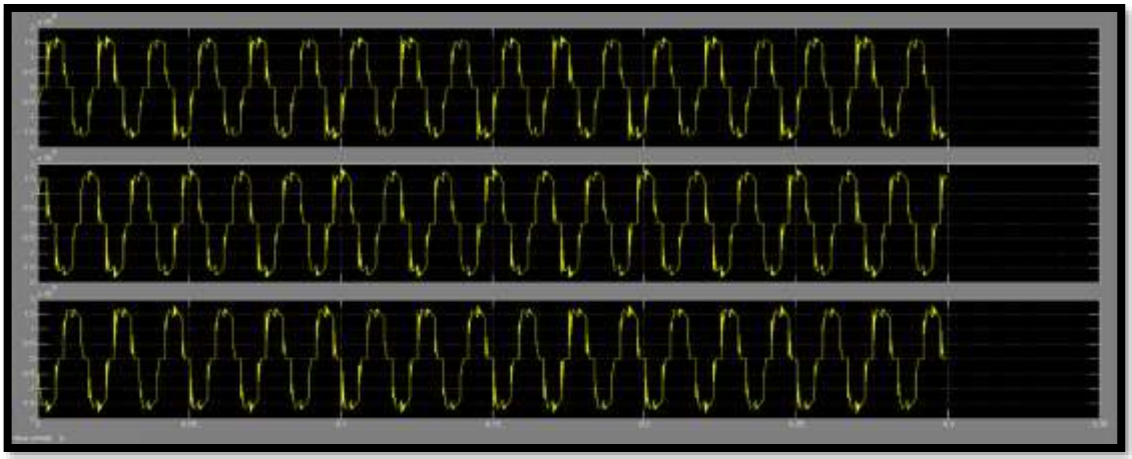

Fig Voltage at B-21

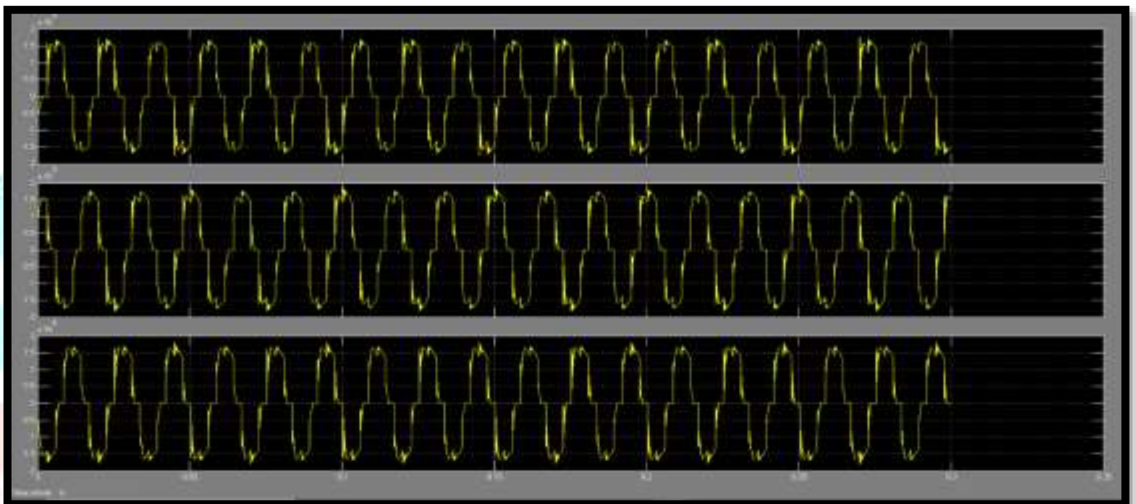

Fig Voltage at B-31

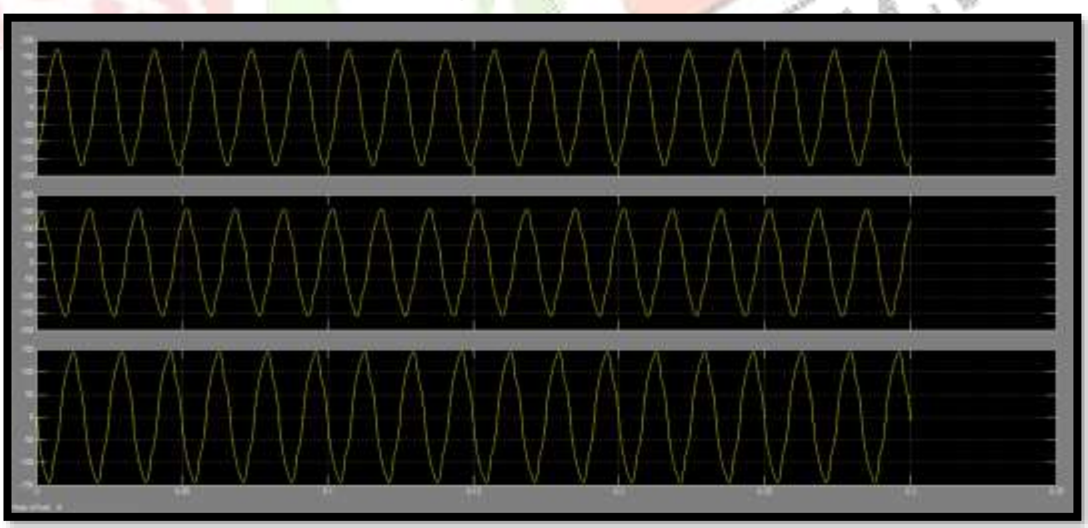

Fig 5.24- Current at B-21

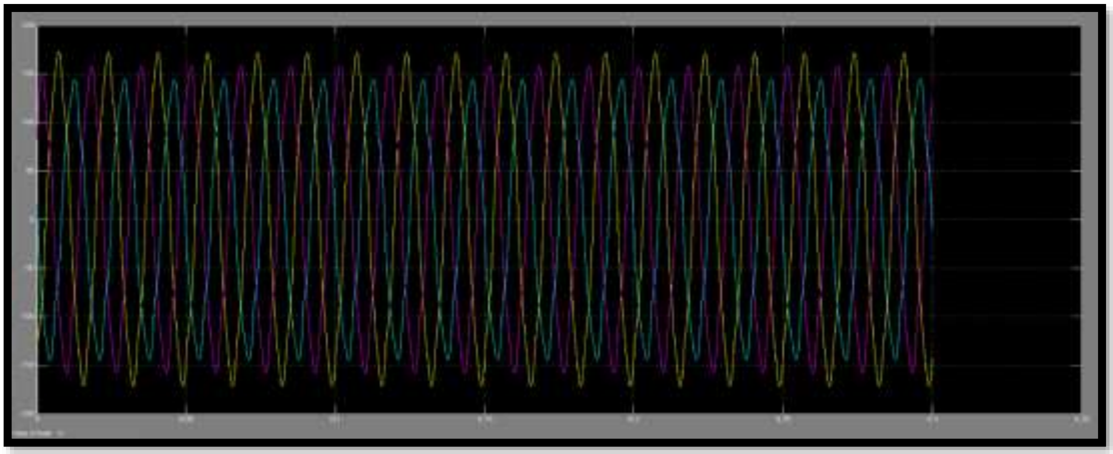

Fig Current at B-21

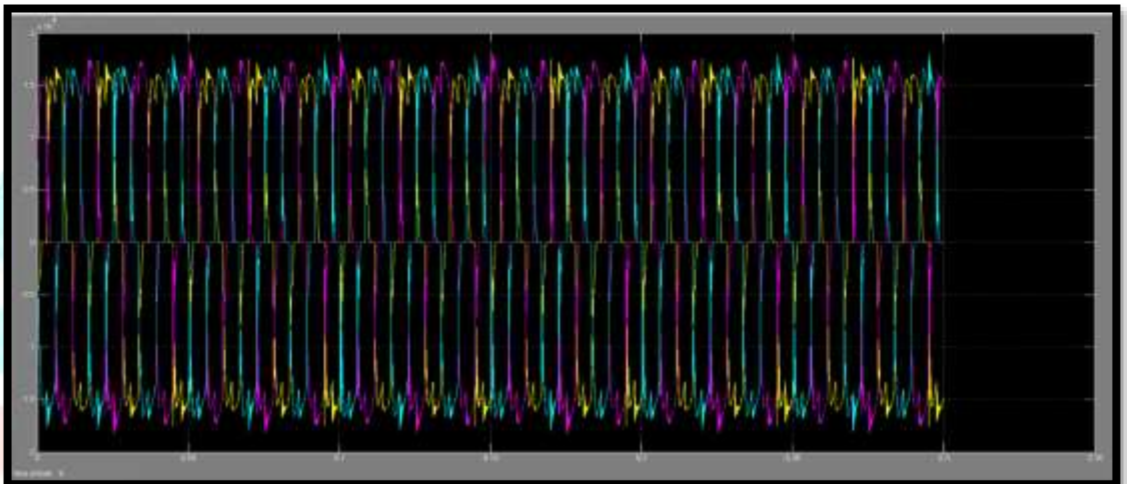

Fig Voltage Fluctuation at B-31

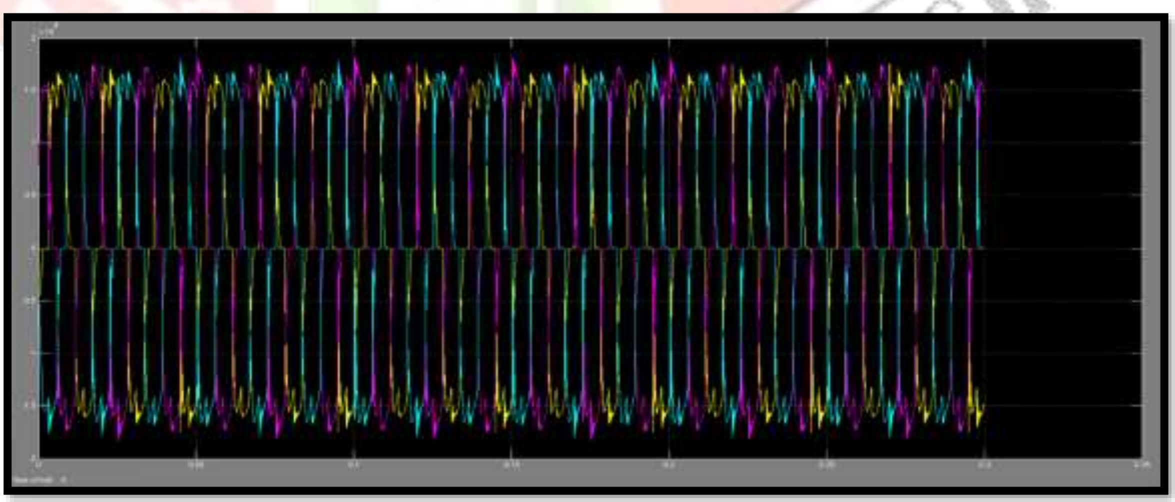

Fig Voltage Fluctuation at B-21

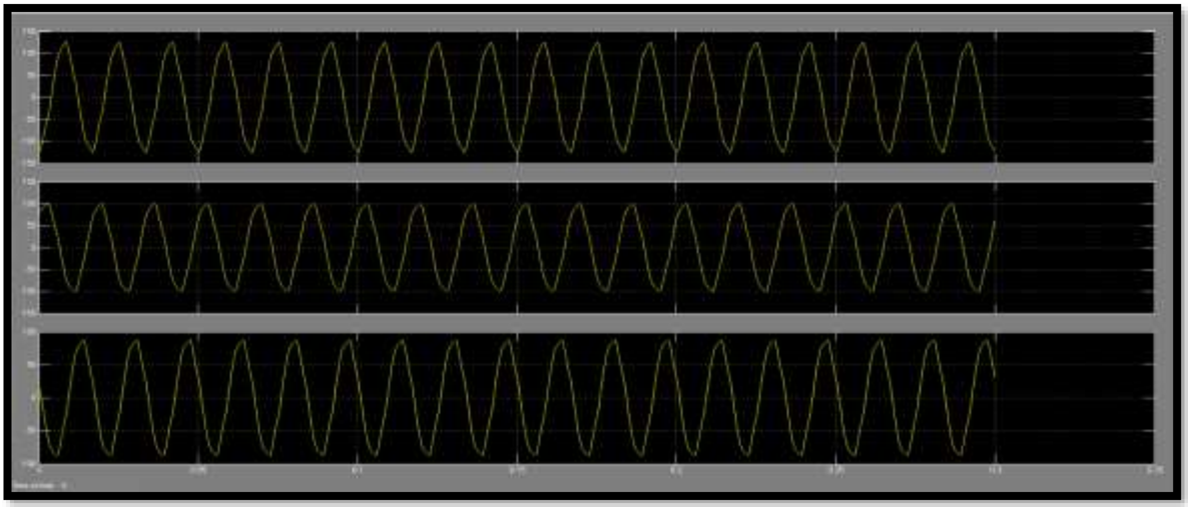

Fig Current at B-31

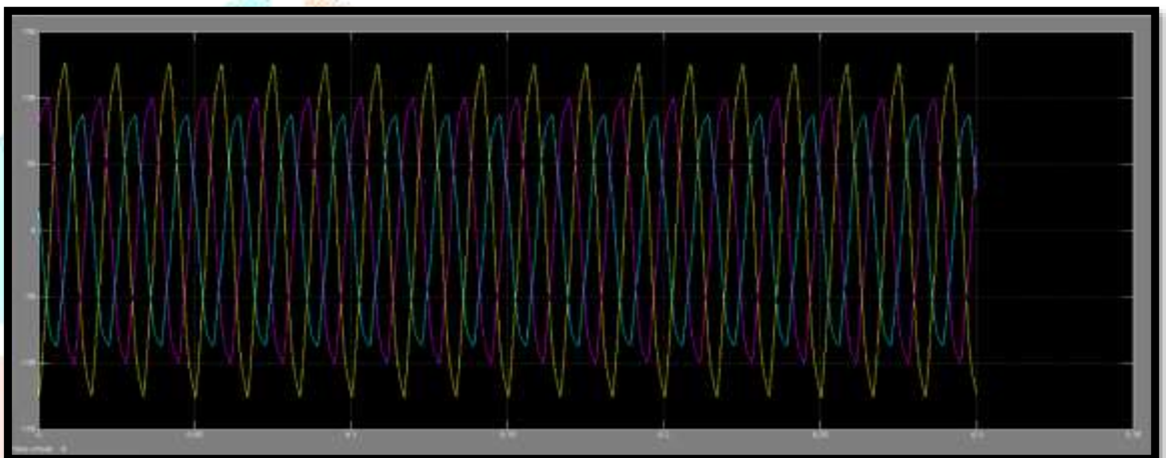

Fig Current Fluctuation at B-31

IPFC integrated with Proposed System

Now in this section the Multilevel converter based IPFC device has been connected interline between two transmission line. The series and shunt converter has been connected between two lines through common d.c. link capacitor. While with the series converter there are three individual capacitors has been integrated for energy bypass or mitigate each phase balancing problems.

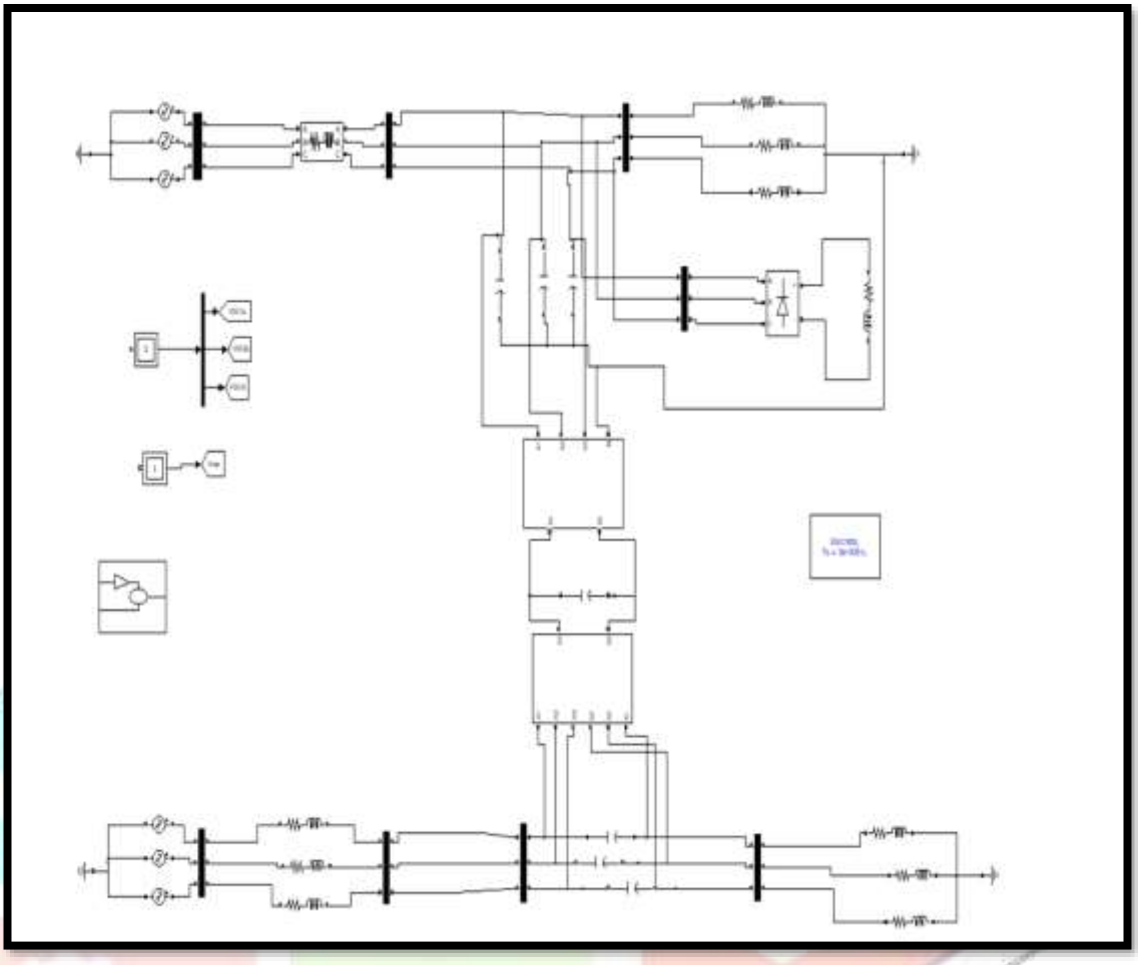

Fig Proposed System with MMC based IPFC System

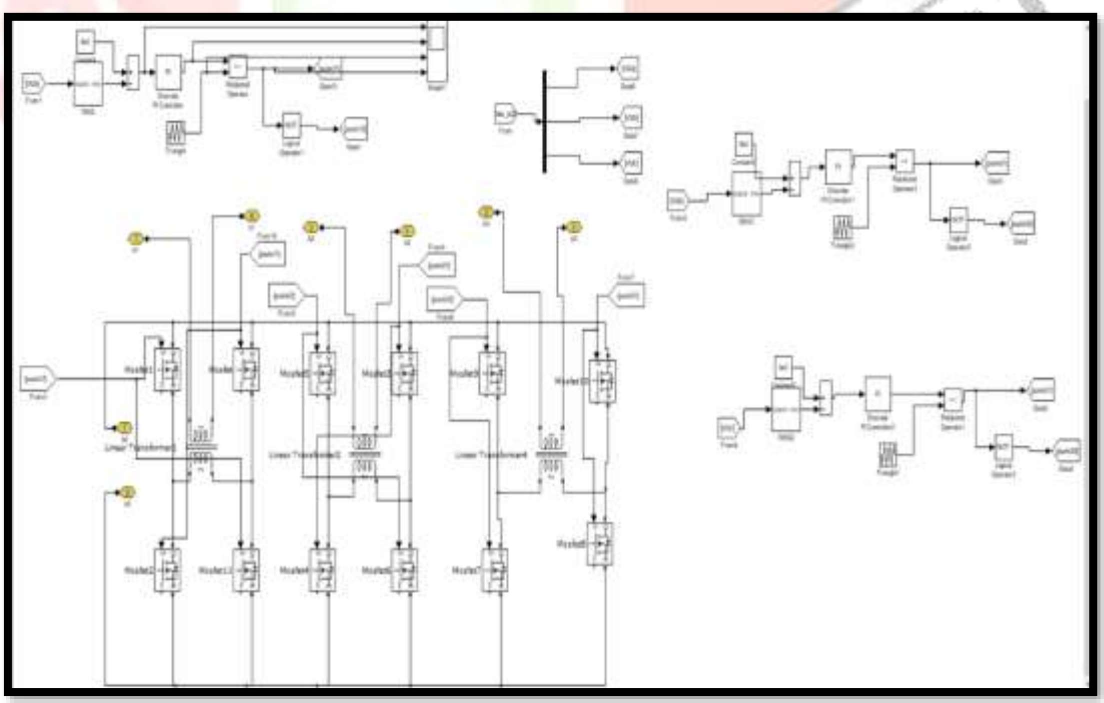

Fig Series control subsystem

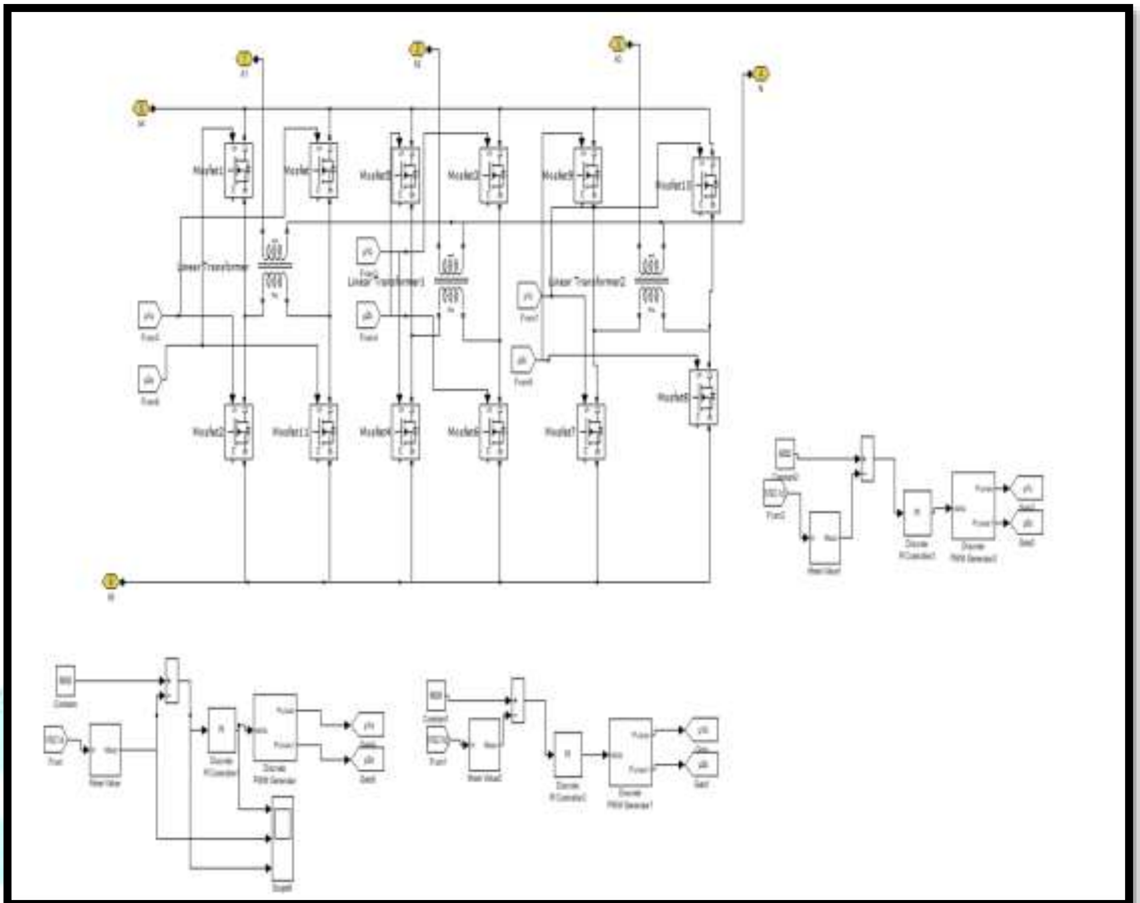

Fig Shunt Control Subsystem

After the proposed series and shunt control subsystem the simulation results improvement in voltage and current at individual bus are shown in fig below.

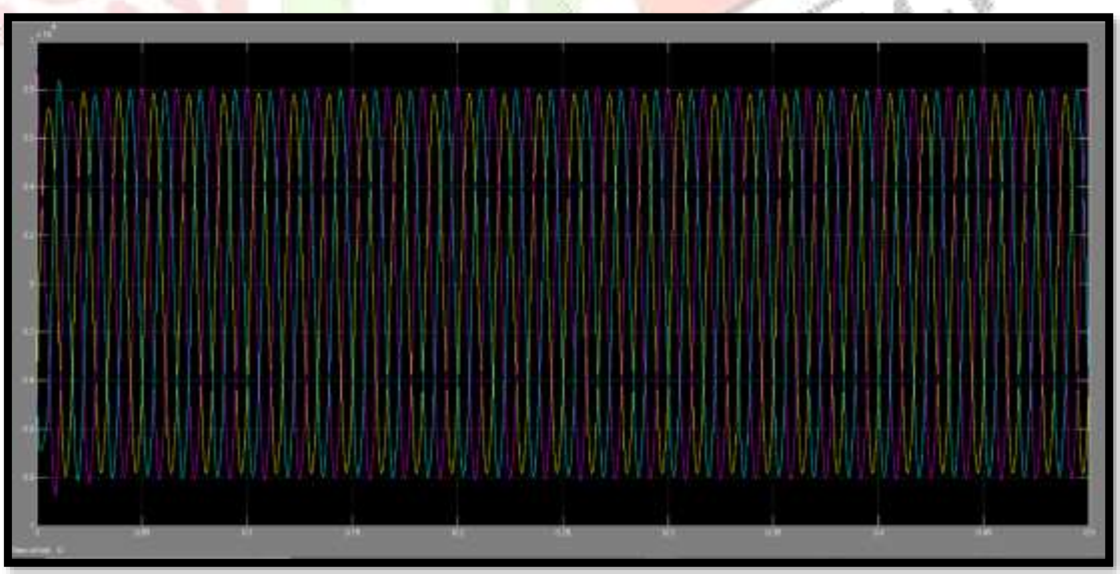

Fig Voltage at B-21

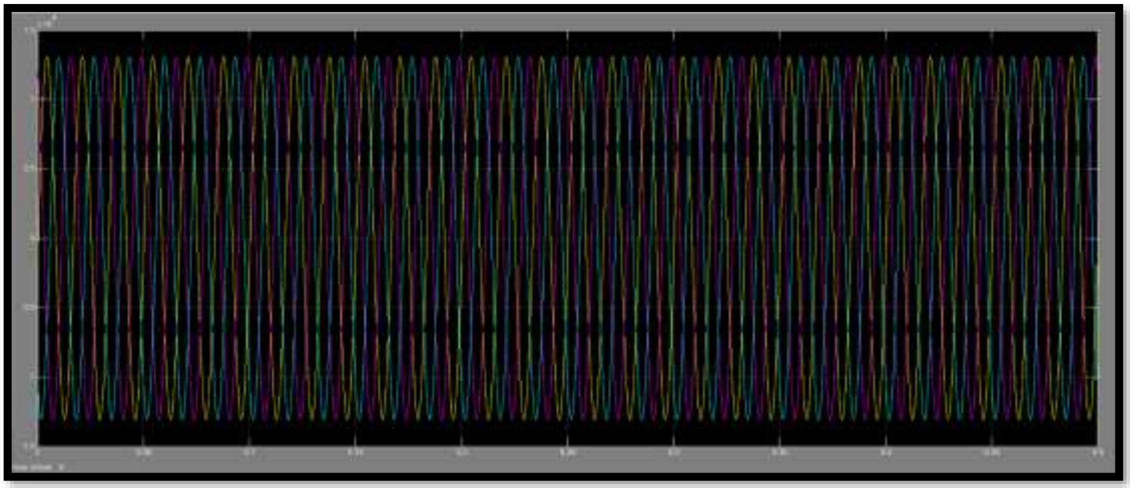

Fig Voltage at B-32

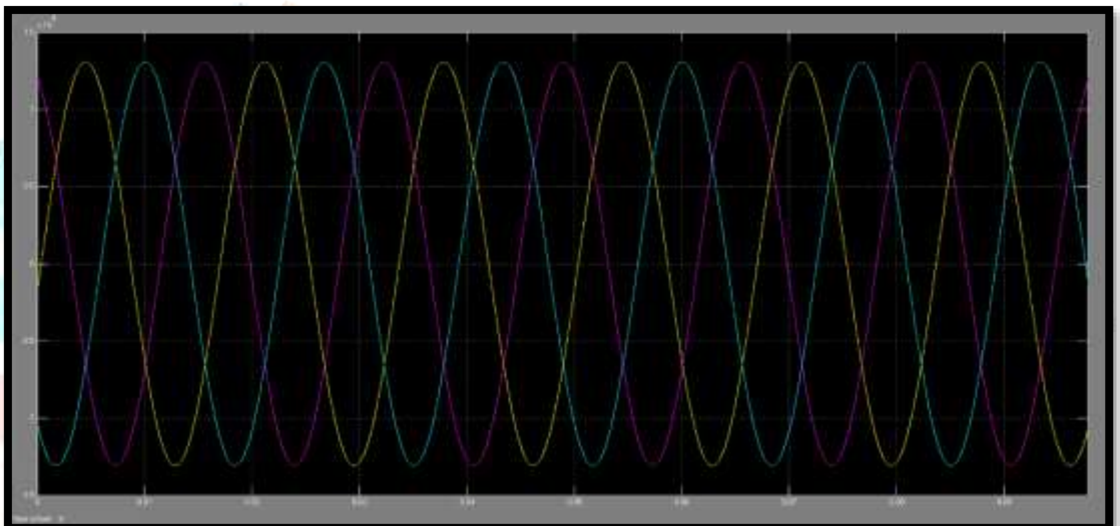

Fig Voltage at B-32 pure Sinusoidal

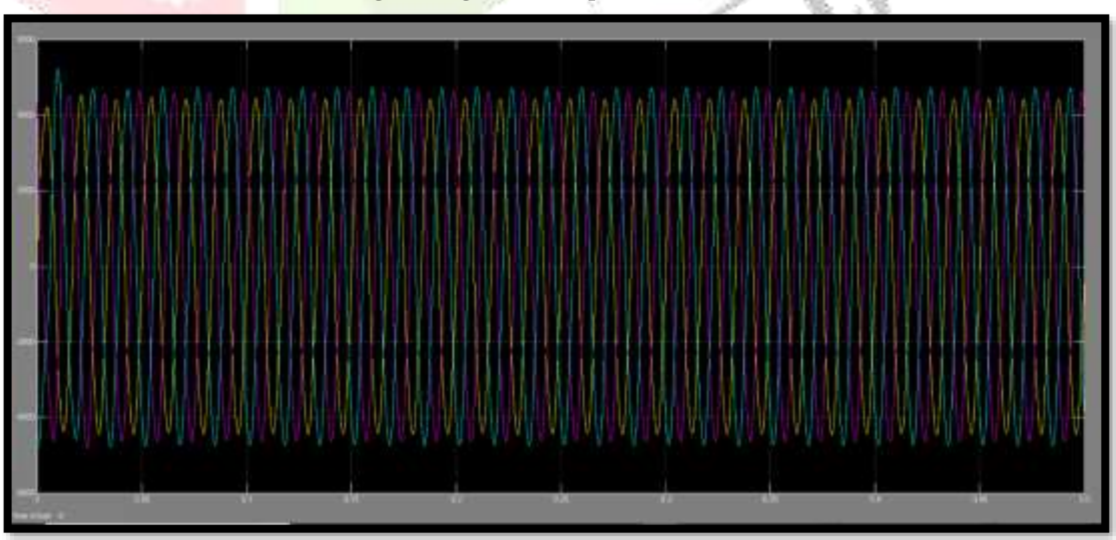

Fig Voltage at B-41

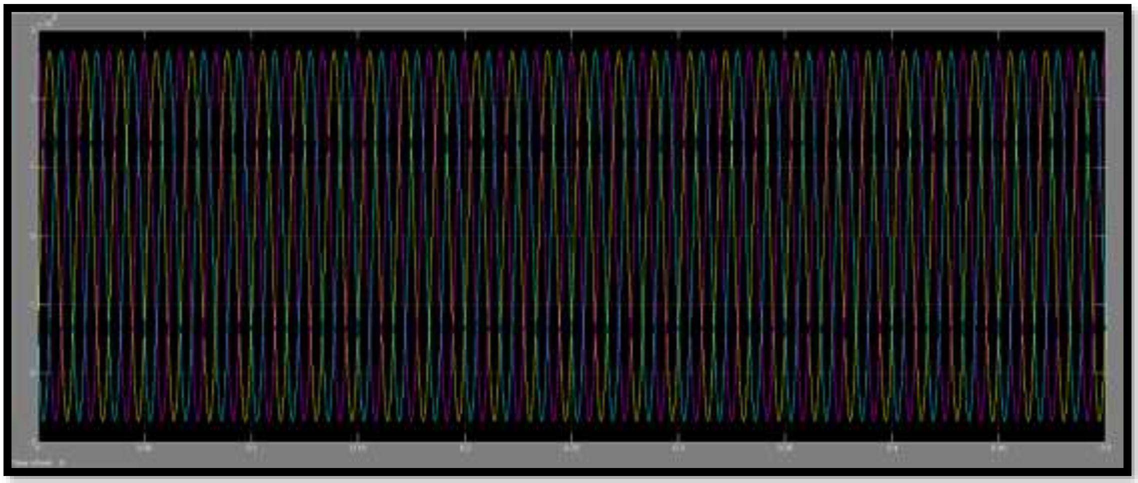

Fig voltage at B-11

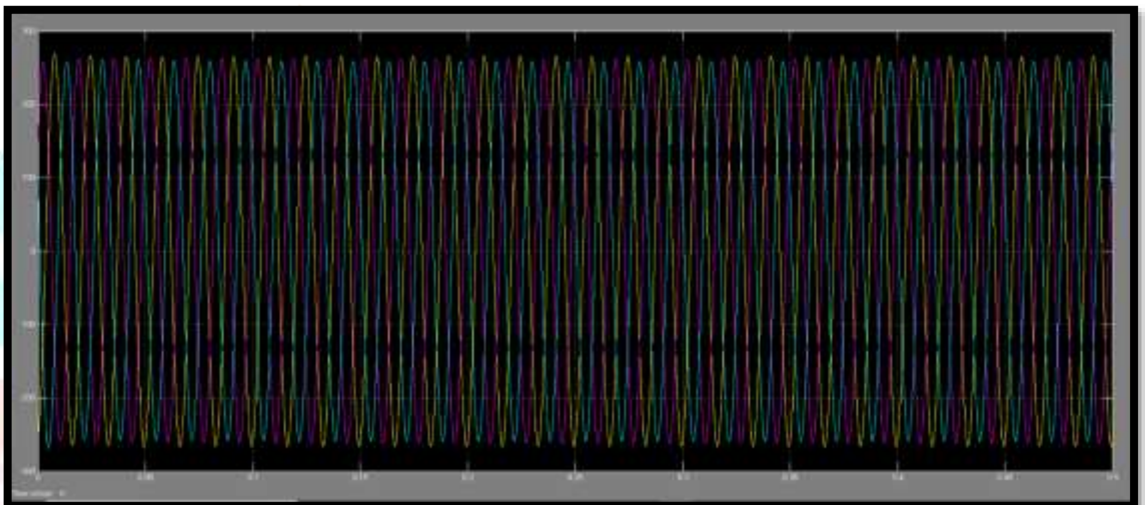

Fig Current at B-11

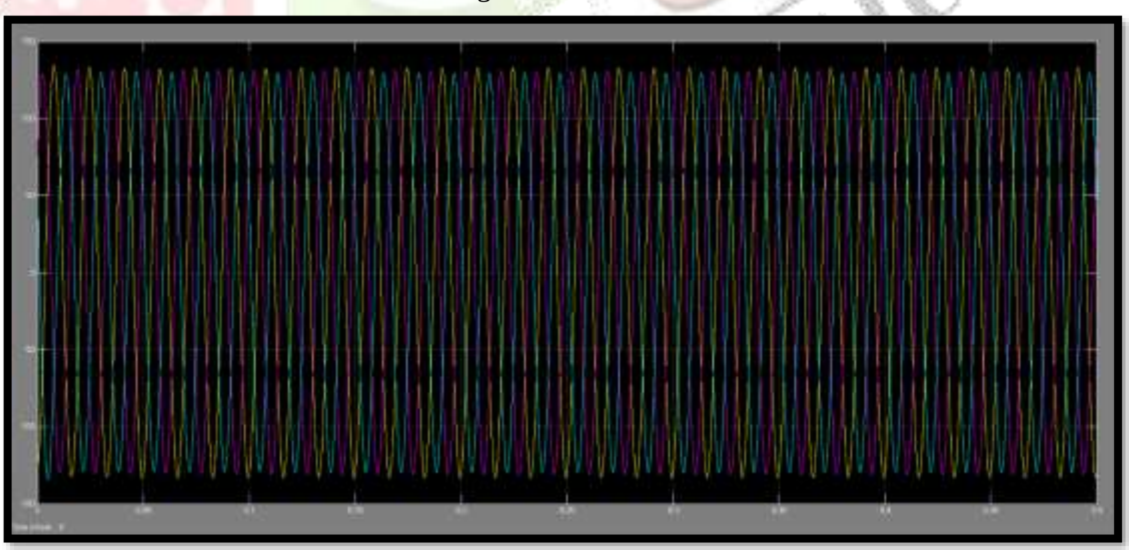

Fig Current at B-21

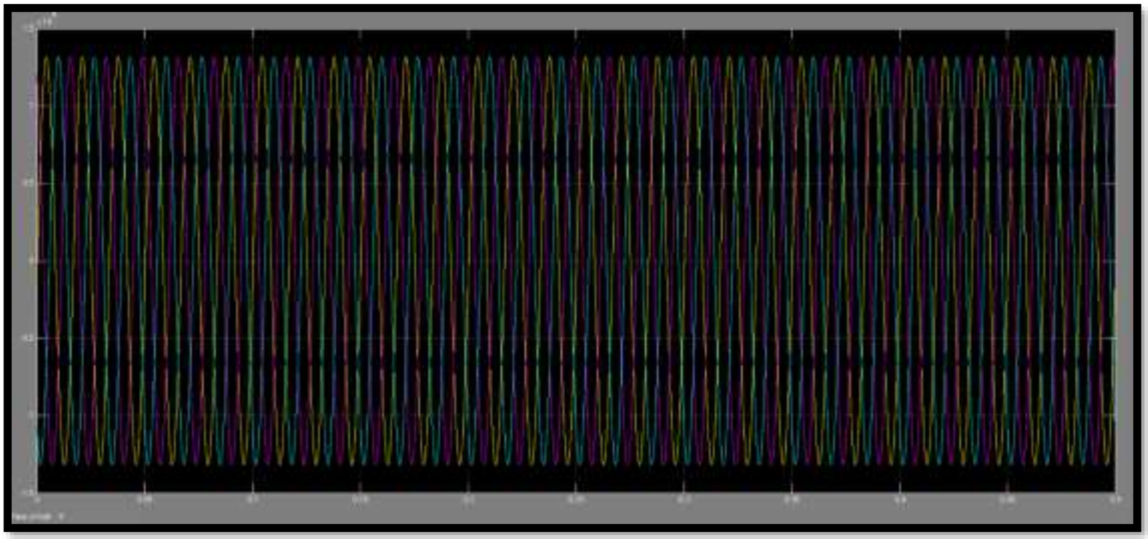

Fig Current at B-22

Summary of Results: -

In the simulation results we can show the power flow control in both the transmission line and controls the different parameters of the given 3-phase system like voltage, current and Active-Reactive power in the system. There are the Voltage and current waveforms at different buses like-11,21,32, etc are shown and compared without IPFC and with IPFC results.

THD Analysis

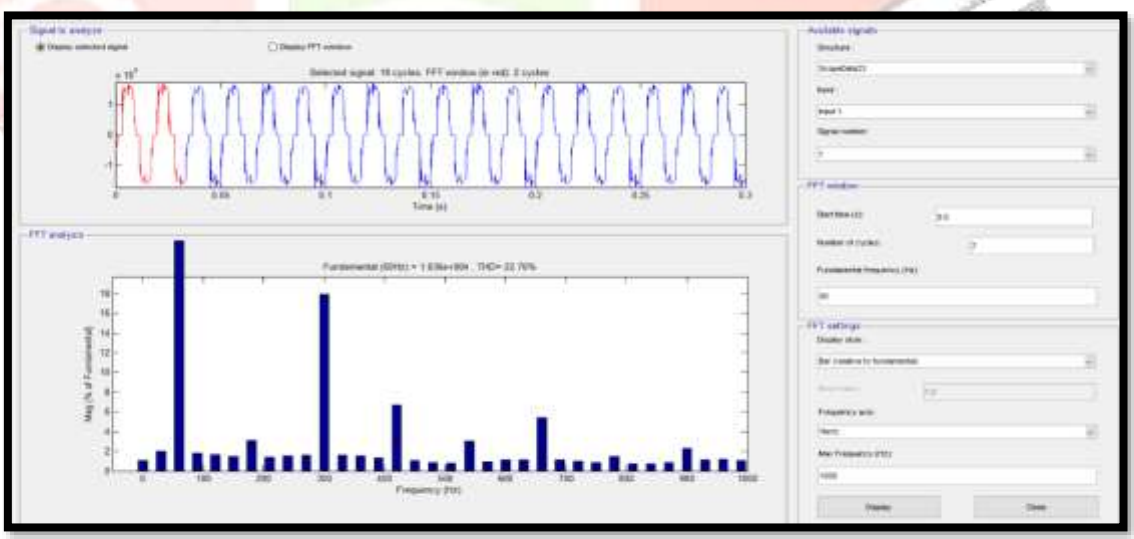

Fig THD of Voltage Level without IPFC

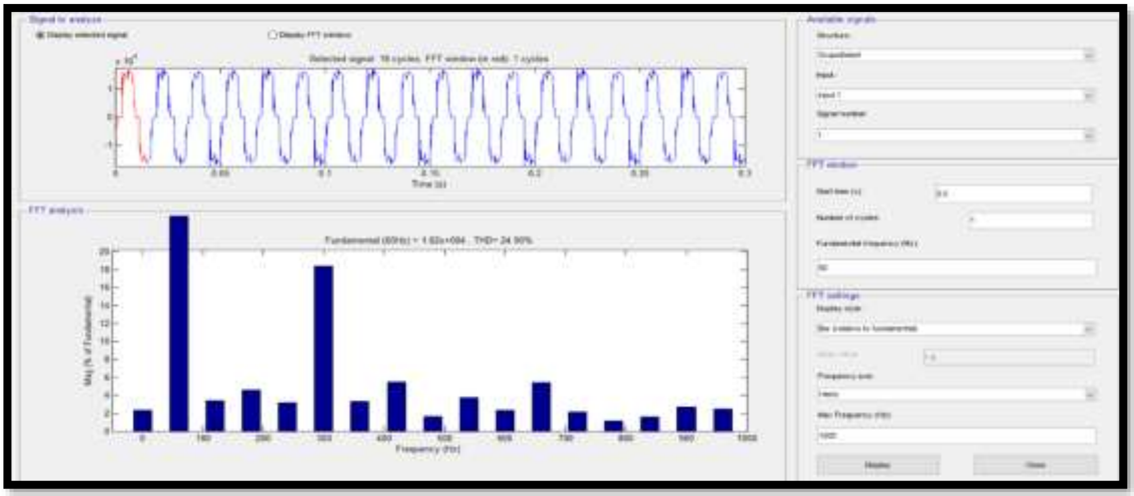

Fig THD of Voltage Level without IPFC

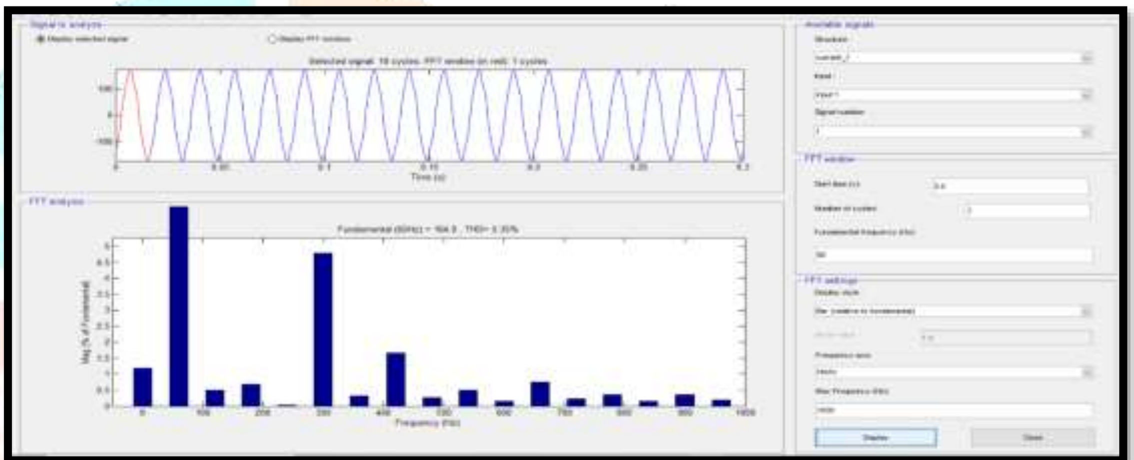

Fig THD of Current Level without IPFC

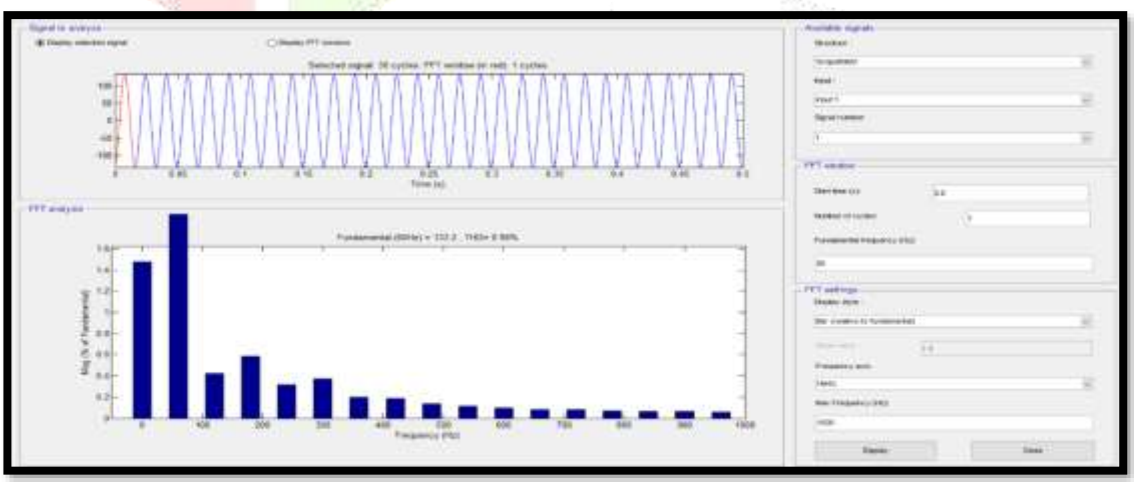

Fig THD of voltage level after IPFC integration

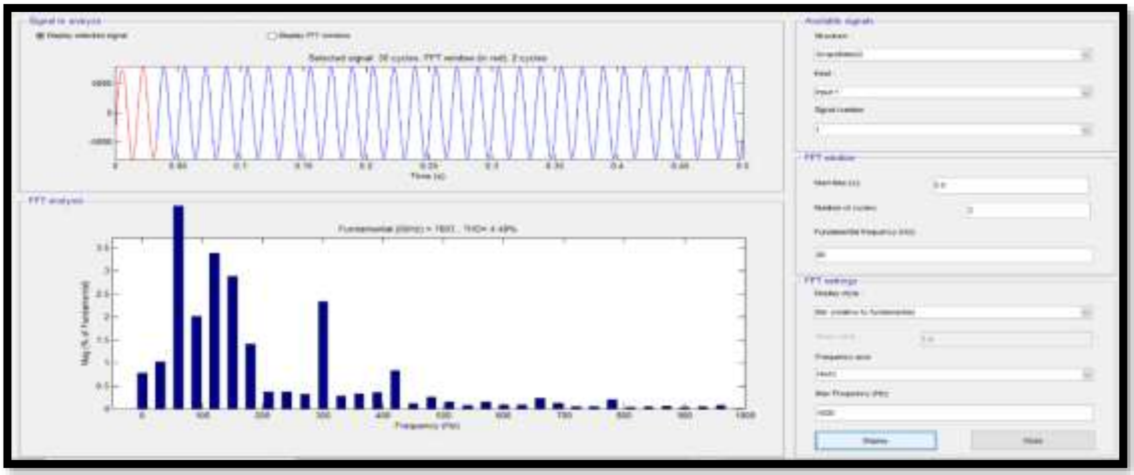

Fig THD of Current with IPFC

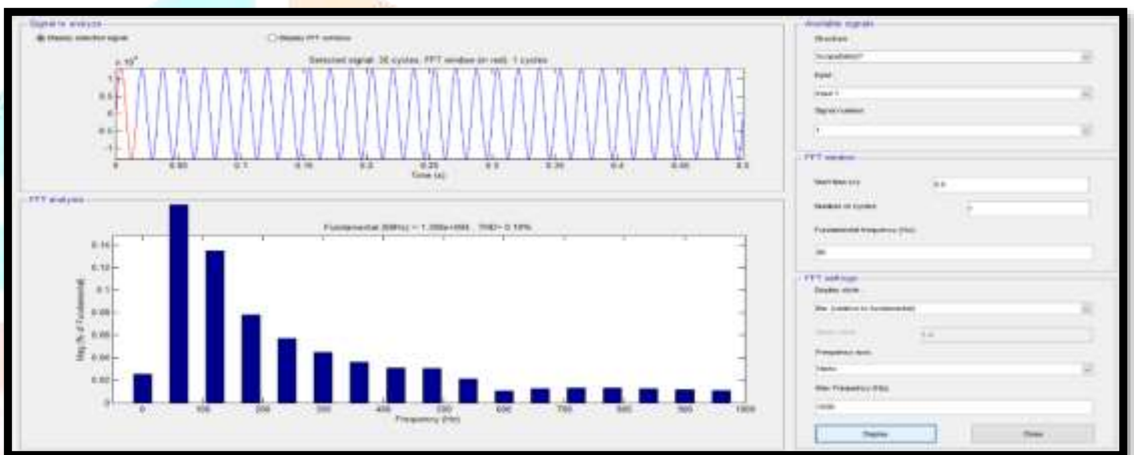

Fig THD of Voltage level with IPFC

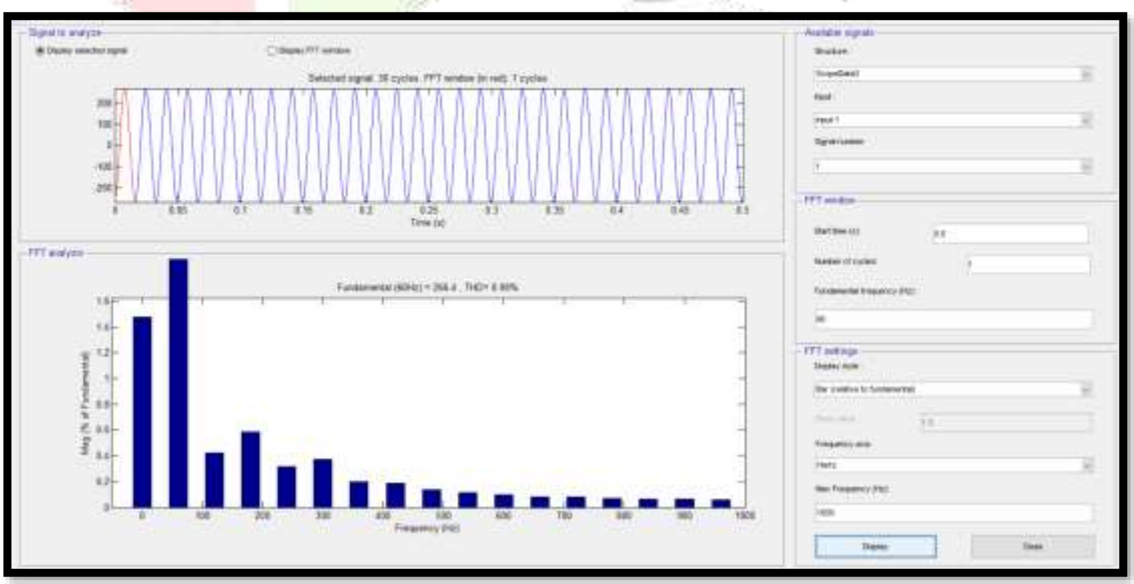

Fig THD of Current with IPFC

THD Comparison: -

Sr.No	FACTS device	THD %
1	THD of Voltage Without IPFC (Bus-21)	22.76%
2	THD of Voltage Without IPFC(Bus-11)	24.90%
3	THD of Current Without IPFC(Bus-21)	5.35%
4	THD of Voltage With IPFC(Bus-11)	0.98%
5	THD of Voltage With IPFC(Bus-21)	0.19%
6	THD of current with IPFC(Bus-21)	4.48%
7	THD of current with IPFC(Bus-32)	0.98%

THD Analysis: -

In the THD comparison of above section we can say that after integration of IPFC in two interline we can improve voltage and current waveform at different buses and improve THD in the proposed system as per the power quality standards.

CONCLUSION

In this paper voltage and power profile has been improved through implementation of IPFC. IPFC is capable of balancing the power through the multiple transmission lines. The power quality is improved since IPFC permits additional power in the system. The circuit models for IPFC system are developed using Matlab- Simulink software. With these simulation results it can be inferred that with the implementation of IPFC, voltage profile, real power flow and reactive power flow can be controlled. The IPFC modelling has been with PI controller for power quality enhancement and power flow control of the given system.

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