"PERFORMANCE ANALYSIS OF QUADRATIC BOOST CONVERTER UNDER CONSTANT AND VARIABLE SWITCHING FREQUENCY OPERATION"

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Abstract—*In the high DC gain applications the Quadratic Boost Converter is explored to operate in different conduction modes. A description for the steady state behaviour of the converter which is operating in four different values of inductor currents are discussed. With the corresponding transitions the boundaries between the different modes are determined. This includes the converter operation using pulse width modulation for constant switching frequency and also employing hysteresis comparator for variable frequency switching. For same set of parameters, both the cases are analysed. The converter is supplied by the voltage ranging from 20 to 30 VDC. Theoretical analysis is predicted and simulations are carried out to verify the waveforms. The efficiency of the DCM can compete with the CCM in high DC gain applications.*

Keywords—Quadratic Boost Converter; Continuous Conduction Mode (CCM); Discontinuous Conduction Mode (DCM)

1. INTRODUCTION

In the modern power electronics the intrigue for the discontinuous conduction operation (DCM) in DC-DC converter has increased in the late 1970's. Due to the advancement of computer programs in the field of simulation, the DC-DC switching converters provoked to the study of DCM operation in different way for the researchers. In comparison with the continuous conduction mode (CCM), the application of DCM is relatively marginal. Even though DCM has very less applications, it has a greater prevalence in many important fields. Thus in the development of Power Factor Correction (PFC) it plays an important role and with the micro inverters, electric vehicles, battery storage and fuel cells applications it has been extended recently. The figure 1.1 indicates the quadratic boost converter circuit. The combination of transformer less topology, it gains a special interest with only one controlled switch. And also it has very high DC gain.

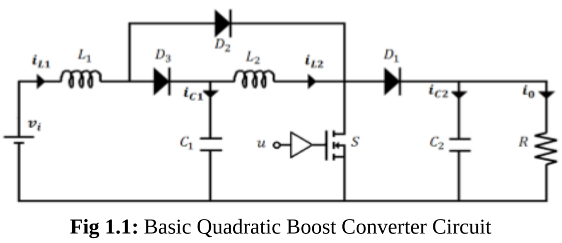

Fig 1.1: Basic Quadratic Boost Converter Circuit

The converter variables related expressions, switching frequency operations in boundary conditions, static function gain. Operation of DCM converter in constant frequency switching. The theoretical predications are verified by conducting experiment for both variable and constant switching frequencies. A straightforward and flexible feed forward (FF) circuit is proposed keeping in mind the end goal to be utilized with the new converter when worked in CCM. Another application is the utilization of the converter as a PFC circuit. UPS applications are utilizing this Quadratic DC-DC converter for supply from the sun powered and wind control supplies. In this newly proposed work of quadratic Boost converter consists of two stage converter with only one switching topology. By using a single switch and approaching in a geometrical way, the output can be obtained between 10-400 volts. The proposed model of the converter is designed to obtain 60W applications. The passive element values and the gain of the converter can be theoretically calculated by design equations. By using MatLab simulations the performance is verified for both constant and variable frequency.

2. OPERATION OF QUARATIC BOOST CONVERTER

In DC-DC converter topologies of PWM which generates square-wave, M is the conversion ratio of the duty cycle for the active transistor switch. The below Fig.-2 shows the five possible structures of quadratic boost converter. Fig. 2.1 and Fig. 2.2 are the circuit which corresponds to continuous conduction mode. Other three are the additional topologies which are used along with these two. Fig. 2.3 & Fig. 2.4 are for when the inductor current L_1 or L_2 is either zero or attains zero before completing the switching period by originating DCL_1 & DCL_2 (Discontinuous conduction on inductor) state. Fig. 2.5 shows both the inductor currents which attain the value zero before completing the switching period (DCL_{12} state).

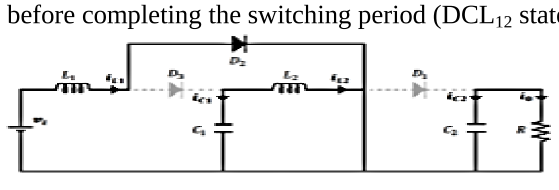

Figure 2.1: Circuit Operation of Quadratic Boost Converter in On-State

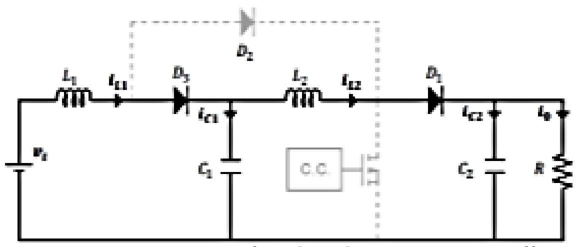

Figure 2.2: Circuit operation of quadratic boost converter in Off-State

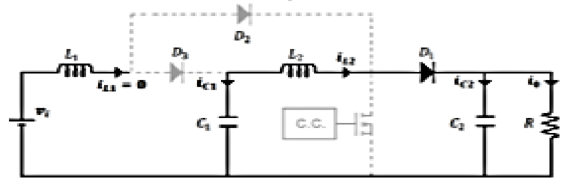

Figure 2.3: Circuit operation of quadratic boost converter in DCL_1-state

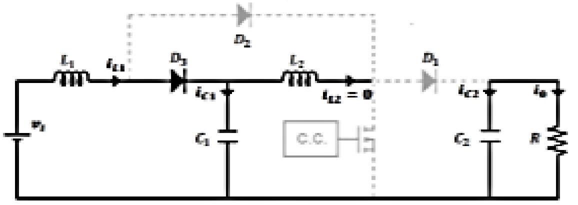

Figure 2.4: Circuit operation of quadratic boost converter in DCL_2 state

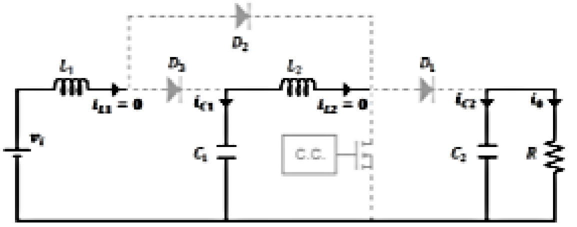

Figure 2.5: Circuit operation of quadratic boost converter in DCL_{12} state

By using any one of the above conduction mode, the quadratic boost converter can be operated. The converter can have two or more structures during the period of switching ($T_s = 1/f_s$). The converter operates in the CCM mode when the system changes its state from OFF to ON-state during the starting of the switching and the same system changes its state from ON to OFF-state before the control signals of the duty cycles is completed. Here initially the system changes its state from OFF-state to any of DCL_1 or DCL_2 state, then at the starting of the new switching period it attains the new ON-state. DCL_{12} mode is operated by attaining to the state DCL_{12} from state DCL_1. DCL_{21} mode can be operated by arriving to DCL_{12} state by DCL_2 state. Any one of the state is attained first before the system state is turned OFF. This is the major difference between last two modes of operation.

Depending on the given input and the output conditions, all the five modes of operation are realized for the given set of converter parameters along with the PWM control. It is not possible to attain all the states when the control system is based on the hysteresis.

3. STEADY STATE OF THE CONVERTER FOR CONSTANT SWITCHING FREQUENCY

As a function of output load (DCL1, DCL2 and DCL12 modes) and the duty cycle, we can obtain the static gain of the converter by using the above equation-1. The average value of the load currents and the inductor currents and also the static relations of the input voltage and the values of capacitor voltages can also obtain from the above equations. In the steady state the mean value of the converter is denoted by ⟨ ⟩. The value of u is substituted by the average value of D, where D represents the duty cycle of converter in the steady state.

3.1 Average values of the converter variables

By balancing the charge on the capacitors and applying volt-second balance on inductors we can obtain the mean values of the converter. When the inductor is operating in CCM, the value of the volt-second balance is given by the below equation-2.

$\langle v_{Lx}\rangle = \frac{v_{Lx_{on}} DT_s + v_{Lx_{off}}(1-D)T_s}{T_s} = 0$ x=1,2 .... (1)

Similarly when the inductor is operating in DCM, the value of the volt-second balance is given by the below equation-3.

$\langle v_{Lx}\rangle = \frac{v_{Lx_{on}} DT_s + v_{Lx_{off}} D_x T_s}{T_s} = 0$ x=1, 2 .... (2)

When the inductor is not operating in DCM, the values for charge balance in a capacitor can be easily obtained by the below equation-4.

$\langle i_{Cx}\rangle = \frac{i_{Cx_{on}} DT_s + i_{Cx_{off}}(1-D)T_s}{T_s} = 0$ x=1, 2 .... (3)

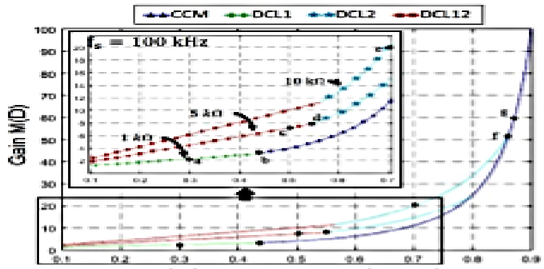

Fig.3.1 Ideal converter gain vs. duty cycle

4. STEADY-STATE OF THE CONVERTER FOR VARIABLE SWITCHING FREQUENCY

To implement the sliding mode controller, the hysteresis comparator doesn't imply any changes to the converter variables in the steady state. Different switching frequencies are present in the operation of converters. Hence considering the different equilibrium points is necessary. The system works in limited with either DCL2 or CCM, this has to be pointed first. Because the L1 inductor ensures the sliding motion above the control surface in the CCM (continuous conduction mode). At the each equilibrium point it is possible to associate a duty cycle. This is used to compare two different kinds of modulation which is employed in this work.

4.1 Operation in CCM

The converter has to be the same behaviour of steady state while operating in CCM mode along with a hysteresis comparator than using a PWM modulator. This is because the steady state and the gain relationship between the variables don't depend on frequencies. Hence the equations 6 to 9 remain valid for all conditions.

4.2 Operation in DCL2 mode

When the system is operating in DCL2 the steady state converter gain and relationships among the variables is the function of the switching frequency and the resistive load. Thus, the equations in first row of the table-1, switching period is given as

$T_s = \frac{2L_1\Delta}{V_{in}D}$.. (4)

Where Δ is the hysteresis band. Substituting equation (4) in equation (3) the duty cycle D is obtained and is given below.

$K_2 = \frac{2L_2 f_s}{R} = \frac{L_2 V_{in} D}{L_1 R\Delta}$.. (5)

Substituting equation (8) in expression for V_{c2} and DCL2 in table-2, we get

$V_{c2} = \frac{V_{in}}{2(1-D)}\left(1\sqrt{1+\frac{4L_1 R\Delta D}{L_2 V_i}}\right)$...................................(6)

4.3 *Boundary conduction mode between CCM and DCL2*

For the variable frequency switching, the boundary condition mode between DCL2 and the CCM is determined by equating the equation for $K_{2_{crit}}$ and equation (5) we get the value foe duty cycle.

$D_{crit} = 1 - \sqrt{\frac{L_2 V_{in}}{L_1 R\Delta}}$...................................... (7)

The converter operates in CCM mode for the given set of parameters, if the obtained duty cycle is greater than D_{crit} and similarly the converter will operate in DCL2 mode if the obtained duty cycle is less than D_{crit}. It is to be noted that, the value of D_{crit} is defined indirectly by converter parameters (L_1, L_2& Δ) and by defining the operating point (V_{in}, R).

The figure-4.1 shows the gain of the converter for the given set of parameters (L_1, L_2, C_1, C_2) when the converter operates in variable switching frequency. As a function of output load R and duty cycle different modes of conductions are represented.

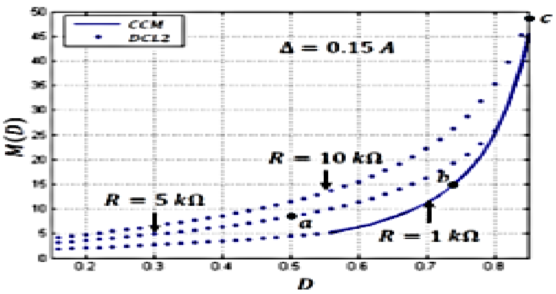

Fig-4.1 Ideal converter gain vs. duty cycle for variable switching frequency operation

5. MATLAB SIMULATION FOR CONSTANT SWITCHING FREQUENCY OPERATION

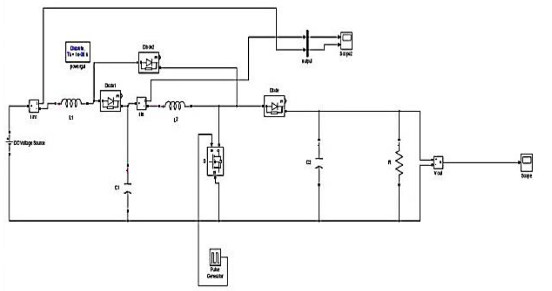

Figure 5.1: Simulation model for constant frequency switching model

TABLE 5.1: SYSTEM PARAMETERS FOR CONSTANT FREQUENCY SWITCHING MODEL

Component	Value
V_{in}	15V
L_1	220 µH
L_2	820 µH
C_1	11 µF
C_2	11 µF
F	100 kHz

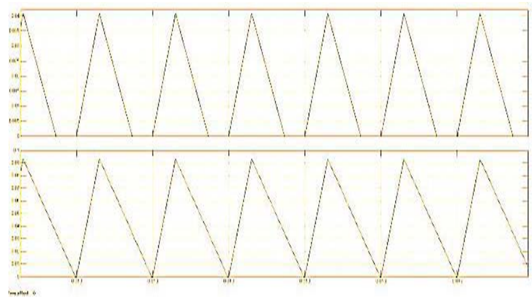

Figure 5.2: Current waveforms for DCL_1 when R=1kΩ, D=0.3

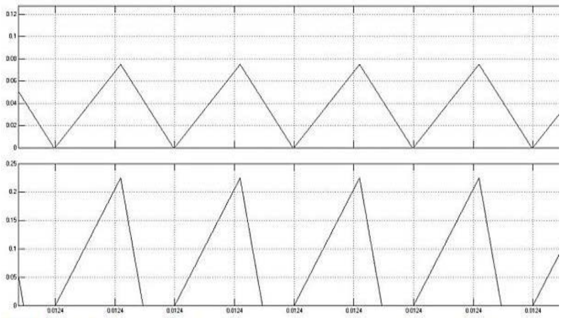

Figure 5.3: Current waveforms for boundary between DCL_2 and DCL_{12} when R= 5kΩ, D=0.5481

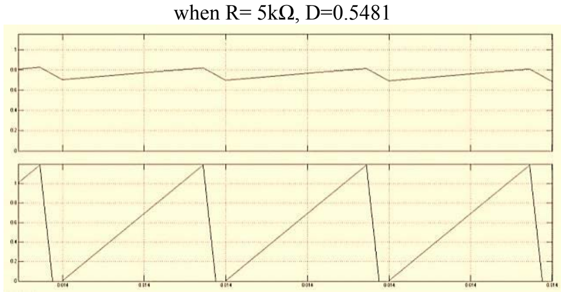

Figure 5.4: Current waveforms for boundary between CCM and DCL_2 when R=10kΩ, D=0.7

6. SIMULATION RESULTS FOR VARABLE SWITCHING FREQUENCY OPERATION

TABLE 8.1: SYSTEM PARAMETERS FOR VARIABLE FREQUENCY SWITCHING MODEL

Component	Value
L_1	220 µH
L_2	820 µH
C_1	11 µF
C_2	11 µF

For different cases of switching frequency, duty cycle and load resistance and with suply voltage V_{DC} = 15V the simulation cases are summarized as below.

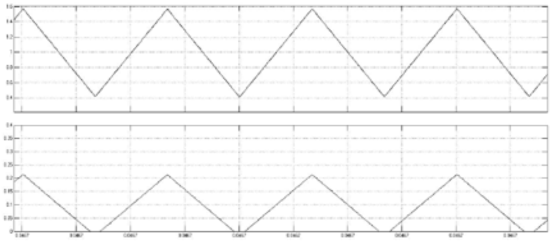

Figure 6.1: Waveform for currents in L_1 and L_2 when R= 1kΩ, D=0.5006, F=75 kHz

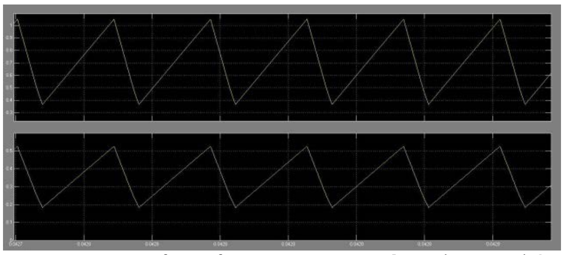

Figure 6.2: Waveforms for currents in L_1 and L_2 when R= 5kΩ, D=0.7405, F=70.59 kHz

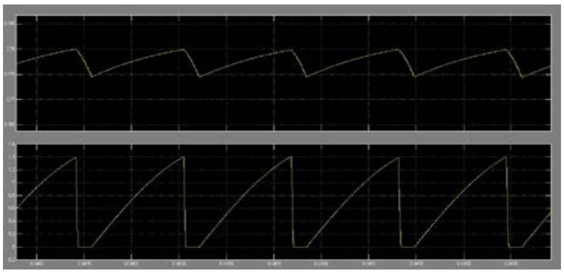

Figure 6.3: Waveforms for currents in L_1 and L_2 when R= 10kΩ, D=0.856, F=88.23 kHz

7. CONCLUSION

The Quadratic boost converter proposed in this project, an analysis is made for steady state and different conduction modes of Quadratic boost converter which is operated either in hysteresis comparator or in PWM control. Along with the conventional CCM extra four modes like DCL_1, DCL_2, DCL_{12} and DCL_{21} for inductor currents operating in discontinuous conduction modes have been explored and analysed. In the comparison only DCL_2 can fight with the CCM for high gain applications because it provides same levels of efficiency which is obtained with a normally set-up parameters for both hysteresis and PWM cases. It is inferred that operate in boundaries between DCL_2 and CCM mode of operation is more advantageous. Further, study is carried out for the dynamic behaviour of Quadratic boost converters when operated in DCL_2 mode with progress in hysteresis modulator.

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