



ISSN ONLINE: 2447-0228



DESIGN OF SINGLE PHASE ACTIVE FRONT END CONVERTER WITH CLOSE LOOP ANALYSIS FOR POWER FACTOR IMPROVEMENT

Vishalkumar Baldevbhai Rathod^{*1}, Bhaveshkumar D Patel², Harsh K Vaghela³,
Nitin H Adroja⁴, Gautam V Bhatt⁵, Hardik T Bhatiya⁶

^{1, 2, 3, 4, 5, 6}Government Engineering College Bhuj, Gujarat Technological University, Gujarat, India.

¹<https://orcid.org/0009-0000-4522-0603>, ²<https://orcid.org/0009-0007-5867-1594>, ³<https://orcid.org/0009-0001-6301-0076>

⁴<https://orcid.org/0009-0007-9182-9322>, ⁵<https://orcid.org/0009-0004-4918-2105>, ⁶<https://orcid.org/0009-0003-9718-778X>

Email: *vbr.gec@gmail.com, bpatel.gecbhuj@gmail.com, harshvaghela02@gmail.com, nitinadroja@gmail.com, gautambhatt99@gmail.com, hardiktbhatiya.123@gmail.com

ARTICLE INFO

Article History

Received: March 5, 2026

Reviewed: August 2, 2026

Accepted: September 2, 2026

Published: September 30, 2026

Keywords:

AC-DC converter,
Harmonic reduction,
Power factor correction,
Single phase front end converter.

ABSTRACT

Some conventional front end converters have many drawbacks like low power factor and high harmonic content. 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. There are some of the major disadvantage of conventional front-end rectifiers like low power factor and high harmonic content. Hence, improvement of power factor and reduction in line current harmonics is required. For Power Factor Correction (PFC) and harmonic reduction development of new circuit topologies and control strategies has become still more essential with the introduction of strong technical IEC standards. This work is basically on power factor improvement using phase shifted technique in which to meet the load demand as well as to improve the power factor two single phase converters are connected in parallel. Power factor of the source side will be maintained nearer to unity. Output DC link voltage will also remain constant irrespective of load as well as supply voltage variation. The control strategy for single phase front end converter consists of inner current-loop and outer voltage-loop.



Copyright ©2026 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

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], [2]. The term front end converter defined as the power converter system consisting of the supply 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 [2]. Controllable DC supply may use in many industrial application 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. [3]. Conventionally, by using uncontrolled diode bridge rectifier with tap changing transformer or auto transformer output dc voltage can be changed. 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 and Diode Bridge based rectifiers so for this IGBT based front end converter discussed 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 [4]. So for power factor improvement and lower order current harmonics elimination front end converters becoming an interesting solution.

II. DIODE BRIDGE RECTIFIER AS FRONT-END CONVERTER

Usually 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 only unidirectional power flow is possible. 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 output voltage is greater or equal to the voltage across DC link capacitor [4], [5], various waveform of Diode Bridge rectifier shown below in Fig.2.

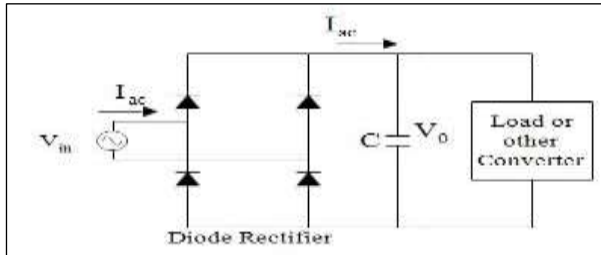


Figure 1: Diode Bridge Rectifier with Output Capacitive Filter.
Source: Authors, (2026).

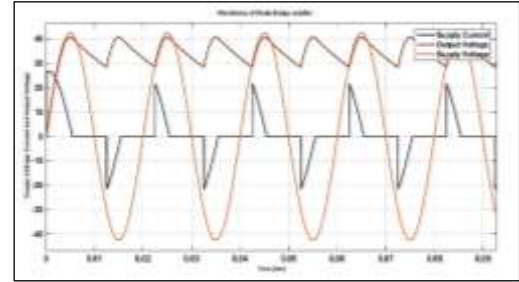


Figure 2: Diode Bridge Rectifier O/P Voltage, Current and I/P Current Waveform.
Source: Authors, (2026).

This system has many disadvantages like [4]:-

- 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 [2].

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 supply voltage applied to the load and the current flowing in it. Power Factor shows how effective the real power utilization of the system is. It is a measure of distortion of the supply side voltage and the current and the phase angle difference between them [4].

III.1 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.3 [6].

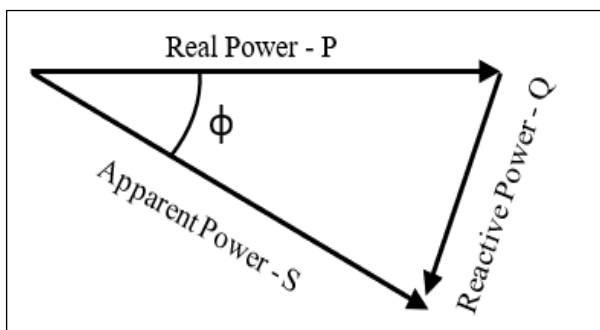


Figure 3: Power triangle for linear system.
Source: Authors, (2026).

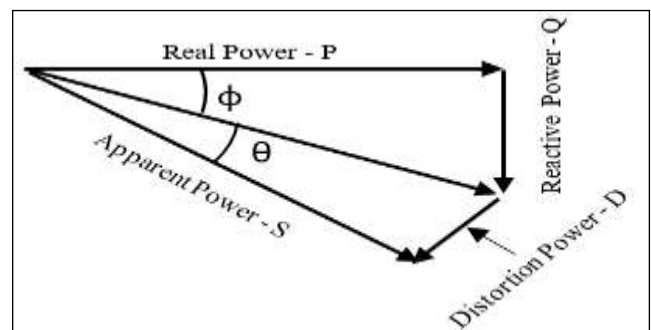


Figure 4: Power triangle for non-linear system.
Source: Authors, (2026).

III.2 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 effective. 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.4 with help of power triangle. The additional angle difference 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 as well as distortion. The effect of the two are combined into the total power factor which is generally known as true power factor [6].

$$\text{True p.f.} = \text{Displacement p.f.} * \text{Distortion p.f.}$$

The displacement power factor defined as 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.

$$\begin{aligned} \text{P.F. disp} &= \cos\Phi \\ &= \frac{\text{Real Power (P)}}{\text{Apparent Power (S)}} \end{aligned}$$

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.

$$\text{P.F. dist} = \frac{I_1}{I} \quad \text{OR} \quad \frac{1}{\sqrt{1+\text{THD}_I^2}}$$

Where, THDI is total harmonic distortion in current waveform.

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

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 [6].

III.3 FRONT END CONVERTER FOR SINGLE PHASE SYSTEM AND PWM SWITCHING SCHEME

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. This topology is mainly used for high power application and it work same as multi pulse converter. 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 [7-9].

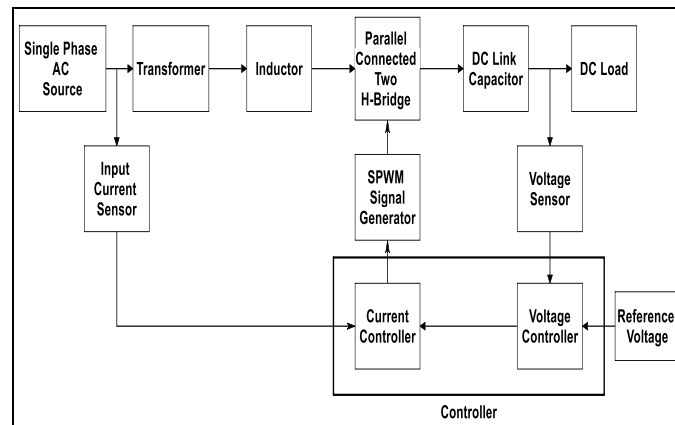


Figure 5: Block diagram of front end converter system.

Source: Authors, (2026).

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° phase shifted from the leg A of same converter. Resultant output voltage of each converter is the subtracted PWM voltage of two legs.

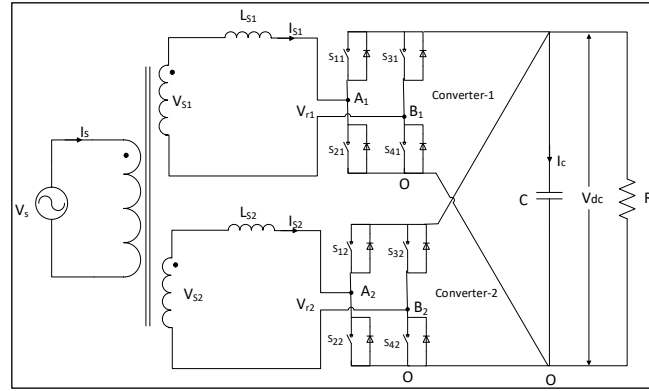


Figure 6: Circuit diagram of front end converter.
Source: Authors, (2026).

So the harmonics at carrier frequency and its odd multiples get cancelled. Triangular wave for converter-2 is phase shifted by 90° 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 [9], [10].

For converter 1

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

For converter 2

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

III.4 DESIGN OF INDUCTOR AND CAPACITOR

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

$$\text{Rated output power (P)} = V_o (\text{max}) * I_o (\text{max})$$

Where, $V_o(\text{max})$ and $I_o(\text{max})$ are output DC voltage and current respectively. So,

$$I_o (\text{max}) = \frac{P}{V_o(\text{max})}$$

Now, if we assume converter efficiency around 80% then,

$$I_s (\text{rms}) = \frac{P}{V_s(\text{rms}) * \eta} = \frac{P}{V_s (\text{rms}) * \eta}$$

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

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

$$V_r (\text{peak}) = m * V_o$$

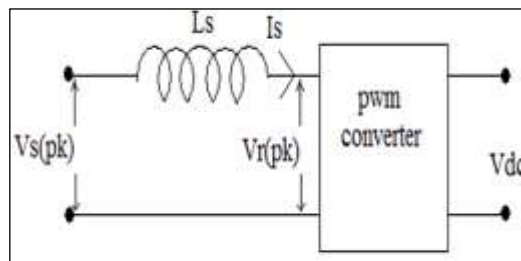


Figure 7: General Circuit Diagram of PWM Rectifier.
Source: Authors, (2026).

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,

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

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

IV. RESULTS AND DISCUSSIONS

In this section simulation model and simulation result of active front end converter open loop and close loop system with permanent magnet DC motor of 48 volt, 3000 rpm and 100 watt is given with its various results shown below.

IV.1 ACTIVE FRONT END CONVERTER OPEN LOOP SYSTEM

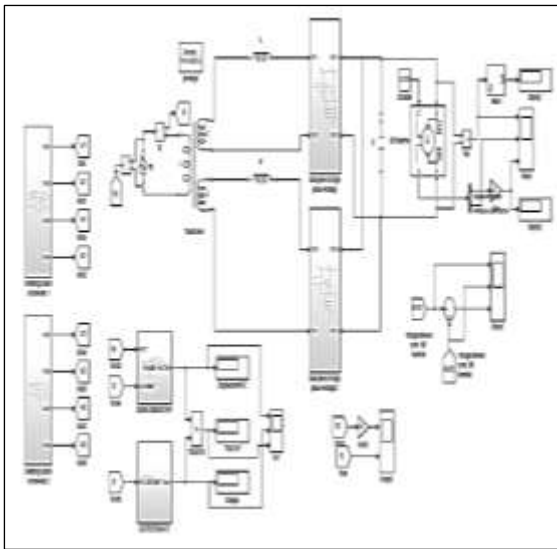


Figure 8: Simulation Model of Active Front End Converter.
Source: Authors, (2026).

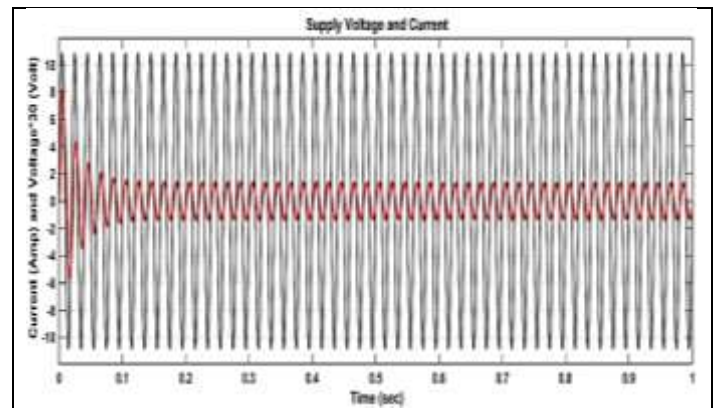


Figure 9: Waveform of Supply Voltage and Current of Active Front End Converter.
Source: Authors, (2026).

Table 1: Simulation parameters for Active front end converter.

PARAMETER	VALUE
Transformer Voltage & Power Rating	230 / 27 / 27 volt 150 VA
Input Inductor	2.13 mH
Output DC Link Capacitor	4700 μ F
Modulation Index	0.8
DC Load (PMDC Motor)	PMDC Motor: 48 Volt 3000 RPM 100 Watt

Source: Authors, (2026).

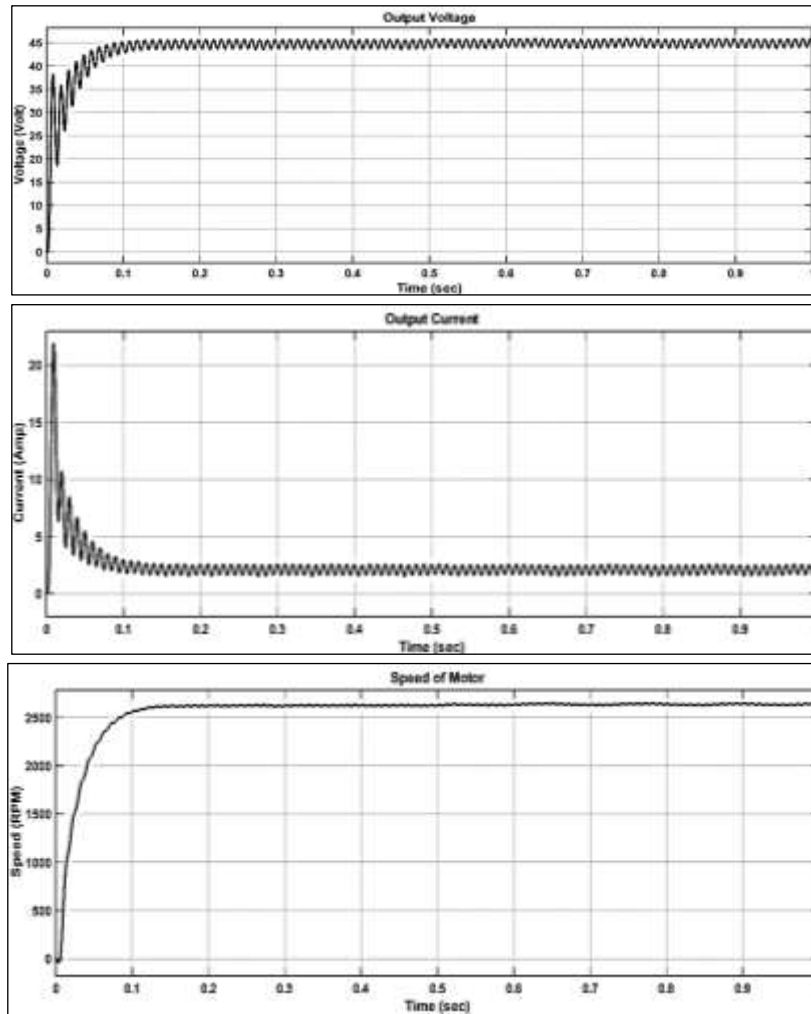


Figure 10: Waveform of output Voltage, Current and Speed of the Motor of Active Front End Converter.
Source: Authors, (2026).

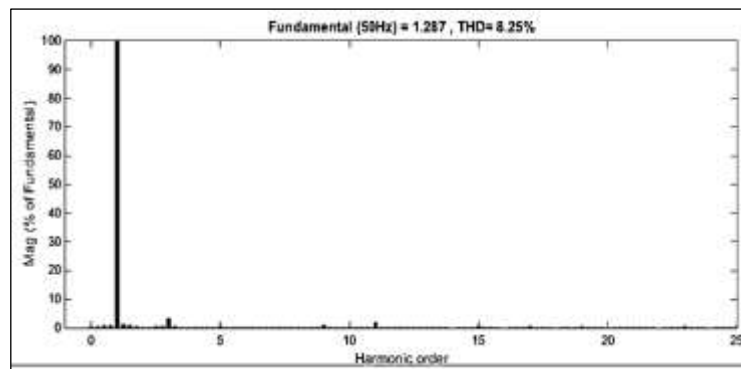


Figure 11: FFT analysis of supply side current.
Source: Authors, (2026).

As shown in Fig.9 supply current is nearly sinusoidal and almost in phase with supply voltage. Fig.11 shows the FFT analysis of supply current which is very less 8.25% as compared to diode bridge rectifier. So overall power factor of the system is improved.

IV.2 ACTIVE FRONT END CONVERTER CLOSE LOOP SYSTEM

Here, simulation model and results of front end converter topology with load torque variation as well as supply variation is shown below as per the parameters shown in Table 1.

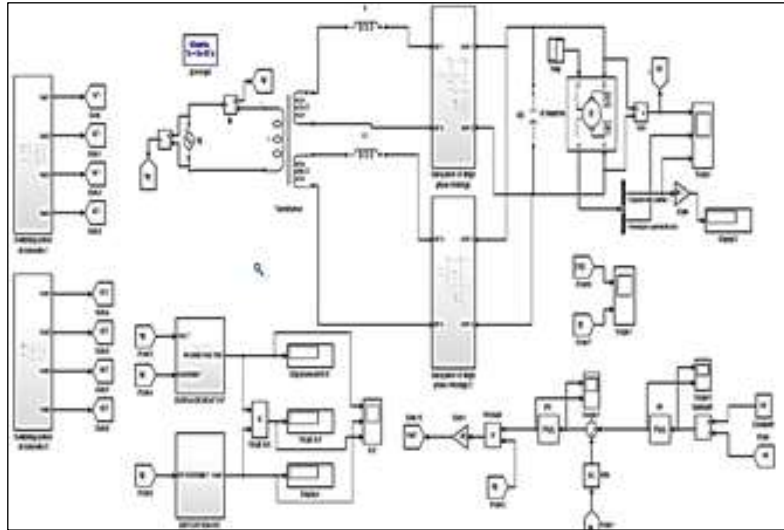


Figure 12: Simulation Model of Active Front End Converter Close Loop System.
Source: Authors, (2026).

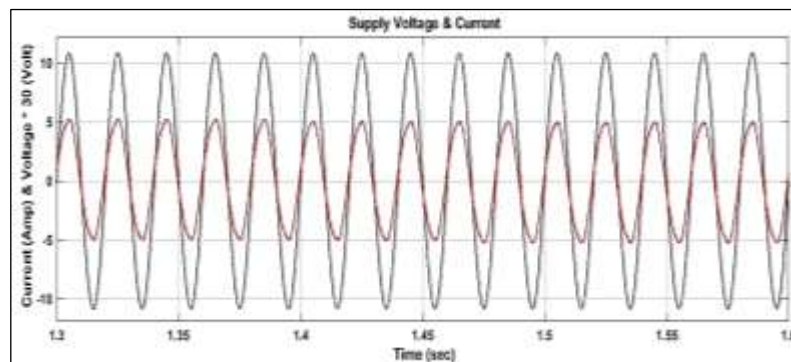


Figure 13: Waveform of Supply Voltage and Current of Active Front End Converter Close Loop System with Load Torque Variation.
Source: Authors, (2026).

In close loop system by sensing the output voltage and input current, power factor maintain near to unity and output DC voltage maintain constant. For close loop control reference voltage is compared with actual voltage of the system and is given to the controller and error of output DC voltage minimized using controller action, this loop known as voltage control loop. Controller output of this voltage control loop act as reference for current control loop and this reference signal compared with supply side current. This current control loop used to minimize %THD and displacement angle between voltage and current. As shown below in Fig.14 initially converter work on 0.318 Nm rated load torque of motor but after 1.8 sec suddenly load torque of motor varies to 0.2 Nm. After that supply current also nearer to sinusoidal as well as phase difference between supply voltage and current also very less and output DC voltage maintain constant. FFT analysis of supply current shown in Fig15 which is very less, 1.66%. So overall power factor of the system maintain nearer to unity.

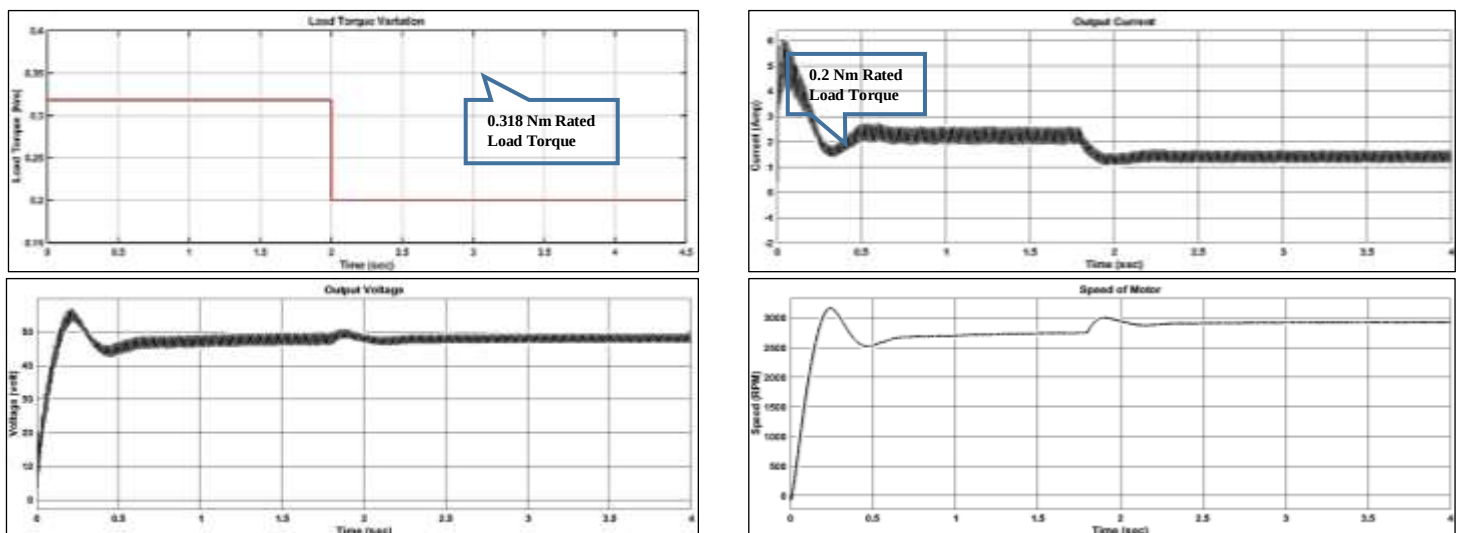


Figure 14: Waveform of output Voltage, Current and Speed of the Motor of Active Front End Converter with Load Torque Variation.
Source: Authors, (2026).

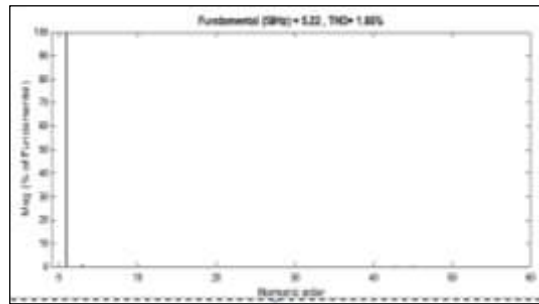


Figure 15: Analysis of Supply Current of Active Front End Converter with Load Torque Variation.
Source: Authors, (2026).

Simulation results of front end converter with $\pm 10\%$ supply voltage variation shown in below figure.

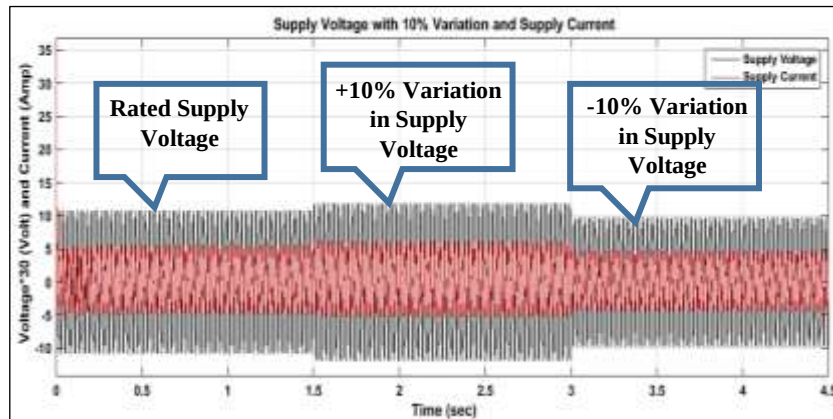


Figure 16: Waveform of Supply Voltage and Current of Active Front End Converter Close Loop System with $\pm 10\%$ Supply Voltage Variation.
Source: Authors, (2026).

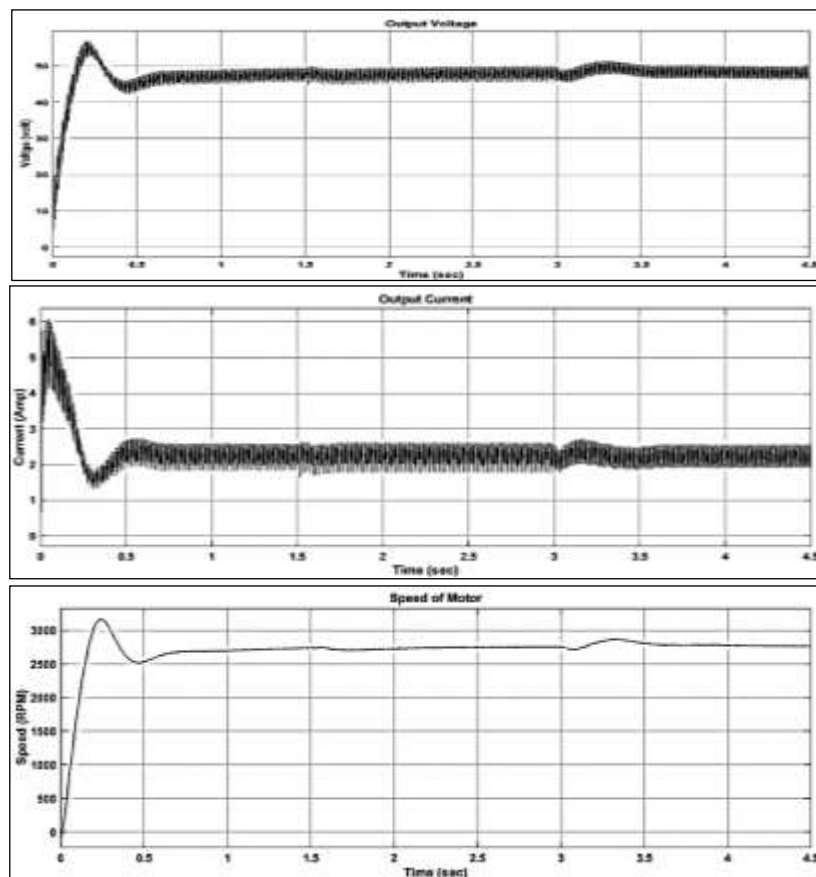


Figure 17: Waveform of o/p Voltage, Current and Speed of the Motor of Active Front End Converter with $\pm 10\%$ Supply Voltage Variation.

Fig.16 and Fig.17 shows the results of front end converter close loop system. Result shows that after supply voltage variation output voltage maintain constant and also supply current is sinusoidal and phase angle difference between supply voltage and current very less. So overall power factor of the system also maintain near to unity.

IV.3 SIMULATION RESULT ANALYSIS

Result of various parameters for active front end converter open loop as well as close loop with load torque variation and supply variation are given below in Table 2.

Table 2: Result analysis of Diode Bridge and Active front end converter.

Parameter	Active Front End Converter Open Loop System	Active Front End Converter Close Loop System	
		With Load Torque Variation	±10% Supply Voltage Variation
Displacement Power Factor	0.9163	0.998	0.9804
Distortion Power Factor	0.9963	0.9998	0.9998
True Power Factor	0.9133	0.9997	0.9802
Output DC Voltage	44.9 Volt	47.98 Volt	48.11 Volt

Source: Authors, (2026).

V. CONCLUSIONS

The results shows the desired operation of active front end converter. Here, true power factor is improved as compared to front end converter open loop system with the help of active front end converter close loop system, and also output DC voltage maintains constant with reduced line current harmonics and very less phase difference between supply voltage and current.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Vishal B. Rathod, Bhavesh D. Patel, Harsh K. Vaghela, Nitin H. Adroja, Gautam V. Bhatt and Hardik T. Bhatia.

Methodology: Vishal B. Rathod, Bhavesh D. Patel and Harsh K. Vaghela.

Investigation: Harsh K. Vaghela and Nitin H. Adroja.

Discussion of results: Gautam V. Bhatt, Harsh K. Vaghela and Nitin H. Adroja

Writing – Original Draft: Harsh K. Vaghela.

Writing – Review and Editing: Vishal B. Rathod and Bhavesh D. Patel.

Resources: Nitin H. Adroja.

Supervision: Bhavesh D. Patel and Hardik T. Bhatia.

Approval of the final text: Vishal B. Rathod, Bhavesh D. Patel, Harsh K. Vaghela, Nitin H. Adroja, Gautam V. Bhatt and Hardik T. Bhatia.

VII. REFERENCES

- [1] M.S. Jamil Asghar "Power Electronics", Prentice Hall of India Pvt. Ltd. New Delhi, 2004. pp. 187.
- [2] Ned Mohan, "Power Electronics and Drives", MNPERE Publication, 2003. pp. 101-116.
- [3] Renju Mathew, Neha Agarwal, Manisha Shah, and P. N. Tekwani, "Design, Modelling and Simulation of Three-Phase Front-End Converter for Unity Power Factor and Reduced Harmonics in Line Current", Nirma University International Conference on Engineering (NUICONE), IEEE, 2013
- [4] Gerry Moschopoulos and Praveen Jain, "Single phase Single Stage Power Factor Corrected Converter Topologies", IEEE TRANSACTIONS on industrial electronics, VOL. 52, NO. 1, February 2005.
- [5] A. K. Jha, B.G. Fernandes and A. Kishore, "A single phase single stage AC/DC converter with high input power factor and tight output voltage regulation", Progress In Electromagnetics Research Symposium, Cambridge, USA, 2006
- [6] W. Mack Grady and Robert J. Gilleskie, "Harmonics and How They Relate to Power Factor", Proc. of the EPRI Power Quality Issues & Opportunities Conference (PQA'93), San Diego, CA, November 1993.
- [7] Whitepaper by SIEMENS, "Harmonics in power system causes, effect and control".
- [8] <http://www.nptel.ac.in>
- [9] G.N. Khanduja, "Design of controller for unity power factor regenerative front end converter", India Conference (INDICON), Annual IEEE.
- [10] P.N. Tekwani and G.N. Khanduja, "Modeling, Controller Design and Simulation of Power System Friendly Power Supply", International Conference on Renewable Energies and Power Quality (ICREPQ'10) Granada (Spain), March, 2010.