B. TECH. PROJECT REPORT

On

Modified Quadratic Boost Converter With High Voltage Step – Up Ratio And Reduced Voltage Stress

BY

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DISCIPLINE OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Modified Quadratic Boost Converter With High Voltage Step-Up Ratio And Reduce Voltage Stress

A PROJECT REPORT

Submitted in partial fulfillment of the
Requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in
ELECTRICAL ENGINEERING

Submitted by:
VIVEK KUMAR

Guided by:
DR. Amod C. Umarikar
(Associate Professor, IIT INDORE)

INDIAN INSTITUTE OF TECHNOLOGY INDORE
December 2017

CANDIDATE'S DECLARATION

I hereby declare that the project entitled **" Modified Quadratic Boost Converter"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Electrical Engineering' completed under the supervision of **Dr. Amod C. Umarikar, Associate Professor, Electrical Engineering,** IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Vivek Kumar
(140002040)

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the student is correct to the best of my knowledge.

Dr. Amod C. Umarikar

Associate Professor

Department of Electrical Engineering

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Preface

This report on " **Modified Quadratic Boost Converter** is prepared under the guidance of **Dr. Amod C. Umarikar**

Through this report, I have tried to dsesign a quadratic boost converter with high voltage step - up ratio and reduce voltage stress . I have designed quadratic boost converter on PCB. And compare the result with simulation result. Fot this ,I have studied conventional boost and quadratic boost converter and their characteristics.

I have also studied for hardware implementation and how can we minimize the size Of converter and losses and give maximum efficiency.

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Acknowledgements

It has been my privilege to work under the supervision of Dr. Amod C. Umarikar, who has been a constant source of strength and inspiration. It is his noble guidance coupled with a helping and affectionate attitude due to which I became able to complete my report. I wish to thank him for his kind support and valuable guidance.

However, there are many others who share the reward of this effort simply because it would never have been this good without their help. Having said that, I would like to express my heartfelt gratitude to Mr. Suvamit Chakraborty and other PhD students who have provided ideas, advice and the good atmosphere that made working in the field of quadratic boost converter.

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Abstract

A new topology of quadratic boost converter is proposed. Compared with the conventional quadratic boost converter, the new quadratic boost converter employs an additional capacitor-inductor-diode (CLD) cell consisting of an inductor, two diodes and two capacitors. The quadratic boost converter with CLD cell presented in this paper shows an improvement of the voltage step-up ratio over the conventional quadratic boost converter and boost converter. Consequently, it is well suited for extreme high voltage step-up ratio applications. The quadratic boost converter with CLD cell also shows a significant improvement in reduced voltage stresses of switch and diodes over the conventional quadratic boost converter and boost converter. The experimental results of the proposed converter have been presented to verify the analysis results.

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Chapter 1

Introduction

1.1 Motivation

Conventional quadratic boost converters have a disadvantage as these are not suited for high voltage step-up ratios. In our topology, our main objective was to develop a quadratic boost converter that is well suited for extreme high voltage step-up ratios. Also, conventionally we need a high duty cycle if we need a high voltage step-up ratio, but with our methodology we have the flexibility of choosing a low duty cycle. The quadratic boost converter proposed in this work reduces the voltage stress on the switch, also reducing the active losses.

1.2 Objective

1. Development of converter topologies based on Quadratic Boost converter which are suitable for PV system.

2. Simulation of the proposed system for testing the performance in all conditions

3. Fabrication and assembling of system for Hardware

4. Experimental verification of the simulation results for the proposed system

Chapter 2

Boost Converter

2.1 Overview

Boost Converter: - It is switched- mode converter that is capable of producing a DC output voltage greater in magnitude than the DC input voltage. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power (P=VI) must be conserved, the output current is lower than the source current.

A practical realization of the switch, using a MOSFET and diode, is shown in Fig 2.1

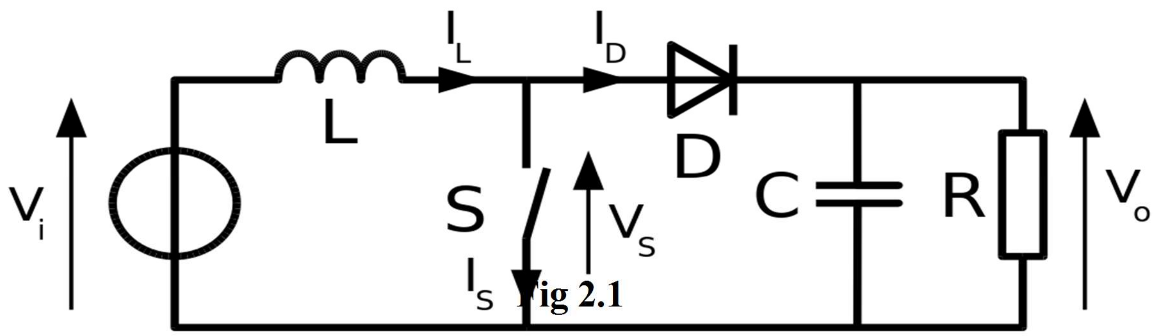


Fig 2.1

2.2 Derivation for output voltage

Continuous Mode Conduction

The basic principle of a Boost converter consists of 2 distinct states: -

(i) $0 \leq t \leq Ton$ circuit as shown in fig. 1.2

switch → On , Diode → Off

During the On-state, the switch S is closed, which makes the input voltage V(appear across the inductor, which causes a change in current IL flowing through the inductor during a time period t

$$Vi = VL \text{ and } i_c = - i_o$$

$$L \frac{diL}{dt} = vs$$

$$\int_{Imin}^{Imax} diL = \int_0^{Ton} \frac{Vs}{L} dt$$

$$(Imax - Imin) = \frac{Vs}{L} Ton$$

$$\text{Ripple in current } \Delta IL = \frac{DVs}{Lf}$$

(ii) Ton ≤ t ≤ T circuit as shown in fig. 2.1

switch → Off , Diode → On

During the Off state the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of IL is:

$$iL = ic + io$$

by KVL

$$-Vs + VL + Vo = 0$$

$$VL = -(Vo - VS)$$

Using volt- second balance :

$$(VL)avg = 0$$

$$Vs*Ton = (Vo - Vs) Toff$$

$$Vs* T = Vo * Toff$$

$\frac{Vs}{Vo} = 1\text{-}D$, Output Voltage $Vo = \frac{Vs}{1-D}$

Ripple in voltage $\Delta Vc = \frac{DIo}{fc}$

Where D = duty cycle ratio

Duty cycle: - A **duty cycle** is the fraction of one period in which a signal or system is active. Therefore, D ranges between 0 and 1.

Vs = input voltage

Vo = output voltage

T = time period

iL = inductor current

f = frequency

c = capacitor value

L = inductor value

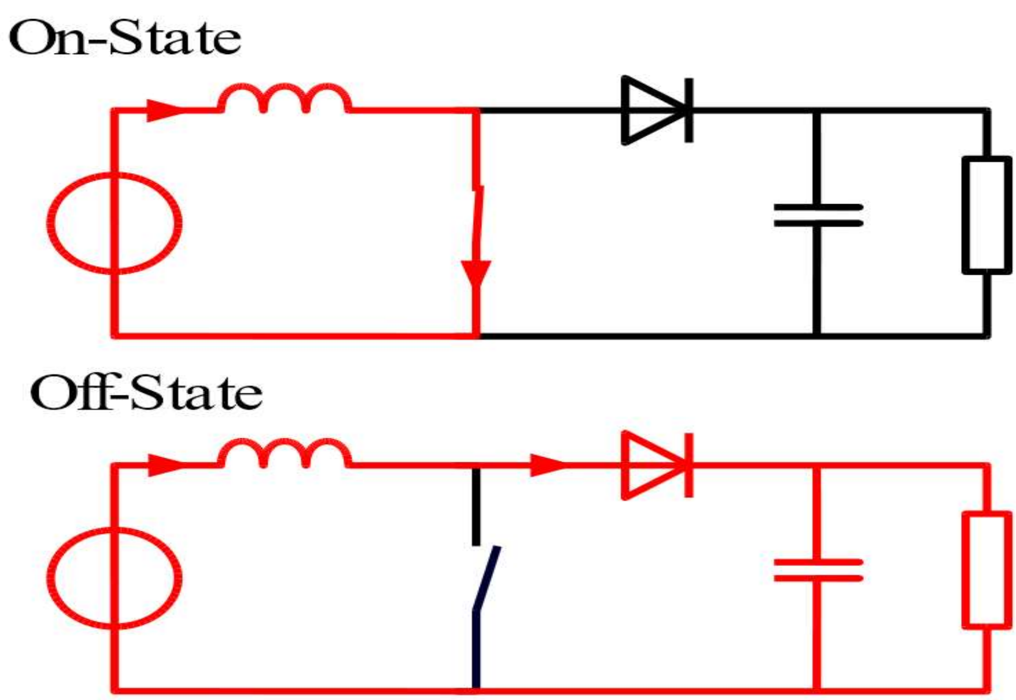


Fig 2.2 and Fig 2.3

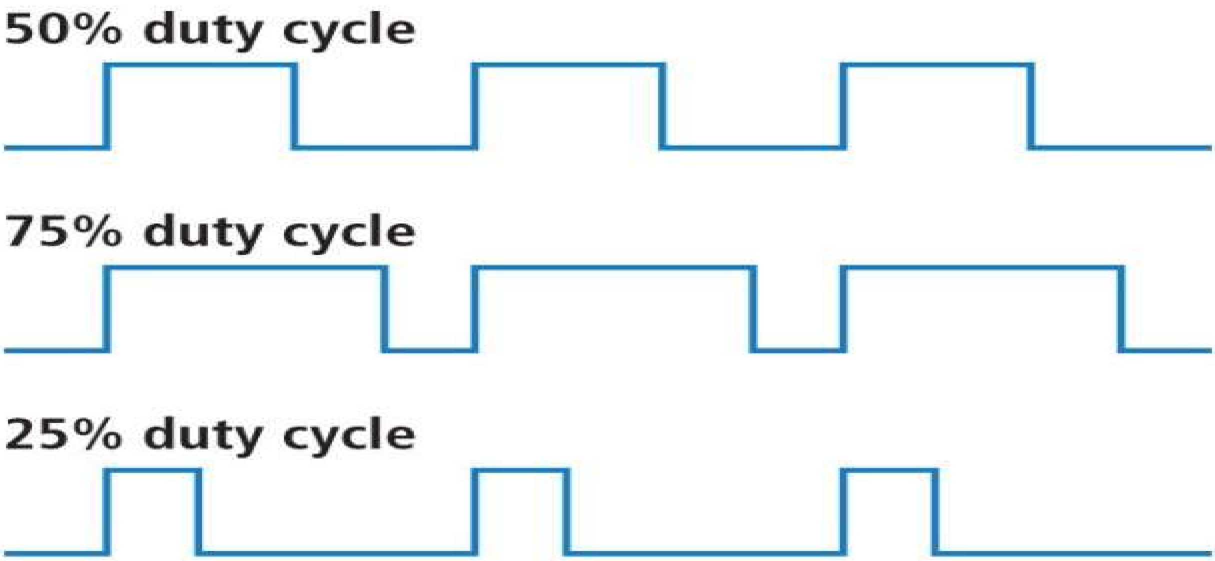


Fig 2.4 Duty cycle

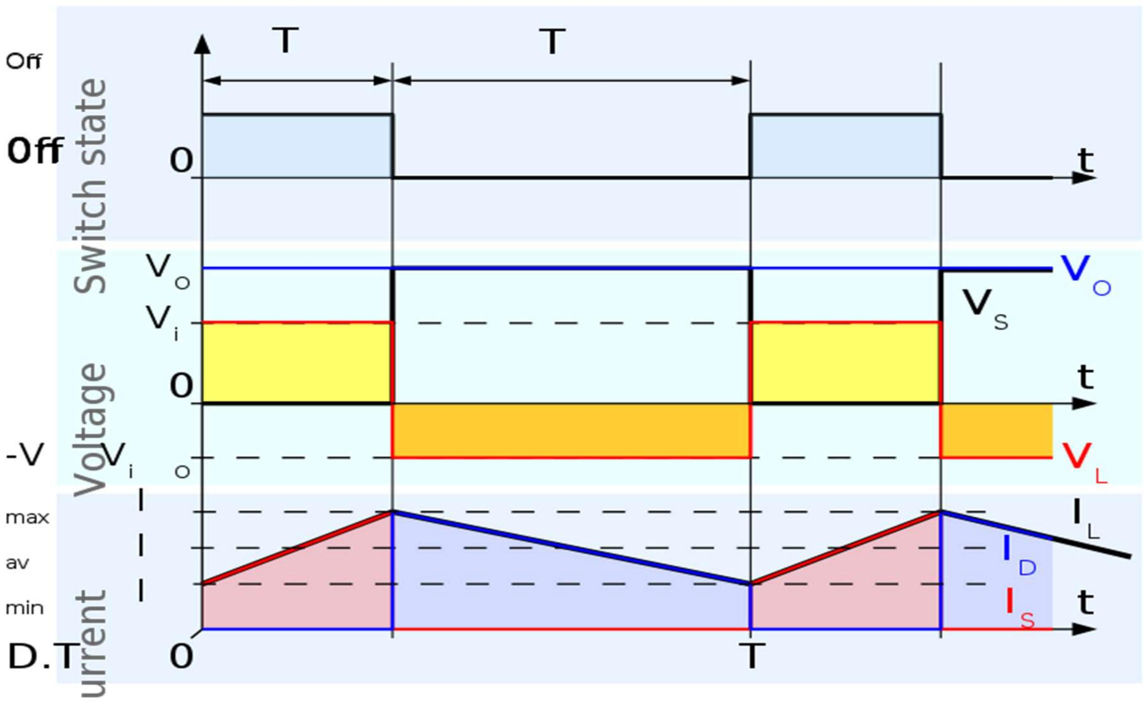


Fig 2.5 Waveforms of current and voltage in a boost converter operating in continuous mode

Chapter 3

Transfer Function Of Boost Converter Using State Space model

3.1 State Space Model

The state space description is a canonical form for writing the differential equations that describe a system. For a linear network , the derivatives of the state variables are expressed as linear combinations of the system independent inputs and the state variables themselves .The physical state variables of a system are usually associated with the storage of energy , and for a typical converter circuit, the physical state variables are the independent inductor currents and capacitor voltage.

The state equations of a system can be written in the compact matrix form as :

$$K \frac{dx(t)}{dt} = Ax(t) + Bu(t) \qquad \text{state equation}$$

$$Y(t) = Cx(t) + D\,x(t) \qquad \text{output equation}$$

X (t) = It is a vector containing all of the state variables ,that is , the inductor currents, capacitor voltages etc.

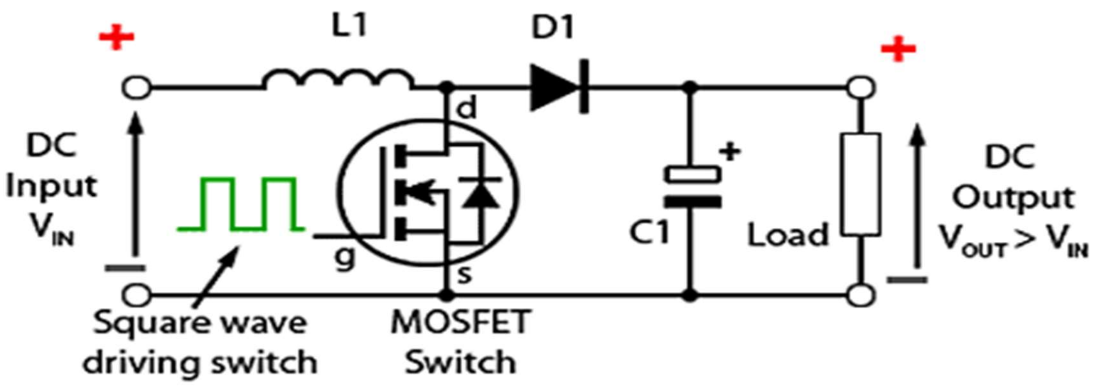
U (t) = It is an input vector contains the independent inputs to the system such as the input voltage source Vs .

$\frac{dx(t)}{dt}$ = It is a vector whose elements are equal to then derivatives of the corresponding elements of the state vector.

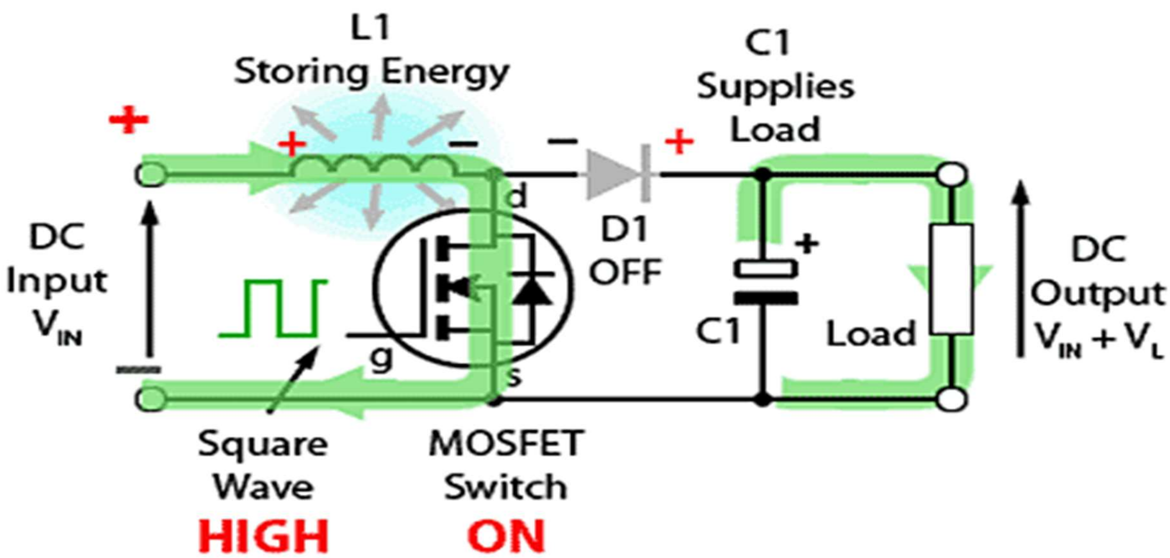
$$X(t) = \begin{matrix} X1(t) \\ X2(T) \\ . \end{matrix} \qquad \frac{dx(t)}{dt} = \begin{matrix} \frac{dx1(t)}{dt} \\ \frac{dx2(t}{dt} \\ \frac{dx3(t}{dt} \end{matrix}$$

3.2 Transfer Function

Now transfer function of boost converter using state space model :



When switch is on then :



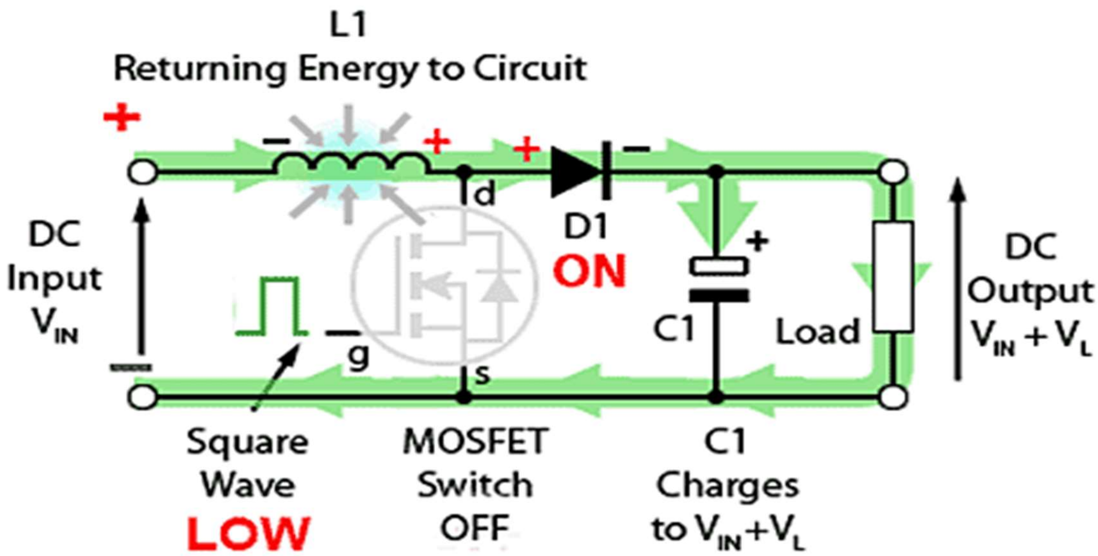
$$L\frac{diL}{dt} = Vs$$

$$C\frac{dVc}{dt} = \frac{-Vc}{R}$$

State space equation

$$\begin{bmatrix} \frac{diL}{dt} \\ \frac{dVc}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{Rc} \end{bmatrix} \begin{bmatrix} x1(t) \\ x2(t) \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix} Vs$$

When the switch is Off :



$$L \frac{diL}{dt} = Vs - Vc$$

$$C \frac{dVc}{dt} = iL - \frac{Vc}{R}$$

State space Equation:

$$\begin{bmatrix} \frac{diL}{dt} \\ \frac{dVc}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{c} & \frac{-1}{Rc} \end{bmatrix} \begin{bmatrix} iL \\ Vc \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix} Vs$$

Average state space model:

$$\frac{dx(t)}{dt} = A\, x(t) + B\, U(t)$$

A = A1D + A2 (1-D)

B = B1D + B2 (1-D)

$$\begin{bmatrix} \frac{diL}{dt} \\ \frac{dVc}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-(1-D)}{L} \\ \frac{(1-D)}{c} & \frac{-1}{Rc} \end{bmatrix} \begin{bmatrix} iL \\ Vc \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix} \text{Vs}$$

Taking in account small signal model:

$$\frac{diL}{dt} = \frac{diL}{dt} + \frac{diL\wedge}{dt}$$

$$\frac{dVc}{dt} = \frac{dVc}{dt} + \frac{dVc\wedge}{dt}$$

iL = $iL + iL\wedge$

Vc = Vc + Vc^

Average state space model :

$$\begin{bmatrix} \frac{diL}{dt} + \frac{diL\wedge}{dt} \\ \frac{dVc}{dt} + \frac{dVc\wedge}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-(1-D-d\wedge)}{L} \\ \frac{(1-D-d\wedge)}{c} & \frac{-1}{Rc} \end{bmatrix} \begin{bmatrix} iL + iL\wedge \\ Vc + Vc\wedge \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix} \text{Vs}$$

Now only taking average value then:

$$\begin{bmatrix} \frac{diL\wedge}{dt} \\ \frac{dVc\wedge}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-(1-D-)}{L} \\ \frac{(1-D-)}{c} & \frac{-1}{Rc} \end{bmatrix} \begin{bmatrix} iL\wedge \\ Vc\wedge \end{bmatrix} + \begin{bmatrix} 1/L & \frac{Vc}{L} \\ 0 & \frac{-iL}{c} \end{bmatrix} \begin{bmatrix} Vs\wedge \\ d\wedge \end{bmatrix}$$

After taking Laplace transform we get

$$\frac{V0\wedge}{d\wedge} = \frac{\frac{-siL}{c} + \frac{(1-D)Vc}{cL}}{s\left(s + \frac{1}{Rc}\right) + \frac{(1-D)\wedge 2}{Lc}}$$

Open Loop transfer function of boost converter.

Chapter 4

4.1 Quadratic Boost Converter

Renewable energy, such as photovoltaic (PV) cell and fuel cell, has attracted much attention recently . The output voltage ranges of the photovoltaic (PV) systems and fuel cell systems are quite wide. Compared with 400V input voltage of inverter , the output voltages of PV system and fuel cell system are extremely low and a conventional boost converter is usually used to boost the output voltage of PV system and fuel cell system, and extremely high duty ratio is required, which limits the switching frequency of the converter because of the minimum OFF-time of the transistor switch.

In order to overcome the disadvantage of the conventional boost converter , an obvious solution would be the use of transformers to get high voltage step-up ratio, such as forward or flyback converters .

However, the use of a transformer increases the cost, the volume, and the losses but they increase cost and compromise efficiency. The quadratic converters are proposed in which use only one switch to obtain quadratic voltage conversion ratio, but they present voltage or current overstresses when voltage conversion ratio is high.

Quadratic Boost Converter : - It possess quadratic conversion ratio which offers significantly high voltage step – up ratio and reduce voltage stress.

Photovoltaic cell :- A photovoltaic cell is a specialized semiconductor diode that converts visible light into direct current DC.

PV system: A power system designed to supply usable solar power by means of photovoltaics.

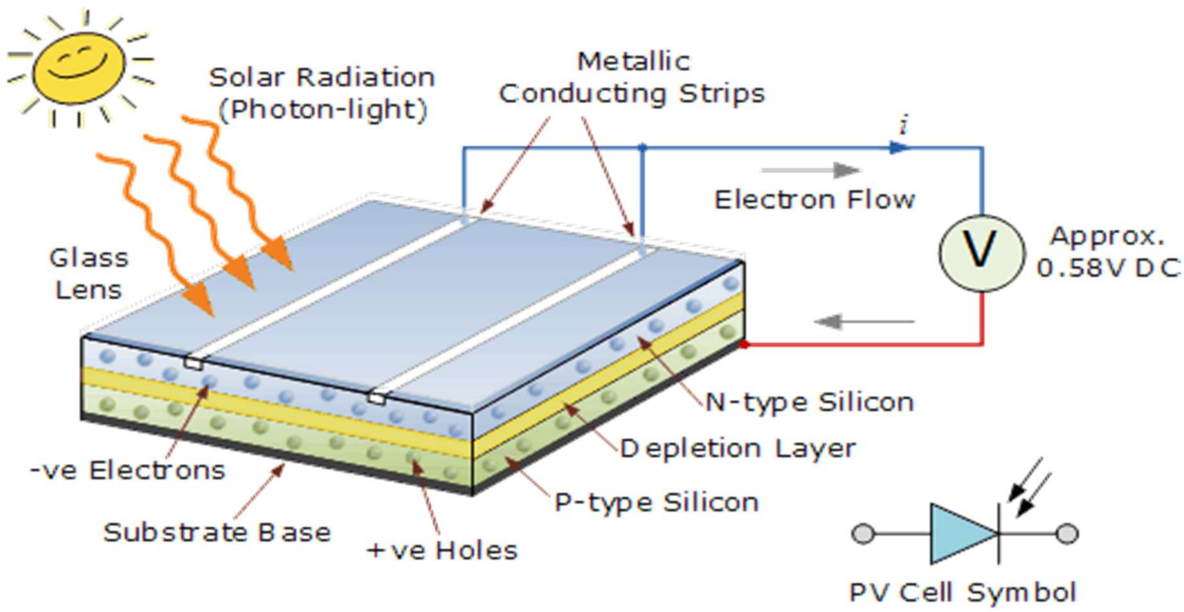


Fig 4.1 Photovoltaic Cell

4.2 Conventional Quadratic Boost Converter

Fig. 1 shows the conventional quadratic boost converter with a single active switch .

It consists of two inductances L1, L2, two capacitors C1, C2 one active switch and three passive switches D1, D2, D3.

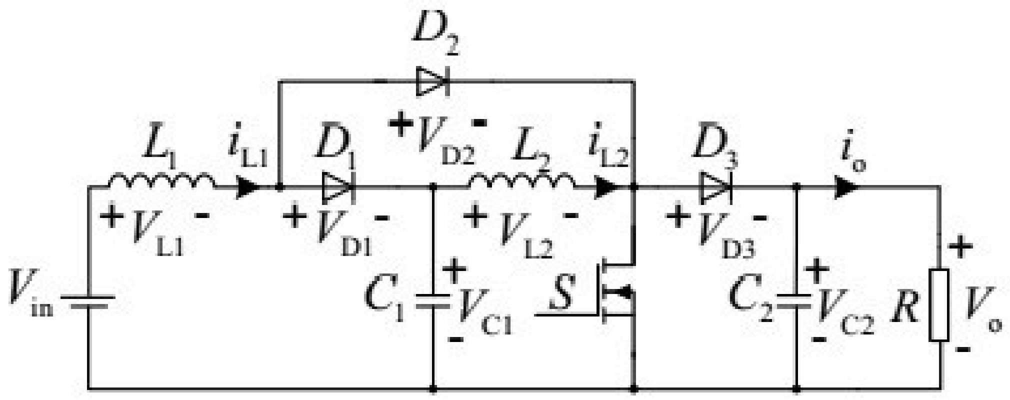


Fig. 1. Conventional quadratic boost converter

The voltage stress of S (VS-stress) and diode D3 (VD3-stress) can be obtained respectively as

Vs-stress = Vo VD 3-stress = Vo

4.3 QUADRATIC BOOST CONVERTER WITH CLD CELL

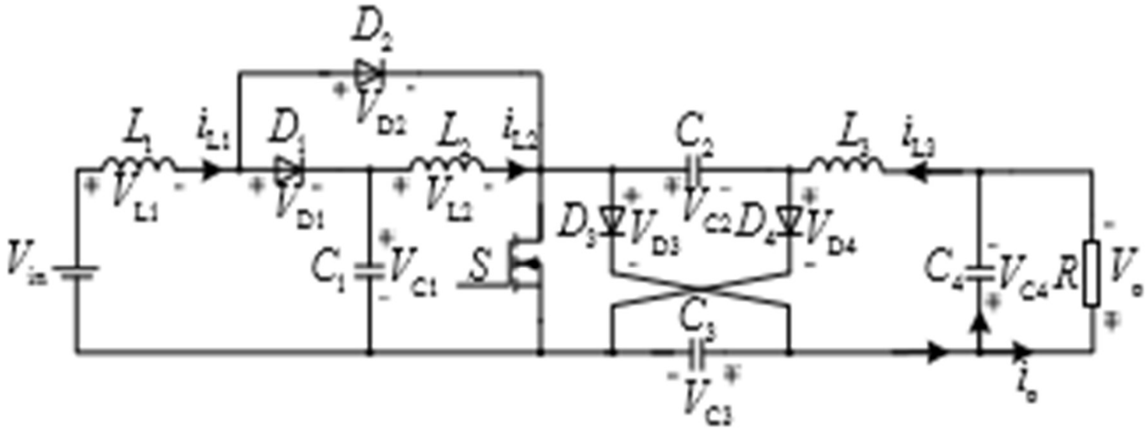


Fig. 3. The quadratic boost converter with CLD cell

4.4 OPERATION OF THE QUADRATIC BOOST CONVERTER WITH CLD CELL

In order to simplify the analysis, all components of the quadratic boost converter with CLD cell are treated as ideal. Assume that the quadratic boost converter with CLD cell operates in continuous conduction mode (CCM) and the switching frequency of the quadratic boost converter with CLD cell is much higher than its natural frequency. Then the capacitor voltages and inductor currents can be regarded as constant with relatively small AC ripple, and the quadratic boost converter with CLD cell has two switching statuses in one switching cycle.

Switching Status 1: S is ON, as shown in Fig. 4.4(a). The input voltage source Vin delivers energy to inductor L1, while capacitor C1 delivers its stored energy to inductor L2, capacitor C 2 and C3 discharge through the switch and the energy is stored in the inductor L3. Consequently, all of the inductor currents iL1, iL2 and iL3 are linearly increasing in the switching status 1

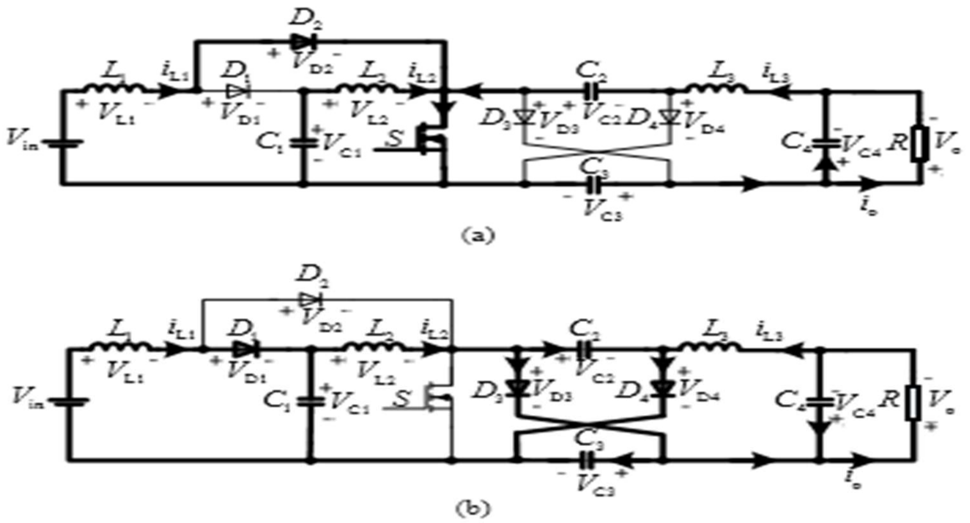


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Fig 4.4 (a) Switch is on (b) Switch if off

The slopes of inductor currents iL1, iL2 and iL3 during this interval are

$$\frac{diL}{dt} = \frac{Vin}{L1}, \qquad \frac{diL2}{dt} = \frac{Vc1}{L2}, \qquad \frac{diL3}{dt} = \frac{2Vc2 - Vo}{L3}$$

Switching Status 2: S is OFF, as shown in Fig. 4.4(b). The inductor L1 delivers the stored energy to C1 and the inductor L2 delivers the stored energy to C2, C3 and R. The energy stored in the inductor L3 is delivered to the output. Therefore, all of the inductor currents iL1, iL2 and iL3 are linearly decreasing in the switching status 2.

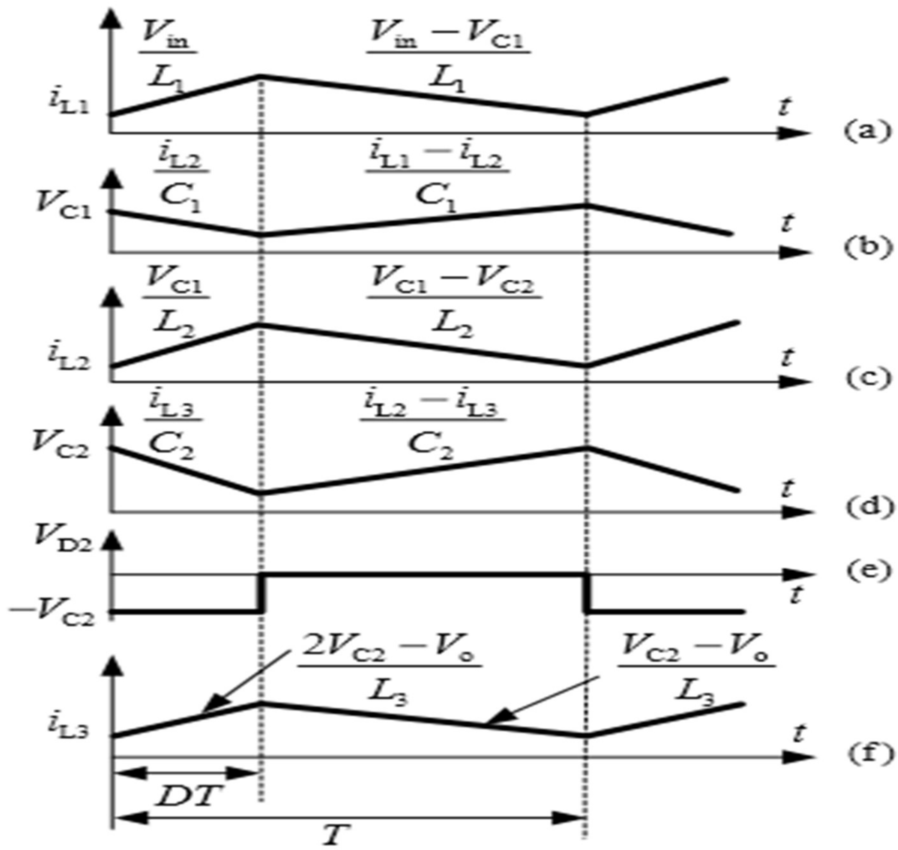


Fig 4.5 The major waveforms of the quadratic boost converter with CLD cell: (a) inductor current iL1, (b) capacitor voltage VC1, (c) inductor current iL2, (d) capacitor voltage VC2, (e) diode voltage VD2, (f) inductor current iL3

The slopes of inductor currents iL1, iL2 and iL3 during this interval are

$$\frac{diL1}{dt} = \frac{Vin-V}{L1}, \quad \frac{diL2}{dt} = \frac{Vc1-V}{L2}, \quad \frac{diL3}{dt} = \frac{Vc2-Vo}{L3}$$

the voltage step-up ratio M can be found from the volt-second balance of inductor L1, L2 and L3 and it is given by :

L1: Vin *Ton +($Vin - Vc1$)*Toff = 0

L2: Vc1*Ton +($Vc1 - Vc2$) $*$Toff = 0

L3: (2Vc2-Vo) + (Vc2-Vo)Toff = 0

After calculating these equations we get:

$$M = \frac{Vo}{Vin} = \frac{(1+D)}{(1+D)^{\wedge}2}$$

the voltage step-up ratio M of the quadratic boost converter with CLD cell, conventional quadratic boost converte

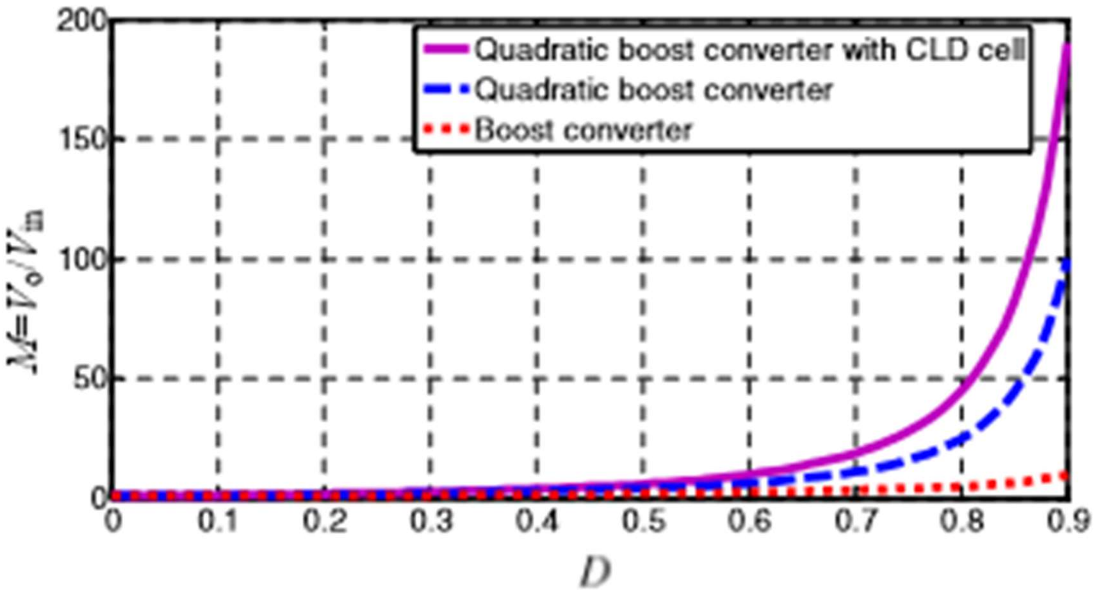


TABLE I. DESIGN SPECIFICATIONS OF THE THREE CONVERTERS

Converter Parameters	Quadratic boost converter with CLD cell	Quadratic boost converter	Boost converter
Voltage step-up ratio	$\frac{(1+D)}{(1-D)^2}$	$\frac{1}{(1-D)^2}$	$\frac{1}{1-D}$
$V_{\text{S-stress}}$(V)	$\frac{V_o}{1+D}$	V_o	V_o
$V_{\text{D1-stress}}$(V)	$\frac{(1-D)V_o}{1+D}$	$(1-D)V_o$	/
$V_{\text{D2-stress}}$ (V)	$\frac{DV_o}{1+D}$	DV_o	/
$V_{\text{D3-stress}}$ (V)	$\frac{V_o}{1+D}$	V_o	V_o

Chapter 5

5.1 Modified Quadratic Boost Converter

Modified Quadratic boost converter is a modification of new quadratic boost converter. It offers high voltage step up ratio and reduce voltage stress across switch as compared to new quadratic boost converter. It is well suited for extreme high Voltage Step- Up ratio applications. It operates at low duty cycle ratio and Gives wide range of operating voltages. Modified quadratic boost converter as shown in Fig 5.1

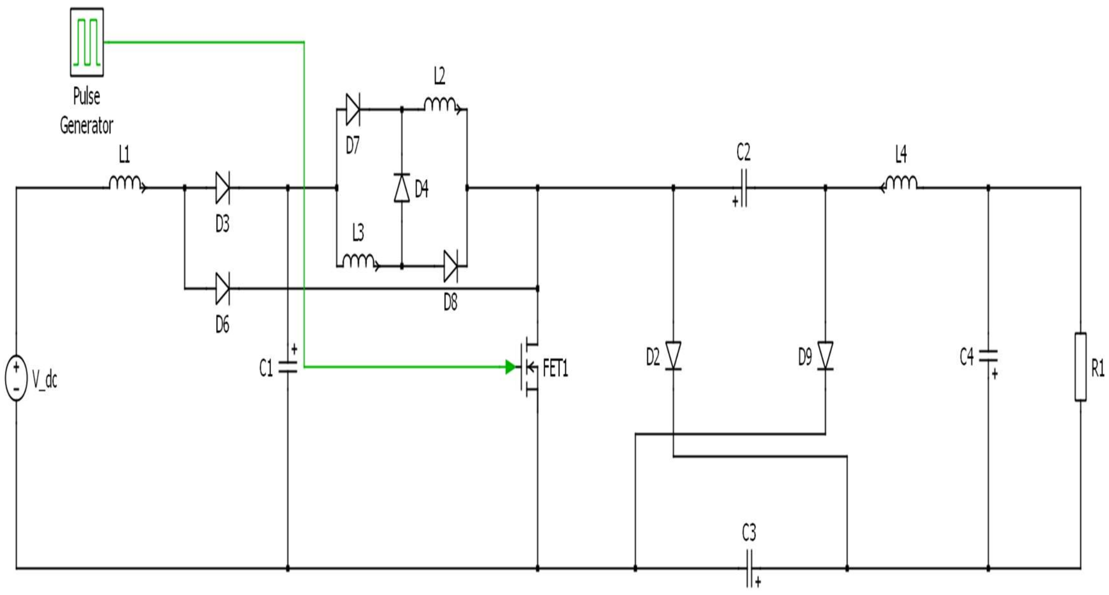


Fig 5.1 Modified quadratic boost converter

5.2 CALCULATIONS

Slope of the inductors currents iL1,iL2 , iL3 ,and iL4 during ON state

$$\frac{diL1}{dt} = \frac{Vin}{L1} \qquad \frac{diL2}{dt} = \frac{Vc1}{L2}$$

$$\frac{diL3}{dt} = \frac{Vc1}{L3} \qquad \frac{diL}{dt} = \frac{(2Vc2-Vo)}{L4}$$

Slope of the inductors currents iL1,iL2 , iL3 ,and iL4 during OFF state :

$$\frac{diL1}{dt} = \frac{(Vin - Vc1)}{L1} \qquad \frac{diL2}{dt} = \frac{(Vc1 - V\ \ )}{L2}$$

$$\frac{diL3}{dt} = \frac{(Vc1 - V\ \ )}{L3} \qquad \frac{diL4}{dt} = \frac{(Vc2 - Vo)}{L4}$$

By applying Volt- Second Balance of inductors L1 , L2,L3,and L4 it gives

$$\frac{Vo}{Vin} = \frac{(1+D)^\wedge 2}{(1-D)^\wedge 2} \qquad \text{Vs - stress} = \frac{Vo}{(1+D)^\wedge 2}$$

5.3 Advantages of Quadratic Boost converter

It has many advantages over conventional quadratic boost converter and simple boost converter. It gives high voltage step – up ratio and reduce voltage stress across switch. It operates at low duty cycle so losses get reduced. It is well suited for extreme high Voltage Step- Up ratio applications and gives wide range of output voltage.

5.4 Applications

Quadratic boost converter can be used in photovoltaic cell system and fuel cell system because the output voltages of PV system and fuel cell system are extremely low. It can be also used in electric vehicles and for the purpose of power amplifier.

Chapter 6

Hardware And Simulation Results

6.1 Simulation Under An Ideal Condition

We are considering an ideal case in which voltage drop across diode and other components are zero. The result of simulation is shown in fig 6.1.

Components Used

L1 = 1mH , L 2 = 2.7 mH,

L3 = 2.7 mH and L4= 3.5mH

C1 = 220uF, C2 = 55uF,

C3 = 55uF and C4 =100 uF

Switch: nMOS , Diodes and a **variable** load

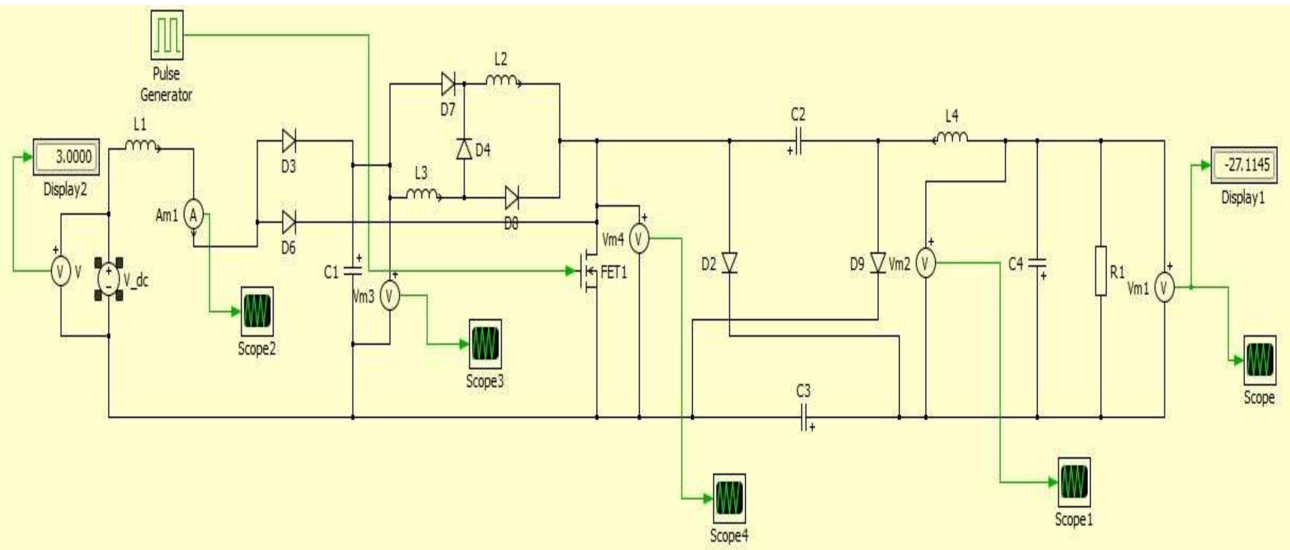


Fig 6.1

Input voltage = 3V = Vin

Duty cycle = 50%

Output voltage is given as:

$$\frac{Vo}{Vin} = \frac{(1+D)^2}{(1-D)^2}$$

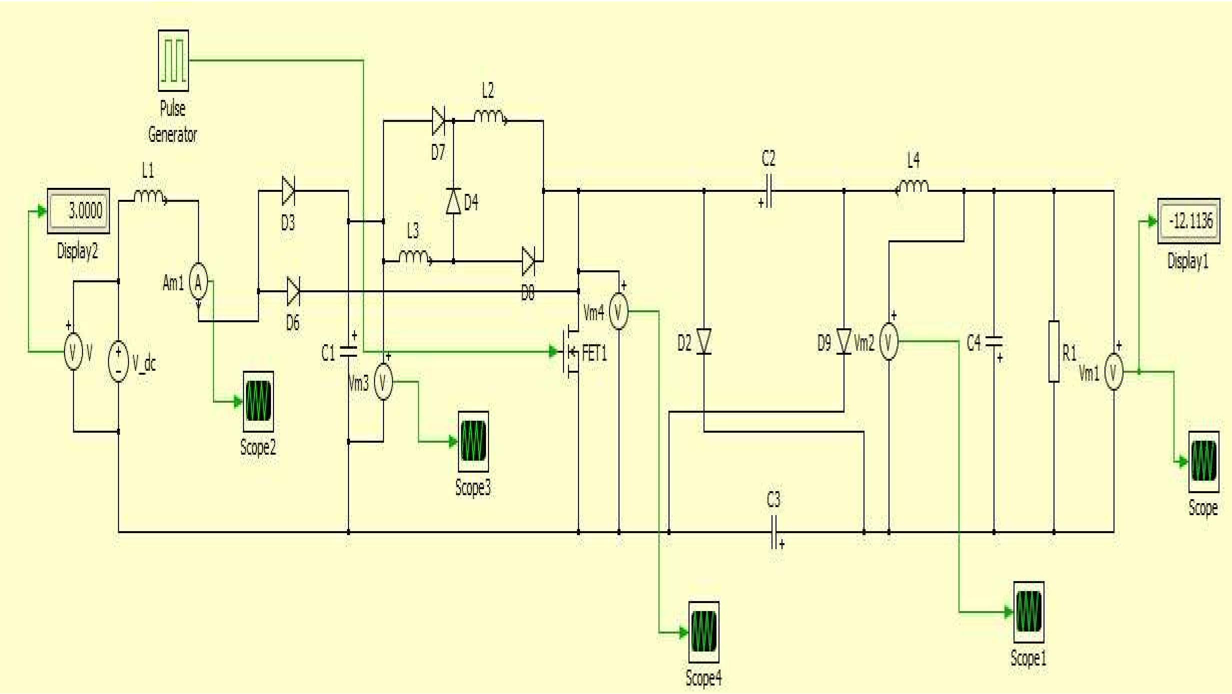
Putting the value of Vin and Duty cycle in output equation then we get :

Vo = 27 v

So output voltage is 9 times input voltage

6.2 Simulation Under Non Ideal Condition

We are considering a non-ideal case with forward resistance of diode = 1.5 Ω. The components are same as in the ideal case. The result of simulation is shown in fig 6.2.



Vin = 3 volts

Duty cycle = 50%

Forward resistance of diode= 1.5 Ω

The output voltage Vo = 12.01 volts

Results : the output voltage is four times of input voltage in non ideal case but in an ideal case the output voltage is nine times.

6.3 Simulation Waveforms

Input current waveform is shown in fig 6.3 ,voltage across switch waveform is shown in fig 6.4 and output voltage waveform is shown in fig 6.5.

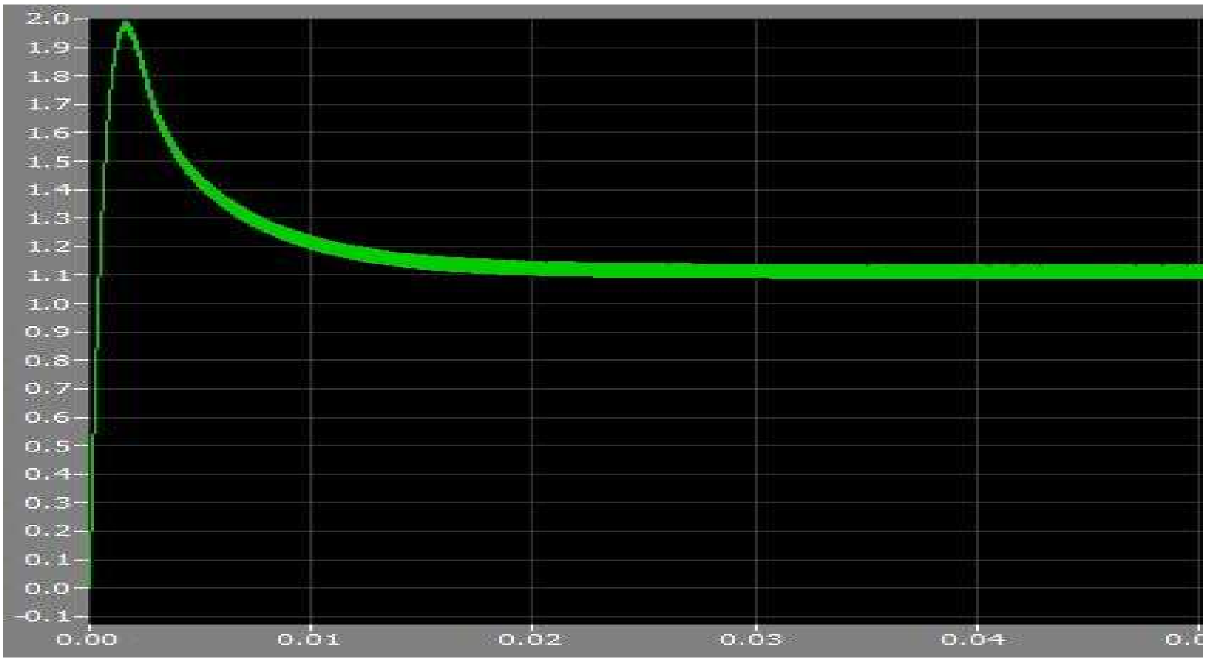


Fig 6.3 Input Current Waveform

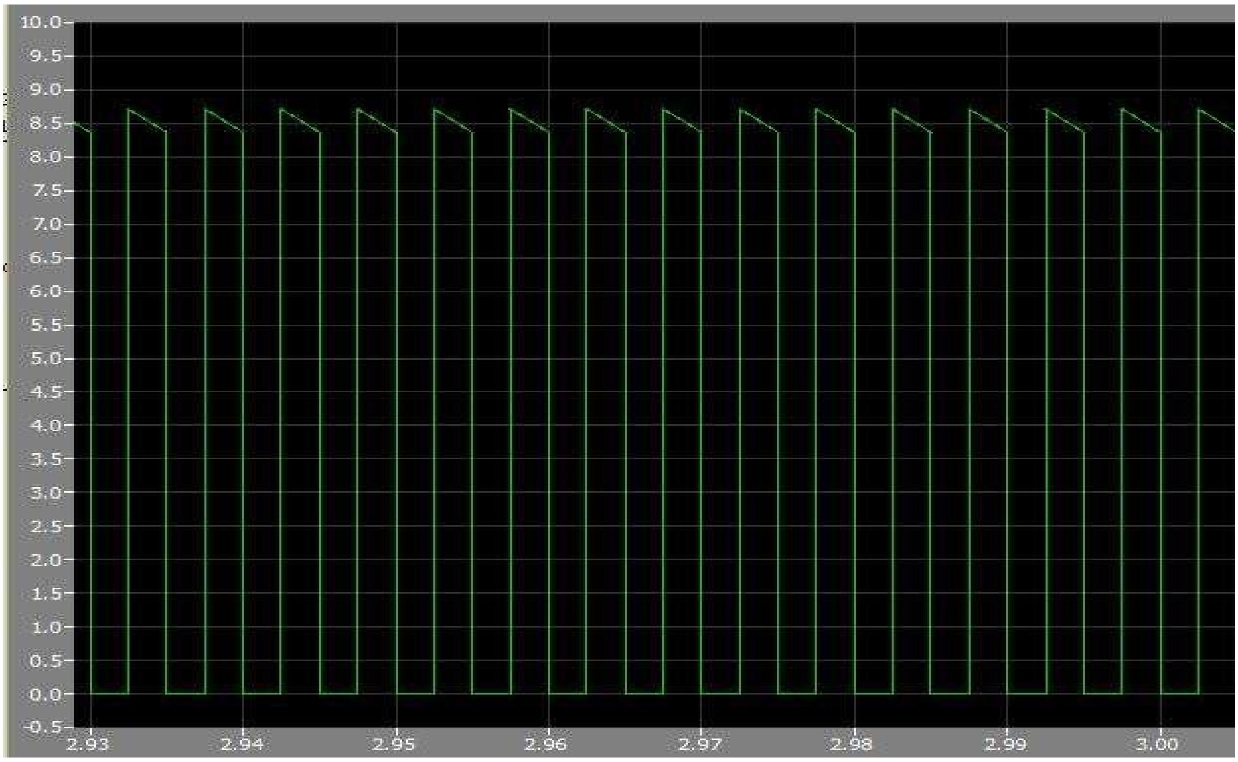


Fig 6.4 Switch Voltage Waveform

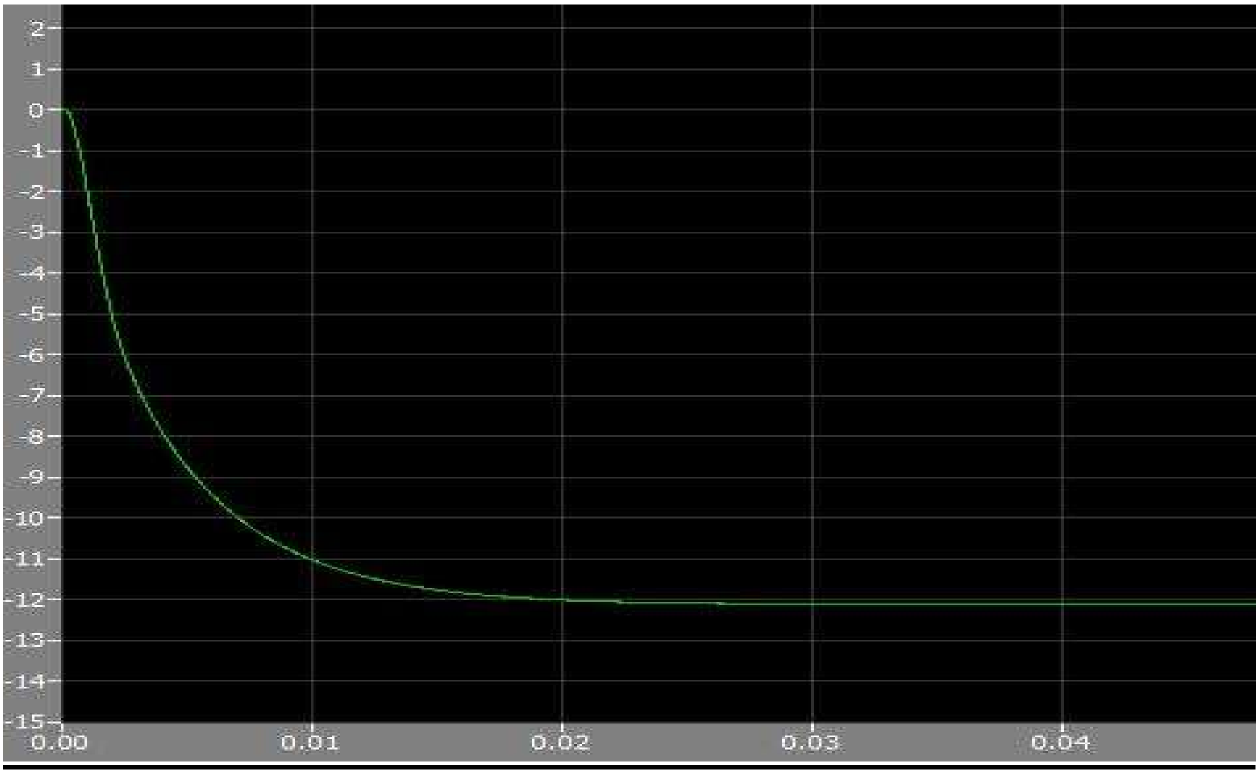


Fig 6.5 Output Voltage Waveform

6.4 Hardware Implementation

PCB Design

Now we finally designed a modified quadratic boost converter on PCB board as shown in fig 6.6. And finally experimental set up as shown in fig 6.7.
The components we used to design modified quadratic boost converter is as follow:

No of inductors = 4

Values of all inductors are :

L1 = 1mH , L 2 = 2.7 mH,

L3 = 2.7 mH and L4= 3.5mH

No of Capacitors = 4

Values of all capacitors are :

C1 = 220uF, C2 = 55uF,

C3 = 55uF and C4 =100 uF

No. of power diodes = 7, One NMOS switch and connecting wires.

Forward resistance of diode= 1.5 Ω

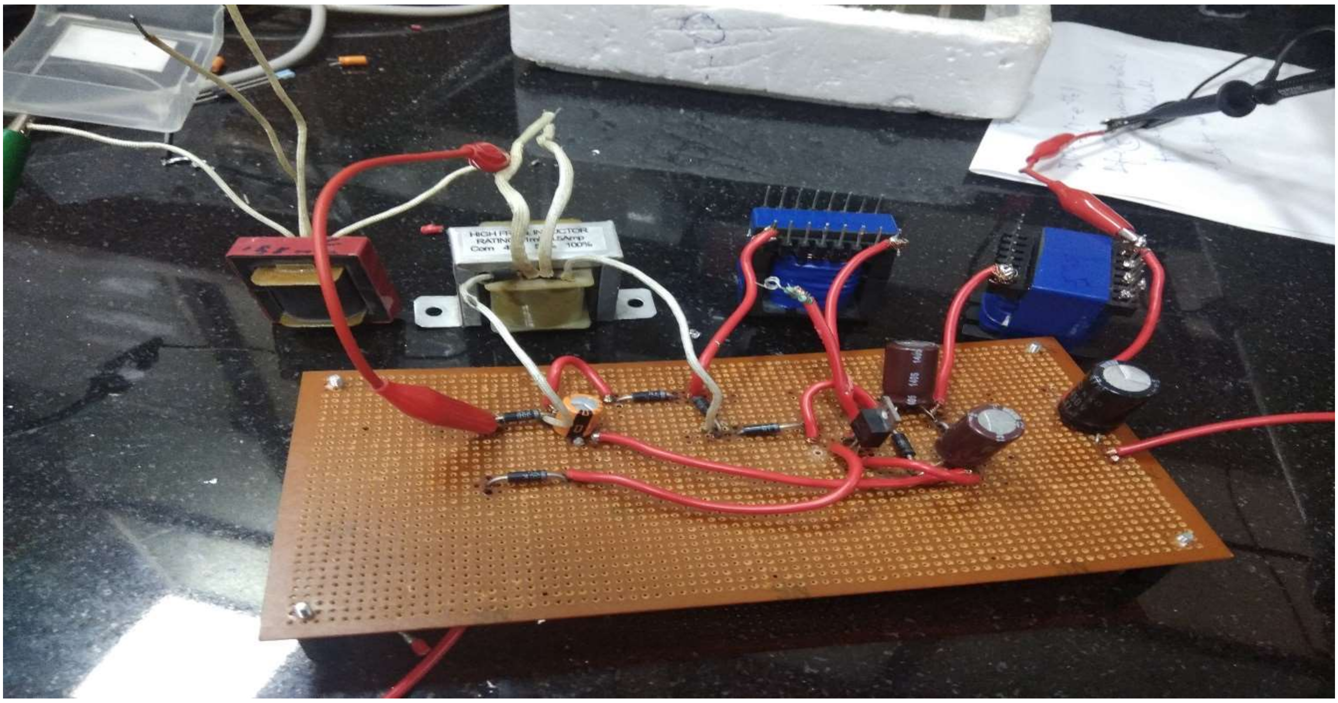


Fig 6.6 PCB Design Of Quadratic Boost Converter

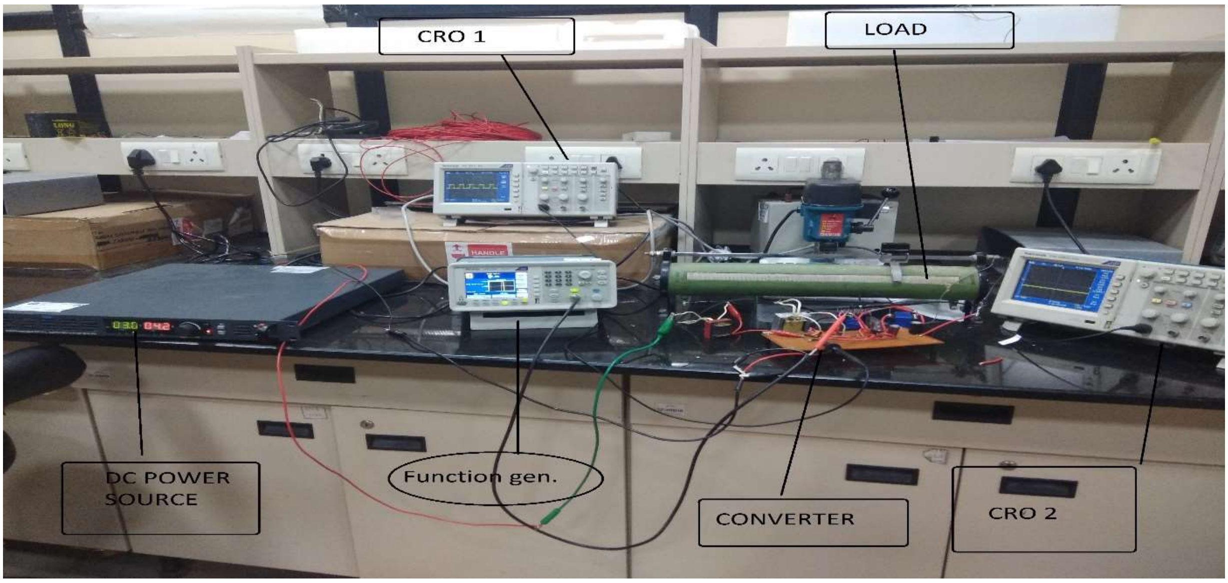


Fig 6.7 Experimental Set Up

6.5 Hardware Results

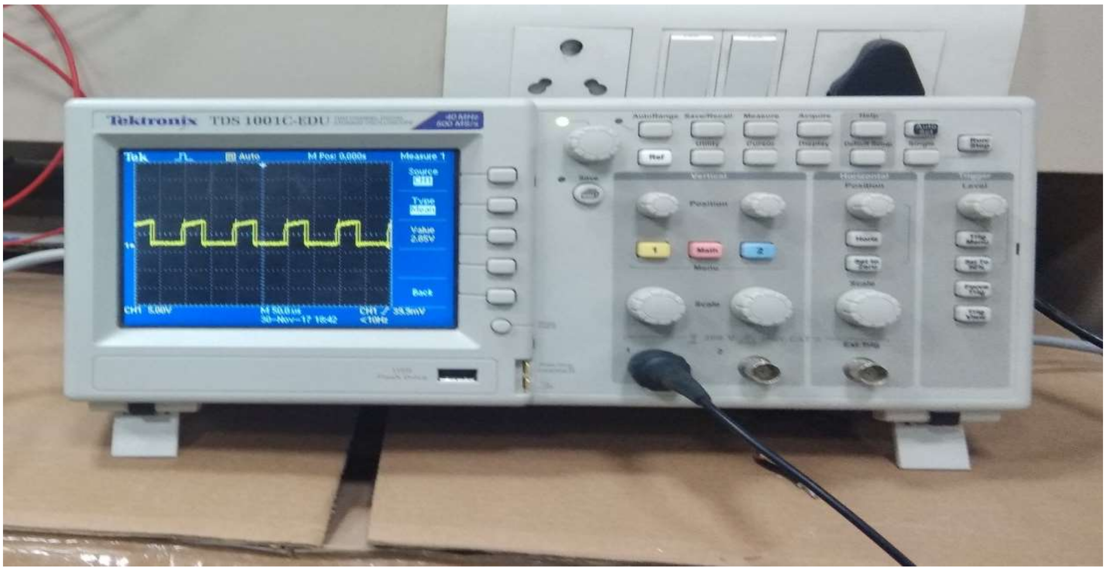


Fig 6.8 Gate Pulse Input

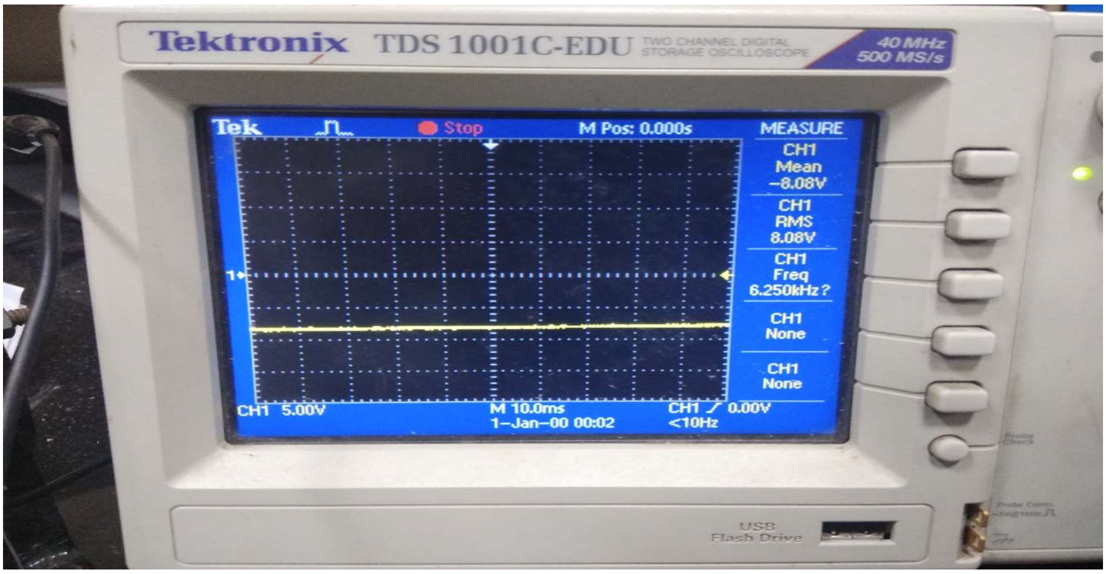


Fig 6.9 Output Voltage waveform

6.6 Limitations

(i) All components must be of high rating

(ii) Increase losses due to more number of diodes

(iii) More no. of inductor substantially increases the size of device

CONCLUSIONS

Modified quadratic boost converter has been presented which suitable for step-up application, in particular for high frequency applications where the voltage conversion ratio calls for an extremely high step-up ratio. Comparison with the conventional quadratic boost converter and boost converter shows that the quadratic boost converter with CLD cell have better characteristics over the conventional quadratic boost converter and boost converter with respect to the high voltage step-up ratio, reduced switch and diodes voltage stress. The experimental results of the quadratic boost converter with CLD cell have been presented. The results clearly demonstrate the validity of analysis results.

FUTURE SCOPE

With increasing stakes on non-conventional sources of energy, dependence on solar energy will be increased. To make the solar energy efficient quadratic boost converter will play the key role.

It can be used in photo voltaic cell for better efficiency with the help of solar charge controller.

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