DEVELOPMENT OF SINGLE-PHASE, SINGLE-SWITCH AC-AC BOOST CONVERTER.

By

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DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET)

JUNE, 2014

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A thesis submitted
to
The Department of Electrical and Electronic Engineering in partial fulfillment for the degree of
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Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidate

…………………………
(Md. Kamrul Islam)

The thesis titled **"DEVELOPMENT OF SINGLE-PHASE, SINGLE-SWITCH AC-AC BOOST CONVERTER."** submitted by Md. Kamrul Islam, Student No.: 0409062108, Session: April, 2009, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING on June, 2014.

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Dedication

To my Parents

Acknowledgement

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Abstract

AC voltage controllers regulate ac power to load. Conventionally they are phase controlled single phase and three phase types. Phase control ac- ac voltage controllers are subclass of matrix converters which converts voltage down. These are mainly used in lighting, heating, ac motor starters and speed controllers and voltage restorers etc. In phase control and integral cycle controllers the load voltage and the input current to the converter are nonsinusoidal. At low output voltages power factor are small and input current total harmonic distortion are high. Low power factor and high THD are detrimental to power lines and apparatus. Switch mode ac-ac converters similar to switch mode dc-dc converters are available which have the advantages of being light weight and efficient. Switch mode ac-ac voltage controllers can produce step down and step up voltages at the load as needed.

Single phase ac-ac boost converters with two and one bi-directional switch topologies are investigated in this thesis. The converters work as boost ac-ac converters on the instantaneous voltage basis. Their voltage gain conversion has buck-boost nature on rms voltage basis. The current gain of the proposed ac-ac boost converters is inverse to their voltage gains. Two topologies investigated show good input current THD and input power factor for a wide range of voltage control by duty cycle change. However, their efficiencies were found to be between 60-85%. Present study did not consider feedback control for voltage regulation and performance enhancement. It is necessary that in future feedback control scheme be incorporated with proper input-current/output-voltage filters in the proposed converters to enhance performance. The proposed circuits work in multi-quadrants (particularly bi-directional two quadrant operation) with R-L and R-L with emf as load.

List of Abbreviation

SMPS	Switch Mode Power Supply
IGBT	Insulated Gate bipolar Transistor
PWM	Pulse Width Modulation
Rms	Root mean square
THD	Total Harmonic Distortion
SCR	Silicon Control Rectifier
V_{in}	Input voltage
T_{ON}	Turn on time.
T_{OFF}	Turn off time.
T	$T_{ON} + T_{OFF}$.= Time period
D	Duty cycle = T_{ON} / T.
I_a	Average load current
f	Switching frequency
L	Inductor
C	Filter capacitance
I_o	Output Current

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CHAPTER -1

INTRODUCTION

1.1 Introduction:

Power quality is the quality of voltage and current. It is an important consideration in industries and commercial applications. Power quality problems commonly faced are transients, sags, swells, surges, outages, harmonics, and impulses. Among these voltage sags and extended under voltages have negative impact on industrial productivity, and could be the most important type of power quality variation for many industrial and commercial customers. It is necessary that some converters are to be used to improve the quality of power supply. Power semiconductor devices are making it possible for utilities to use a variety of power control equipment to improve power quality to meet the requirements.

Principle of four DC-DC converters (Buck, Boost, Buck Boost, Ĉuk) can be applied for AC-AC Conversion by proper circuit topologies. Previously such conversion was reported using two switches, one was the main switch and the other replaced the freewheeling diode of the converter circuit. Two switches were alternately turned ON and OFF making AC-AC conversion possible.

In two switch AC-AC conversion two gate pulses are required and for proper operation, the changes of gate pulses every half cycle were made by current sensing. Change in the topology of ac-ac converter will allow conversion with a single switch and with gate pulse generation without current sensing.

Single switch AC-AC conversion by Boost topology can be achieved by the principle of half cycle to half cycle conversion of power between source and load.

Such conversion has the advantages of input current chopped AC current which can be filtered by a small filter. Duty cycle variation of such AC-AC converter will allow Buck and Boost voltage variation across the load. Filtered high frequency chopped input current will provide near sinusoidal input current at high power factor. Proper control of proposed ac-ac boost switching converter would also have high conversion efficiency.

1.2 Background and Present of the State Problem:

AC voltage controllers are widely used in power systems to obtain variable AC voltages from fixed utility voltages. Conventional Phase Angle Control (PAC) and integral cycle control thyristors AC voltage controllers suffer from disadvantages of high low order harmonics and discontinuity of power flow between input and output sides [1-2]. Serial voltage controllers used for AC voltage stabilization suffer from weight and volume problems [3-5]. AC voltage controllers with thyristor technology can be replaced by PWM AC chopper controllers which have advantage of good performances [6] like near sinusoidal input current, improved input power factor and absence of low order harmonics [7]. The reduction in the number of switches is essential for control simplicity, cost and reliability [8]. The switch reduction may be possible in chopper ac-ac voltage controllers.

The PWM switched AC-AC conversion was reported using two and four switches in [9-11]. In two switch implementation, one is the main switch and the other acts as freewheeling path across the load. Two switches were alternately turned ON and OFF to make the AC-AC conversion possible. In two switch AC-AC conversion, two trains of gate pulses are required for proper operation. The change of gate pulses is made by current sensing. However change in topology of a DC-DC converter may allow AC-AC conversion with a single switch.

1.3 Review:

The review consists of two parts. The review of DC-DC converters and review of AC-AC converters. The review of DC-DC converter is necessary because the proposed work is derived from the circuits based on Boost conversion circuit of DC-DC converter.

1.3.1 Review of DC-DC Converter:

A DC converter is equivalent to an ac transformer with a continuously variable turns ratio. Like a transformer it can be used to step down or step up a dc voltage or a current. DC conversion is of importance in applications, starting from low power to high power. For low power levels, linear regulators can provide a quality output voltage. For medium power levels, switching regulators are used. Switching regulators use power semiconductor switches in ON and OFF states. Because there is a small power loss in these states, switching regulators ideally has high efficiency. A block diagram of a general dc-dc switching regulator is shown in Fig 1.1

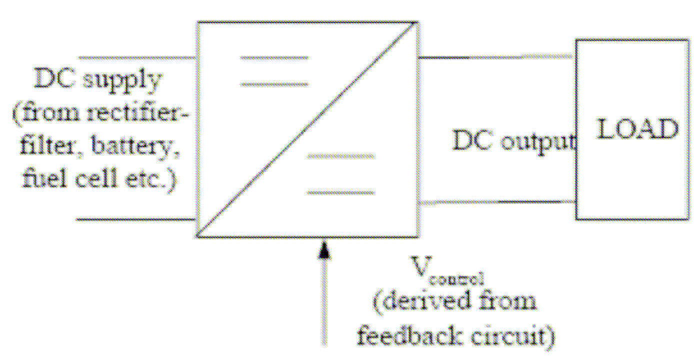


Fig.1.1: General block diagram of a dc-dc switching regulator.

The functions of dc-dc converters are:

- Convert a DC input voltage into a DC output of same higher or lower voltage,
- Regulate the DC output voltage against load and line variations,
- Reduce the voltage ripple on the DC output voltage,
- Provide isolation between the input source and the load (if required) and
- Protect the supplied system and the input source from electromagnetic interference (EMI)

1.3.2 Switch Mode DC- DC Converters (SMPS): [12-19]

Conventional switch mode dc-dc converters (SMPS) operate either in single quadrant or in two quadrants [12-13]. A switch mode DC-DC power supply is switched at high frequency. Conversion of both step-down and step-up dc can be accomplished with small input/output filter having facility of feedback regulation by ON/OFF switching. Usually SMPSs are used in dc-dc conversion for their light weight, high efficiency and isolated multiple outputs with or without voltage regulation. Uses of SMPS are generic in space power applications, computers, TV, biomedical equipment and industrial units etc. SMPSs have advantage of being low cost, compact, self regulating and self protected.

A DC-DC SMPS consists of a rectifier fed dc source, a filter and a static switch. The SMPS is switched by control circuitry at a very high frequency to step-down or step-up dc voltage by ON/OFF ratio (duty cycle) control. The filter and the feedback circuit are the other components of a dc-dc SMPS. Figure-1.2 shows the block diagram of a DC-DC SMPS.

Main components of a dc-dc SMPS are,

1. Power circuit ,
2. Control circuit and

3. Magnetic circuit.

The control circuit of an SMPS generates high frequency gate pulses for the switching device to control the dc. Switching is performed in multiple pulse width modulation (PWM) fashion according to feedback error signal from the load to serve two purposes,

1. Produce high frequency switching signal and
2. Control ON / OFF period of switching signal to maintain constant voltage across the load.

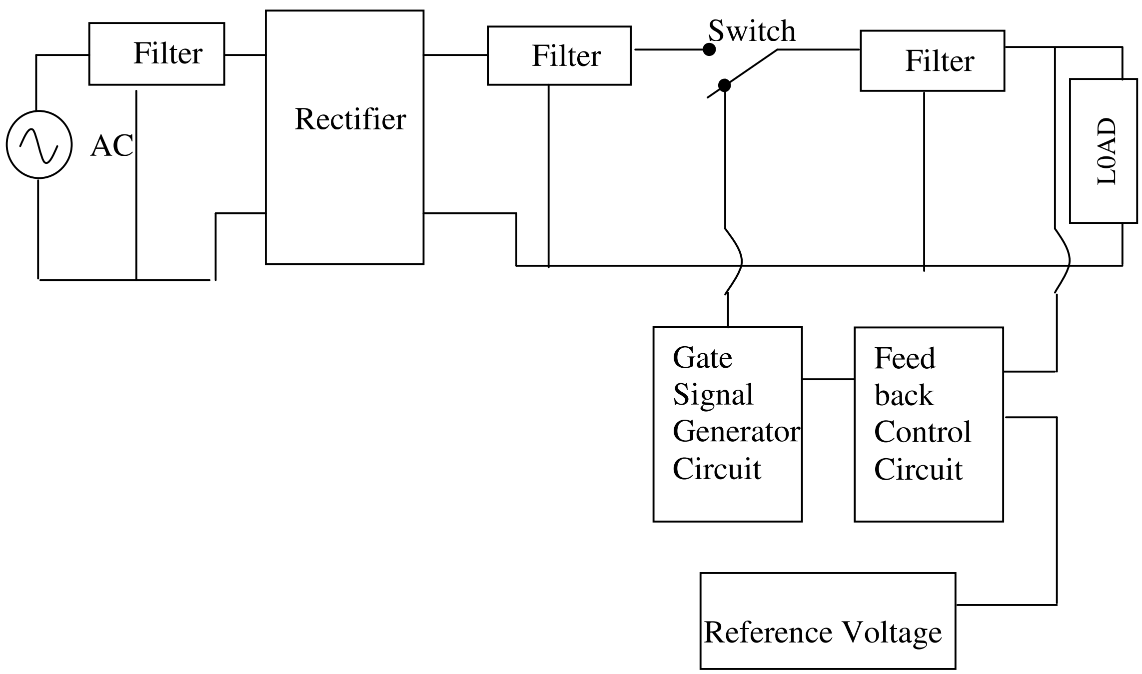


Fig. 1.2: Block diagram of an SMPS.

High frequency switching reduces filter requirements at the input/output sides of the converter. Simplest PWM control uses multiple pulse modulations generated by comparing a dc with a high frequency carrier triangular wave.

At present a switching regulator is available as integrated circuit. The designer can select the switching frequency by choosing the value of RC to set oscillator frequency. Switching frequency limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and as a result the efficiency decreases. In addition, the core loss of inductor limits the high frequency operation.

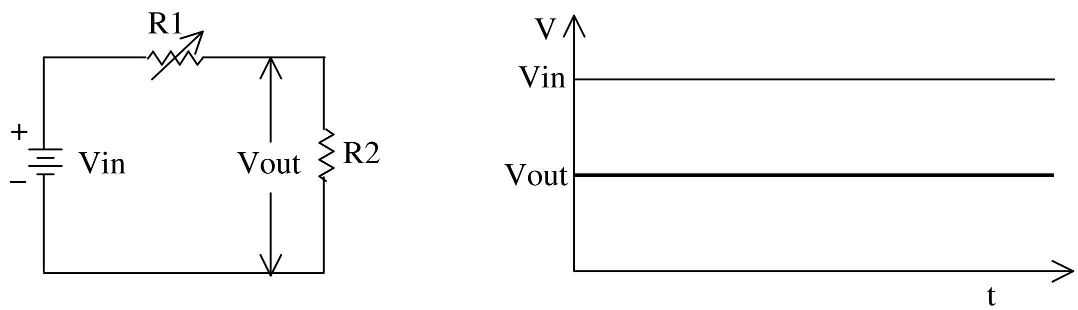


Fig.1.3: Linear (dissipative) power conversion circuit.

Figure-1.3 illustrates the circuit of a linear power conversion. Here power is controlled by a series linear element; either a resister or a transistor is used in the linear mode. The total load current passes through the series linear element. In this circuit greater the difference between the input and the output voltage, more is the power lost in the controlling device. Linear power conversion is dissipative and hence is inefficient. The efficiency range is typically 30 to 60% for linear regulators.

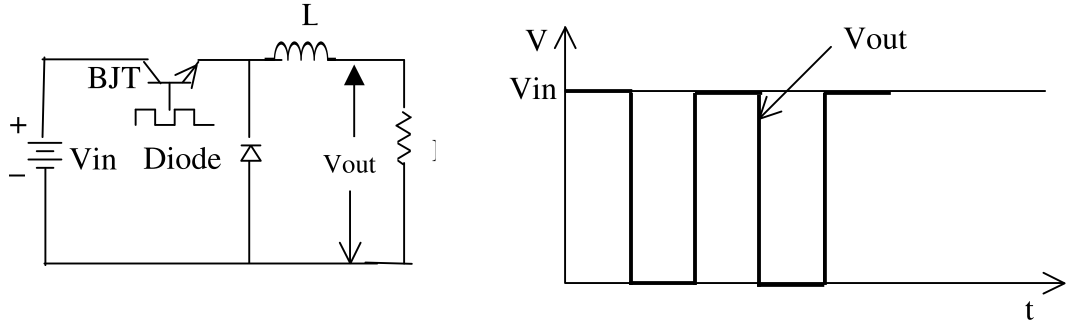


Fig.1.4: Switch mode (non dissipative) power conversion circuit.

The circuit of Figure-1.4 illustrates basic principle of a Buck dc-dc switch mode power conversion. The controlling device is a switch. By controlling the ratio of the time intervals spent in ON and OFF positions (defined as duty ratio), the power flow to the load can be controlled in an efficient way. Ideally this method is 100% efficient. In practice, the efficiency is reduced as the switch and circuit elements are non-ideal. The dc voltage to the load can be controlled by controlling the duty cycle of the rectangular waveform supplied to the base or gate of the switching device. When the switch is fully ON, it has only a small saturation voltage across it. In the OFF condition the current through the device is zero.

The output of the switch mode power conversion (Figure-1.4) is not pure dc. This type of output is applicable, where, proper filtration is not needed. If constant dc is required, then output of an SMPS has to be smoothed out by the addition of a low-pass filter. Switches are required as basic components for efficient electric power conversion and control. Inductors and capacitors are used to smooth the pulsating dc originating from the switching action.

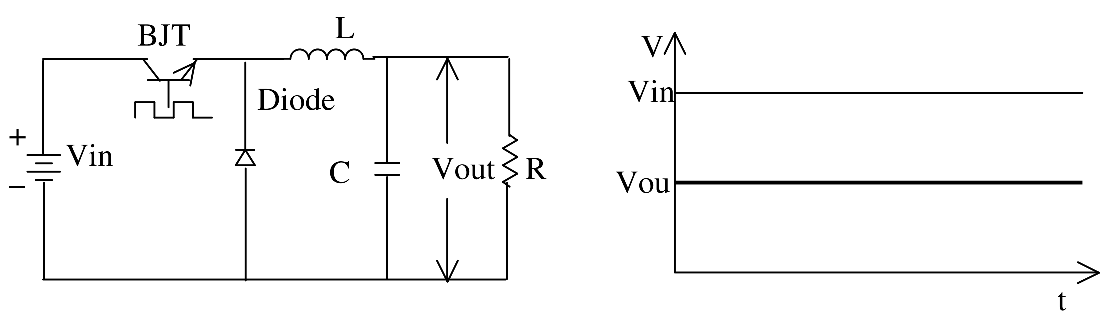


Fig.1.5: Typical buck switch mode dc-dc conversion circuit.

Although the conversion would be 100% efficient in the ideal case of lossless and voltage dropless components (Figure-1.5), in practice all components are lossy and voltage drop across them take place during their conduction interval. Thus, efficiency is reduced. The objective in switch mode power conversion is to realize conversion with the least number of components with better efficiency and reliability.

1.3.2 Types of DC-DC Converters:

There are four basic topologies of switching regulators:

a. Buck converter

b. Boost converter

c. Buck-Boost converter and

d. Ĉuk converter.

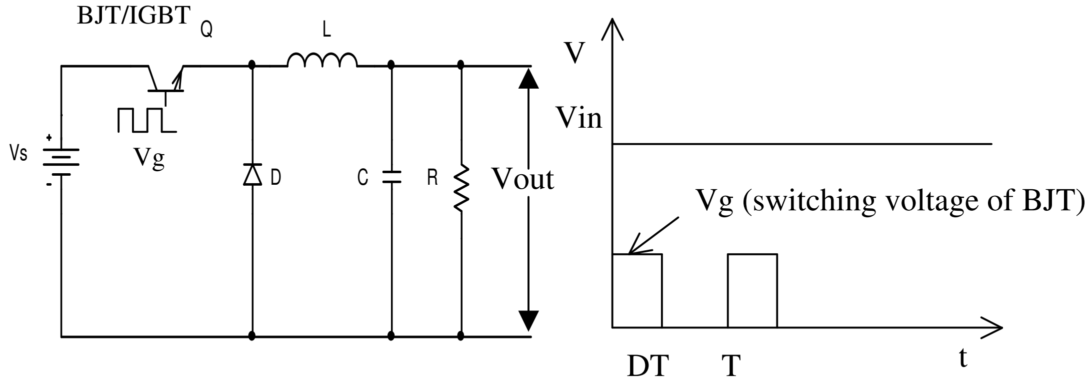
1.3.3.1 Buck Converter: [20-24]

In Buck converters, output voltage is regulated to less than the input voltage, hence the name "Buck". The circuit diagram is shown in Fig.-1.

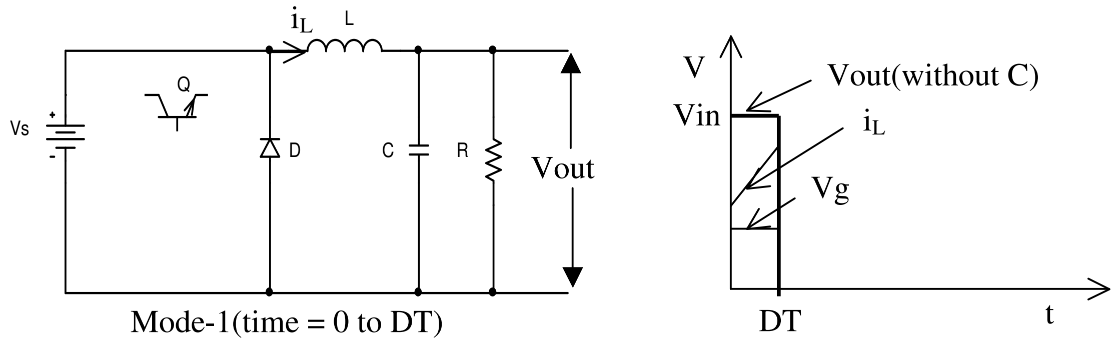
The ideal voltage and current gain equations of the circuit of 6 (a) are,

$$\frac{V_0}{V_{in}} = D \tag{1.1}$$

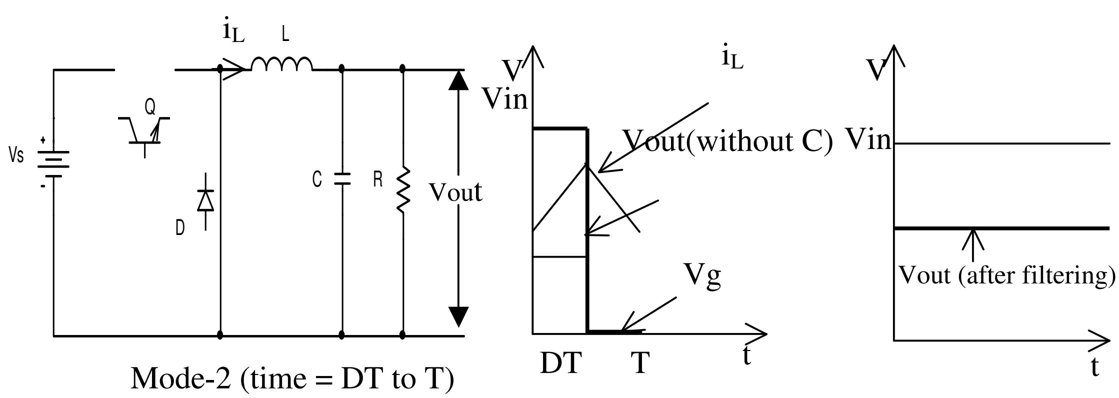
$$\frac{I_0}{I_{in}} = \frac{1}{D} \tag{1.2}$$



(a) Buck dc-dc converter, input voltage and the gate signal of the switch.



(b) Equivalent circuit of Fig 1.6(a) when switch is ON



(c) Equivalent circuit of Fig 1.6(a) when switch is OFF

Fig.1.6: Buck converter with continuous i_L.

Where D is the duty cycle defined as $D = \frac{T_{ON}}{T_{OFF}}$,

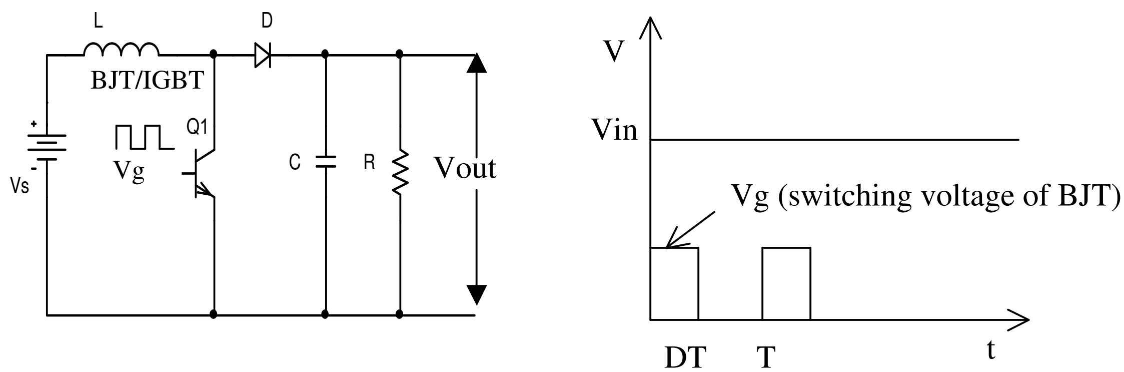
T_{ON} is the ON time, T_{OFF} is the OFF time and T is the period of the controlling signal of the switch.

1.3.3.2 **Boost Converter:** [20- 22, 25]

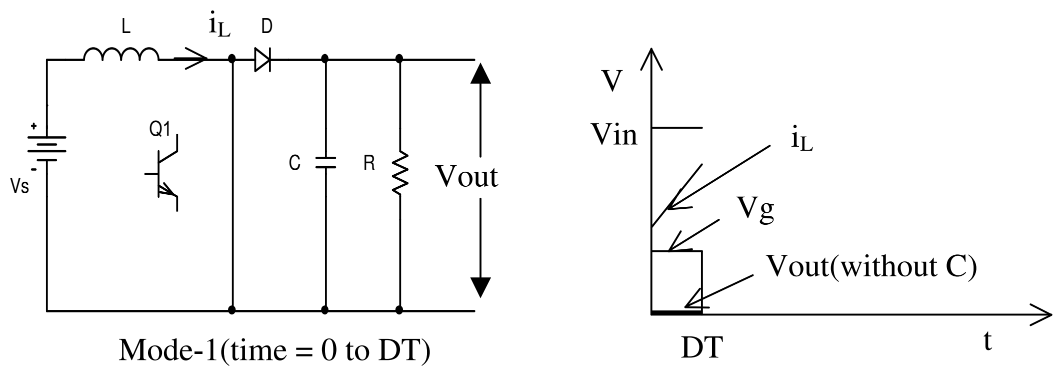
In Boost converters, the output voltage is greater than the input voltage, hence the name "Boost". The circuit diagram is shown in Figure-1.7

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} \tag{1.3}$$

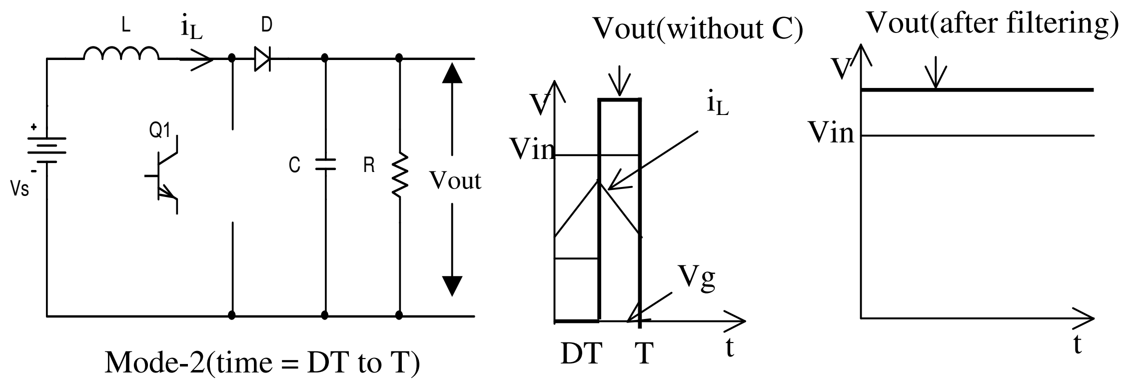
$$\frac{I_0}{I_{in}} = 1-D \tag{1.4}$$



(a) Boost dc-dc converter, input voltage and the gate signal of the switch.



(b) Equivalent circuit of Fig 1.7(a) when the switch ON



(c) Equivalent circuit of Fig 1.7(a) when the switch OFF

Fig.1.7: Boost converter with continuous i_L.

D is the duty cycle defined as $D = \frac{T_{ON}}{T}$,

T_{ON} is the ON time, T_{OFF} is the OFF time and T is the period of the controlling signal of the switch.

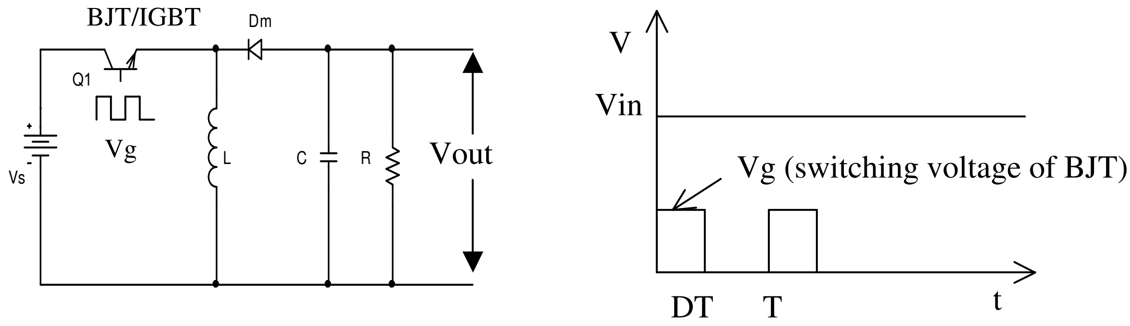
1.3.3.3 Buck- Boost Converter: [20, 22, 25-28]

Buck converters can step-down and boost converters can step-up dc voltages individually. The Buck-Boost converter in which the inductor is grounded can perform either of these two conversions. The output voltage polarity is opposite to input voltage and as a result the converter is also known as an inverting converter. The circuit of a of the Buck-Boost converter in shown Fig.1.8.

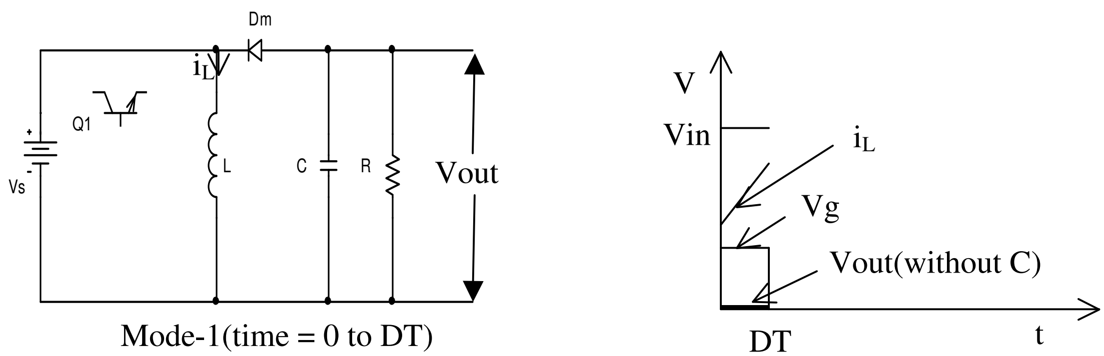
The ideal voltage and current gain equations are,

$$\frac{V_o}{Vin} = \frac{D}{1 - D} \quad (1.5)$$

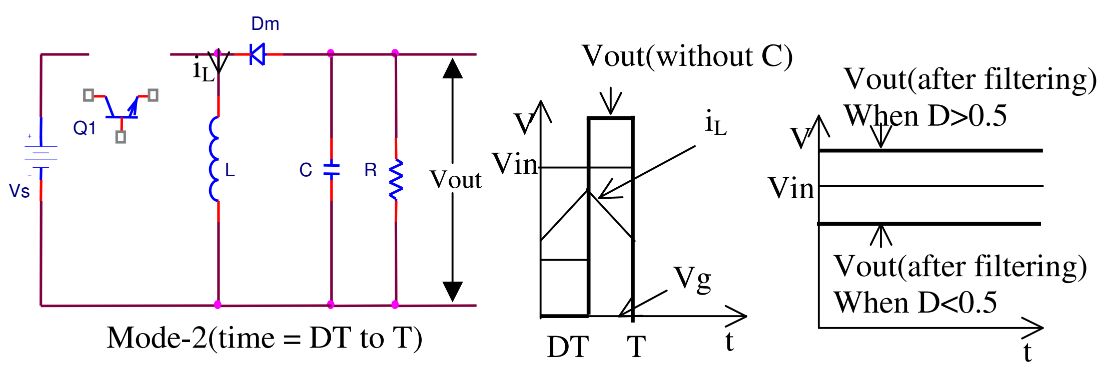
$$\frac{I_o}{Iin} = \frac{1 - D}{D} \quad (1.6)$$



(a) Buck Boost dc-dc converter, Input voltage and the gate signal of the switch.



(b) Equivalent circuit of Fig1.8 (a) when the switch is ON



(c) Equivalent circuit of Fig1.8 (a) when switch is OFF

Fig.1.8: Buck-Boost converter with continuous Inductor current.

Where D is the duty cycle defined as $D = \frac{T_{ON}}{T}$

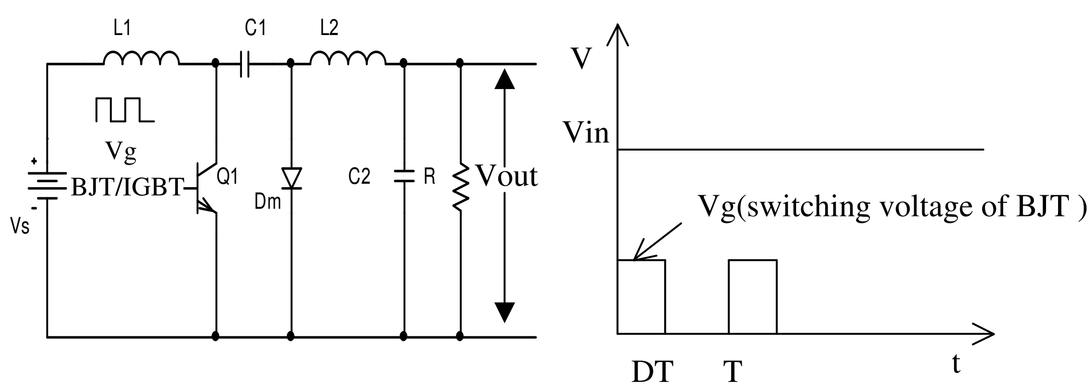
T_{ON} is the ON time, T_{OFF} is the OFF time and T is the period of the controlling signal of the switch.

1.3.3.4 Ĉuk Converter: [17-18, 21- 22, 28]

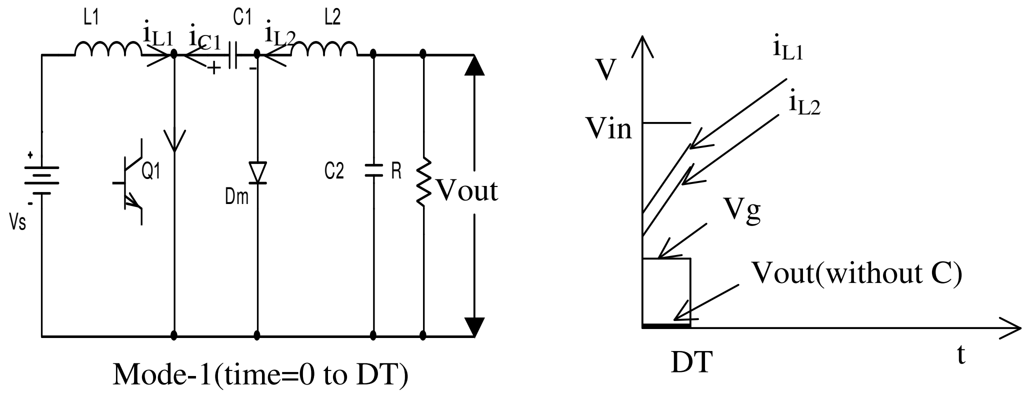
It is the modified form of Boost- Buck converter having the capability to regulate input voltage in both buck and boost way. The power circuit of the Ĉuk Converter shown In Fig 1.9. The ideal voltage and current gain relationships of the Ĉuk converter are,

$$\frac{V_0}{V_{in}} = \frac{D}{1-D} \quad (1.7)$$

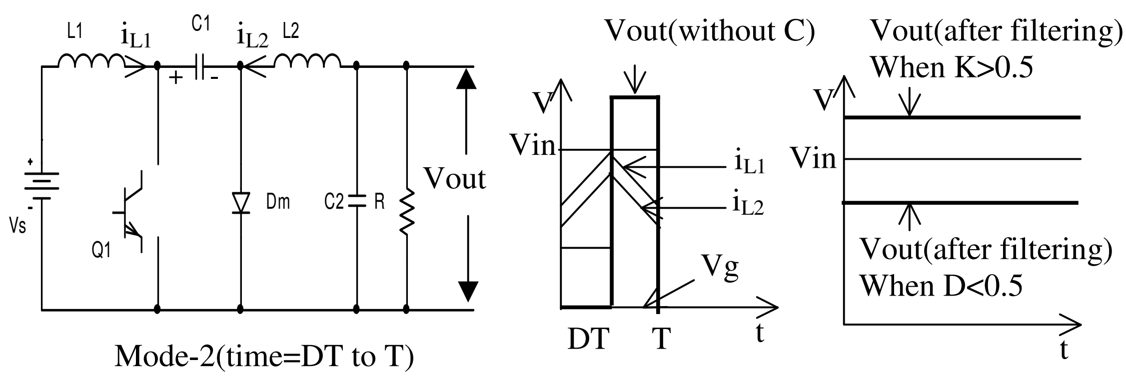
$$\frac{I_0}{I_{in}} = \frac{1-D}{D} \quad (1.8)$$



1.9 (a) Ĉuk dc-dc converter, input voltage and gate signal of the switch.



(b) Equivalent circuit of Fig. 1.9(a) when switch ON



(c)Equivalent circuit of Fig 1.9(a) when switch OFF

Fig.1.9: Ĉuk converter with continuous i_L.

Where, D is the duty cycle defined as $D = \frac{T_{ON}}{T}$

T_{ON} is the ON time, T_{OFF} is the OFF time and T is the period of the controlling signal of the switch.

1.3.3.5 Advantages of an SMPS: [12-15, 18, 20, 23, 28-40]

Switch mode power supplies have following advantageous features,

* Isolation between the source and the load (if necessary),
* High power density with reduction of size and weight,
* Controlled direction of power flow,
* High conversion efficiency,
* Input and output waveforms with low total harmonic distortion for small filters and
* Controlled power factor if the source is an ac voltage.

1.4 Review of AC Voltage Regulators: [21, 28-29, 31-65]

AC voltage regulators have utility ac supply as input and incorporate semiconductor switches to vary the rms voltage of the load. These regulators fall into the category of naturally commutating converters since their switches are commutated by the alternating current of the supply. The regulator current may be discontinuous or non sinusoidal. As a consequence input power factor correction and harmonic reduction are usually necessary, particularly at low output voltage levels. A feature of direct conversion of ac to ac is the absence of any intermediate stage, such as a dc link. Therefore, ac to ac converters are efficient but involve a larger number of switching devices, There are three basic ac regulator which have following characteristic along with fixed or variable output voltage,

- Output frequency increased, $f_o > f_s$,
- Output frequency decreased, $f_o < f_s$ and
- Output frequency fundamental = supply frequency, $f_o = f_s$.

1.4.1 AC Voltage Controller Circuit:

AC voltage controllers (ac line voltage controllers) are employed to vary the RMS value of the alternating voltage applied to a load by introducing thyristors of other types of semiconductor switch between the load and source. The RMS value of alternating voltage applied to a load circuit is controlled by controlling the triggering angle of the semi conductor switches.

AC voltage controller is a type of static power converter which is used to convert a fixed voltage, fixed frequency ac supply to a constant or variable voltage ac at the load. The RMS value of the ac output voltage and the ac power flow to the load is controlled by varying (adjusting) the trigger angle ‘α’. The block diagram of a single phase ac-ac voltage controller shown in Fig 1.10

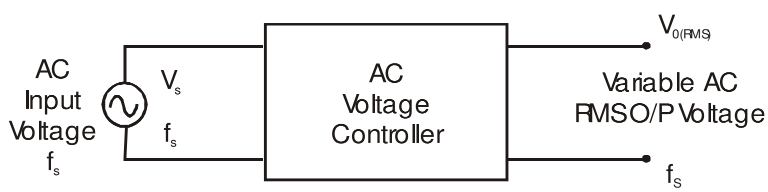


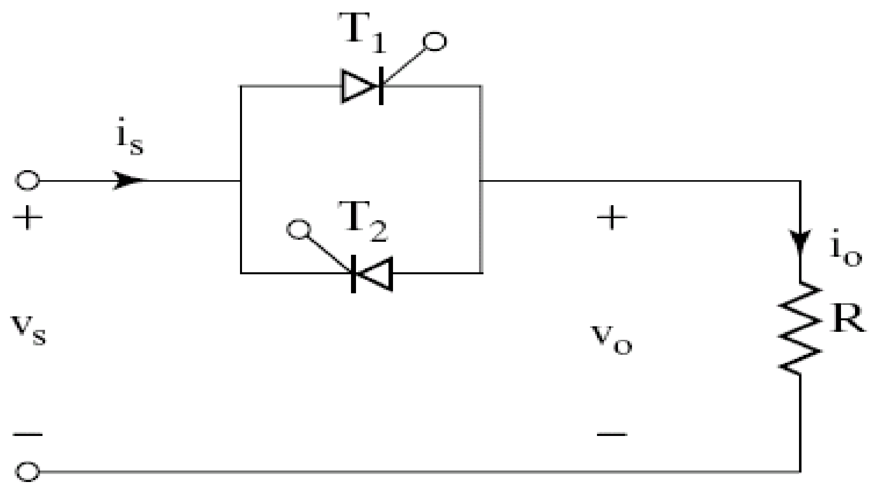
Fig. 1.10: Block diagram of a single phase of AC voltage controller.

There are two different types of control which are used in practice to control the ac power flow of a single phase ac voltage controller which are,

- On-Off control and
- Phase angle control

1.4.1.1 ON-OFF Control (Integral Cycle Control):

The principle of ON-OFF control of voltage controller circuit of Fig 1.11 is shown in Fig: 1.12. The thyristor switches T_1 and T_2 are turned on by applying appropriate gate trigger pulses to connect the input ac supply to the load for ‘n’ number of input cycles during the time interval T_{on}. The thyristor switches T_1 and T_2 are turned off by blocking the gate trigger pulses for 'm' number of input cycles during the time interval t_{off}. The ac controller ON time t_{on} usually consists of an integral number of input cycles.



Load Resistance is R

Fig1.11: Single phase full wave AC voltage controller circuit.

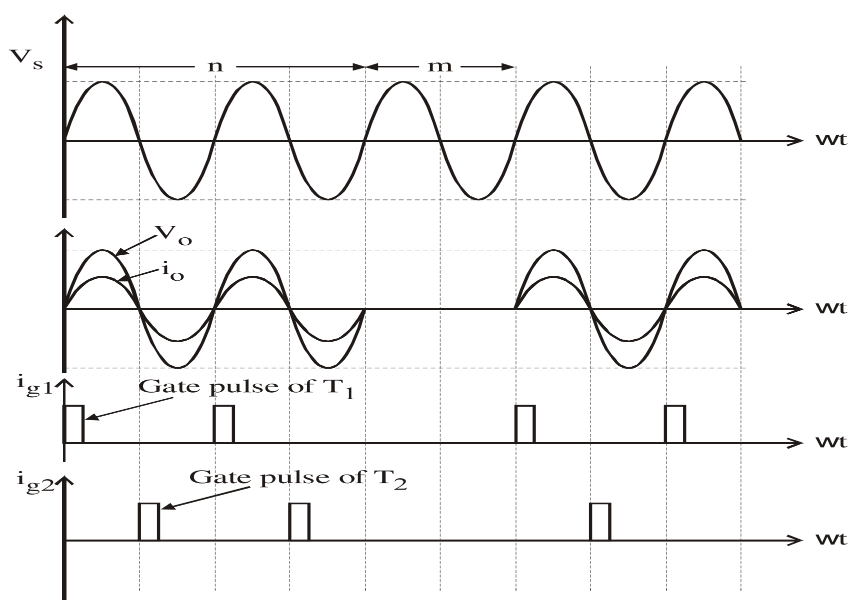


Fig.1.12: Waveforms of Single phase full wave AC voltage controller circuit.

1.4.1.2 Half Wave AC Phase Angle Control:

The ac phase angle control of a single phase half wave ac voltage controller of Fig 1.13 (unidirectional controller) circuits is shown in the Figure1.14.

The half wave ac controller uses one thyristor and one diode connected in parallel across each other in opposite direction, that is anode of thyristor T_1 is connected to the cathode of diode D_1 and the cathode of T_1 is connected to the anode of D_1. The output voltage across the load resistor 'R' and hence the ac power flow to the load is controlled by varying the trigger angle 'α'.

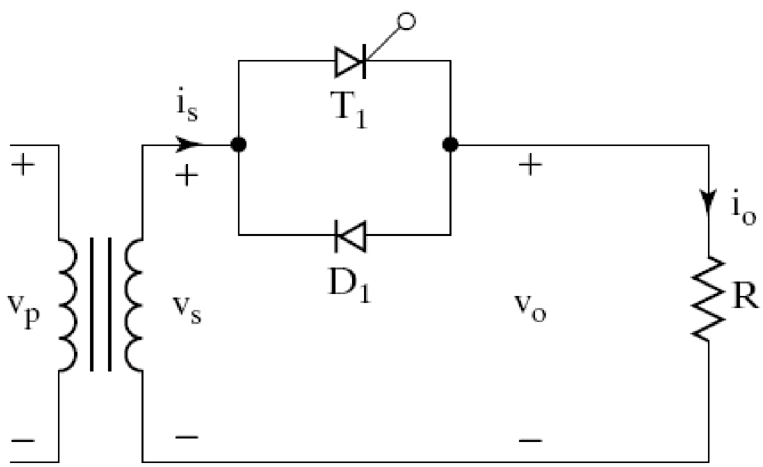


Fig.1.13: Half-wave AC phase controller (Unidirectional Controller).

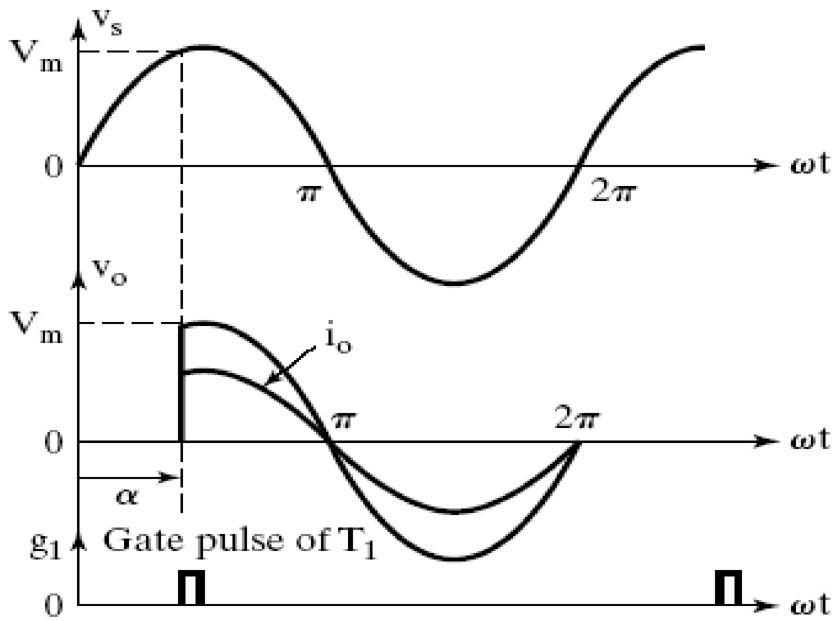


Fig.1.14: Waveforms of Half-wave AC phase controller.

1.4.1.3 Full Wave Phase Control:

Single phase full wave ac voltage controller circuit using two SCRs, or a single triac or a bi-directional switch is generally used in most of the ac control applications. The ac power flow to the load can be controlled in both half or the supply cycles by varying the trigger angle ‘α’.

The RMS value of load voltage can be varied by varying the trigger angle ‘α’. The input supply current is alternating in the case of a full wave ac voltage controller and due to the symmetrical nature of the input supply current waveform there is no dc component of input supply current i.e., the average value of the input supply current is zero.

A single phase full wave SCR ac voltage controller with a resistive load is shown in Fig 1.15. It is possible to control the ac power flow to the load in both the half cycles by adjusting the trigger angle ‘α’. Full wave ac voltage controller is also referred to as to a bi-directional controller.

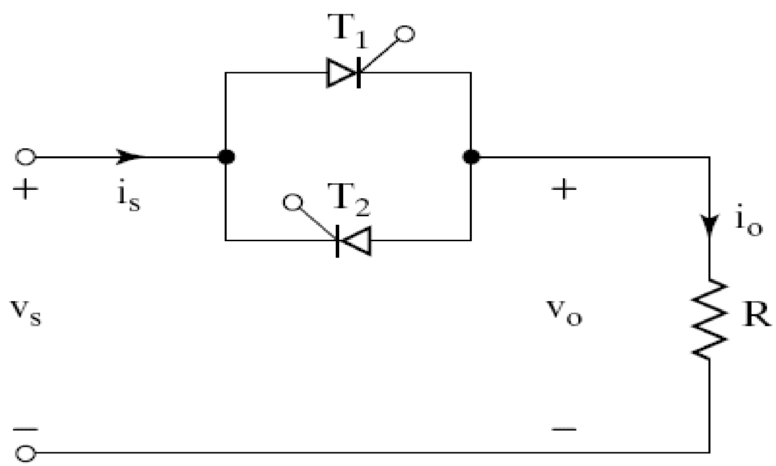


Fig.1.15: Single phase full wave ac voltage controller (Bi-directional Controller) using SCRs.

In Fig.1.15 the thyristor T_1 is forward biased during the positive half cycle of the input supply voltage. The thyristor T_1 is triggered at a delay angle of α ($0 \leq \alpha \leq \pi$ radians). Considering the ON thyristor T_1 as an ideal closed switch the input supply voltage appears across the load resistor R_L and the output voltage V_0=Vs during ωt=α to π radians. The load current flows through the ON thyristor T_1 and through the load resistor R_L in the downward direction during the conduction time of T_1 from ωt=α to π radians.
At ωt=π, when the input voltage falls to zero the thyristor current (which is flowing through the load resistor R_L) falls to zero and hence T_1 naturally turns off. No current flows in the circuit during ωt=π to (π+α).

The thyristor T_2 is forward biased during the negative cycle of input supply and when thyristor T_2 is triggered at a delay angle (π+α), the output voltage follows the negative half cycle of input from ωt=(α+α) to 2π. When T_2 is ON, the load current flows in the reverse direction (upward direction) through T_2 during ωt = (π+α) to 2π radians.

The time interval (spacing) between the gates trigger pulses of T_1 and T_2 is kept at π radians or 180^0. At ωt=2π the input supply voltage falls to zero and hence the load current also falls to zero and thyristor T_2 turn off naturally.

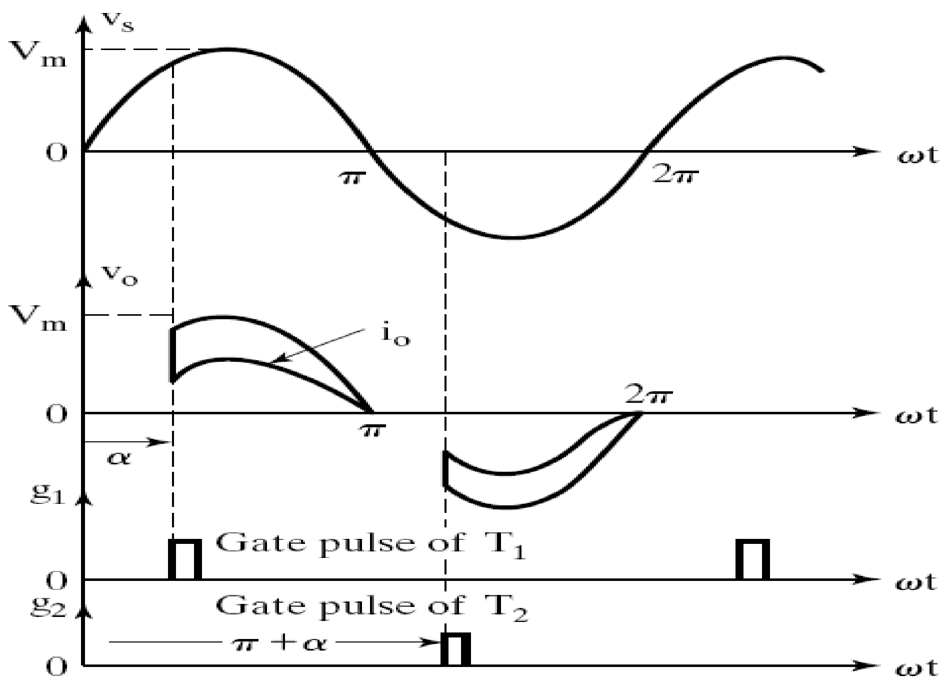


Fig1.16: Waveforms of single phase full wave ac voltage controller.

1.4.1.4 Full Wave Controlled Three Phase AC-AC Voltage Controller:

The circuit of a three-phase, three-wire ac regulator (termed as ac to ac voltage converter) with balanced resistive (star-connected) load is shown in Fig. 1.17. Two thyristors connected back to back are used per phase.

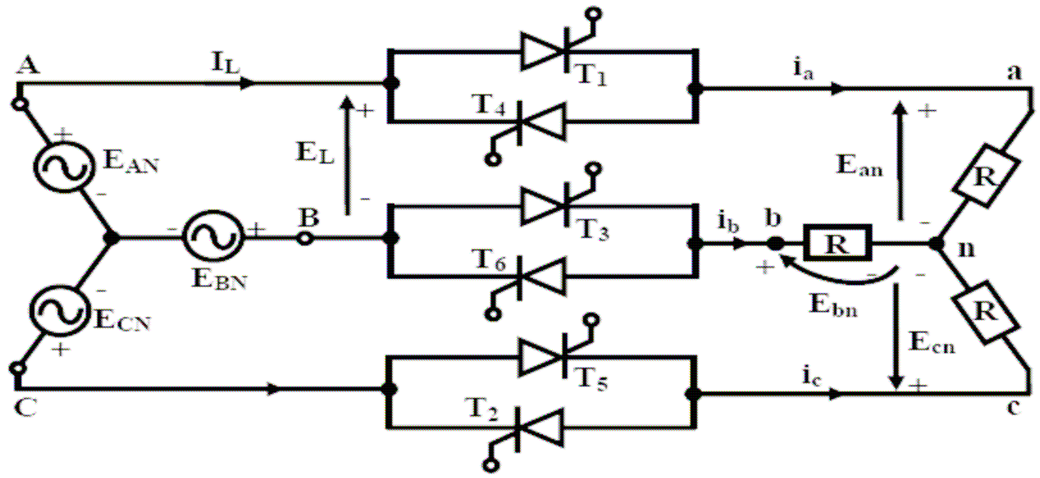


Fig.1.17: Three-phase, three-wire AC regulator.

1.5 Problem of Phase Angle Controlled AC-AC Voltage Controller:

Single and three phase angle controlled voltage controller have following limitation,

i. The converters are Buck type only,
ii. Input current, output voltage and output current of these converters are non-sinusoidal. The waveform are rich in low frequency harmonics which require large size filters and
iii. Due to non-sinusoidal nature of input currents, the input power factor of a phase controlled single or three phase AC-AC voltage controller is low.

To illustrate the above problems of phase controlled AC-AC voltage controllers typical waveform of single phase and three phase controlled voltage controller with tabular values of input current THD, input power factor, and rms output voltage are provided in section 1.5.1 and 1.5.2

1.5.1 Performance of a Single Phase AC-AC Voltage Controller (Phase Angle Controlled-Load Resistive)

The single phase thyristor based full wave voltage controller circuit is redrawn in Fig1.18

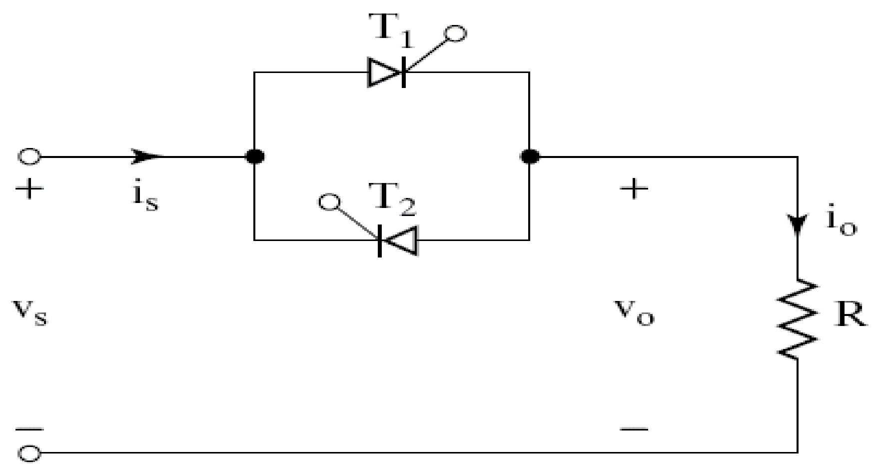


Fig.1.18: Single phase AC-AC voltage controller.

Figures 1.19 -1.26 depict the output voltages and input currents of a single phase voltage controller of Fig 1.18 for phase angles of 30^0 and 135^0 (resistive load). The spectrum for $\alpha=30^0$ and $\alpha=135^0$ are also shown in the Figures. Table 1.1 provides the performance of the voltage controller for $\alpha=15\text{-}165^0$ variation. Table shows that the THD of the input current of the controller increase from 6.33 to 250 for variation of firing angle through 15-165 degrees, whereas, the input power factor deteriorates from 0.81 to 0.21.

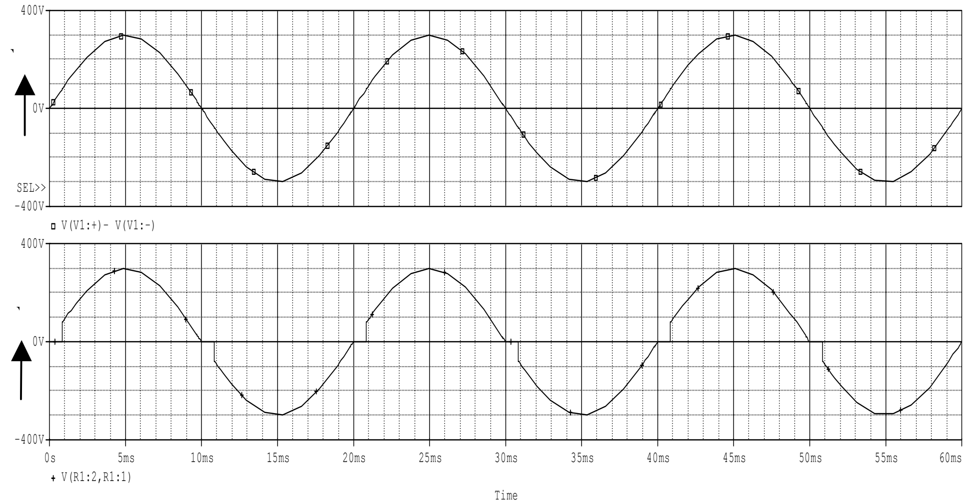


Fig. 1.19: Inputs and output vol ges of a single phase controlled AC-AC voltage Controller $\alpha = 30^0$

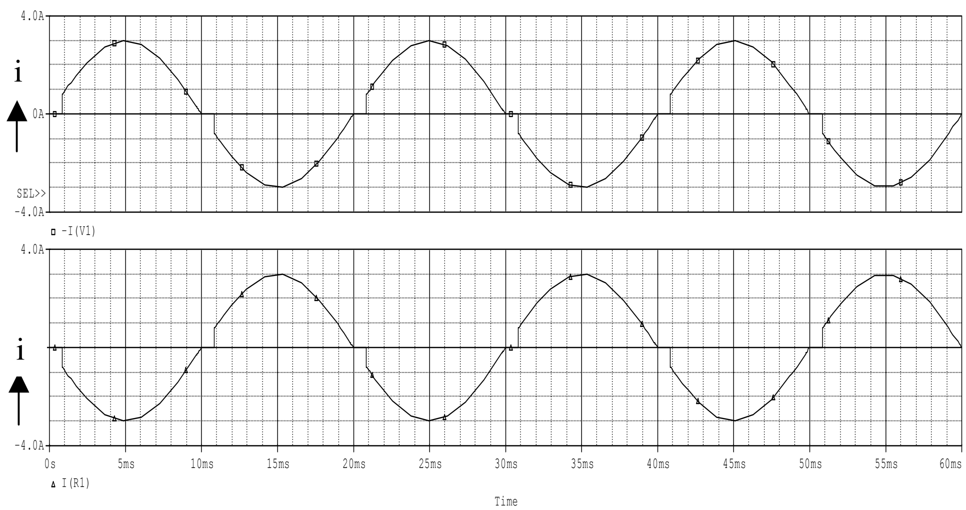


Fig. 1.20: Input and output current of ingle Phase controlled AC-AC voltage Controller $\alpha = 30^0$

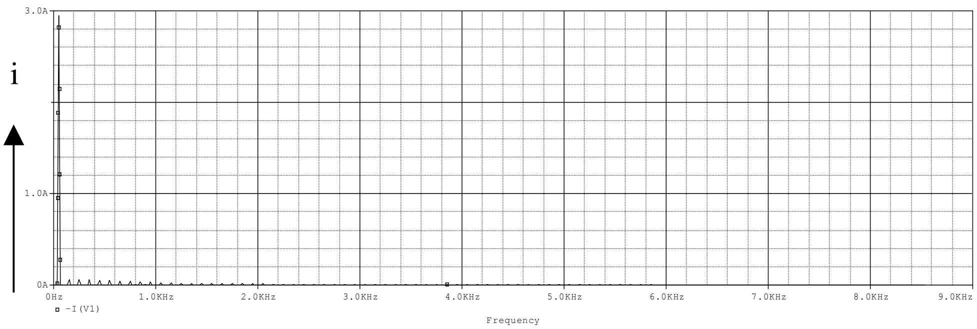


Fig: 1.21: Sp f f a single phase controlled AC- AC voltage
Controller α =30

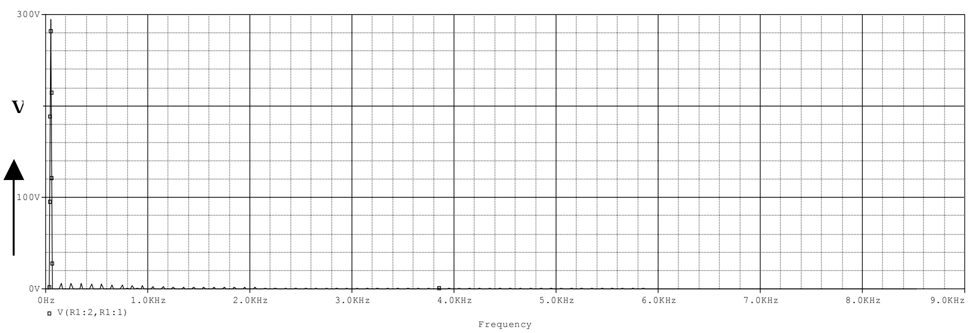


Fig. 1.22: Spec f a single phase controlled AC- AC voltage
Controller α =30

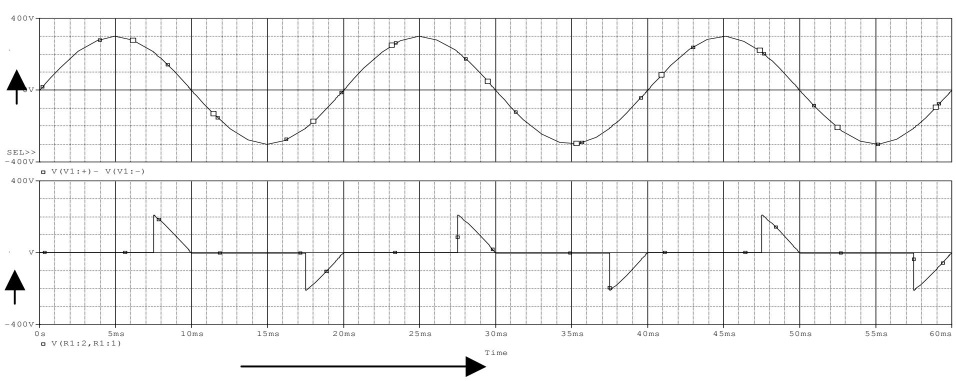


Fig.1.23: Inp single phase controlled AC-AC Voltage
Co

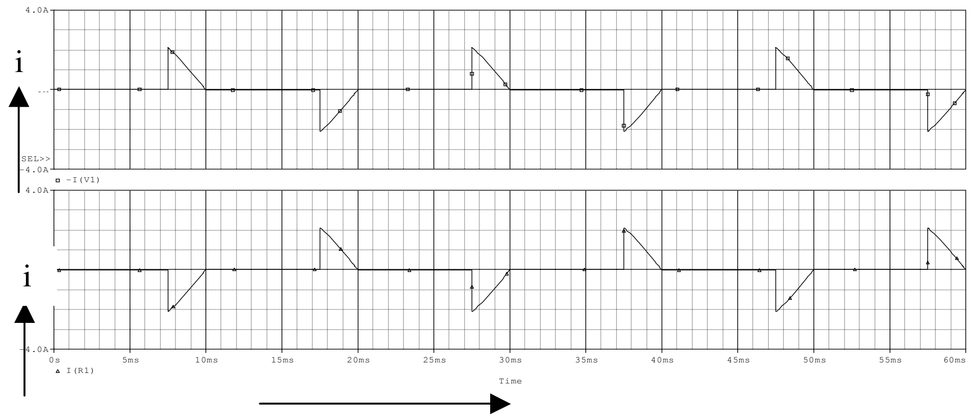


Fig 1.24 Inpu f ngle phase controlled AC-AC voltage
Controller α =135

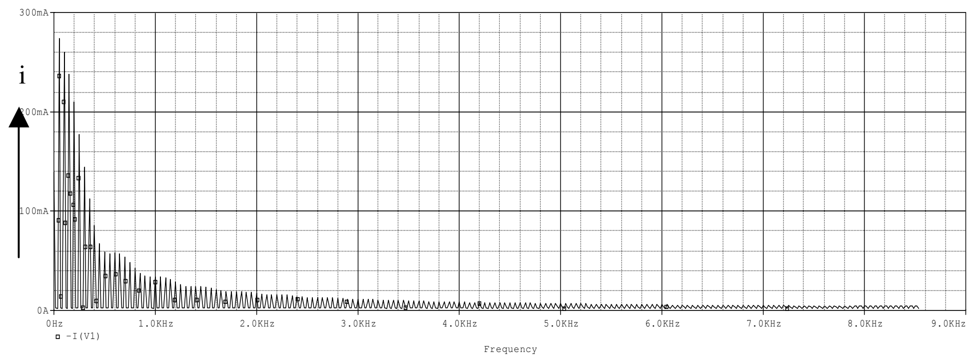


Fig: 1.25: Spectrum of input current of a single phase controlled AC- AC voltage
Controller α =135^0

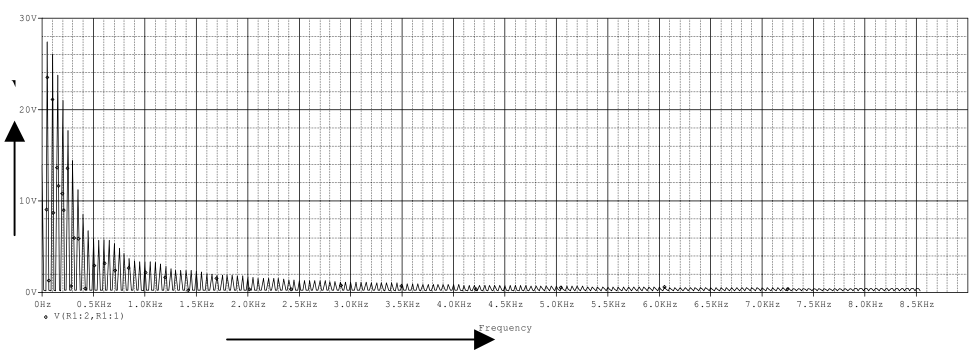


Fig. 1.26 f of a single phase controlled AC- AC voltage

Table: 1.1 Performance of a Single Phase Voltage Controller (Without Input and Output Filter) Load Resistor:

α	Vin (rms) Volt	Vout (rms) Volt	Iin (rms) Amp	Iout (rms) Amp	Input current THD	Input PF
15	212	207	2.12	2.07	6.33	0.81
30	212	209	2.09	2.09	15	0.797
45	212	203	2.01	2.03	25	0.759
60	212	191	1.88	1.91	37	0.701
75	212	172	1.73	1.72	49	0.642
90	212	150	1.5	1.5	66	0.575
105	212	124	1.24	1.24	83	0.511
120	212	89	0.89	0.89	100	0.447
135	212	45	0.46	0.45	196	0.27
150	212	26	0.26	0.26	195	0.257
165	212	12	0.12	0.12	250	0.2

1.5.2 Performance of a Three Phase AC-AC Voltage Controller (Phase Angle Controlled-Load Y connected Resistive)

An SCR based three phase ac voltage controller is redrawn in Fig 1.27. Figures 1.28-1.35 show the output voltages and input currents of a three phase controlled voltage controller of Fig 1.27 for firing angle 30 and 135 degrees (resistive load). The spectrum of input current and output waveforms for $\alpha=30^0$ and $\alpha=135^0$ are also shown in the Figures. Table 1.2 show the performance of the phase angle controlled these phase voltage controller for α=15 to 165 degrees. Table shows that the THD of the input current of the voltage controller increases from 6 to above 180 for variation of $\alpha=30^0$ to $\alpha=135^0$ degrees. Whereas, the power factor during the same α variation decreases from 0.98 to below 0.2.

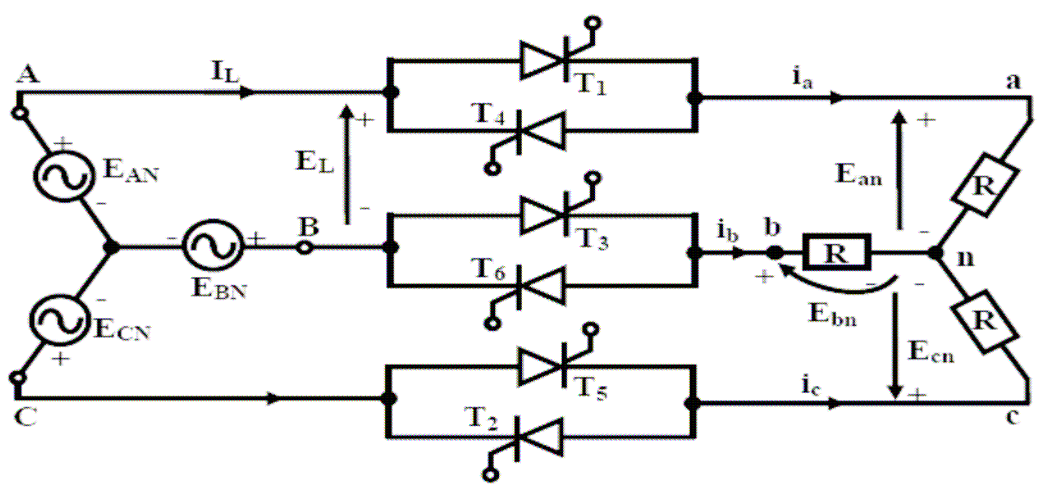


Fig. 1.27: A three phase AC-AC voltage controller.

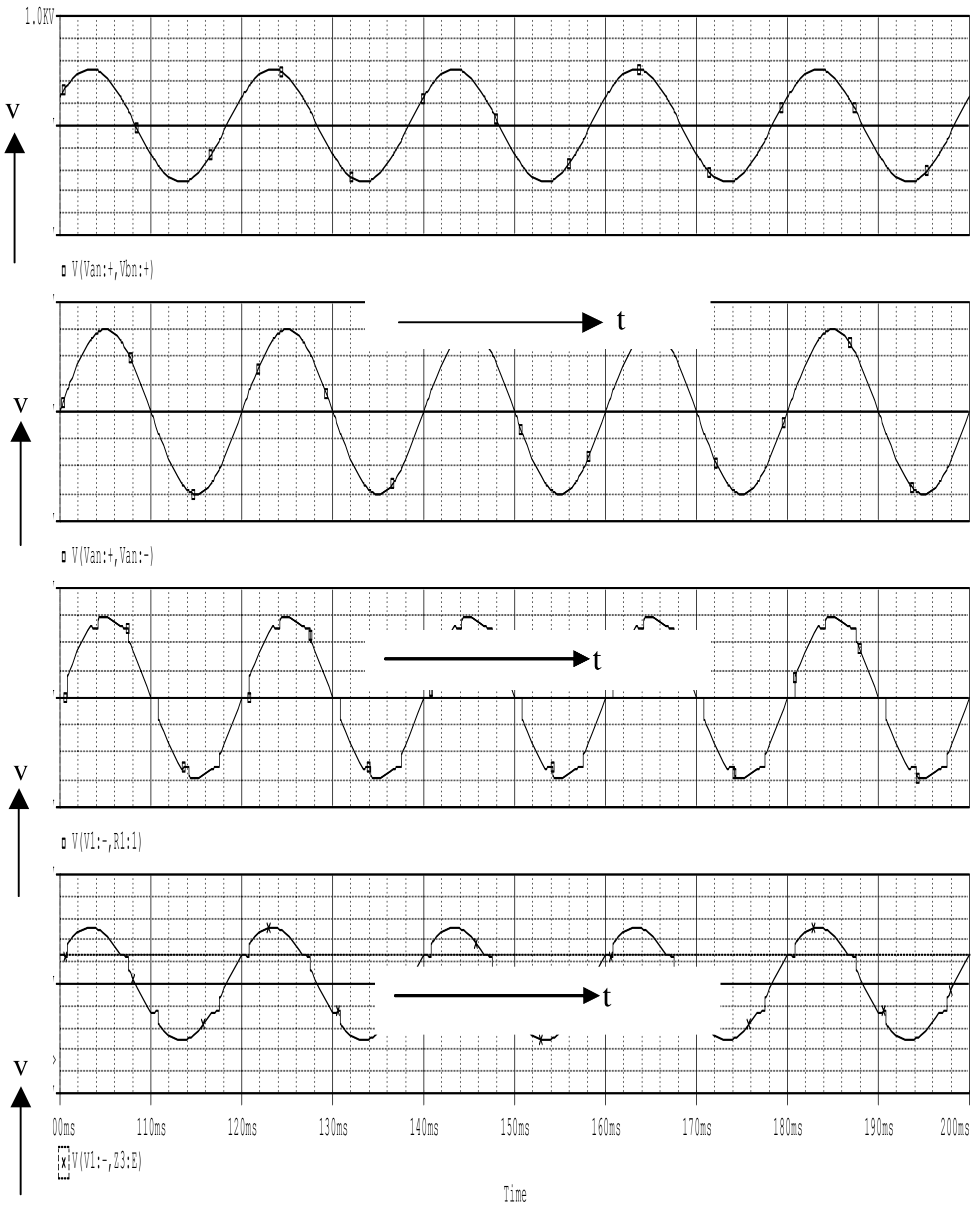


Fig.1.28: Input, output (L-N) and output (L-L) voltage of one phase of phase Controlled 3- phase voltage controller $\alpha = 30^0$

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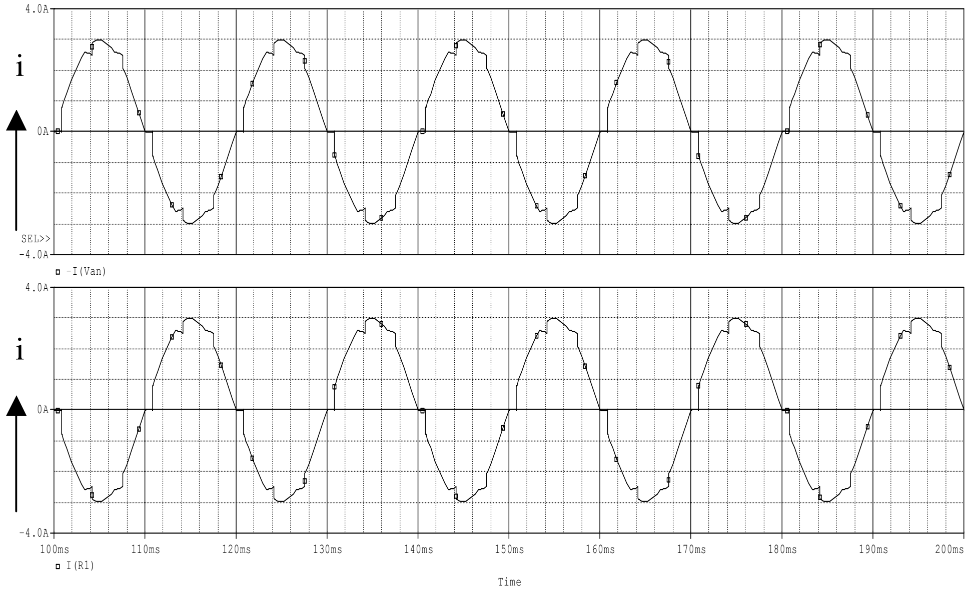
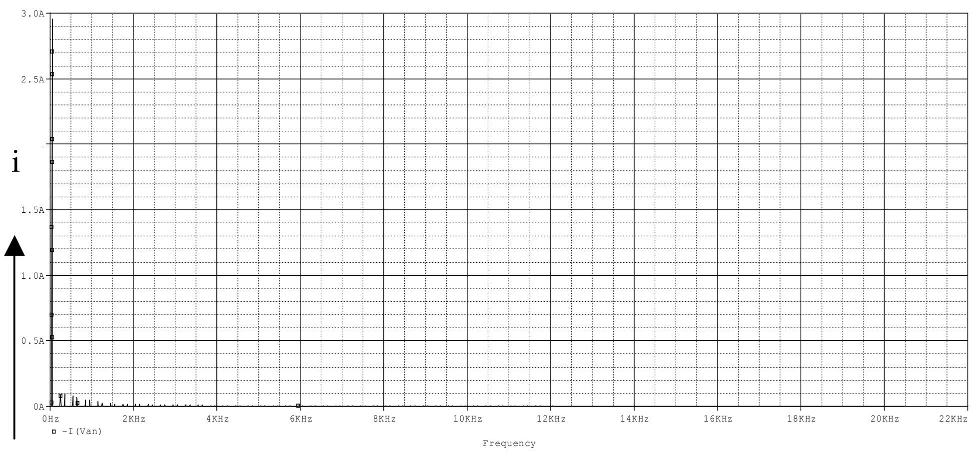


Fig.1.29: Input, output current of a phase controlled 3 phase voltage controller

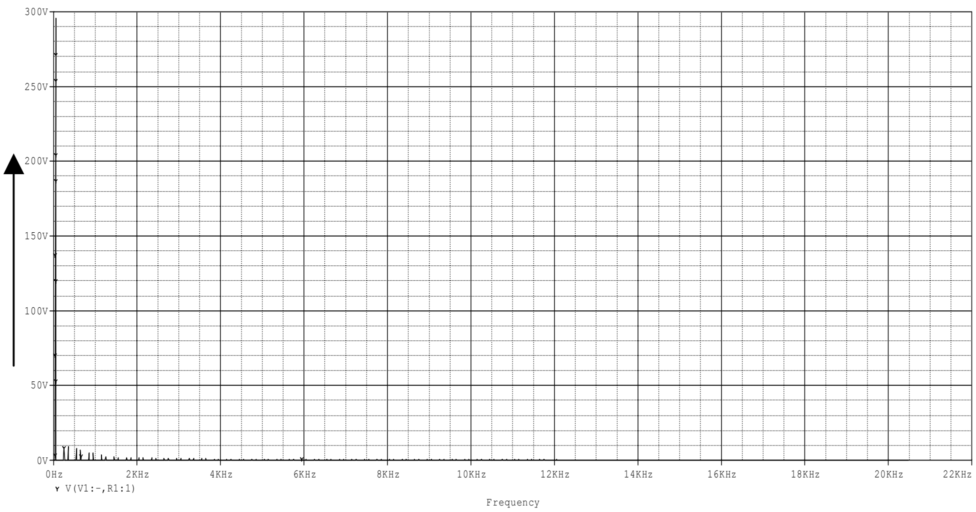
$\alpha = 30^0$ ⟶ t



⟶ f

Fig. 1.30 of a phase controlled three phase AC-A C

Voltage controller α =30



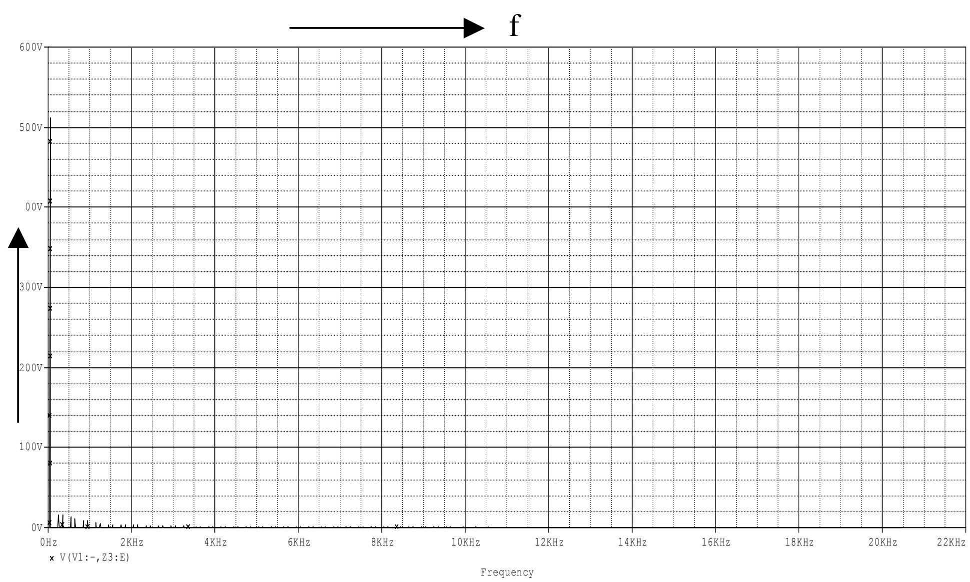


Fig. 1.31: Spectrum of L-N and L-L f ɔut voltages of a phase controlled three phase AC-AC voltage controller $\alpha = 30^0$

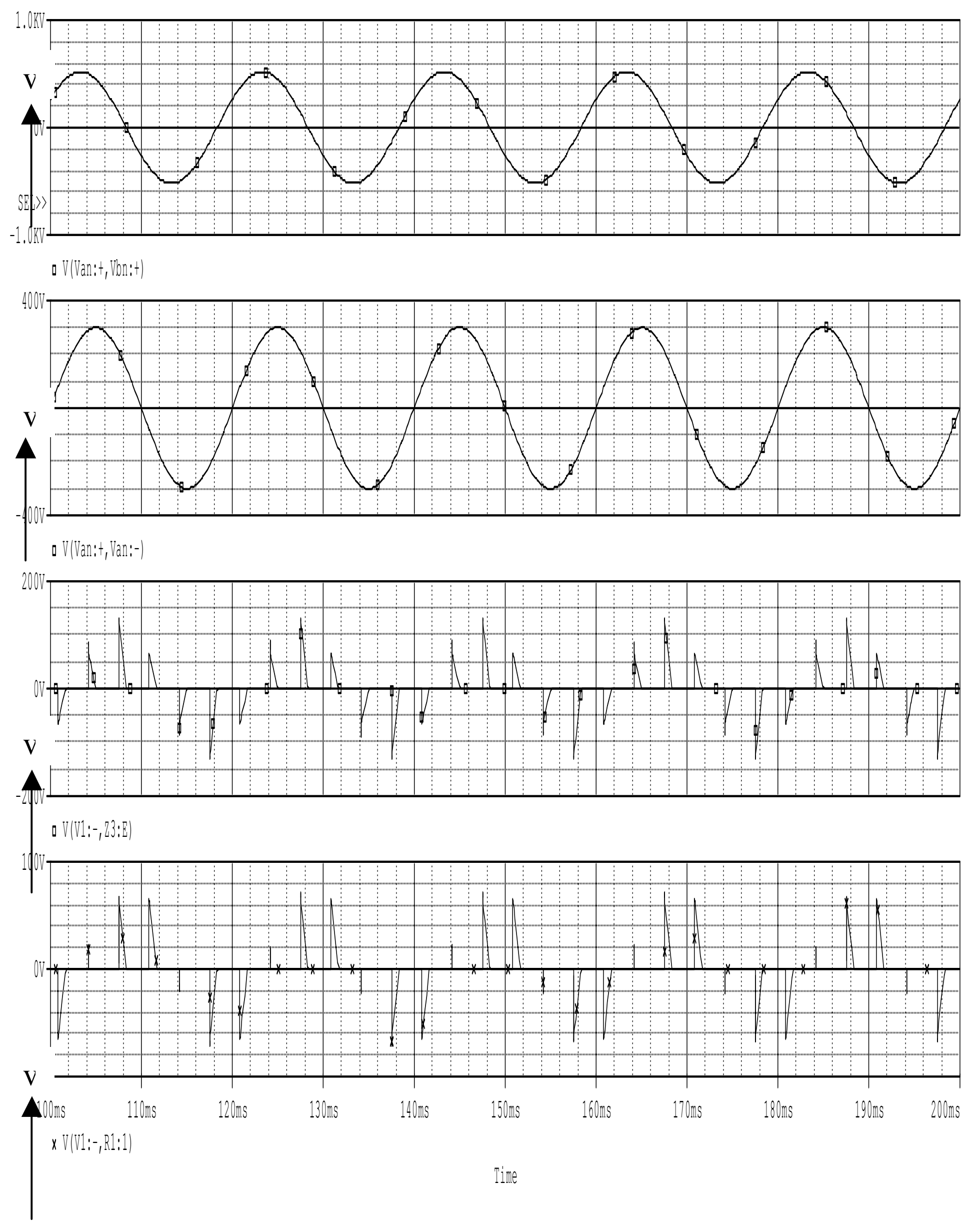
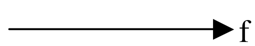


Fig. 1.32: Input, output (L-N) and output (L-L) voltage of one phase of phase controlled Three phase voltage controller $\alpha = 135^0$



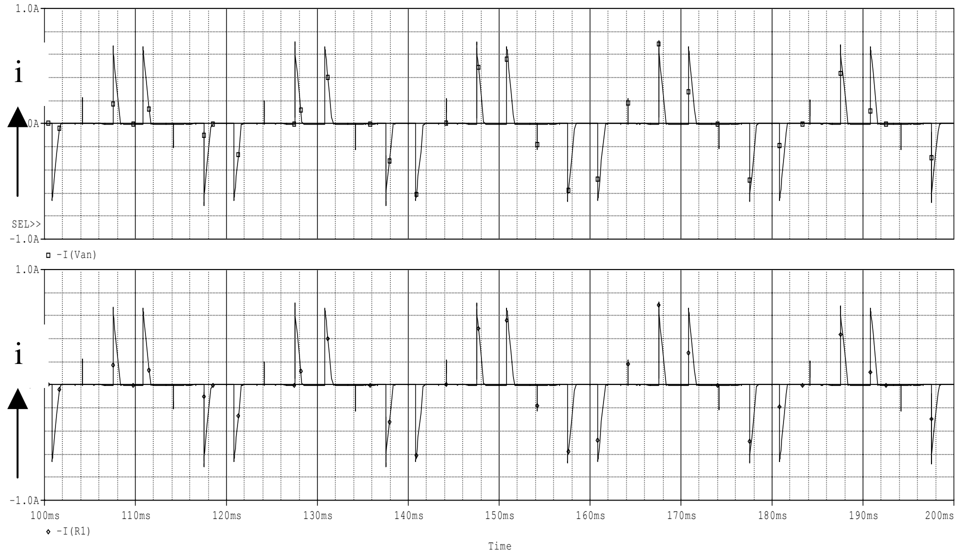


Fig. 1.33: Input, output current of a phase controlled 3 phase voltage controller $\alpha = 135^0$

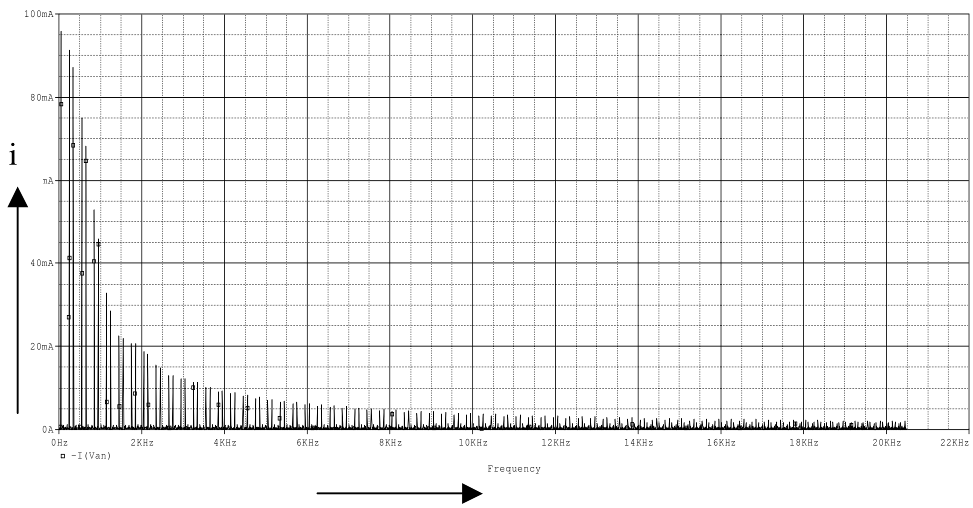
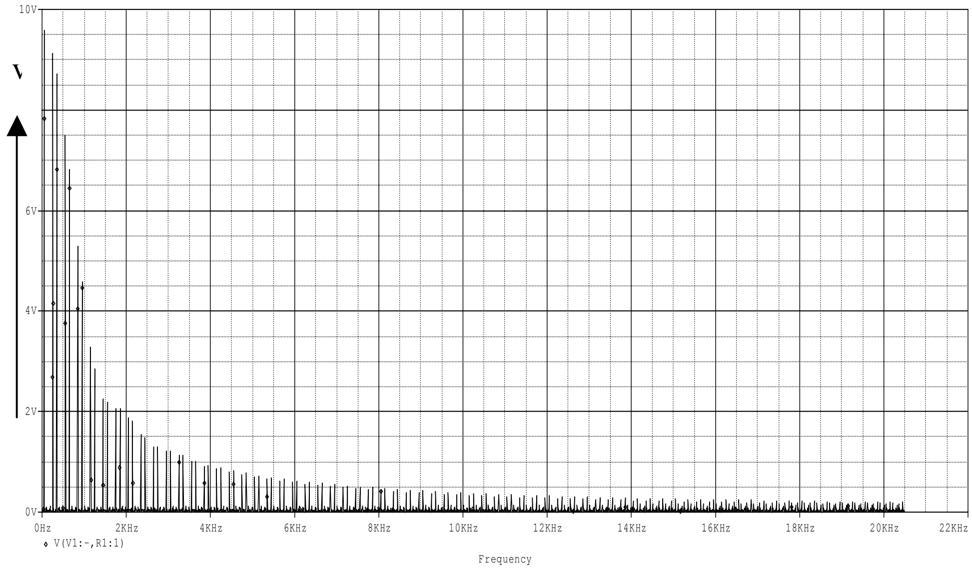


Fig. 1.34: Spectrum of input current of a phase controlled three phase AC-AC Controller $\alpha = 135^0$



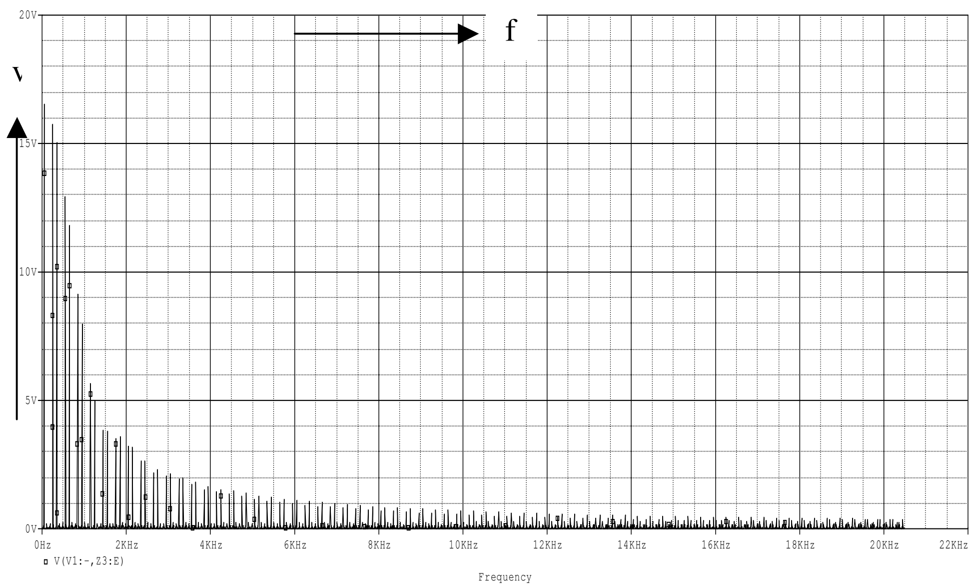


Fig. 1.35: Spectrum of L-N and L-L output voltages of a phase controlled three phase AC-AC voltage contr f $\alpha = 135^0$

Table: 1.2 Performance of a Phase Controlled Three Phase Voltage Controller (Without Input and Output Filter- Load Y Connected Resistive):

α	Vin(L-N) rmsVolt	Vout(L-N) rmsVolt	Iin(rms) Amp	Iout(rms) Amp	Input Current THD	Input PF
15	212	209	2	2	6	0.98
30	212	206	2.06	2.06	16	0.96
45	212	194	1.94	1.94	27	0.9
60	212	166	1.66	1.66	34	0.68
75	212	147	1.47	1.47	42	0.66
90	212	113	1.13	1.13	60	0.5
105	212	135	0.77	0.77	82	0.33
120	212	50	0.506	0.506	123	0.178
135	212	15.86	0.16	0.16	192	0.16
150	212	0.118	0.0019	0.0019	664	0.15
165	212	0.042	0.000427	0.000427	29	0.24

1.6.1 Objectives and Methodology of Research of the Thesis:

Conventional SCR based integral cycle and phase controlled voltage controllers have power quality problems like high input current THD and low input power factor at low voltage output. They are buck (step down) type voltage controllers and their control is complex in pwm mode. It is desirable that power converters be composed of as small number of switches as possible and their control should be simple. With a view to minimize the disadvantages of current single phase voltage controllers, a Boost topology based AC voltage regulator will be investigated in this research. The proposed topology will be derived from two switch boost ac-ac converter. Two switch mode ac-ac converters of various configurations have been investigated in the past. But it seems that only the boost configuration may have the possibility of reducing the switch number to one. The propose converter will differ from the previously reported circuits in positioning the switch at the input and the switch being bi-directional. The switch in the input will ensure input current chopping at high frequency and current in phase with the input voltage. In previously reported circuits, one switch was the main chopping switch, whereas, the second switch was the freewheeling switch. The two switches were turned ON and OFF alternately for all the time of operation of power converters. Both two switch and one switch single phase boost ac-ac converter is expected to be investigated in the research, where in the one switch boost ac-ac converter the freewheeling bidirectional switch will be replaced by a bidirectional freewheeling diode.

Input Power factor, input current, total harmonic distortion (THD) and efficiency of the proposed circuits will be investigated and it is expected that the performance of them will good in terms of input current THD, Input power factor, output voltage shape, efficiency and size of the converter. at different duty cycles. Performance study of the proposed boost single phase ac voltage controllers will be carried out by simulation with ORCAD pspice software.

The circuit can be used in low and medium power applications. The main advantage of the new AC-AC converter will be its superior power quality, buck-boost voltage and current gain capability and light weight.

1.7 Outline of the Thesis:

Chapter I introduces the thesis topic. Overviews of DC and AC Voltage regulators are provided. This chapter contains the objective and outline of the thesis.

Chapter II addresses the harmonics and power factor of the proposed circuit. Total harmonic distortion, causes of low efficiency, inter relationship between THD, power factor and efficiency of power converters are outlined in this chapter.

Chapter II also presents the performance study results of two switch and proposed one switch AC-AC Boost converters. Analysis and observations are discussed in this chapter.

Chapter III draws the conclusion of this work. This chapter puts forward suggestions for future scopes of works related to this thesis.

CHAPTER-II

SINGLE-PHASE, SINGLE-SWITCH AC-AC BOOST CONVERTER.

The Boost topology of dc-dc converters can be adopted for single phase AC-AC voltage controller. The proposed single phase voltage controller would reduce the problem of single phase voltage controllers, particularly the problems of harmonics retaining the efficiency of the converter. Also the input power factor will improve. The benefits will also allow the Buck and Boost operation of the voltage controller. The investigation includes with harmonics study in voltage controllers, discussion on power factor improvement and the description of the proposed Boost ac-ac converter of 2-switch and 1-switch topologies.

2.1 Harmonics and their Effects:

Harmonics can be defined as sinusoidal components of a periodic no sinusoidal wave having frequencies which are integral multiple of the fundamental frequency. Harmonics causes distortion in a waveform.

Harmonics are problem in electric power systems and their presence is increasing in power system because of the increase of nonlinear loads such as power electronic equipment. Harmonics can cause a number of unwanted effects. Electric utility transmission and distribution equipment may be adversely affected by ac line harmonics which may cause higher transformer loss, capacitor failure, and failure of protective relay operation etc. When connected to an ac line which has severe harmonics; sensitive loads may malfunction. The power line harmonics can be coupled to the communication circuits by either induction or by direct conduction and cause interference with communication circuits.

2.2 Power Factor and Power Factor Improvement: [41-42]

Power Factor (PF) is the ratio of the real/working power to apparent power. The power factor can vary between 0 and 1, and can be either inductive (lagging) or capacitive (leading).

The advantages of having high power factor are:

a) Voltage distortion is reduced,
b) the power is predominantly active,
c) Smaller rms current,
d) More loads can be fed and
e) Helps to preserve harmonic pollution.

Power Factor Correction (PFC) circuit helps to minimize the input current distortion and make the current is nearly in phase with the voltage. When the power factor is not equal to 1, the current waveform does not follow the voltage waveform. This not only cause power loss but also results harmonics that travel down the line and disrupt other devices connected to the line. The input stage of AC-AC and AC-DC converters comprise of switching circuit. The input current of such circuits create discontinuous current which causes input current distortion. Input current distortion and input power factor may be improved by either passive method or by active methods. The passive filter method use inductive filter at the input [43]. The active PFC techniques use switching converters between the converter and load in [43]. Harmonic current injection method is also used as active PFC for ac-dc and ac-ac converters [43]. In order to adopt active power factor correction and harmonic distortion reduction in single phase voltage controller the technique of switching power conversion may be adopted.

In this research AC-AC boost conversion method is adopted for single phase voltage control across load and PFC purposes.

AC Boost voltage regulator is a modified version of the dc-dc Buck-Boost converter to work with ac voltage as input and ac voltage as output. This regulator provides output voltage less or greater than the input voltage.

The advantages to be gained by this voltage controller will include nearly sinusoidal current/voltage waveforms, improved input power factor, elimination of the low order harmonics and small input–output filter. A single bidirectional switch is used which chops the ac in both the positive and negative cycle at high frequency By utilizing boost conversion principle step-up/step-down regulated output voltages are obtained with reduced circuit components.

2.3: Single Phase Boost AC-AC Converter With Two Bi- Directional Switches (Without Input Filter):

The single phase ac-ac boost converter proposed in this research is shown in Fig 2.1.It consists of two bi-directional switches composed of diode bridge and an unudirectional switch. In this circuit the input V1 is an ac source. Inductor L is the boost inductor and R_L is the load resistor. The operation of the circuit of Fig 2.1 is explained with Figures 2.2-2.5. During positive cycle of the supply switch S1 and S2 alternately turned ON and OFF

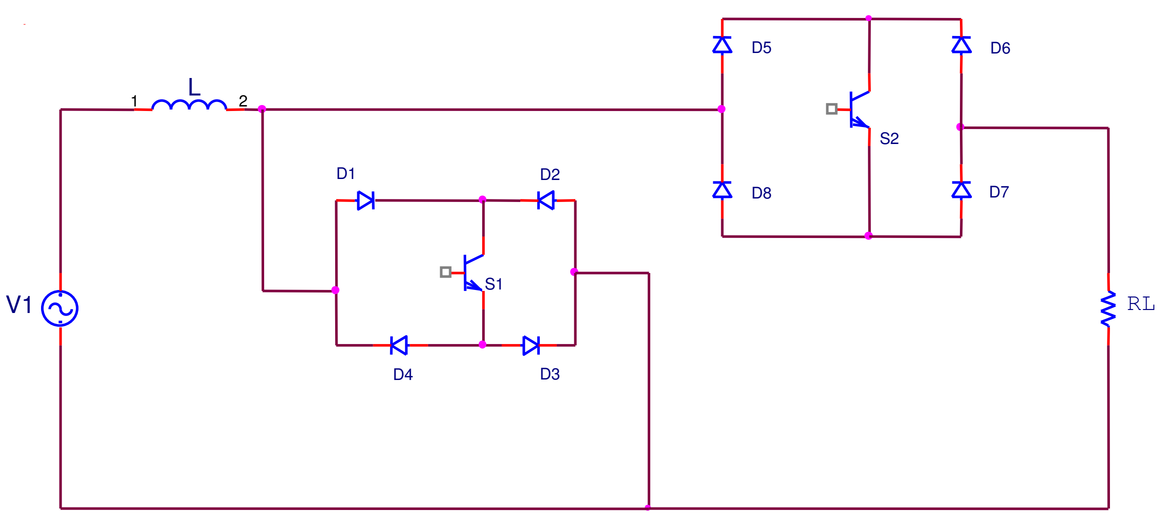


Fig. 2.1: Single phase circuit with two bi-directional switches (S1 and S2)

Mode 1: When switch S1 is ON and S2 is OFF, current flows from source-source via boost inductor L and switch S1 while current path via load is broken due to switch S2 being OFF (Fig 2.2)

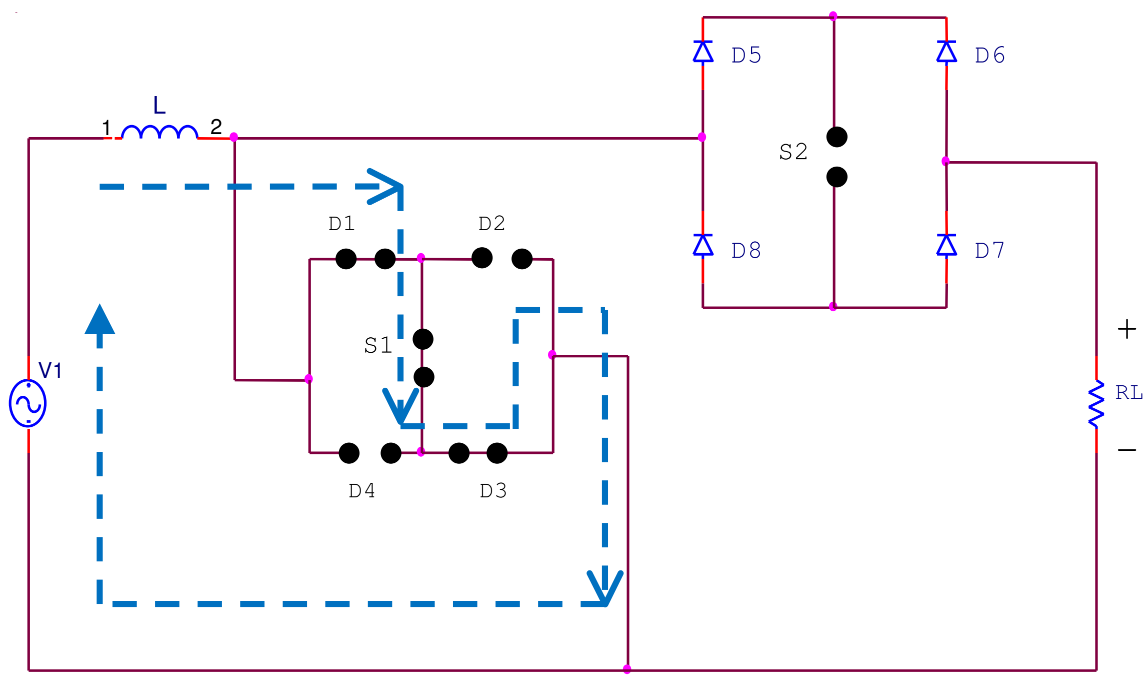


Fig. 2.2: Circuit of Fig 2.1 during positive cycle when switch S1 is ON and switch S2 is OFF

Mode 2: When switch S1 is OFF and S2 is ON, current flows from source to source via boost inductor L, switch S2; load R_L (Fig 2.3.). As a result input voltage and boost inductor voltage appear across R_L, the instantaneous value of which is more than the input voltage.

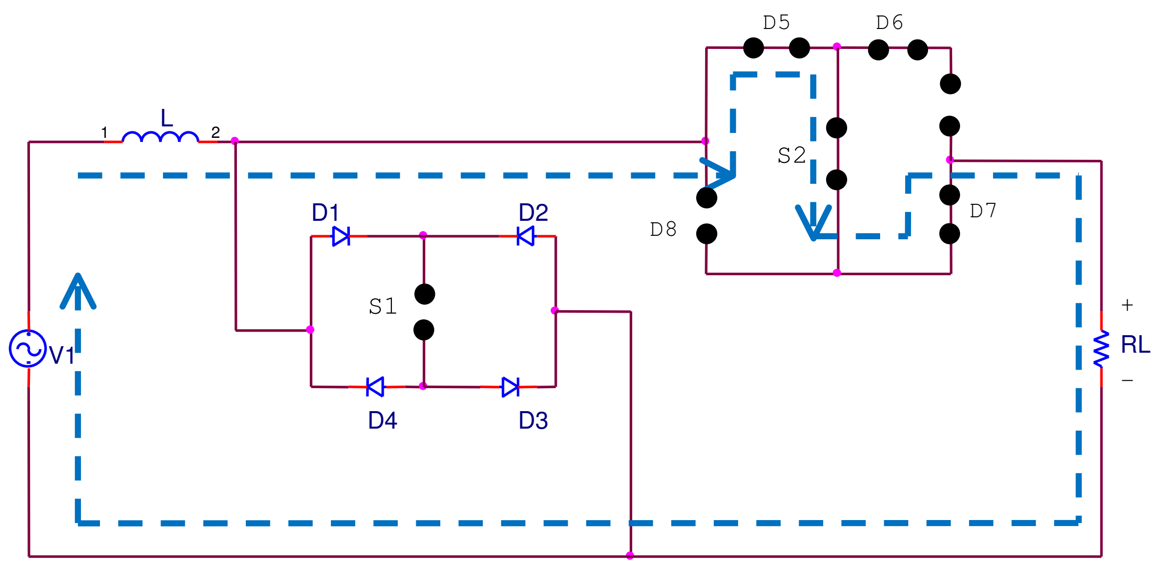


Fig. 2.3: During positive cycle when switch S1 is OFF and switch S2 is ON

During negative cycle of the supply: switch S1 and S2 alternately turned ON and OFF.

Mode 3: When S1 is ON and S2 is OFF during negative cycle of the input voltage, current flows from source to source via switch S1 and boost inductor L while no current flows through load R_L because switch S2 is OFF [Fig 2.4]

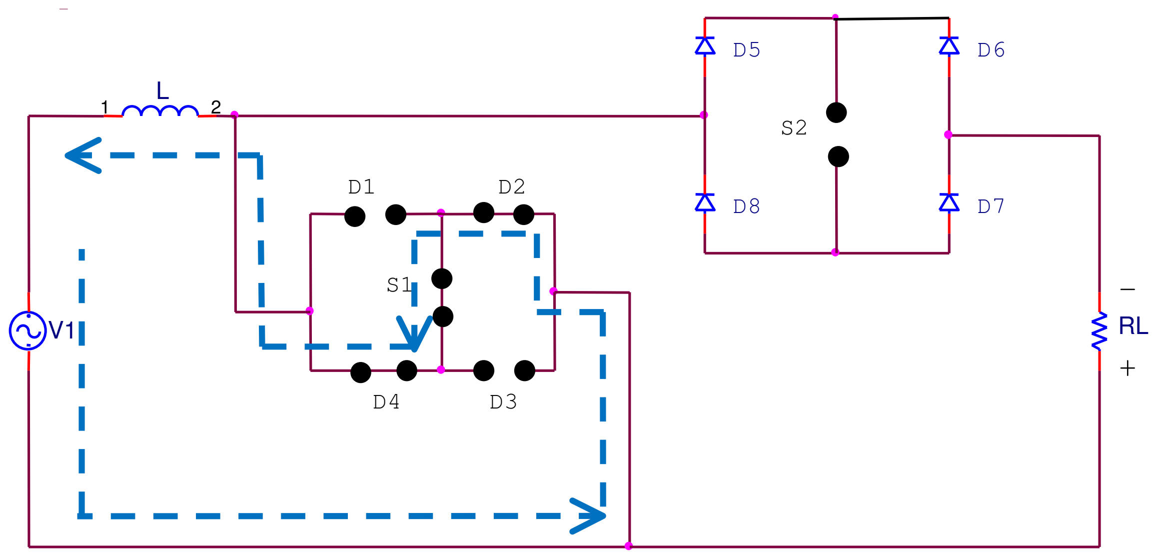


Fig. 2.4: Circuit of Fig 2.1 during negative supply cycle when S1 is ON, S2 is OFF

Mode 4: When S1 is OFF and S2 is ON, during negative cycle of the input ac, current flows from source to source via load resistance R_L and switch S2 and no current flows through switch S1. During this mode negative input voltage and negative inductor voltage appear across load resistor R_L give boost to the instantaneous voltage across [Fig 2.5]

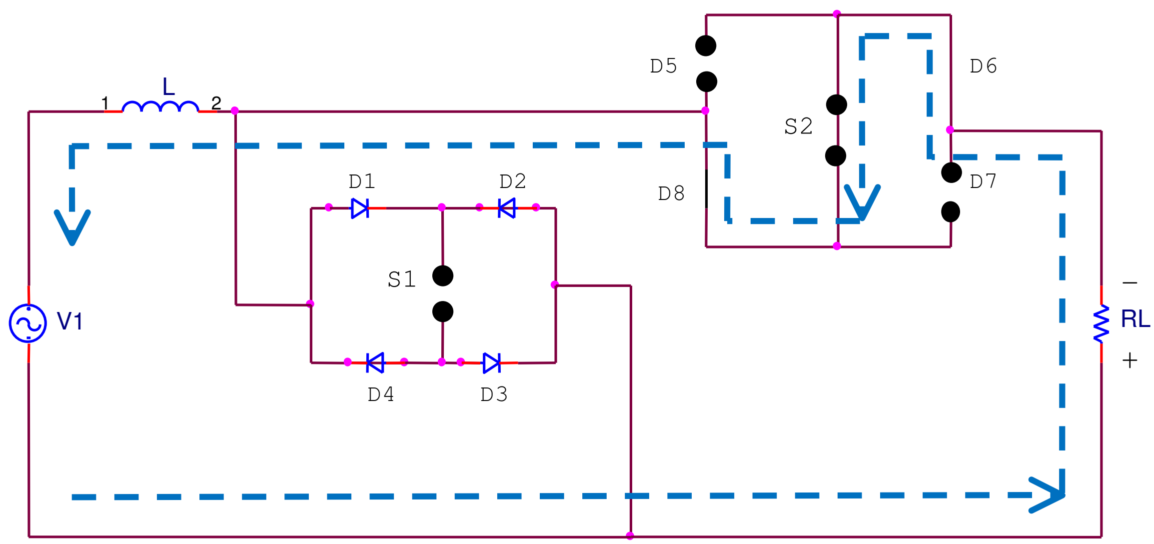


Fig. 2.5: Circuit of Fig 2.1 during negative supply cycle when S1 is OFF, S2 is ON

2.4 Proposed One Switch Boost AC-AC Converter (Without Input Filter):

The single phase ac-ac boost converter proposed in this research is shown in Fig 2.6. It consists of one bi-directional switch S1 and one bi-directional freewheeling diode instead of switch S2 of 2.1. In the circuit V1 is the input ac source. In the boost inductor and R_L is the load. The operation of the circuit of Fig 2.6 is explained with Figures 2.7-2.10

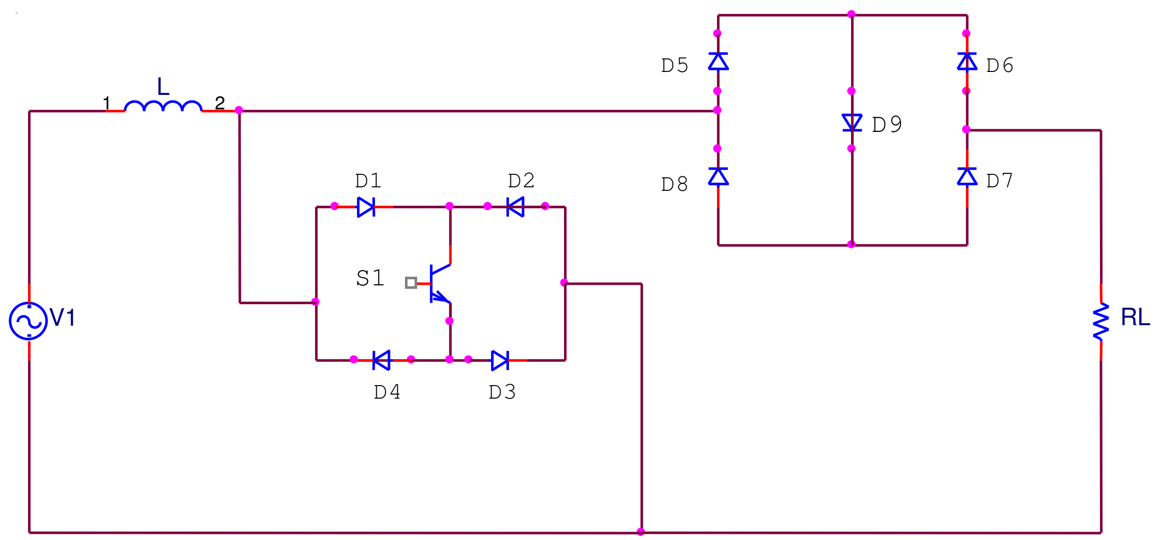


Fig. 2.6: Single phase boost AC-AC circuit one bi-directional switch and one Bi-Directional Diode.

During positive cycle of the supply switch S1 is turned ON and OFF:

Mode 1: When switch S1 is ON and bi-directional freewheeling diode is reverse biased, current flows via boost inductor L and switch S1 while current path via load is broken due to freewheeling diode is reverse biased [Fig 2.7]

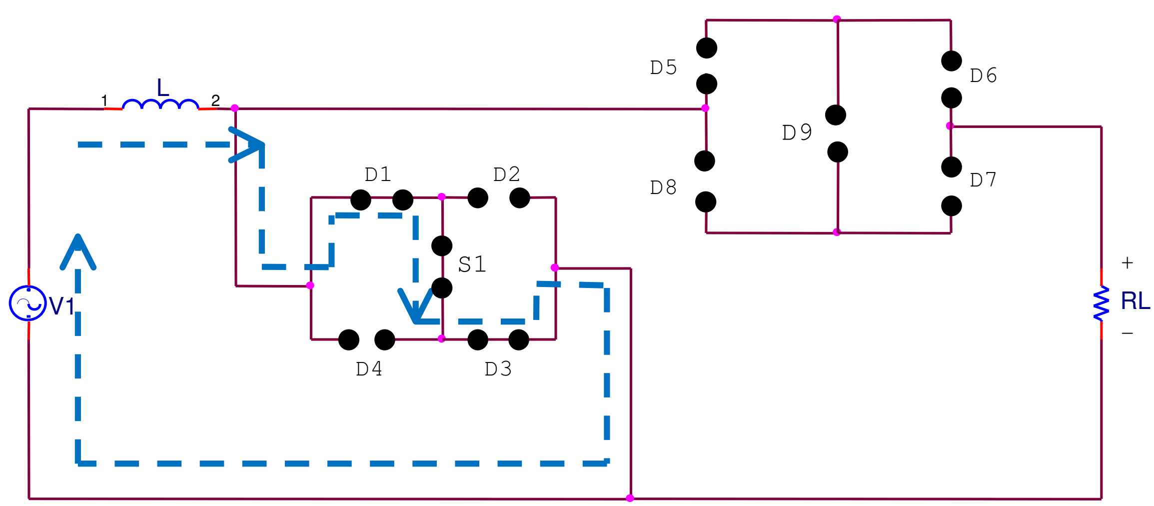


Fig. 2.7: Circuit of Fig 2.6 during positive supply cycle when S1 is ON

Mode 2: When switch S1 is OFF, input voltage plus inductor voltage forward biased the freewheeling diode and current flows from source to source via freewheeling diode and load R_L [Fig 2.8]. As a result input voltage and boost inductor voltage together appears across the load resistor R_L.

During negative cycle of the ac supply at input ,S1 is continuously turned ON/OFF and freewheeling bi-directional diode is alternately reverse and forward biased, the circuit modes are,

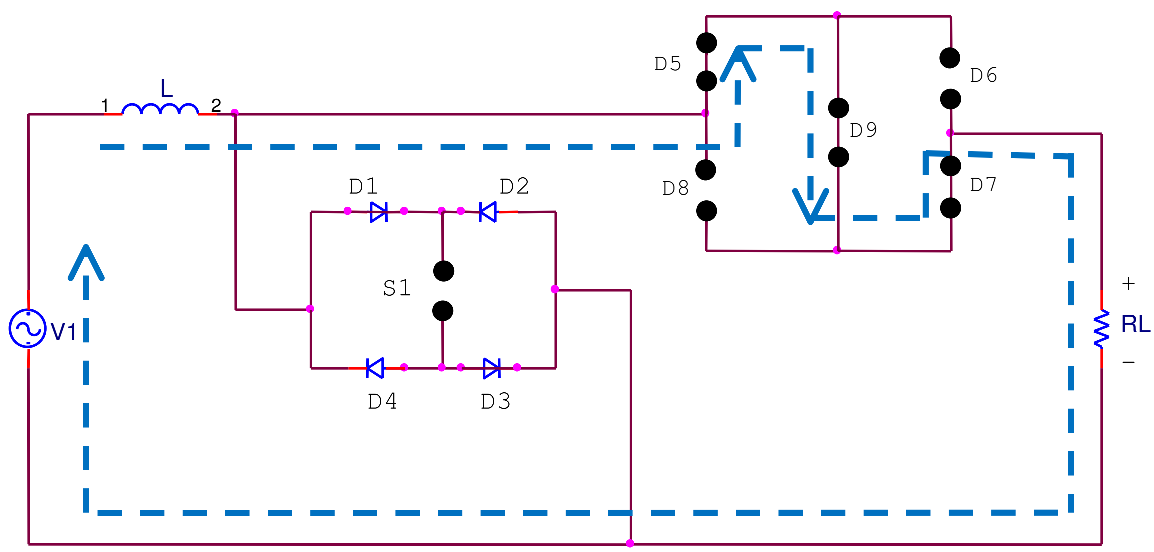


Fig. 2.8: Circuit of Fig 2.6 during positive supply cycle when S1 is OFF

Mode 3: When S1 is ON and freewheeling diode is reverse biased, current flows from source to source via switch S1 and boost inductor L. The path through freewheeling diode and load is broken; boost inductor current increases and inductor voltage increases [Fig 2.9]

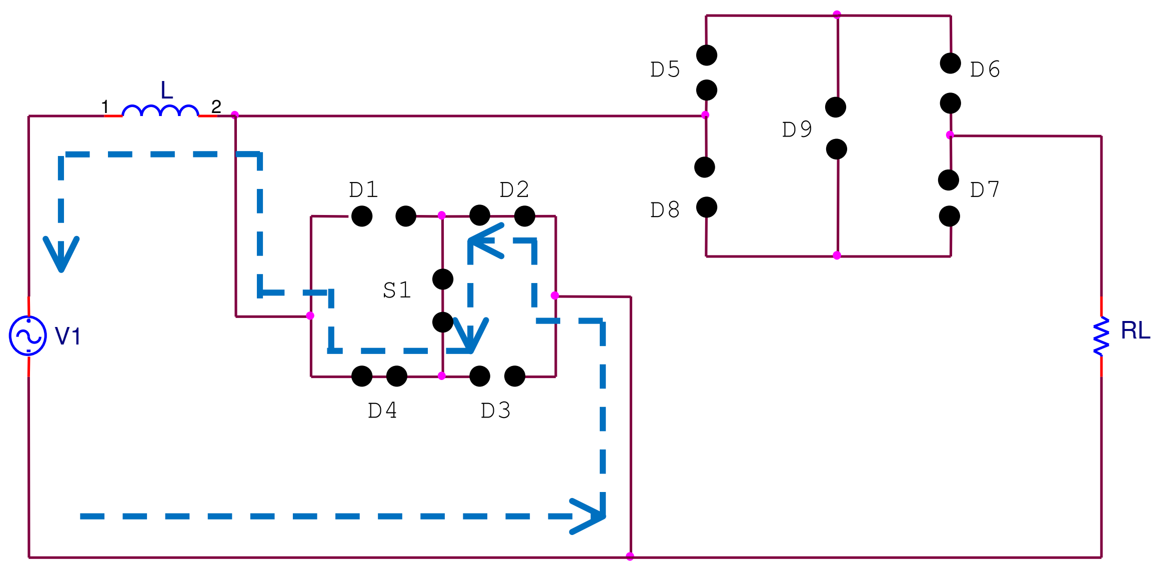


Fig. 2.9: Circuit of Fig 2.6 during negative supply cycle when S1 is ON

Mode 4: When switch S2 is OFF, the freewheeling bi-directional diode becomes forward biased and current flows from source to source via boost inductor L and load resistance R_L. Input voltage plus inductor voltage is impressed across the load resistor R_L is opposite direction [Fig 2.10]

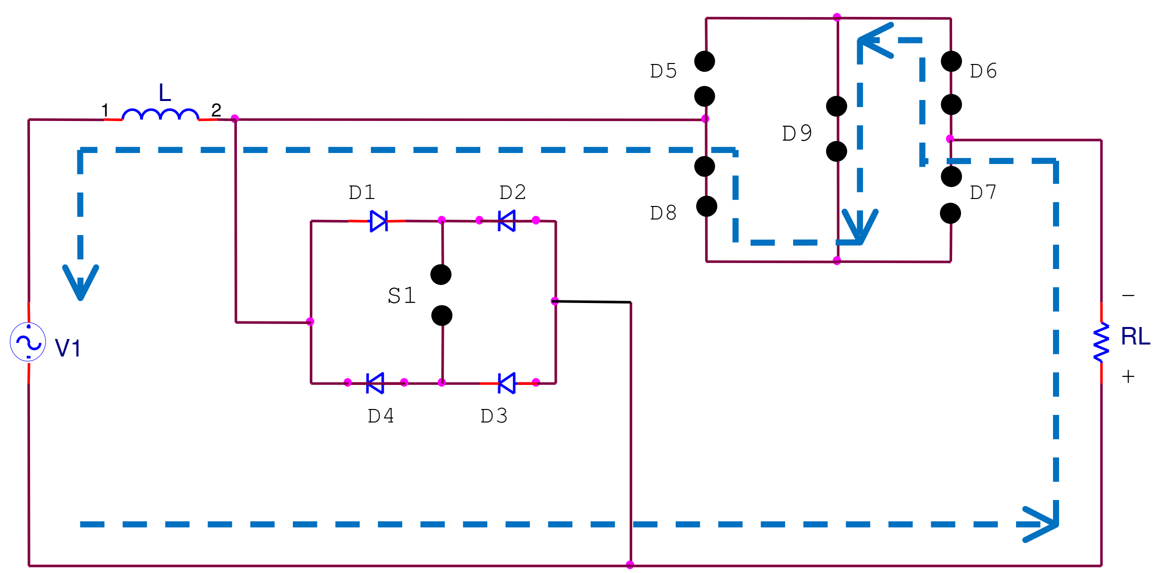


Fig. 2.10: Circuit of Fig 2.6 during negative supply cycle when S1 is OFF

2.5 Simulation of Two-Switch AC-AC Boost Converter:

In the simulation study, the circuit of Fig 2.11 for two switch single phase boost ac-ac converter is used.

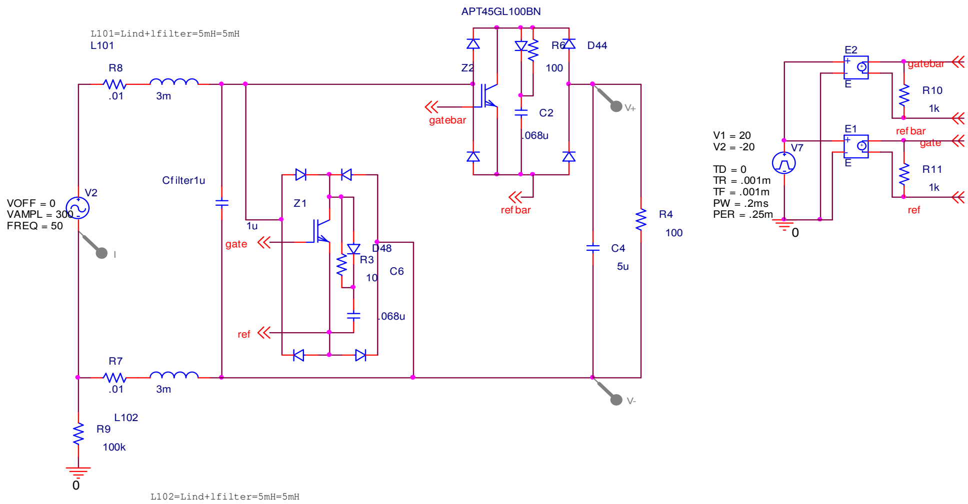


Fig.2.11: Simulation Circuit of Two switches Boost AC-AC Converter.

The bi-directional switch of Fig. 2.11 consists of an IGBT (Z_1) and four diodes. It also has snubber circuit consisting of a diode, a capacitor and a resistor across it as shown in the Fig. 2.11. At the gate of the IGBT parallel R-C is provided for ensuring fast switching of the IGBT. For performance study following expressions have been used for calculation of output power, input power, input power factor and efficiency of the converter at different duty cycles,

Input Power = Average ( )

Output Power = Average ( )

Input Power factor = (Input power) / (Input VA)

Efficiency =

The THD of the input current and Spectrum of the input current are obtained from ORCAD simulation output file. Simulation is carried out for duty cycles of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7. Typical output-Input voltages, Input current and Spectrum of input current are shown in Fig 2.21 to 2.23 for duty cycles D=0.2, D=.5, D=.6 and D=0.7 . The performance summary is provided in table 2.1. For duty cycle variation of the two switch Boost ac-ac converter the THD of input current is always below 11.5%. The input power factor of the circuit is above 0.8 for duty cycle between 0.2 and 0.7. However, input power factor falls below 0.7 above duty cycle 0.7. The efficiency of the circuit is between 60-67% and it needs to be improved. Investigation should be continued to improve the efficiency beyond 90%. Fig. 2.24-2.27 are graphical illustrations of data of Table 2.1

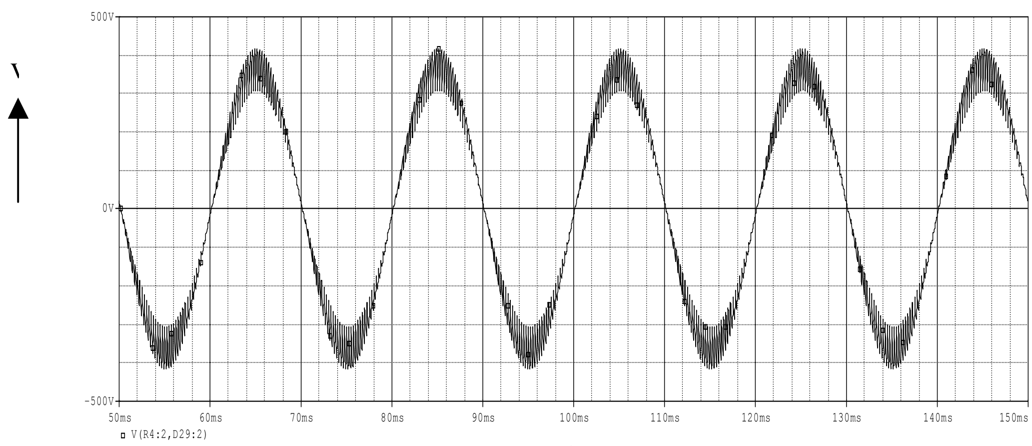


Fig. 2.12: Output volt: for duty cycle D= 0.2

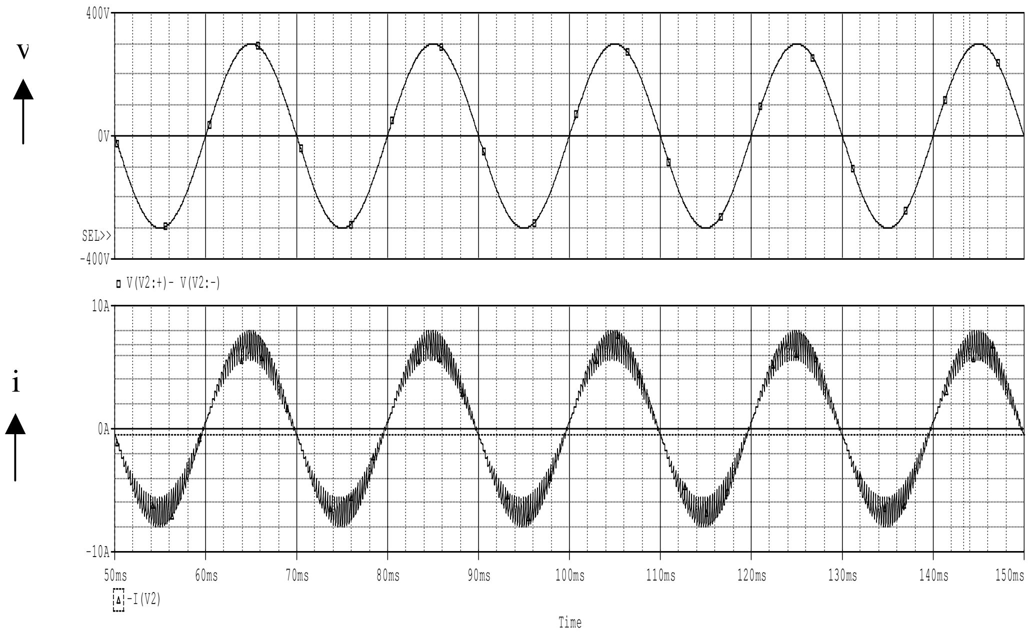


Fig. 2.13: Input voltage and input current for duty cycle D= 0.2

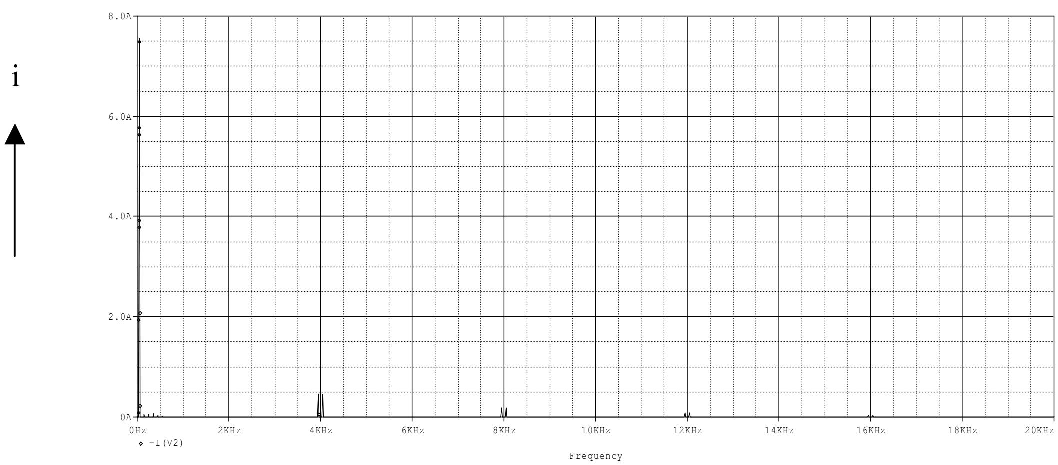


Fig. 2.14: Frequency spectrum of input current of Fig 2.13

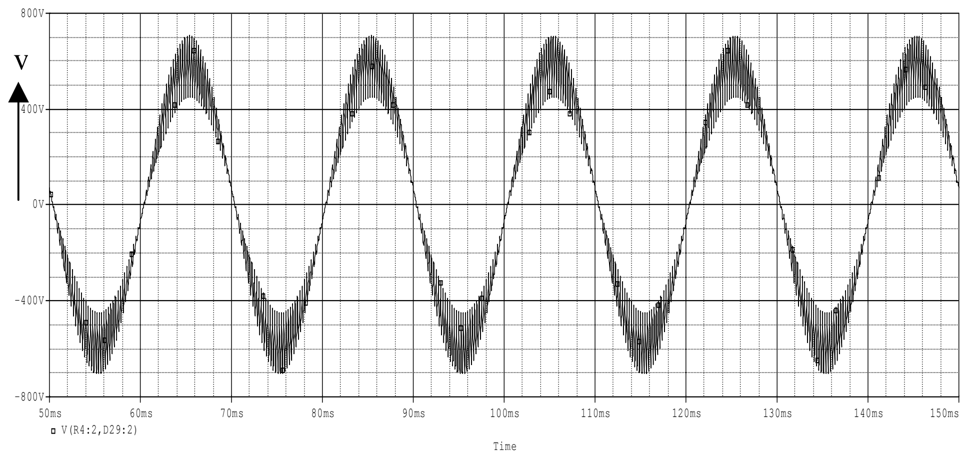


Fig. 2.15: Output voltage for duty cycle D= 0.5

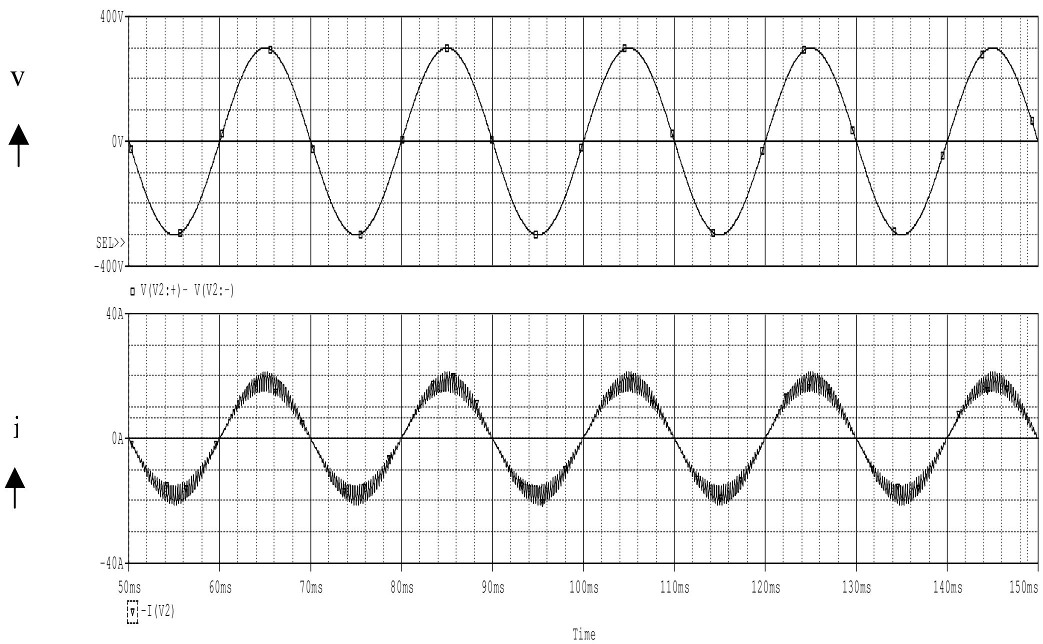


Fig. 2.16: Input voltage and input current for duty cycle D= 0.5

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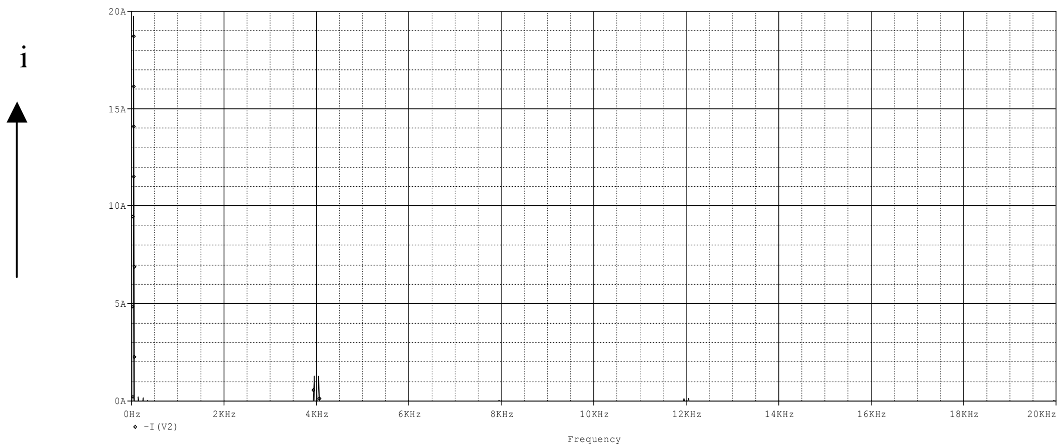


Fig. 2.17: Frequency ectrum of input current of Fig 2.16

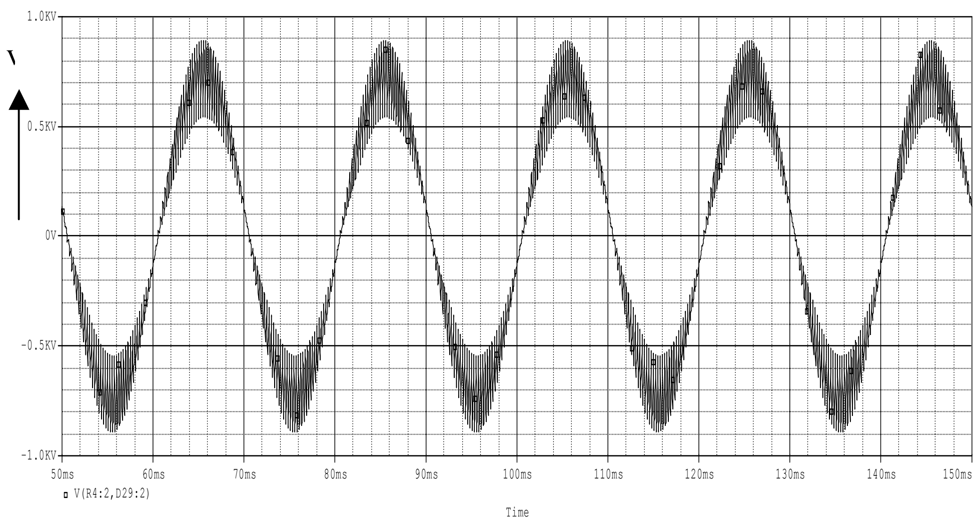
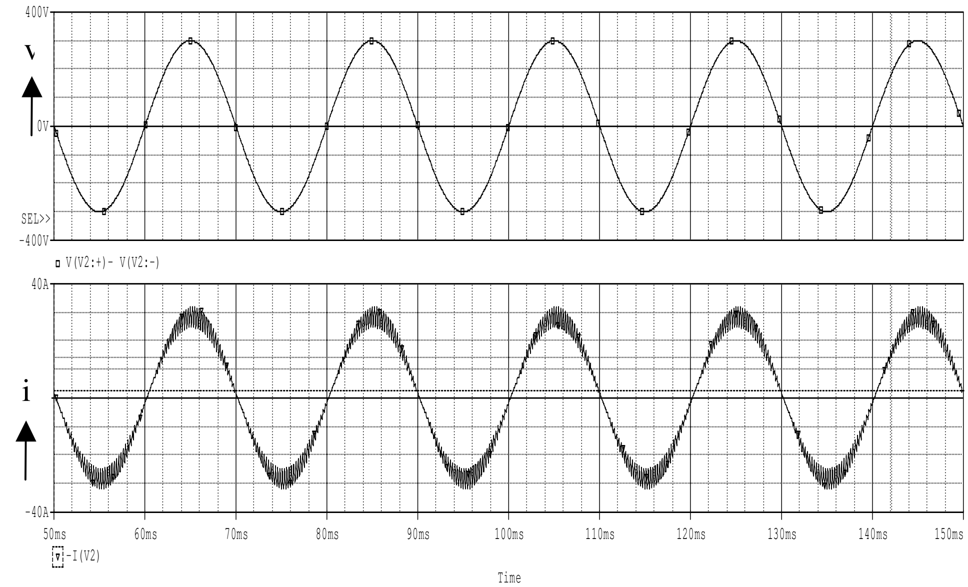


Fig. 2.18: Output vo t e for duty cycle D= 0.6



2.19: Input voltage and input current for duty cycle D= 0.6

t

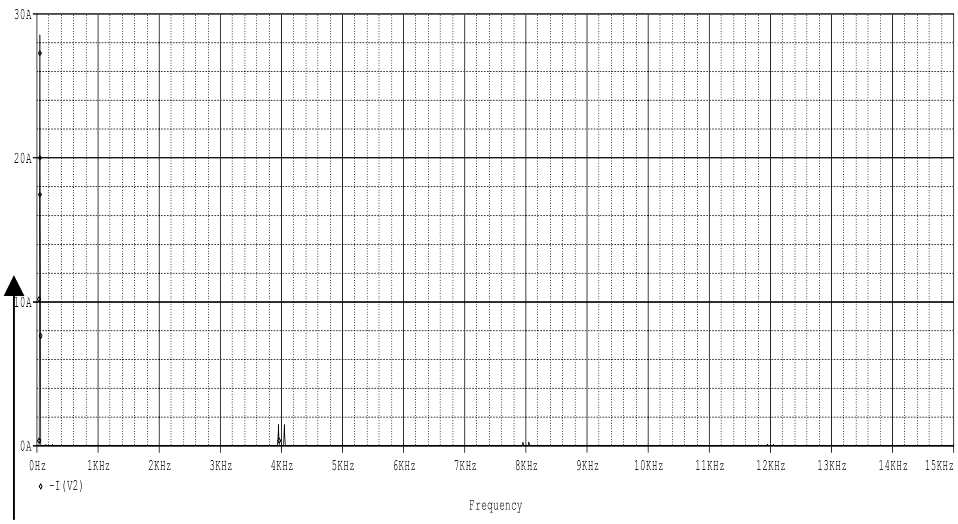


Fig.2.20: Frequenc f ectrum of input current of Fig 2.19

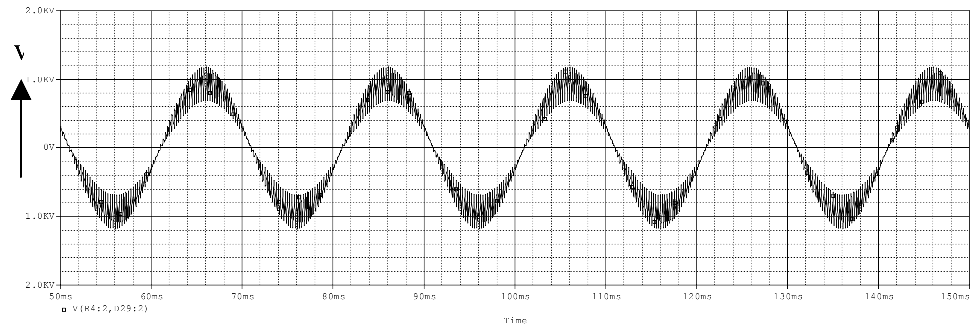
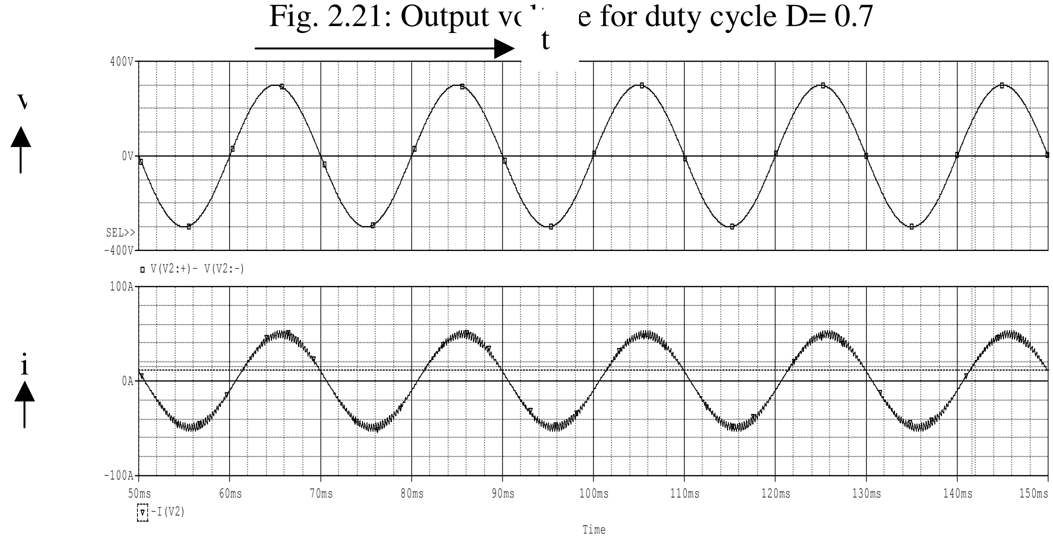


Fig. 2.21: Output vc e for duty cycle D= 0.7



2.22: Input voltage and ir current for duty cycle D= 0.7

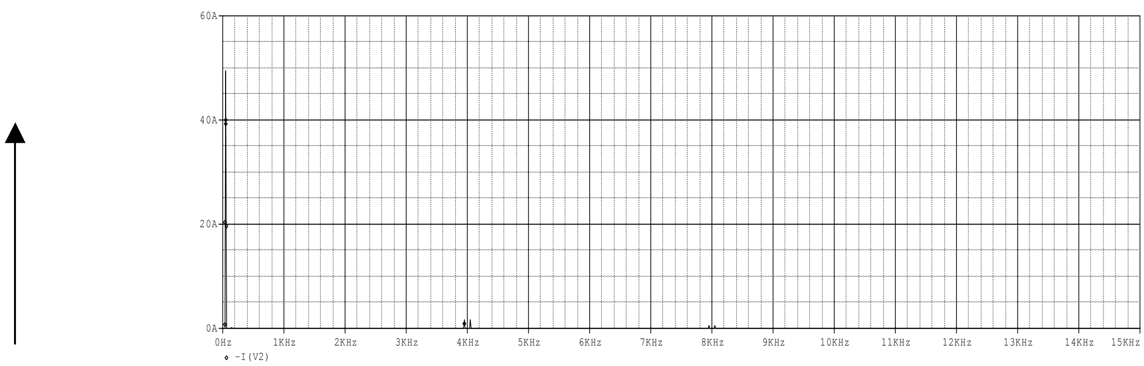


Fig. 2.23: Frequency sp rum of input current of Fig 2.22

Table: 2.1 Performance of Two Switch Boost AC-AC Converter:

Duty Cycle	Input voltage rms (v)	Output voltage rms (v)	voltage gain	Input current rms (amp)	Output current rms (amp)	current gain	Input pf	Input power (kw)	Output power (kw)	Efficiency (%)	THD of input current (%)
0.2	212	263	1.24	5	2.63	0.53	0.811	1.04	0.7	67	9.8
0.3	212	306	1.44	6.5	3.06	0.47	0.813	1.4	0.9	64	11.4
0.4	212	353	1.67	8.9	3.53	0.40	0.809	1.8	1.2	67	11.3
0.5	212	428	2.02	12.8	4.28	0.33	0.815	2.7	1.7	63	9.8
0.6	212	524	2.47	20	5.24	0.26	0.806	4.1	2.7	66	7.4
0.7	212	680	3.21	34.7	6.8	0.20	0.807	7.2	4.6	64	4.7

Fig.2.24: Voltage gain vs. duty cycle curve of two switch boost ac-ac converter

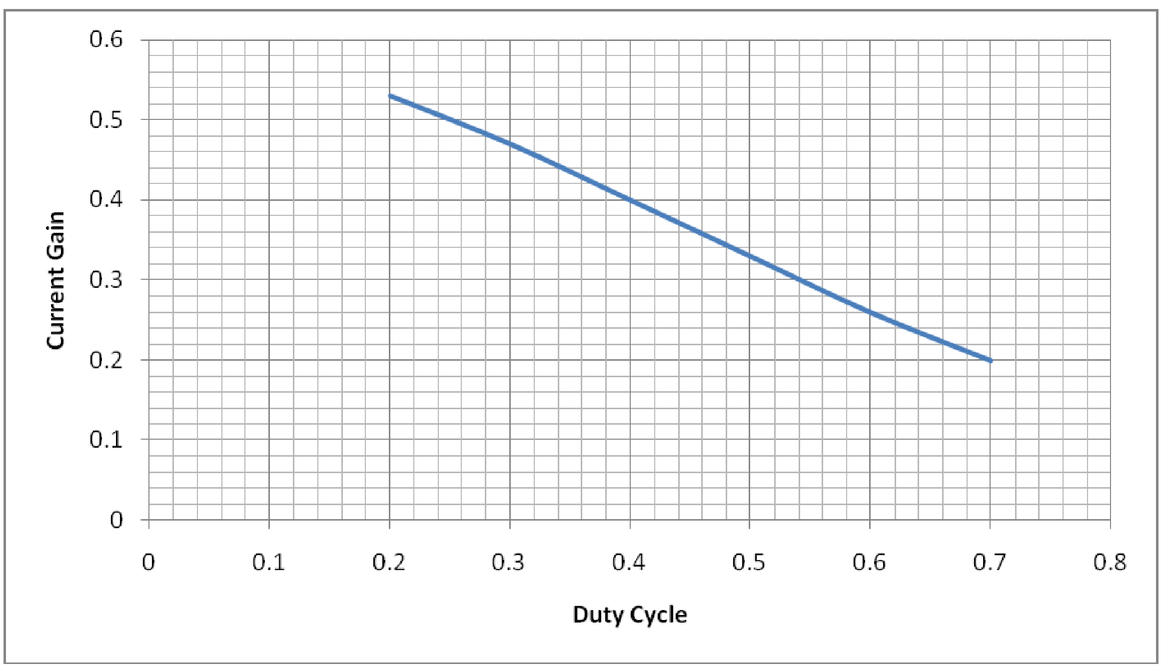


Fig.2.25: Current gain vs. duty cycle curve of two switch boost AC-AC converter

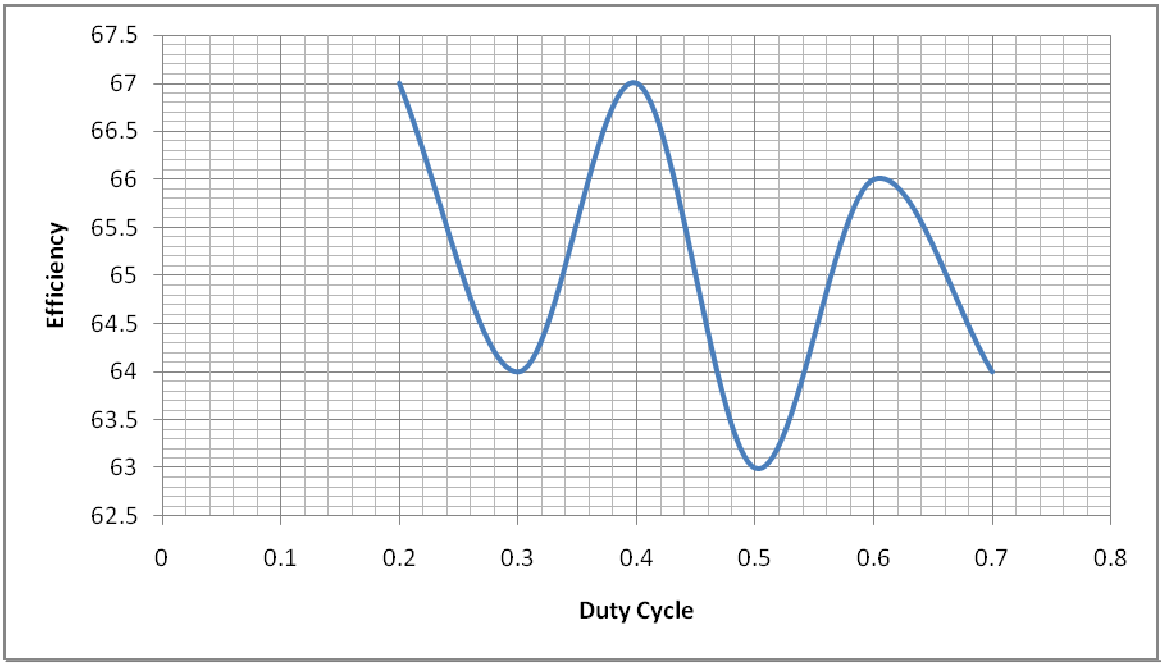


Fig.2.26: Efficiency vs. duty cycle curve of two switch boost AC-AC converter

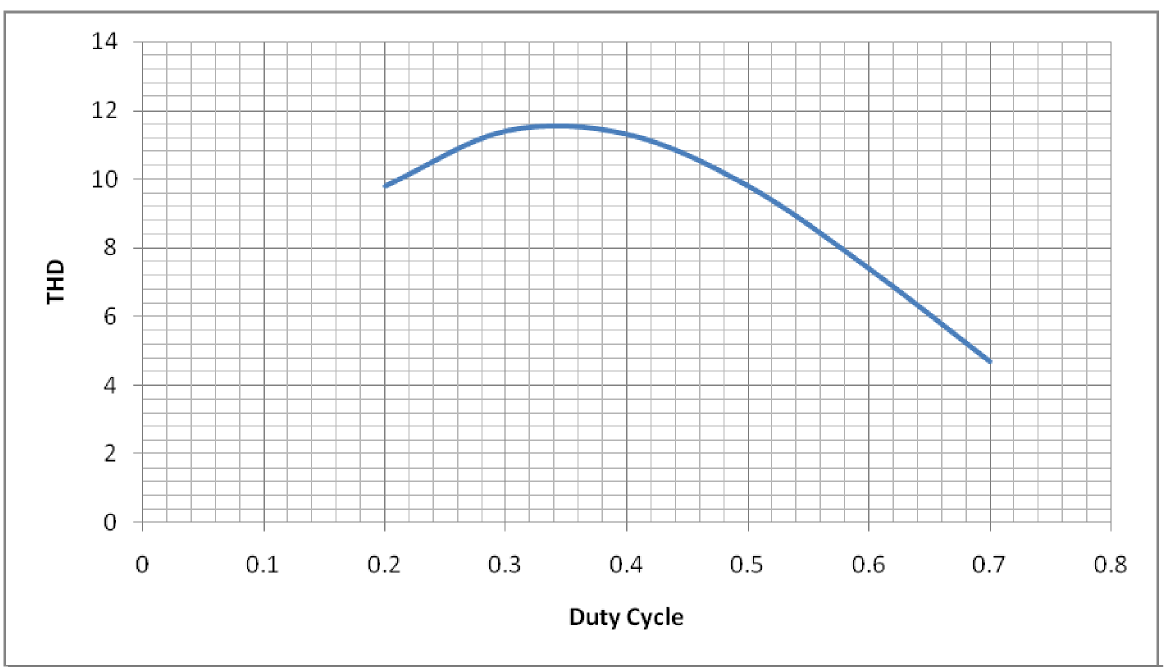


Fig.2.27: THD vs. duty cycle curve of two switch boost AC-AC converter

2.6 Simulation of Proposed Single-Switch AC-AC Boost Converter:

In the simulation study of one switch single phase boost ac-ac converter the circuit shown Fig 2.28 has been used. The circuit consists of a bi-directional switch S1 and a bi-directional freewheeling diode. It also has a boost inductor L and the load resistor R_L

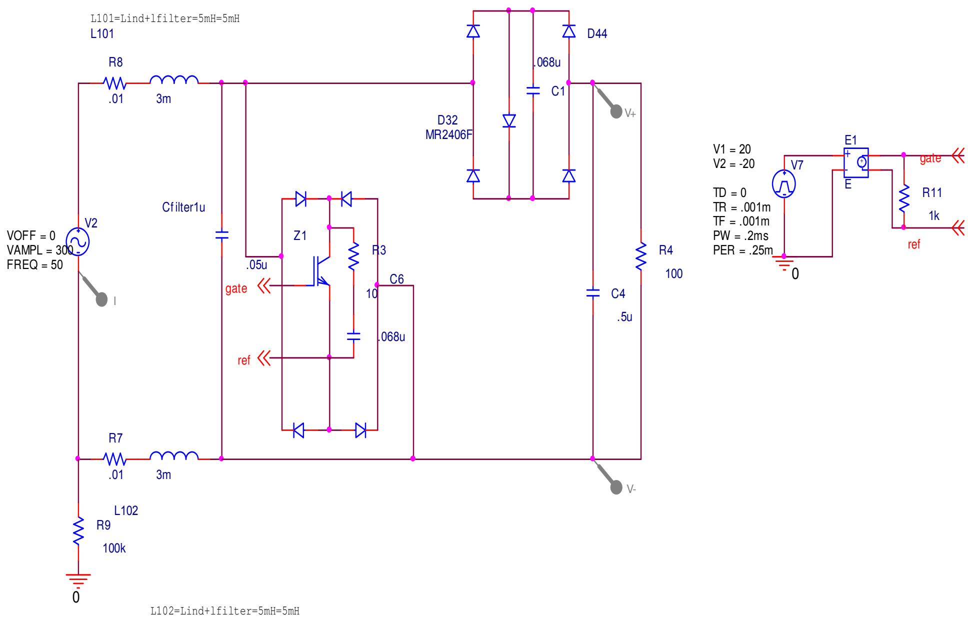


Fig.2.28: Simulation Circuit of proposed Single switch Boost AC-AC Converter

The bi-directional switch of Fig.2.18 consists of an IGBT (Z_1) and four diodes. The snubber circuit across the switch consists of a diode, a capacitor and a resistor. For performance study the expressions used for circuit of Figure 2.11 are used again.

The THD of the input current and Spectrum of the input current are obtained from ORCAD simulation output file. Simulation is carried out for duty cycles of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 Typical output-Input voltages, Input current, Spectrum of input current and traces of Input Power-output power and power factor-efficiency are shown in Figs 2.29 to 2.37 for duty cycles D=0.2 to 0.7 respectively. The performance summary of the single switch boost AC-AC converter is provided in Table 2.2. For duty cycle variation from 0.2 to 0.7 the THD of the input current in below 24%, input power factor is always above 0.79% and the efficiency varies from 57 to 89%. The efficiency reduces below 80% at higher duty cycles. The voltage gain during this duty cycles always increases. The graphical representations of result of Table 2.2 are presented in Figures 2.38-2.40. In terms of efficiency, the single switch single phase AC-AC converter shows better performance which are graphically depicted in Figures 2.42 and 2.43.

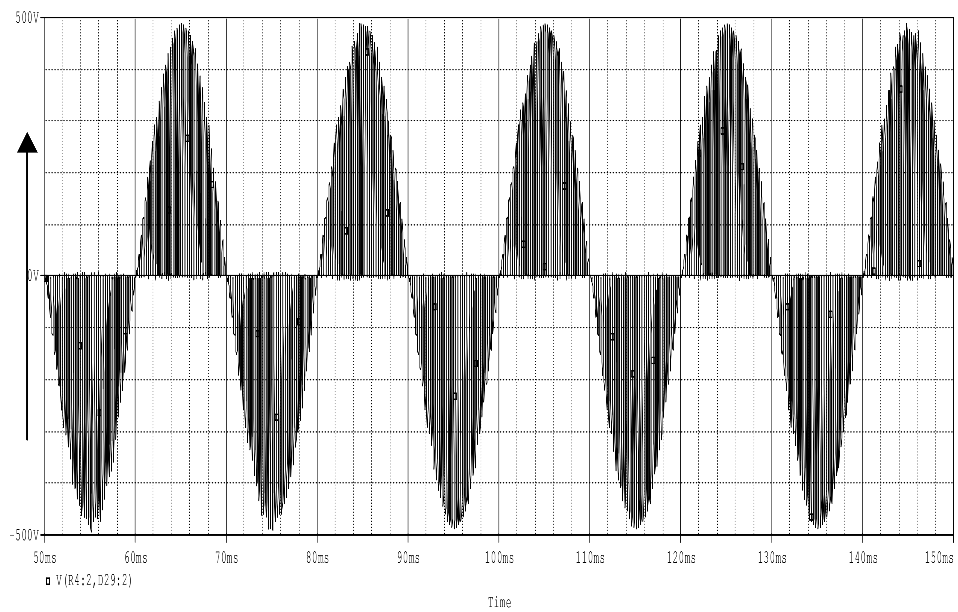


Fig. 2.29: Output voltage for duty cycle D= 0.2

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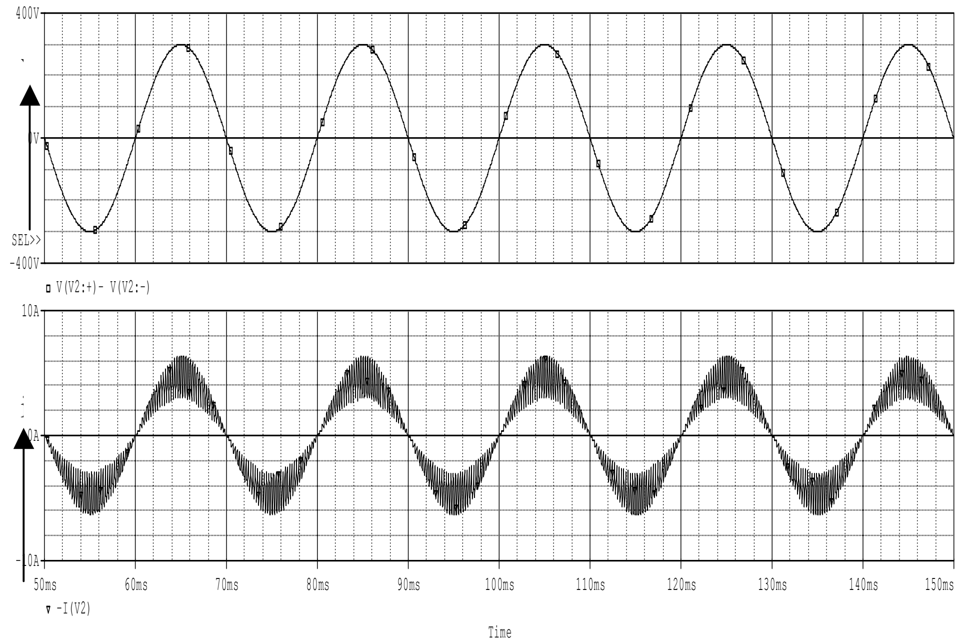

Fig. 2.30: Input voltage and input current for duty cycle D= 0.2

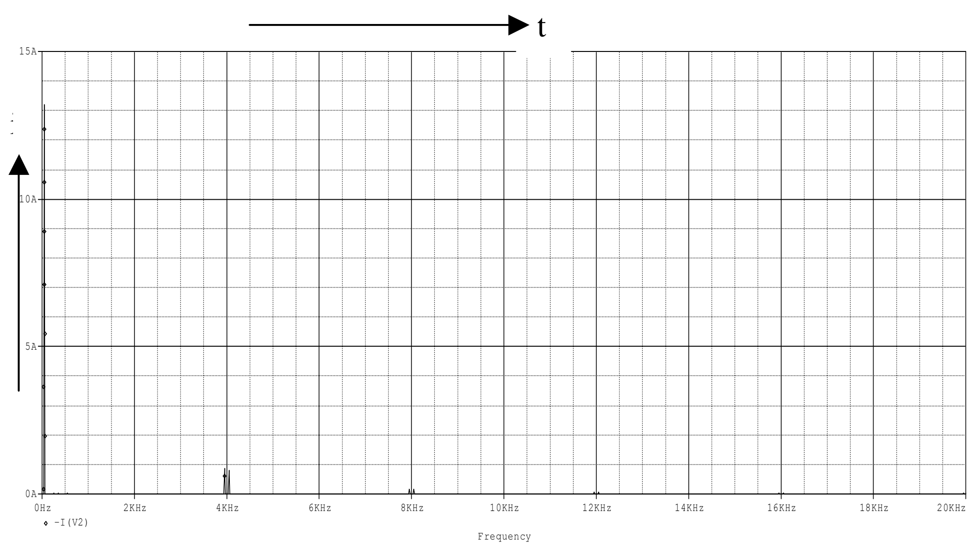

Fig. 2.31: Frequency spectrum of input current of Fig 2.30

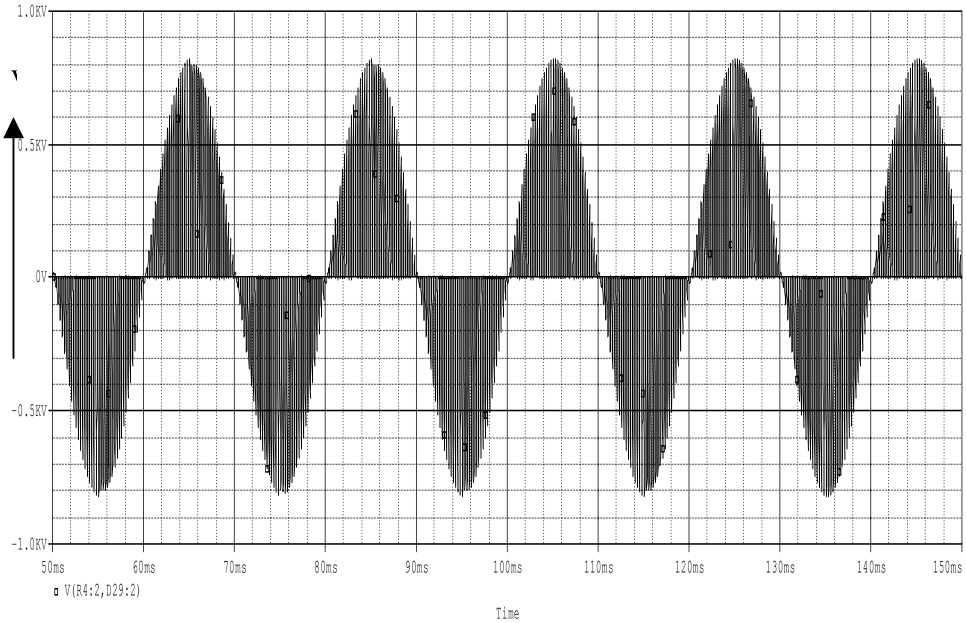

Fig. 2.32: Output voltage for duty cycle D= 0.5

t

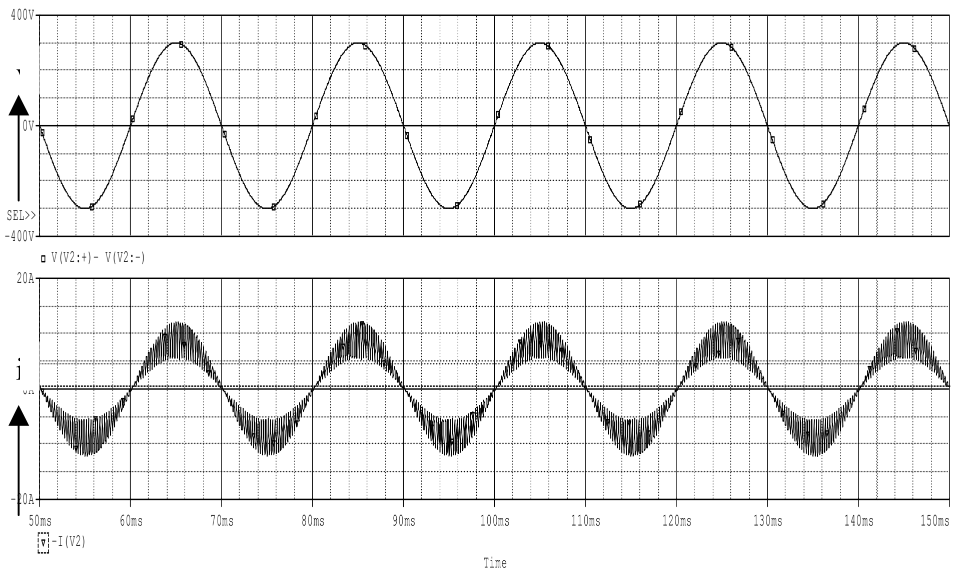

Fig. 2.33: Input voltage and input current for duty cycle D= 0.5

t

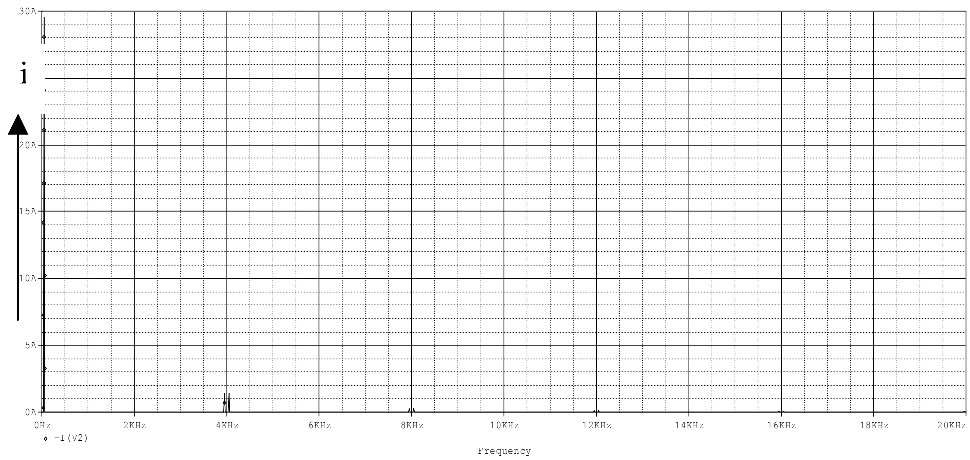

Fig. 2.34: Frequency spectrum of input current of Fig 2.33

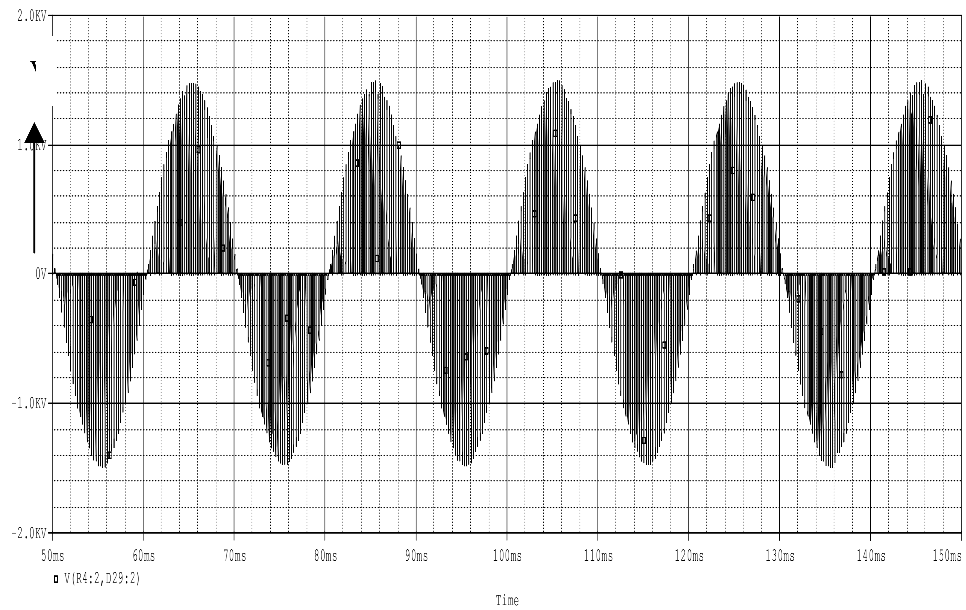

Fig. 2.35: Output voltage for duty cycle D= 0.7

t

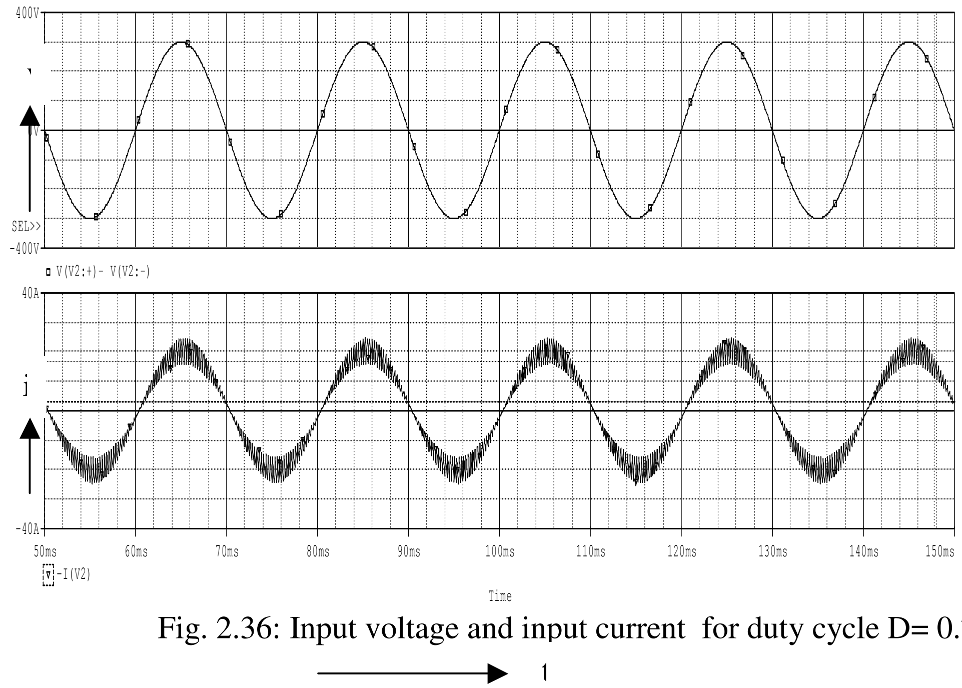

Fig. 2.36: Input voltage and input current for duty cycle D= 0.7

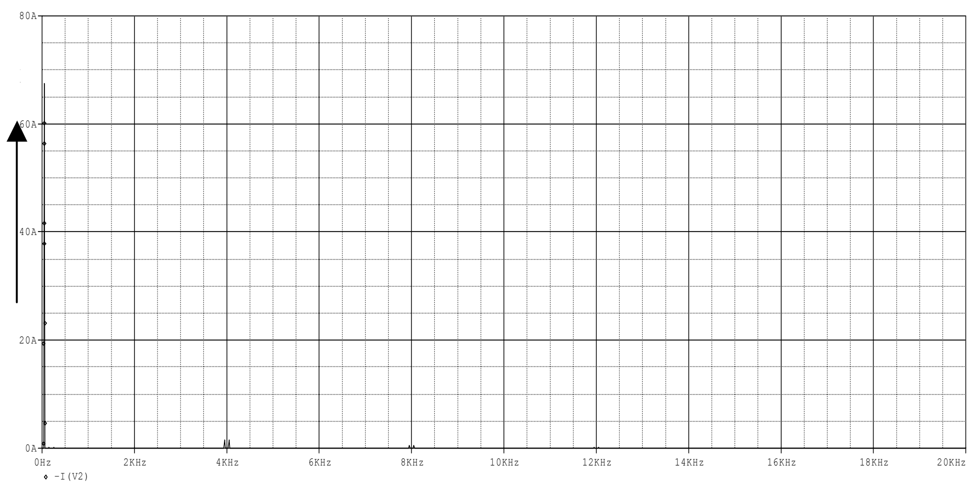

Fig. 2.37: Frequency spectrum of input current of Fig 2.36.

f

Table: 2.2 Performance of Proposed Single Switch Boost AC-AC Converter:

Duty cycle	Input voltage rms (v)	Output voltage rms (v)	Voltage gain	Input current rms (amp)	Output current rms (amp)	Current gain	Input pf	Input power (kw)	Output power (kw)	Efficiency (%)	THD of input current (%)
0.2	212	257	1.21	3.53	2.57	0.73	0.795	0.74	0.66	89	21.3
0.3	212	274	1.29	4.14	2.74	0.66	0.793	0.86	0.75	87	23.3
0.4	212	299	1.41	5.16	2.99	0.58	0.792	1.08	0.918	85	23.3
0.5	212	325	1.53	6.69	3.25	0.49	0.798	1.38	1.05	76	21.4
0.6	212	362	1.71	9.41	3.62	0.38	0.796	1.95	1.31	67	17.2
0.7	212	417	1.97	14.5	4.17	0.29	0.805	3.06	1.73	57	12.02

Table 2.3: Comparison of Two Switch & Single Switch Boost AC-AC Converter:

Duty Cycle	Two Switch				Single Switch			
	Voltage Gain	THD%	pf	η%	Voltage Gain	THD%	pf	η%
0.2	1.24	9.8	0.811	67	1.21	21.3	0.795	89
0.3	1.44	11.4	0.813	64	1.29	23.3	0.793	87
0.4	1.67	11.3	0.809	67	1.41	23.3	0.792	85
0.5	2.02	9.8	0.815	63	1.53	21.4	0.798	76
0.6	2.47	7.4	0.806	66	1.71	17.2	0.796	67
0.7	3.21	4.7	0.807	64	1.97	12.02	0.805	57

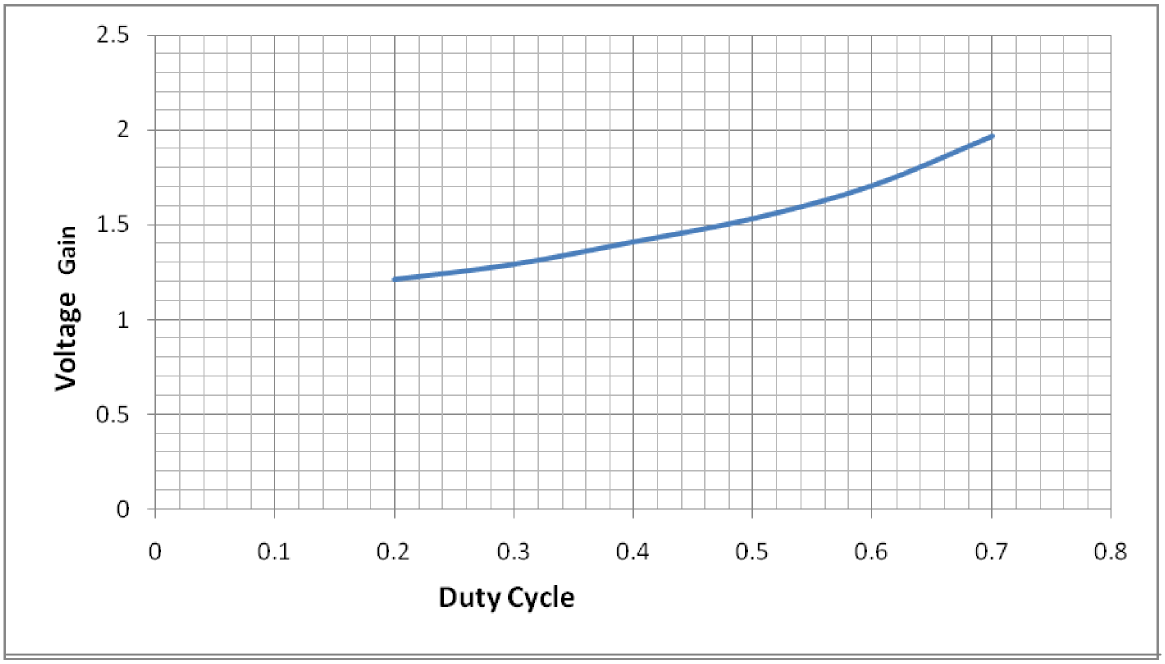

Fig.2.38: Voltage gain vs. duty cycle curve of single switch

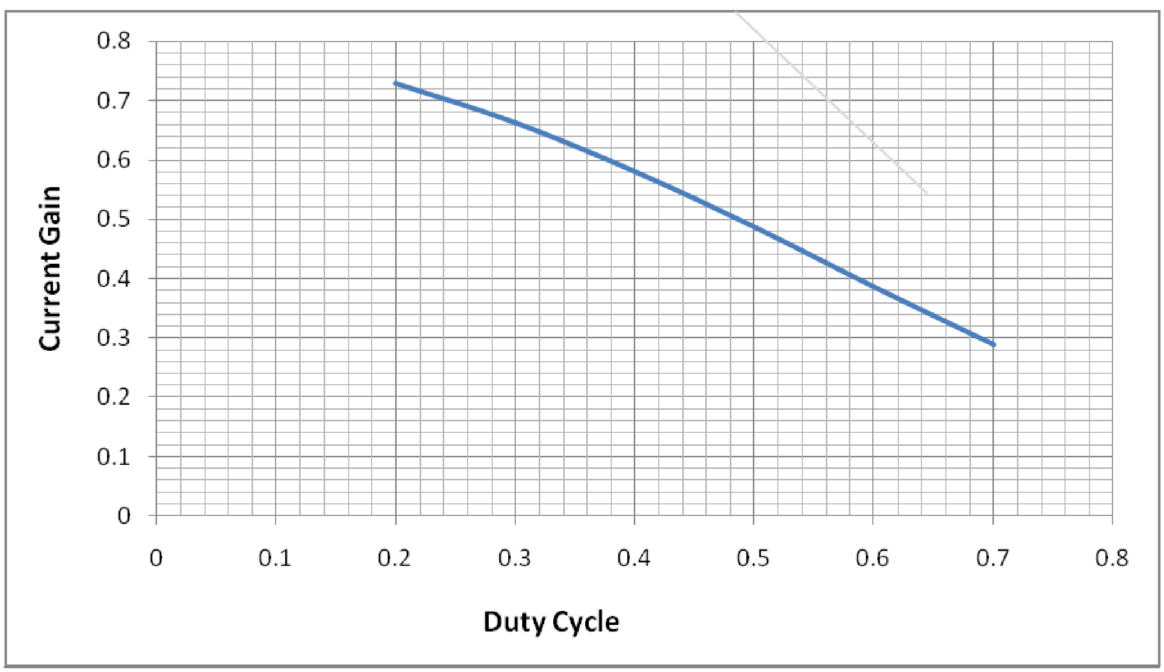

Fig.2.39: Current gain vs. duty cycle curve of single switch

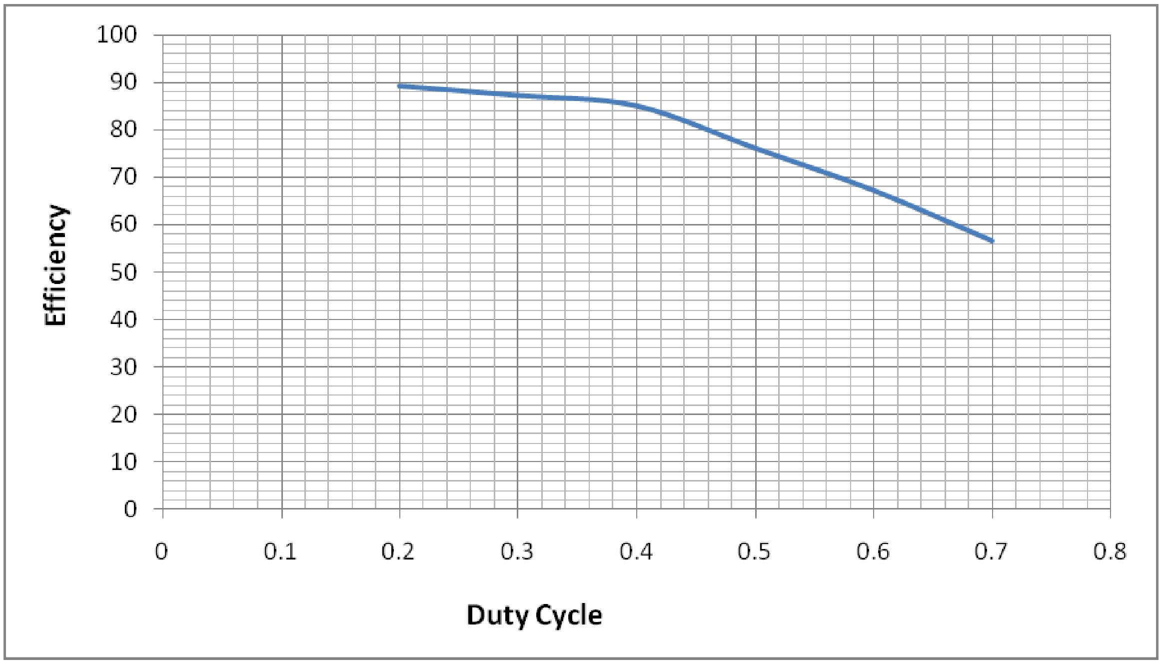

Fig.2.40: Efficiency vs. duty cycle curve of single switch

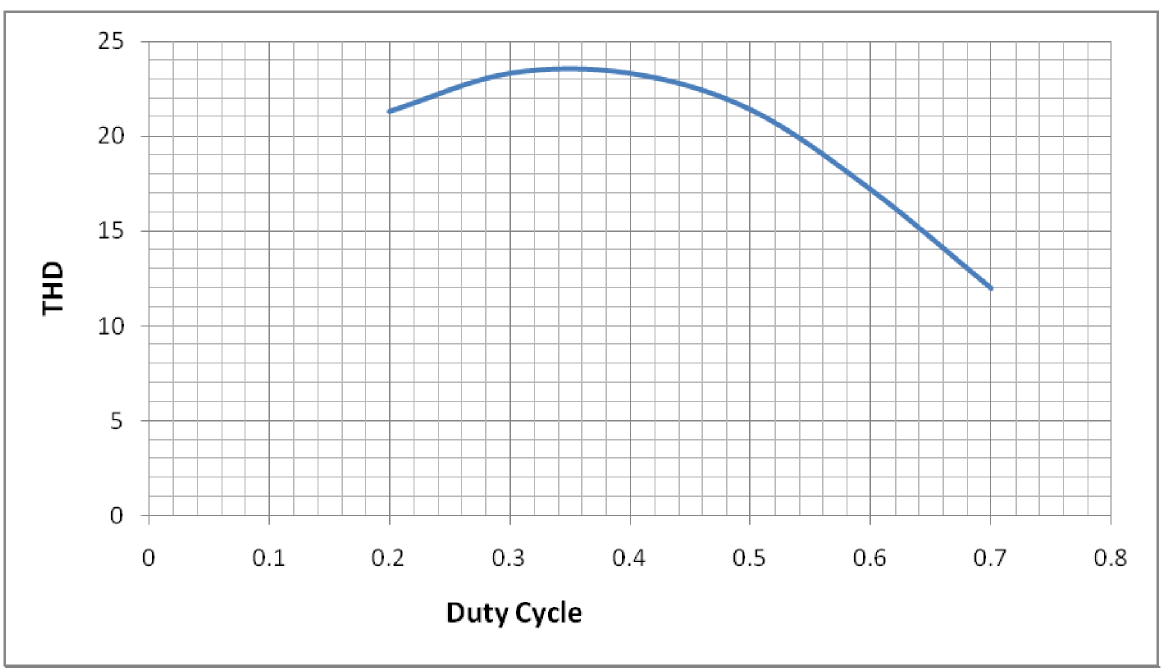

Fig.2.41: THD vs. duty cycle curve of single switch

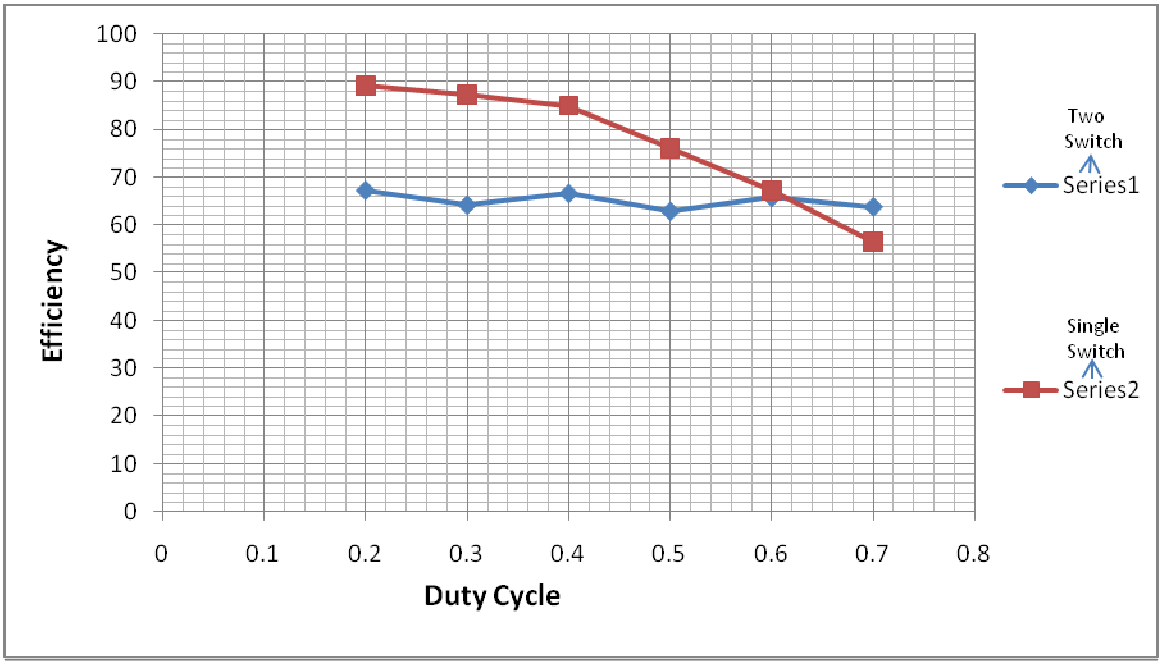

Fig.2.42: Efficiency differences between single switch and two switches.

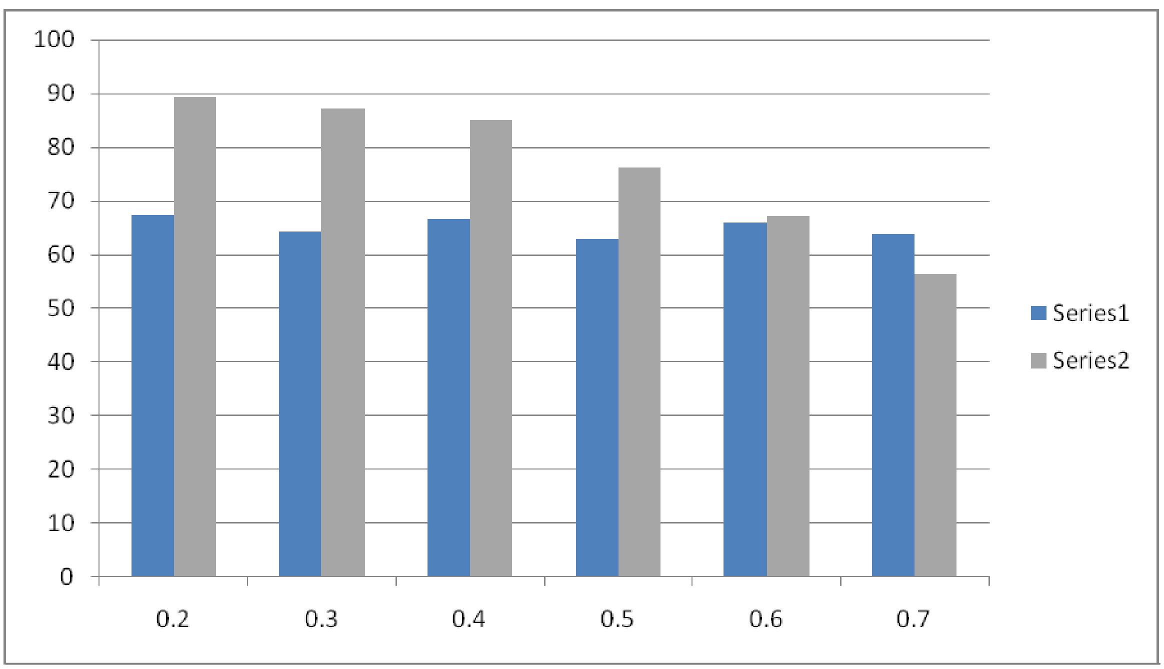

Fig.2.43: Efficiency differences between single switch and two switches.

CHAPTER-3

CONCLUSION AND RECOMMANDATIONS

3.1 Conclusion:

A scheme based on Boost topology for single-phase AC- AC conversion is proposed. The circuit has low input current distortion and high input power factor and operates with good efficiency for a wide range of duty cycle. Based on the results obtained from simulation, the proposed scheme can be considered for AC-AC conversions with low distortion and high input power factor. High efficiency and power factor control with output voltage regulation are yet to be achieved.

In this thesis a new scheme for single phase AC-AC Boost converter is proposed that has low input current THD and good input power factor. It also has efficiency above 80% for duty cycles 0.2, 0.3 and 0.4. Based on the results obtained from simulation, the proposed circuit can be considered for AC-AC conversion with low harmonic distortion, high input power factor and acceptable range of efficiency. The circuit is investigated and reported with low switching frequency which is desired for its applicability in medium and high power applications. As a starting work towards obtaining a practical light weight, efficient and reliable AC to AC voltage regulator the proposed Boost converter show promising aspects.

The proposed Boost converter operates in Boost mode on instantaneous voltage basis. If the rms value of the output voltage is considered, the proposed converter has both Buck and boost characteristic. Two topologies of the proposed converter, one with two switches and other with one switch have been studied. The one switch boost ac-ac converter has minimum switch AC-AC voltage controller reported so far. Both topologies are bi-directional ac-ac single phase voltage controller and have improved input current

THD and input power factor. Constant output voltage regulation of the proposed switch mode AC-AC Boost regulator was not studied in the research. Constant output voltage regulation of the proposed AC- AC voltage regulator will require feedback control of the proposed circuit. Feedback control of the proposed circuit will ensure good power factor, low input current THD and high efficiency of the circuit throughout the duty cycle range.

3.2 Recommendation of Future Work:

The proposed AC-AC Boost converter may be implemented practically in the laboratory in future. For the proposed circuit to obtain a good efficiency we have to vary both the duty cycle and switching frequency by feedback control. The circuit will require sensing input/output voltages and the boost inductor current of the proposed boost ac-ac voltage controller. The switching signal will be generated by the controller circuit tuned for hysteresis current control, output voltage regulation and input voltage following. The control design will require tuning of two PI controllers in the control circuit.

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