Input Current Shaping and Power Factor Improvement of a Three Phase Rectifier by Buck-Boost Regulator

By

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APPROVAL

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DEDICATED

TO

MY PARENTS

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LIST OF ABBREVIATION

SMPS = Switch Mode Power Supply

IGBT = Insulated Gate Bipolar Transistor

PWM = Pulse Width Modulation

OPAMP = Operation Amplifier

rms = Root Mean Square

EMI = Electromagnetic Interference

THD = Total Harmonics Distortion

SMRR = Switch Mode Regulated Rectifier

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ABSTRACT

Three phase rectifiers are commonly used in high power applications due to their low cost and ease of control. Rectifiers are non-linear in nature and draw non sinusoidal input current from the ac power sources. This causes a number of problems in sensitive electronic equipments and in the power distribution networks. Moreover, increase in reactive power, low input power factor, large input voltage distortion etc. raises the degree of the problems. In this respect, switch mode regulated rectifiers offer efficient, compact and high efficiency operation. The improvement of input current is possible by addition of Buck, Boost, Buck-Boost and Ĉuk regulator with single or three phase rectifier. A high frequency pulse width modulation (PWM) technique is used to control the switching devices of these regulators. In this thesis, a three phase full wave diode rectifier is analyzed with Buck-Boost regulator. A three phase rectifier with buck-boost regulator has been analyzed first with constant switching frequency for different duty cycles. It has been found that though the THD remains low, the overall efficiency was not over 80% at all duty cycle. This thesis works shows, when a variable carrier frequency is applied for different duty cycle, the THD of the input current is low and the overall efficiency is more than 80% for lowest and highest output voltage as well. It provides the facility of control of output voltage to lower and greater than the input voltage efficiently by the wide variation of duty cycle.

CHAPTER-1

INTRODUCTION

1.1 Introduction

DC power supply is widely used in electronic equipments. There are two types of power supply, regulated and unregulated. Unregulated dc supply is used where fixed voltage is not required. But for reliable and stable operation, regulated dc supply is used. The regulation can be performed by using Buck, Boost, Buck-Boost and Ĉuk regulators. Several techniques are available to improve the power factor, shape of input current. All power electronic equipments are fed from suitable stepped down ac utility lines with. Diode rectifiers are used to convert ac to dc. Single phase or three phase diode bridge rectifiers between source and load are used in conversion of ac to dc. But, only single phase rectifiers with resistive load draws sinusoidal current from the load. All others rectifiers' input currents are non-sinusoidal in nature. There are many reason for which input current disturbance occurs. Of them sources and load voltages fluctuations, switching losses of diodes, iron losses of inductors, EMI and radio frequency interference are important

1.2 Literature Review

An AC voltage regulator based on Buck-Boost conversion principle has been proposed in [1]. The ac Buck-Boost regulator has the ability to regulate the output voltage to the desired value. But the input power factor of the regulator is very low (less than 0.5) and it decreases with duty cycle. Due to very low input power factor, the input current becomes high and distorted, which causes higher loss. As a result, the efficiency tends to be low. Design of the input and output filter has the lack of proper freewheeling path.

In universal-input PFC applications, the capability of providing both step-up and step-down conversion is attractive because the output DC voltage can be set to any value. However, conventional single-switch buck-boost topologies, including the plain buck-boost, fly back, SEPIC, and Ĉuk converters [2, 3] have increased component stresses, component sizes, and reduced efficiency compared to the Boost converter.

To enable a unity power factor operation of the 3-phase buck boost rectifier, a constant inductor current is required [4]-[6].The pulse load in combination with a conventional high dynamic voltage control, however, would result in periodic peak currents in the buck-boost inductor and also in the input/mains current. These current distortions make a unity power factor operation of the converter impossible. Hence, a control strategy for pulse load applications, which achieves a unity power factor as well as an accurate regulation of the output voltage, must be applied.

Three-phase PWM Buck-Boost rectifier has been proposed in [7]. A Ĉuk-Ĉuk bidirectional ac-dc converter with power regenerating capability is presented in this reference. This structure can process both inversion and rectification function. Gate pulses are generated by zero voltage space vector realization to control the switching element. High order harmonic control analysis has been done. Combination of rectification and inversion function increases the complexity of operation and control of the scheme. Pulse generation is difficult because it is divided into three classes which increase difficulty of implementation. Simplicity is a high consideration to design a regulator. In [7] input current was found very high and no analysis has been reported to reduce the input current.

A power factor correction diode bridge rectifier has been proposed in [8]. Duel slope delta modulation technique was used to generate gate pulses. Window width variation changes the switching frequency. Slope of modulated wave is varied for output voltage variation. The result was distorted input current and output voltage. THD is high due to inefficient design of input and output filter.

An active power factor correction technique for three phase diode rectifiers has been proposed in [9]. This paper addresses the analysis and design of a three phase ac to dc conversion with Boost topology. A three phase rectifier handles high input current harmonics and low input power factor. Low power factor increases the reactive power requirement causing increased losses. The output voltage of this topology is always greater than the input voltage. With slight variation of the duty cycle output voltage varies widely. And become uncontrollable. The input and output current was found discontinuous. But for smooth load change, input and output current should be continuous. Discontinuous input current increases ripple amplitude and electromagnetic interference (EMI). Voltage stresses and switching stress is another drawback of the proposed method.

A novel high performance voltage regulator for single-phase ac source has been presented in [10]. Both rectification and inversion was offered there. It is a single phase regulator having a common capacitive arm between the rectifier and inverter. For switching pulse generation, a digital signal processor TMS320F240 has been used. It is a fully digital controller. So proper algorithm and hardware have to be designed for each power converter and calculate the required PWM duty ratio. The size of the regulator becomes large due to huge number of self turn on/off switches. It has control complexity and high cost. From economical view, the design should be less expensive as much as possible with high power quality.

An improved ac voltage regulator has been proposed in [11]. It has been analyzed for manual and automatic control of ac voltage regulator. The proposed configuration can maintain constant output voltage at various input voltage and load. Output voltage can be made constant by varying the duty cycle of the control circuit automatically through electronic control circuit. The input current is found almost sinusoidal and power factor is found almost unity. But the regulator becomes bulky due to large input and output filter and for using a low frequency transformer at the output. From economical view, the design of input and output filter should be as small as possible. Efficiency also decreases due to large impedance, high magnetic leakage and leakage reactance.

A three phase rectifier based on Boost topology has been proposed in [12]. Active switching pulse width modulation (PWM) module has been studied to improve input side currents. The nature of Boost regulator is to provide greater output voltage than input voltage. But, both greater and less output voltages than input voltage are required practically. Another drawback of the proposed method is that the output voltage is very sensitive with the slightest change in duty cycle makes difficult to stabilize the regulator output. Large EMI and series resonating filters have been used (L_1=50mH, C_1=500uF, L_2=15.83mH, C_2=0.1mF). Though input current is found sinusoidal with high efficiency, it is not practically implementable due to large voltage drop across filters. Electromagnetic interference also increases which badly affects the performance of the regulator.

A unity power factor rectifier has been presented in [13]. In this paper a novel active power factor correction technique named scalar control is proposed and analyzed. The control scheme is provided for single phase Boost converter, where, power factor controller is independent of input voltage. A large output capacitor is used to correct the power factor; the result is higher peak current in input and unstable output voltage. This method is suitable only to control the single phase power flow. It is difficult to control the three phase power flow with the proposed method.

A switch mode regulator based on Ĉuk principle has been proposed in [14] to regulate ac voltage to a desired value irrespective of the input voltage and load. This regulator voltage provides a negative polarity regulated output voltage with respect to the common terminal of the input voltage. It has the ability to change the output voltage widely by varying the duty cycle. But limited range of variation of load and input voltage has been analyzed here. The size of the regulator becomes large which causes higher losses. As a result the efficiency is poor. No analysis has been done to improve the input current. Where, input current quality is an important factor to improve the performance of any regulator.

A single stage push-pull Boost converter has been proposed in [15]. Dc/dc Boost converter with improved integrated magnetic and low input current is presented. The proposed structure includes a Boost inductor, coupling capacitor and a capacitor network, a step-down transformer and four diodes for switching. A constant duty cycle (greater than 50%) is used to switch the diodes. At this duty cycle, overlapping conduction problem occurs. Diodes are poor switching elements due to switching stresses, losses and commutation problem across them. Coupling capacitor should be nearly infinity to achieve low ripple input current which results high current stress. The amount of leakage reactance and mutual reactance is very high due to transformer and inductive network which influence the regulation of the transformer or the conversion efficiency of the Boost converter. Core losses and copper losses occur in magnetic core and coil of the transformer which dissipated in the form of heat and raises its temperature. If temperature exceeds the permissible limit, it may damage the insulation of the core and short the transformer.

As a result, converter may burnout. The proposed model without transformer may be helpful to reduce such problem and become more useful.

1.3 Objective of thesis

The objective of this thesis is to design analyze and propose a practically implementable high frequency switching ac to dc voltage regulator. Through the proposed regulator output voltage can be stepped up or stepped down. In this thesis, switch mode converter is used to regulate the dc to dc voltage. To achieve the goal of ac to dc regulation, Buck-Boost regulator is used in between the three phase full wave diode rectifier and the load. A control circuit with variable frequency switching is to be associated with the power circuit for generating gate pulse of the switching element. Output voltage can be made variable by changing the duty cycle and switching frequency. Duty cycle is to be controlled by changing a reference voltage within a permissible limit. It is observed in recent work that rectifier size becomes bulky and to get ripple free sinusoidal input current, filter size also becomes large. Our objective is to obtain a regulator with small size input filter to provide sinusoidal input current and efficiency more than eighty percent.

The specific objective of the present research works are as follows:

(a) A new modified Buck-Boost regulator will be investigated to improve the shape of the input current of a three phase diode rectifier,

(b) Simulate and study of the proposed new scheme for input current improvement of a three phase diode rectifier,

(c) To design the input filter to reduce the total harmonics distortion and hence reduce the input current of the converter,

(d) To increase the overall efficiency of the converter and

(e) To analyze the result, furthermore, comparison of performance between the simulated result considering switches to be ideal.

It is expected that this study will yield a three phase rectifier with improved input power quality which will be practically implementable.

1.4 Outline of the thesis

Chapter-1 contains introduction of a three phase rectifier and switch mode regulated rectifier (SMRR). This chapter also includes objectives of the thesis work and outline of the thesis.

Chapter-2 deals with the major part of the thesis. A three phase diode rectifier without filter and then passive filter has been studied. It also presents the analysis of three phase Buck-Boost rectifier without input filter, with passive input filter at constant switching frequency. The analysis of Buck-Boost regulator with input filter and variable switching frequency associated with three phase full wave diode rectifier is also included in chapter -2. Simulated results, wave shapes and graphical representations are included in this chapter.

Chapter-3 concludes the thesis with conclusion, summary and suggestion on future works.

CHAPTER-2

IMPROVEMENT OF THREE PHASE RECTIFIER INPUT CURRENT BY BUCK-BOOST REGULATOR

2.1 Input Current of Three Phase Uncontrolled Rectifier

In industrial and commercial applications where three phase ac voltage are available, it is preferable to use three phase rectifier circuits, compared to single phase rectifier because of their lower ripple current in waveforms and high power handling capability. There are two types of rectifier namely diode rectifiers (uncontrolled) and thyristor rectifier (controlled) for ac to dc conversion. Since these rectifiers' draws non-sinusoidal currents, the power quality of the distribution network is greatly deteriorated, resulting in high THD of utilities. The power factor of the three phase rectifier with resistive load remains close to unity. But with reactive load the power factor becomes lower. It is possible to improve input current to sinusoidal and power factor to unity by applying various control strategies. Here a diode bridge three phase rectifier is discussed with resistive load because of their simplicity and ideal characteristics.

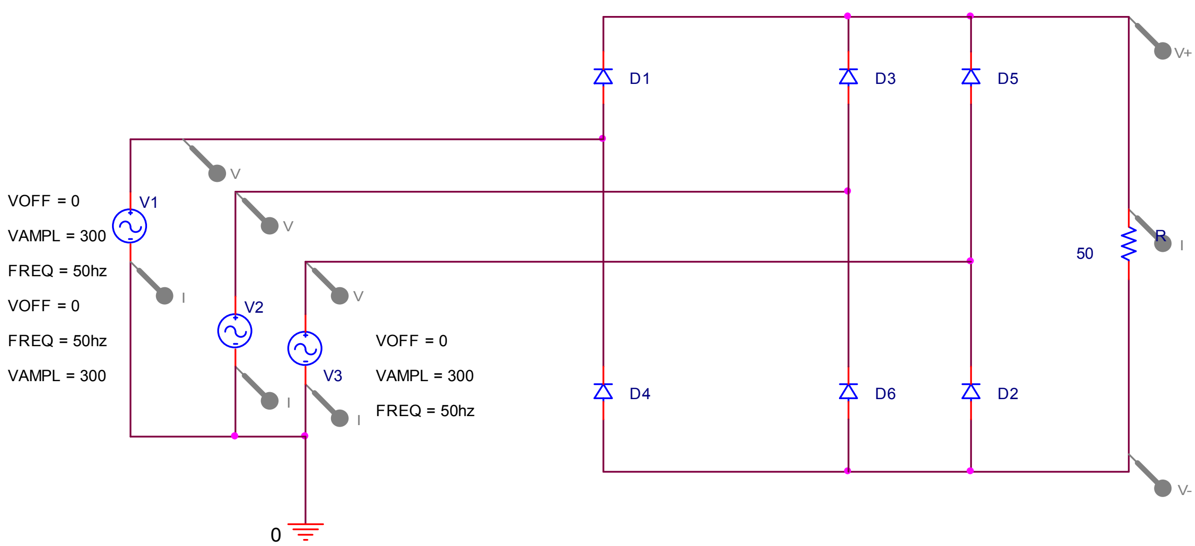


Figure 2.1: Circuit diagram of three phase rectifier with resistive load

A three phase six diode full wave rectifier is shown in figure 2.1. The rectifier is fed from a three phase star connected ac utility source having constant voltage of amplitude and at constant frequency. Each phase is apart by 120^0 from each other. If V_m is the peak value of the phase voltage, then the instantaneous phase voltage can be described by equation 1, 2 and 3 respectively.

$$V1 = V_m \text{ Sin } (\omega t) \text{ ------------------------------- ------ } (1)$$

$$V2 = V_m \text{ Sin } (\omega t\text{-}120^0) \text{ ------------------------------- } (2)$$

$$V3 = V_m \text{ Sin } (\omega t\text{-}240^0) \text{ ------------------------------- } (3)$$

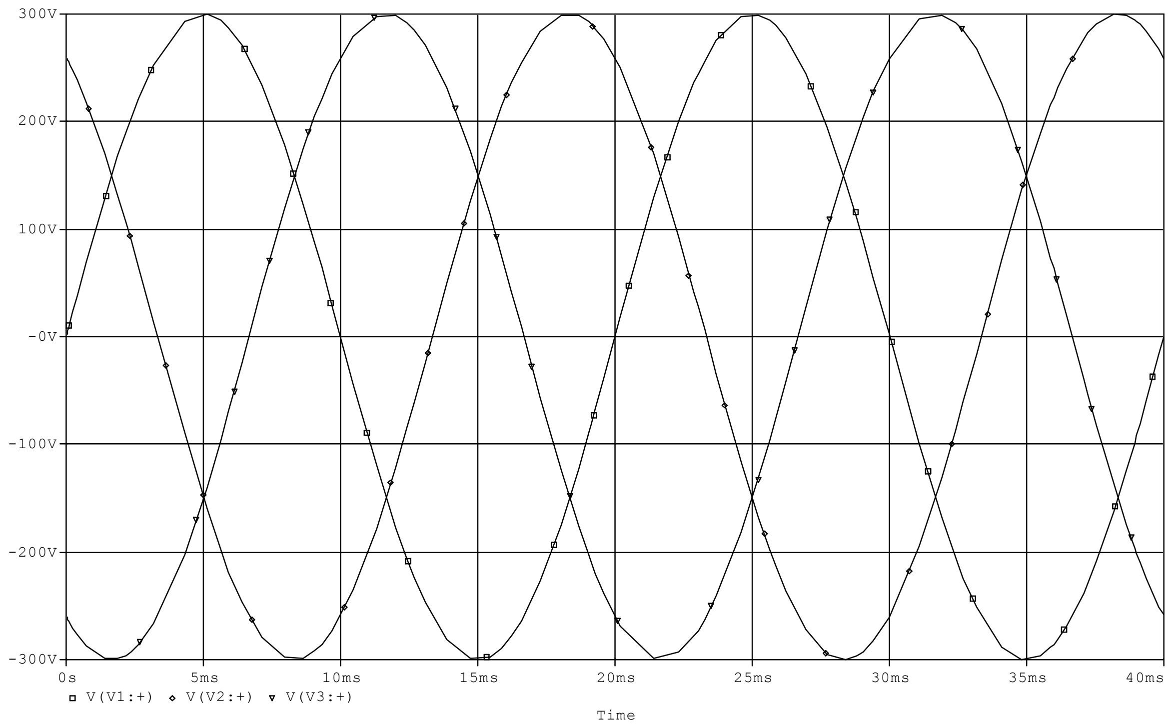


Figure 2.2: Input voltage of three phase full wave diode rectifier

The input voltage waveform of the circuit is shown in Figure 2.2. The diode of each phase conducts in D1D2, D3D2, D3D4, D5D4, D5D6 and D1D6 sequences through highest positive line to line voltage. The input current waveforms in the circuit of phase 1, 2 and 3 are as shown in Figure 2.3, 2.4 and 2.5 respectively.

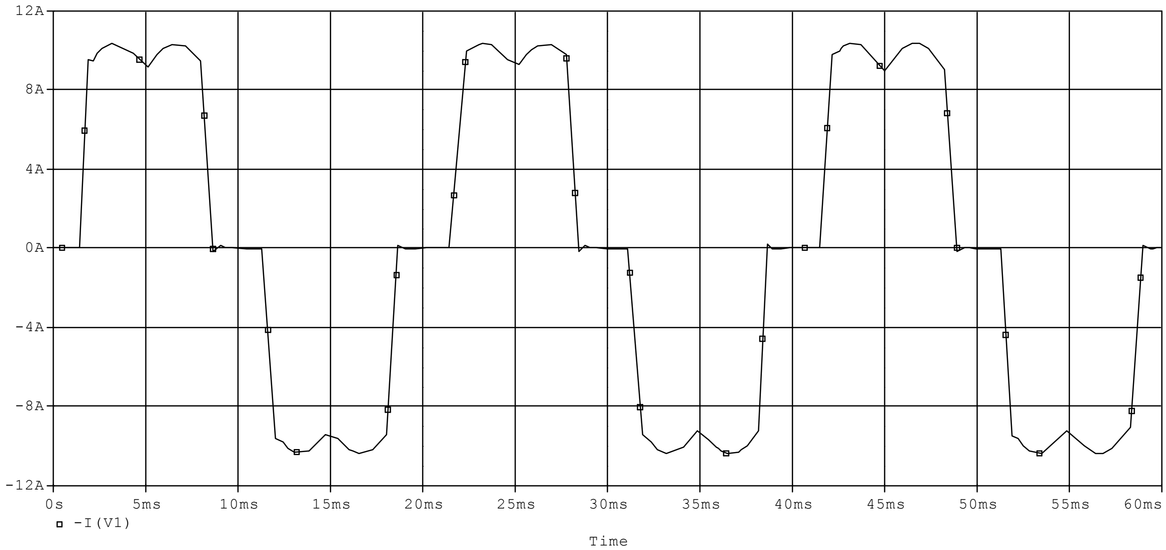


Figure 2.3: Input current of phase 1 of a three phase full wave diode rectifier

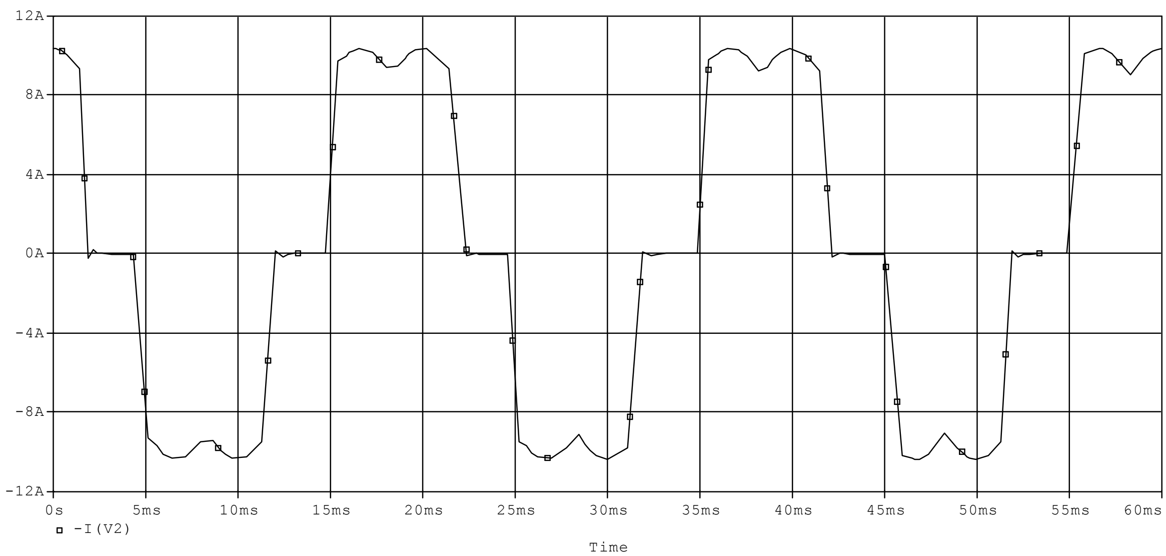


Figure 2.4: Input current of phase 2 of a three phase full wave diode rectifier

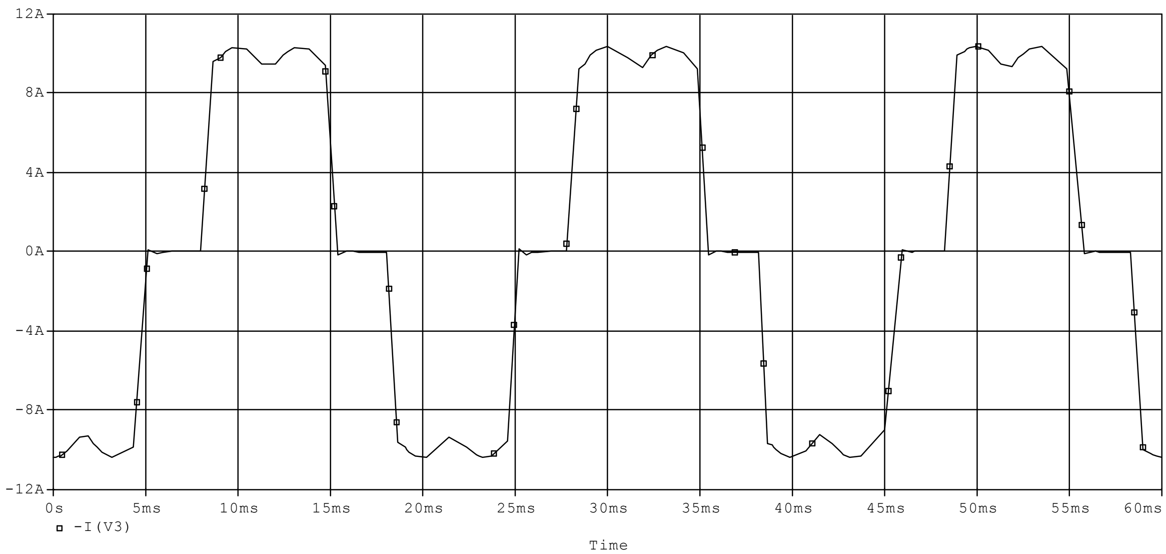


Figure 2.5: Input current of phase 3 of a three phase full wave diode rectifier

The operation of the rectifier circuit can be explained from the above figure. It is seen that the period of one cycle is 20ms. Consider the first period of each phase. From 0 to 5 ms, diode D1 and D3 conducts with highest positive voltage in phase 1 and 2, diode D2 is conducts with highest negative voltage in phase 3. Then D3-D2 and D1-D2 makes close path and allows flowing current from 2 to 3 and 1 to 3 through load. From 5 to 10 ms, diode D1 and D5 conducts with highest positive voltage in phase 1 and 3, at the same time diode D6 conducts with highest negative voltage in phase 2. Then D1-D6 and D5-D6 makes close path and allows flowing current from phase 1 to 2 and 3 to 2 through load. Similarly, from 10ms to 15ms the current flows from phase 3 to 2 and 3 to 1, from 15ms to 20ms the current flows from phase 2 to 1 and 2 to 3. It is seen that, in every cycle diode D1, D3, D5 conducts positively for 120^0 and D2, D4, D6 conducts negatively for 120^0. No diode conducts for 120^0 in a cycle. So, input current in each phase is found zero at the time. The waveforms of output voltage (V_o) and current (I_o) across the load R is shown in Figures 2.6 and 2.7 respectively.

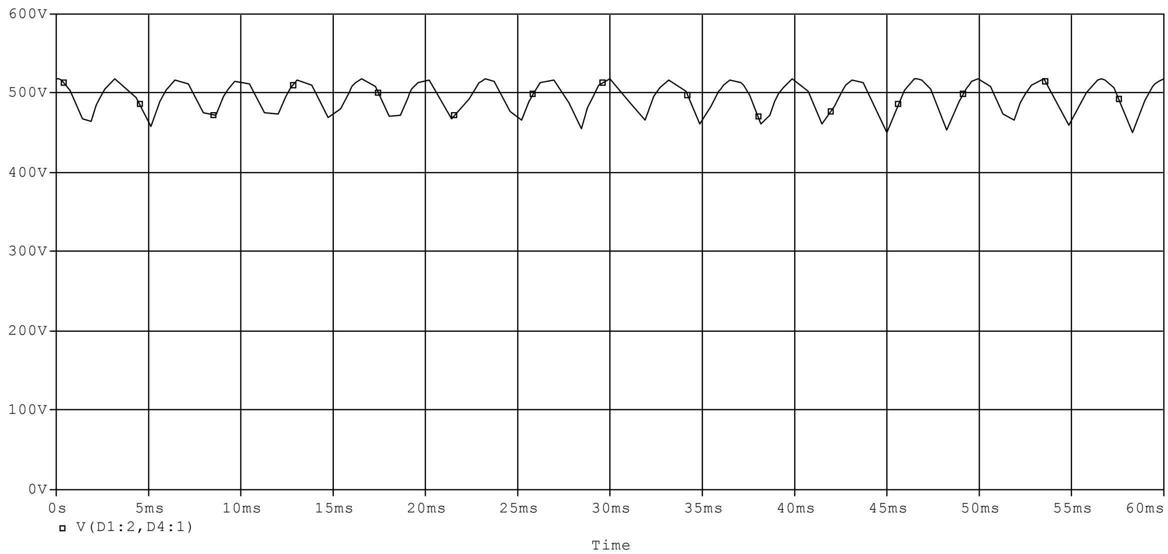


Figure 2.6: Output voltage of three phase 6-diode full wave rectifier

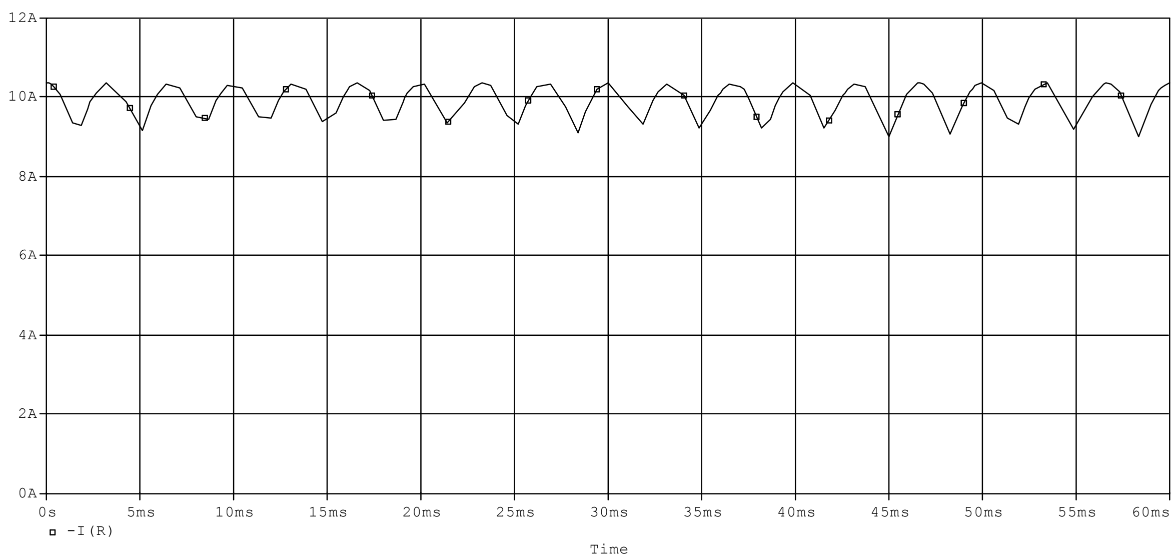


Figure 2.7: Output current of three phase 6-diode full wave rectifier

It is observed that the instantaneous waveforms of V_0 and I_0 consist of six segments per cycle. Each segment belongs to one of the six line to line voltage combinations. The performance parameter of three phase rectifier with resistive load is shown in Table 1. The above analysis shows that input current is non-sinusoidal and contains THD% of 2.583394E+01 PERCENT. The output voltage and current are not pure dc. The solution of these problems is to use filter in input and output side.

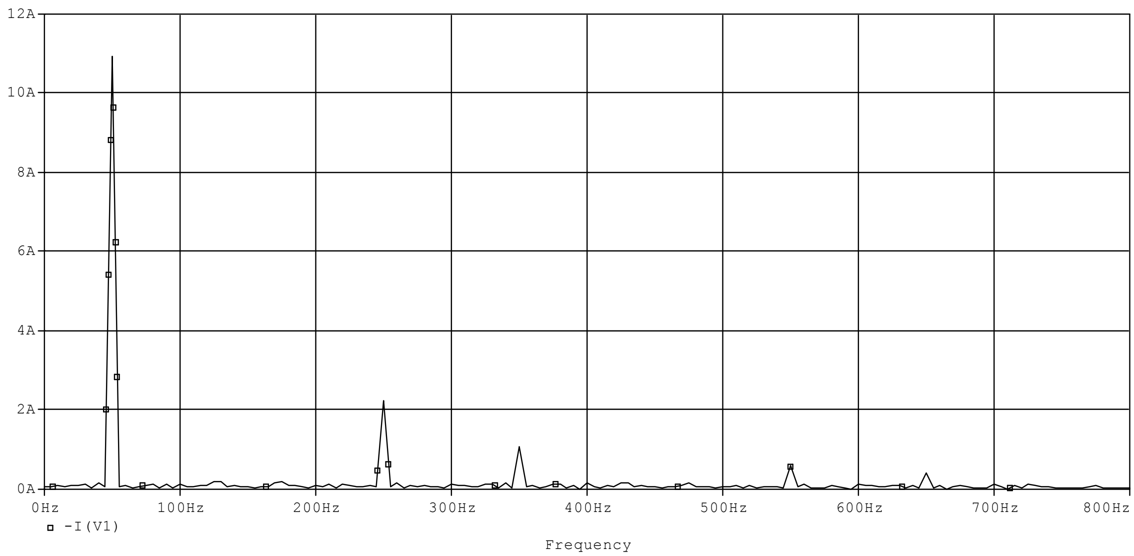


Figure 2.8: FFT of input current of three phase full wave diode rectifier

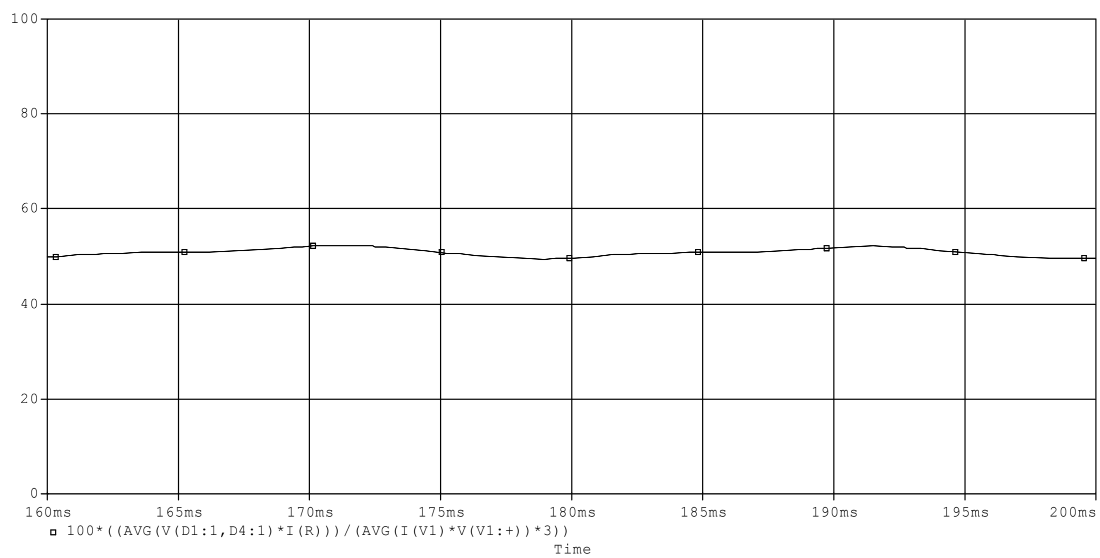


Figure 2.9: Efficiency of three phase full wave diode rectifier

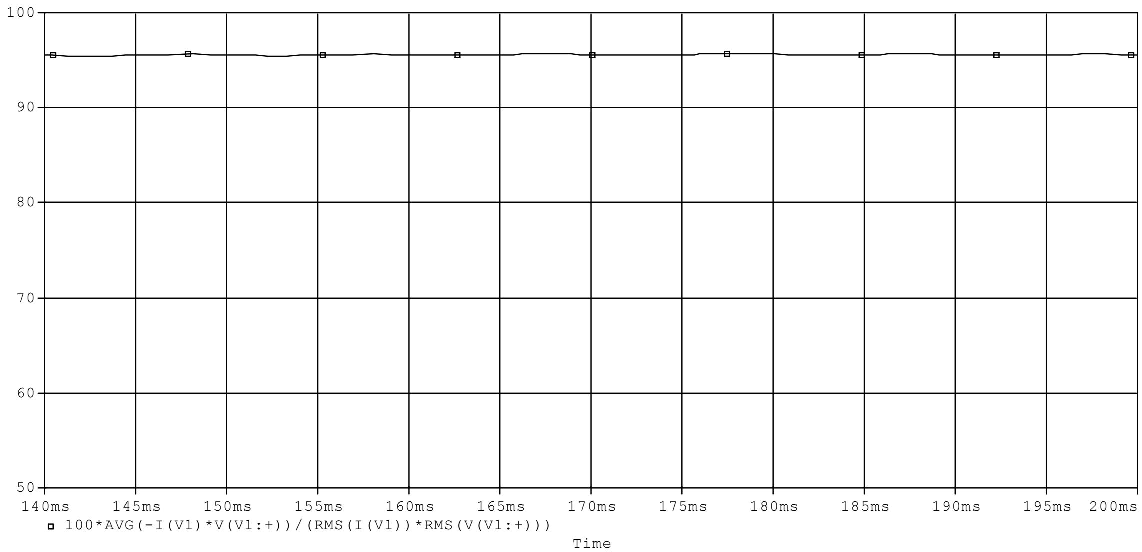


Figure 2.10: Power factor of three phase full wave diode rectifier

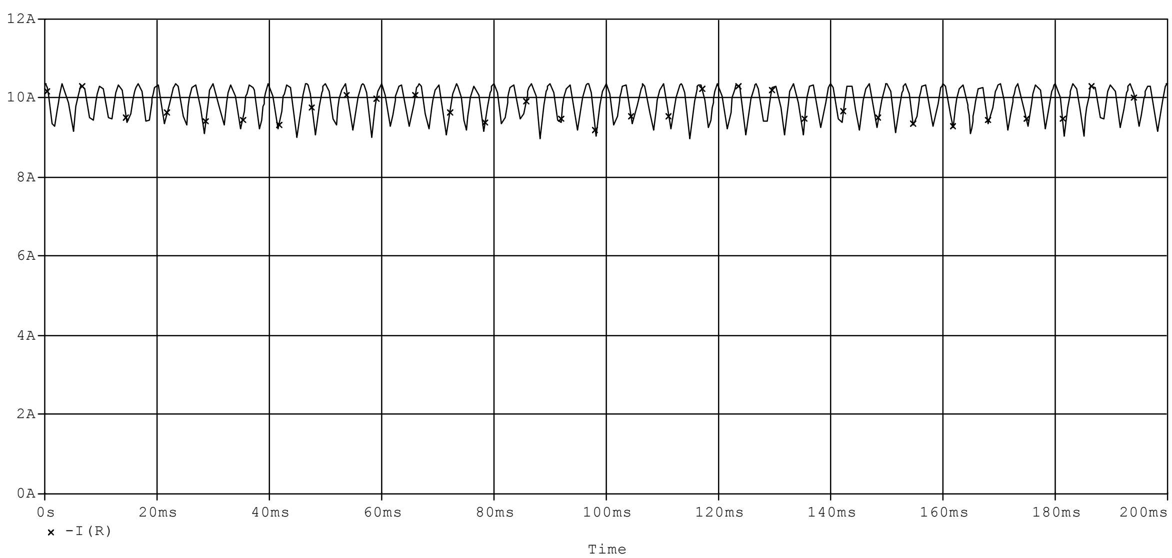


Figure 2.11: Output current of three phase full wave diode rectifier

Table 1: Performance parameter of three phase rectifier with resistive load

2.2.1 Input Current of Three Phase Rectifier

The efficiency of a three phase rectifier depends on mainly three factors. They are amplitude of input current, output voltage of the rectifier and the power factor. The average input and out put power is calculated from the following equations.

$$P_{in} = AVG\ (I_{in} * V_{in}\ (L\text{-}N))*3 \text{--} (4)$$

$$P_{out} = AVG\ (V_{out} * I_{out}) \text{--} (5)$$

It is observed from the discussion that input current of a three phase diode rectifier is non-sinusoidal. The presence of harmonics in input current can cause several problems. They are as follows.

i) Draws large rms value of input current which increase the Volt-Ampere ratings of the utilities such as generator, transmission line and transformer,

ii) Causes stability problem in source application,

iii) Reduce power factor means reduce capacity of line to supply energy,

iv) Creates noise, over voltage and loading in power equipments,

v) Resonance may occur between the capacitors and rectifiers circuit in the system which can blow fuses and damage capacitors and other electronic equipment,

vi) Create additional heating due to harmonic I^2R losses in wires,

vii) Causes lower rectifier efficiency due to large rms value of input current and

viii) Can lead to flow large current in neutral conductor in three phases, four wire system which may easily exceed the conductor's rms current rating.

Considering these facts and the adoption of IEEE standards 1000-3-2, there is need for power

THD(%)	PF	I_{in}(rms) amp	V_{in}(rms)volt	V_{out}(dc) volt	I_{out}(dc) amp	Efficiency(η)%
2.583394E+01	95.5	8	212.13	500	10	50

supply that draws current with low harmonic content and also have power factor close to unity. For this reason, the use of the passive and active filters may be the desired solutions.

2.2.2 Input Current Shaping of Three Phase Rectifier by Passive Filter

The effect of addition of passive filter in three phase rectifier is analyzed here. LC (passive) filter acts as a sink to the harmonic current. The circuit is simulated with various filter parameters. When the filter is designed with the parameter L=20mH and C=100uF, then the input current is observed to be pure sinusoidal with low harmonics. The ripple from the output voltage and current can be eliminated using output filter between the load and the rectifier. By using L=10mH and C=100uF, the output voltage and current can be made ripple free. The circuit diagram of a three phase rectifier including input and output filter is shown in Figure 2.12. The input current, output voltages, output current, efficiency, power factor, FFT of input current are shown in Figures 2.13-2.18 sequentially. The performance parameter of three phase rectifier with passive input output filter is shown in Table 2.

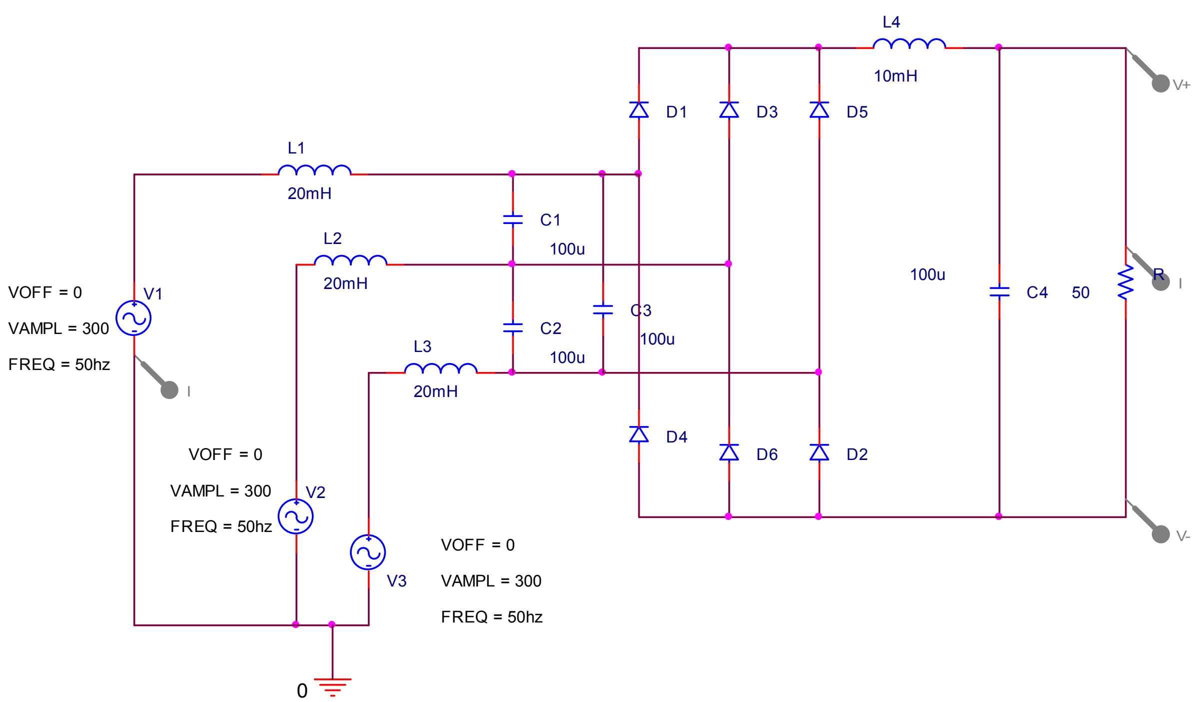


Figure 2.12: Circuit diagram of three phase full wave diode rectifier with input and output filter

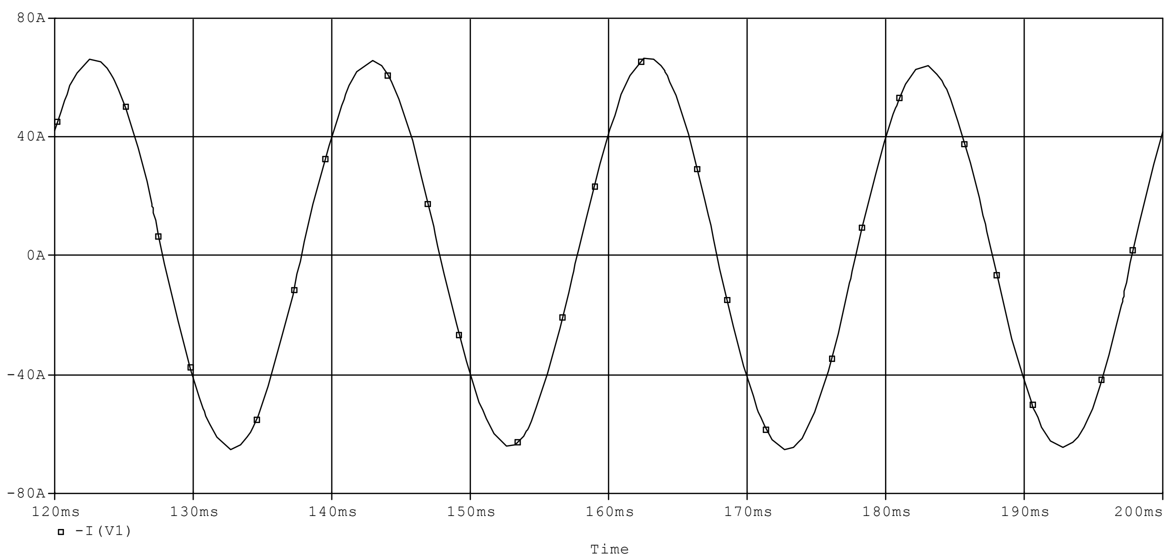


Figure 2.13: Input current of a three phase full wave diode rectifier with input and output filter

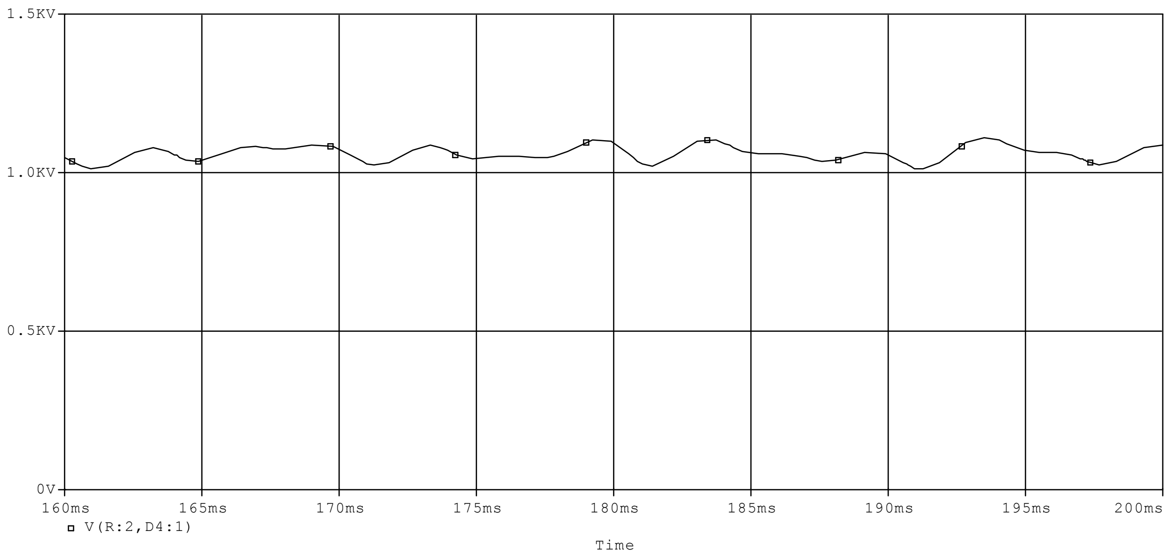


Figure 2.14: Output voltage of a three phase full wave diode rectifier with input and output filter

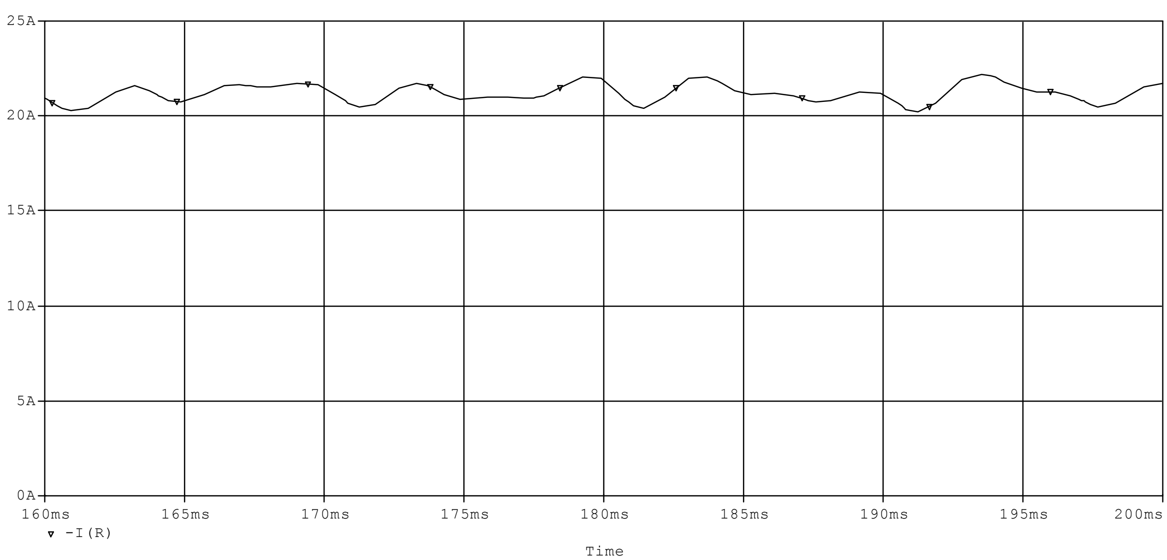


Figure 2.15: Output current of a three phase full wave diode rectifier with input and output filter

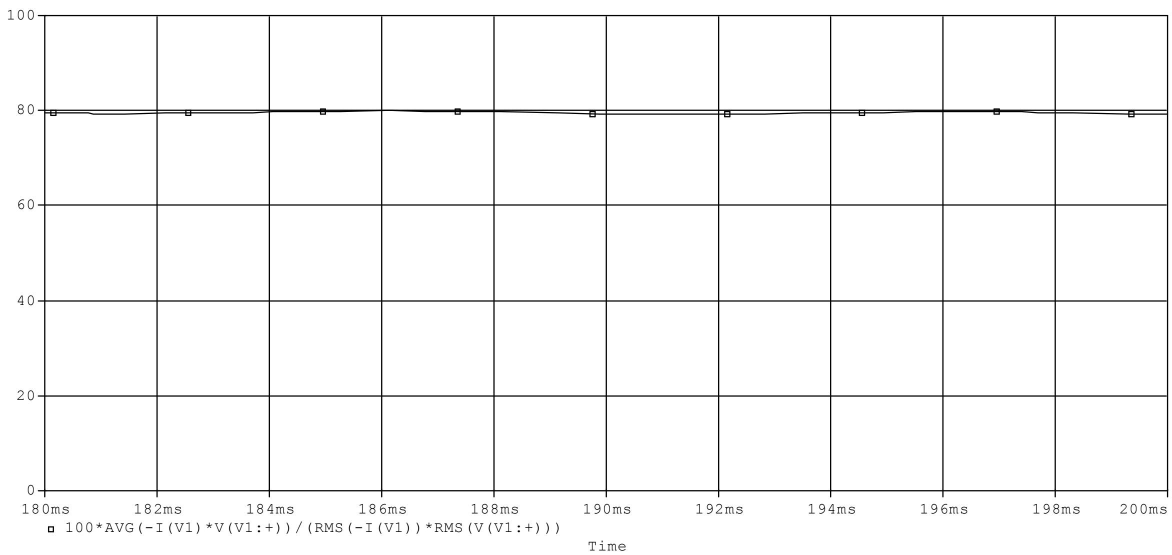


Figure 2.16: Power factor of a three phase full wave diode rectifier with input and output filter

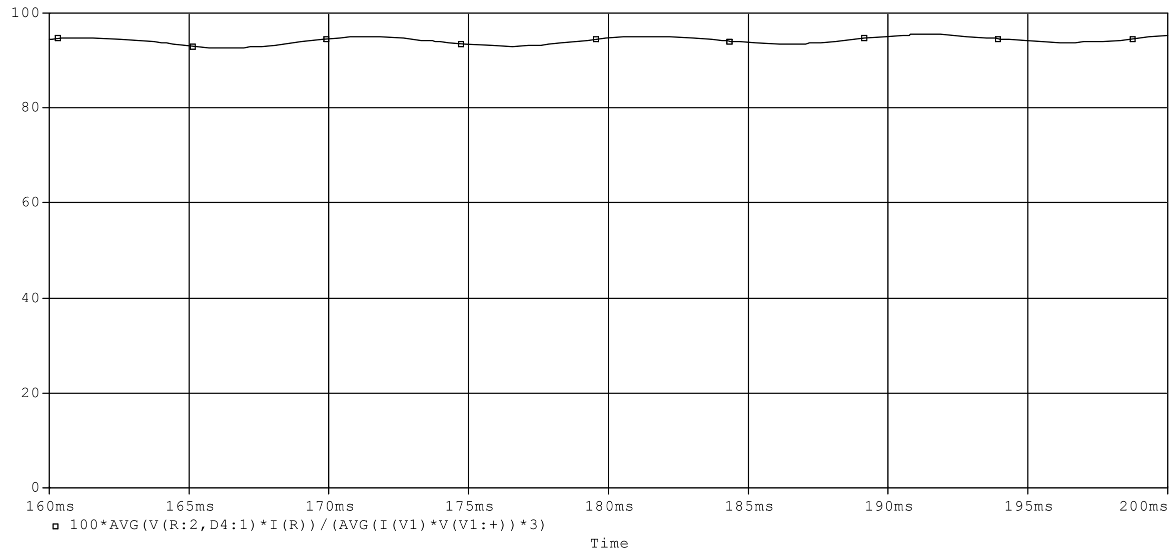


Figure 2.17: Efficiency of a three phase full wave diode rectifier with input and output filter

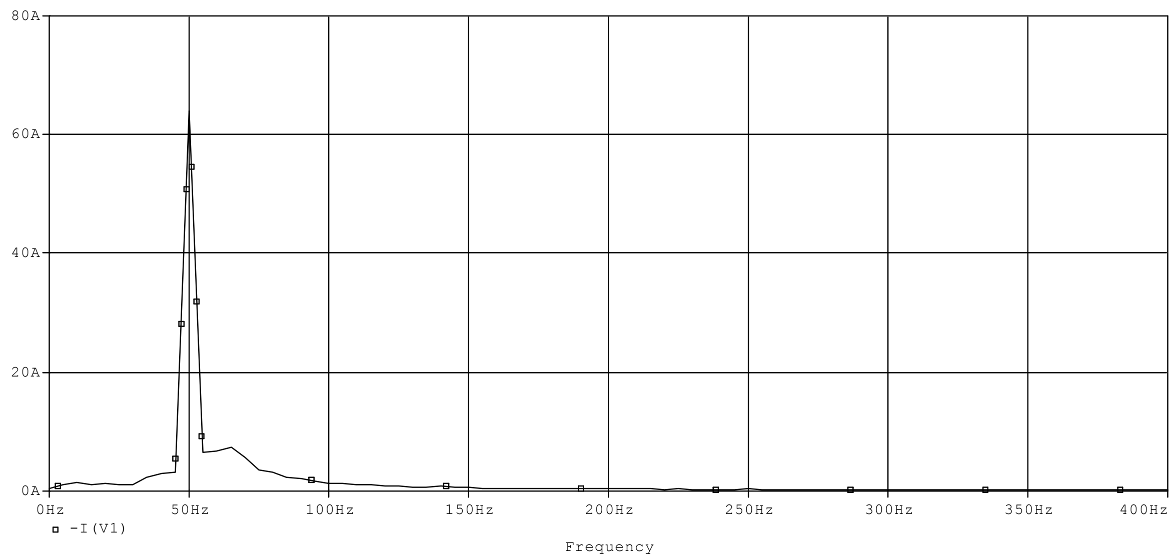


Figure 2.18: FFT input current of a three phase full wave diode rectifier with input and output filter

Table 2: Performance parameter of three phase rectifier with resistive load

From the above analysis, it is seen that, though harmonics of input current becomes low and output voltage and current becomes ripple free, the filter size is very large. As the important goal is to vary the output voltage, the above mentioned circuit cannot fulfill the requirement.

THD(%)	PF	I_{in}(rms) amp	V_{in}(rms)volt	V_{out}(dc) volt	I_{out}(dc) amp	Efficiency(η)%
1.098277E+00	80	48	212.13	1000	20	94

2.2.3.1 Input Current Shaping of Three Phase Rectifier by Buck Boost Regulator and Passive Filter

From the previous discussion it is clear that, a three phase rectifiers have several problems such as power flow from input to output is unidirectional and it cannot be controlled. The output voltage is uncontrolled. The filter size becomes very large. In many applications output voltage is required to be regulated and power is required to be controlled. In this circumstance, switch mode (SMPS) rectifiers have gained attention as a solution, since they draw almost sinusoidal current with low harmonics and provide a voltage control strategy. The addition of a single switch boost regulator between rectifier and load can be a good solution. Boost rectifier is very popular because of simple control strategy and high output voltage with small ripple. The power factor correction and THD reduction is also possible by shaping of input current. Here a control circuit is used to control the boost switch. In control circuit, pulse width modulation (PWM) technique is used to generate required gate pulse of boost switching element of varying duty cycle. Duty cycle is varied with change of reference voltage V_{dc} in control circuit. The PWM control not only can manage the active power, but reactive power also, allowing this type of rectifier to correct power factor. Besides, the input current waveform can be maintained almost sinusoidal, reducing harmonic contamination to the main supply.

2.2.3.2 Buck Boost Rectifier Analysis without Filter

The circuit diagram of single switch Buck-Boost rectifier is shown in Figure 2.19. The wave shape of input current and frequency spectrum at every duty cycles are shown in figure respectively. It is found that, input current is non-sinusoidal in nature and it has harmonic contents including 5^{th},7^{th},11^{th},13^{th},17^{th} and so on. The current distortion is quantified by the total harmonics distortion (THD) parameter. The value of THD is calculated by the following equation.

$$THD\% = \frac{\sqrt{\sum_{h=2}^{h=\infty}(I_h)^2}}{I_1} x100$$

Where, I_h is the harmonic component of the input current and I_1 is the fundamental component of the input current. The performance parameters of a single switch buck-boost rectifier are shown in Table 3. Performance parameter represents the quality of input current, output voltage, THD and power factor. It is seen that power factor is improved from 24% to 90 % with the increase of Duty Cycle from 10% to 90%. On the other hand, the overall efficiency of the converter decreases (from 93% to 07%) with the increase in Duty Cycle (from 10% to (90%). It is also observed that the total harmonics distortion (THD) is also improved (2.000072E+02 % to 3.558909E+01 %) with the greater Duty cycle (10% to 90%). Typical input current wave shape, output current wave shape, output voltage, FFT of input current, power factor and efficiency wave shapes are shown in Figures 2.20-2.43 for duty cycle 0.1,0.4,0.7 and 0.9. The results of the table 3 are shown graphically in Figures 2.44-2.47.

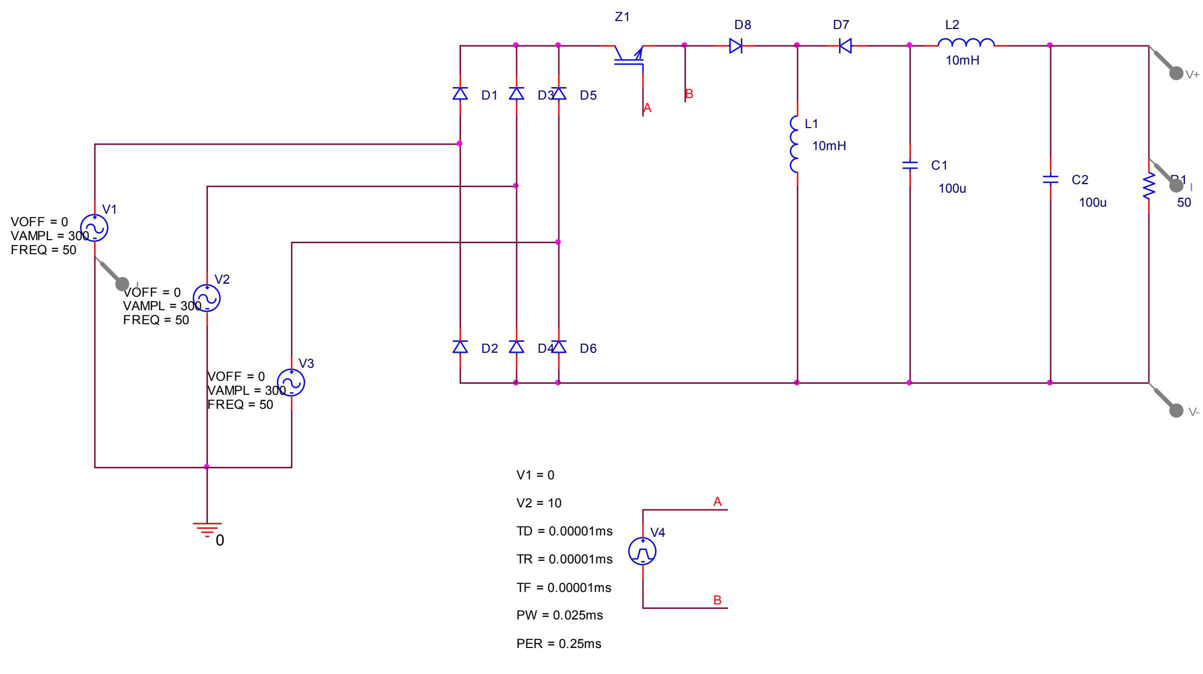


Figure 2.19: Circuit diagram of a buck-boost regulated three phase rectifier with output filter

AT DUTY CYCLE=10%

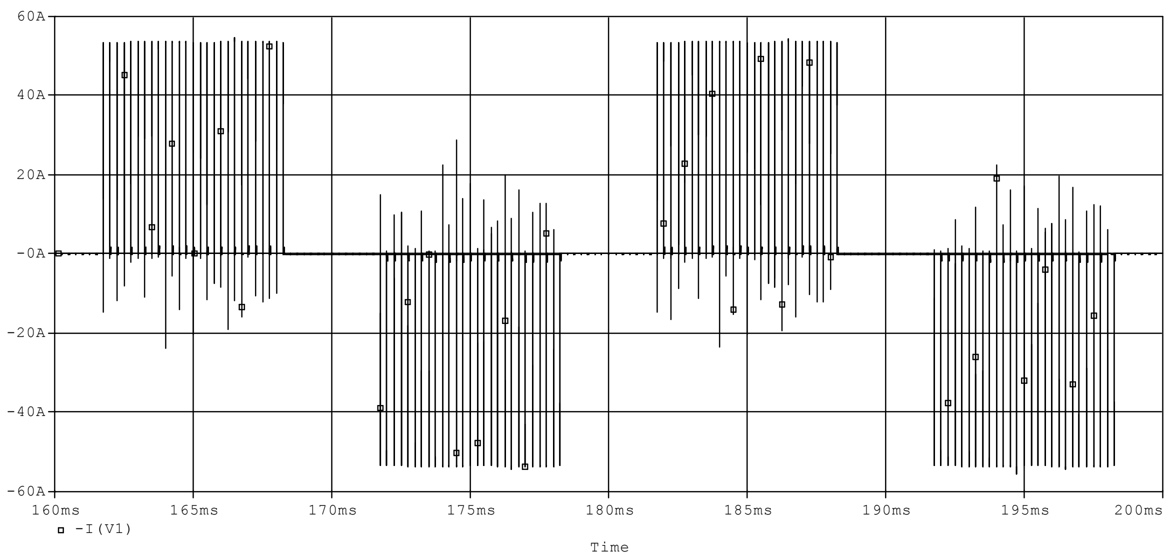


Figure 2.20: Input Current of a buck-boost regulated three phase rectifier with output filter at D=10%

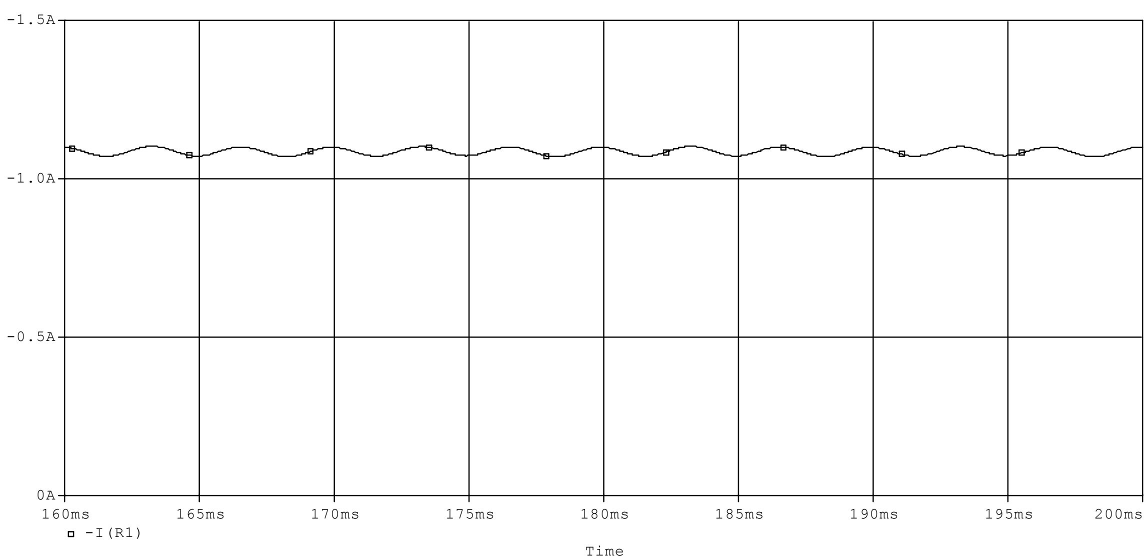


Figure 2.21: Output Current of a buck-boost regulated three phase rectifier with output filter at D=10%

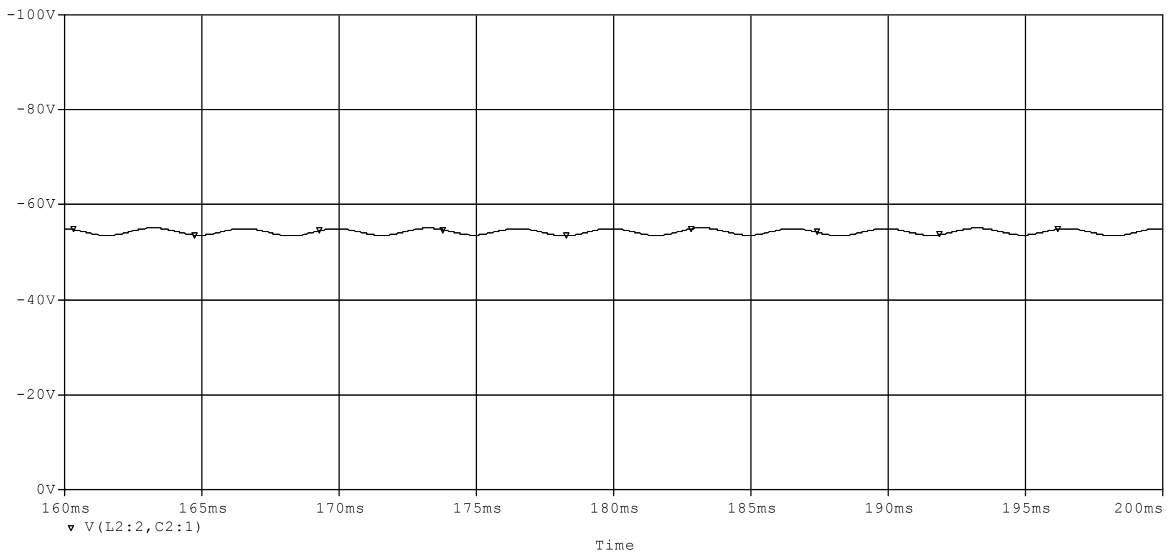


Figure 2.22: Output Voltage of a buck-boost regulated three phase rectifier with output filter at

D= 10%

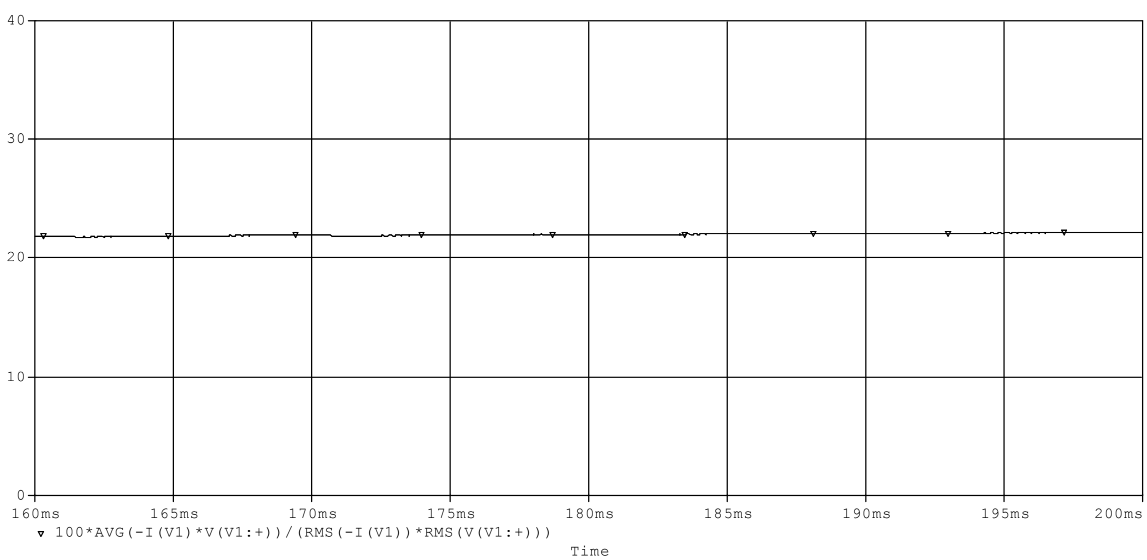


Figure 2.23: Power Factor of a buck-boost regulated three phase rectifier with output filter at D=10%

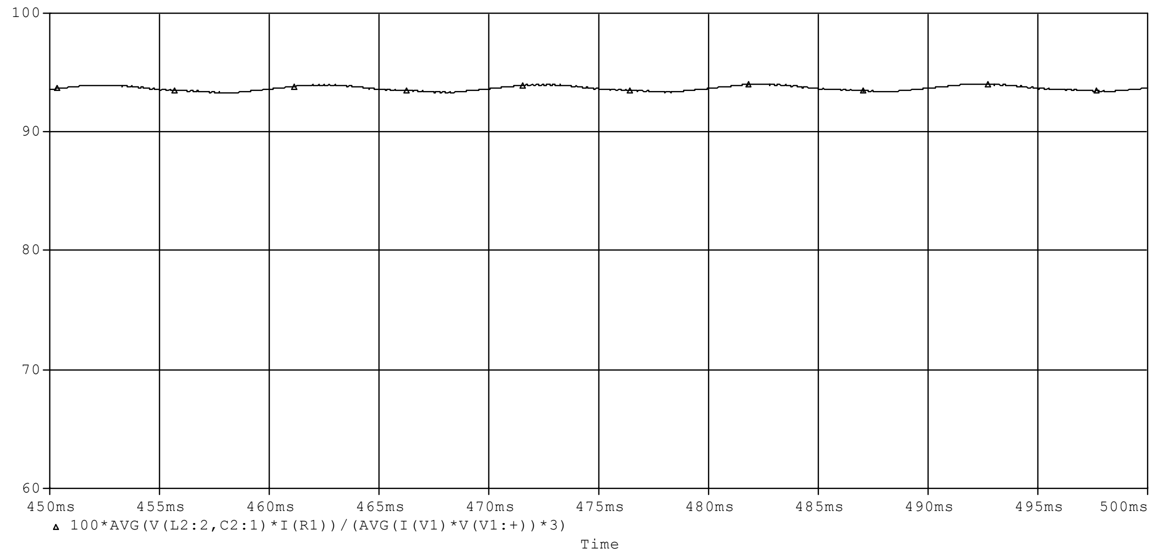


Figure 2.24: Efficiency of a buck-boost regulated three phase rectifier with output filter at D=10%

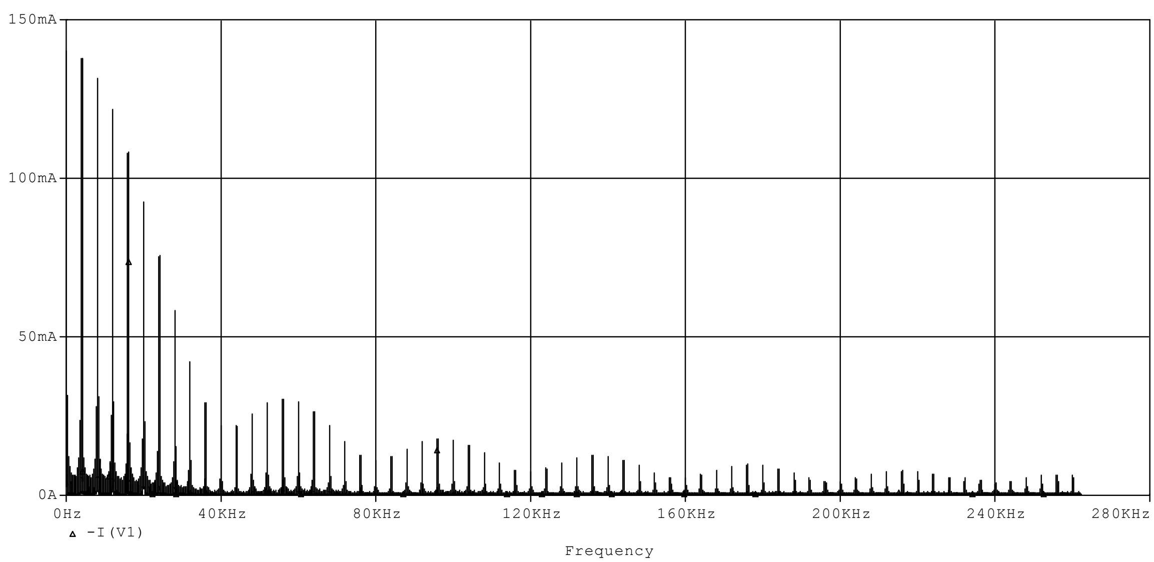


Figure 2.25: FFT of Input Current of a buck-boost regulated three phase rectifier with output filter at D=10%

AT DUTY CYCLE=40%

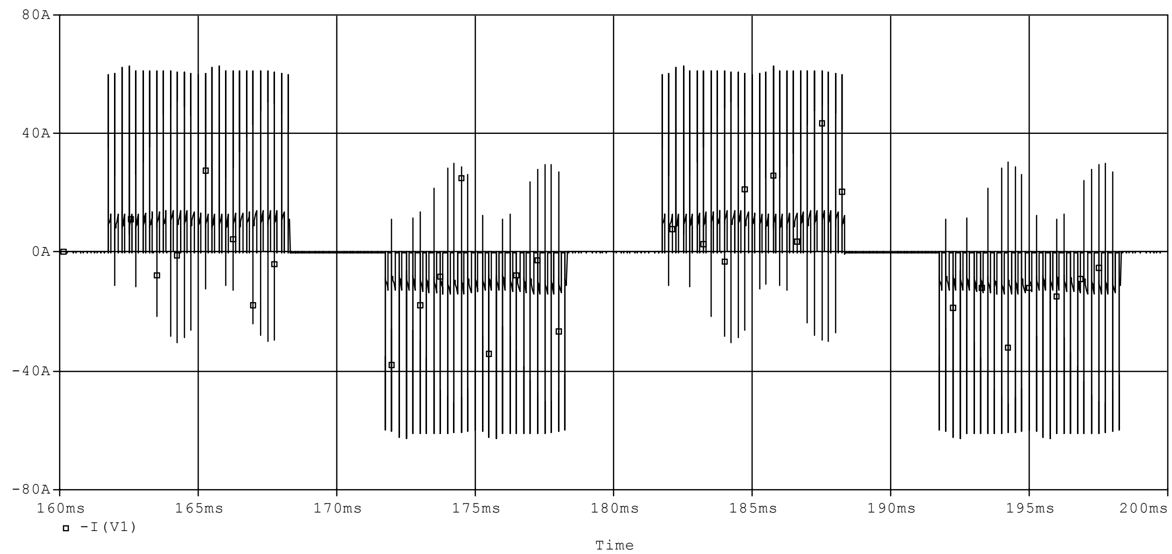


Figure 2.26: Input Current of a buck-boost regulated three phase rectifier with output filter at D= 40%

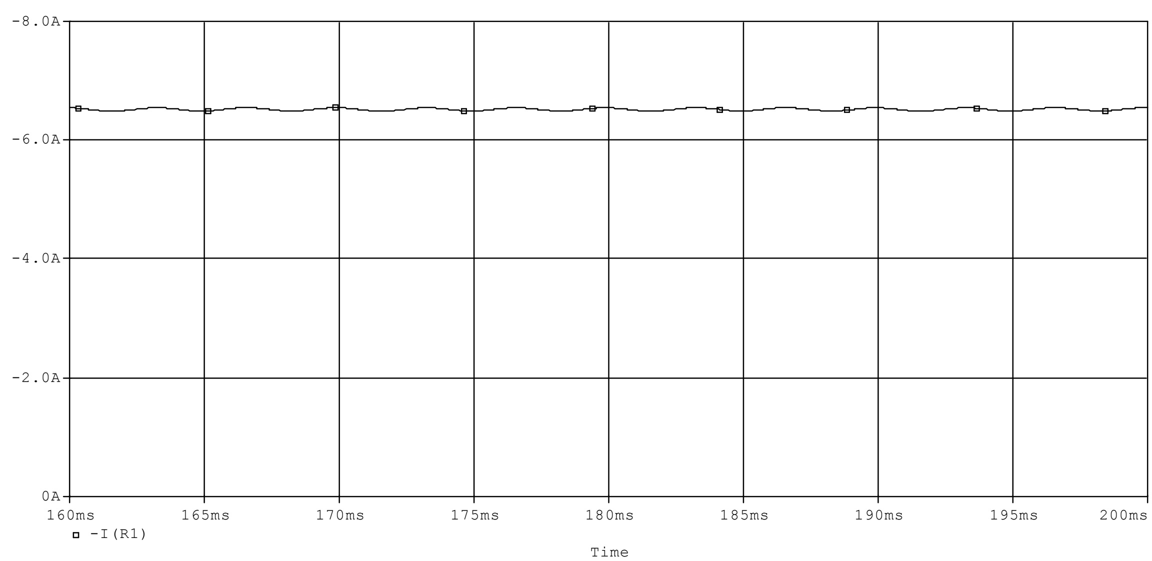


Figure 2.27: Output Current of a buck-boost regulated three phase rectifier with output filter at D=40%

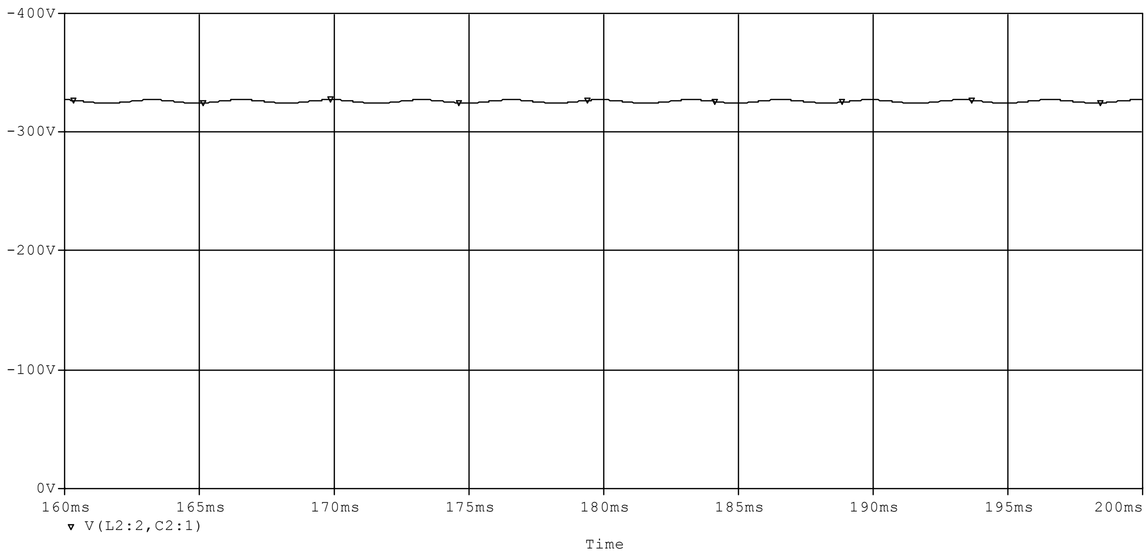


Figure 2.28: Output voltage of a buck-boost regulated three phase rectifier with output filter at D=40%

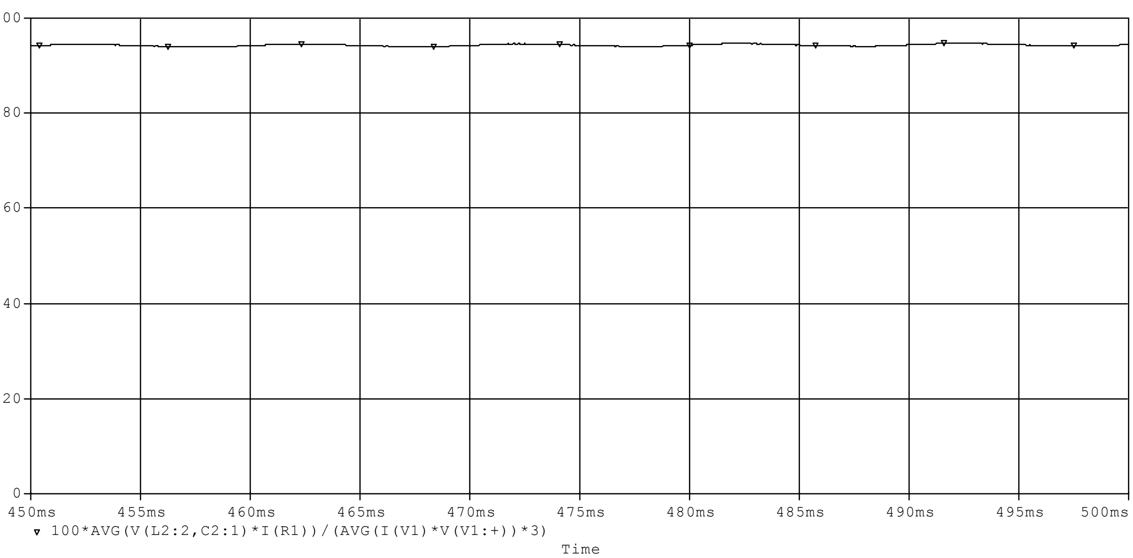


Figure 2.29: Efficiency of a buck-boost regulated three phase rectifier with output filter at D= 40%

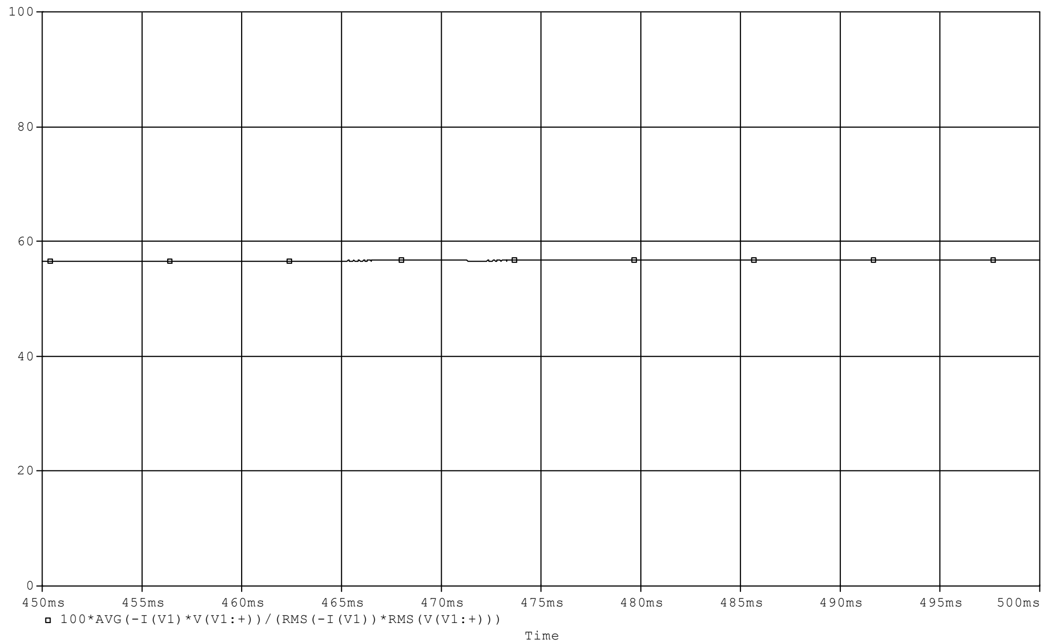


Figure 2.30: Power factor of a buck-boost regulated three phase rectifier with output filter at D= 40%

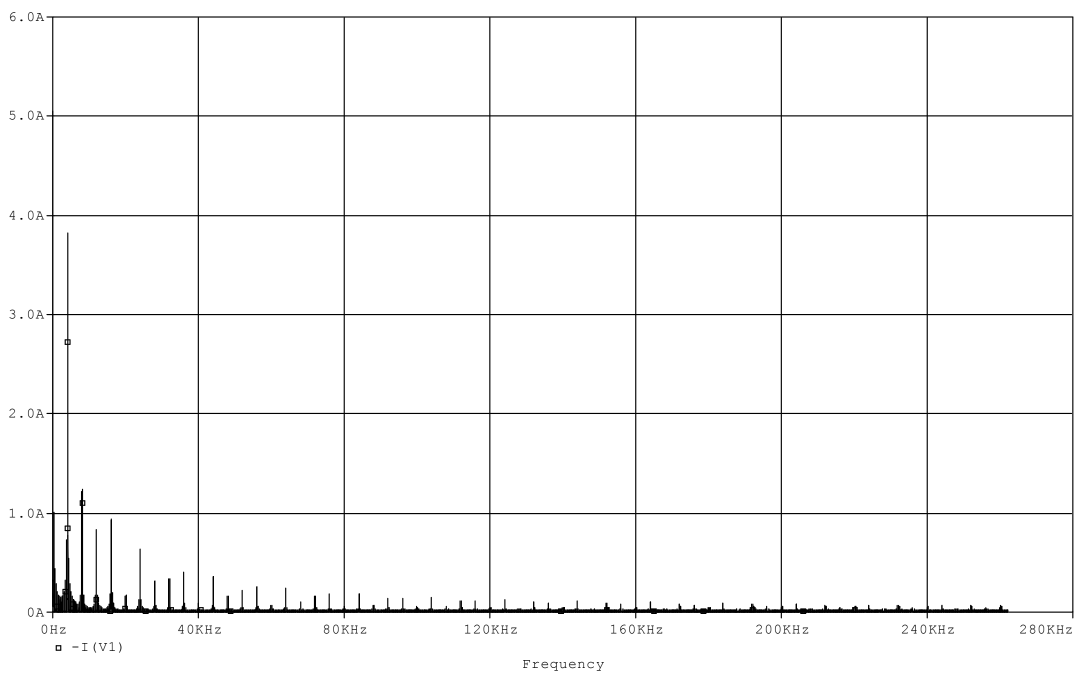


Figure 2.31: FFT of Input Current of a buck-boost regulated three phase rectifier with output filter at D= 40%

AT DUTY CYCLE=70%

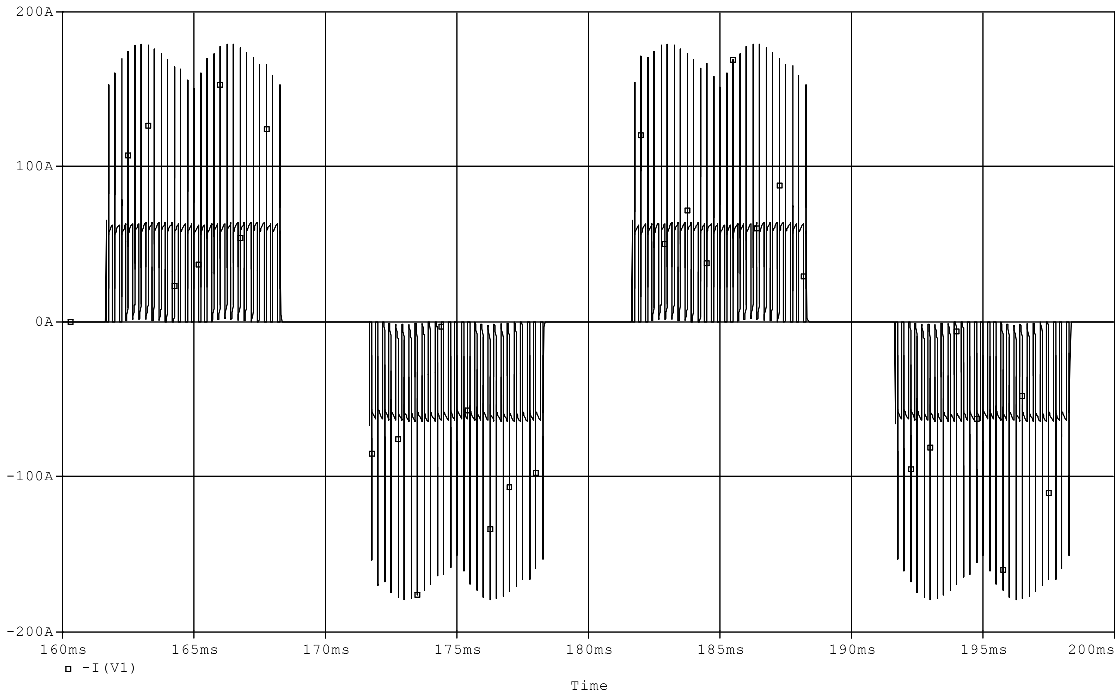


Figure 2.32: Input current of a buck-boost regulated three phase rectifier with output filter at D= 70%

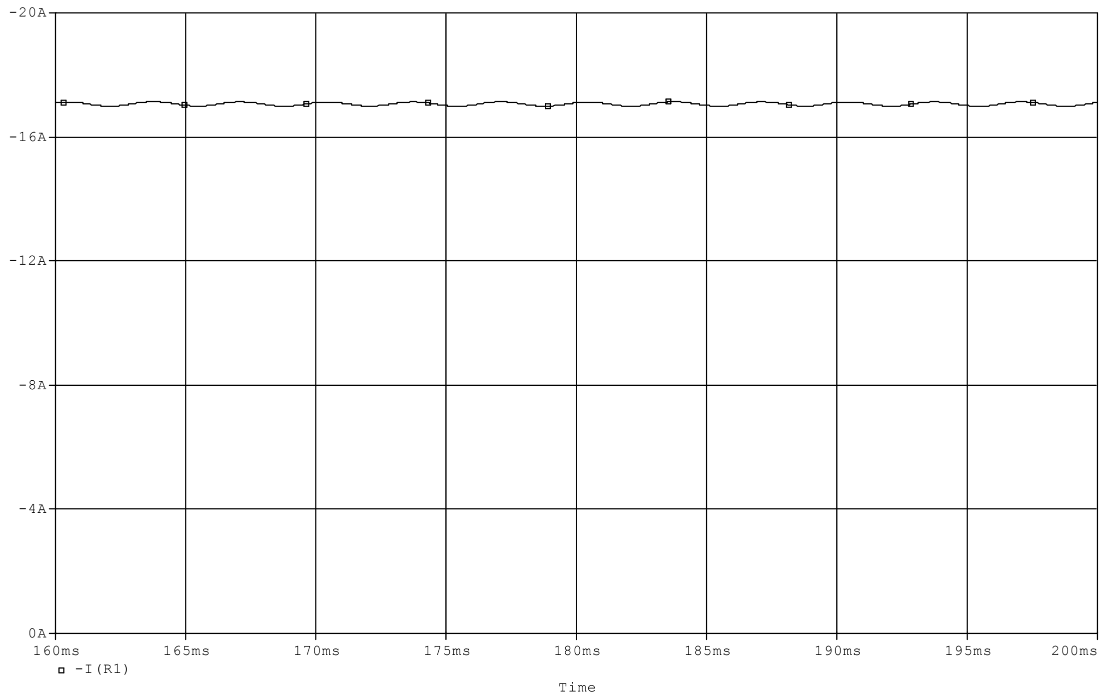


Figure 2.33: Output current of a buck-boost regulated three phase rectifier with output filter at D= 70%

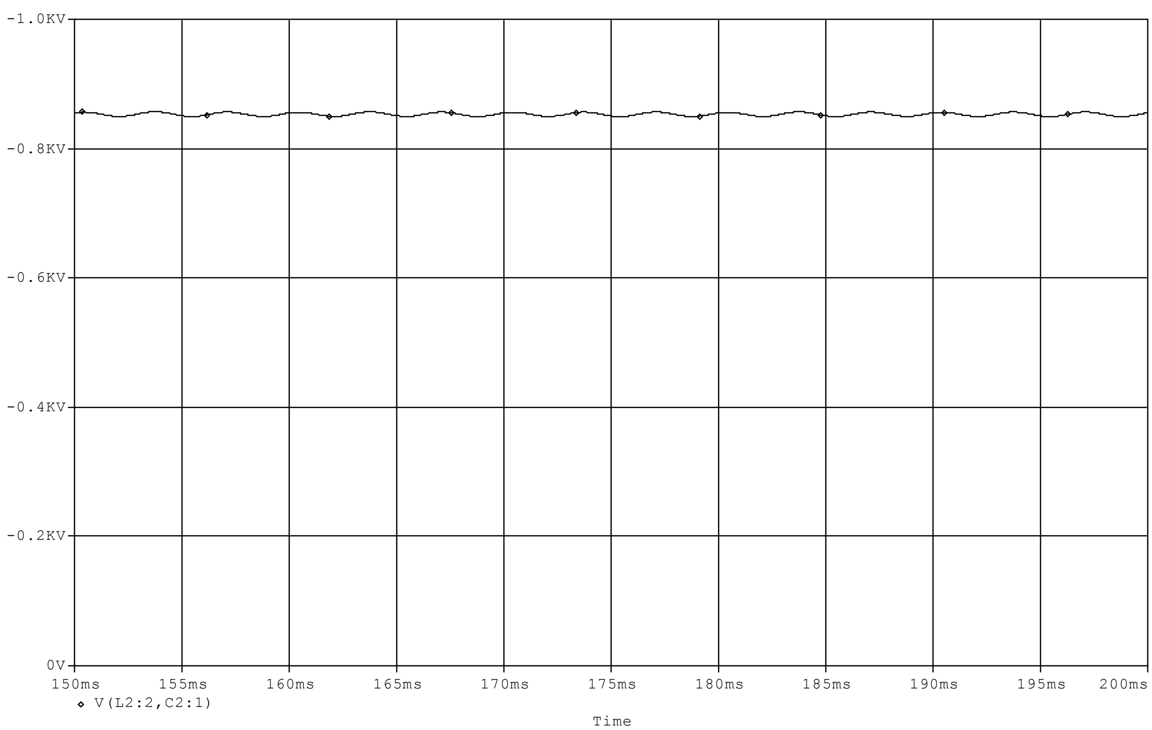


Figure 2.34: Output voltage of a buck-boost regulated three phase rectifier with output filter at D= 70%

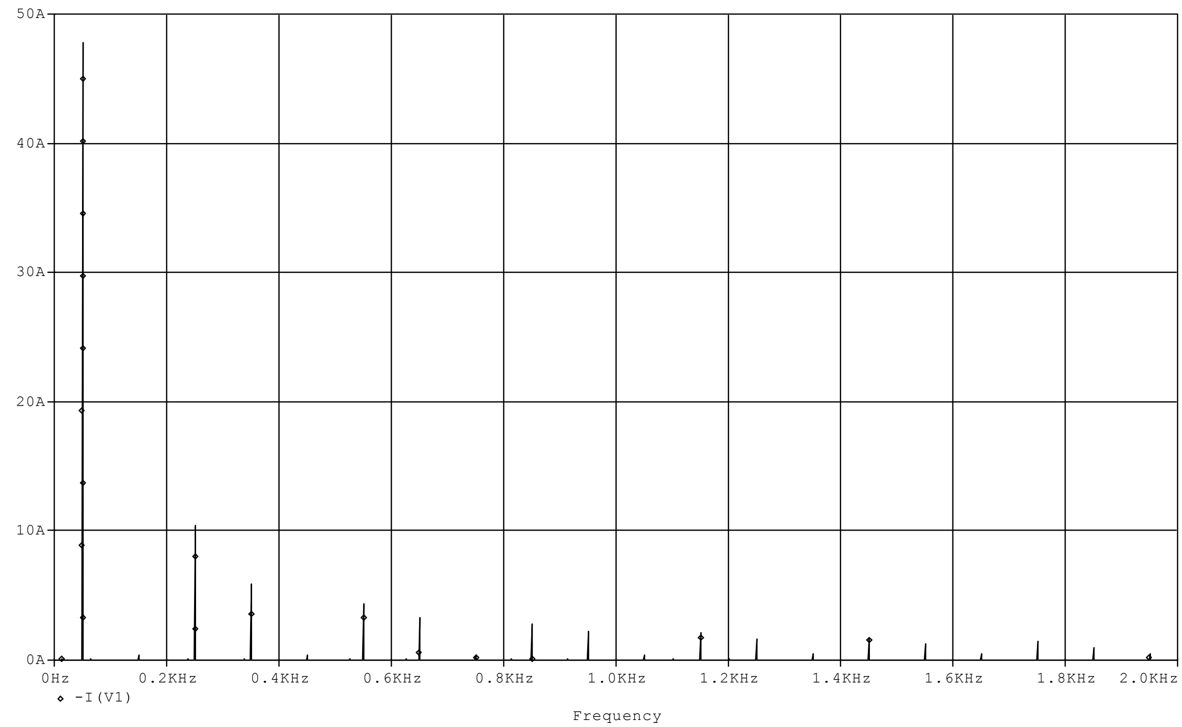


Figure 2.35: FFT of Input current of a buck-boost regulated three phase rectifier with output filter at D=70%

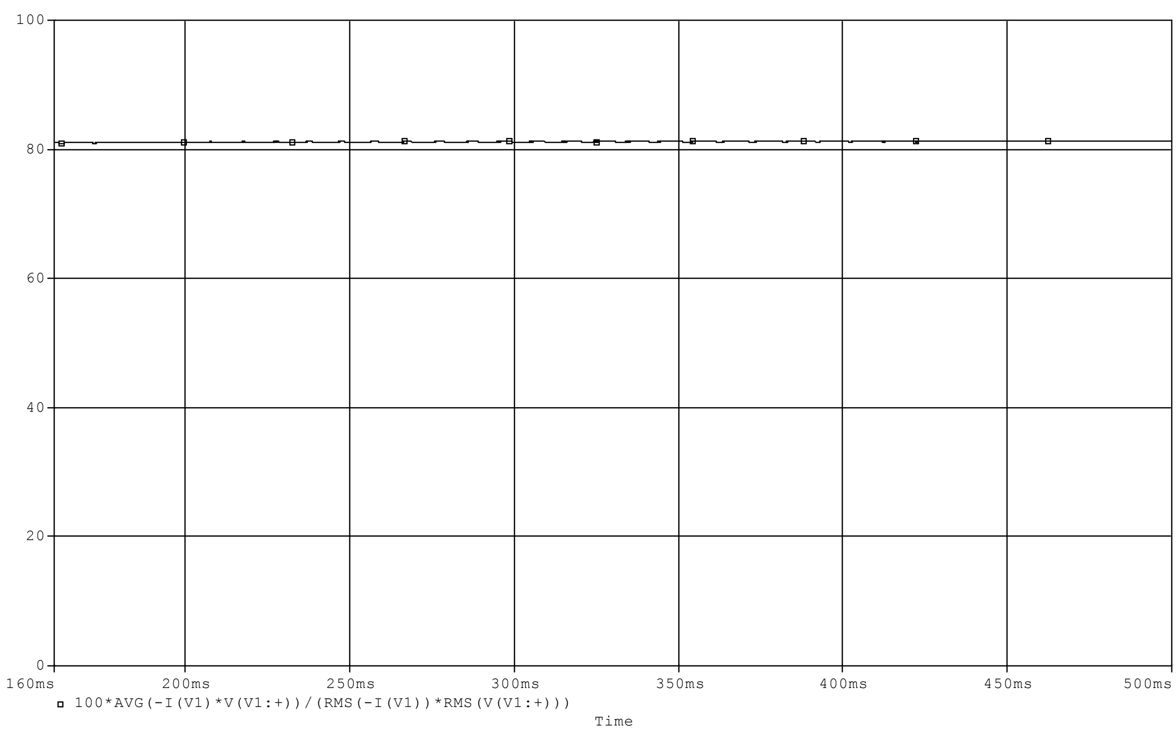


Figure 2.36: Power factor of a buck-boost regulated three phase rectifier with output filter at D= 70%

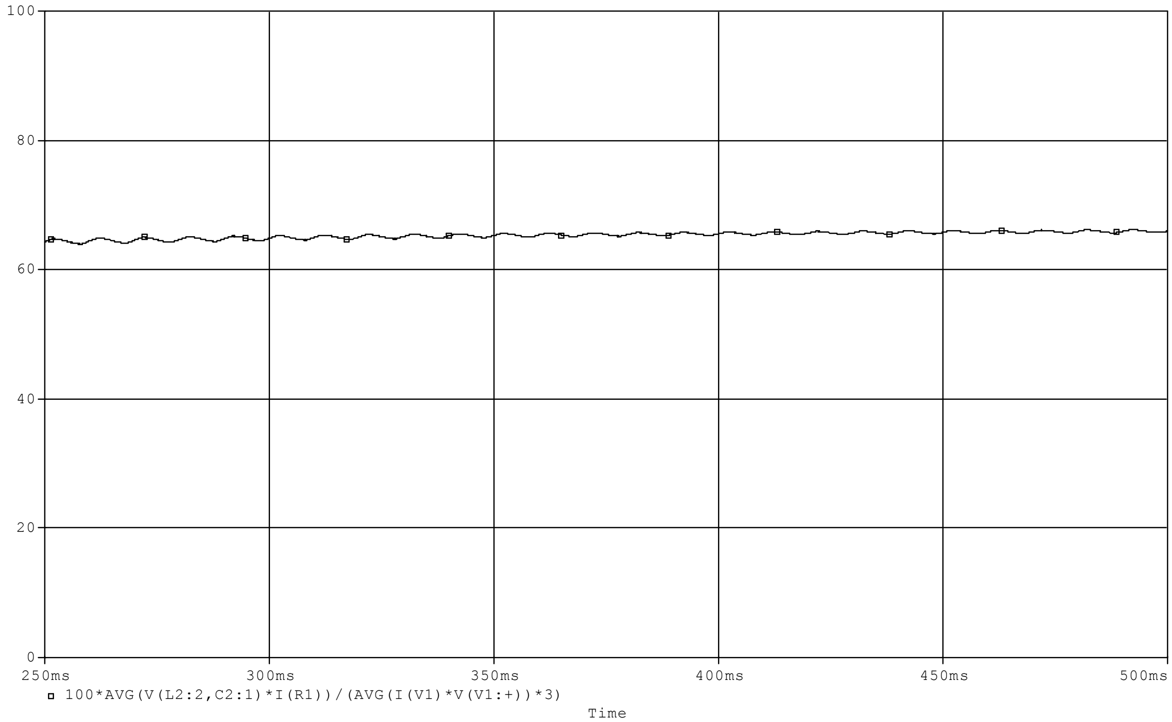


Figure 2.37: Efficiency of a buck-boost regulated three phase rectifier with output filter at D= 70%

AT DUTY CYCLE=90%

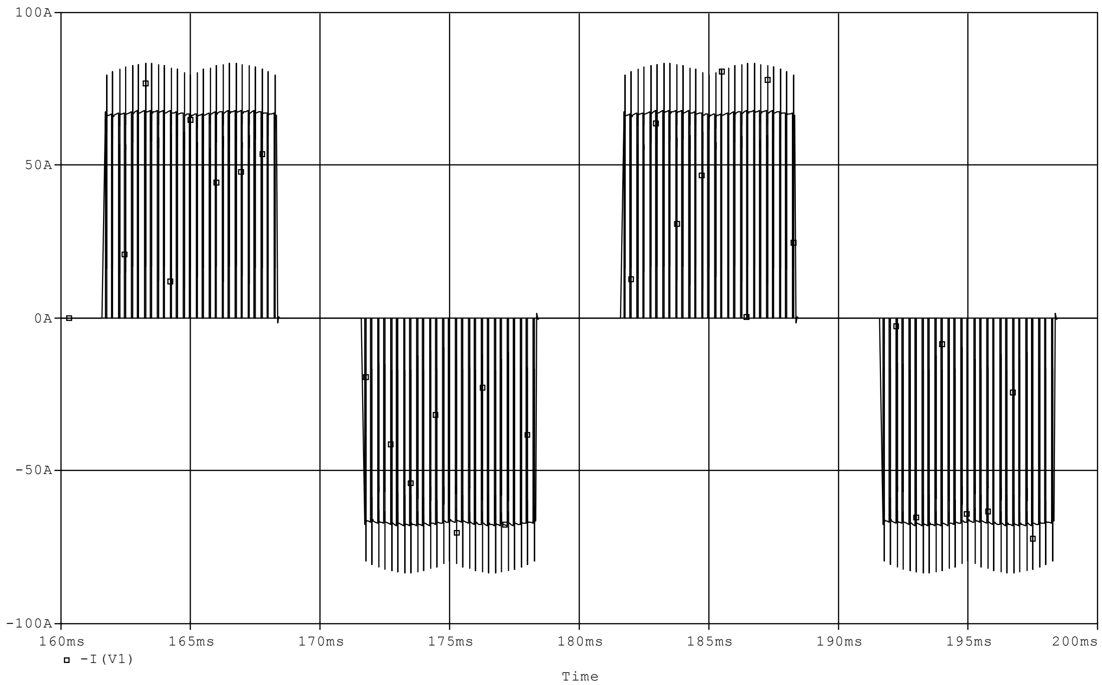


Figure 2.38: Input Current of a buck-boost regulated three phase rectifier with output filter at D= 90%

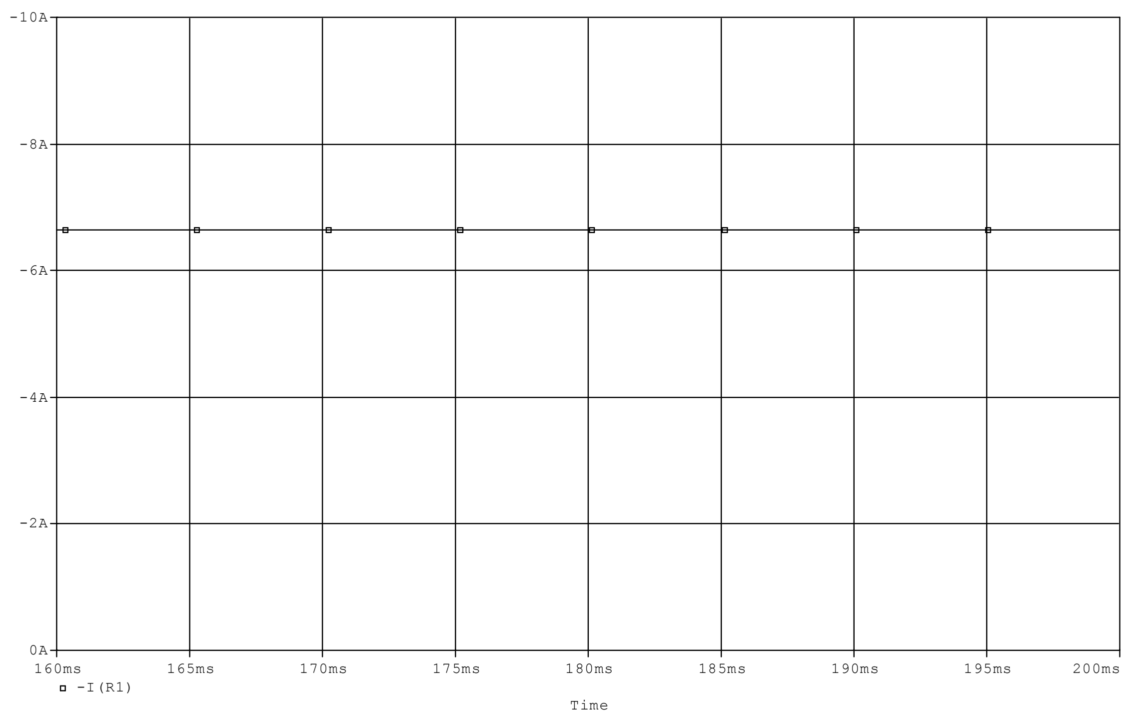


Figure 2.39: Output Current of a buck-boost regulated three phase rectifier with output filter at D= 90%

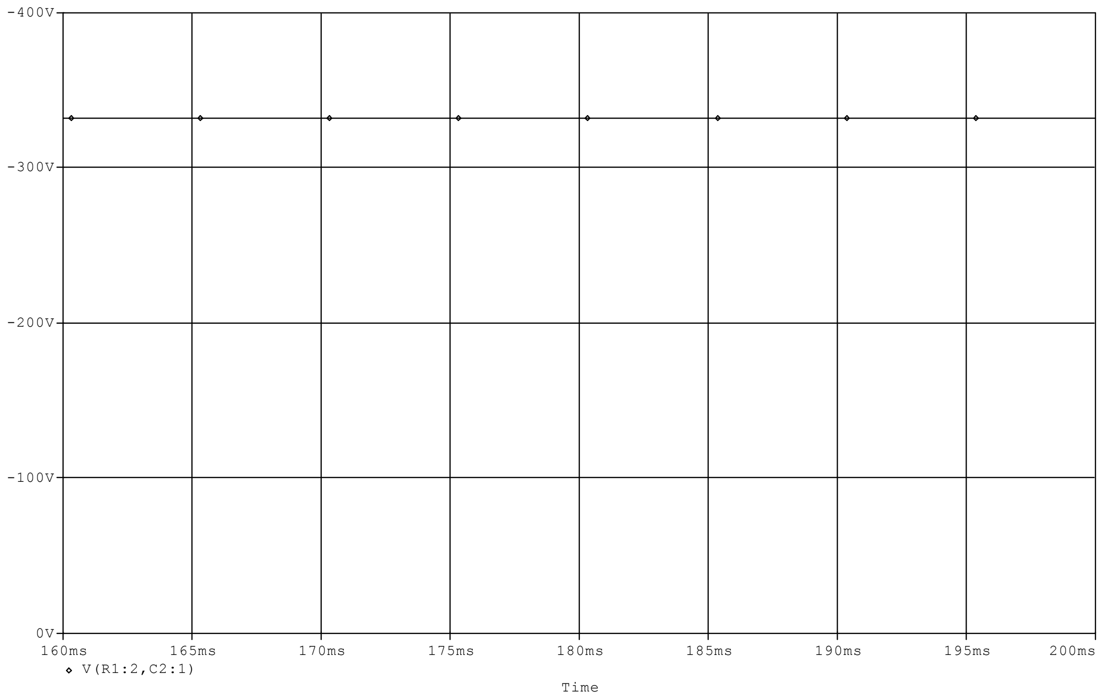


Figure 2.40: Output Voltage of a buck-boost regulated three phase rectifier with output filter at D= 90%

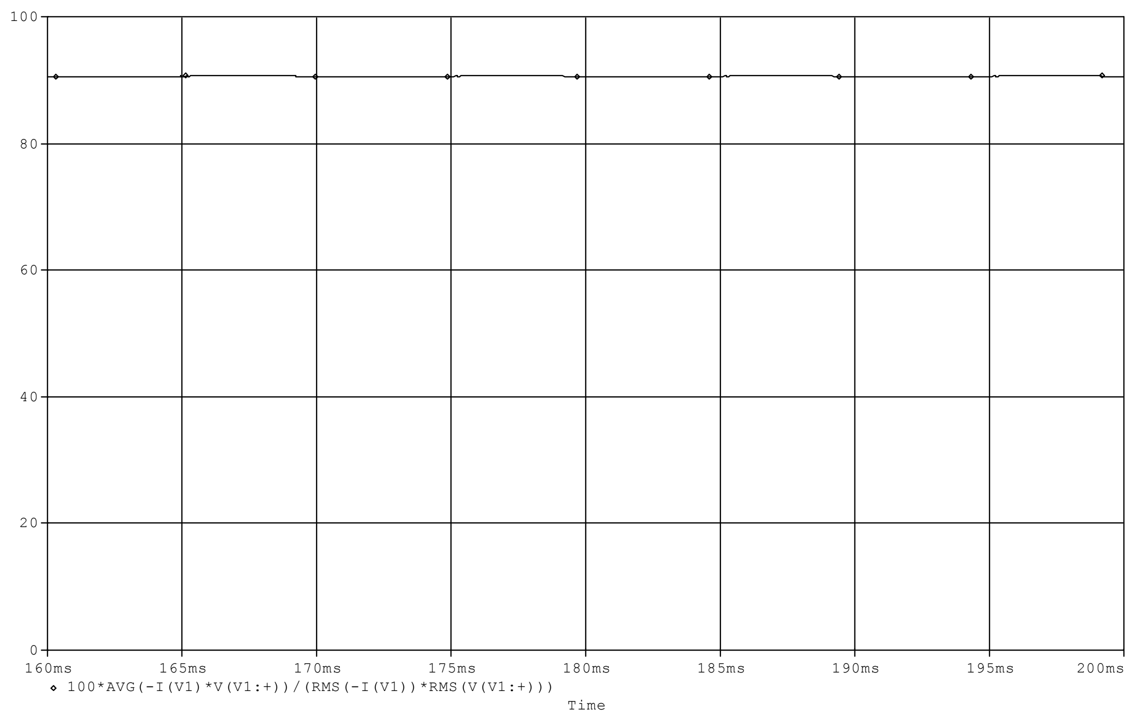


Figure 2.41: Power Factor of a buck-boost regulated three phase rectifier with output filter at D= 90%

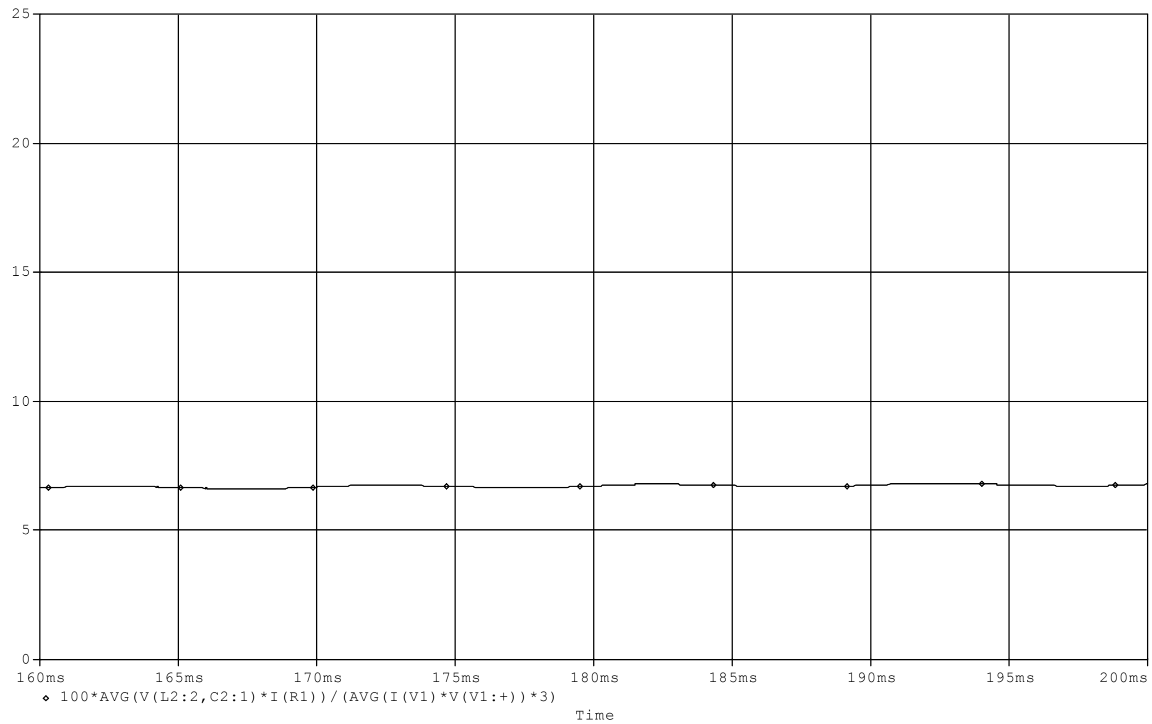


Figure 2.42: Efficiency of a buck-boost regulated three phase rectifier with output filter at D= 90%

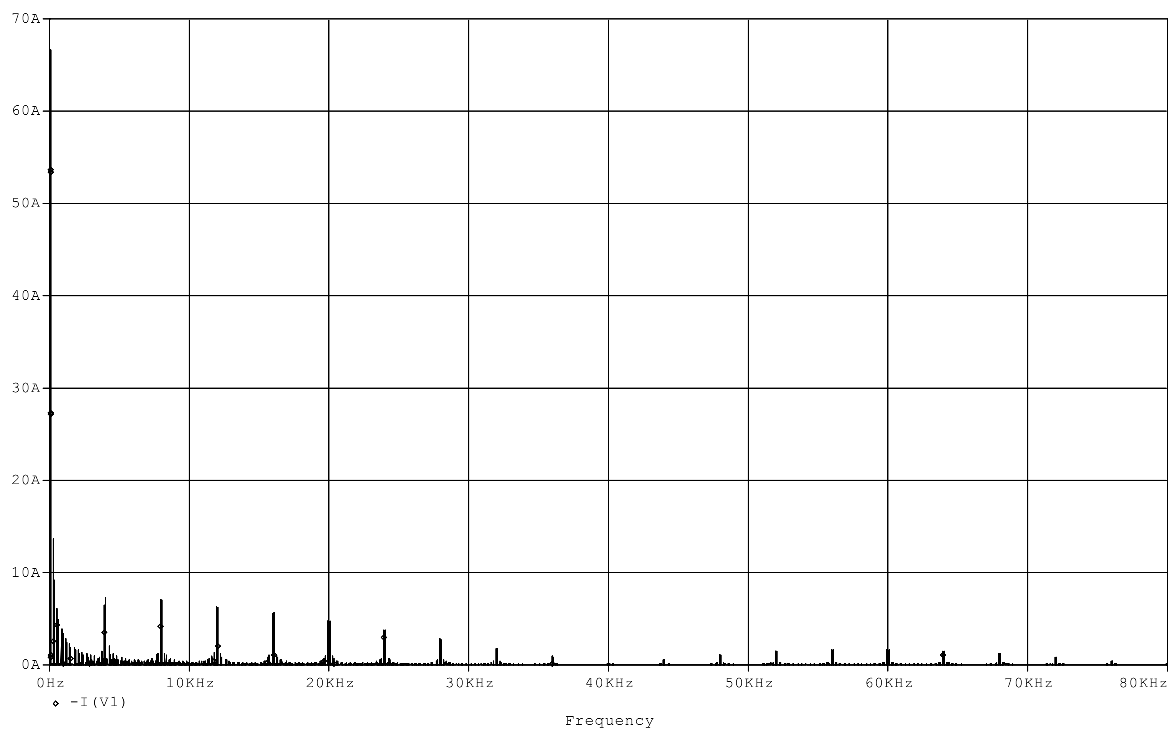


Figure 2.43: FFT of Input Current of a buck-boost regulated three phase rectifier with output filter at D= 90%

D	THD (%)	PF	I_{in}(rms) amp	V_{in}(rms)volt	V_{out}(dc) volt	I_{out}(dc) amp	Efficiency(η)%
10	2.000072E+02	22	0.4	212.13	55	1.1	93
20	1.083449E+02	40	1.25	212.13	120	2.5	96
30	1.082867E+02	50	2.85	212.13	210	4.2	96
40	8.612004E+01	57	5.8	212.13	325	6.5	95
50	8.565316E+01	65	12	212.13	485	9.75	94
60	6.502440E+01	72.5	24.5	212.13	725	14.5	90
70	5.787060E+01	80	42	212.13	850	17	65
80	3.486253E+01	85	47	212.13	636	12.75	30
90	3.558909E+01	90	52	212.13	332	6.65	07

TABLE 3: PERFORMANCE PARAMETER OF BUCK-BOOST RECTIFIER WITHOUT INPUT FILTER

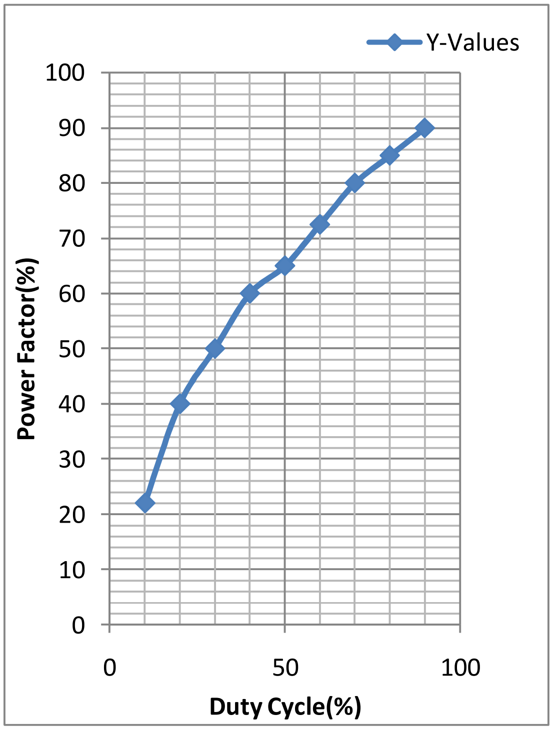


Figure2.44: Duty Cycle Vs Power Factor

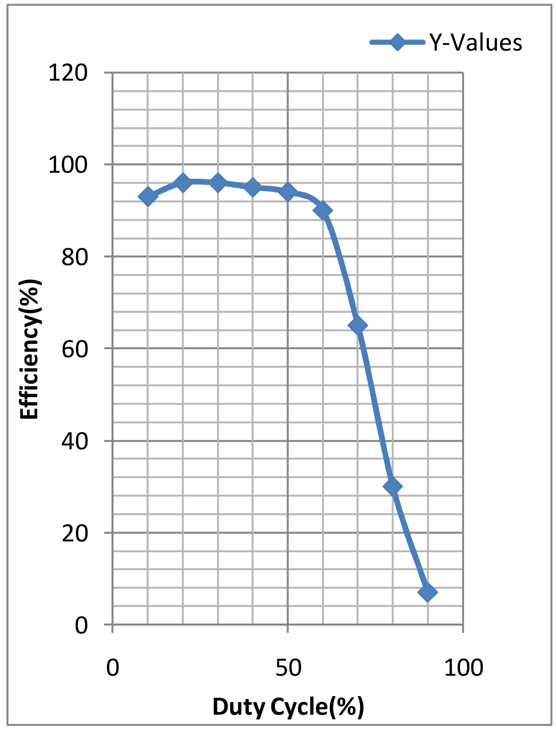


Figure 1.45: Duty Cycle Vs Efficiency

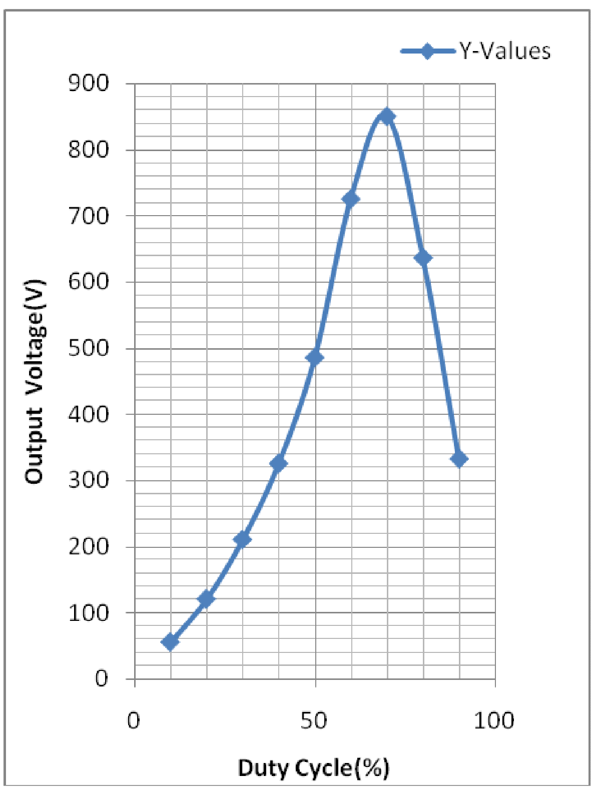


Figure 2.46: Duty Cycle Vs Output Voltage

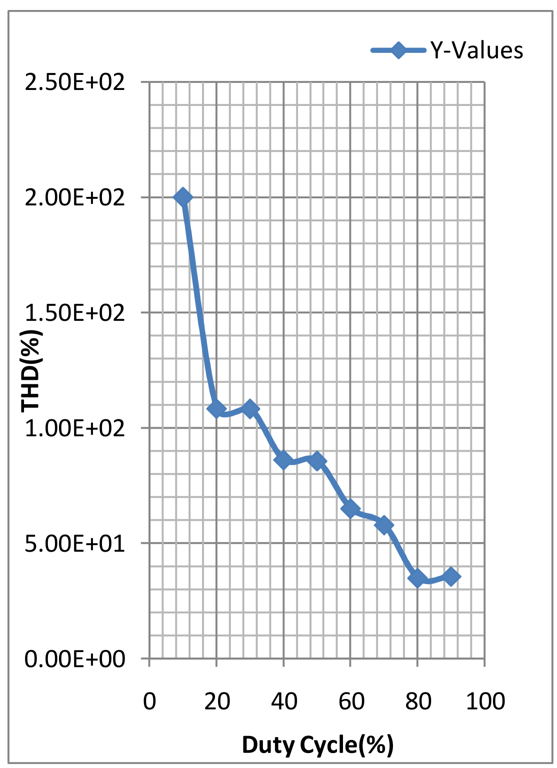


Figure2.47: Duty Cycle Vs THD(%)

2.2.3.3 Buck Boost Regulator with Input Filter and Constant Carrier Frequency

To improve the performance of switch mode rectifier with power factor correction, the quality of input current is an important parameter. To improve the input current quality the Buck-Boost rectifier is analyzed with passive input filter and output LC filter [Fig 2.48]. The analysis was done with input filter parameter L=10mh and C= 60 uF. The wave shape of the input current, output current, output voltage, FFT of input current, power factor, efficiency at all duty cycle (10% to 90%) is shown in Figure 2.49-2.72. The performance parameter of Buck-Boost regulated three phase rectifier with passive input filter is shown in Table 4. From the analysis it was found that the THD of the input current is remain within the IEEE standard at all duty cycle, except at 10% duty cycle. The entire even and odd harmonics component was eliminated. Output voltage varies from 65 V (at 10% duty cycle) to 800 V (at 70% duty cycle). But the power factor and efficiency are not good enough at all duty cycle. The power factor is very poor at low duty cycles and the efficiency is not satisfactory at maximum duty cycles. Our main concern is to improve the overall efficiency at regulated output voltage i.e. more than 80% efficiency at below and above the input voltage with tolerable THD is yet to be achieved. Results of Table 4 are graphically shown in Figures 2.73-2.76.

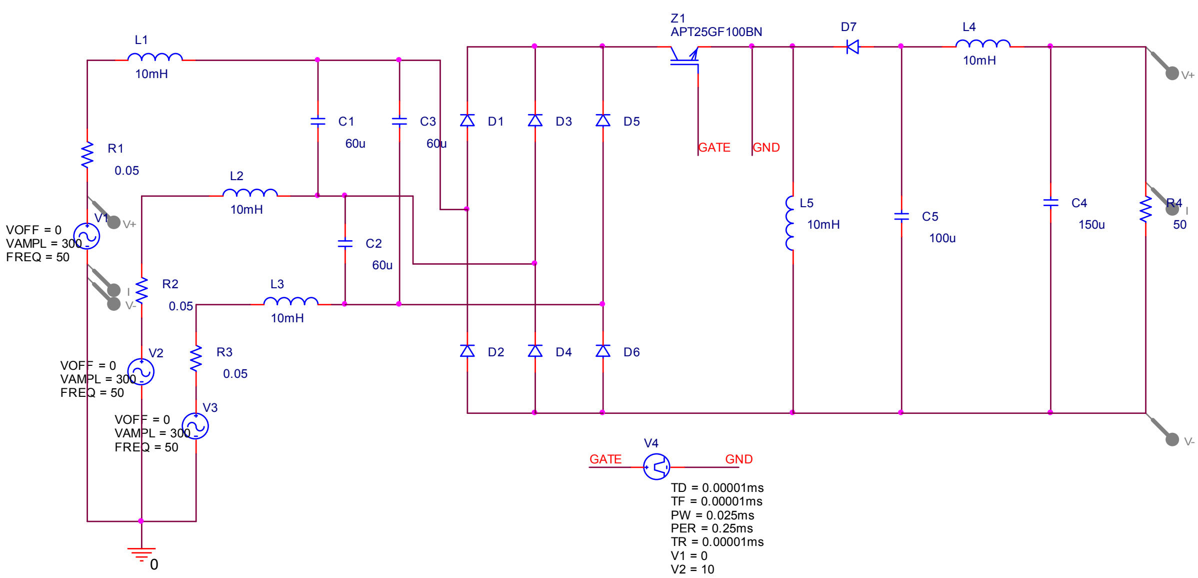


Figure 2.48: Circuit diagram of buck-boost regulated three phase rectifier with passive input filter (and output filter)

DUTY CYCLE= 10%

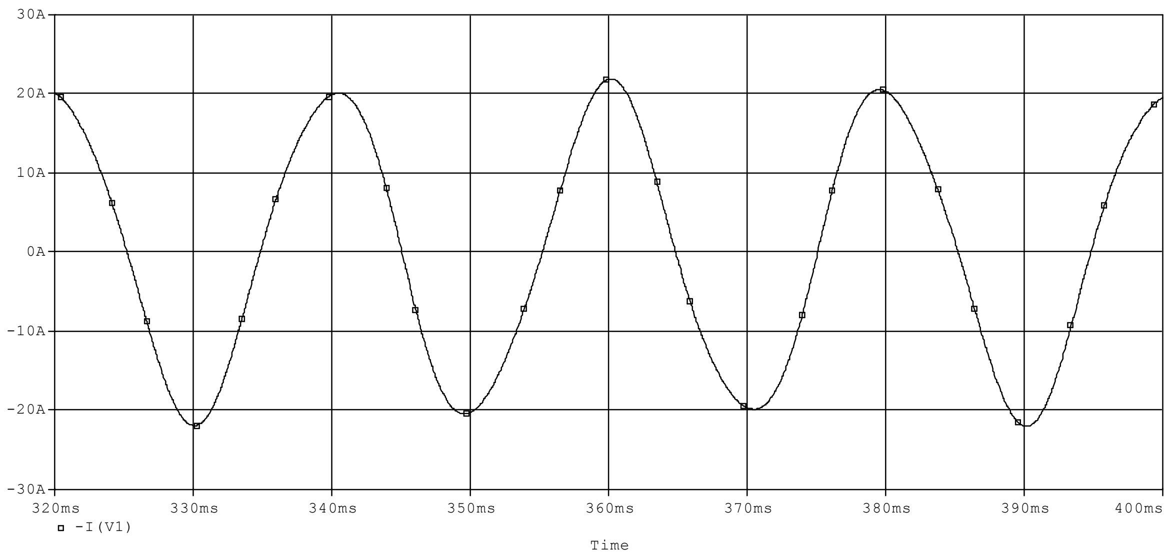


Figure 2.49: Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 10%

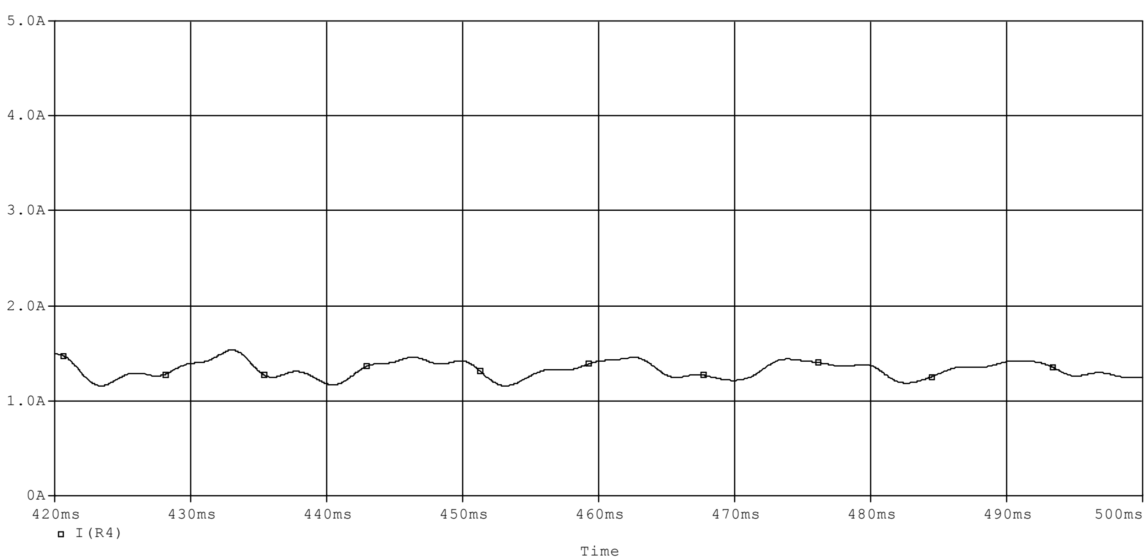


Figure 2.50: Output Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 10%

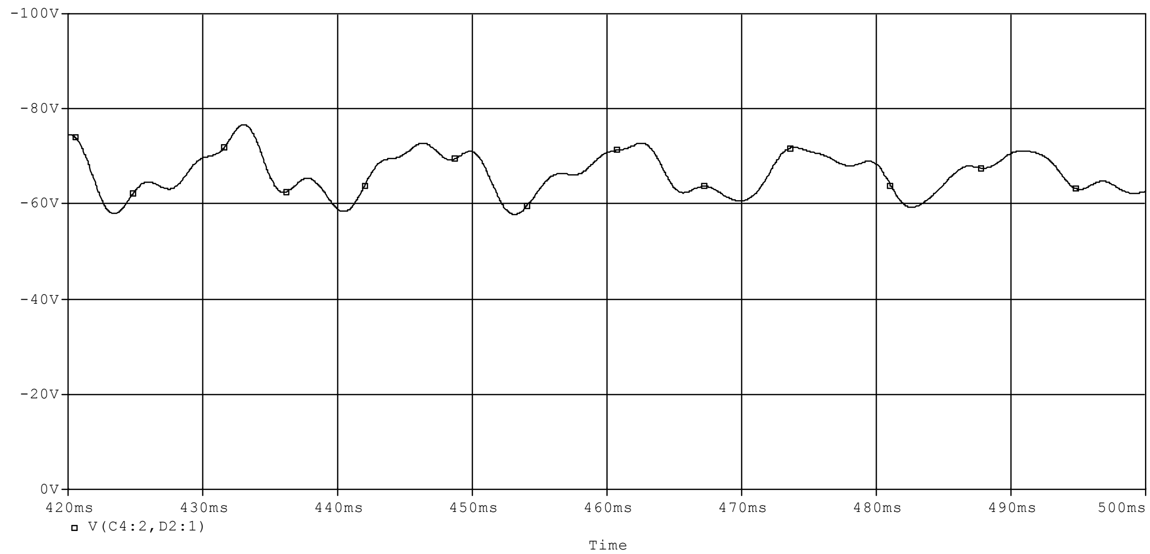


Figure 2.51: Output Voltage of a buck-boost regulated three phase rectifier with passive input & output filter at D= 10%

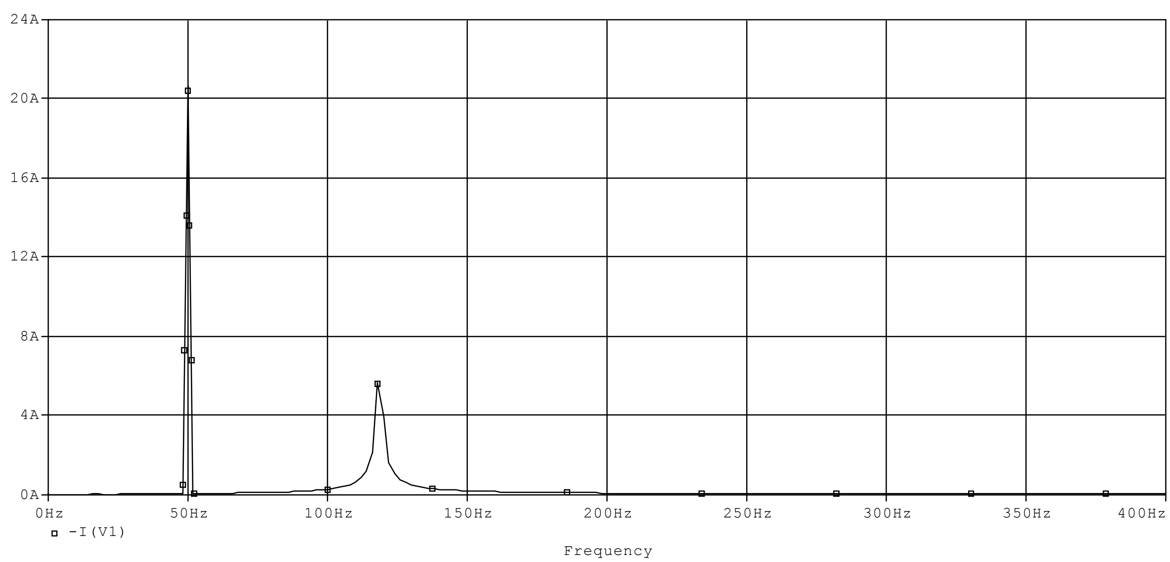


Figure 2.52: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D=10%

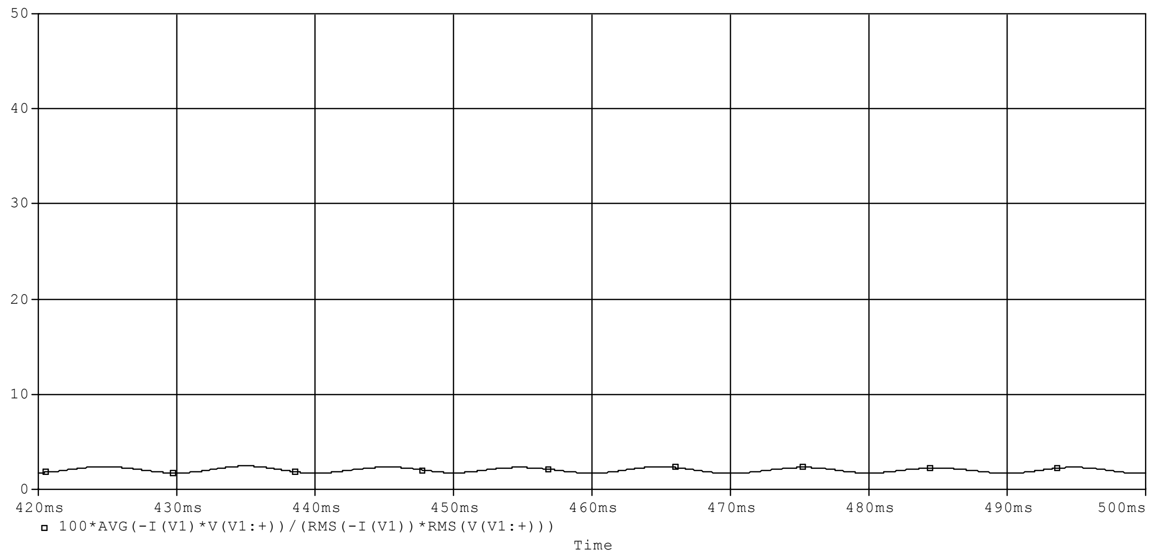


Figure 2.53: Power Factor of a buck-boost regulated three phase rectifier with passive input & output filter at D= 10%

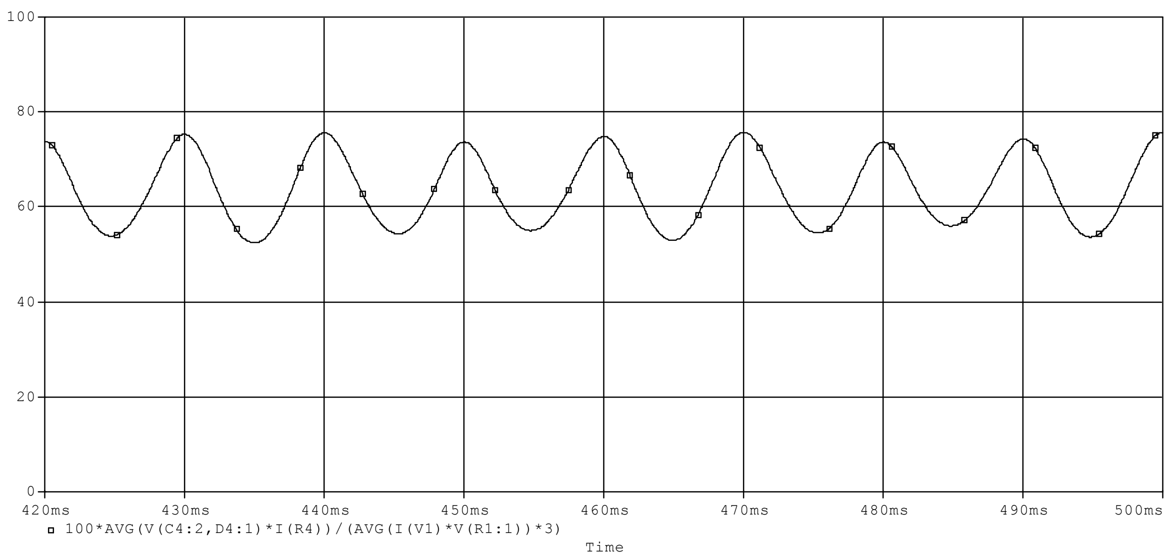


Figure 2.54: Efficiency of a buck-boost regulated three phase rectifier with passive input & output filter at D= 10%

DUTY CYCLE= 40%

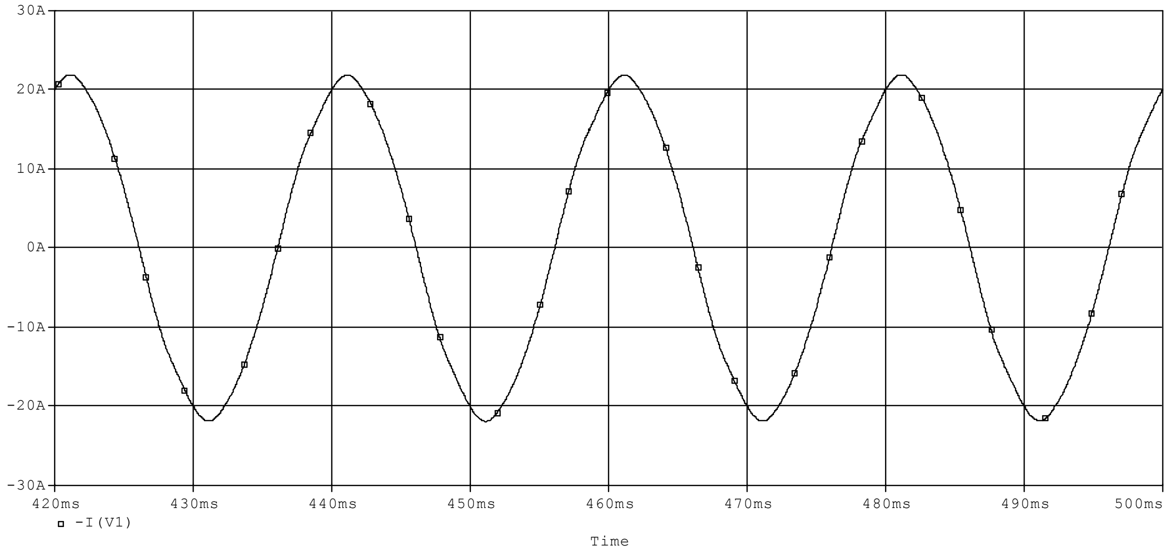


Figure 2.55: Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 40%

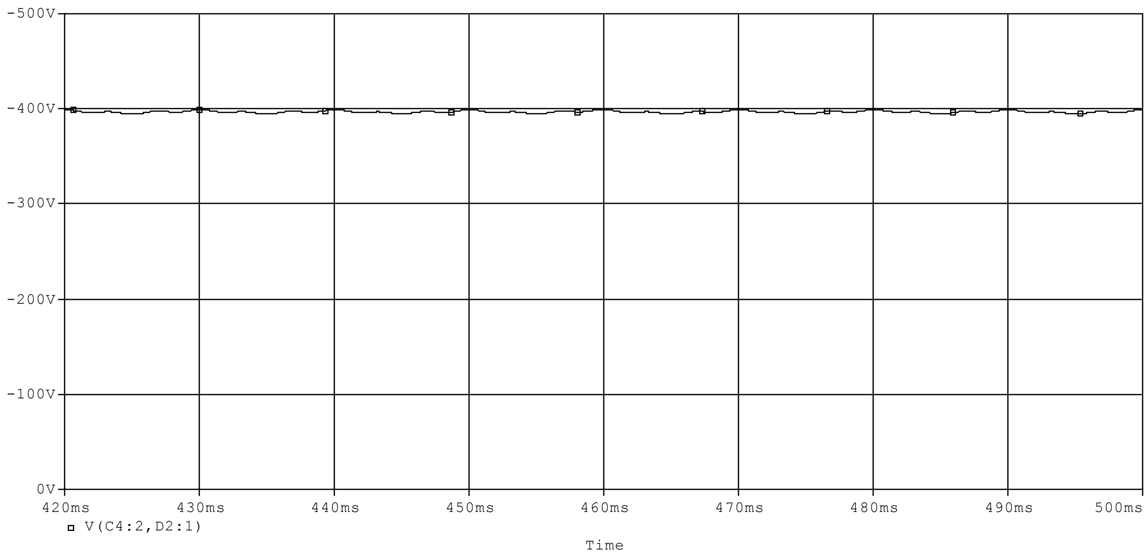


Figure 2.56: Output Voltage of a buck-boost regulated three phase rectifier with passive input & output filter at D= 40%

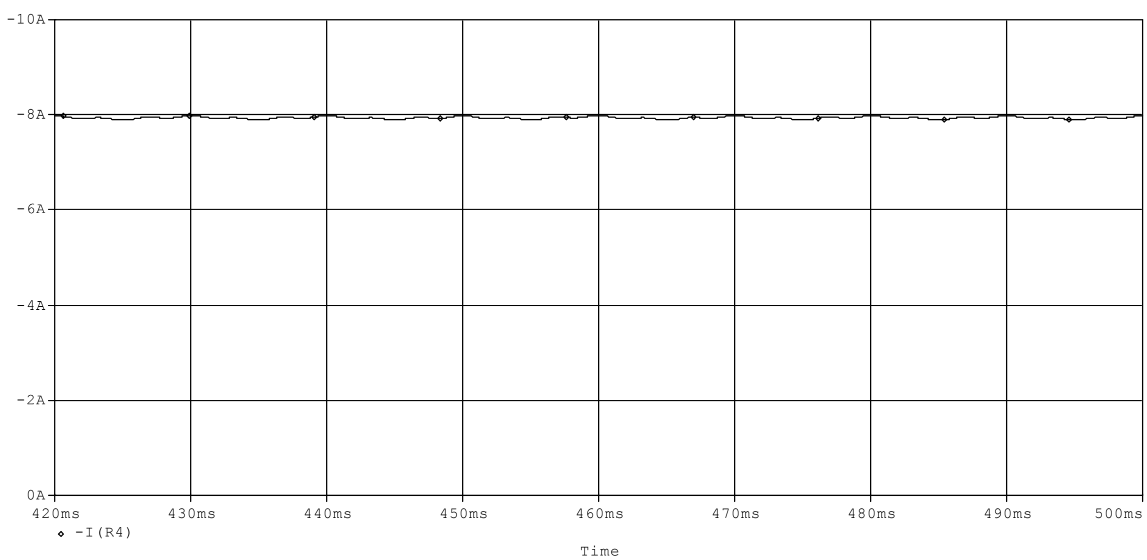


Figure 2.57: Output Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 40%

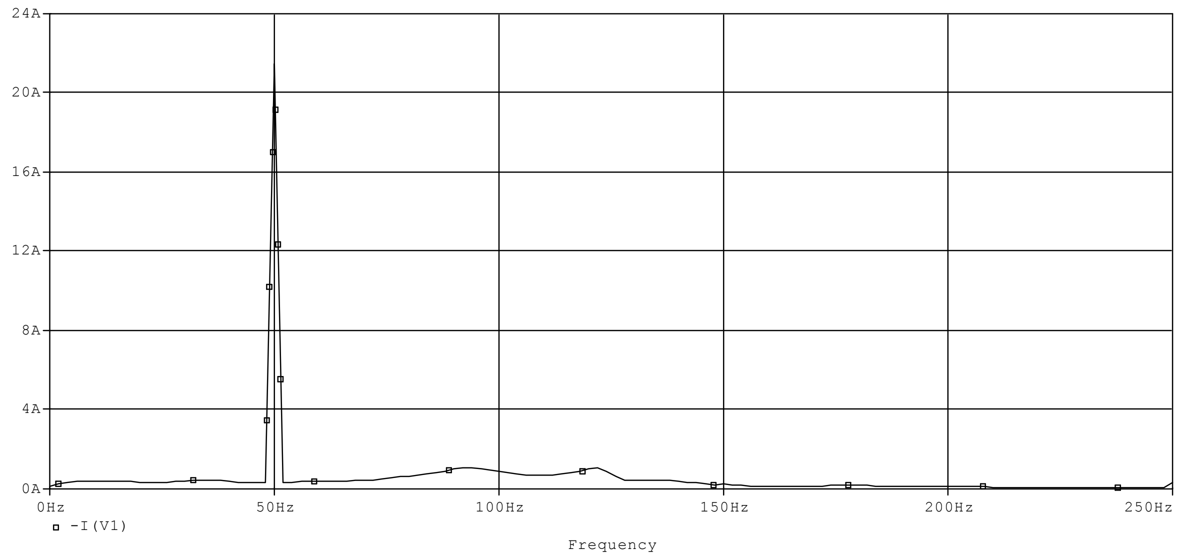


Figure 2.58: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 40%

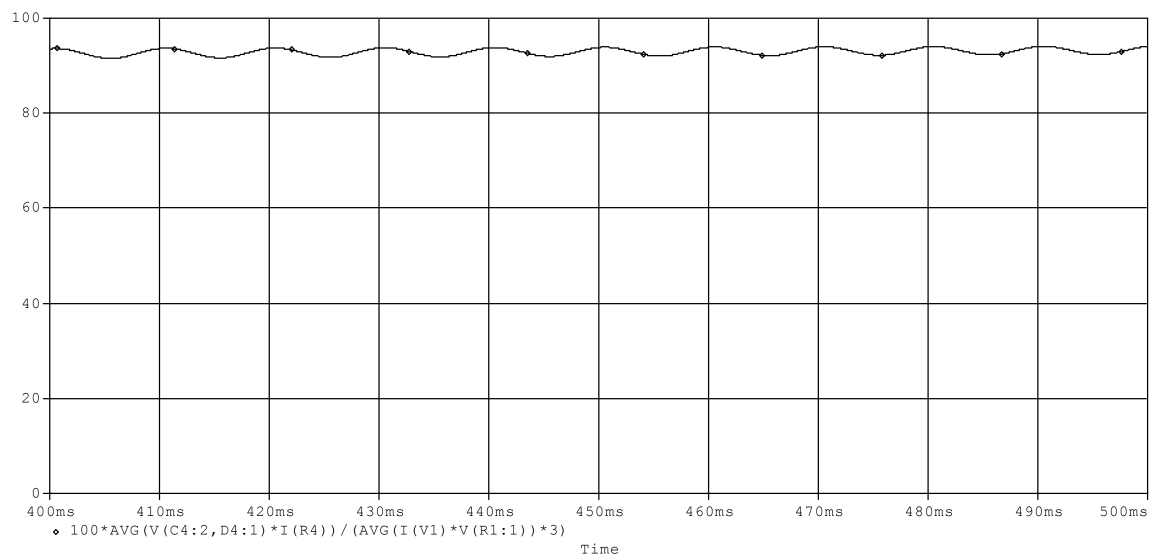


Figure 2.59: Efficiency of a buck-boost regulated three phase rectifier with passive input & output filter at D= 40%

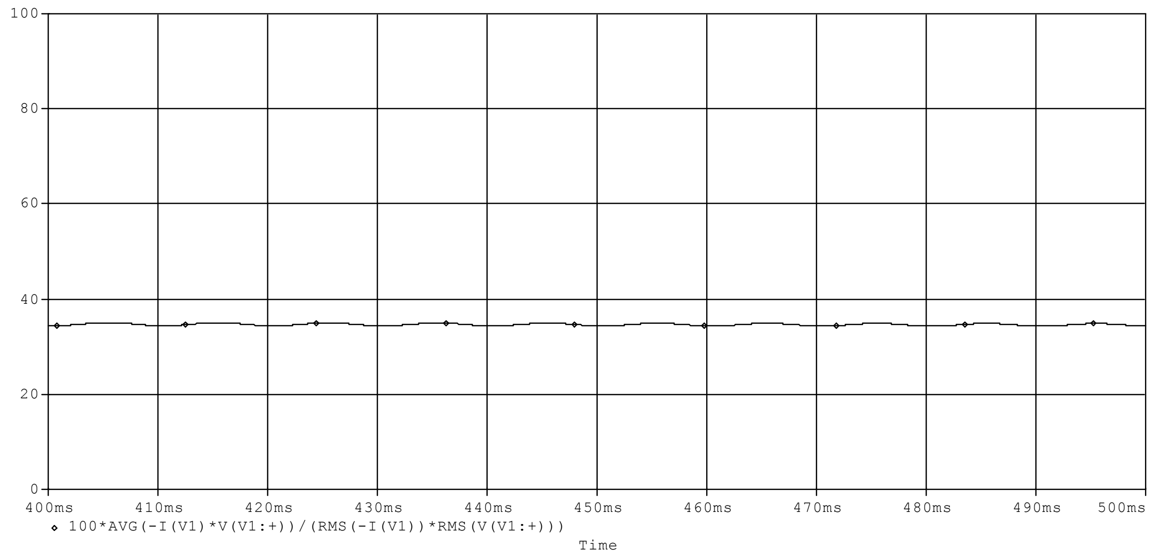


Figure 2.60: Power Factor of a buck-boost regulated three phase rectifier with passive input & output filter at D= 40%

DUTY CYCLE= 70%

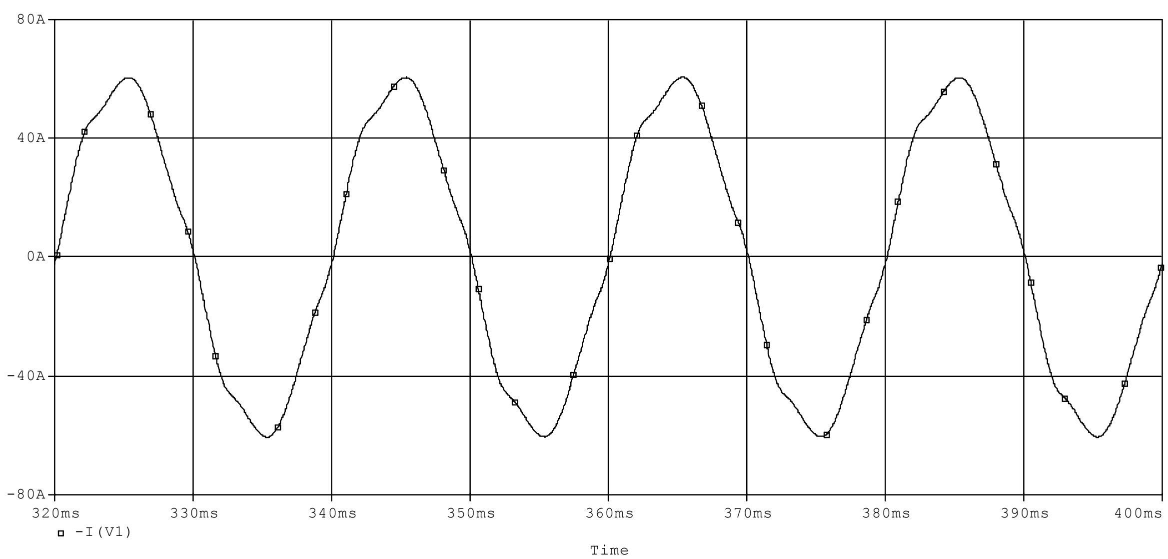


Figure 2.61: Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 70%

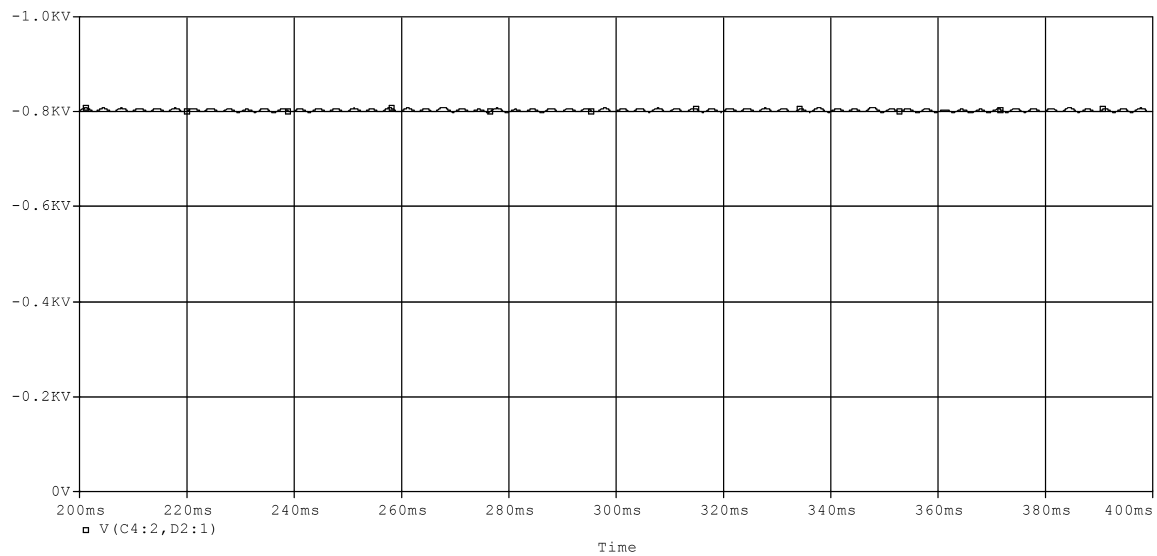


Figure2.62: Output Voltage of a buck-boost regulated three phase rectifier with passive input & output filter at D= 70%

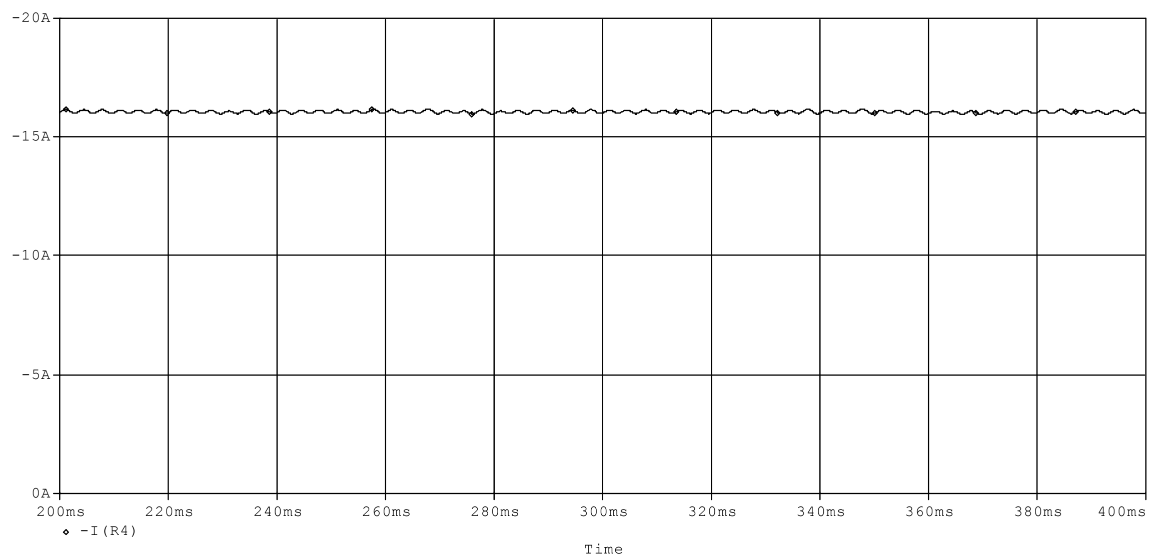


Figure2.63: Output Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 70%

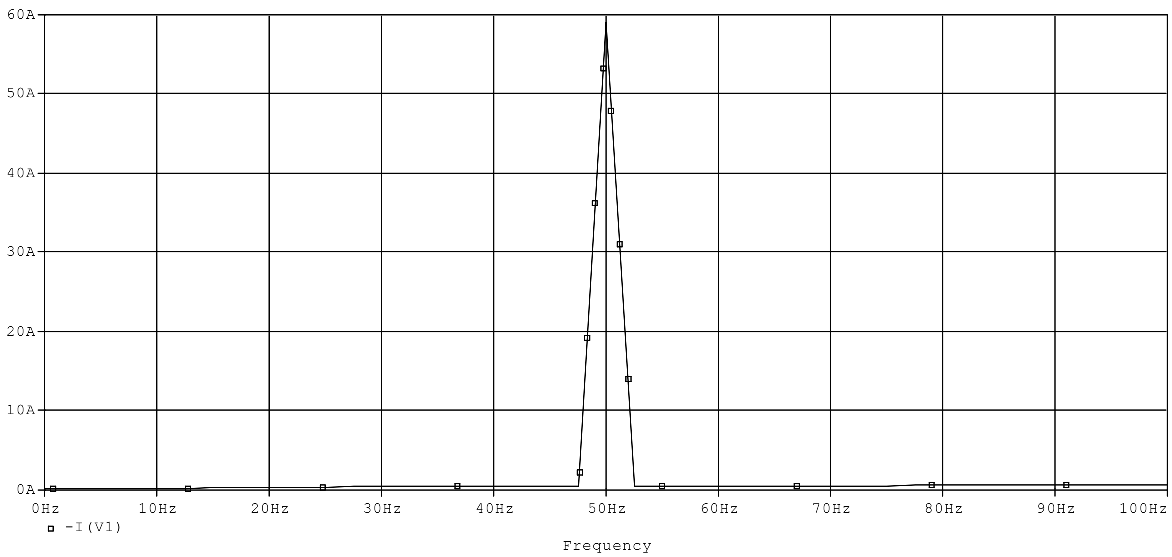


Figure2.64: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 70%

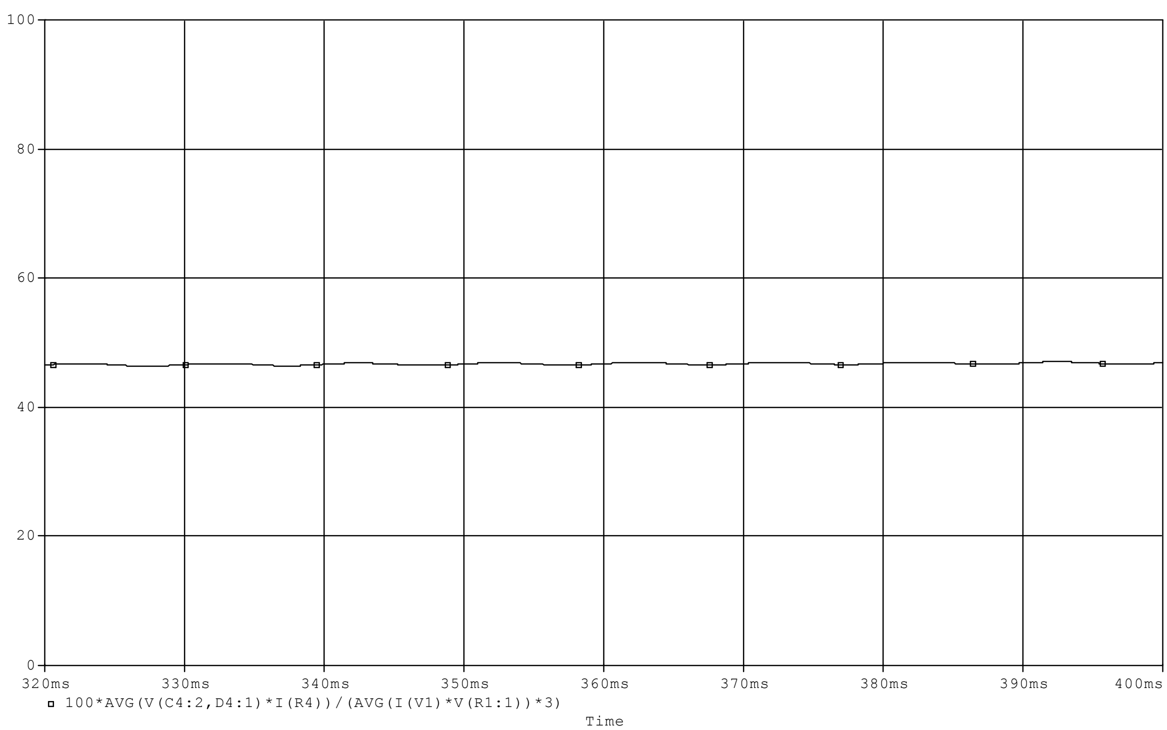


Figure2.65: Efficiency of a buck-boost regulated three phase rectifier with passive input & output filter at D= 70%

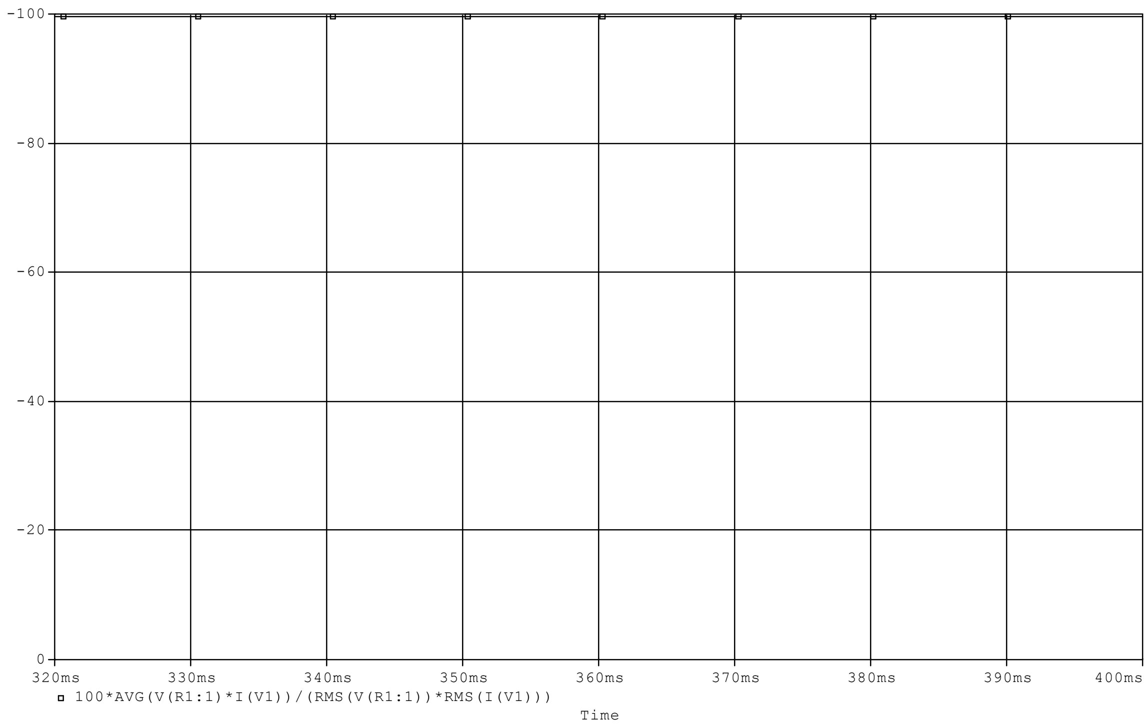


Figure2.66: Power Factor of a buck-boost regulated three phase rectifier with passive input & output filter at D= 70%

DUTY CYCLE= 90%

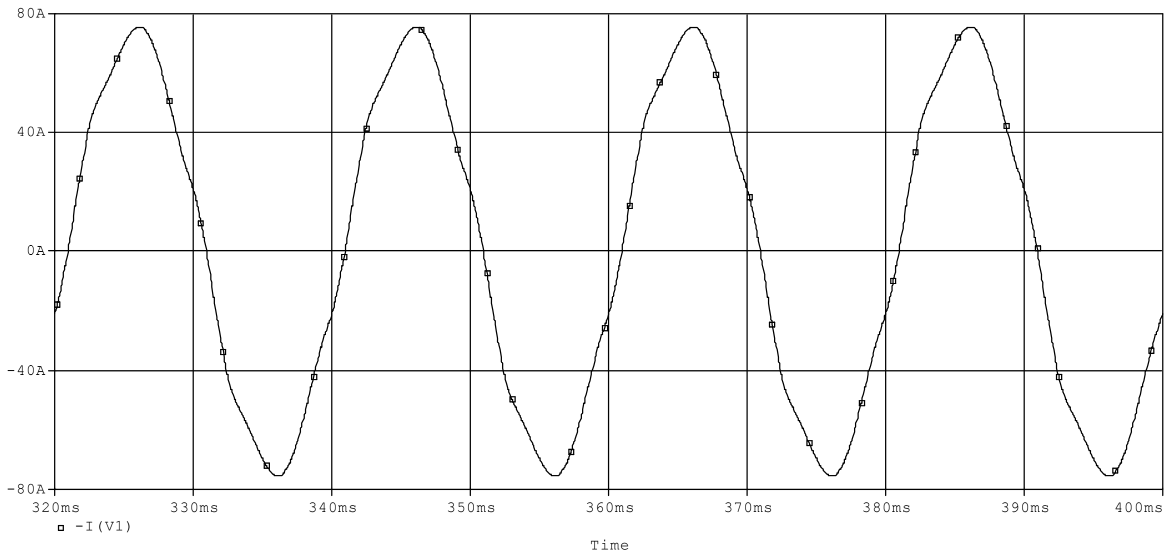


Figure 2.67: Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 90%

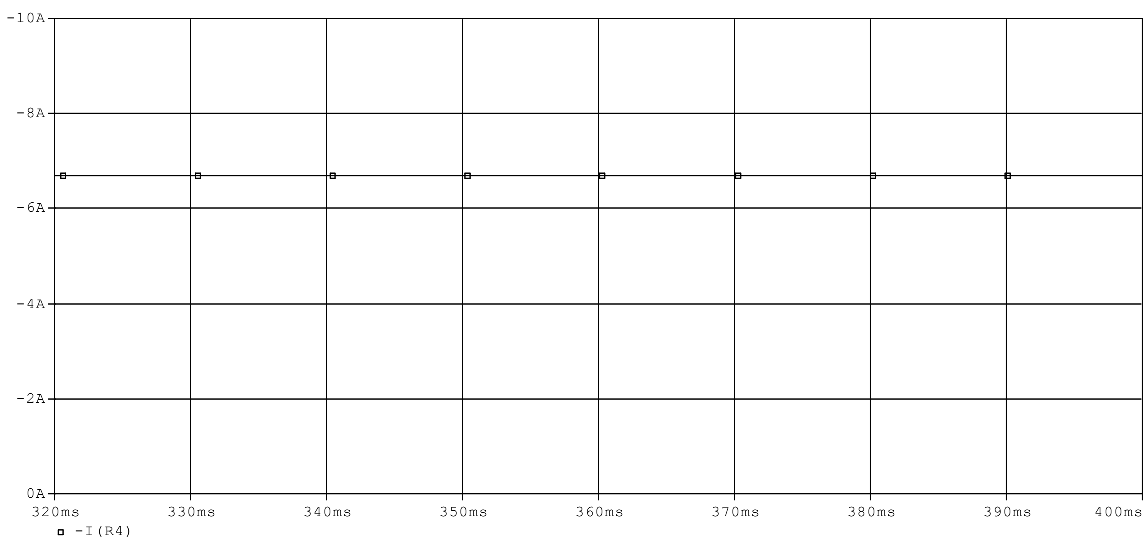


Figure 2.68: Output Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 90%

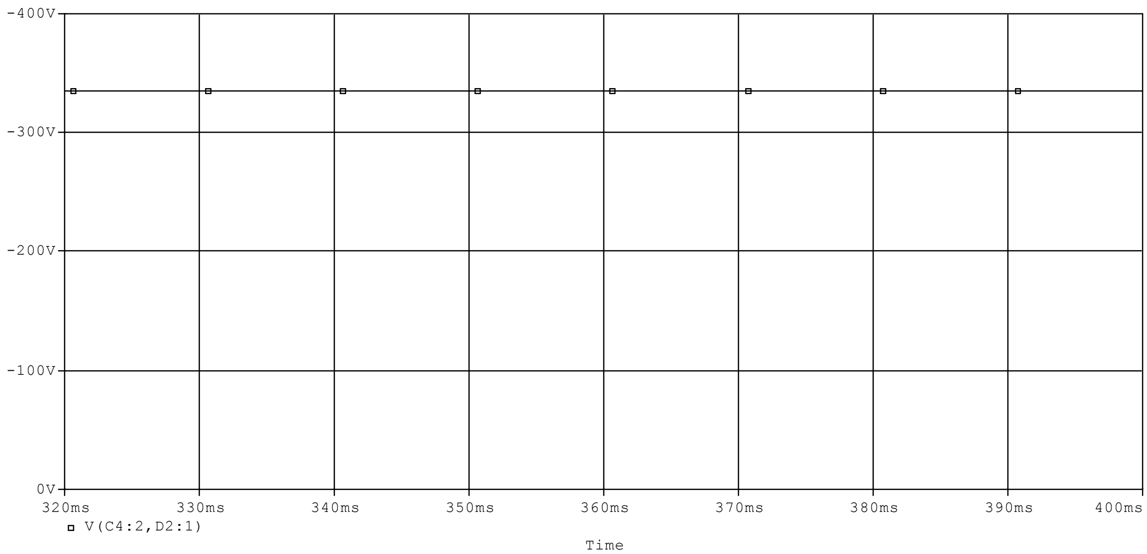


Figure 2.69: Output Voltage of a buck-boost regulated three phase rectifier with passive input & output filter at D= 90%

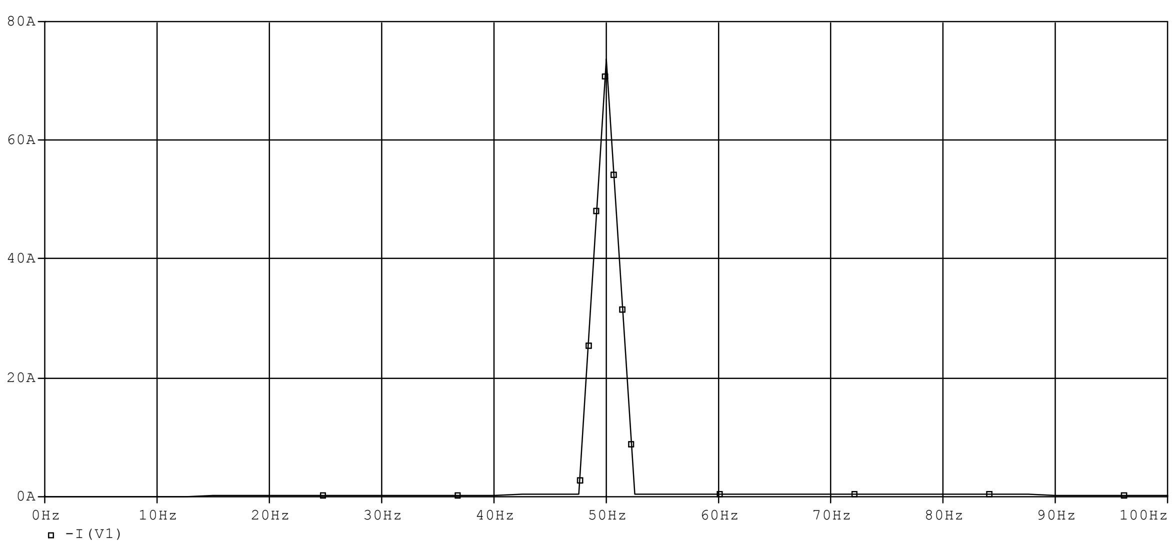


Figure 2.70: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input & output filter at D= 90%

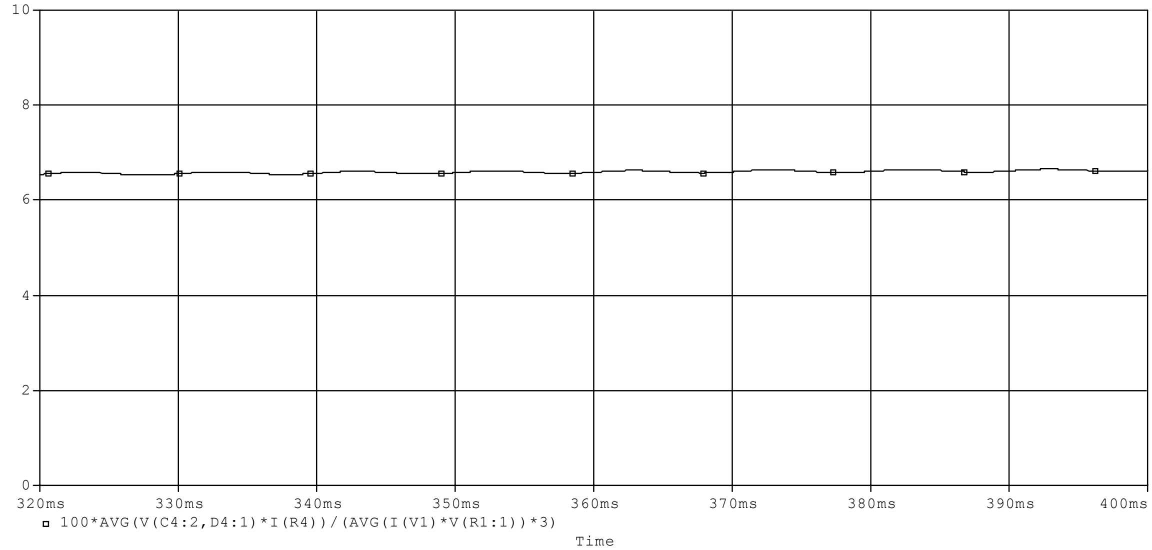


Figure 2.71: Efficiency of a buck-boost regulated three phase rectifier with passive input & output filter at D= 90%

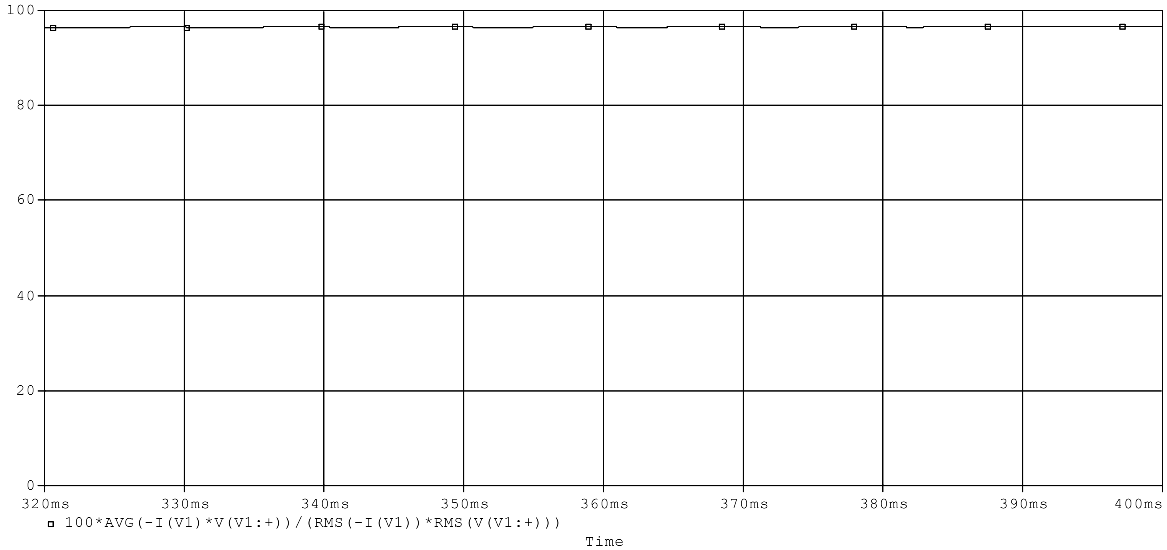
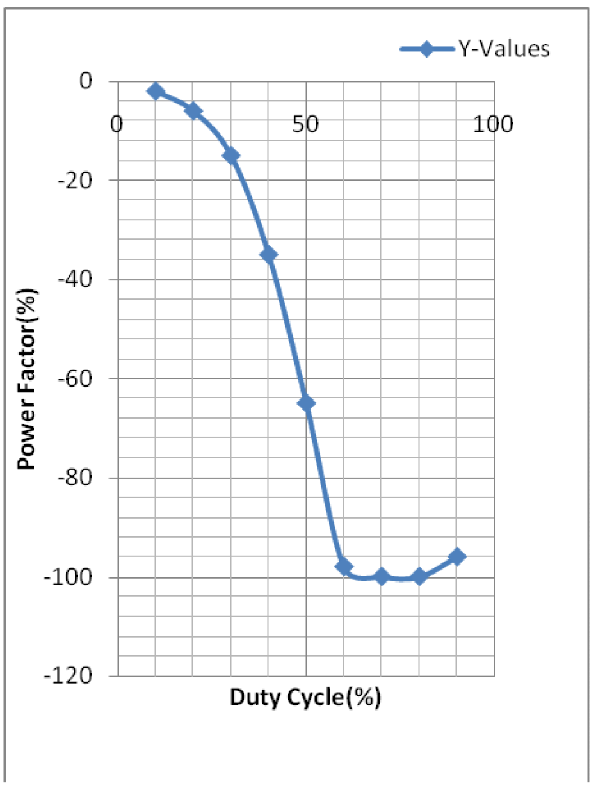


Figure 2.72: Power Factor of a buck-boost regulated three phase rectifier with passive input & output filter at D= 90%



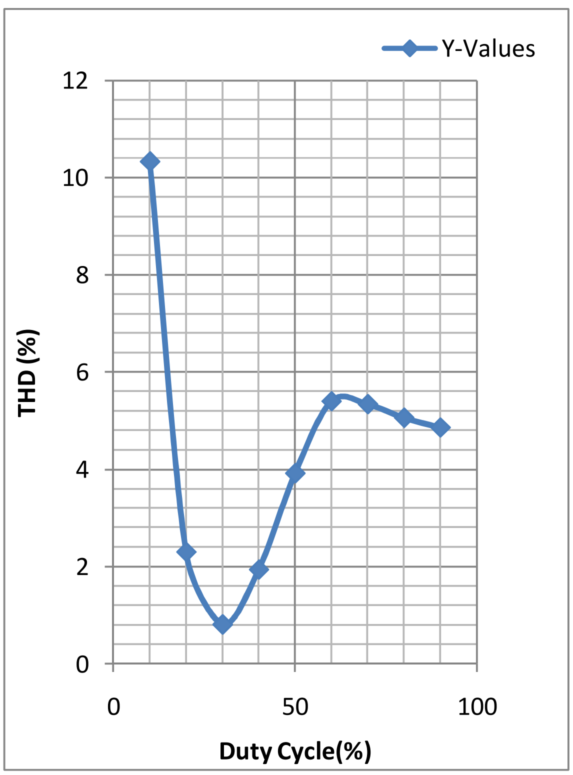
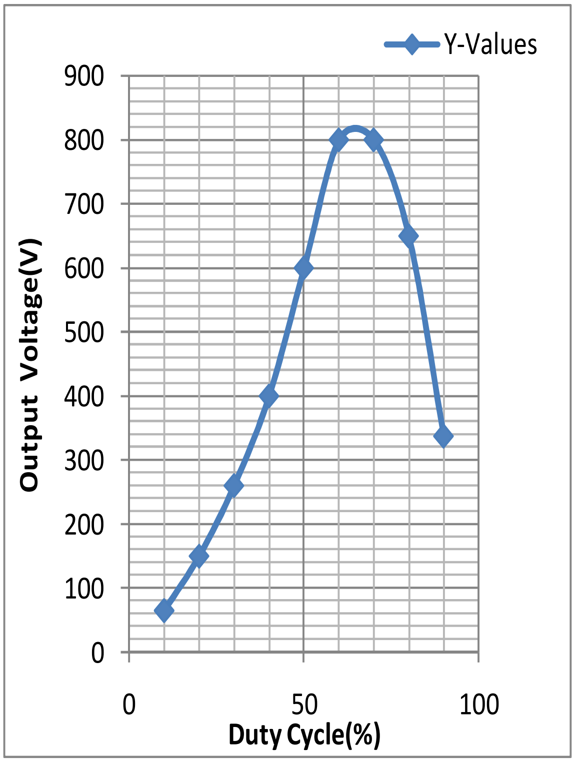


Figure2. 73: Duty Cycle Vs Power Factor

Figure 2.74: Duty Cycle Vs Efficiency



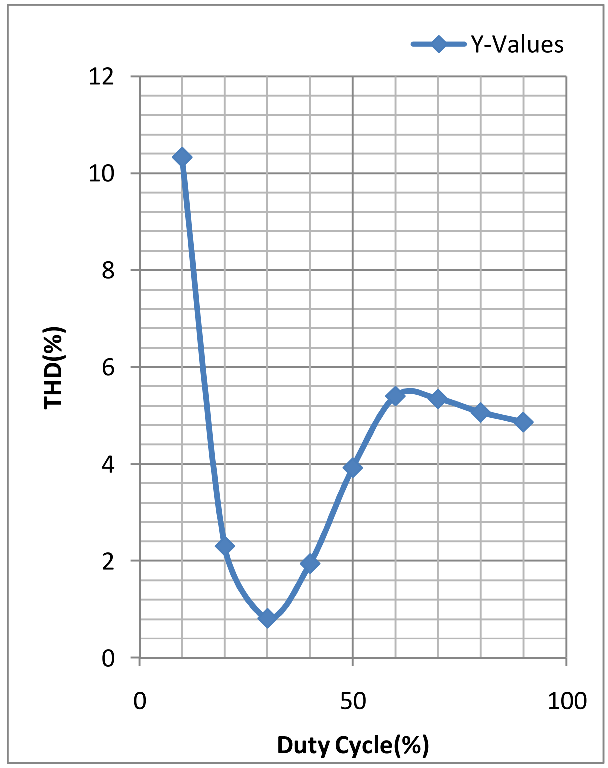


Figure 2.75: Duty Cycle Vs Output Voltage

Figure2.76: Duty Cycle Vs THD(%)

TABLE 4: PERFORMANCE PARAMETER OF BUCK-BOOST RECTIFIER WITH INPUT FILTER AND CONSTANT SWITCHING FREQUENCY

D	THD (%)	PF(%)	I_{in}(rms) amp	V_{in}(rms)volt	V_{out}(dc) volt	I_{out}(dc) amp	Efficiency(η)%
10	1.033098E+01	-02	15.5	212.12	65	1.3	70
20	2.299002E+00	-06	15	212.12	150	3	80
30	8.114441E-01	-15	15	212.12	260	5.2	90
40	1.938710E+00	-35	15.55	212.12	400	8	93
50	3.918602E+00	-65	18.75	212.12	600	12	90
60	5.400664E+00	-98	37	212.12	800	16	55
70	5.339146E+00	-100	42	212.12	800	16	47
80	5.060963E+00	-100	46	212.12	650	13	27
90	4.864253E+00	-96	52	212.12	337.5	6.75	6.5

2.2.3.4 Buck Boost Regulator with Input Filter and Variable Carrier Frequency

From our previous discussion it is clear that by introducing passive filter at the input side of a three phase buck-boost regulator, the input current shape can be improved. But the efficiency was not satisfactory at all cases. A new topology is introduced here to improve the efficiency. A mixed passive filter is applied here. A lift circuit is also introduced in between the load and the regulator. So, the output voltage is not negative any more. The most important factor is that the switching frequency is not maintained constant here. The switching frequency is varied from 1.43 kHz to 6.66 kHz (for 10% duty cycle to 60% duty cycle). The wave shapes of input current, output current, output voltage, FFT of input current, power factor and efficiency are shown in Figure 2.78 to 2.95. The performance parameter is shown in Table 5. We found that, the out voltage can be varied from 180V (below the input voltage) to 800V (more that input voltage). So, one of our primary goal is achieved here. Again, the efficiency remains over 80% at all cases, which was the most important improvement. The THD remains below 7%. In this analysis, we didn't go for all duty cycle, because it wasn't necessary as we can regulate the output voltage from below the input voltage to above the output voltage by varying the duty cycle from 10% to 60%. The THD, efficiency, power factor and output voltage are plotted with respect to duty cycle in figure 2.96 to 2.99. The circuit diagram is shown in figure 2.77.

SNUBBER CIRCUIT

Power semiconductors are the heart of power electronics equipment. Snubbers are circuits which are placed across semiconductor devices for protection and to improve performance. Snubbers can do many things:

- Reduce or eliminate voltage or current spikes·
- Limit dI/dt or dV/dt
- Shape the load line to keep it within the safe operating area (SOA)·
- Transfer power dissipation from the switch to a resistor or a useful load·
- Reduce total losses due to switching·
- Reduce EMI by damping voltage and current ringing

There are many different kinds of snubbers but the two most common ones are the resistor-capacitor (RC) damping network and the resistor-capacitor-diode (RCD) turn-off snubber. In the proposed Buck-Boost regulator, resistor-capacitor damping network is used.

OPERATION OF THE PROPOSED CIRCUIT

The operation of the proposed circuit can be explained simply. When the IGBT is in on state, current flows through L1. Another part of the current flows through load and the capacitor C5. So the load gets positive current. When the IGBT is in off state, the L1 inductor current freewheels through diode D2. The charged capacitor C6 discharges through the load. So the voltage across the load is always positive. IGBT is used here as a switching device instead of MOSFET because of its high voltage rating.

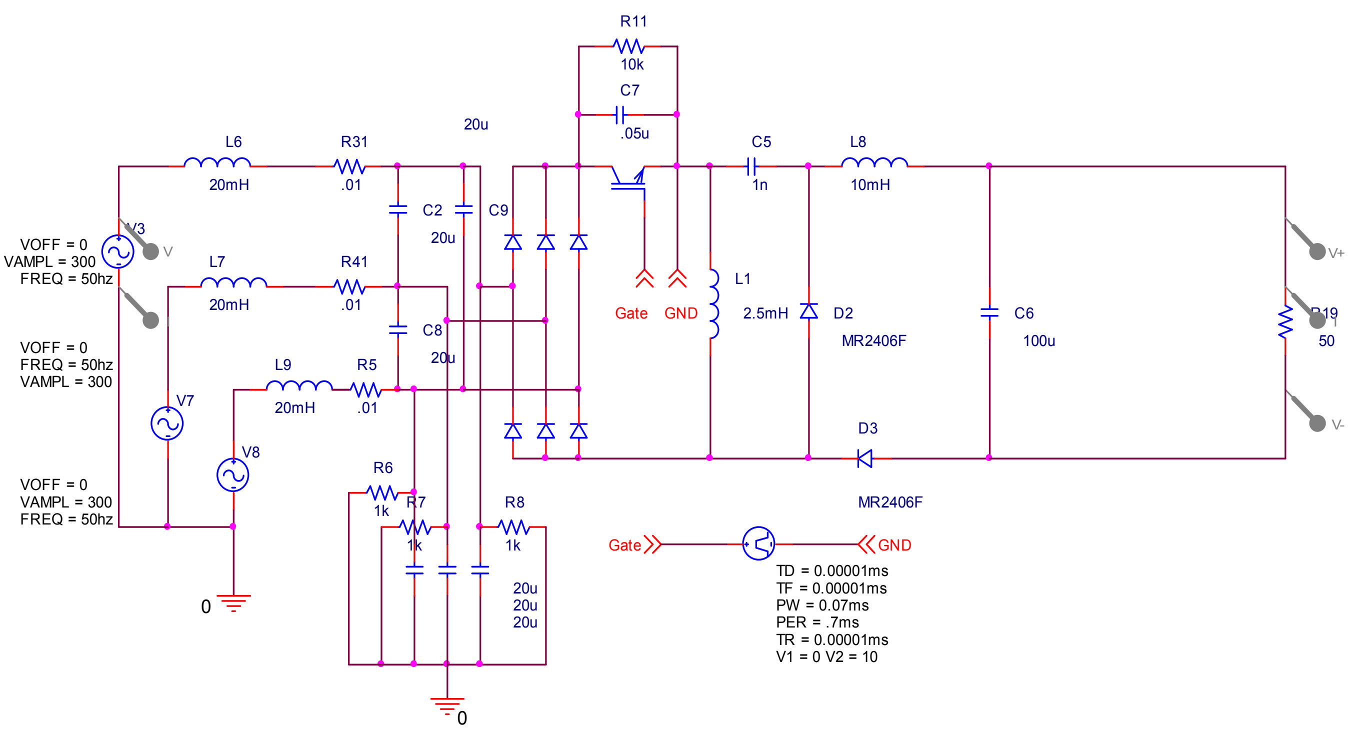


Figure 2.77: Circuit diagram of three phase buck-boost rectifier with passive input filter and variable carrier frequency

DUTY CYCLE = 10%

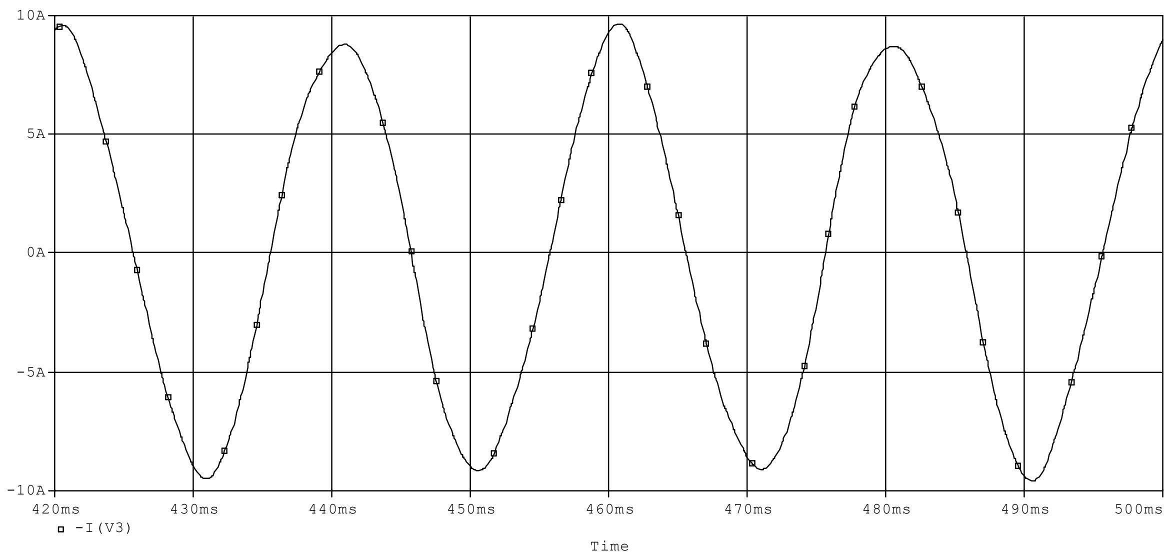


Figure 2.78: Input Current of a buck-boost regulated three phase rectifier with passive input filter

(Carrier frequency =1.43 kHz, Duty Cycle = 10%)

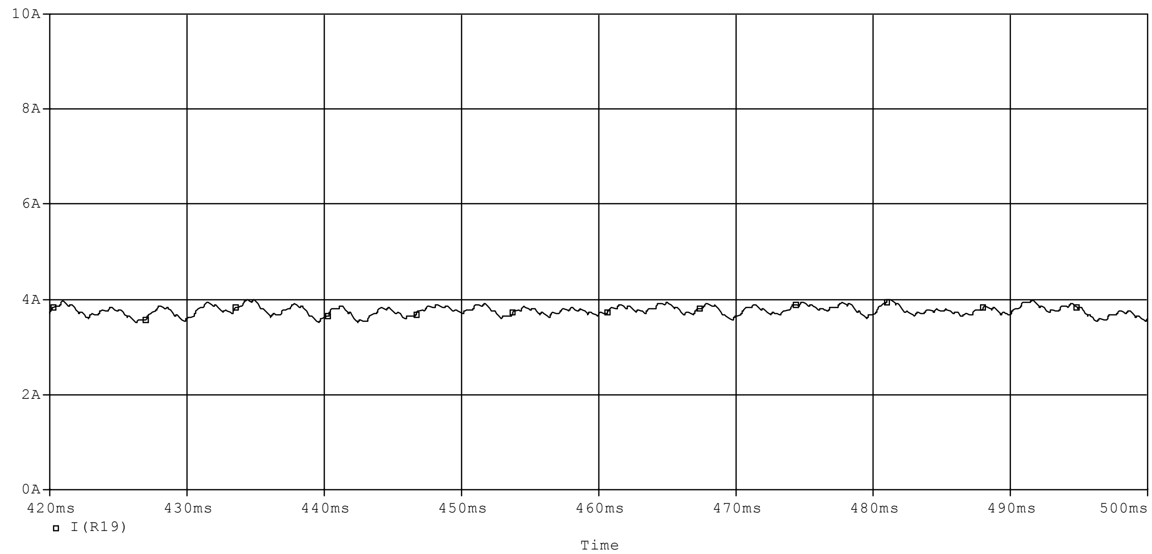


Figure 2.79: Output Current of a buck-boost regulated three phase rectifier with passive input filter

(Carrier frequency =1.43 kHz, Duty Cycle = 10%)

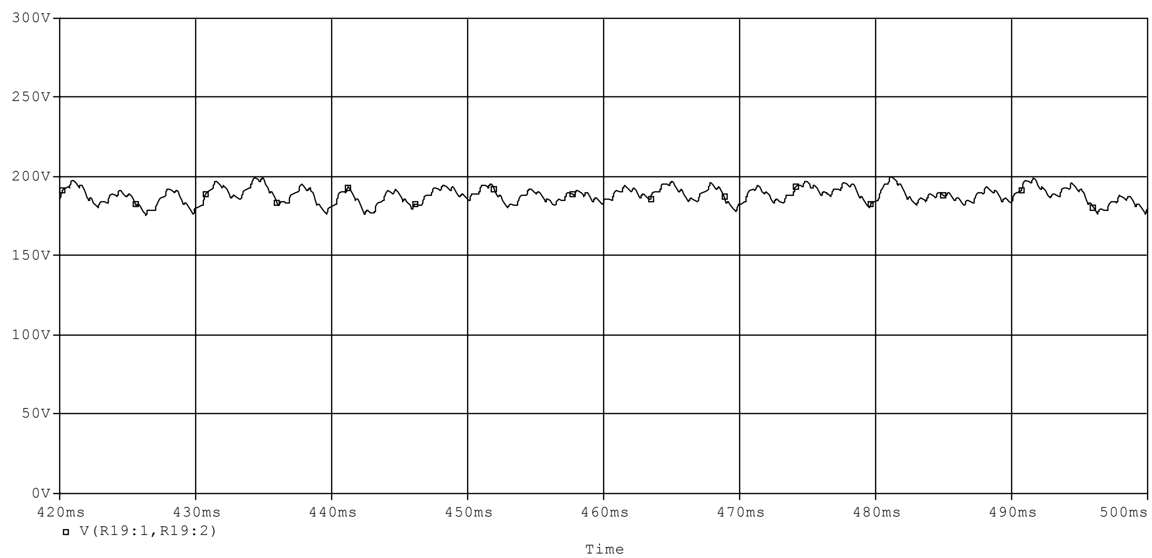


Figure 2.80: Output Voltage of a buck-boost regulated three phase rectifier with passive input filter

(Carrier frequency =1.43 kHz, Duty Cycle = 10%)

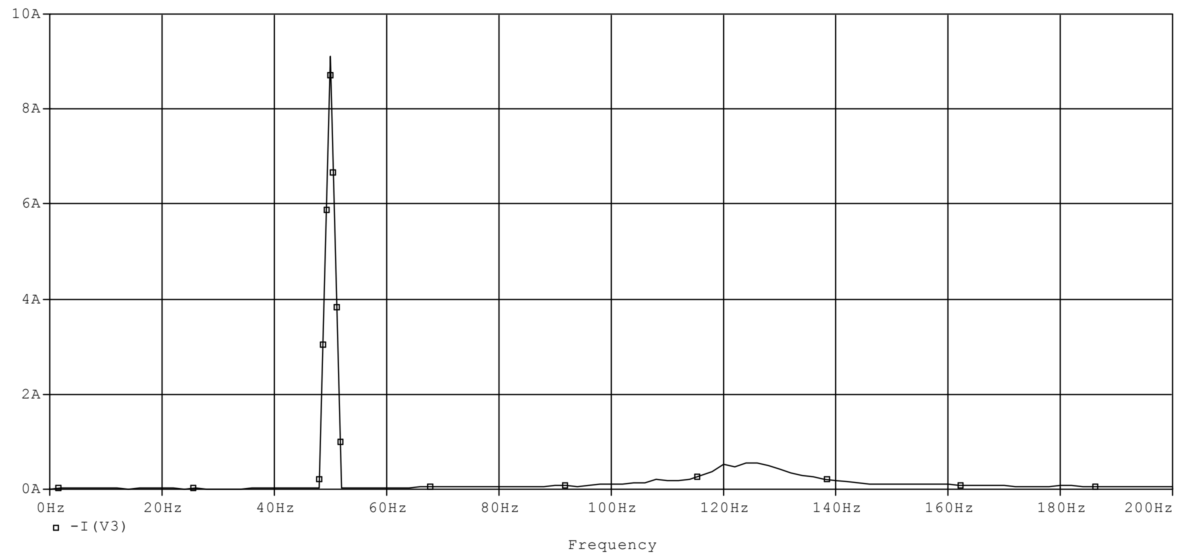


Figure 2.81: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =1.43 kHz, Duty Cycle = 10%)

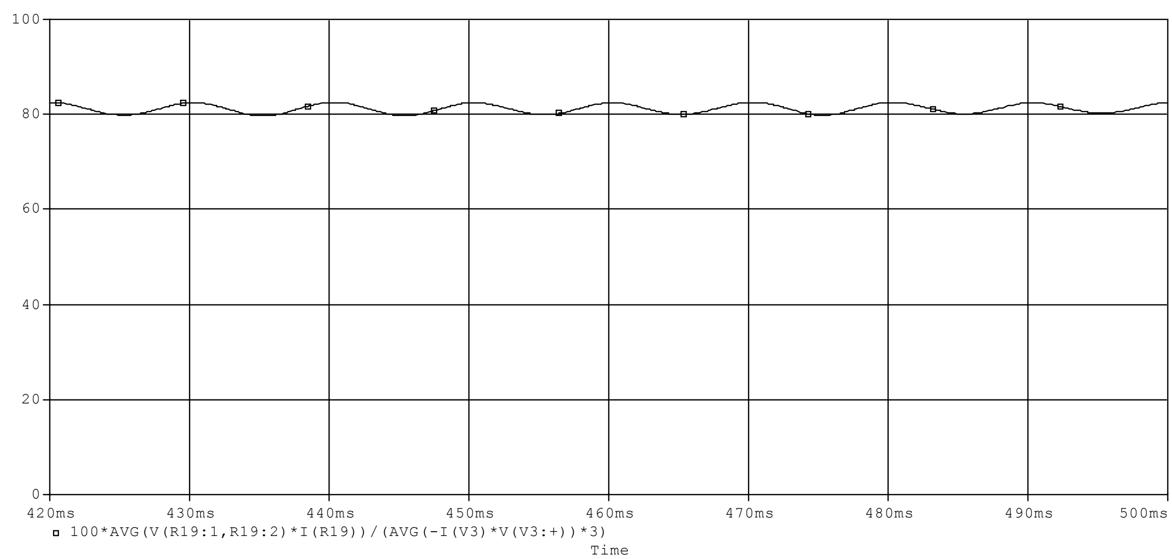


Figure 2.82: Efficiency of a buck-boost regulated three phase rectifier with passive input filter

(Carrier frequency =1.43 kHz, Duty Cycle = 10%)

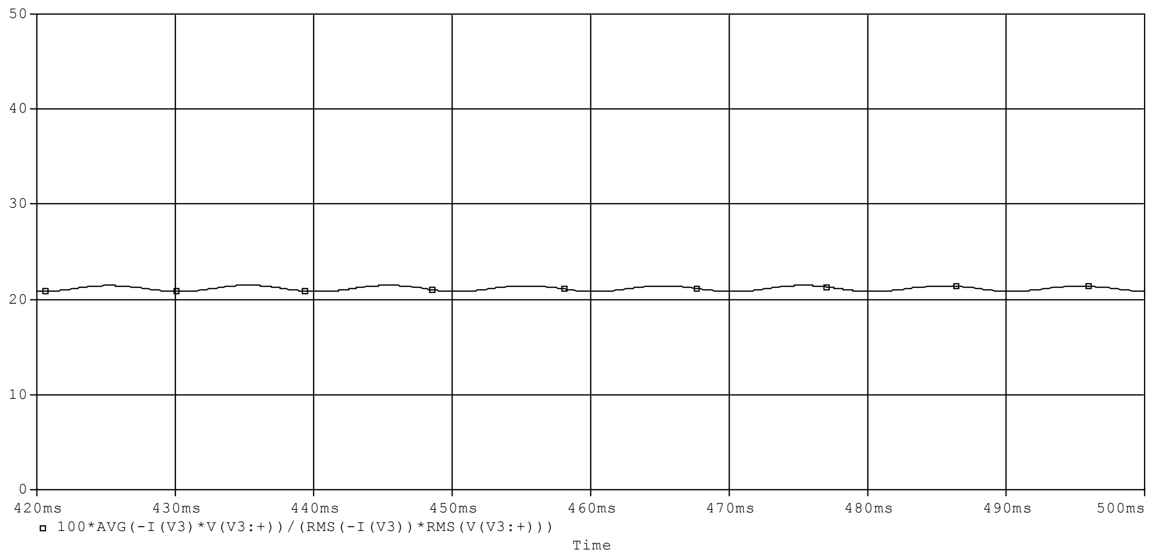


Figure 2.83: Power Factor of a buck-boost regulated three phase rectifier with passive input filter

(Carrier frequency =1.43 kHz, Duty Cycle = 10%)

DUTY CYCLE = 40%

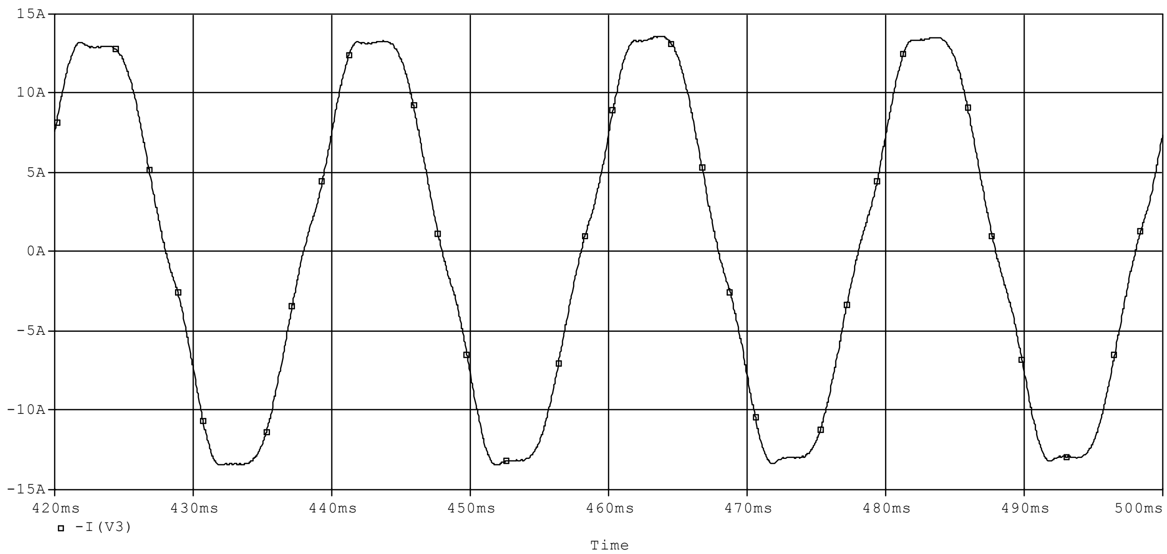


Figure 2.84: Input Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =2.86 kHz, Duty Cycle = 40%)

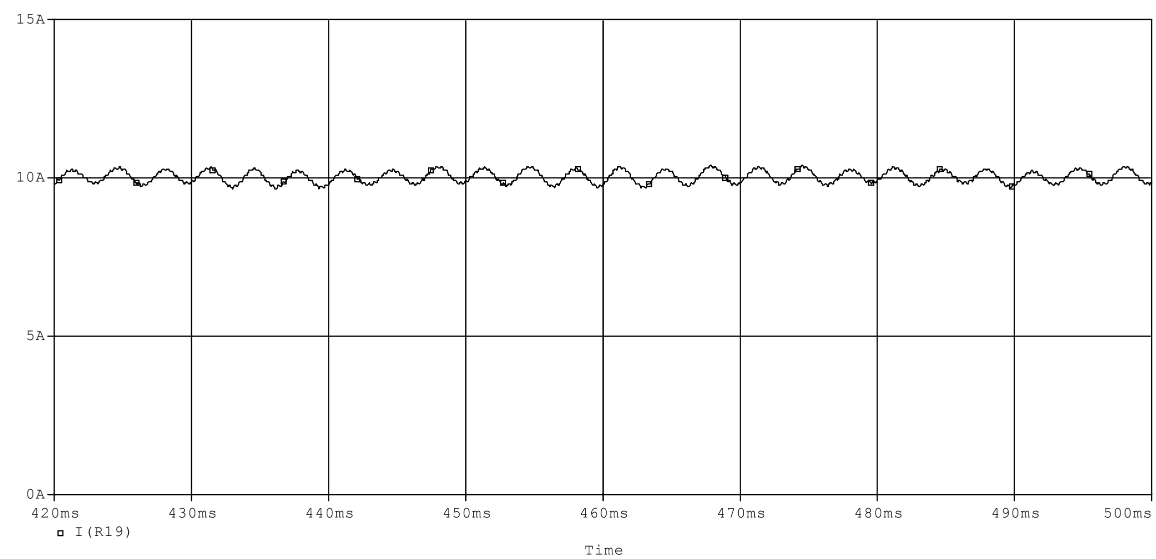


Figure 2.85: Output Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =2.86 kHz, Duty Cycle = 40%)

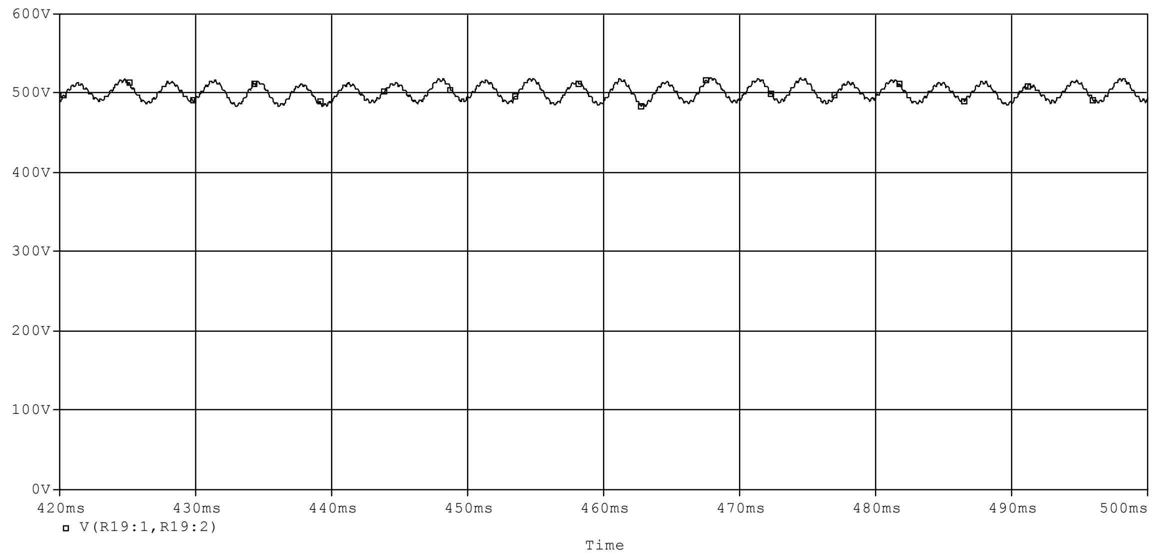


Figure 2.86: Output Voltage of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =2.86 kHz, Duty Cycle = 40%)

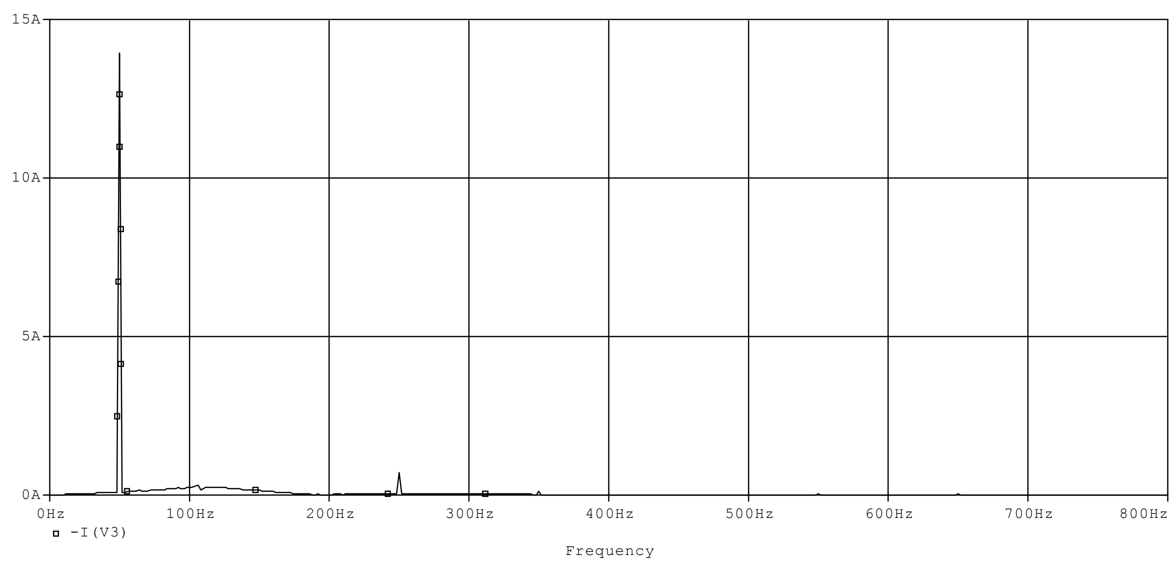


Figure 2.87: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =2.86 kHz, Duty Cycle = 40%)

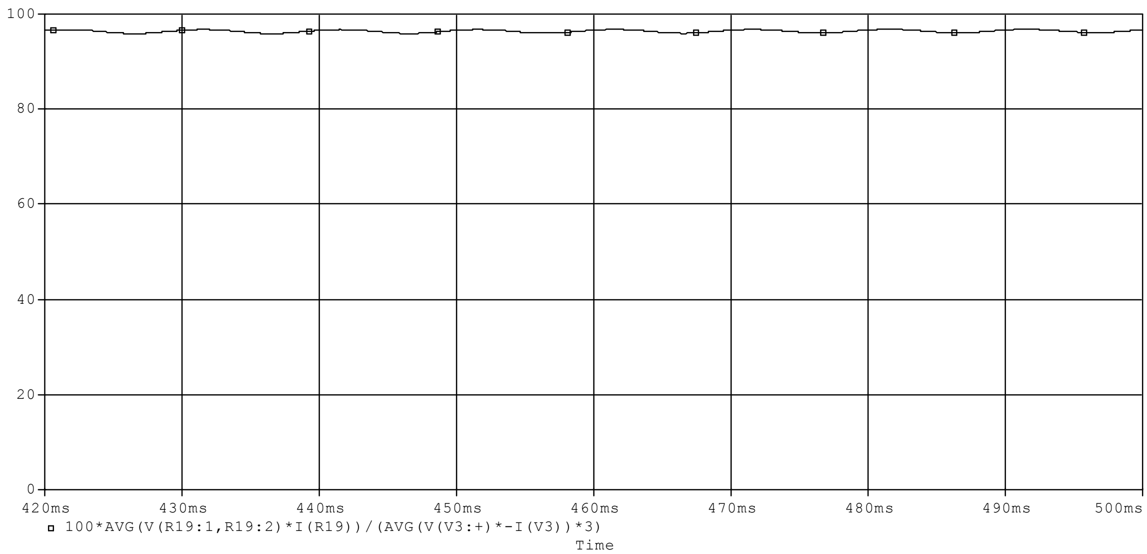


Figure 2.88: Efficiency of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =2.86 kHz, Duty Cycle = 40%)

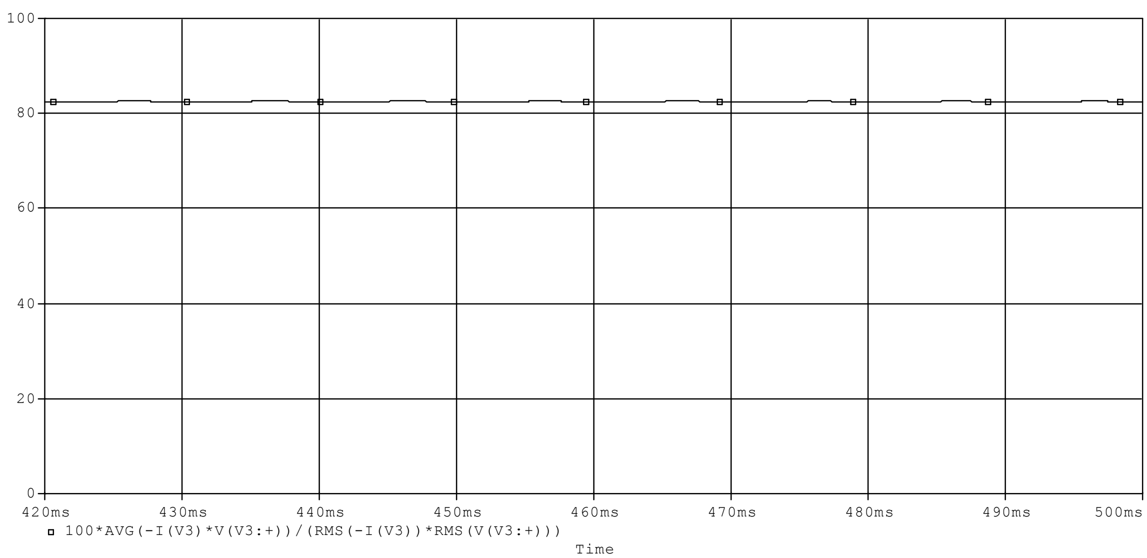


Figure 2.89: power Factor of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =2.86 kHz, Duty Cycle = 40%)

DUTY CYCLE = 60%

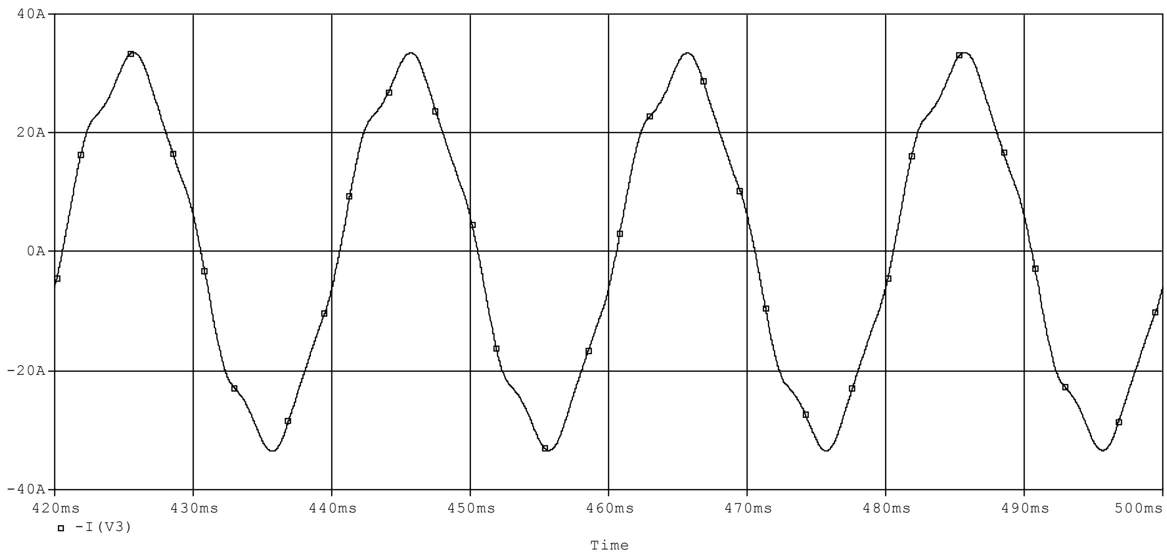


Figure 2.90: Input Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =6.66 kHz, Duty Cycle = 60%)

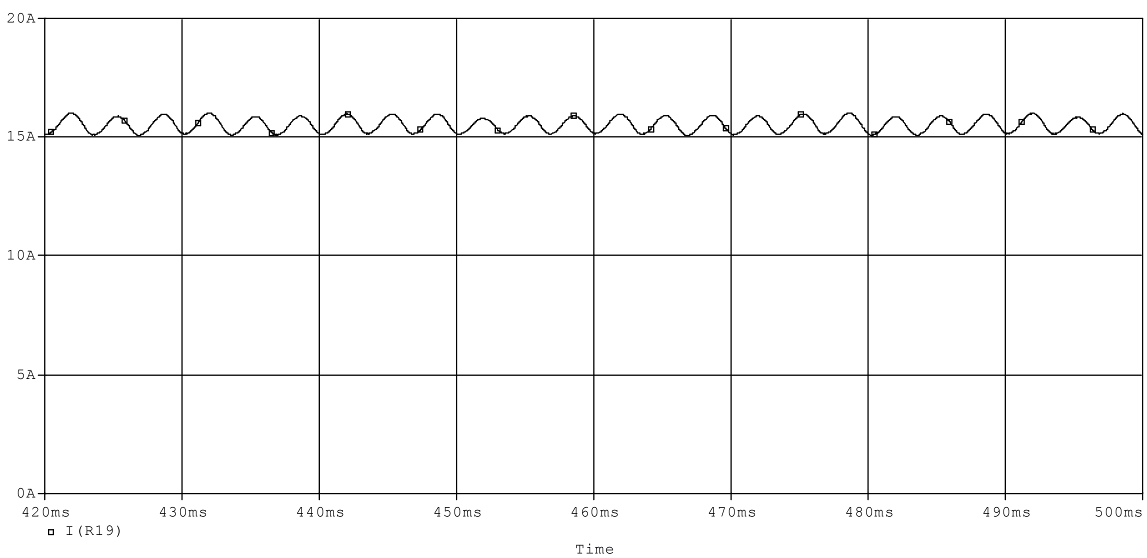


Figure 2.91: Output Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =6.66 kHz, Duty Cycle = 60%)

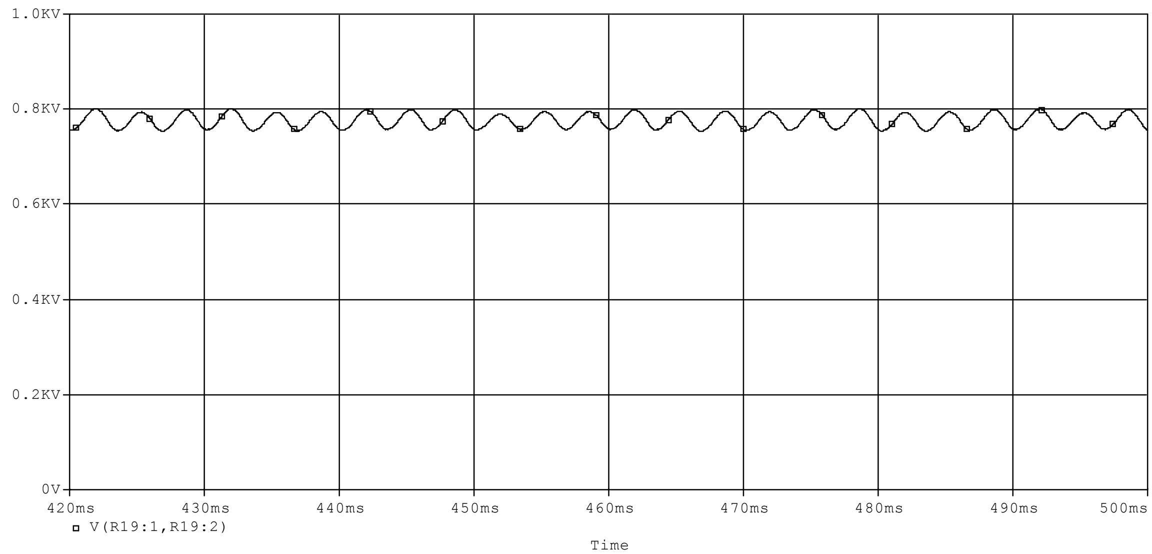


Figure 2.92: Output Voltage of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =6.66 kHz, Duty Cycle = 60%)

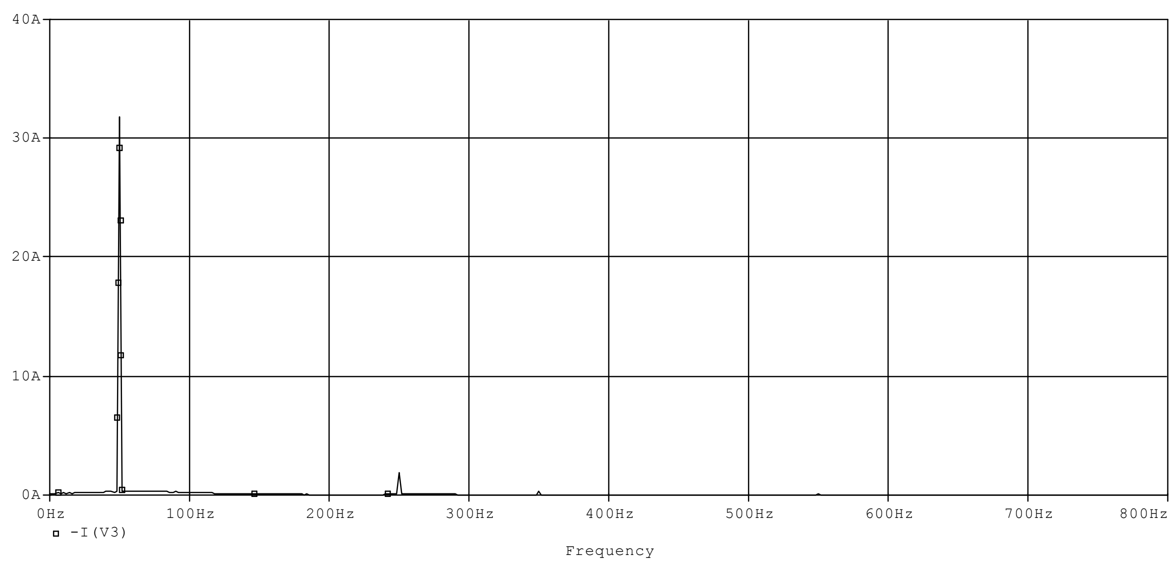


Figure 2.93: FFT of Input Current of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =6.66 kHz, Duty Cycle = 60%)

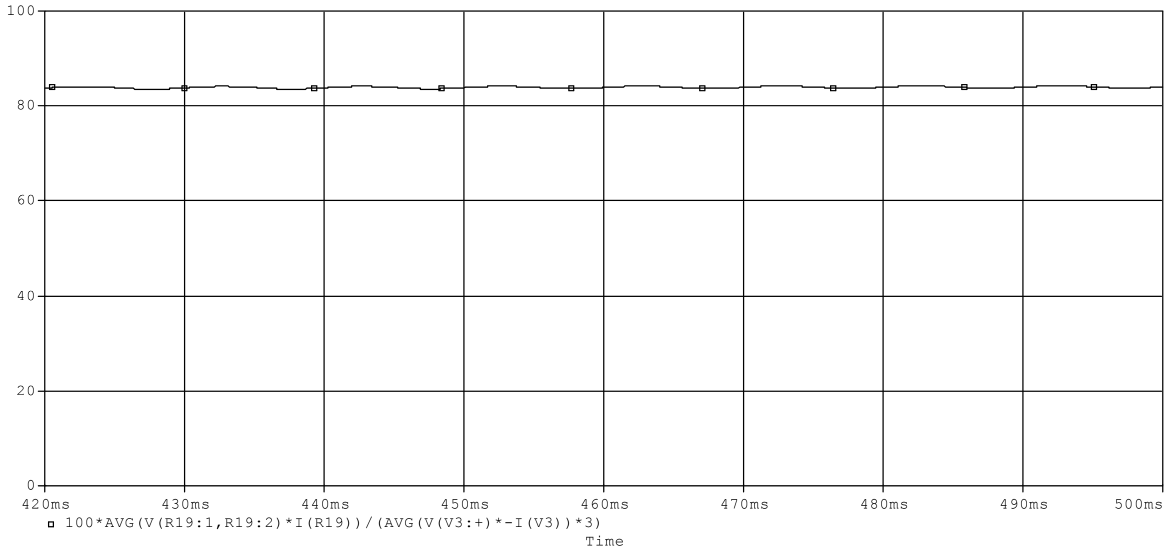


Figure 2.94: Efficiency of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =6.66 kHz, Duty Cycle = 60%)

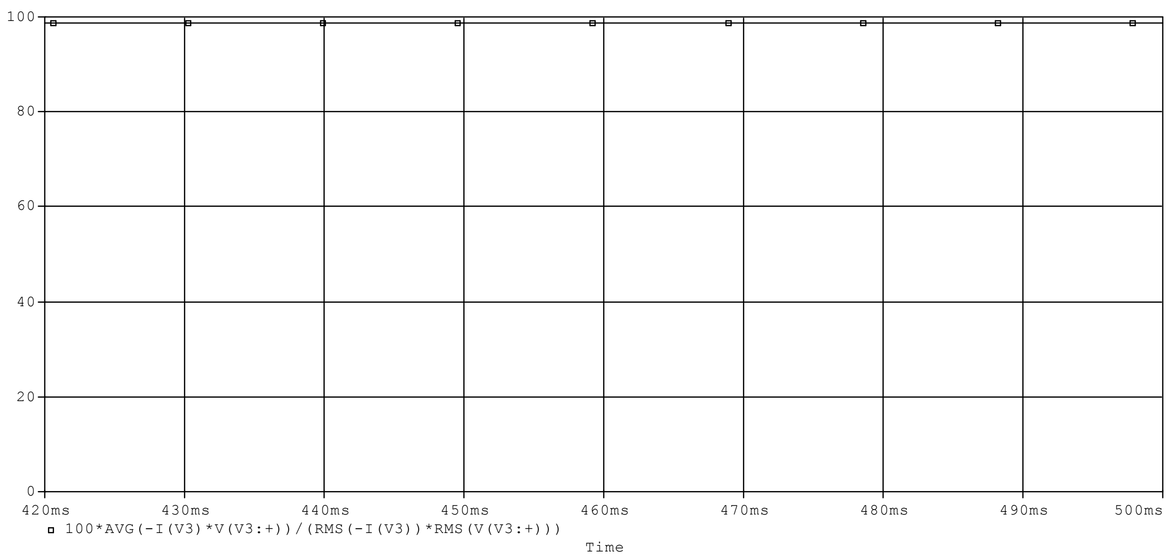
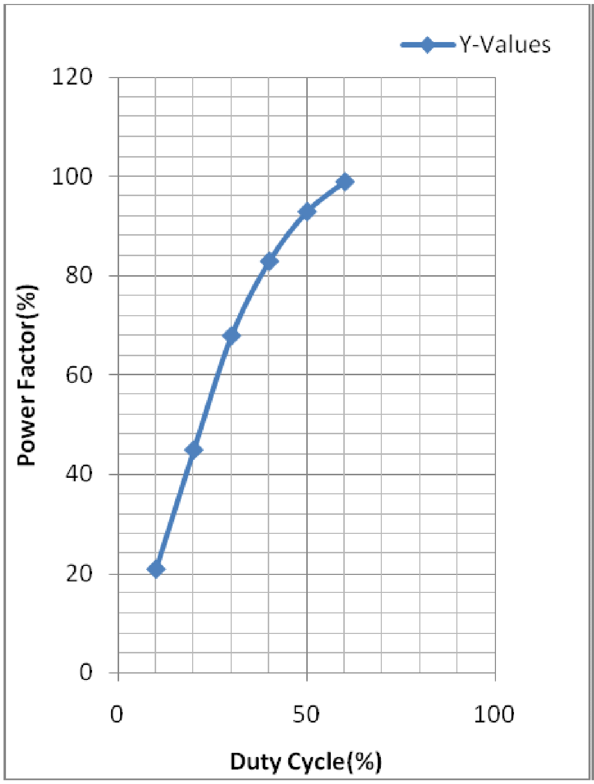


Figure 2.95: Power Factor of a buck-boost regulated three phase rectifier with passive input filter (Carrier frequency =6.66 kHz, Duty Cycle = 60%)

TABLE 5: PERFORMANCE PARAMETER OF BUCK-BOOST RECTIFIER WITH INPUT FILTER AND

D (%)	THD (%)	PF (%)	I_{in}(rms) amp	V_{in}(rms)volt	V_{out}(dc) volt	I_{out}(dc) amp	Efficiency(η)%	Carrier Frequency (KHz)
10	5.122498E+00	21	6.5	212.12	180	4	80	1.43
20	3.751713E+00	45	7	212.12	300	6	95	2.00
30	4.379524E+00	68	8	212.12	400	8	95	2.50
40	5.473630E+00	83	10	212.12	500	10	96	2.86
50	6.319966E+00	93	12.5	212.12	600	12	92	3.33
60	6.389346E+00	99	22.5	212.12	800	16	85	6.67

VARIABLE SWITCHING FREQUENCY



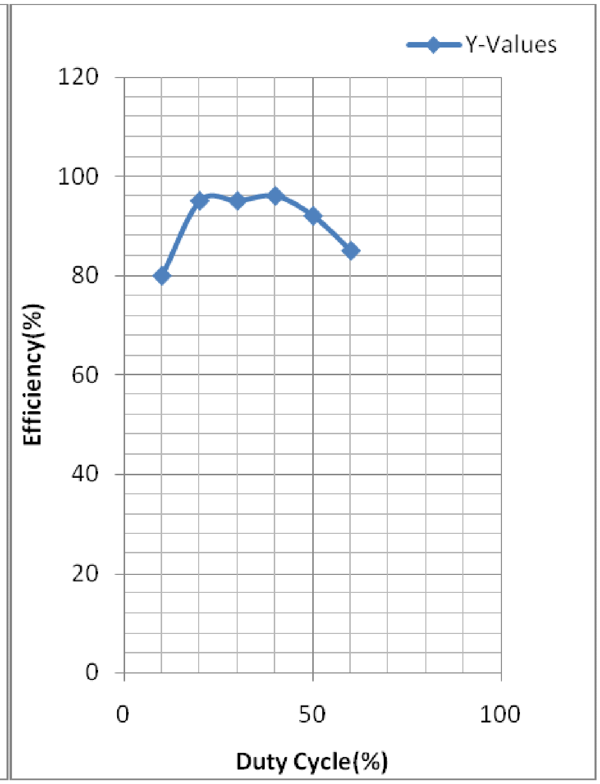
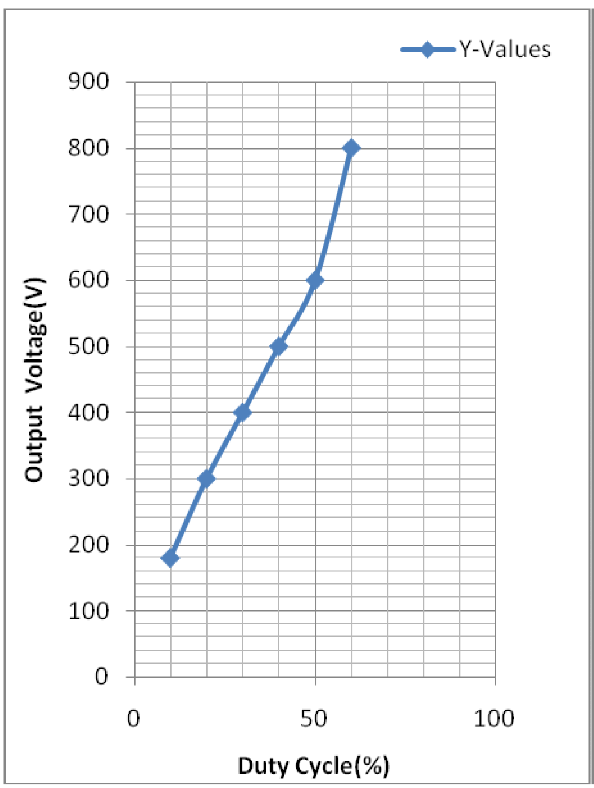


Figure2.96: Duty Cycle Vs Power Factor

Figure 2.97: Duty Cycle Vs Efficiency



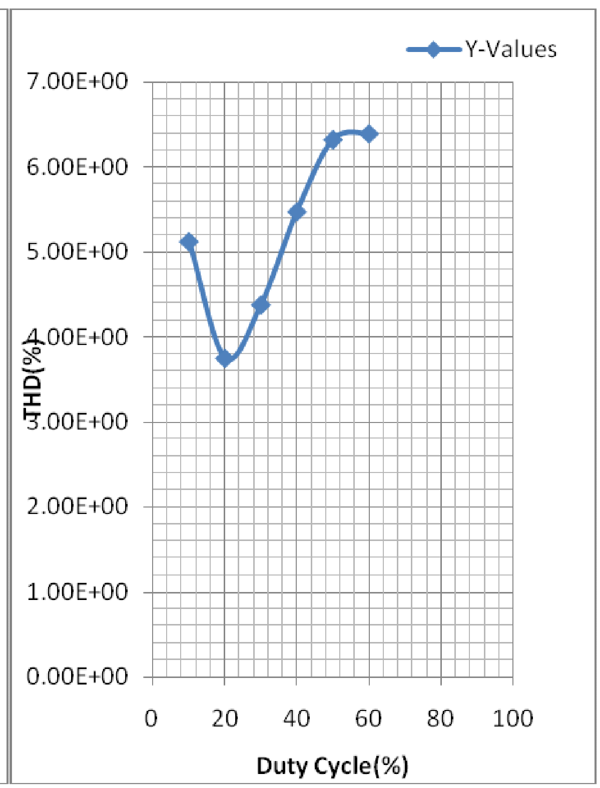


Figure 2.98: Duty Cycle Vs Output Voltage **Figure2.99: Duty Cycle Vs THD(%)**

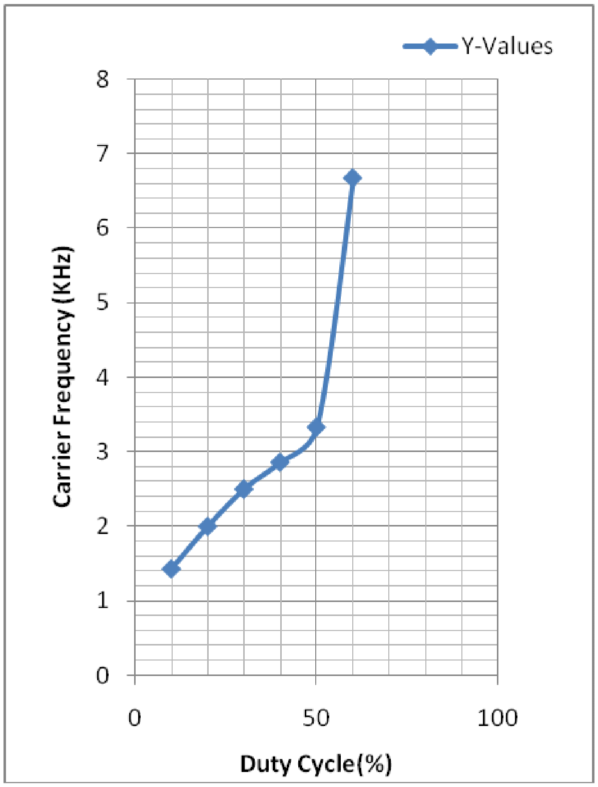


Figure 2.100: Duty Cycle Vs Carrier Frequency

CHAPTER 3

CONCLUSION

3.1 Conclusion

The quality of input current indicates the efficient performance of a rectifier. Normally a three phase rectifier draws distorted input current which causes many undesirable problems. The presence of harmonics components in input current is mostly responsible for the distortions of input current. In individual and household applications, this distorted input current is harmful for stable and long operations of power electronic equipments. Low power factor, additional heating, over voltage and over loading increased volt amperes ratings and increased line and utility losses are some of these problems. Distortion free sinusoidal input current is a major consideration in a rectifier design. Many techniques have been developed by researchers in previous works. But large size of input filters are required to minimizes the distortion. Another important thing is, regulated output voltage both below and above the input voltages are required in many cases. Only Ĉuk and Buck-Boost regulators are able to supply regulated voltage below and above the input voltage. In this thesis, a Buck-Boost regulator with some modification is proposed for improvement of input current and efficiency of a three phase rectifier.

At first a three phase full wave diode rectifier has been studied. The input current was found non sinusoidal pulsating and THD was found 2.583394E+01%. Then a passive input filter has been employed to make the input current sinusoidal. Then the THD and efficiency was fond 1.098277E+00% and 94% respectively. But the input filter was very large (L=20mH, C= 100uF) which results in increase in input current. As a result the VA rating of the rectifier increases and weight becomes large as well. The output voltage was not controllable.

To overcome the previous problem, a buck-boost regulated three phase rectifier has been studied without input filter. It was observed that the input current was highly distorted with large THD, though the efficiency was good in some cases. The output voltage is controllable. To improve the shape of input current of Buck-Boost regulated three phase rectifier with passive input filter was studied next. The switching frequency was kept constant. It was found from the analysis that the THD has improved for many of the duty cycles, but the overall efficiency of the regulator was not acceptable at all duty cycles. It was also observed that efficiency and THD cannot be kept at the desired level simultaneously with ch.nge in duty cycle

To improve the overall efficiency and to maintain the THD of the input current at acceptable limit a new topology was proposed and studied. A mixed passive filter was introduced at the input side of a Buck-Boost regulator. At the same time, the switching frequency was varied from low to high frequency with the variation duty cycles. Lastly a lift circuit was added in between the load and the Buck-Boost regulator, which makes the output voltage positive. Here, it was found that THD remains under 7% at all duty cycle. The output voltage can be varied from 180 volts to 800 volts with more than 80% efficiency. The value of input current is also acceptably low. So, where regulated output voltage (below the input voltage and above the output voltage) is required with high efficiency, the proposed converter can be used.

3.2 Suggestions on future works

1. During the change of the output voltage by varying the duty cycle, it has been observed that the power factor also changes and becomes very low in some cases. To maintain the power factor unity at all duty cycle and output voltage, a new control strategy may be suggested which will keep the power factor close to the unity and keep the THD and efficiency at acceptable as well.

2. The parameter of the input filter is still large, which increase the VA rating of the converter. To reduce the filter size further higher frequency switching above audible range may be investigated in future works.

3. Switching losses and EMI interference is not considered here. The losses can be calculated in future works.

4. A control circuit, which will operate the converter, can be suggested.

5. The lowest output voltage of the proposed converter is 180 V with acceptable performance. Ways may be investigated for control scheme to obtain output voltage variation from zero to high required voltage with acceptable performance parameters i.e. low THD, high power factor and efficiency etc.

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