Loss Analysis of Modified Quadratic Boost Converter For Switching & Conduction Losses

Yashaswini H N
M.Tech, Power Electronics Engineering
R V College of Engineering
Bengaluru, India

Dr. S.G.Srivani
Associate professor, Dept of EEE
R V College of Engineering
Bengaluru, India

Abstract—This paper describes about a performance analysis of Modified Quadratic Boost Converter for switching and conduction loss. Modified Quadratic Boost Converter has single active switch with control strategy. MQBC eliminates the requirement of additional driver circuit and improves the output voltage. High voltage gain was the main advantage of MQBC. The circuit was simulated in PSIM software for both open loop and closed loop by using ideal MOSFET switch. The PID controller is used as a feedback loop to attain the faster stability. The switching and conduction losses are estimated by considering a thermal module of MOSFET in PSIM and compare it with the ideal MOSFET switch. These losses are estimated even for the diodes. The characteristics of N-Channel Power MOSFET IRFP460 are nanosecond switching speed with the 20A, 500V rating specifications. The specifications present in IRFP460 MOSFET data sheet are added to PSIM software by using device database editor. The design specification of proposed converter is Vin = 24V, Vo= 92V and P= 40W. The comparative simulation of ideal switch of MOSFET with the thermal module of IRFP460 includes a power value of 20A, 500V, 0.270 Ohm, N-Channel Power MOSFET are analyzed. The converter gain of 60% and designed values of inductors, capacitors and resistance are 71.28 uH, 288uH, 11.57 uF, and 230ohm respectively. The open loop and closed loop simulation results of transistor conduction losses and transistor switching losses are 9.059W, 9.02W, 6.08W, 5.42W respectively.In this proposed paper the switching and conduction losses of both the transistor and the diodes of the Modified Quadratic Boost Converter by using the PSIM software tool.

.

Index Terms – Modified Quadratic Boost Converter, PID controller, Switching loss, Conduction loss, Power supply unit

1. INTRODUCTION

Distributed energy sources are diverting the intention of power producers to fulfill their energy demands and mitigate energy crises. Different renewable energy sources such as wind, solar photovoltaic, fuel cell are commonly used sources, but solar photovoltaic attracted the intention of research in recent years because of its abundant availability [1]. The output voltage of photovoltaic and fuel cell system is very low. Mostly conventional boost converter is used to increase the output voltage from low input voltage systems. The main disadvantage of conventional boost converters does not work in high ratio duty cycle because of limited switching frequency and minimum OFF time of transistor switches.

The disadvantage of conventional boost converter is mitigated by successfully implementing the high voltage step up ratio like forward or fly back converter [2]. The disadvantage of this type of converter are increases the loss, cost and size of the transformer. Hence the conventional quadratic boost converter is proposed with includes only one switch for voltage conversion ratio. The disadvantage of Quadratic Boost Converter is step-up switching structure.QBC is not suitable because there is no energy storing elements. To achieve the high voltage gain and decrease the voltage stress on semiconductor switches, a new topology of Modified DC - DC Quadratic Boost Converter (MQBC) with high voltage gain is presented.

The performance is analyzed by simulating the MQBC in PSIM software. The semiconductor switches has zero rise time and zero fall time in ideal condition. But in the practical condition, the semiconductor switches has finite rise time and fall time leading to conduction loss and energy loss. The proposed MQBC is simulated for both open loop and closed loop by using ideal MOSFET switch. The thermal module of IRFP460 is added to PSIM software tool by using device database editor. N-Channel Power MOSFET IRFP460 has a feature of high input impedance, nanosecond switching speed, linear transfer characteristics with the power level of 20A, 500V, rds(on) = 0.270 ohm. The comparison of ideal switch of MOSFET with the thermal module of IRFP460 switch is analyzed by using simulation results. Thus switching loss and conduction loss of the transistor and diode are estimated.

2. BLOCK DIAGRAM & METHODOLOGY OF MODIFIED QUADRATIC BOOST CONVERTER

The DC - DC boost converter includes Vin = 24V and Vo = 92V but has a limitations of higher switching losses and reduces efficiency. These limitations are eliminated by introducing MQBC. The characteristic of MQBC are simple in structure, less ripple, higher efficiency and operates at high switching frequency [13]. The block diagram of closed loop of MQBC is as shown in the Fig 2

- DC supply: The function of DC supply is to provide power for operation of proposed converter i.e. 24V DC like battery
- Design and development of MQBC: The structure of IBC is simple and requires less complex controller to regulate the output voltage. The proposed converter is non-isolated, high step up conversion ratio helps to reduce voltage and current ripples and increases efficiency with high voltage gain.
- Design and development of PID Controller: This controller meets the steady state stability by minimizing the transients present in initial conditions. It avoids fluctuations and ripple present in output voltage.

Design and loss analysis of proposed Converter: Switching losses are "Frequency" dependent and conduction losses are "Duty ratio" dependent. Hence both losses are estimated in PSIM software tool.

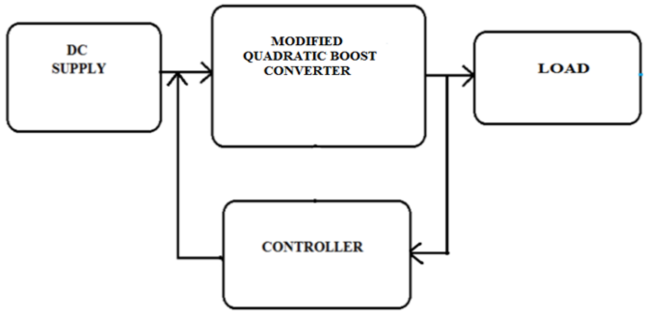


Fig 2: Block diagram of closed loop of Modified Quadratic Boost Converter

Modified Quadratic Boost Converter topology is of a single switch operation with high voltage gain. The proposed converter is designed for the specifications of input voltage of 24V and output voltage of 90V with the power rating of P=40W. The proposed MQBC is designed for both ideal switch and practical switch IRFP460 of MOSFET. The performance of proposed converter is analyzed by simulating for both open loop and closed loop in PSIM software.PID controller is used in feedback loop to attain faster stability. The open loop and closed loop simulation of MQBC includes a ideal switch of MOSFET. In order to analyze the proposed converter for practical condition, IRFP460 MOSFET switch are considered. The thermal module of practical MOSFET has characteristics of nanosecond switching speed leading to switching and conduction losses. The specification present in IRFP460 MOSFET datasheet is added to PSIM software using device database editor. The switching and conduction of switches and diodes are estimated. Comparison of ideal switch of MOSFET with that of thermal module of IRFP460 MOSFET has been analyzed with the simulation results.

3. POWER LOSSES IN SWITCHES

Power loss generated in the switch is the product of the current through the switch and voltage across the switch. When the switch is ON, it has a current of (Vs/Rl) but there is no voltage drop hence no power loss..The circuit diagram of the power switch is closed which connecting to the resisitive load is shown in the figure 4.1 The equation of the current and the voltage when the switch is closed is given by Isw(closed) = I load and Vsw (closed) = 0. Hence power absorb by the switch is given by P closed = Vsw (closed)* I sw(closed) = 0. When the switch is OFF, there is no current through it (no Vs across it) hence there is no power dissipation. The circuit diagram of the power switch is open which connecting to the resisitive load is shown in the figure 3.8. The equation of the current and the voltage when the switch is open is given by Isw(open) = 0 and Vsw (open) = V source. The power absorbed by the switch is given by P open = Vsw (open)* I sw(open) = 0. Hence the total power loss in the switches is given by P loss = P closed + P open = 0 thus the switching loss & conduction loss are zero.

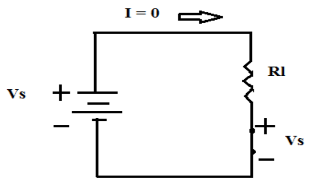


Fig 4.1: Circuit Diagram of the Power switch is closed

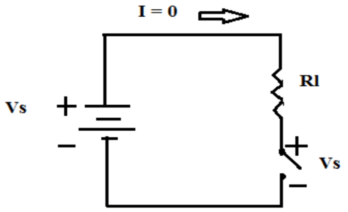


Fig 4.2: Circuit Diagram of the Power switch is open

Ideally the fall & rise time of the switch (i.e on time & off time of switch) are zero.Ideal switches have zero on-state drop, hence no conduction losses i.e conducting forward drop is zero. It has a zero leakage current hence there is no off-state losses. The turn on and turn off of the power switches transition are instantaneous thus there is no energy loss during switching transitions (Voltage collapse immediately & current rise immediately). When the switch is ON state, the voltage across the device is zero and when the switch is OFF state, the current flowing through the device is zero.The switching period is the time taken to change the from ON state to OFF state and vice-versa.The waveform of the voltage and the current in the ideal conduction is shown in the Fig 3.1

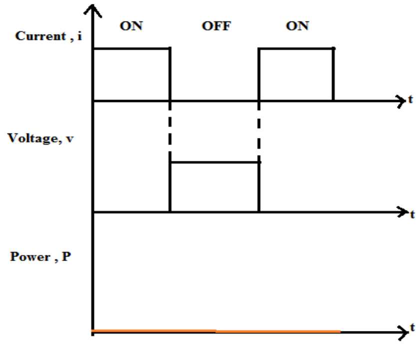


Fig 3.1: Waveform of the voltage and the current in the ideal conduction of switches

Practically the fall & rise time of the switch (i.e on time & off time of switch) are not zero. In this practical switching of the devices there is a finite forward drop presence hence conduction loss exists.There is a negligible leakage current & off state loss are also present in this practical switches. The turn on and turn off of the power switches transition are not instantaneous thus there is significant energy loss during switching transitions (Voltage does not collapse immediately & current rise does not immediately)When the switch is ON state, the voltage across the device is not zero and when the switch is OFF state, the current flowing through the device is not zero.The switching period is the time taken to change the from ON state to OFF state and vice-versa. Hence the switching losses and the conduction losses are present in the practical switches such that switching losses are greater than conduction losses. The waveform of the voltage and the current in the ideal conduction is shown in the figure 3.2

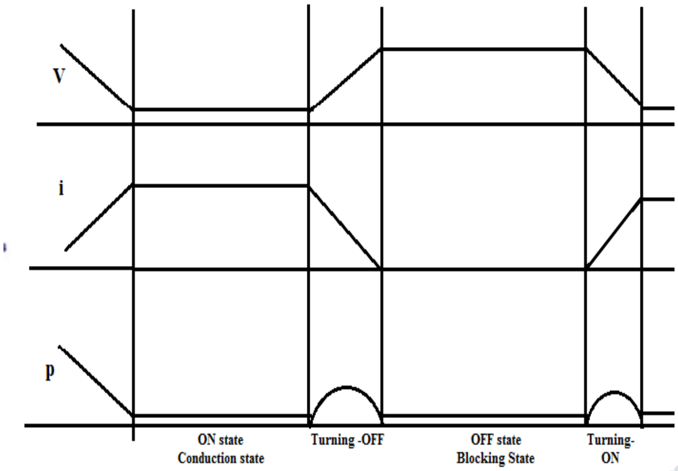


Fig 3.2: Waveform of the voltage and the current in the practical conduction of switches

Total power loss of the power semiconductor devices is equal to the sum of the conduction loss or ON- state loss and switching losses i.e (turn on loss + turn off loss).For the switching operation of any device, power loss are mainly classified into two types namely

- Switching losses occurs when the device is transitioning from the blocking state to the conducting state and vice-versa.This interval is characterized by a significant voltage across its terminals and a significant current through it. The energy dissipated in each transition needs to be multiplied by the frequency to obtain the switching losses Switching losses occurs during turning on and turning off time of the devices.
- Conduction losses: It occurs when the device is in full conduction. The current in the device is whatever is required by the circuit and the voltage at its terminals is the voltage drop due to the device itself. These losses are in direct relationship with the duty cycle not on frequency dependent. The way to reduce conduction losses is by lowering the forward drops across the diode and switch

There are 4 extra nodes on each thermal module of IGBT than the normal IGBT. These 4 nodes are for the power losses, and they are (from top to bottom)

1. Transistor conduction losses
2. Transistor switching losses
3. Diode conduction losses
4. Diode switching losses.

They are in the form of electric currents, and flows out of these nodes in order to measure the losses values, connect an ammeter to each node.

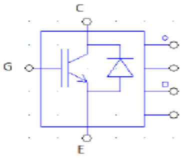


Fig 3.3: Thermal module of IGBT

4. CIRCUIT DIAGRAM OF MODIFIED QUADRATIC BOOST CONVERTER

MQBC is a non isolated, step up conversion ratio with the increased output voltage. The structure of proposed converter is simple and requires a less complex controller to maintain the constant output voltage with minimum ripple. Fig 4.1 depicts the circuit diagram of MQBC.

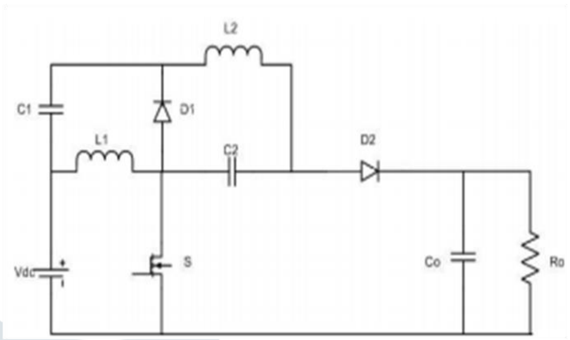


Fig 4.1: Circuit diagram of the MQBC

MQBC helps to reduce the switching loss and voltage stress across all active switches in ideal condition. It is suitable for high output voltage applications with the duty ratio greater than 50%. The value of capacitor is large to maintain output voltage (Vo) constant. All the semiconductors are ideal in nature. The circuit diagram of MQBC consists of 2 modes namely

- Mode 1: The circuit diagram of mode 1 operation is illustrated in Fig 4.2. In this mode, the switch S is closed and capacitors along with the inductors are charged. The diode D1 is reverse biased since anode is more negative than the cathode across the diode. Current flowing through the inductor L1 and L2 increases linearly. The voltage across inductor L1 is equal to gate voltage. The expressions of inductor and capacitor voltages are represented in equations (4.1) (4.2) and (4.3).

$$V_{L1} = V_g \qquad \text{.......} (4.1)$$

$$V_{C1} = V_{C2} = \frac{D*Vg}{(1-D)} \qquad \text{.......} (4.2)$$

$$V_{L2} = V_g + V_{C1} - V_{C2} \qquad \text{.......} (4.3)$$

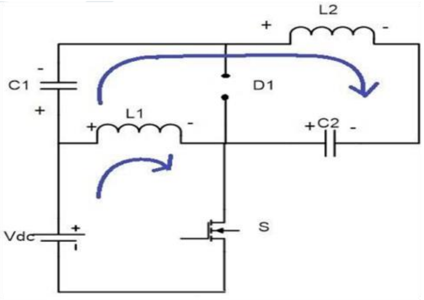


Fig 4.2: Circuit diagram for Mode 1 operation

- Mode 2: The circuit diagram of mode 2 operation is shown in the Fig 4.3 and waveforms are represented in Fig 4.4. During mode 2 operation, MOSFET switch turns off and diode D1 is forward biased. Inductor current discharges along with the capacitors. Since capacitors and inductor are in parallel, two capacitors voltage along with dc source voltage appears across the output resistive load. Current flows through the inductor L1 and L2 are decreasing linearly. The voltage across inductor L1 is equal to gate voltage. The inductor voltages and output voltage are represented by equations (4.4) (4.5) and (4.6).

$$V_{L1} = - V_{C1} \quad \text{......... (4.4)}$$

$$V_{L2} = - V_{C2} \quad \text{......... (4.5)}$$

$$V_o = V_G + V_{C1} + V_{C2} \quad \text{......... (4.6)}$$

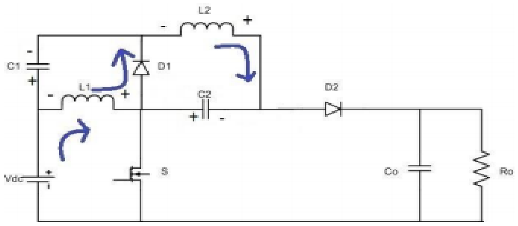


Fig 4.3: Circuit diagram for Mode 2 operation

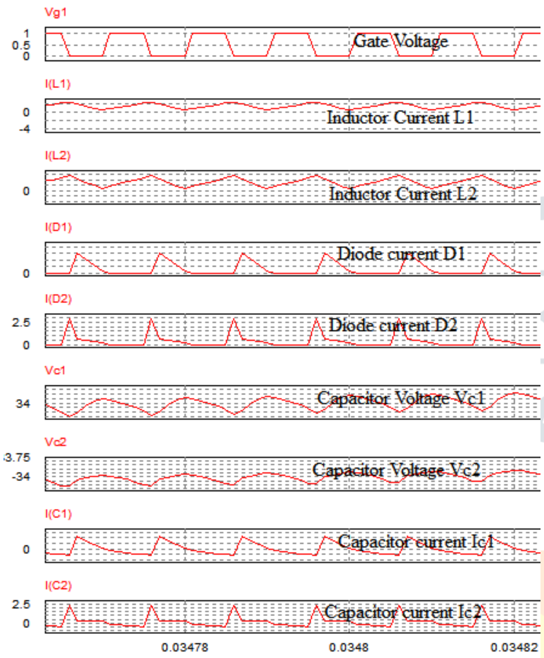


Fig 4.4: Waveform of MQBC

4.1 Controller

In closed loop control system, the difference between desired output and actual output is fed back to the controller to meet desired system output. There are mainly classified into three controllers namely

- ➢ Proportional Controller [P]: P controller stabilizes the unstable process by using single energy storage and generally used in first order process. The proportional gain factor (K) is inversely proportional to steady state error. This controller never eliminates steady state error and causes overshoot in the system. If there is a higher order or lags in the system increases then it directly amplify the noise process. The advantages are minimizes dead time from backlash and stiction, reduce rise time, less peak error, decreases error of integration. The disadvantages are sudden change in the output value and abrupt variation in any other loops, noise amplification [16].
- ➢ Integral Controller [I]: In this controller, error value is integrated with respect to the time and approaches to set point as error value is negative. The output is delayed by reducing the limits hence causes overshoot in the system. Excessive action of the integral controller leads to runway problem of increased temperature. Eliminating offset, decreased integration error and smooth movement of output are the main advantage. The disadvantages are limited number of cycle operation, overshoot problem, unstable reactors runaway in open loop condition [20].
- ➢ Derivative Controller [D]: The rate of change of error with respect to time is proportional to output value in this controller. The step changes in error parameter causes a spike. Hence the variation in error action leads to oscillation. After reaching the set point, these oscillations are persisted. Improvements in transient response are the main advantage of the system. The combinations of other controller and no improvement in the steady state error are the main disadvantage.
- ➢ PI Controller [PI]: PI controller is the combination of proportional and integral controller that eliminates steady state error. This controller is economical and easy to design. The disadvantages of this controller are slow reaction to disturbance or noise, increases oscillation PI controller [15].
- ➢ PID Controller [PID]: PID controllers are widely used in feedback controllers, varieties of industrial control systems, automatic devices and equipment, signal modulation for digital devices. The constant value is obtained by modifying the input value. The feasibility and easy implementation are the main advantage of this controller [18]. They operate optimally for enhanced productivity, improved quality and reduced maintenance requirements. Hence PID controller is chosen for design and development of Interleaved Buck Converter. The characteristics of various controllers with respect to time is shown in the Fig 4.5

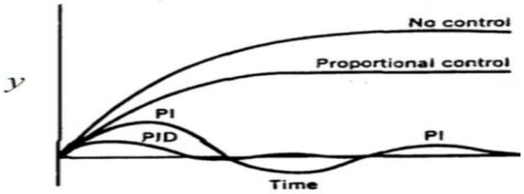


Fig 4.5: Characteristics of Controller with respect to Time

4.2 Design Specifications

The specifications of proposed MQBC are tabulated in Table.4.1. The proposed MQBC is designed for two level converters. It has an input voltage of 24 Volts and the maximum rated current is 1 A [5]. The MQBC is designed for 100 kHz of Frequency

Table 4.1: Design Specifications of MQBC

Name of the components	Design rating
Input Voltage	24V
Output Voltage	92V
Power rating	40W
Voltage ripple	20%
Current ripple	10%

According to the design specifications, resistance value is represented in equation (4.7)

$$R_o = \frac{Vo^2}{Po} = \frac{92^2}{40} = 230\text{ohm} \quad \text{......... (4.7)}$$

Inductor value of L1 and L2 is expressed by the equation (4.8) and (4.9)

$$\text{L1} > \frac{(1-D)^2 * D * Ro}{2 * (1+D)^2 * Fs}$$

$$\text{L1} > \frac{(1-0.6)^2 * 0.6 * 230}{2 * (1+0.6)^2 * 100K}$$

i.e. L1 = 65% of L1

$$\text{L1} = 71.28\text{uH} \quad \text{......... (4.8)}$$

$$\text{L2} > \frac{(1-D) * D * Ro}{2 * (1+D) * Fs}$$

$$\text{L2} > \frac{(1-0.6) * 0.6 * 230}{2 * (1+0.5) * 100K}$$

i.e. L2 = 65% of L2

$$\text{L2} = 287.975\text{uH} \quad \text{......... (4.9)}$$

Capacitor value is represented by the equation (4.10) and (4.11)

$$C1 = C2 = \frac{Io*D*T}{\Delta Vc1} = \frac{0.4166*0.6*1/100K}{0.20}$$

$$= 11.575uH \qquad \ldots\ldots\ldots (4.10)$$

$$Co = \frac{Io*D*T}{\Delta Vco}$$

$$= \frac{0.4166*0.6*1/100K}{0.6}$$

$$= 4.34uH \qquad \ldots\ldots\ldots\ldots (4.11)$$

The relationship between input and output voltage is given by the equation (4.12)

$$\frac{Vo}{Vin} = \frac{1-D^2}{(1-D)^2} \qquad \ldots\ldots\ldots\ldots (4.12)$$

The final designed value of the proposed MQBC converter is tabulated in table 4.2

Table 4.2: Design Specifications of MQBC

Switching frequency	100KHz
Inductors L1	71.28uH
Inductors L2	287.95uH
Capacitor (C1= C2)	11.575uF
Capacitor Co	4.3uF

4.4 Design of MQBC for practical condition

In practical condition of proposed converter, the switching and conduction loss are present such that input power is not equal to output power. The conduction loss is mainly dependent on the ON state resistance of the MOSFET and resistance is dependent on the junction temperature and applied gate-source voltage (VGS). The conduction loss design is represented in the equation (4.13)

$$I^2_{drain} = \frac{\Delta i*\sqrt{D}}{3} + \sqrt{D*(Imax - \Delta i)^2}$$

$$= \frac{4.04*\sqrt{0.6}}{3} + \sqrt{0.6*(1.68 - 4.04)^2}$$

$$= 2.396A$$

$$Imax = \frac{2*I\ out*\Delta i*(1-D)}{2*(1-D)}$$

$$= \frac{2*0.4166*4.04*(1-0.6)}{2*(1-0.6)} = 1.68A$$

$$\Delta i = \frac{D*Vin}{L1*Fsw} = \frac{0.6*24}{71.28u*100k} = 4.04W$$

$$P_{loss\_Rds\_on} = I^2_{drain} * Rds\_on \qquad \ldots\ldots\ldots\ldots (4.13)$$

$$= 2.396 * 0.27 = 0.64692W$$

The expression of loss due to diode is dependent on the forward voltage of diode is represented in the equation (4.14)

$$I_{rms\_diode} = \frac{\Delta i*\sqrt{(1-D)}}{\sqrt{3}} + Imin * \sqrt{(1-D)}$$

$$= \frac{4.04*\sqrt{(1-0.6)}}{\sqrt{3}} + 0.9785 * \sqrt{(1-0.6)}$$

$$= 0.8563A$$

$$Imin = \frac{Iout*\Delta i*(D-1)/2}{(1-D)}$$

$$= \frac{0.4166*4.04*(0.6-1)/2}{(1-0.6)}$$

$$= -0.9785$$

$$P_{loss\_diode} = I_{rms\_diode} * Vf \qquad \ldots\ldots\ldots (4.14)$$

$$= 0.8563 * 0.6 = 0.51216W$$

5. LOSS CALCULATION BY USING PSIM SOFTWARE TOOL

The thermal module of the MOSFET switching losses and conduction loss are calculated using Powersim (PSIM) software tool which is the leading simulation and design software for power electronics, motor drives, and dynamic system simulation. The main advantage of this PSIM tool provides the fast simulation and easy-to-use interface and also provides a powerful and efficient environment to meet needs of the simulation requirements. In order to calculate the loss of the switching and conduction losses of the transistor and the diodes, need to have the thermal module of the semiconductor devices. Thermal Module is an additional option for the PSIM software which allows users to add semiconductor device data sheet information into a database, and use these devices in the simulation for the loss calculation and provides a quick way of estimating device conduction losses and switching losses.

For the MQBC, the switching and conduction losses analysis the data sheet of IRFP460 is the 20A, 500V, 0.270 Ohm, N-Channel Power MOSFET module has been selected. Initially in order to create and add the database to the software tool, go the 'Utilities' and then to Device Database editor which is shown in the Fig 5.6. Finally add CIRFP460 is added to the database and run the circuit to get the obtained results of the losses of both the conduction and switching losses of the transistor and diodes. Device database selection for thermal module of MOSFET and graph of freewheeling diode Vd versus If is shown in Fig 5.7 and Fig 5.8 respectively.

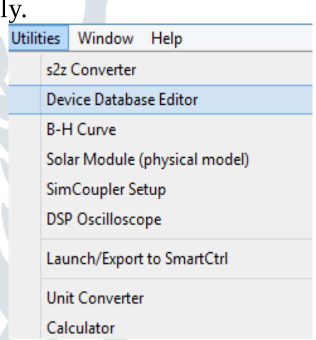
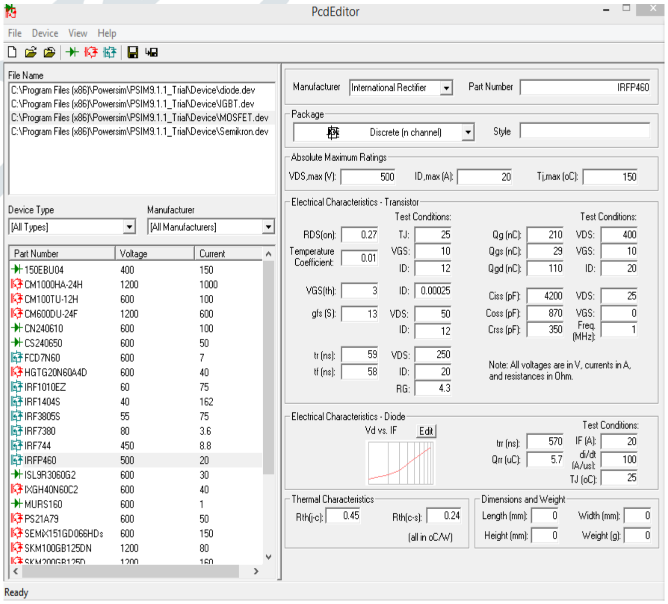


Fig 5.6: Instructions for Selecting Device Database



File Name
C:\Program Files (x86)\Powersim\PSIM9.1.1_Trial\Device\diode.dev
C:\Program Files (x86)\Powersim\PSIM9.1.1_Trial\Device\IGBT.dev
C:\Program Files (x86)\Powersim\PSIM9.1.1_Trial\Device\MOSFET.dev
C:\Program Files (x86)\Powersim\PSIM9.1.1_Trial\Device\Semikron.dev

Device Type: [All Types]
Manufacturer: [All Manufacturers]

Part Number	Voltage	Current
150EBU04	400	150
CM1000HA-24H	1200	1000
CM100TU-12H	600	100
CM600DU-24F	1200	600
CN240610	600	100
CS240650	600	50
FCD7N60	600	7
HGTG20N60A4D	600	40
IRF1010EZ	60	75
IRF1404S	40	162
IRF3805S	55	75
IRF7380	80	3.6
IRF744	450	8.8
IRFP460	500	20
ISL9R3060G2	600	30
IXGH40N60C2	600	40
MURS160	600	1
PS21A79	600	50
SEMiX151GD066HDs	600	150
SKM100GB125DN	1200	80
SKM200GB125D	1200	160

Manufacturer: International Rectifier
Part Number: IRFP460
Package: Discrete (n channel)
Style:

Absolute Maximum Ratings
VDS,max (V): 500
ID,max (A): 20
Tj,max (oC): 150

Electrical Characteristics - Transistor

		Test Conditions:				Test Conditions:	
RDS(on):	0.27	TJ:	25	Qg (nC):	210	VDS:	400
Temperature Coefficient:	0.01	VGS:	10	Qgs (nC):	29	VGS:	10
		ID:	12	Qgd (nC):	110	ID:	20
VGS(th):	3	ID:	0.00025	Ciss (pF):	4200	VDS:	25
gfs (S):	13	VDS:	50	Coss (pF):	870	VGS:	0
		ID:	12	Crss (pF):	350	Freq. (MHz):	1
tr (ns):	59	VDS:	250				
tf (ns):	58	ID:	20				
		RG:	4.3				

Note: All voltages are in V, currents in A, and resistances in Ohm.

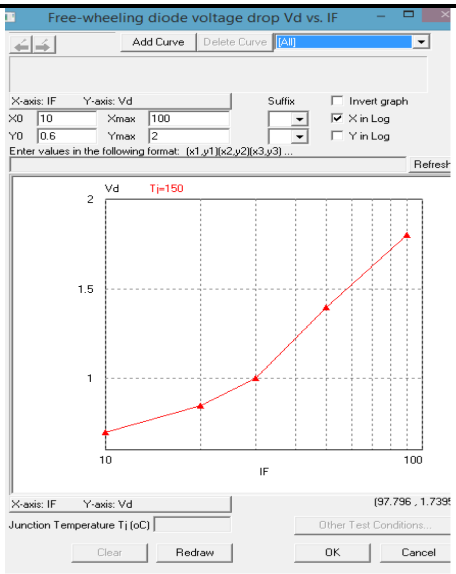
Electrical Characteristics - Diode
Vd vs. IF Edit

		Test Conditions:	
trr (ns):	570	IF (A):	20
Qrr (uC):	5.7	di/dt (A/us):	100
		TJ (oC):	25

Thermal Characteristics
Rth(j-c): 0.45
Rth(c-s): 0.24
(all in oC/W)

Dimensions and Weight
Length (mm): 0
Width (mm): 0
Height (mm): 0
Weight (g): 0

Fig 5.7: Device Database Selection for Thermal Module of MOSFET



X-axis: IF Y-axis: Vd

Suffix

☐ Invert graph

X0 10 Xmax 100 ☑ X in Log

Y0 0.6 Ymax 2 ☐ Y in Log

Enter values in the following format: (x1,y1)(x2,y2)(x3,y3) ...

X-axis: IF Y-axis: Vd (97.796 , 1.739

Junction Temperature Tj (oC)

Fig 5.8: Graph of Freewheeling Diode Voltage Vd versus IF

6. SIMULATION RESULTS OF MODIFIED QUADRATIC BOOST CONVERTER

Certain assumptions are made during simulation of the project for easy analysis. The assumptions are listed as follows:

- For maintaining output voltage of the converter constant, the capacitor Co value is large.
- Two inductors L1 and L2 have same value of the inductor L.
- The simulation is carried out in PSIM software tool because of its simplicity, diversity of applications and dynamic response to any changes made.

6.1 Open loop simulation for ideal condition

The simulation circuit for proposed MQBC is illustrated in Fig 6.1. MQBC includes one MOSFET switch, two Inductors, two Diodes and load. The voltmeter is connected across the load to measure the output voltage of the converter. In the open loop simulation of MQBC, the input voltage of 24V produces the output voltage of 92V and output current of 0.4166A. The controlled switches taken in this simulation are MOSFET due to its lower cost than IGBT [7]. It is also employed due to its higher immunity towards Electromagnetic interference compared to IGBT. The simulation results of Vo and Io, inductor currents and voltage of L1 and L2 along with the gate pulse is illustrated in the Fig 6.2(a)(b)(c)

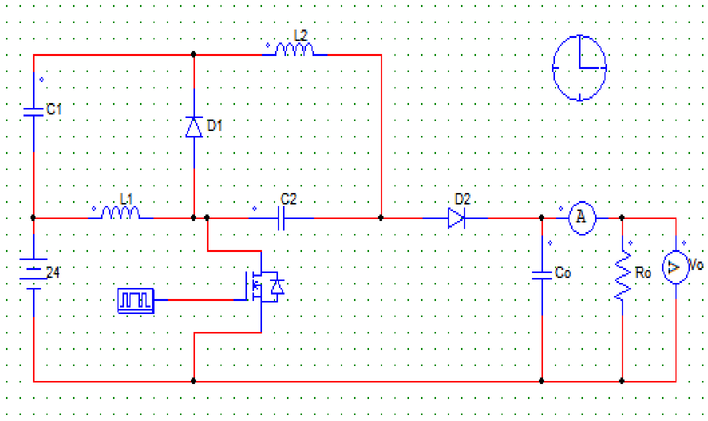


Fig 6.1: Circuit of Open loop MQBC

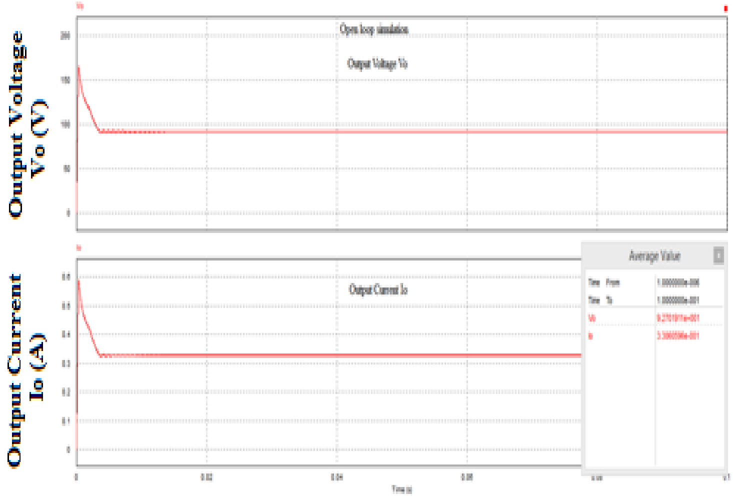
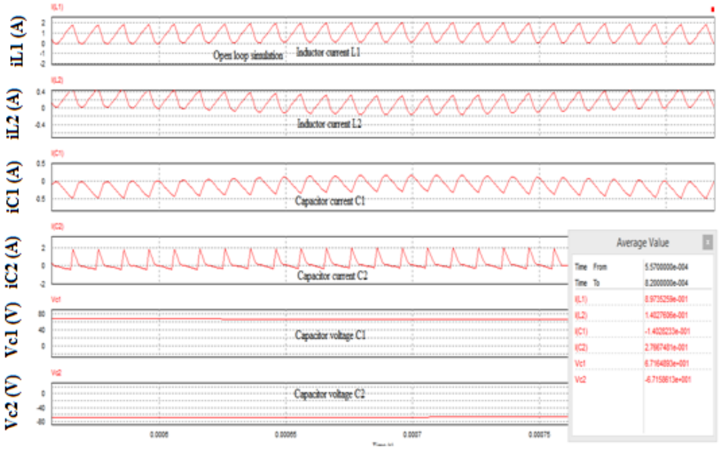


Fig 6.2 (a): Open loop Results for Vo and Io



Time From 5.5700000e-004

Time To 8.2000000e-004

I(L1) 8.9735259e-001

I(L2) 1.4027606e-001

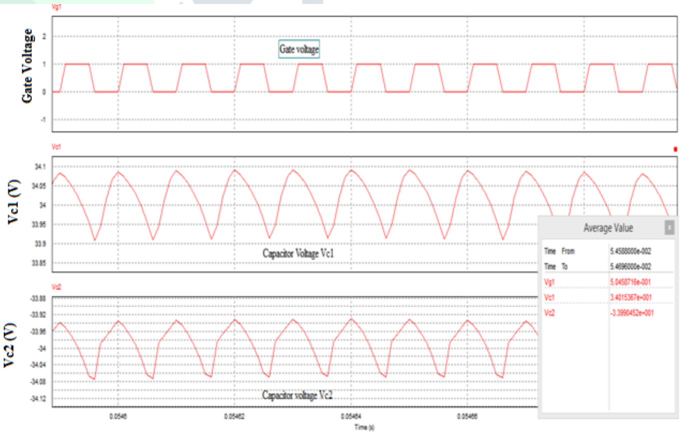
I(C1) -1.4028233e-001

I(C2) 2.7867481e-001

Vc1 6.7164883e+001

Vc2 -6.7158613e+001

Fig 6.2(b): Open Loop MQBC Waveforms of Inductor Current (L1, L2), Capacitor Voltage and Current (C1, C2)



Time From 5.4588000e-002

Time To 5.4696000e-002

Vg1 5.0458716e-001

Vc1 3.4015367e+001

Vc2 -3.3990452e+001

Fig 6.2 (c): Gate pulse of switch S1 and capacitor voltage (C1, C2)

6.2 Closed loop simulation for ideal condition

The simulation circuit of proposed MQBC for closed loop controller is illustrated in Fig 6.3. The closed loop PID controller includes comparator, triangular waveform to generate the PWM pulses in order to maintain the output voltage constant [16]. The controller used for this simulation is PID which helps to give the regulated, stabilized constant voltage. MQBC has two MOSFET switch, two Inductors, two Diodes and load. The voltmeter is connected across the load to measure the output voltage of the converter. The closed loop simulation of MQBC of the inductor voltage and current of L1 and L2 is shown in the Fig 6.4(a)(b).

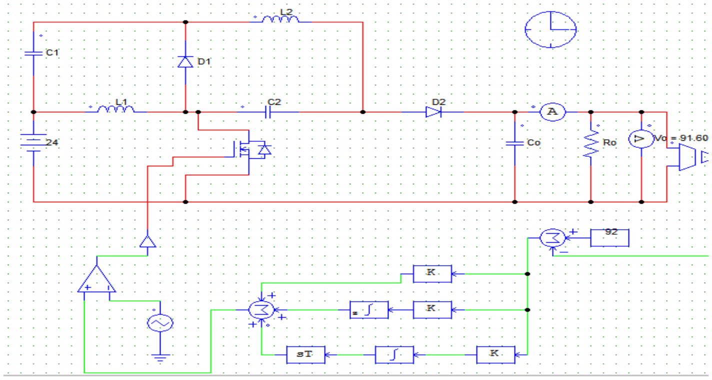
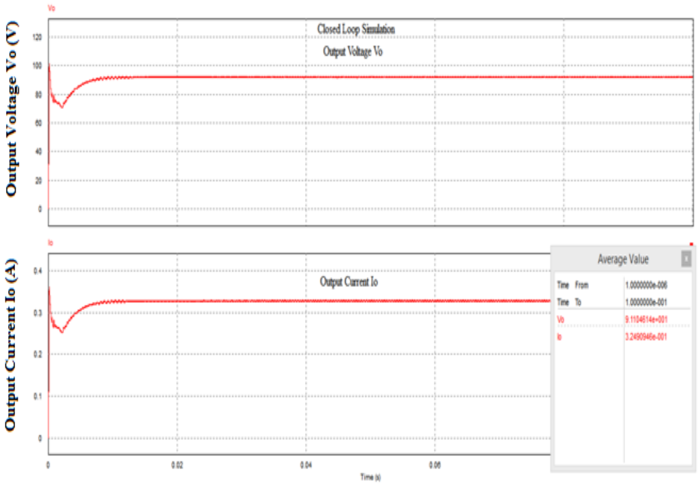
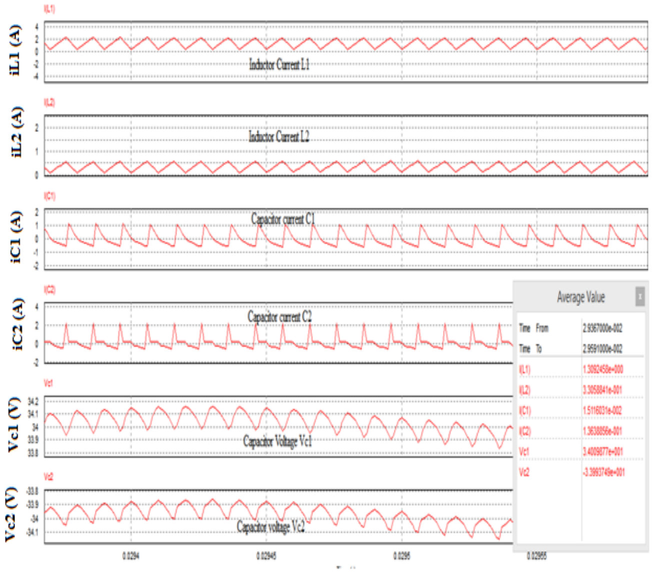


Fig 6.3: Closed Loop Diagram of MQBC



Average Value	
Time From	1.0000000e-006
Time To	1.0000000e-001
Vo	9.1104614e+001
Io	3.2490946e-001

Fig 6.4(a): Waveforms of Output Voltage and Current



Average Value	
Time From	2.9367000e-002
Time To	2.9591000e-002
I(L1)	1.3092458e+000
I(L2)	3.3058841e-001
I(C1)	1.5116031e-002
I(C2)	1.3638856e-001
Vc1	3.4009877e+001
Vc2	-3.3993749e+001

Fig 6.4(b): Waveforms of Inductor Current (L1, L2) and Capacitor Current & Voltage (C1, C2)

6.3 Open loop simulation for practical condition

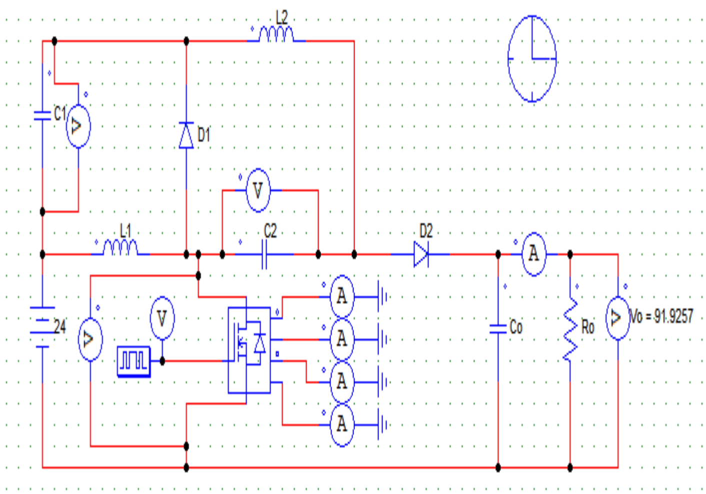
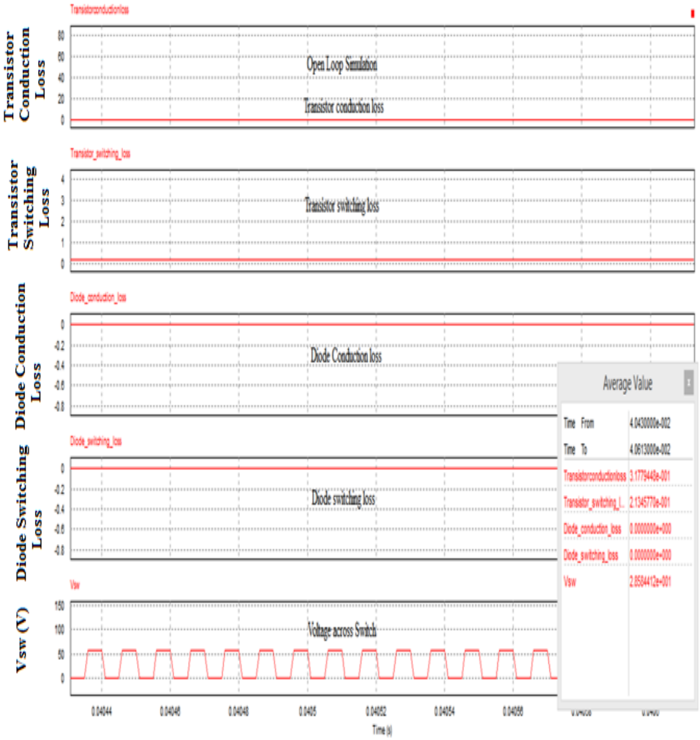


Fig 6.5 (a): Open Loop Simulation for Thermal Module of MOSFET



Average Value	
Time From	4.0430000e-002
Time To	4.0613000e-002
Transistorconductionloss	3.1779448e-001
Transistor_switching_l...	2.1345770e-001
Diode_conduction_loss	0.0000000e+000
Diode_switching_loss	0.0000000e+000
Vsw	2.8584412e+001

Fig 6.5 (b): Open Loop Simulation for Switching & Conduction loss of Transistor & Diodes

6.4 Closed loop simulation for practical condition

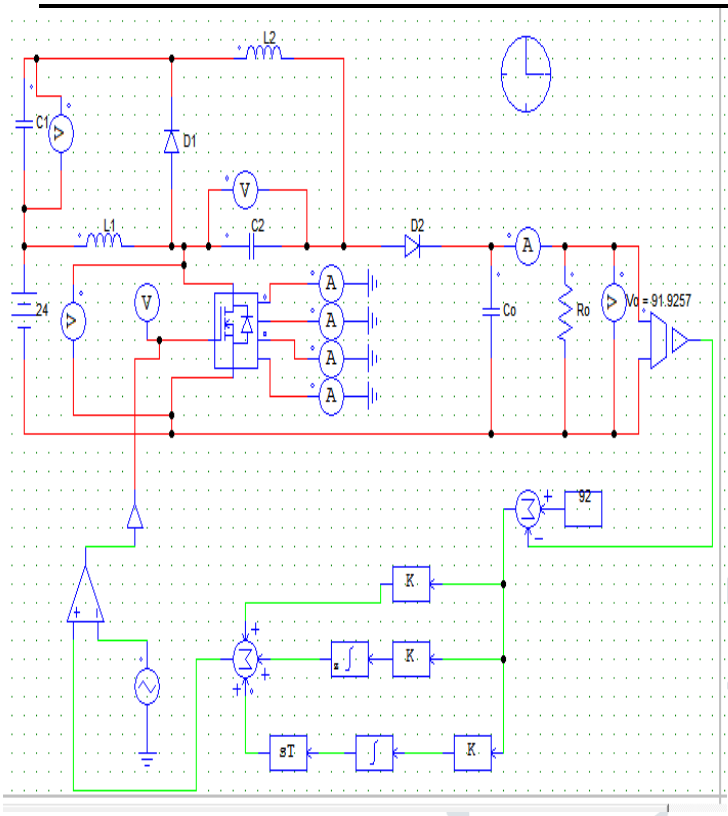


Fig 6.5(c): Closed loop simulation for thermal module of MOSFET

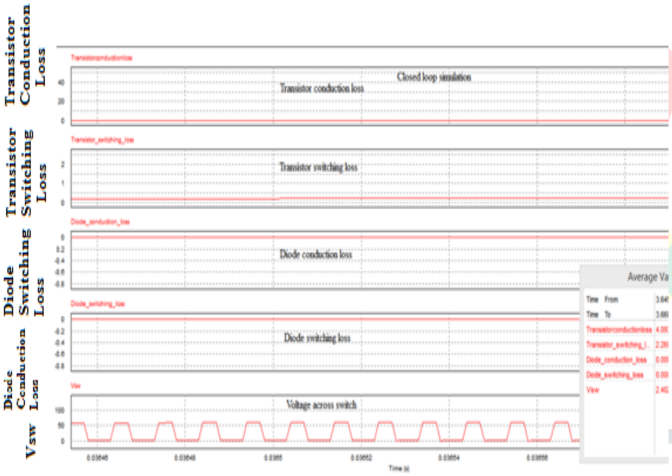


Fig 6.5 (d): Closed Loop Simulation for Switching & Conduction Loss of Transistor & Diodes

7. RESULTS AND DISCUSSION

The simulation results of both open & closed loop produces an equivalent value in ideal condition. The closed loop simulation of MQBC produces a constant output voltage even though the input is varying in the system. The specifications of Vin = 24V, Vo = 92 V and power rating of P = 40W is designed.

Table 7.1: Result of Open & Closed Loop Simulation

Name of the parameters	Open loop simulation results	Closed loop simulation results
Input voltage Vin	24V	24V
Output voltage Vo	91.05V	91.92V
Output current Io	0.395A	0.396A
Inductor current IL1	1.36A	1.36A
Inductor current IL2	0.330A	0.338A

Table 7.2: Power loss Result of MOSFET Switch

Name of the parameters	MOSFET switch 1			MOSFET switch 2		
	Open loop simulation			Closed loop simulation		
	Isw (A)	Vsw (V)	Psw (W)	Isw (A)	Vsw (V)	Psw(W)
Transistor Conduction loss	0.317	28.58	9.059	0.409	24.02	9.02
Transistor switching loss	0.213	28.58	6.08	0.226	24.02	5.42
Diode conduction loss	0	28.58	0	0	24.02	0
Diode switching loss	0	28.58	0	0	24.02	0

8. CONCLUSION

In this paper, the proposed converter is designed for input voltage of 24V and output voltage of 92V with the power rating of 40W. The proposed MQBC is designed for both ideal switch and practical switch IRFP460 of MOSFET. In closed simulation, the PID controller is used in feedback loop to attain faster stability. The open loop and closed loop simulation of MQBC includes a ideal switch of MOSFET. In order to analyze the proposed converter for practical condition, IRFP460 MOSFET switch are considered. The thermal module of practical MOSFET has characteristics of nanosecond switching speed leading to switching and conduction losses. The suitably selected duty ratio was 60% and designed values of inductors, capacitors and resistance are 71.28 uH, 288uH, 11.57uF, and 230ohm respectively. The open loop simulation results of output voltage and output current are Vo= 91.05V, Io=0.395A. The output voltage and output current in closed loop simulation are Vo= 91.92V, Io=0.396A. . The results obtained from the simulation analysis for the MOSFET conduction loss and switching loss in open loop are 9.059W and 9.02W. In closed loop the respective losses obtained are 6.08Wand 5.42W. The extensive study was carried out to analyze the loss of proposed converter validates that the switching and conduction losses are reduced in MQBC as compared to conventional quadratic boost converter. The extensive thermal analysis validates the estimation of losses on dynamic state of the MQBC.Hence the comparison of the open loop and the closed operation loss analysis of the modified quadratic boost converter has been done with the increasing in the stability along with the dynamic performance by using PID controller has been achieved with the simulation results .

REFERENCES

[1] Il-Oun Lee,Shin-Young Cho,and Gun-Woo Moon, "Boost Converter Having Low Switching Losses and Improved Step-Down Conversion Ratio", IEEE Journal Innovation of Research in Power Electronics, vol. 27, pp. 2235-2238, August 2018.

[2] Ashwini A. Patil1, D. S. Chavan, "Comparative Analysis of Boost Converter and Modified Quadratic Boost Boost Converter for Standalone Wind Energy System", International Journal of All Research Education and Scientific Methods (IJARESM) ISSN: 2455-6211, vol. 4, pp. 235-238, May- 2018.

[3] Wuhua Li and Xiangning He," A Family of Isolated Quadratic Boost Converters With Winding-Cross-Coupled Inductors," IEEE International Journal of Applied Engineering Research (IJAER), vol. 6, pp. 256-260, 2017.

[4] M.Pushpavalli, M.L.Bharathi, "Comparison of Quadratic Boost Two and Three Stages Boost Converter", IEEE International Conference on Intelligent Computing and Control(I2C2), Santa Monica, California, November 2017.

[5] Aoun Muhammad, Awang Jusoh and M. Salem "A two switch topology with Quadratic Boost boost-boost converter for low stress PFC applications", IEEE Power Electronics Conference, pp-307-313,12 March 2017.

[6] Dae-Joong Cha, Ji-Eun Baek, Young-Maan Cho, Kwang-Cheol Ko and Woo-Cheol Lee, "Development of Quadratic Boost Converter using Soft-Switching for High Current Applications", IEEE International Journal on Converter and Electronics communication ,vol.5, pp-0024-0029,8th February 2015.

[7] Ishwarya.M, Dhanalakshmi.R, "Investigations on Multiphase Modified Quadratic Boost Boost Converters for High Step Down Voltage", IEEE International Conference on Electrical Engineering, Dhaka, Bangladesh, Nov. 2016.

[8] Farag S. Alargt, Ahmed S. Ashur, Ahmad H. Kharaz, "Adaptive Delta Modulation Controller for Quadratic Boost DC-DC Converter", IEEE Journal on Power and Advanced Computing Technologies(i-PACT), vol. 8, pp.1-6,January 2018.

[9] A. Jahanian Tehran, M.S. Zamani, " Multi-level converter with its switching loss and conduction loss for design circuits", IEEE International Conference on Electrical , Instrumentation and Communication Engineering(ICICE), Toronto, Canada, 14th December 2017.

[10] J Cheng-Tao Tsai and Chih-Lung Shen, "Quadratic Boost Soft-Switching Boost Converter with Coupled Inductors", IEEE, International Conference on Inventive system and control(ICISC),Singapore, October,2017.