

**Review Article**

**THE IMPLEMENTATION OF QUADRATIC METHOD USING PV BI-DIRECTIONAL CONVERTER IN CLOSED LOOP CONTROL WITH PI CONTROLLER**

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**Abstract**

In this enormous development of technology, the requirements are new per each day. The needs must be satisfied but fulfilling each requirement will generate new desire or need. The technology is evolving day by day because of this recycling process. The invention of fuel-based vehicles shows some de-merits to evolve and shift over to the electrical vehicles. The proposed paper concentrates its main application to be the electrical vehicles, With an improved form of boost as well as buck converter with high voltage gain and efficiency. This shows close loop operation because of its ability to control a drive or electrical vehicle in the place of load. The bi-directional converter adopts quadratic method in proposed model for highly efficient utilization. This paper focuses on the high efficient utilization of bi-directional converter with quadratic property using proportional integral controller for its switching.

**Keywords:** social and legal competence, structure, future engineer, professional competence.

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**INTRODUCTION**

In the domain of electric world, the converters place most prominent role. The conversion of energy for the requirement will lead to the required outputs. There are so many kinds of converters which are useful for the proper conversion at proper time is required. The alternating current is turned to direct current by rectifier and the direct current is turned to alternating current in case of inverter. But there were some converters which tends to improve the voltage gain with in the direct current like boost, buck, buck-boost, sepic and cuk [1]. Some of these converters will focus on betterment of voltage gain [2] with a help of currents stored in inductor. The duty ratio plays the vital role in converters. With the help of increment in duty ratio the voltage gain increases, and decrement of duty ratio will reduce the output voltage. The value of duty ratio lies between zero and one. Even though the voltage gain is obtained by the converters (like boost, buck-boosts, etc...) amount of voltage gain is limited when the duty-ratio of the converter reaches to its maximum value (0.8-0.9 in practical case). To increase the voltage gain [3] so many methods have been implemented regarding the converters, but they are not in usage considering their disadvantages like complexity, cost and size. The boost converter with an inductor, switch and diode will tend to have another stage by adding one more level as same as the multi-level inverter method. Adding an inductor will lead to complexity because of the turns of an inductors. By making it note the elements should be added in cascading method. The elements where kept in cascading manner the both inductors get the time to charge the inductors parallelly, this helps to discharge high amount of power at a time. The method of involving cascading connection in the converter is named to be quadratic method. The name quadratic is derived in the converters because the output voltage obtained from the cascading method as a particular quadratic equation mentioned [4]. The voltage gain is perfectly modeled in the mathematical way. Applying this quadratic method specially for the boost and buck converters because of its handful of applications in an efficient manner. The usage of energy storage devices will be efficient for this proposed model [5]-[6].The process is same as the conventional boost-converter but with some of the added components without more complexity. Capacity of the inductor charge is increased by connecting them in cascade method that makes the converter to obtain more amount of

output voltage. But there are some models proposed regarding the quadratical boost converters[7], those models where proposed using a coupled inductor/ transformer in which the turns of an inductor can be increased or decreased as per the requirement of output voltage. Using the coupled inductor is advantageous in a way that capacity of charge in inductance increases proportionally the output voltage level also increases. This method consists of demerits like more weight, and cost. This can be avoided by proposed quadratic method.

There were some models which proposes about quadratical boost converters in a single direction but for some applications like Ev's (electrical vehicles) bi-directional comes to usage. The bi-directional converter in case of the Ev application has a mode of charge and mode of discharge. Considering the power storage devices has the source and load is parallelly connected, the cyclic process can be carried out by the bi-directional converter[8]-[10]. They will operate in mode of charge as well as mode of discharge. This paper proposes the bi-directional converter having quadratic property for high voltage gain and the efficient use of power. The method of charging and discharging in the bi-directional converter helps the energy to be used in efficient manner, using the quadratic method which adds a stage of inductor and switches. Because of the parallel operation of modes as per usage the switching losses will not be high. There will be four switches in the circuit but the operation requires only two particular switches. There are two mode of operations, the boost mode is considered as discharging mode and buck mode can considered as charging mode. The switching in the circuit can be operated by using proportional integral controller. There will be one main switch for operation in each mode which is connected with the PI controller. The proposed model shows the operation of drive using bi-directional conversion by the quadratic method.

**PROPOSED BI-DIRECTIONAL CONVERTER WITH QUADRATIC METHOD**

The research upon the voltage gain improvement introduced lot more methods increasing voltages with different methodologies. The level of improvement in voltage is obtained because of voltage demand applications. These demands en-route to the proposed bi-directional converter with quadratic topology. There are some models which

proposed about quadratic converters and also explains about voltage gain betterment. Previous research on voltage gain proposes the high-voltage conversion ratio using the bi-directional converter by the star-delta transformer[11-12], it consists of an important source, chopper unit, three phase transformer, rectifier unit and filter unit with the load connected at the end. The transformer in the circuit is used for the voltage improvement from one level to another level. But the main problem occurs in the case of weight, complexity, bulk size and costly. The conversion here needs the increment of turns ratio. In the same way the quadratic boost converter is proposed in another model with the use of coupled inductor. The coupled inductor is used because increasing the turns ratio parallelly increases the voltage gain without any interference of the duty ratio having the same kind of disadvantages using ZCS and ZVS techniques with focusing on zero output ripple[13]. The proposed model avoids the disadvantages by handling the single level cascading of the main passive elements. To show the  $E_v$ [14] as main application the drive is operated as a load. Controlling circuit in a closed loop [15] operating mode resembles the working process of a electric vehicles. The switching can be controlled using the proportional integral controller[16-18][21-23].

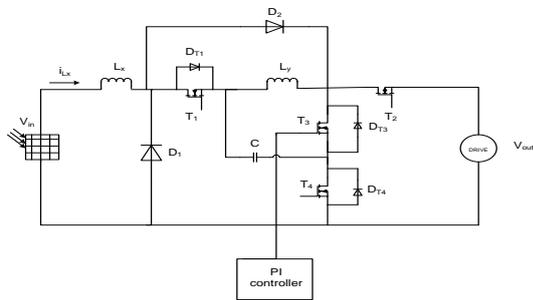


Fig.1. The proposed model for the closed loop quadratic bi-directional converter with pi controller

The some of the switching conditions operating in different modes are

1. Boost continuous conduction mode
2. Buck continuous conduction mode
3. Boost critical conduction mode
4. Boost discontinuous conduction mode

**METHODOLOGY**

**BOOST CONTINEOUS CONDUCTION MODE OF OPERATION**  
 The continuous conduction mode is an ideal mode of operation. In the case of quadratic methods both the inductors get charged and stores the amount of energy with respect to the required amount of voltage gain. This mode is considered as the Ideal mode because of the flow of charge which is un-interrupted. The switching strategy of the boost continuous conduction mode without any interruption is shown in figure.

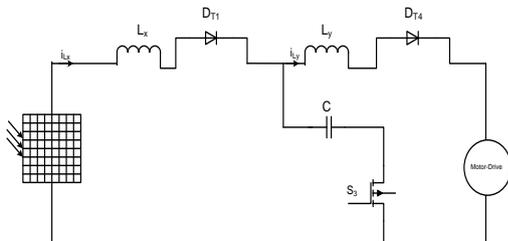


Fig.2. Block diagram of Boost CCM stage1 closed loop operation

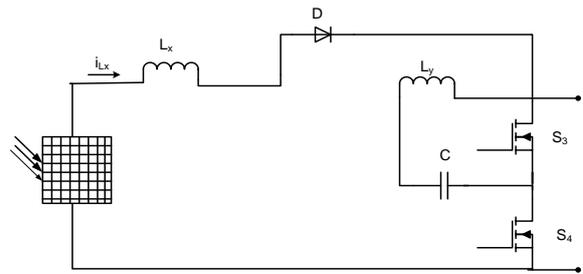


Fig.3. Block diagram of Boost CCM stage2 closed loop operation

**Stage1 -**

This is the stage where the switches S2 and S3 are used mainly. The switch S2 is switched on for the period  $Dt_s$  ( $Dt_s < t < ts$ )

When the switch S2 is turned on the inductances in the circuit will be under charging condition. The current in the inductors will be increased linearly in this case. The Operation of stage1 in boost mode is shown in figure2.

**Stage 2-**

The switches S2 and S3 are used here. But, the switch S2 is turned off for the discharging case. The inductances which are charged in the previous case is now discharged by turning off the switch S2. The currents in this case will be linearly decreased in this case. This switch will be in off condition during  $(1-Dt_s)$  i.e ( $Dt_s < t < ts$ ).

The switching of the boost continuous conduction mode is shown in figure3

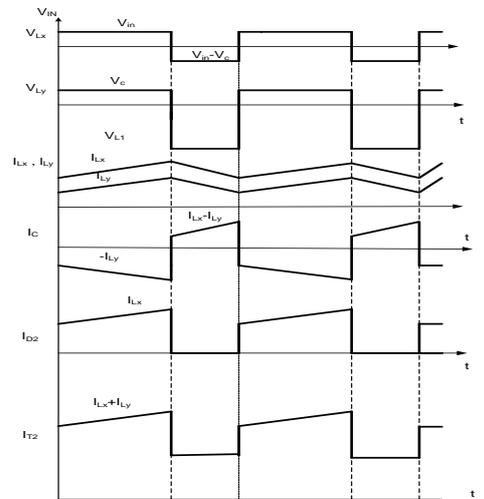


Fig.4. Switching for the boost mode continuous conduction mode.

The equations obtained by the switching relationships for boost CCM are

$$Dv_{in} + (1 - D)(v_{in} - v_c) = 0$$

$$Dv_c + (1 - D)(v_c - v_{out}) = 0$$

Taking volt-sec balance in this case the main equation to display the output to input relationship is,

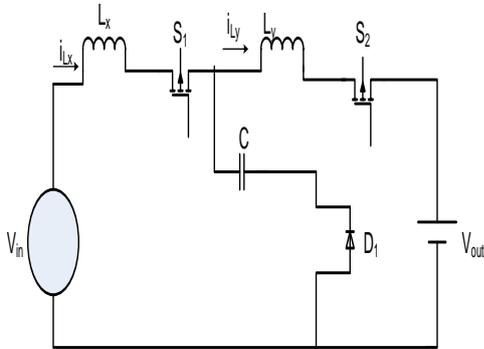
$$\frac{v_{out}}{v_{in}} = \frac{1}{(1 - D)^2}$$

$$v_c = \frac{v_{in}}{(1 - D)}$$

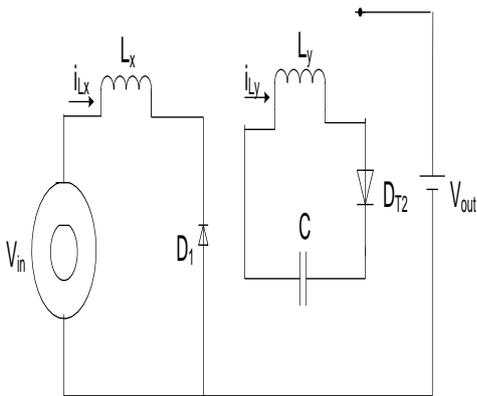
$$I_{avg} = I_{Lx}(1 - D)^2 = I_{Ly}(1 - D)$$

**BUCK CONTINEOUS CONDUCTION MODE-**

The operation of buck mode differs from boost mode in load point of view. To test the mode of charging the and operation of drive as well the load is placed in the place of boost source. The switches which operate in this mode are S1 and S4. The switches S2 and S3 are always Off. The Switch S4 is always turned on in this mode. Same as boost CCM the buck CCM also have the to stages to operate [19-20]. The figure 5 and figure 6 shows the stages of operation in buck mode.



**Fig.5. Block diagram of Buck CCM stage1 closed loop operation**



**Fig.6. Block diagram of Buck CCM stage2 closed loop operation**

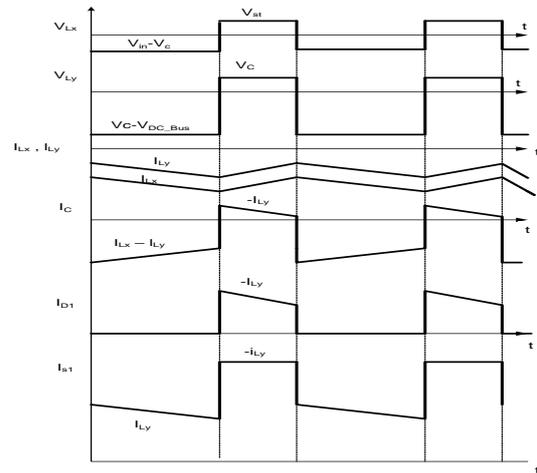
**Stage 1-**

The constant turn on switch is S4 in the buck continuous conduction mode. The switch S1 is operated with PI controller. The main operating switch is the Switch S1 so the operation of switch is commanded by using the controller. To show the operation of the Ev this paper shows the operation of drive in boost mode. The figure 5 shows the stage1 operation.

**Stage2 -**

The Inductors discharge their stored current in stage2. The switch S1 will be in the off condition and switch S4 remains same. The figure6 shows the discharging process in stage2.

The switching of buck continuous conduction mode is shown in figure7.



**Fig.7. Switching for the buck mode continuous conduction mode.**

The equations obtained by the buck continuous conduction mode is,

$$D(v_{in} - v_c) + (1 - D)v_{in} = 0$$

$$D(v_c - v_{out}) + (1 - D)v_c = 0$$

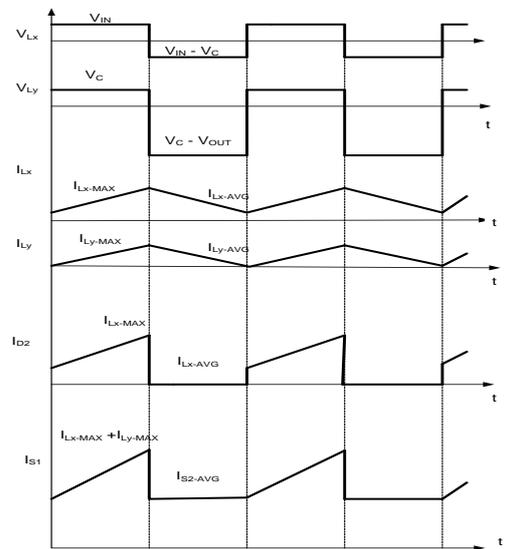
The voltage gain in buck operating mode is known to be

$$\frac{v_{in}}{v_{out}} = D^2$$

**BOOST CRITICAL CONDUCTION MODE OF OPERATION-**

The critical conduction mode stabilizes the current whenever it reaches to zero point. It is the barrier between the continuous conduction mode and discontinuous conduction mode. The switching stress in this mode is high because of the subtle switching of the converter.

This mode helps in the study of both the continuous and discontinuous conduction modes.



**Fig.7. Switching for the boost mode critical conduction mode.**

The inductor carries the current known to be,

$$\frac{di_{Lx}}{dt} = \frac{v_{Ly}}{L_y}$$

Taking  $i_{Ly-min}$  as zero,

$$\frac{\Delta i_{Ly}}{\Delta t} = \frac{i_{Ly-max} - i_{Ly-min}}{\Delta t} = \frac{i_{Ly-max}}{\Delta t} = \frac{V_{Ly}}{L_y}$$

The switch S2 is in ON condition, taking  $\Delta t=Dt$ ,  $T= 1/Fs$   
 $V_{LB}=V_c$  the maximum  $L_B$  value is

$$i_{Ly-max} = \frac{V_c}{L_2 f_s} D$$

There are some limitations to follow CCM,

To avoid the continuous conduction mode,

$$i_{Ly-min} \geq 0 = i_{Ly-min} \geq i_{Ly-avg} - \frac{i_{Ly-min}}{2}$$

$L_y$  is the function of duty cycle  $d$ ,

$$L_y \geq \frac{v_{out}}{2I_{ly-avg}f_s}(1-D)D$$

Considering  $D$  as 0.5, then the critical value is known to be

$$L_y \geq \frac{1}{8} \frac{v_{out}}{I_{ly-avg}f_s}$$

The value of  $L_x$  is

$$L_x \geq \frac{v_{out}}{2I_{lx-avg}f_s}(1-D)^2D = \frac{2}{27} \frac{v_{out}}{I_{ly-avg}f_s}$$

Calculation of capacitance,

$$I_{avg} = c \frac{\Delta v_o}{\Delta t}$$

$$c = \frac{D I_o}{\Delta v_o f_s} = (1-D)^2 D$$

$$\frac{I_{lx-avg}}{\Delta v_o f_s} = \frac{4}{27} \frac{I_{lx-avg}}{\Delta v_o f_s}$$

### BOOST DISCONTINUOUS CONDUCTION MODE OF OPERATION-

This is the case where the current across the load falls to zero before the switching operation starts. This mode creates more harmonics in the system which makes the conduction angle to be decreased.

The stages present in the discontinuous conduction operation are,

First stage operates similar to the continuous conduction mode

The  $L_y$  current is discharged in the second stage of operation in discontinuous conduction mode

The energy from the inductor  $L_x$  is shifted towards the capacitor

The current will be zero at the last stage.

The switching of discontinuous conduction mode is shown in figure9.

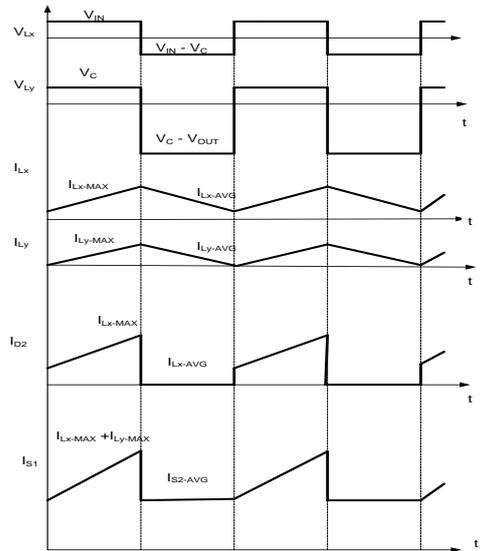


Fig.7. Switching for the boost mode dis-continuous conduction mode.

The average current across the diode4 is known to be,

$$I_{avg} = I_{DT4-avg} = \frac{i_{Ly-max}}{2} D_2$$

Considering  $L_x$  and  $L_y$

$$D v_{in} + (1-D)(v_{in} - v_c) = 0$$

$$D v_c + D_2(v_c - v_{out}) = 0$$

The voltage gain can be shown as,

$$\frac{v_{out}}{v_{st}} \Big|_{DCM} = \frac{(D + D_2)}{(1-D)D_2}$$

Considering the resistance,

$$D_2 = \frac{2L_2 f_s (1-D) V_{out}}{R_o D V_{in}}$$

The operating mode of DCM

$$D_2 < (1-D)$$

Hence, to avoid DCM

$$D > \frac{2L_2 f_s V_{out}}{R_o D V_{in}}$$

### SIMULATION RESULTS-



Fig10. The output voltage of the quadratic bi-directional converter with closed loop control



FIG11. The simulation results of output voltage, capacitor voltage and input voltage

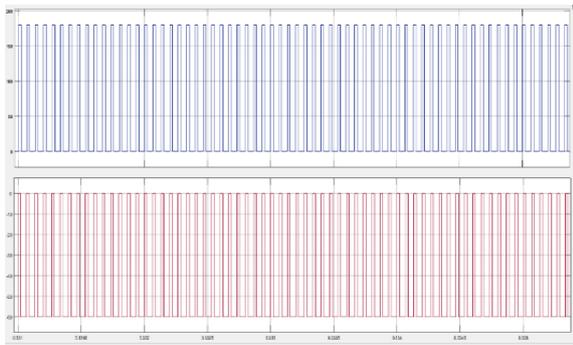


Fig12. The waveforms of main operating switch S2 and its antiparallel diode

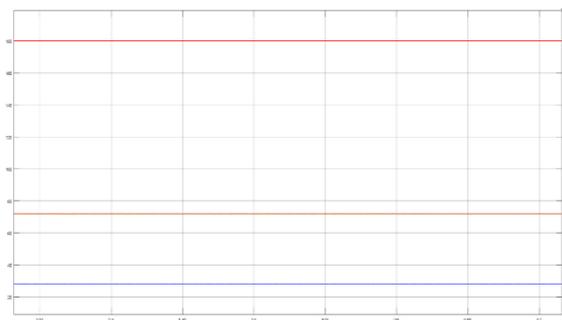


Fig.13 The simulation results of output voltage, capacitor voltage and input voltage in buck mode

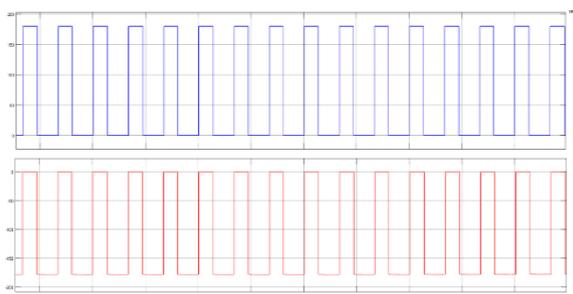


Fig.14 The waveforms of main operating switch S1 and its antiparallel diode

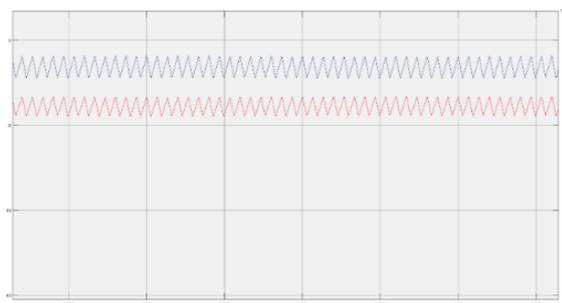


Fig.15 The waveforms of the currents passing through inductors L1 & L2

## CONCLUSION

The operation of quadratic method with the help of bidirectional converter in a closed loop manner is very useful for the future applications like Electric vehicles. The bi-directional converter can be implemented directly when introduced practically without dividing into cases. The bi-directional converter can be used efficiently with an Eco-

friendly environment with the required high voltage gain output. The switches of the bi-directional converter are controlled by using the Proportional Integral controller. Hence the bi-directional converter is shown with implementing the quadratic property with its application is simulated in Boost and Buck operating modes.

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