Mathematical modelling and Performance analysis of Quadratic Boost Converter

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***Abstract*—the output voltage from the sustainable energy like photovoltaic (PV) arrays and fuel cells will be at less amount of level. This must be boost considerably for practical utilization or grid connection. A conventional boost converter will provides low voltage gain while Quadratic boost converter (QBC) provides high voltage gain. QBC is able to regulate the output voltage and the choice of second inductor can give its current as positive and whereas for boost increases in the voltage will not able to regulate the output voltage. It has low semiconductor device voltage stress and switch usage factor is high. Analysis and design modelingof Quadratic boost converter is proposed in this paper. A power with 200 W is developed with 12 V input voltage and yield 60 V output voltage and the outcomes are approved through recreation utilizing MATLAB/SIMULINK MODEL.**

***Keywords*— Quadratic Boost converter (QBC), Photovoltaic (PV), DC-DC converter**.

I. INTRODUCTION

The traditional quadratic boost converter surrenders booting transformation change without high increment due the hindrance of conduction hardships in the circuit parameters. The gain depends upon the I2R adversities in the inductors and the impact electronic gadget related [6]. The voltage pick up is difficult to secure with standard lift topologies in perspective of the parasitic portions, which limits the repeat and the structure appraise as the fuel cell voltage is of low voltage Quadratic boost converter is utilized as an interface for high voltage applications [3]. Theoretically, conventional boost converters can accomplish low voltage gainModified Quadratic boost converter offer significant advantages, including simplicity, size, reduction, especially in high-powered applications [2].

A. Efficiency of DC-DC Converter

DC-DC converter comprises components like inductor, capacitors and semiconductor devices like diodes, MOSFET, IGBT.

The components don't work in a perfect world. An appropriate choice of parts for modeling is portrayed.

B. DC-DC Converter applications

Single fuel cell voltage output is roughly1.5V. To increase the voltage fuel cells arranged in a stacked manner The voltage is then fed to DC-DC boost converter Further the boosted voltage is fed to an inverter to achieve desired ac voltage and frequency for utility grid

Conventional boost converter works at high duty period for higher gain. At high duty cycle, inductor may get saturates. QBC boost converter works at low duty cycle.

The need of recent days is to lessen the employments of non-sustainable sources [1]. The change of oil based vehicles to half breed electrical vehicles and afterward to electric vehicles has been seen. Recent advancements in DC-DC converters check them appropriate for electric vehicles. Number of dc supplies is expected to charge electrical vehicles. A QBC DC-DC converter is inferred to fill the need.

II. QUADRATIC BOOST CONVERTER (QBC)

A. Operation of quadratic boost converter

The capacity of a quadratic boost converter to venture up the input voltage (Vo= 1/(1-K)*Vs) is restricted by the debasement of the proficiency and the impact of the parasitic protections everywhere estimations of D [7]. Fig 1 demonstrates the displaying and control of Quadratic boost converter and Fig 2 and 3 predicts on and off an area of CBC and If the application requires a greater voltage change proportion and the minimum troublesome game plan is to use the two sorts of converters in course [4] [9]. Regardless, however it isn't worth in light of the fact that the dynamic and detached part check is duplicated which prompts high cost and flightiness. The circuit outline of a quadratic boost converter is appeared in Fig 1. The circuit includes a solitary switch S, three diodes D1, D2 and D3, two

capacitors C1 and C2, two inductors L1 and L2 and a heap resistor R [8].
The circuit operation is totally in perspective of the supposition that the switch S is impeccable in operation and capacitors C1 and C2 are believed to be significant. So, the voltage over the capacitors VC1 and VC2 are relatively steady finished an exchanging period. at the point when switch S is turned on D2 is forward uneven, while D1 and D3 upset uneven. Streams are given to L1 and L2 by Vin besides, C1
In the side of the point at the transform is OFF: in this state D1 Furthermore D3 would ahead biased, same time D2 switch will be reverse predisposition. L1 What's more L2 are charging C1 What's more C2 separately. Throughout this state, iL1 Furthermore iL2 will be reduced separately.

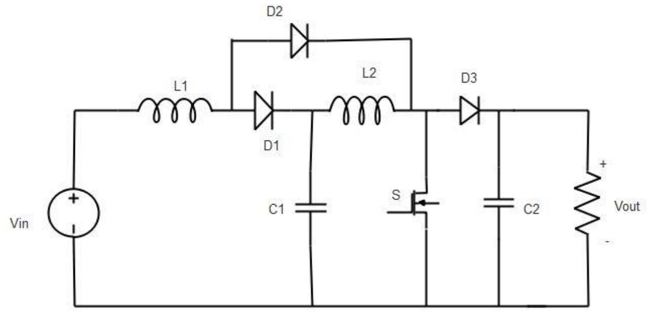

Fig 1 Quadratic boost converter

III. Steady state analysis of Quadratic BoostConverter

The fundamental circuit of QBC constitutes a boost converter with a supposition of totally resistive load, consummate switch and a reliable quick voltage Vd [5]. The circuit operation is entirely in light of the presumption that the switch S is perfect in operation and capacitors C1 and C2 is thought to be extensive with the goal that the voltage over the capacitors VC1 and V C2 are about steady finished an exchanging period. The state variable for relentless state investigation are IL1, IL2, VC1 and VC2 (V0).

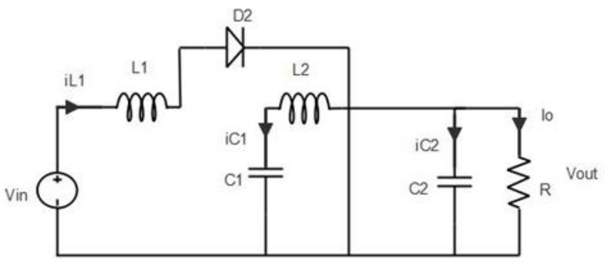

Fig 2 Quadratic Boost converter when Switch is ON

The identical circuit schematic of the QBC between the ON state is appeared in Fig 2. when switch S is turned on D 2 is forward one-sided, though the voltage crosswise over invert inclination D1 and D3 . Between this mode both inductor L1 and L2 get charged by input voltage Vd and Vc1 Respectively, IL1 and IL2 increments from Imin to Imax. The Load current is provided by C2.

Differential equations relating the state variables are when switch is ON

$$\Delta iL_1 = \frac{V_{in}}{L_1} \quad (1)$$

$$\Delta iL_2 = \frac{Vc_1}{L_2} \quad (2)$$

$$\Delta Vc_1 = -\frac{iL_2}{C_1} \quad (3)$$

$$\Delta Vc_2 = -\frac{V_{out}}{Rc_2} \quad (4)$$

The identical circuit schematic of the QBC between the OFF state is appeared in Fig 3. Diode D2 get switch one-sided and D1 and D3 get forward one-sided. The inductor released its put away vitality through C1 and C2.

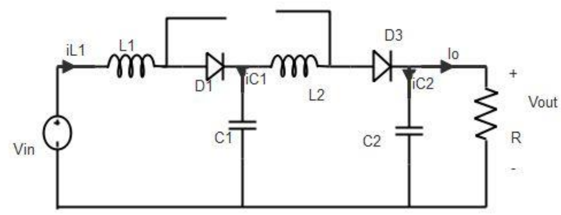

Fig 3Quadratic Boost converter when Switch is OFF

Differential equations relating the state variables are when switch is OFF.

$$\Delta iL_1 = \frac{V_{in}}{L_1} - \frac{Vc_1}{L_1} \quad (5)$$

$$\Delta iL_2 = \frac{Vc_1}{L_2} - \frac{V_{out}}{L_2} \quad (6)$$

$$\Delta Vc_1 = \frac{IL_1}{C_1} - \frac{IL_2}{C_1} \quad (7)$$

$$\Delta V_{out} = \frac{IL_2}{C_2} - \frac{V_{out}}{Rc_2} \quad (8)$$

Average Model Equation of QBC

$$\Delta iL_1 = \frac{V_{in}}{L_1} - \frac{Vc_1}{L_1}(1-D) \quad (9)$$

$$\Delta iL_2 = \frac{Vc_1}{L_2} - \frac{V_{out}}{L_2}(1-D) \quad (10)$$

$$\Delta Vc_1 = \frac{IL_1}{c_1}(1-D) - \frac{IL_2}{C_1} \quad (11)$$

$$\Delta V_{out} = \frac{IL_2}{C_2} - \frac{V_{out}}{Rc_2} \qquad (12)$$

For steady state operation of an inductor in a DC-DC Converter, net inductor voltage in a switching period must be zero.

For inductor L1

$$\Delta\, iL_{1(closed)} + \Delta iL_{1(open)} = 0 \qquad (13)$$

$$\frac{V_{in}}{L_1}DT + \frac{V_{in}}{L_1}(1-D)T - \frac{Vc_1}{L_1}(1-D) = 0$$

$$\frac{V_{in}}{L_1}T = \frac{Vc_1}{L_1}(1-D)T$$

$$\boldsymbol{Vc_1 = \frac{V_{in}}{(1-D)}} \qquad (15)$$

For Inductor L2

$$\Delta iL_{2(on)} + \Delta iL_{2(off)} = 0 \qquad (16)$$

$$\frac{Vc_1}{L_2}DT + \frac{Vc_1}{L_2}(1-D)T - \frac{V_{out}}{L_2}(1-D)T = 0$$

$$Vc_1 D + Vc_1(1-D) - Vc_1 D = V_{out}(1-D)$$

$$Vc_1 = V_{out}(1-D) \quad and \quad \frac{V_{in}}{(1-D)} = V_{out}(1-D)$$

$$\boldsymbol{V_{out} = \frac{V_{in}}{(1-D)^2}} \qquad (17)$$

Average current passing through any ‘i’ is zero

$$i_{c(on)} + i_{c(off)=0} \qquad (18)$$

$$\frac{-iL_2}{C_1}(DT) + \frac{iL_1}{C_1}(1-D)T - \frac{iL_2}{C_1}(1-D)T = 0$$

$$-iL_2 D + iL_1 - iL_1 D - iL_2 + iL_2 D = 0$$

$$iL_1(1-D) = iL_2$$

$$\boldsymbol{iL_1 = \frac{iL_2}{(1-D)}}$$

$$iL_1 = \frac{I_o}{(1-D)^2}$$

$$V_s I_L = \frac{V_{out}^2}{R} = \frac{V_s^2}{(1-D)^4 R}$$

$$I_{L1} = \frac{V_s}{(1-D)^4 R}$$

From equation 1

$$\Delta I_{L1} = \frac{V_{in}}{L_1}DT$$

$$V_{out} = \frac{V_{in}}{(1-D)^2}$$

$$V_{in} = V_{out}(1-D)^2$$

$$\Delta I_{L1} = \frac{V_{out}(1-D)^2}{L_1}$$

$$\boldsymbol{L_1 = \frac{V_{out}(1-D)^2 D}{\Delta IL_1 f}}$$

simillarly From equation 2

$$\Delta I_{L2} = \frac{V_{c1}}{L_2}DT$$

$$V_{c1} = \frac{V_{in}}{(1-D)} = \frac{V_0(1-D)^2}{L-D}$$

$$\Delta IL_2 = \frac{V_0(1-D)\,DT}{L_2}$$

$$\boldsymbol{L_2 = \frac{V_0(1-D)D}{\Delta I_{L2} f}}$$

For steady state operation of a capacitor in a DC-DC Converter, net capacitor current in a switching period must be zero

$$\frac{-I_0}{C_2}(DT) + \frac{ic_2}{C_2}(1-D) - (1-D)\frac{I_0}{C_2} = 0$$

$$-I_0 D + iC_2(1-D) - I_0(1-D) = 0$$

$$-I_0 D - I_0 + I_0 D + IL_2(1-D) = 0$$

$$\boldsymbol{IL_2 = \frac{I_0}{(1-D)}}$$

$$|AQ| = DT * iL_2$$

$$C_1 \Delta Vc_1 = DTiL_2$$

$$\Delta Vc_1 = \frac{DTiL_2}{C_1}$$

$$iL_2 = \frac{I_0}{(1-D)}$$

$$\Delta Vc_1 = \frac{\Delta T(\frac{I_0}{1-D})}{C_1}$$

$$\boldsymbol{C_1 = \frac{DI_0}{f(1-D)\Delta Vc_1}}$$

$$|AQ| = DT * I_0$$

$$C_2 \Delta Vc_2 = DTI_0$$

$$\Delta Vc_2 = \frac{DT\, I_0}{C_2}$$

$L_1 + L_2$ interms of V_{in}

$$L_1 = \frac{V_0(1-D)D}{\Delta IL_1\, f}$$

$$L_1 = \frac{V_{in}D}{\Delta IL_1\, f}$$

$$L_2 = \frac{V_0(1-D)d}{\Delta IL_2\, f}$$

$$L_2 = \frac{\frac{V_{in}}{(1-D)^2}(1-D)D}{\Delta IL_2\, f}$$

$$L_2 = \frac{V_{in}\, D}{(1-D)\Delta IL_2 f}$$

IV. SPECIFICATION OF QUADRATIC BOOST CONVERTER

The Quadratic boost converter was analyzed by MATLAB SIMULINK model. The circuit parameters for the simulation are listed in Table 1.

TABLE I
Specification of Quadratic Boost converter

Parameter	**Values**
Input voltage	12V
Output voltage	60V
Power	100
Switching Frequency	100Hz
ΔIL_1	$20\%\ of\ IL_1$
ΔIL_2	$20\%\ of\ IL_2$
ΔVc_1	$2\%\ of\ Vc_1$
ΔVc_2	$2\%\ of\ Vc_2$

Design of load resistor

Power =100Hz

$$I_0 = \frac{P}{V} = \frac{100}{60} = 1.67A$$

$$R_{load} = \frac{V}{I} = \frac{60v}{1.67A} = 35.9\,\Omega \quad 36\Omega$$

Duty ratio

$$D = 1 - \sqrt{\frac{V_{in}}{V_0}} = 0.55$$

$$V_0 = \frac{V_{in}}{(1-D)^2}$$

Rate of change of inductor L1 and L2 values

The average inductor value for current flows through L1an L2 is given by

$$IL_{1(avg)} = \frac{I_0}{(1-D)^2}$$

$$= \frac{1.67}{(1-0.55)^2}$$

=8.25A

$$IL_{2(avg)} = \frac{I_0}{(1-D)}$$

$$= \frac{1.67}{(1-0.55)}$$

$$= 3.711A$$

The rate of change of inductor current value L1 and L2 is given by

$$\Delta IL_1 = 20\%\ of\ IL_1$$

$$= \frac{20}{100} * 8.25$$

$$= 1.65A$$

$$\Delta IL_2 = 20\%\ of\ IL_2$$

$$= \frac{20}{100} * 3.711A$$

To find the maximum inductor current values is given by

$$iL_{1(max)} = \frac{\Delta IL_1}{2} + IL_1$$

$$= 0.825 + 8.25$$

$$= 9.75A$$

To find the value for minimum inductors current is given by

$$iL_{1(min)} = \frac{\Delta IL_1}{2} - IL_1$$

=7.425A

$$iL_{2(max)} = IL_2 + \frac{\Delta IL_2}{2}$$

$$= 3.711 + 0.371$$

$$= 4.082A$$

Value of inductor and capacitor

To find the value for L1

$$L_1 = \frac{V_{in}D}{\Delta IL_1 f}$$

$$= \frac{12 * 0.55}{1.65 * 100k}$$

$$= 40\mu H$$

To find the value for L2

$$L_2 = \frac{V_{in}D}{(1-D)\Delta I_2 f}$$

$$= \frac{12 * 0.55}{(1-0.55) * 0.742 * 100k}$$

$$= 197\mu H\Omega\ 200\mu H$$

To find the value for C1

$$C_1 = \frac{I_0 * D}{f(1-D)\Delta Vc_1}$$

$$\Delta Vc_1 = 2\% \; of \; Vc_1$$

$$= \frac{2}{100} * \frac{V_{in}}{(1-D)}$$

$$\Delta Vc_2 = 2\% \; of \; Vc_2$$

$$= 0.53\%$$

Capacitor voltage V_{C2} is given by

$$Vc_2 = V_0 = \frac{V_{in}}{(1-D)^2} = 60V$$

$$\Delta Vc_2 = \frac{2}{100} * 60 = 2V$$

The value for C1 is

$$C_1 = \frac{1.67 * 0.55}{100k * 0.45 * 0.53}$$

$$= 38.51\varphi f$$

$$= 40\varphi f$$

The value of C2 is given by

$$C_2 = \frac{DI_0}{f\Delta Vc_2}$$

$$= \frac{0.55 * 1.67}{100k * 2V} = 4.6\varphi f$$

To find $L_{critical}$ *and* $C_{critical}$

$$I_{L(\min)} = 0 = IL_1 - \frac{\Delta IL_1}{2} = 0$$

$$\Delta IL_1 = 2IL_1$$

$$\frac{V_{in}D}{L_{1(rst)}f} = 2IL_1$$

$$L_{1(rst)} = \frac{V_{in}D}{2IL_1 f} = \frac{12 * 0.55}{2 * 2.25 * 100k}$$

$$L_{1(rst)} = 4\mu H$$

$$IL_{2(\min)} = 0$$

$$\Delta IL_2 = 2IL_2$$

$$\frac{V_0(1-D)D}{L_{2(rst)}f} = 2IL_2$$

$$L_{2(rst)} = \frac{V_0(1-D)D}{2IL_2 f}$$

$$L_{2(rst)} = 20\mu f$$

$$\frac{dv_0}{dt} = \frac{(1-d)}{c_2} iL_2 - \frac{1}{RC_2} V_0$$

Dynamic control of the output voltage

$$C_2 \frac{dV_0}{dt} + \frac{1}{R} V_0 = 1 - d \; iL_2 = \mu$$

μ − output of PI controller

$$d = 1 - \frac{\mu}{iL_2}$$

V.SIMULATION RESULTS

Simulation of quadratic boost converter (QBC)

Substitute the design values, obtain the mathematical model of QBC and validate the design values with simulation results in MATLAB/SIMULINK.

TABLE II

Design specification of Quadratic boost converter

Input Voltage(V_i)	12 V
Output Voltage(V_o)	60 V
Output Power(Po)	250 W
Ripple voltage (ΔV_{c1})	2% of Vc1
Ripple voltage (ΔV_{c2})	2% of Vc2
Ripple current (ΔI_{L1})	20% of IL1
Ripple current (ΔI_{L2})	20% of IL2
Switching Frequency(f_s)	100 KHz

Simulink Model of Quadratic Boost Converter:

The averaged large signal equations of QBC is modelled as

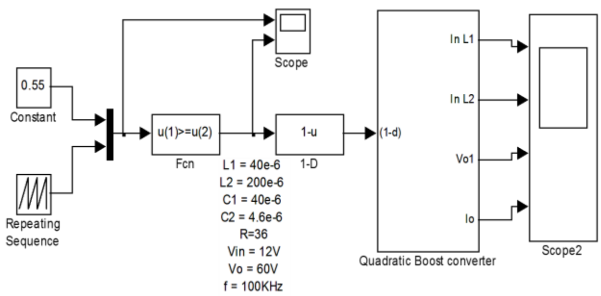

Fig 4 Mathematic Model of QBC

TABLE III

Parameters of Quadratic boost converter

Output Current(I_o)	1.67A
Duty Cycle(D)	0.55
Load Resistance(R_o)	36 ohm
Inductor L1	40µH
Inductor L2	200 µH
Capacitor C1	40 µf
Capacitor C2	4.6 µf
Max IL1 & Min IL1	9.075A & 7.425A

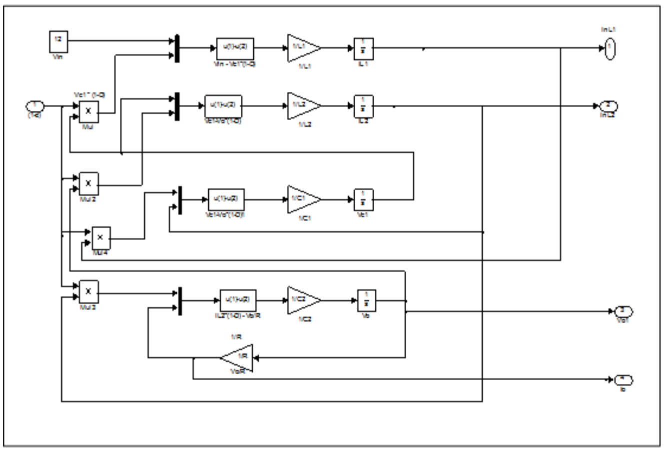

Fig 5 Mathematic Model of QBC

Inductor Ripple (ΔI_{L1}):

Inductor ripple current for L1 is(IL1(max)-IL2(min))=7.4-8.9 *=1.5A*

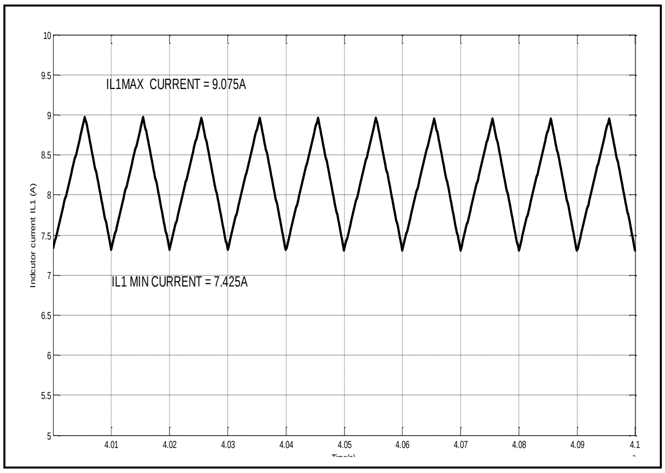

Fig 6 Inductor Ripple (ΔI_{L1})

Inductor Ripple (ΔI_{L2}):

Inductor ripple current for L2 is (IL2 (max) – IL2 (min)) = 4.1-3.4 = 0.7A

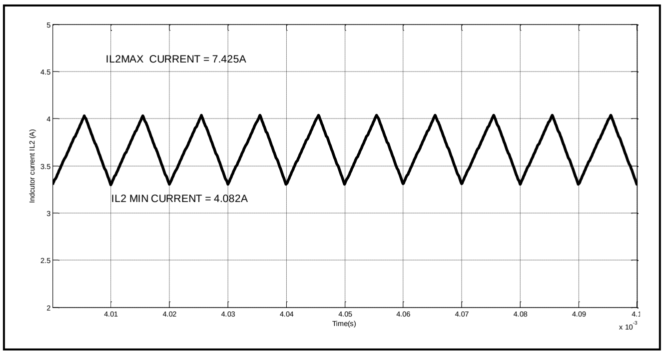

Fig 7 Inductor Ripple (ΔI_{L2})

Output voltage Ripple (ΔV_0):

Output voltage Ripple (ΔV0) 2% of Vo = 60.2 - 58.2 = 2V

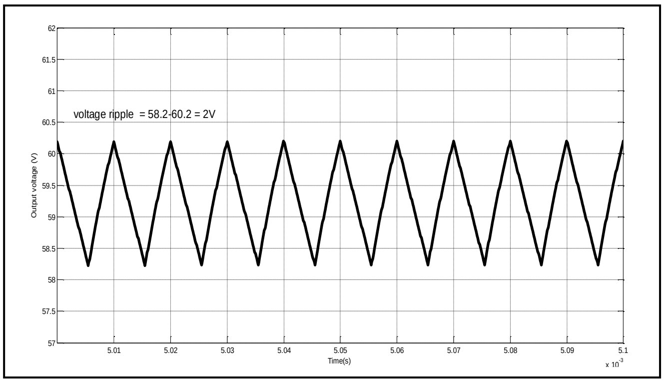

Fig 8 Output voltage Ripple (ΔV_0)

Closed loop model of Quadratic Boost Converter

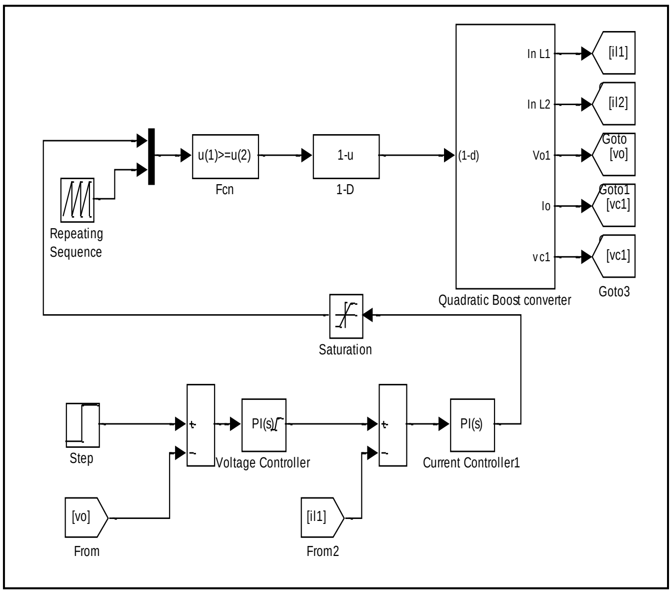

Fig 9 Closed Loop Model of QBC

Simulation Results for Step change in reference voltage:

Output voltage and output current response for a step change in Voltage reference 25V to 80V at 0.005s

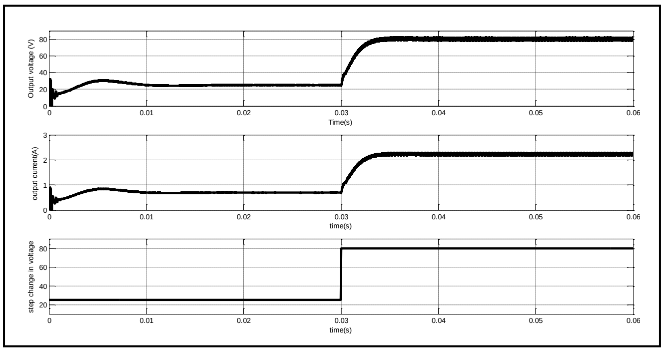

Fig 10 Voltage and current response for step change in Voltage reference

VI.CONCLUSION

The Proposed Converter has a gain relies upon the outline utilized as a part of the topology. The most extreme power can be followed in the Photovoltaic system for better execution. The Outline of the converter decides the execution of the system. The smaller estimation of duty cycle builds the powerful working of the photovoltaic framework. The distinctive techniques are relevant for different application, for example, decrease in conduction losses, voltage stress over the switch, spillage energy reusing, better productivity and gain. Further, the model of the proposed converters design, test, and indictment is to be inspected tentatively in future.

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