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Power Factor Improvement in Single Phase System Using Active Front End Converter

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Abstract* — There are some major drawbacks of conventional front end converter like low power factor and high harmonic content. Hence, there is a continuous need for power factor improvement and reduction of line current harmonics. Development of new circuit topologies and control strategies for Power Factor Correction (PFC) and harmonic reduction has become still more essential with the introduction of strong technical IEC standards. This work is based on the difference between the performance of single phase diode bridge rectifier and the active front-end converter in terms of the %THD of the line current and power factor improvement. This work is basically on Power Factor improvement using phase shifted Technique in which the two single phase converters are connected in parallel to meet the load demand as well as to improve the power factor. Power factor of the source side will be maintained nearly unity. The proposed converter operates in forward power as well as in reverse power conditions.

***Keywords*—AC-DC converter, Harmonic reduction of line current, power factor correction, Single phase active front end converter.**

I. INTRODUCTION

Now a day's use of power electronics devices are increased with day to day life. The main task of power electronics is to convert available power from source into the best suited for user load for this purpose power electronics converters are widely used. The converter itself may be an AC-DC or AC-AC converters with or without transformer isolation as per the load requirements like Diode Bridge or phase controlled front end converter [1][9]. The term front end converter refers to the power converter system consisting of the line side converter with the dc link capacitor and load side inverter. These front end converters are broadly classified as, Diode bridge rectifier, switch mode converter, and thyristor converters [9][10]. Many industrial application make use of controllable DC such as steel rolling mills, paper mills, traction system, HVDC transmission and also in UPS, battery chargers, adjustable speed drives, utility interface with non-conventional energy sources such as solar PVs, wind etc. [7].

Conventionally, output dc voltage can be changed by using uncontrolled diode bridge rectifier with tap changing transformer or auto transformer. But this scheme is bulky, costly and its response is very poor due to the use of transformer. Line commutated or SCR rectifiers can be used to eliminate the need of tap changing transformer as in the above scheme. Hence it overcomes the disadvantages of size weight and cost. But bidirectional power flow not possible in SCR based rectifiers so for this IGBT based front end converter reported in this paper. Here Diode Bridge or phase controlled front end converters behaves as a non-linear loads on the power system. As a result they will lead to certain problems like high current spikes to charge the DC link capacitor leading to undesirable harmonics on the line resulting into poor power factor [2]. Front end converters becoming and interesting solution for power factor correction and low frequency current harmonics elimination in static power conversion systems.

II. DIODE BRIDGE RECTIFIER AS A FRONT END CONVERTER

Conventionally most power electronics system use Diode Bridge as front end converter even though they draw power from source with highly distorted current and also in this power can flow only in one direction. Diode rectifiers rectify the line frequency AC into DC across the DC link capacitor without any control over the output DC voltage as shown below in Fig.1. The current drawn from the AC utility source by above system is very non-sinusoidal because the bridge diode conduct current only when the rectified voltage is greater or equal to the voltage across DC link capacitor [2], various waveform of Diode Bridge rectifier shown below in Fig.2.

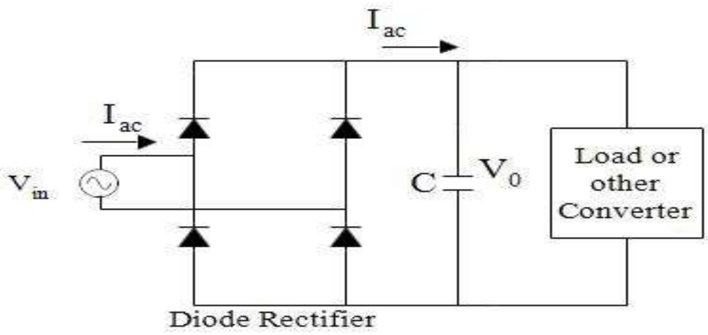

Fig.1 Diode Bridge rectifier with output capacitive filter

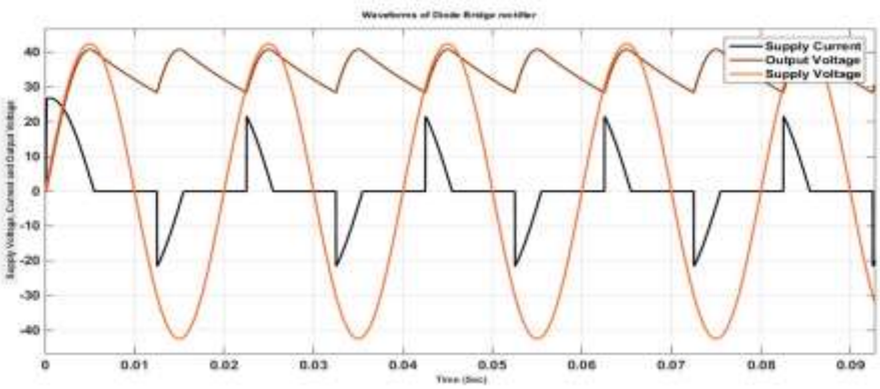

Fig.2 Diode Bridge rectifier o/p voltage, current and i/p current waveform

This system has many disadvantages like [2]:-

- Creation of harmonics and EMI
- High losses
- Requires over dimensioning of parts
- Reduced maximum power transfer capability from the line.

The significant rise in the use of electrical equipment in recent year due to increased consumer demand has made the inefficient use of power less tolerable than in past. Stricter regulatory agency standard on harmonic current have led to the demise in popularity of the simple Diode Bridge rectifier as front end converter in electrical equipment off of an AC supply [9].

III. POWER FACTOR IN ELECTRICAL POWER SYSTEM WITH NON-LINEAR LOAD

The electrical supply industry has placed requirements on the power factor of electrical equipment for many years. Historically, these requirements were developed around powered equipment consisting of resistive and reactive (inductive or capacitive) loads, which will present varying phase angles between the sinusoidal voltage applied to the load and the current flowing in it. Power Factor gives a measure of how effective the real power utilization of the system is. It is a measure of distortion of the line voltage and the line current and the phase shift between them [2].

A. Power factor for linear load system

In a linear system, the load draws purely sinusoidal current and voltage, hence the power factor is determined only by the phase difference between voltage and current. A power triangle between active, reactive and apparent power for linear load as shown below in Fig.4 [3].

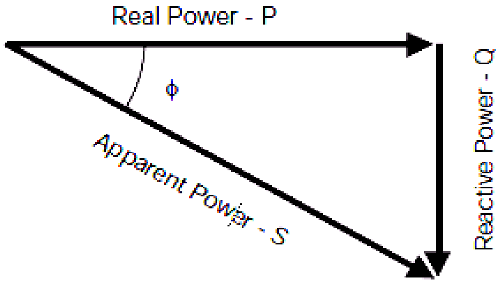

Fig.3 Power triangle for linear system

From Fig.4 equation for power factor is given below:-

Power factor = COSΦ

= Real power (P) / Apparent power (S)

B. Power factor for non-linear load system

In power electronic system, due to the non-linear behavior of the active switching power devices, the phase angle representation alone is not valid. A non-linear load draws typical distorted line current from the line. For the non-linear load with distortion on the current waveform, all of the current will not be at the fundamental line frequency, but rather be composed of the fundamental summed with various harmonic currents. This adds yet another type of power to the mix, which we will refer to as distortion power. Distortion power is similar to the reactive power in that it does not contribute directly to the useful power dissipated in the load, but rather adds to the reactive power to create a higher apparent power, which is shown below in Fig.5 with help of power triangle.

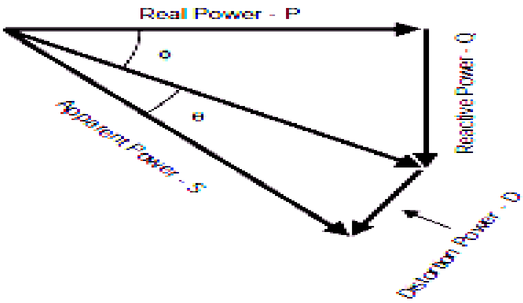

Fig.4 Power triangle for non-linear system

The additional angle between the real and apparent powers due to a non-sinusoidal current waveform is defined as the distortion angle θ. From this the power factor of a non-linear load or converter is made up of two components: displacement and distortion. The effect of the two are combined into the total power factor which is generally known as true power factor [3].

True p.f. = Displacement p.f. * Distortion p.f.

The displacement component is the ratio of the active power (P) of the fundamental wave, in watts, to the apparent power (S) of the fundamental wave, in volt amperes.

P.F. disp = COSΦ

= Real power (P) / Apparent power (S)

It depends on the phase angle between the voltage and the fundamental component of the current, and it is similar to the power factor calculated with linear loads and sinusoidal voltage. The distortion component is that part associated with the harmonic voltages and currents present. It is defined as the ratio of the fundamental component of the AC line current to the total line current.

P.F. dist = I1 / I OR 1/ {1+ (THD I)2 } 1/2

Where, THDI is total harmonic distortion in current waveform.

$$THD = \sqrt{\frac{\text{Sum of all squares of amplitude of all harmonic voltages or current}}{\text{Square of the amplitude of the fundamental voltage or current}}}$$

Total power factor correction can only be achieved when displacement and distortion power factors are corrected. This requires two step of process:-

1. Reduced the displacement angle between voltage and current,
2. Reduced the total harmonic distortion of current.

The greater the reactive power, the phase shift angle between voltage and current will high so the power factor is low. If the reactive power of the loads increases, the displacement angle between the voltage and the fundamental component of the current also increases and the total power factor decreases. Likewise, if the total harmonic current distortion increases, the total harmonic current distortion increases, the total power factor decreases [3].

IV. FRONT END CONVERTER FOR SINGLE PHASE SYSTEM AND PWM SWITCHING

In order to reduce value of THD, the single phase active front end converters are used which are connected parallel for high power application. Overall block diagram of the system shown below in Fig.6. In this topology as shown in Fig.7 two single phase converters are connected parallel to reduce the line current harmonics and ripple content in dc output voltage as well as it improves the power factor of the system near to unity[4][5][6].

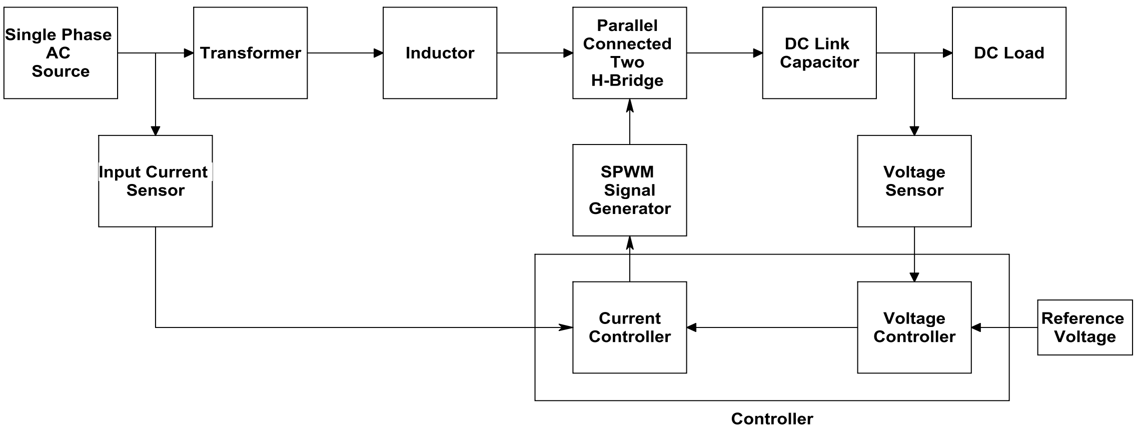

Fig.5 Block diagram of front end converter system

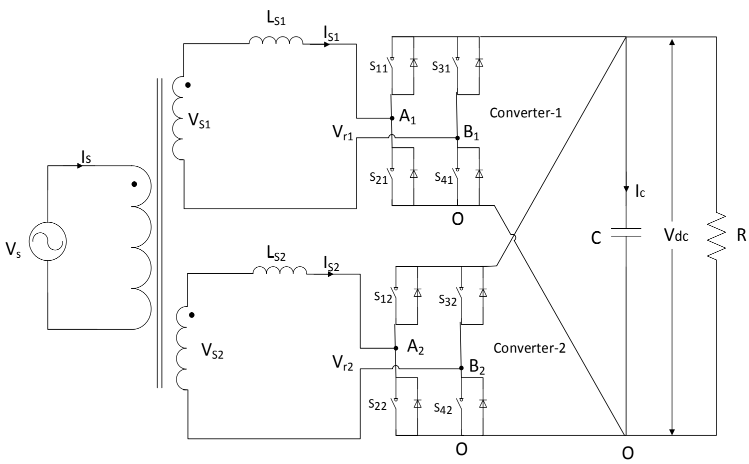

Fig.6 Circuit diagram of front end converter

Phase shifted sine-triangle PWM technique is used for the control of this converter. Reference sine wave remains same for both of the converters. Leg-B triangle wave is 180^0 phase shifted from the leg A of same converter. Resultant output voltage of each converter is the subtracted PWM voltage of two legs. So the harmonics at carrier frequency and its odd multiples get cancelled Triangular wave for converter-2 is phase shifted by 90^0 as in comparison with converter-1 so that second multiple frequency harmonics get cancelled out. So the harmonics present in the primary side of transformer is at the side bands of four times the carrier frequency with very less amplitude. Firing Sequence for both converter-1 and converter-2 is given below as per the above explanation [6] [8].

For converter 1

S_{11} is ON when ON Sine > Triangle
S_{21} is ON when ON Sine < Triangle
S_{41} is ON when ON Sine > Triangle
S_{31} is ON when ON Sine < Triangle

For converter 2

S_{12} is ON when ON Sine > Triangle
S_{22} is ON when ON Sine < Triangle
S_{42} is ON when ON Sine > Triangle
S_{32} is ON when ON Sine < Triangle

V. DESIGN OF INDUCTOR AND CAPACITOR FOR ACTIVE FRONT END CONVERTER

For PWM rectifier design for DC link capacitor and boost inductor value is given below:-

$$\text{Rated output power } (P) = Vo(max) * Io(max)$$

Where, Vo(max) and Io(max) are output DC voltage and current respectively. So,

$$Io(max) = \frac{P}{Vo(max)}$$

Now, if we assume converter efficiency around η% then,

$$Is(rms) = \frac{P}{Vs(rms) * \eta} = \frac{P}{V_s(rms) * \eta}$$

$$Is(max) = Is(rms) * \sqrt{2}$$

For PWM rectifier if the modulation index is 'm' so net input voltage across rectifier is,

$$Vr(peak) = m * Vo$$

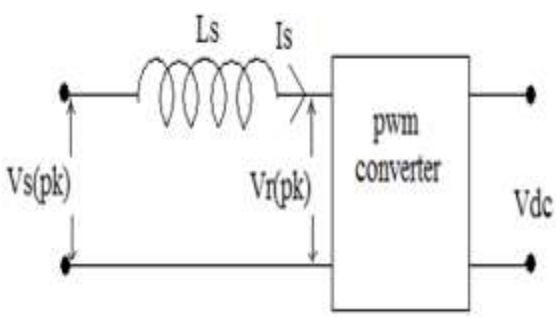

Fig.7 General Circuit diagram of PWM rectifier

Now from Fig.7 equation for boost inductor,

$$V_{r(pk)} = \sqrt{{V_{s(pk)}}^2 + (\omega * I_{s(pk)} * L_s)^2}$$

From the above equation,

$$L_s = \sqrt{\frac{V_{r(pk)}^{2} - V_{s(pk)}^{2}}{(\omega * I_{s(pk)})^{2}}}$$

For DC link capacitor,

$$C \geq \frac{V_r(t)\, I_s(t)}{4 * 2\pi f * V_d \Delta V}$$

$$C \geq \frac{m\, I_s(t)}{4 * 2\pi f * \Delta V}$$

VI. SIMULATION AND RESULTS

In this section simulation model and simulation result of Diode Bridge front end converter and active front end converter with permanent magnet DC motor of 48 volt, 3000 rpm and 100 watt is given.

A. Diode bridge front end converter

Table 1 Simulation parameters for Diode Bridge front end converter

PARAMETER	VALUE
Transformer voltage	230 / 35 volt rms
Input Inductor	2.13 mH
Output DC link capacitor	4700 uF

Simulation model of Diode Bridge front end converter is shown below in Fig.8 as per the parameter given in Table 1.

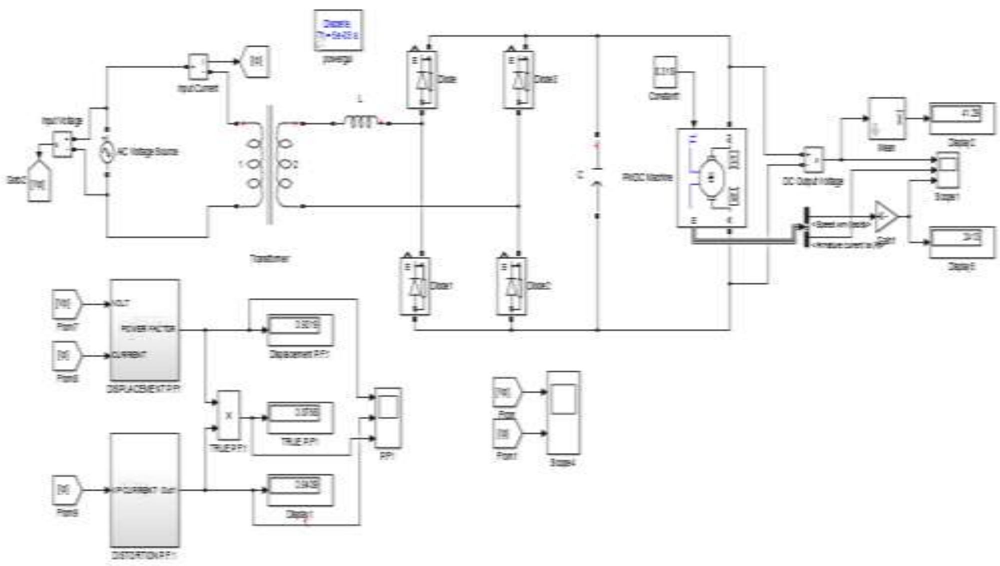

Fig.8 Simulation model of Diode Bridge front end converter

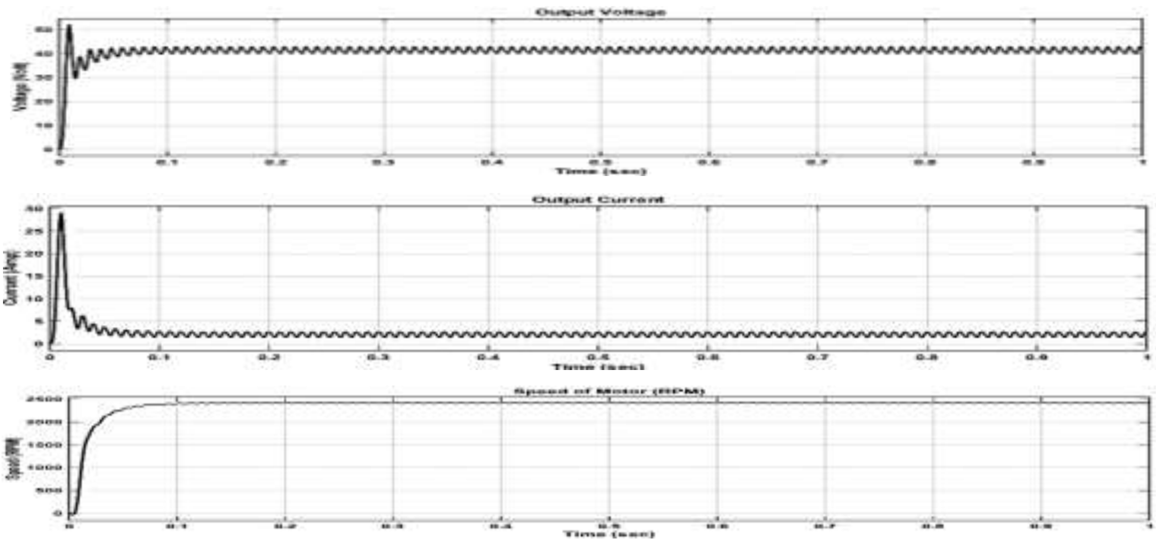

Fig.9 Waveform of o/p voltage, current and speed of the motor of Diode Bridge front end converter

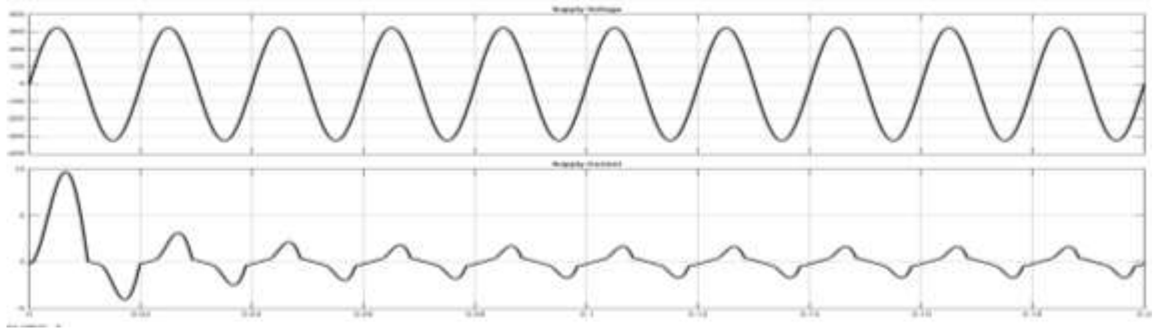

Fig.10 Waveform of supply voltage and current of Diode Bridge front end converter

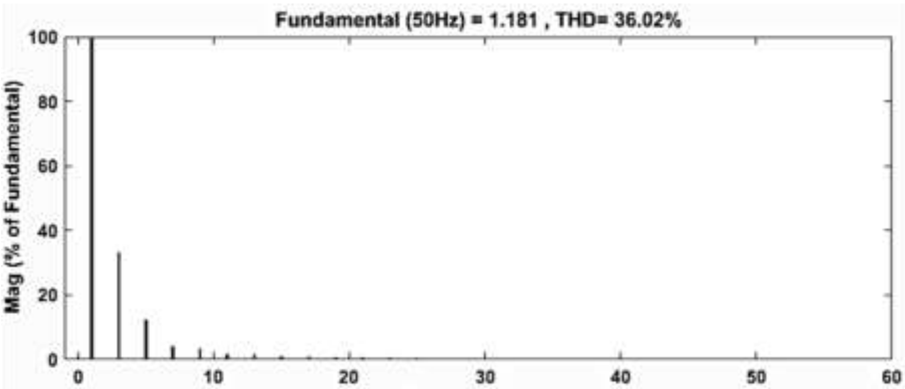

Fig.11 FFT analysis of supply side current

B. Active front end converter

Table 2 Simulation parameter for Active front end converter

PARAMETER	VALUE
Transformer voltage	230 / 27 volt rms
Input Inductor	2.13 mH
Output DC link capacitor	4700 uF
Modulation Index	0.8

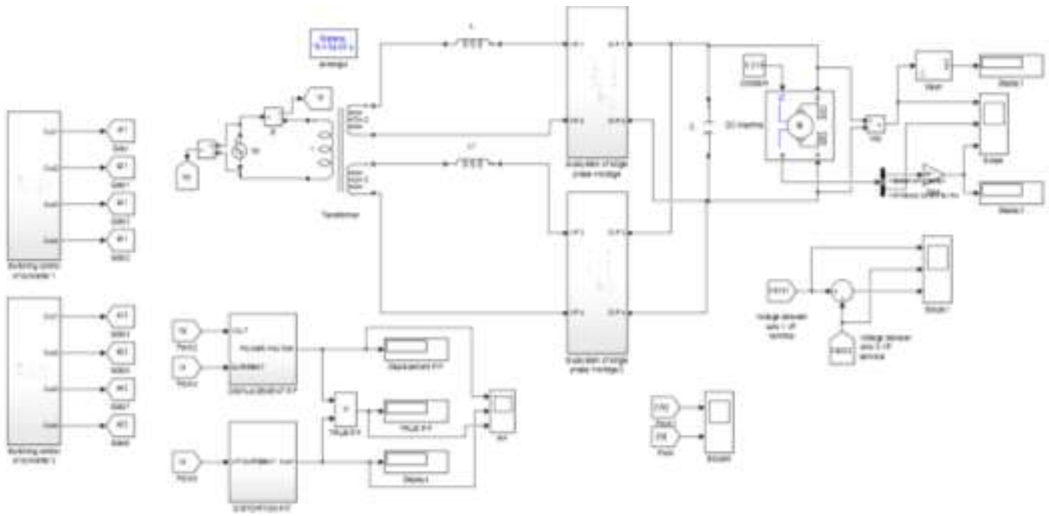

Fig.12 Simulation model of Active front end converter

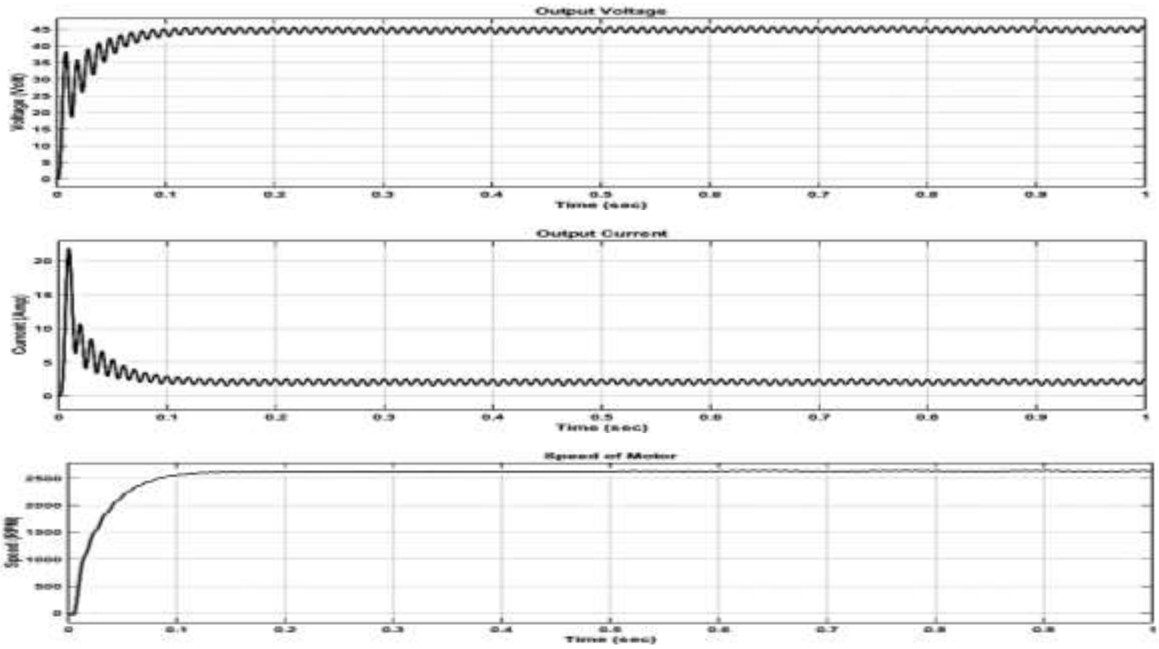

Fig.13 Waveform of o/p voltage, current and speed of the motor of Active front end converter

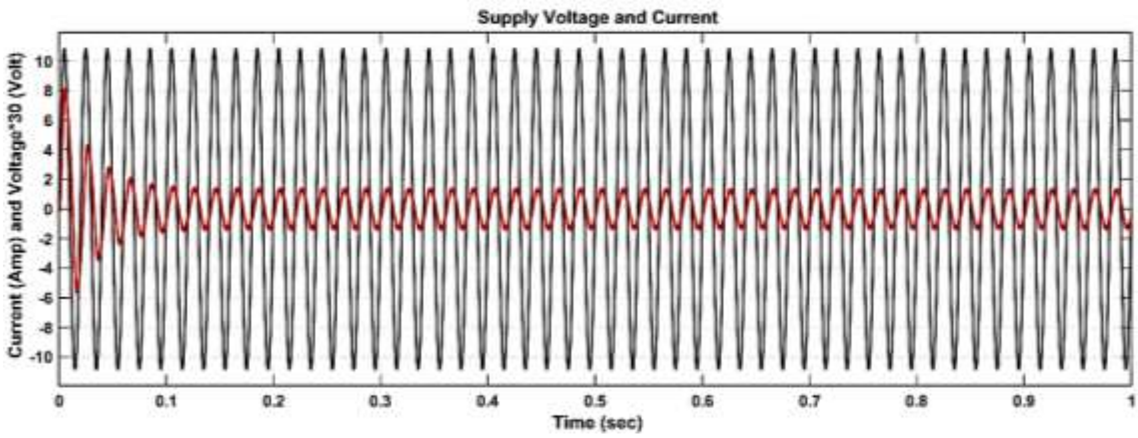

Fig.14 Waveform of supply voltage and current of Active front end converter

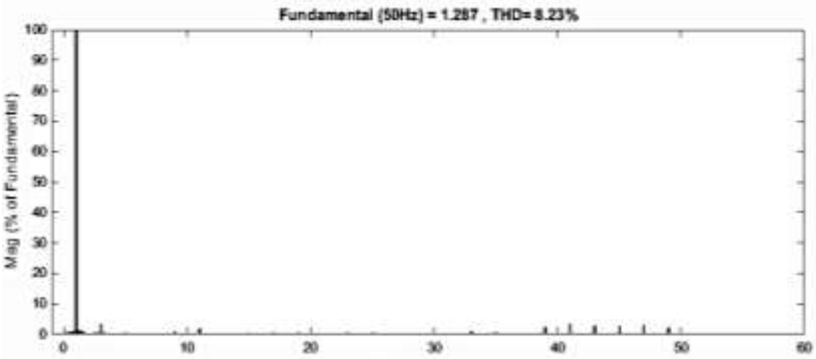

Fig.15 FFT analysis of supply side current

C. Result analysis

Result of various parameters for Diode Bridge and Active front end converters are given below in Table 3

Table 3 Result analysis of Diode Bridge and Active front end converter

Parameter	Diode Bridge front end converter	Active front end converter
% THD of supply current	36.6%	8.25 %
Displacement Power Factor	0.9319	0.9163
Distortion Power Factor	0.9409	0.9968
True Power Factor	0.856	0.9133
Ripple in Output voltage	3 volt	1.7 volt

VII. CONCLUSION

The result obtained shows the desired operation of Active front end converter. Here, %THD, true power factor and ripple content in output voltage are improved as compared to Diode Bridge rectifier with the help of Active front end converter. Now, with the help of close loop operation of Active front end converter output voltage of the converter will maintain constant as well as input power factor of the system improved near to unity.

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