Renewable Energy Combined Unified Power Flow Control in Transmission Line

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ABSTRACT

This paper presents a particular inter harmonic control method of using photovoltaic sun powered homestead inverter as Photovoltaic Unified Power Flow Controller (PV-UPFC), for improving stable force move restricts and remunerating the reactive power of the interconnected transmission system. A typical inverter is utilized for both sun based yield DC-AC transformation and UPFC consecutive Voltage Source Converter (VSC) process.By the use of UPFC both real and reactive power can be controlled and voltage profile is maintained. Selective inter harmonic compensation is introduced to improve performance of the line. The approach is based on the Park transform typically adopted for Statcom control. The improvement is obtained by selective interharmonic filter. The Unified Power Flow Controller is a combination of STATCOM (Static Synchronous Compensator) and SSSC (Static Synchronous Series Compensator). It is generally represented by two back to back voltage source converter (VSC) connected through DC capacitor link. A STATCOM is a voltage source converter (VSC) based device, which having voltage source behind a reactor. The voltage source is made from a DC capacitor and thus a STATCOM has little or no active power capability. It is a shunt controlling device. The SSSC is a series controlling FACTS device that is used to control real power flow and improve power oscillation damping on the power grid. It injects voltage in series with the transmission line where it is connected. The proposed system having the advantage that rather than using separate inverters for solar DC-AC conversion and UPFC converter operation, a standard inverter is employed. This can be achieved through connecting the solar farm DC output terminal across the UPFC DC capacitor link there by reducing the number of inverter required. This tends to increase the stable power transfer limits and enhance the transient stability in the power transmission system.

Keywords: *Light flicker (LF), power quality, STATCOM and proportional integral (PI) control, photovoltaic unified power flow controller (PV-UPFC)*

INTRODUCTION

Power quality refers to the power of electrical equipment to consume the energy being supplied to it. A number of power quality issues including electrical harmonics, poor power factor, voltage instability and imbalance impact on the efficiency of kit. Voltage Flicker is that disturbance of lightning induced by voltage fluctuations [1]. Very small variations are enough to induce lightning disturbance for human eye for a typical

230V, 60W coiled-coil filament lamp. The disturbance gets recognizable for voltage variation frequency of 10 Hz and relative magnitude of 0.26%. Huge non-linear industrial loads like electrical arc furnaces, Pumps, welding machines, rolling mills etc. are referred to as flicker generators[1]. In this respect, the standard of supplied voltage is significantly reduced in an electrical power system and therefore the oscillation of supplied voltage appears to be a serious problem. Electric arc furnace, the most generator of voltage flicker, behaves within the sort of a constant reactance and a variable resistance. The transformer-reactance system is demonstrated as a lumped reactance, a furnace reactance (included association cables and transports) and a variable resistance which models the arc. Connecting this sort of load to the network produces voltage variation at the common point of supply to other consumers. The relative voltage drop is expressed by equation (1)

$$\Delta U/Un=R\Delta P + X\ \Delta Q/Un \quad (1)$$

Where,

- ΔP and ΔQ are the variation in active and reactive power
- Un is the nominal voltage
- R and X are short circuit resistance and reactance. R is normally very little in contrast to X, ΔU is proportional to Q (reactive power). Voltage flicker mitigation relies upon reactive power control.

Two types of structures are often used for the compensation of the reactive power.

- Shunt structure
- Series structure

In addition to the above procedures for the compensators, the active filters are also used for the voltage flickers mitigation. Furthermore, the mitigating devices supported Static VAR Compensator (SVC) like Thyristor Switched Capacitor TSC, Thyristor Controlled Reactor (TCR), and Fixed Capacitor Thyristor Controlled Reactor – (FCTCR), are the most frequently used devices for reduction within the voltage flicker. SVC devices achieved a suitable level of mitigation, but due to their complicated control algorithms, they have problems like injecting an outsized amount of current harmonics to the system and causing spikes in voltage waveforms. Advent of FACTS devices make them ideal to be used during a power grid and particularly within the voltage flicker mitigation. In this respect, the FACTS devices supported voltage-source converters are ready to improve the issues associated with SVC [2] [3]. A new technique supported a unique control algorithm, which extracts the voltage disturbance to suppress the voltage flicker, is presented in this paper. The technique is to use STATCOM for voltage flicker compensation to overcome the aforementioned problems related to other techniques. All the simulations are done using MATLAB software.

FACTS DEVICES

FACTS technology exposes new opportunities for controlling power and enhancing the usable capacities of present, also as new and upgraded lines, the likelihood that current through a line are often controlled at an inexpensive cost empower huge potential of quickening the capacity of existing lines with enormous conductors. Also, the utilization of one of the FACTS controllers to enables corresponding power flow through such lines under normal and contingency conditions. These opportunities arise through the power of FACTS controllers to regulate the interrelated parameters that govern the operation of transmission system. “Series Impedance, Shunt Impedance, Current, Voltage, Phase angle etc.,” are some of the interrelated parameters that are controlled. Figure 1 shows the essential kinds of facts controller

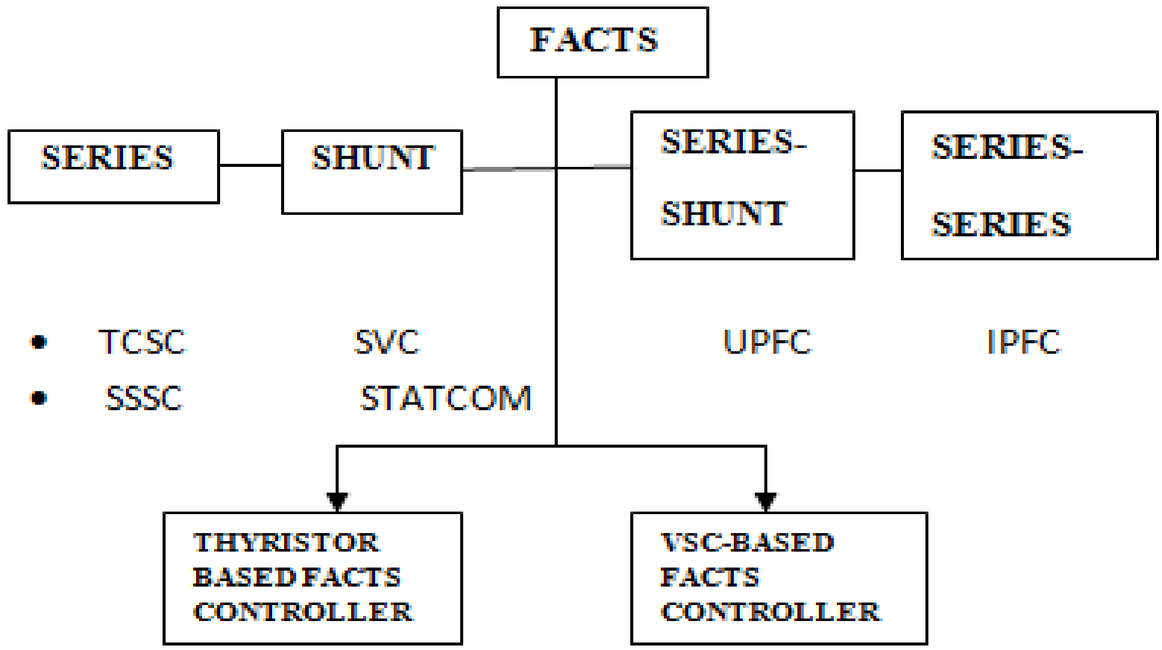

Fig. 1: *Basic Types of Facts Controllers.*

SELECTIVE INTERHARMONIC COMPENSATION

Specific interharmonic remuneration is acquainted with improve STATCOM execution for LF mitigation, which makes it conceivable to compensate just the interharmonics during a proper band round the fundamental frequency. The approach is based on Park transformation which is adopted for STATCOM control.Various control methods are proposed for STATCOM control. In numerous STATCOM models, the control logic is executed with the PI controllers. The control parameters or gains play a key think about STATCOM performance.The proposed modification of the control algorithm is shown in Figure 2 “Selective Interharmonic Filter” (SIF) is added to the classic control algorithm based on the Park transformation [4]. The SIF block is implemented as three equal band pass filters, one for each phase obtained by means of a cascade of a low-pass filter and high-pass filter with cut-off frequencies in symmetric positions with respect to the fundamental frequency.

Interharmonics

Some devices and equipment in power systems can generate voltages and/or currents that contain components that are non-integer multipliers to the fundamental frequency. These components are called interharmonics. Inter harmonics can appear as discrete frequencies or as a wideband spectrum. Devices and situations that can result in interharmonics in industrial and commercial power systems are cycloconverters, Adjustable Speed Drives (ASDs)/Variable Frequency Drives (VFDs), arc furnaces, and loads that do not pulsate synchronously with the fundamental power system frequency, etc.

Phase sequence of interharmonics requires special attention to determine, because they are important in harmonic power flow studies. The example shown in Figure 3 simulates the effect of an interharmonic source. Considering the interharmonic source effect clearly shows harmonic distortion; whereas if the interharmonic source is ignored, the voltage waveform will hardly present harmonic distortion.

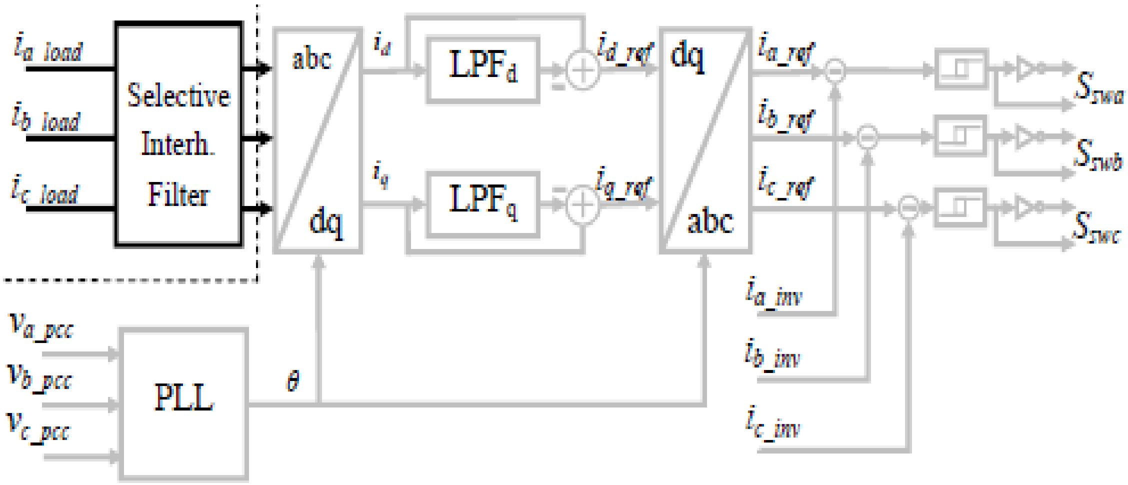

Fig. 2: *Selective Interharmonic Compensation Scheme.*

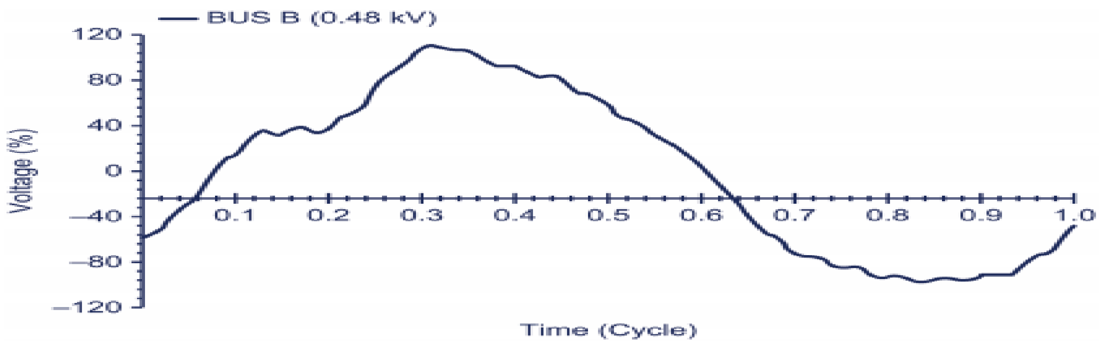

Fig. 3: *Study Results with Consideration of Interharmonics.*

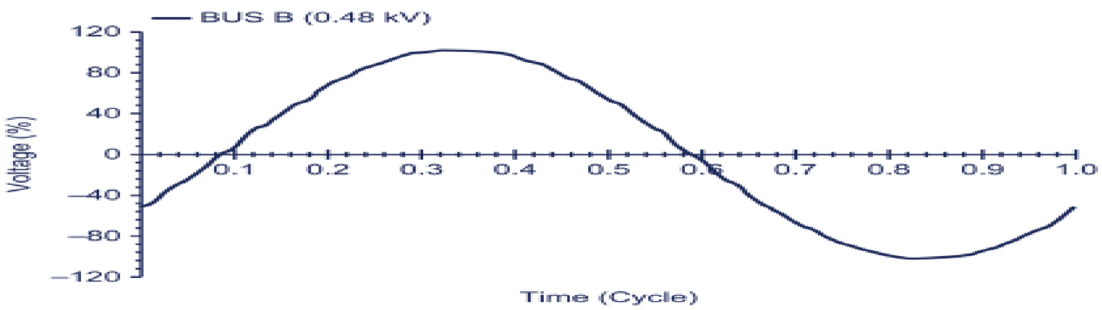

Fig. 4: *Study Results without Consideration of Interharmonics.*

If interharmonics are not considered, calculated TIF at BUS B would be 75.1% and harmonic distortions at voltage waveform would be missed as shown in Figure 4. Interharmonics can cause light glimmer, over-burden of customary arrangement tuned filters over-burden of outlet strip filters, and CT saturation.

STATCOM AND ITS CONTROL ALGORITHM

One of the various devices under the FACTS family, a STATCOM may be a regulating device which may be used to regulate the flow of reactive power within in the system independent of other system parameters. STATCOM has no future support on the dc side and it cannot exchange real power with the ac system [5] [6]. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and supply voltage support to buses by modulating bus voltages during dynamic disturbances so on supply better transient characteristics, improve the transient stability margins and to damp out the system oscillations owing to these disturbances.

Statcom Control Algorithm Clarke's Transformations

The transformation of stationary circuits to a component is added [7] [8]. The resulting transformation is given by equation (2).

$$[f_{abc}] = T_{\alpha\beta 0}[f_{\alpha\beta 0}] \quad (2)$$

Inverse Clarke's Transformation

The inverse transformation is given by equation(3)

$$[f_{abc}]=T_{\alpha\beta 0}\text{-}1[f_{\alpha\beta 0}] \quad (3)$$

Where the inverse transformation matrix $T_{\alpha\beta 0}$-1 is presented by equation (4)

$$T_{\alpha\beta 0}\text{-}1=\begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \end{bmatrix} \quad (4)$$

Park's Transformation

Park's transformation may be a well-known three-phase to two-phase transformation in synchronous machine analysis. The Park's transformation is given by equation (5)

$$[f_{qd0s}]=T_{qd0s}(\theta)[f_{abcs}]... \quad (5)$$

whereT_{qd0s} is presented by (6)

$$T_{qd0s} =\frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2(\pi)}{3}\right) \\ \sin(\theta) & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2(\pi)}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

(6)

θ is the angular displacement of Park's reference frame.

Inverse Park's Transformation

It can be shown that for the inverse transformation is given by equation (7)

$$[f_{abcs}]=T_{qd0s}(\theta)^{-1}[f_{dq0s}] \quad (7)$$

where the inverse of Park's transformation matrix is given by (8)

$$T_{qd0s}(\theta)^{-1}= \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2(\pi)}{3}\right) \\ \sin(\theta) & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2(\pi)}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (8)$$

UPFC-UNIFIED POWER FLOW CONTROL

The UPFC consists of two voltage source converters; series and shunt converter, which are connected to every other with a standard dc link. Series converter or Static Synchronous Series Compensator (SSSC) is employed to feature controlled voltage magnitude and phase angle in series with the line, while shunt converter or Static Synchronous Compensator (STATCOM) is employed to provide reactive power to the ac system, besides that, it will provide the dc power required for both inverter. Each of the branches consists of a transformer and power converter [9][10][11]. These two voltage source converters shared a standard dc capacitor. The energy storing capacity of this dc capacitor is usually small. Therefore, active power drawn by the shunt converter should be adequate to the active power generated by the series converter. The reactive power in the shunt or series converter is often chosen independently, giving greater flexibility to the power flow control. The coupling transformer is employed to connect the device to the system. Figure 5 represents the UPFC circuit diagram. Figure 7 represents the Simulink model of UPFC. Figure 6 represents the DC link capacitor voltage.

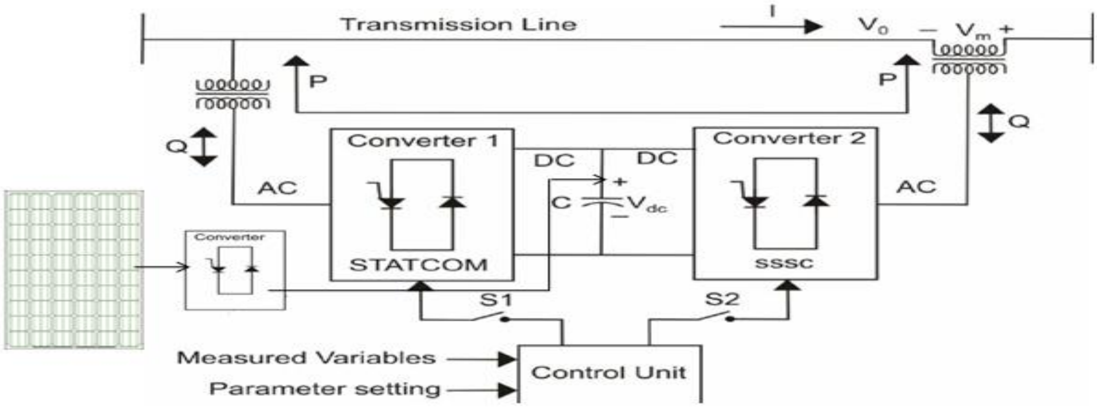

Fig. 5: *UPFC Circuit Diagram.*

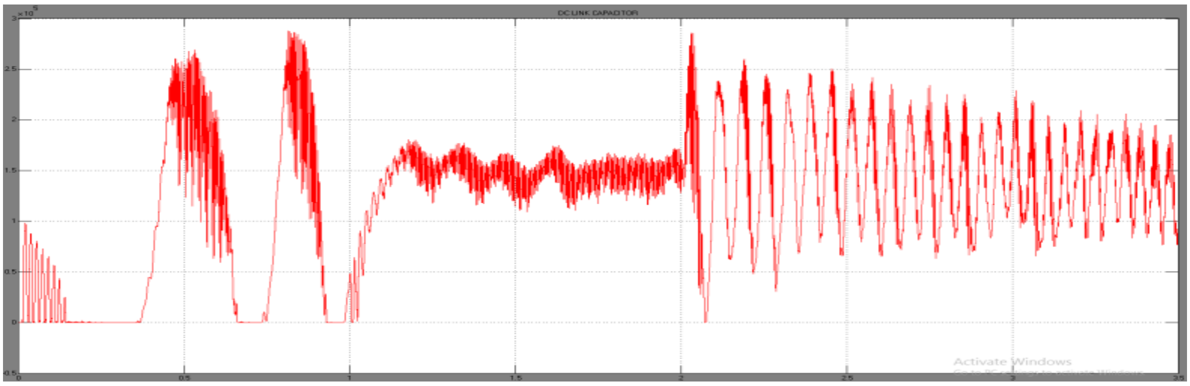

Fig. 6: *DC link Capacitor Voltage.*

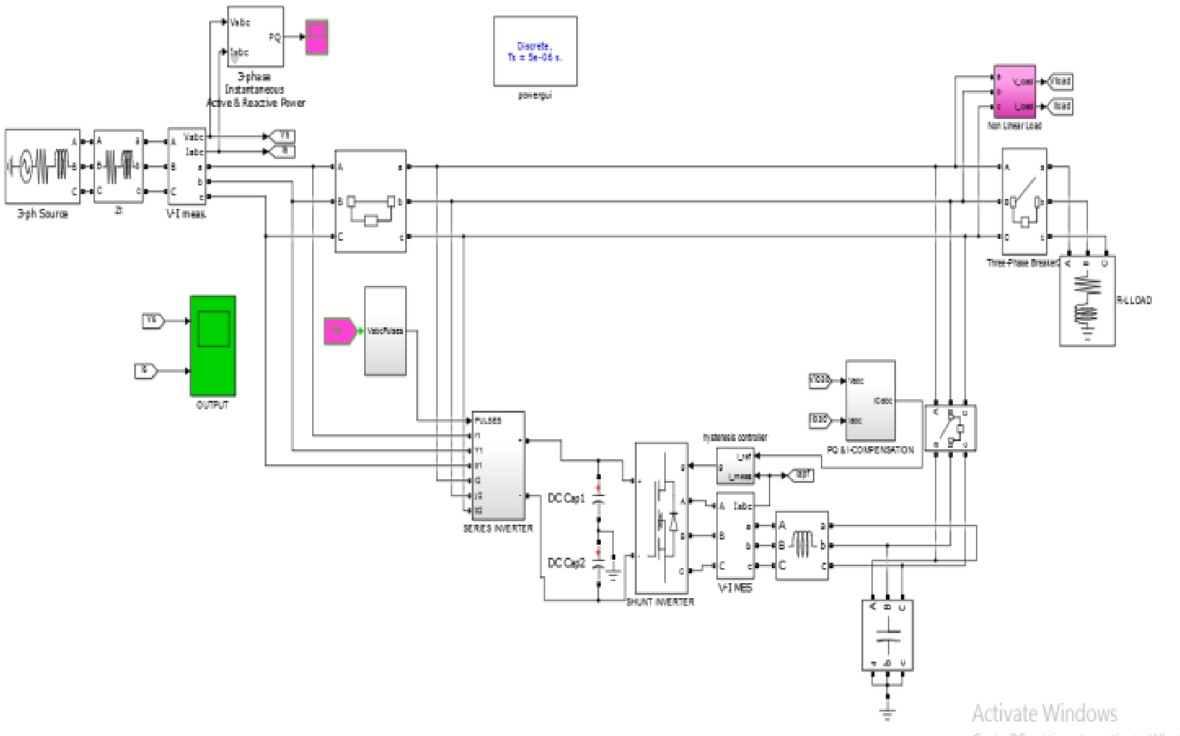

Fig. 7: *Simulink Model of UPFC.*

BOOST CONVERTER

Aboost converter shown in figure 8(step-up converter) may be a DC-to-DC power converterthat steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a category of switched-mode power supply(SMPS) containing a minimum oftwo semiconductors (adiodeand atransistor) and a minimum of one energy storage element: a capacitor, inductor, or the two in combination. To diminish voltage ripple, filters produced using capacitors (at times along with inductors) are ordinarily added to such a converter's output (load-side filters) and input (supply-side filter).Power for the boost converter can come from any suitable DC source, like batteries, solar panels, rectifiers, and DC generators. A process that changes one DC voltage to another DC voltage is named DC to DC conversion. A boost converter is usually called a step-up converter since it "steps up" the source voltage.

PV ARRAY

A photovoltaic array (also called a solar array) consists of multiple photovoltaic modules, known as solar panels, to convert radiation (sunlight) into usable direct current (DC) electricity. Photovoltaic may be a method of generating electrical power by converting radiation into DC electricity using semiconductors that exhibit the photovoltaic effect. Figure 9 represents the PV voltage signal

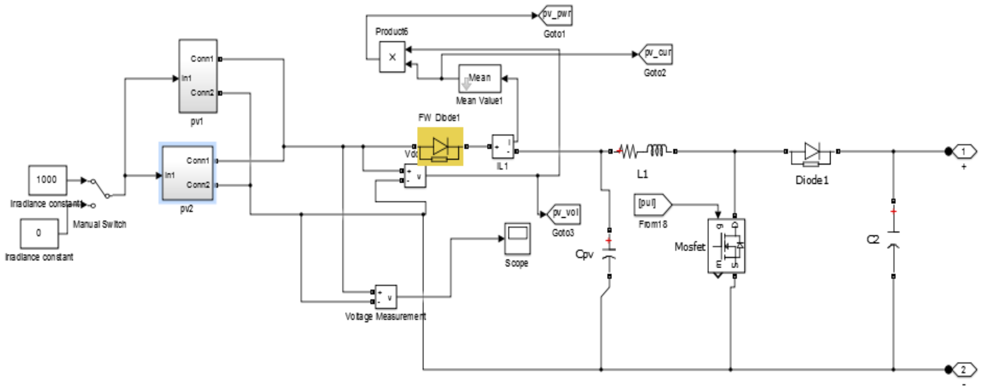

Fig. 8: *Boost Convertor.*

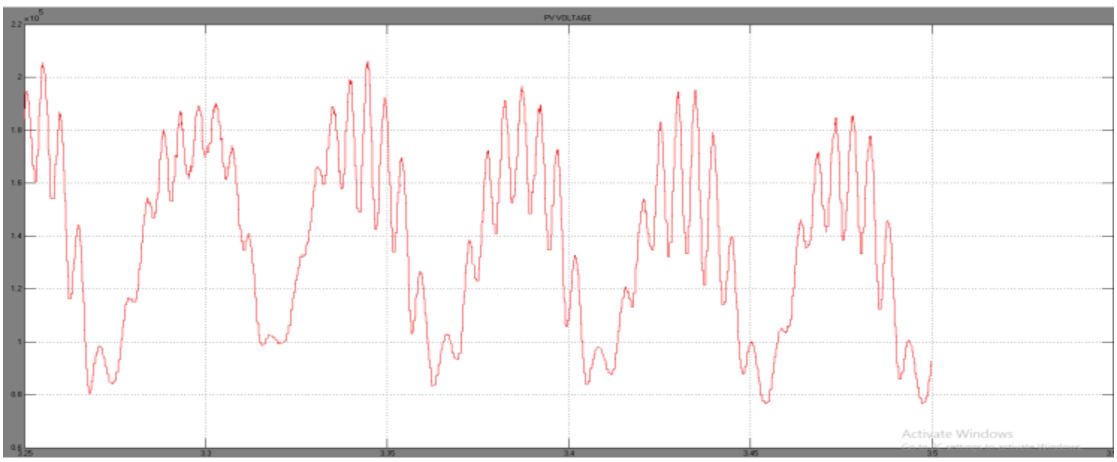

Fig. 9: *PV Voltage Signal.*

SIMULATION AND RESULTS

Simulation Model Without Using STATCOM

The MATLAB SIMULINK without using STATCOM is given by figure 10

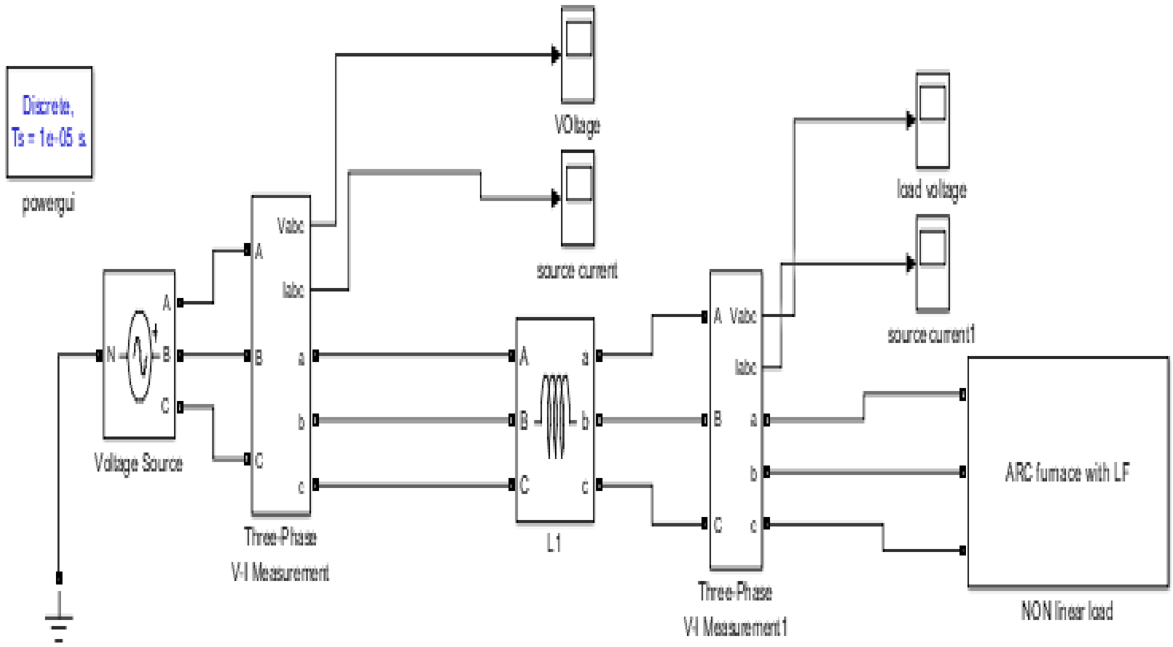

Fig.10: *Simulation Model without Using Statcom.*

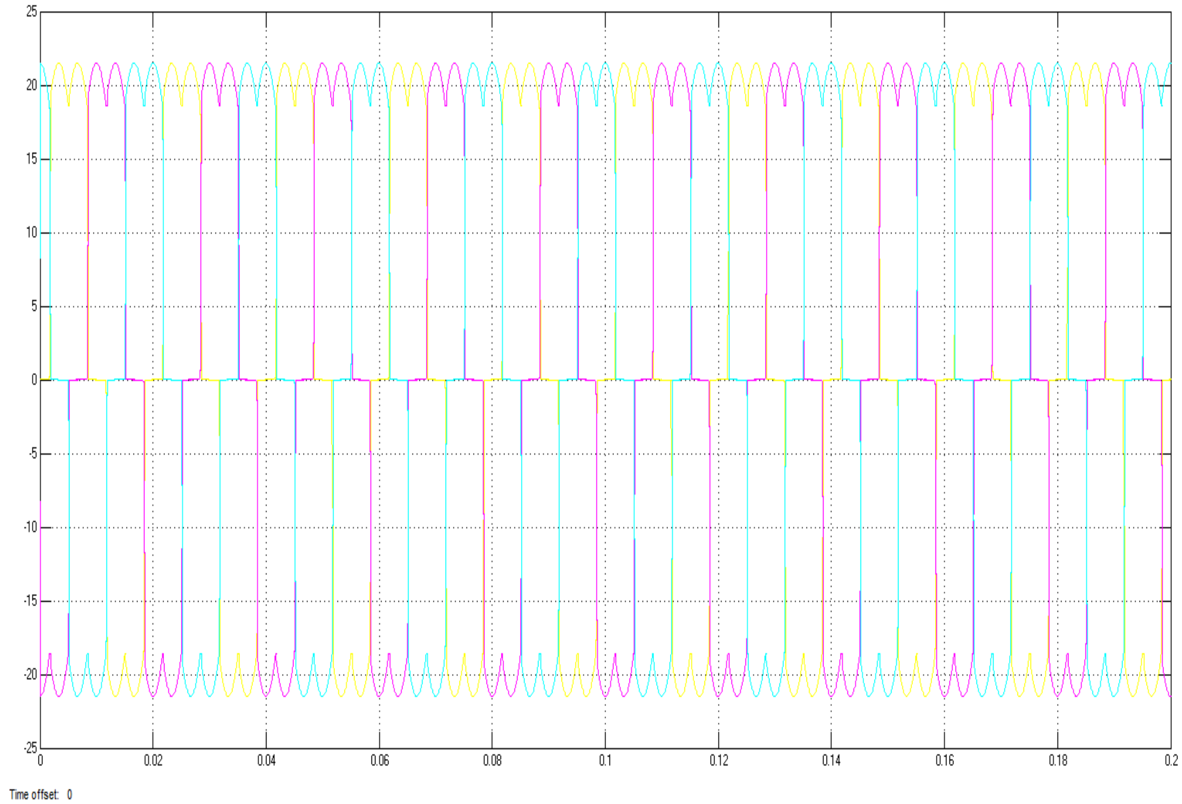

Fig. 11: *Simulation Output with Flicker*

FFT Analysis
Figure 12 represents the FFT analysis

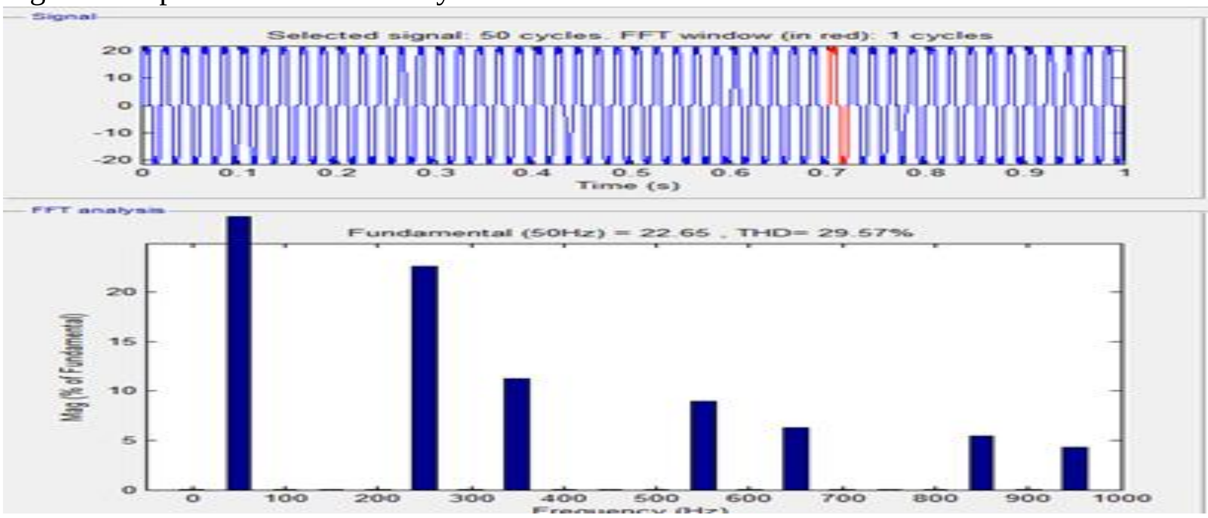

Fig. 12: *FFT Analysis with THD Value 29.57%*

Without PI Controller
Figure 13 represents the simulation output without PI controller

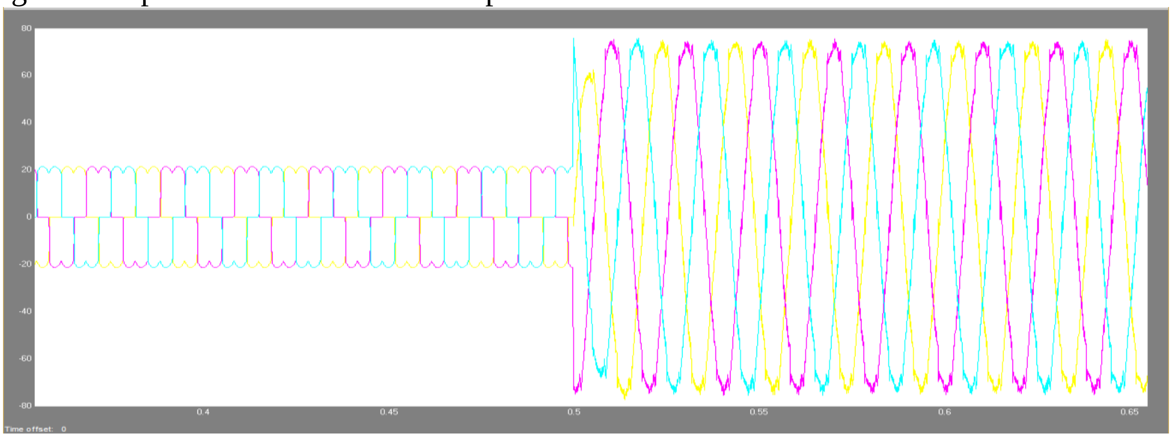

Fig.13: *Simulation Output without PI Controller*

PI Controller
For systems where consistent aggravations or model errors are available, PI-controller might be a regularly utilized control technique, since it will in by and eliminate static control errors. For some disperse systems be that as it may, decentralized PI-control is known to destabilize the system.It shows that for an outsized class of systems, decentralized PI-control is not a feasible control strategy. As a substitute, we suggest a distributed controller, which mimics a decentralized P-controller with a centralized I-controller by distributed averaging. Even though the proportional part of this controller is decentralized, the overall controller is distributed due to the communication needs of the distributed integral part. For a certain class of dynamical systems, the proposed controller is able to eliminate static errors in the output, provided that the closed loop system is output stable, in the sense that all observable modes of the system are stable.

With PI Controller
Figure 14 is the Simulink with PI Controller. Figure 15 is the simulation circuit of selective interharmonic compensation.

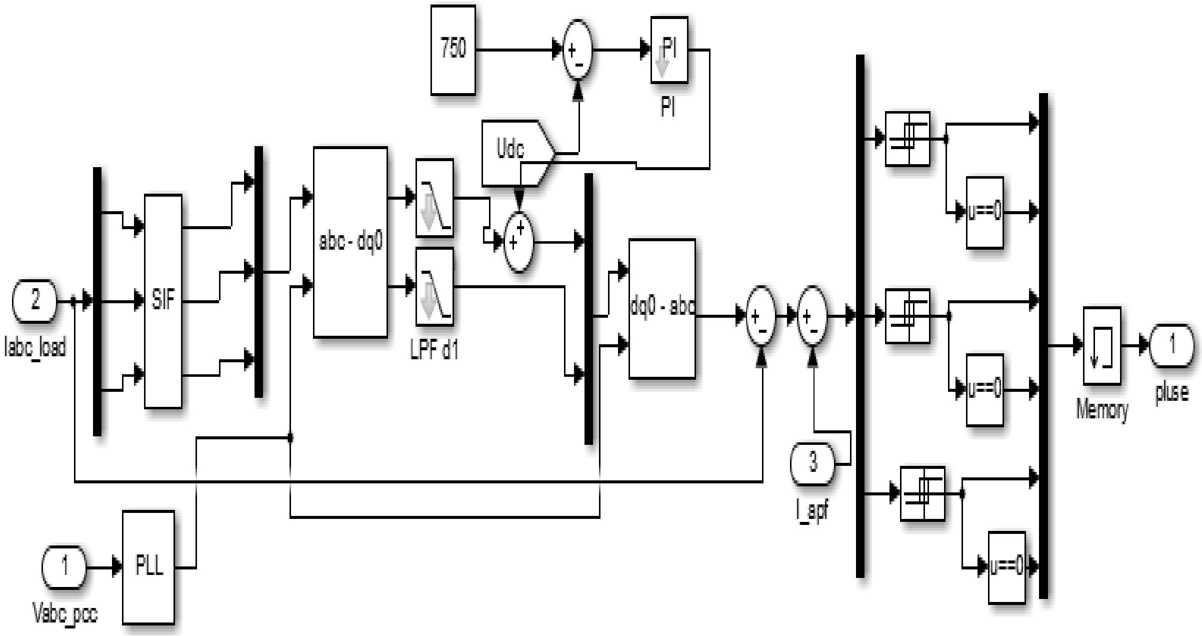

Fig.14: Simulation with PI Controller

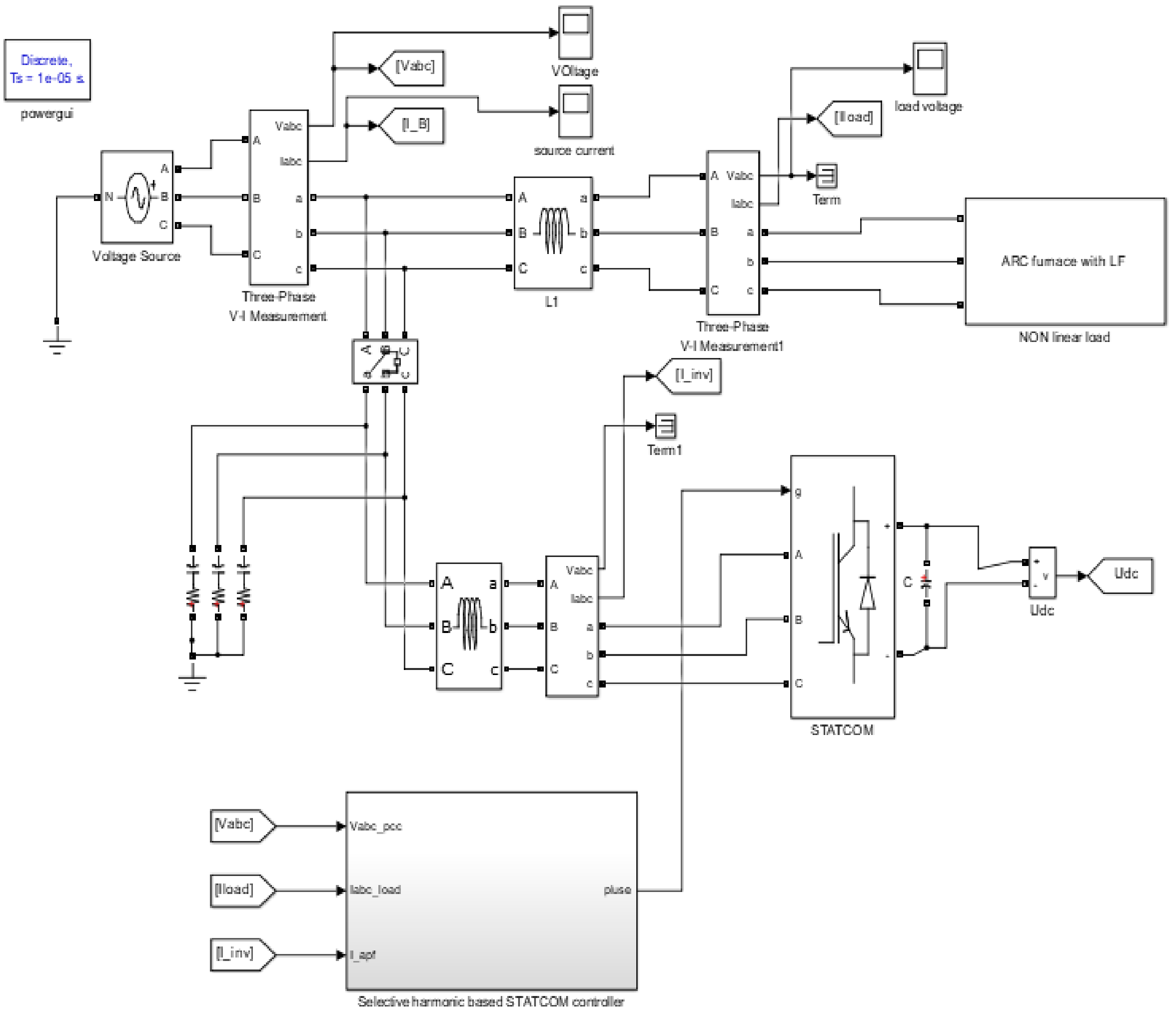

Fig. 15: Simulation Circuit Diagram.

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Output Voltage Compensation

The figure 16 shows how much amount of voltage compensated during peak loaded condition. STATCOM compensates the fault current in an efficient manner to equalize the input and output effectively.

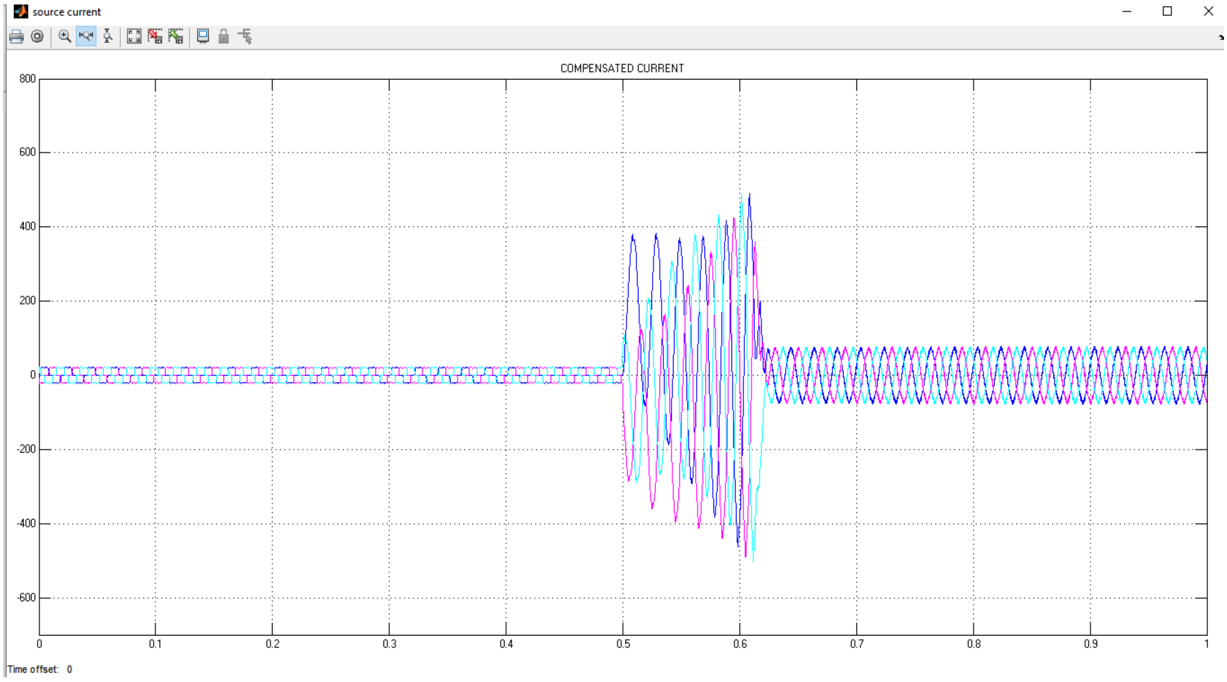

Fig. 16*: *Compensated Output Voltage.

FFT Analysis

The figure 17 shows that THD value after the compensation by STATCOM is reduced

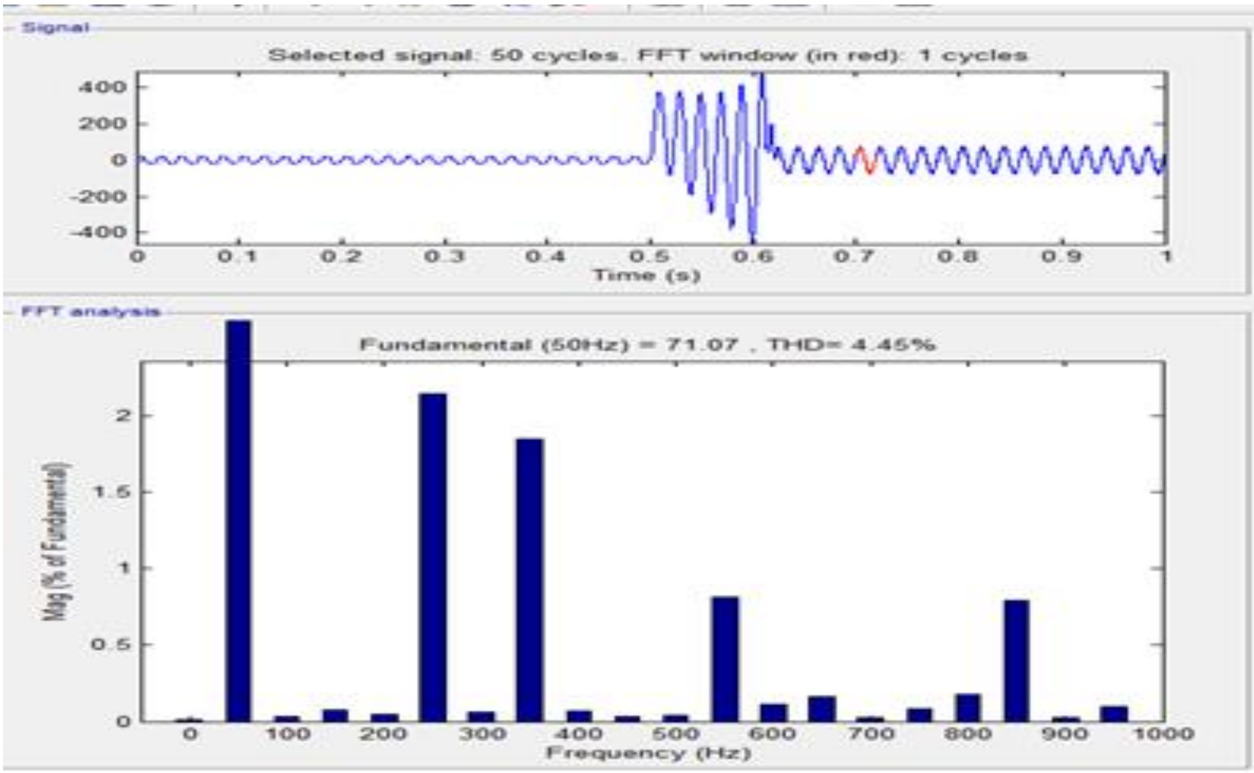

Fig. 17*: *FFT analysis which shows the THD 4.45%

Figure 18 represents the overall Simulink circuit

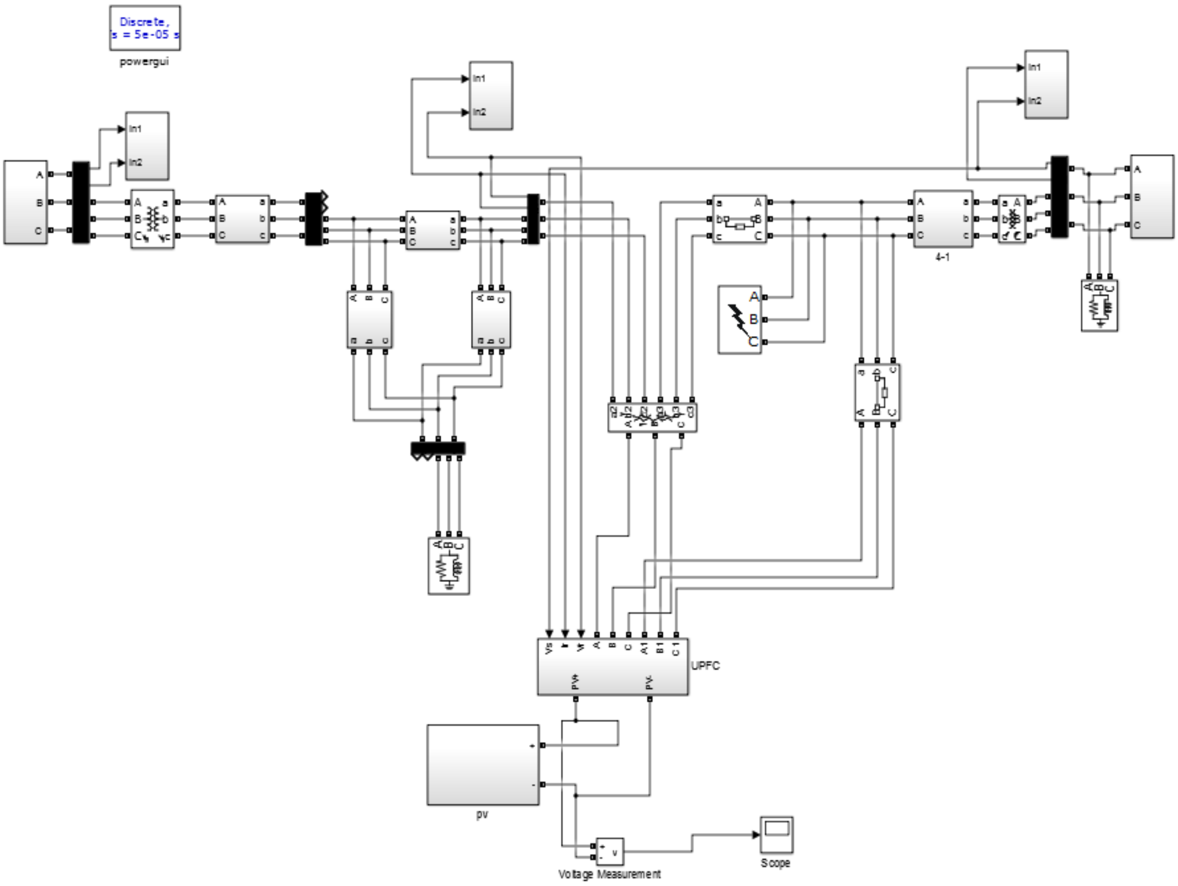

Fig. 18: *Simulation Block Diagram of the Power System with a UPFC in MATLAB/Simulink.*

Real and Reactive Power

Figure 19 represents the waveform of real and reactive power with UPFC

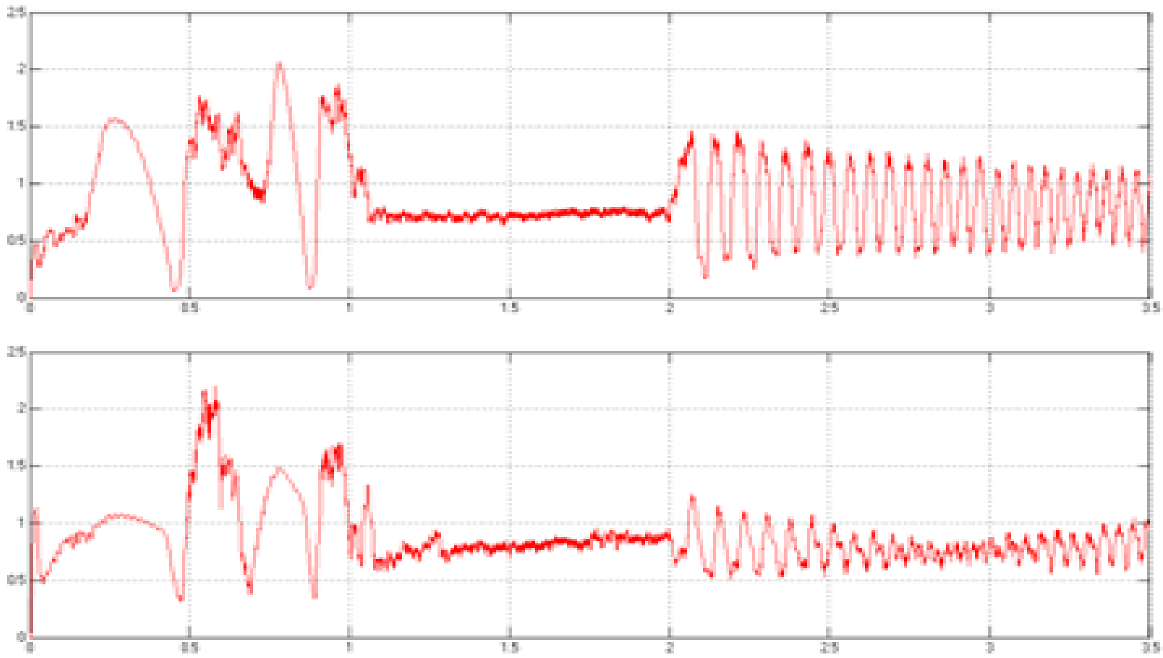

Fig. 19: *Real and Reactive Power.*

FAULT MITIGATION

Figure 20 represents the waveform of fault mitigation

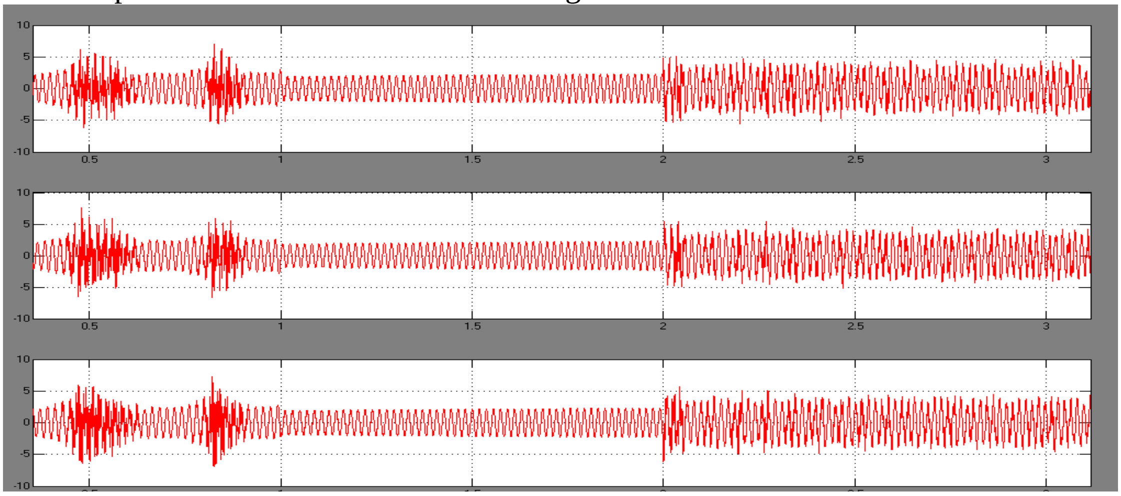

Fig. 20*Fault mitigation*

CONCLUSION

This paper presents the electrical arc furnace model in time domain analysis which was modelled using MATLAB/simulink and therefore major power quality issues caused by furnace has been studied. From the simulation results, voltage flicker and THD on current were reduced and therefore the power factor correction for arc furnace load was obtained closer to unity. Selective interharmonic compensation was introduced to improve the performances of STATCOMS for LF mitigation. This makes it possible to compensate only the interharmonics in a proper band around the fundamental frequency, which mainly affects LF. The same system has been simulated with UPFC and analyzed under different fault conditions

FUTURE SCOPE

- Reducing STATCOM sizing in the design stage for LF mitigation or, for a fixed size, reserving more available power for other STATCOM features (e.g., voltage, power factor, reactive power, unbalance, harmonics);
- Optimizing the performances of existing STATCOMS just by upgrading their control algorithms
- The more advanced controllers such as fuzzy controller, artificial neutral network, etc can be implemented

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