An Investigation On Power Factor and THD In Distributed Power System For Practical RL Load

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ABSTRACT

This paper discusses the investigation over power factor and total harmonic distortion of system for dc RL load. Poor power factor costs our community in increased electricity charges and unnecessary effect in the system and poor power quality. In electrical plants, the loads draw from the network electric power (active) as power supply source (e.g. personal computers, printers, etc.) or convert it into another form of energy (e.g. electrical lamps or stoves) or into mechanical output (e.g. electrical motors) or rectifier. To smooth such negative effect, the power factor correction of the electrical plants is carried out. The power factor correction obtained by using power factor correction switch banks to generate locally the reactive energy necessary for the transfer of electrical useful power, allows a better and more rational technical-economical management of the plants. The system is capable of correcting power factor up to unity or adjusting it according to user desire. The proposed system is characterized by, less generation of harmonics, and reduction of transmission losses. Also, this paper is somehow different from conventional base paper in the sense that here load is taken as practical inductive load which is abundantly found in the industry instead of highly inductive load where load current is assumed to be constant for the simplification of design. Simulation results are reported and proved to be in good agreement with the relevant experimental results.

KEYWORDS – Fast fourier transform, Harmonics, Linear and Non-linear Loads , Matlab, Power factor correction, Total Harmonic Distortion, Simulink.

1 INTRODUCTION

In present situation, the increase in the utilization of computers, laptops, uninterruptable power supplies, telecom and bio-medical equipments has become uncontrollable as its growth is rising exponentially. Hence, increase in functionality of such equipments leads to the higher power consumption and low power density which provided a large market to distributed power systems (DPS). The distorted input current waveform extracted by the capacitive input filter of the power converters produces unwanted harmonics which propagates to other line powered equipments [2]. The harmonic pollutes the AC lines and interferes with the operations of sensitive line powered equipments [1]. The distorted current waveform also leads to inefficient utilization of the available power from the AC outlet. This is because the AC line power is transferred to the load only when each frequency component of the line voltage is an in-phase, scalar related quantity with respect to the same frequency component of the extracted current [1],[2],[3].

The power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit and is a dimensionless number between 0 and 1 [2]. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power [8]. In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment [9]. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor [8].

1.1 Importance of power factor in distributed system: Power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts). This increases generation and transmission costs. For example, if the load power factor were as low as 0.7, the apparent power would be 1.4 times the real power used by the load. Line current in the circuit would also be 1.4 times the current required at 1.0 power factor, so the losses in the circuit would be doubled (since they are proportional to the square of the current) [1],[5]. Alternatively all components of the system such as generators, conductors, transformers, and switchgear would be increased in size (and cost) to carry the extra current.

Utilities typically charge additional costs to customers who have a power factor below some limit, which is typically 0.9 to 0.95 [2]. Engineers are often interested in the power factor of a load as one of the factors that affect the efficiency of power transmission. With the rising cost of energy and concerns over the efficient delivery of power, active PFC has become more common in consumer electronics [1],[2],[3],[8],[9].

1.2 Major problems associated with lagging power factor: i) Total harmonic distortion increases, ii) Extra losses and heating in rotating machines, iii)Overvoltage due to resonance. so, the machine can damage, iii) Interferences in the AC line, iv) Load power is reduced. As a consequence, revenue earned falls to a great extent, v) Load voltage falls, vi) System utilization is reduced. It means that system infrastructure has to be utilized upto a great extent of its installed capacity [3].

1.3 Differences between linear and non-linear loads: Since, nowadays we are using non-linear loads to a great extent such as personal computers(single phase loads), uninterruptible power supplies(UPSs), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC. Non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner (see Figure 1). It can be clearly seen here voltage profile is same for both the loads but there is a discontinuity in the current waveform that means it is no more sinusoidal [4].

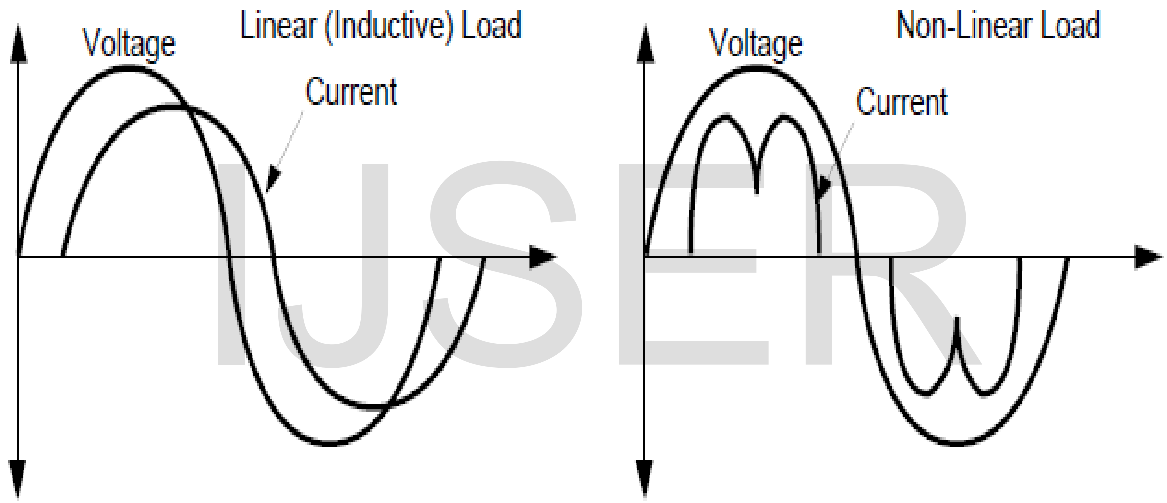


Fig.1: Differences between Linear and Non-Linear Loads

2 CAUSES OF POOR POWER FACTOR

The main cause of poor power factor is Inductive Load. As in pure inductive circuit, Current lags 90° from Voltage, this large difference of phase angle between current and voltage causes zero power factor. Basically, all those circuit having Capacitance and inductance (except resonance circuit (or Tune Circuit) where inductive reactance = capacitive reactance (X_L = Xc), so the circuit becomes a resistive circuit), power factor would be exist over there because Capacitance and inductance causes in difference of phase angle (θ) between current and voltage [6],[10].

2.1 Following are the causes of low Power factor:

i)Single phase and three phase induction motor(Usually, Induction motor works at poor power factor i.e. at: Full load, Pf = 0.8 -0.9, Small load, Pf = 0.2 -0.3, No Load, Pf may come to Zero (0).
ii)Varying Load in Power System(As we know that load on power system is varying. During low load period, supply voltage is increased which increase the magnetizing current which cause the decreased power factor).
iii) Industrial heating furnaces.
iv)Electrical discharge lamps (High intensity discharge lighting) Arc lamps (operate at very low power factor).
v)Transformers.

vi)Harmonic Currents-As harmonics are the leading cause of low power factor in distributed system, so here presents full concentration on it.

2.2 Harmonics: A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency of 50 Hz in India. Harmonics are the multiples of the fundamental frequency. Total harmonic distortion is the contribution of all the harmonic frequency currents to the fundamental. Harmonics are the by-products of modern electronics. They occur frequently when there are large numbers of personal computers (single phase loads), uninterruptible power supplies (UPSs), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC [5],[8].

*2.3 How Harmonics affect the voltage and current profile in a system***:** Since signals (voltage and current) pass through rectifier, harmonics introduce in the system and these are the integral multiples of fundamental frequency i.e.50 Hz. It affects the load voltage profile as well as input current profile. Load voltage profile is maintained by maintaining input current. All inductive loads inject harmonics in the supply current. So, supply current harmonics are the matter of concern and also THD measurement is done over supply current. These harmonics make the sinusoidal current waveform into Non-sinusoidal waveform ultimately, the load voltage profile also disturbs very vigourously. How current waveform is disturbed, it can be seen clearly from the figure 1.

3 RESEARCH METHODOLOGY

Passive PFC: The simplest way to reduce the harmonic current is to use a filter. It is possible to design a filter that passes current only at line frequency (50 or 60 Hz).This filter reduces the harmonic current, which means that the non-linear device now looks like a linear load. At this point the power factor can be brought to near unity, using capacitors or inductors as required. This filter requires large-value high-current inductors, however, which are bulky and expensive. A passive PFC requires an inductor larger than the inductor in an active PFC, but costs less. This is a simple way of correcting the nonlinearity of a load by using capacitor banks. It is not as effective as active PFC. One example of this is a valley-fill circuit [7].
Active PFC: An active power factor corrector (active PFC) is a power electronic system that changes the wave shape of current drawn by a load to improve the power factor. The purpose is to make the load circuitry that is power factor corrected appear purely resistive (apparent power equal to real power).In this case, the voltage and current are in phase and the reactive power consumption is zero. This enables the most efficient delivery of electrical power from the power company to the consumer. Some types of active PFC are: i)Boost, ii)Buck, iii)Buck-Boost, iv)Synchronous Condenser. Active power factor correctors can be single-stage or multi-stage [7].

In this research paper, a topology is going to propose in which a comparison is made among different parameters such as THD, Power Factor and output voltage with and without the use of filters for RL load. The specifications are taken as:

i)AC Source: Supply = single phase, Voltage(rms value)=230V,Frequency=50Hz.
ii)Load(RL): Resistance = 100 ohms and Inductance = 1 Henry.

4 SIMULATION AND RESULTS

This paper involves simulation of basic power electronic circuits and the analysis of the current and voltage waveforms. It starts with simple circuits with a gradual increase in complexity by inclusion of new components and their subsequent effect on the current and voltage waveforms. We focus on the objective of improving the input current waveform i.e. making it sinusoidal by tuning the circuits. All the simulation work is done in MATLAB Simulink.

4.1 Simulation and Results for Conventional Converter

Figure 2 shows the signal flow or block diagram of how Inductive load is getting signal by means of AC Voltage source and single phase diode bridge rectifier. Figure 3 shows that this circuit consists of two groups of diodes: top group with diodes 1 and 3 and bottom groups with diodes 2 and 4. It is easy to see the operation of each group of diodes with Ls =0. The current id flows continuously through one diode of the top group and one diode in the bottom group.

The circuit is simulated using Simulink and input current with respect to input voltage waveform are plotted in graph as shown in figure 3. The input current waveform consists of Total Harmonic Distortion. The figure 4 shows THD of input current and THD percentage is 47.33. This problem will effect at the supply side equipments.

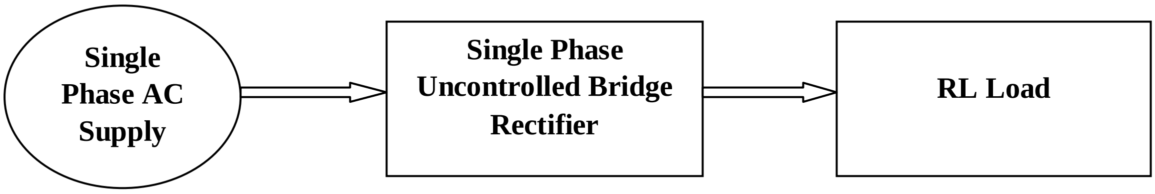


Fig.2: Block Diagram

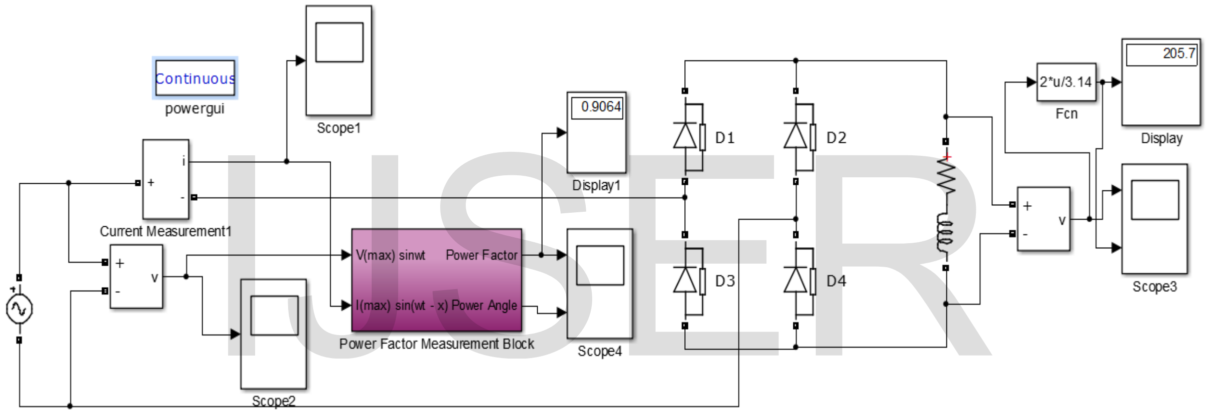
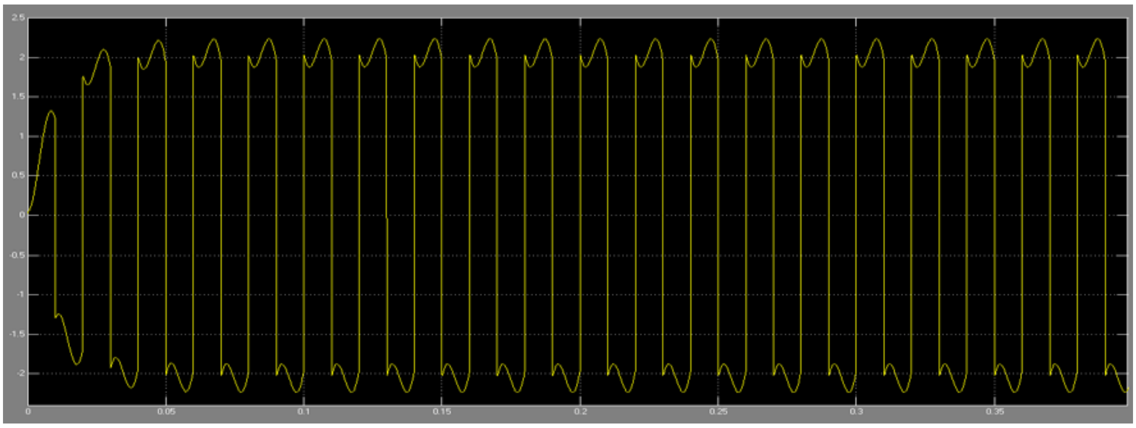
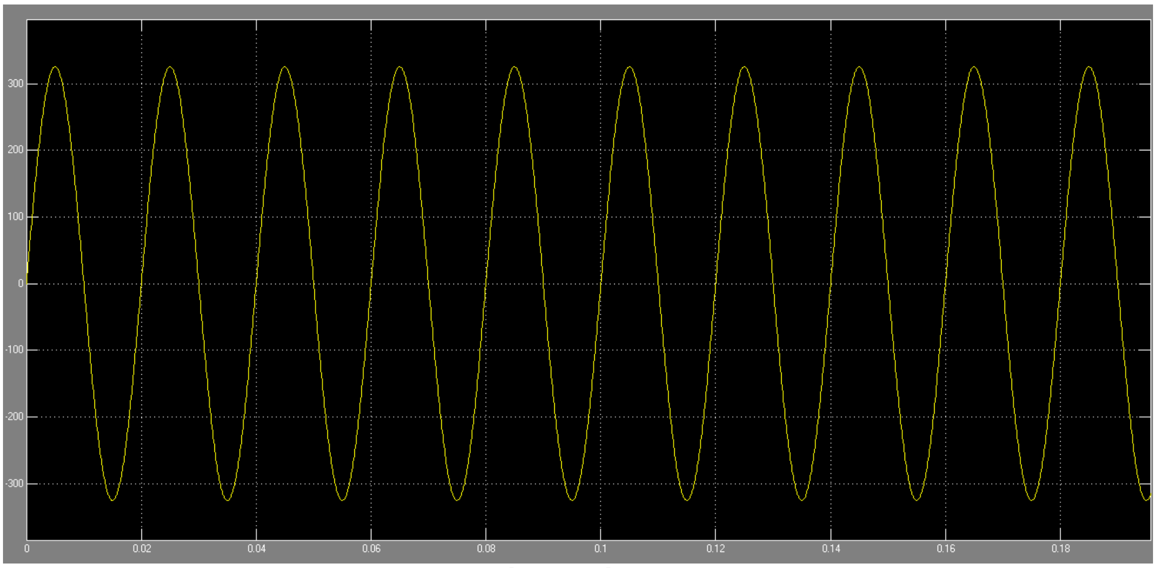


Fig.3: Simulation Model



(a)**Input current**



(b)Input voltage

Fig.4: Input Current and Voltage waveforms

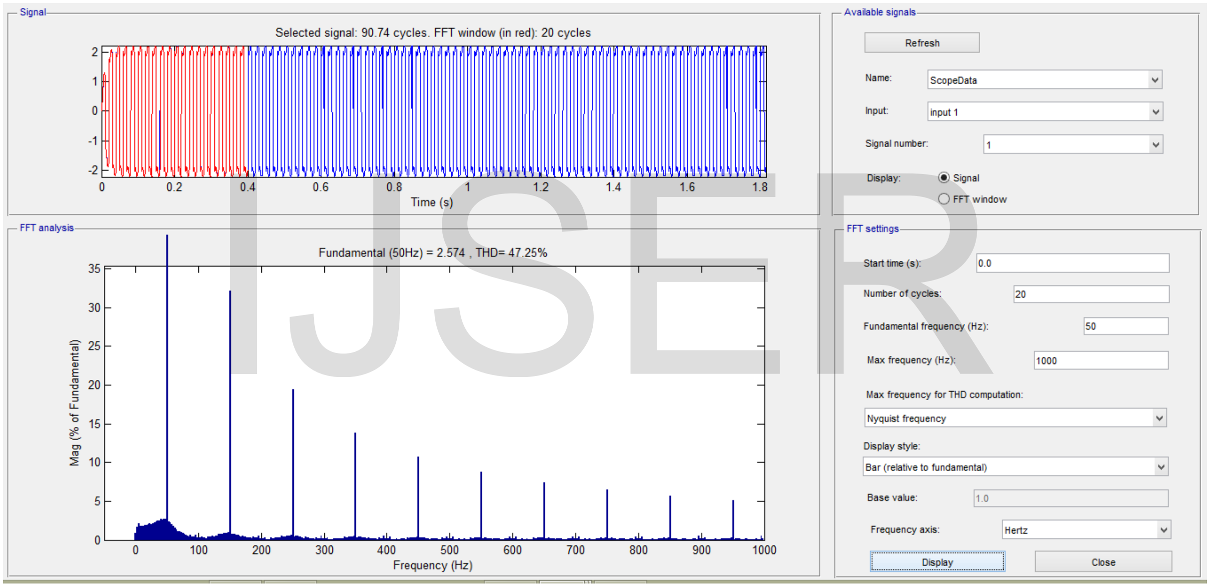


Fig.5: FFT Analysis

Comments: By selecting 20 cycles from the given signal in the input current, it is to be found that Total Harmonic Distortion (THD) is 47.25%, Power factor is 0.9 and output voltage is 205.7 Volts for RL Load. Also here current waveform distorts due to inductive load as well as passing from the rectifier circuit and not in phase with the voltage waveform. Hence, it has to improve for proper system utilization.

4.2 Simulation and Results for Rectifier circuit with C Filter

A rectifier should provide an output voltage that should be as smooth as possible. In practice, however, output voltage from rectifiers consists of dc component plus ac component, or ac ripples. The ac component is made up of several dominant harmonics. It is so more in single phase rectifiers with RL load. The ac component does no useful work from the context of DC load. Ac component merely causes more ohmic losses in the circuit leading to reduced efficiency of the system. This shows that it is of paramount importance to filter out the unwanted ac component present in the rectifier output. For this purpose, Filters are used. When used on the rectifier output side, these are called DC filters. These tend to make the DC output voltage and current as level as possible. Also the non-sinusoidal output current in rectifier circuit causes the supply line current to contain harmonics and due to this power factor is reduced. For reducing these harmonics in supply current, C Filter is used with appropriate rating across the load so that it causes leading supply current and ultimately THD becomes reduce.

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The circuit is simulated using Simulink and input current with respect to input voltage waveform are plotted in graph as shown in the figure 8.

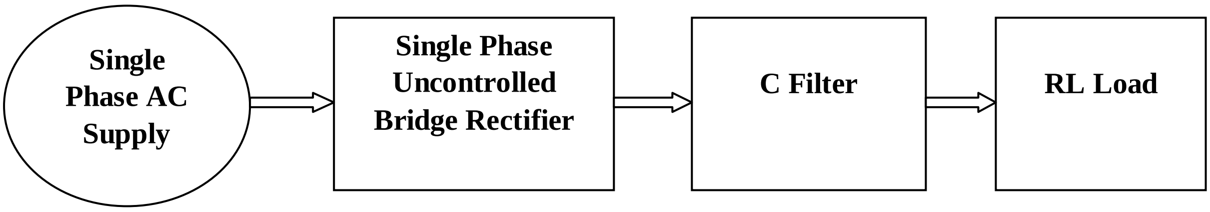


Fig.6: Block Diagram With C Filter

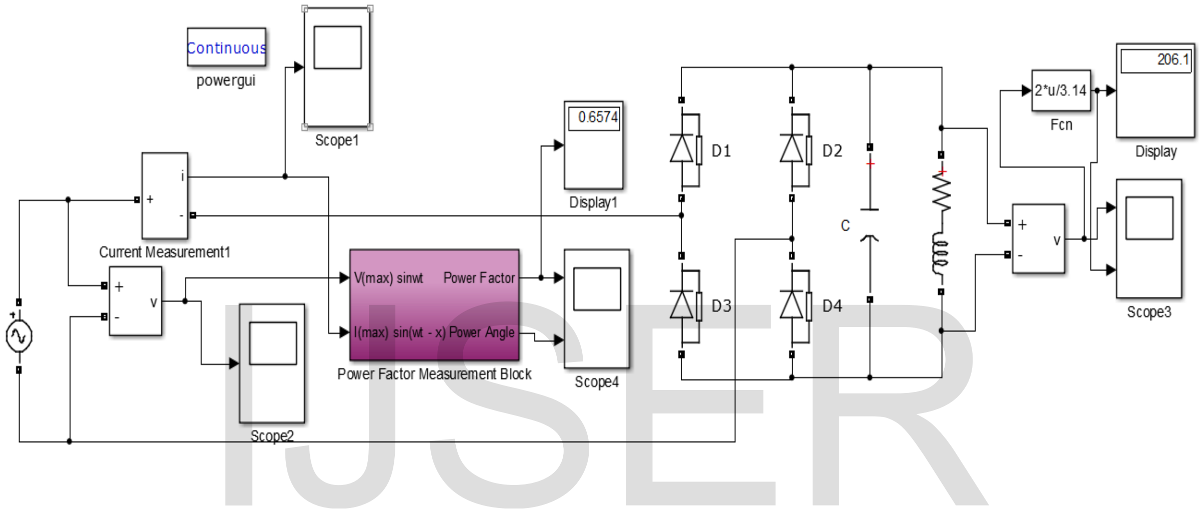
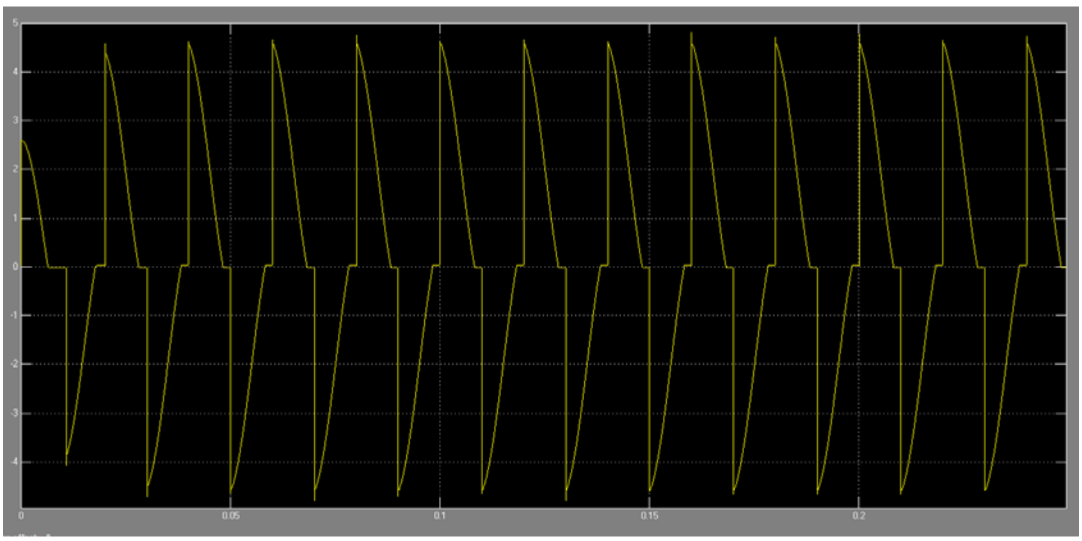


Fig.7: Simulation Model



(a)Input current

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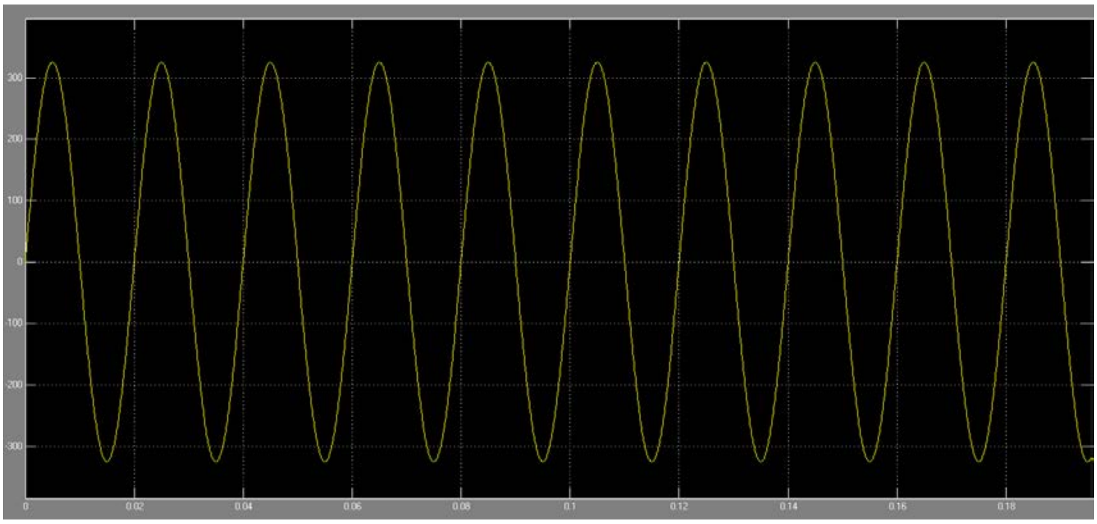

(b)Input voltage

Fig.8: Input Current and Voltage waveforms

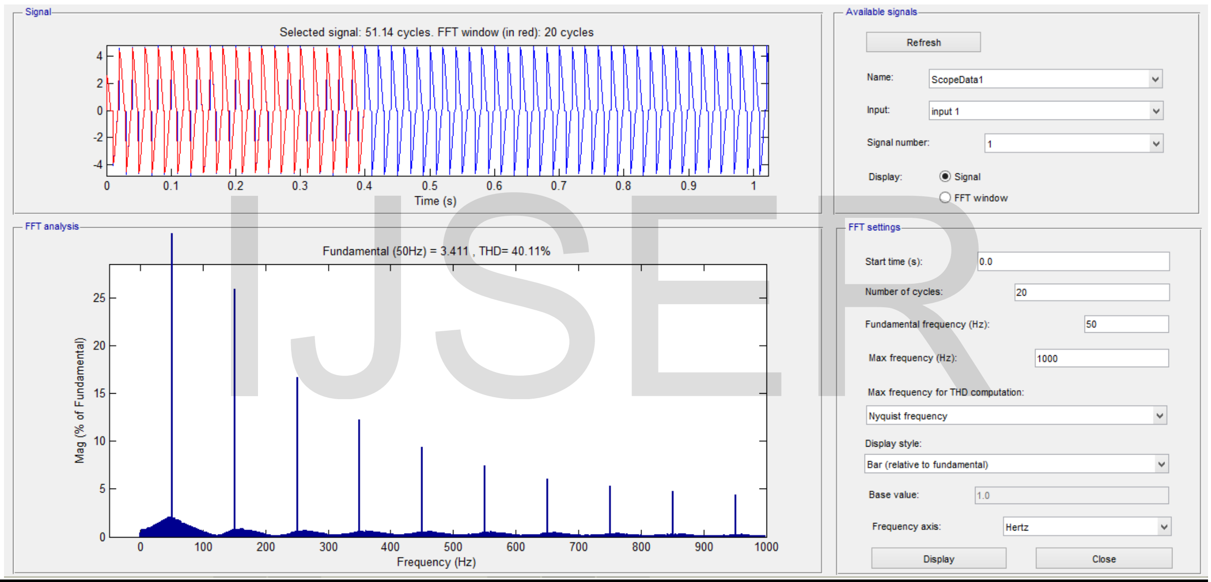

Fig.9: FFT Analysis

Comments: By selecting 20 cycles from the given signal in the supply current, it is to be found that THD is 40.11%, Power Factor is 0.65 and Output Voltage is 206.1.Here it is clearly seen that THD is reduced from 47.25% to 40.11% but Power Factor is reduced drastically. Also output voltage remains approximately same. This all happens due to the inductive nature of load from which we cannot escape.

COMPARISON TABLE

S.No.	Circuit Topologies	THD	Input Power Factor	Output Voltage
1	Conventional Rectifier without C Filter	47.25	0.9064	205.7
2	Conventional Rectifier with C Filter	40.11	0.6574	206.1

5 FUTURE SCOPE

Boost converter is a DC-DC Converter which provides output voltage is greater than input voltage. Here, the inductor responds to changes in current by inducing its own voltage to counter the change in current, and this voltage adds to the source voltage while the switch is open [5]. If a diode-and-capacitor combination is placed in parallel to the switch, the peak voltage can be stored in the capacitor, and the capacitor can be used as a DC source with an output voltage greater than the DC voltage driving the circuit. This boost converter acts like a step-up transformer for DC signal. Current mode control as usually implemented in switching power supplies actually senses and controls peak inductor current. This gives rise to many serious problems, including poor noise immunity, a need for slope compensation, and peak-to-average current errors which the inherently low current loop gain cannot correct [8],[9]. Average current mode control eliminates these problems and may be used effectively to control currents other than inductor current, allowing a much broader range of topological application [2],[3],[4]. Also if low pass filter is placed before the rectifier circuit with proper low rating further THD is reduced drastically and hence improves the source as well as load power factor. Apart from this output voltage profile gets improve which is the desired result of any system to make it economical.

6 CONCLUSION

DC Drive loads can have a low displacement power factor, resulting in a need for power factor correction. The power factor correction can be sized based on the displacement power factor of the load but all of the compensation should be installed as harmonic filters to avoid harmonic resonance problems and excessive voltage distortion levels. Filters tuned below the fifth harmonic will usually be adequate to keep voltage distortion levels below 5% and current harmonics injected onto the utility system below the levels specified in IEEE 519 [10]. The proposed system performs better than the traditional methods in mitigating harmonics and power factor improvement. Also this paper is different from other papers in the context of load. Here DC inductive load is connected which is lagging in nature instead of R load in which current is already in phase with supply voltage.

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