Frequency Controlled Buck Boost Converter with High Efficiency

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***Abstract*- In this paper, a new dc/dc converter with high efficiency using soft switching by partial resonant circuit is studied. The proposed converter circuit is used to replace the conventional snubber circuit of Buck-Boost converter with a pair of diodes, lossless capacitor and a step up inductor. In addition the output voltage is regulated by varying the switching frequency with varying load making it a frequency dependent converter rather than a load dependent converter. In comparison to the conventional Buck Boost converter with some simulation results confirm the validity of analytical results of the proposed converter.**

***Index Terms*- ZVS, ZCS, Buck boost converter.**

I. INTRODUCTION

Machines which supply dc electric energy requires boost DC-DC converter of high efficiency by active switching modes to make most use of provided energy. In order to achieve small size, light weight [1]-[3], the power converter must be of high switching frequency. Due to increased frequency, the switching loss also increases. As a result, the efficiency is reduced. Recently to improve the efficiency large numbers of soft switching topologies including resonant converters topologies have been introduced [4]-[7]. But these increase number of switches and complicate sequence of switching operation.

The paper describes a new buck boost converter with improved efficiency. The switching devices in the proposed converter use soft switching technique with a partial resonant circuit. The partial resonant circuit makes use of a step up inductor and a loss less capacitor regenerating accumulated energy into the input power source. The partial resonant converter makes zero current switching (ZCS) and zero voltage switching (ZVS) for the control switches without switching power losses so called soft switching [8], [9]. The resonant operation of the partial resonant circuit is partially enforced at only switching turn on or turn off time, thus reducing the switching losses. The output voltage of the converter is also regulated by frequency control of the switching devices. As a result, the proposed converter is operated with high efficiency by soft switching and partial resonant circuit.

II.CIRCUIT CONFIGURATION

Fig 1 shows conventional buck boost converter that is generally used. Continuous conduction mode (CCM) and discontinuous conduction mode (DCM) [10] of dc current are the two modes of operation for this converter. The turn on of the switch is in DCM that is when the current is zero (ZCS). On the other hand in order to relive turn off stress of the switching device, a snubber circuit is connected in parallel to the switch of conventional converter. However, the efficiency of the conventional converter is very low due to the power loss of the snubber circuit.

A new dc-dc buck boost converter is proposed [11], in order to improve the efficiency as shown in fig. 2. The proposed converter in comparison to the conventional converter is composed of a series connected diode pair, along with a resonant capacitor and a inductor. The controlling switches in the proposed converter are operated with soft switching by partial resonance. When switches S1 and S2 are turned off, inductor Lr current charges the capacitor

Cr by partial resonant operation. Therefore turn off of S1 and S2 is ZVS. Furthermore, the turn on of S1 and S2 begin at zero current due to DCM operation. And thus, it is for an accumulated energy in the capacitor to regenerate into the input power source by partial resonant operation without power loss of the snubber, which is generally produced in the conventional buck boost dc-dc converter.

As a result the proposed converter achieves soft switching, the power losses are drastically decreased, and the converter operates with high efficiency.

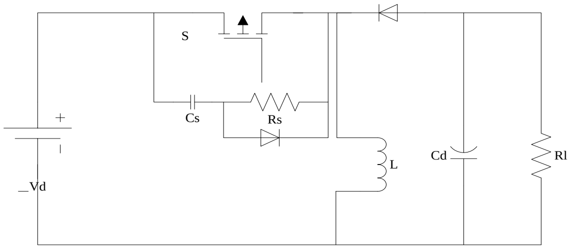

Fig.1.Conventional DC-Dc buck boost converter.

III. OPERATION PRINCIPLE

Fig.3 shows four equivalent circuits of each operational mode in one cycle of the switching frequency of the proposed converter. At initial condition, the current flowing through the inductor Lr is zero, main switch S1 and S2 are in off state, and the capacitor Cr is charged to thye sum of input voltage Vd and output voltage Vcd. The operation of converter can be explained by showing four modes in one switching cycle of frequency. The DCM can also be shown in the simulation results of the proposed converter. The modes of operation are given as below.

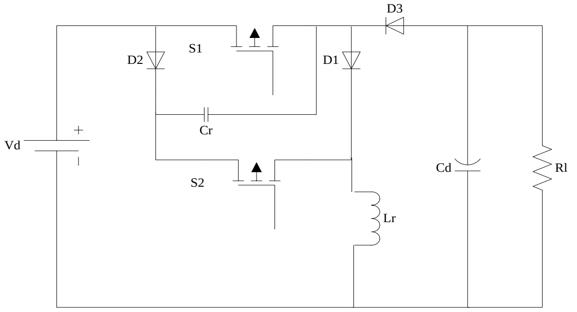

Fig 2. Proposed Buck Boost Converter

1) Mode 1 (T1: t0<t<t1) : Mode 1 begins by turning on both S1 and S2 at the same time. The input voltage Vd and the capacitor voltage Vcr are added and applied to the inductor Lr. Then this mode takes the form of a series LC resonant circuit. The turn on of the switching devices occurs at zero current state. Hence, this is ZCS. The capacitor voltage is expressed in (1) and the inductor current iLr increases according to (2)

$$vcr = (2Vd + Vcd)cos\omega t - Vd \quad (1)$$

$$iLr = ((2Vd + Vcd)/X)sin\omega t \quad (2)$$

Where $\omega = 1 / \sqrt{(LrCr\ )}, X = \sqrt{Lr/Cr}$

This mode ends when Vcr = 0. The time duration of this mode can be obtained by the following.

$$T1 = \sqrt{LrCr}cos^{-1}(Vd/(2VD + Vcd)) \quad (3)$$

The inductor current I1 at the end of this mode can be given as

$$I1 = \sqrt{(2Vd + Vcd)^2 - Vd^2}/X \quad (4)$$

2) Mode 2 (T2: t1<t<t2): Mode 2 begins when voltage across Cr becomes zero. The diodes across D1 and D2 start conducting. The inductor follows two paths of S1- D1 and D2- S2. The linear rise in inductor current is given by,

$$iLr = (Vd/Lr)t + I1 \quad (5)$$

This mode ends when both S1 and S2 are turned off at the same time.

$$T2 = Ton - T1 \quad (6)$$

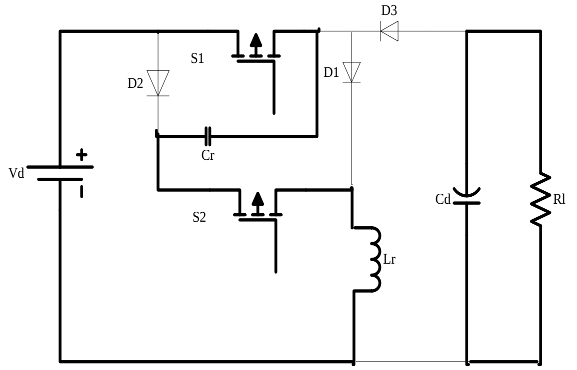

Fig3.1. Equivalent circuit of mode 1

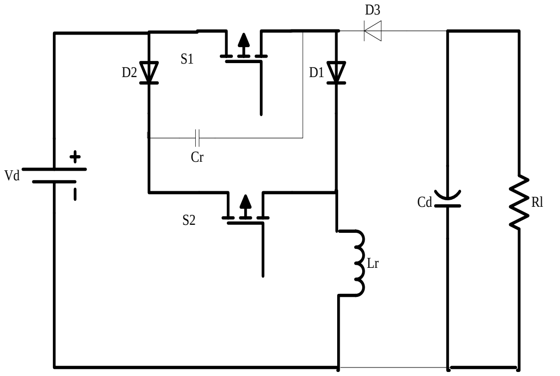

Fig3.2. Equivalent circuit of mode 2

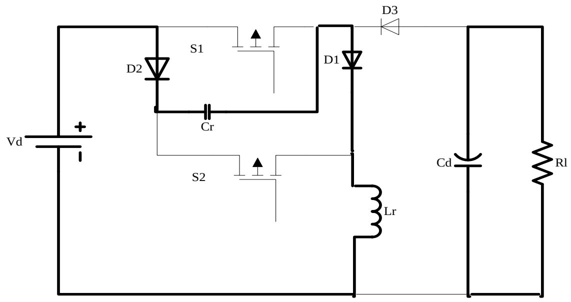

Fig3.3 Equivalent circuit of mode 3

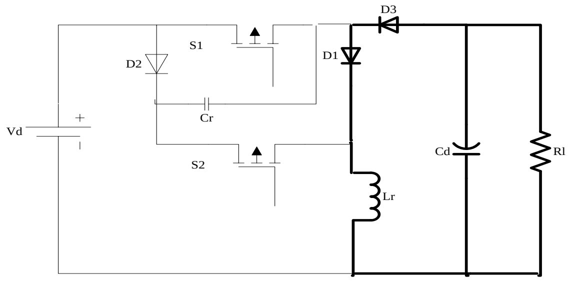

Fig3.4 Equivalent circuit of mode 4

Where Ton is the turn-on period of switch S1 and S2, and the inductor current I2 at the end of this mode can be given as,

$$I2 = I1 + \frac{Vd}{Lr}\left(Ton - \left(\sqrt{LrCr}cos^{-1}\left(\frac{Vd}{2Vd+Vcd}\right)\right)\right) \quad (7)$$

3) Mode 3 (T3: t2<t<t3): Mode 3 begins by turning off the switches S1 and S2 at the same time. The current flowing through Lr takes the route of D2-Cr-D1, charging Cr. The turn off of S1 and S2 occurs at ZVS as the voltage across Cr is zero. The capacitor voltage and the inductor current are given by the following expressions

$$Vcr = Vd + \sqrt{Lr/Cr}\, Ia \sin(\omega t + \theta) \quad (8)$$

$$ilr = Iacos(\omega t + \theta) \quad (9)$$

Where, $Ia = \sqrt{(Cr/Lr)Vd^2 + I2^2}$,

$$\theta = sin^{-1}\left(-\frac{Vd}{\sqrt{Vd^2 + \frac{Lr}{Cr}I2^2}}\right)$$

When the capacitor voltage becomes equal to $Vd + Vcd$ and the D3 starts conducting the mode 3 ends. The time duration T3 can be expressed as (10) and the inductor current at the end of this mode can be given by (11)

$$T3 = \sqrt{LrCr}\left\{sin^{-1}\left(\frac{Vd}{\sqrt{Vd^2 + \frac{Lr}{Cr}I2^2}}\right) - \theta\right\} \quad (10)$$

$$I3 = \sqrt{I2^2 - \frac{Cr}{Lr}(Vcd^2 - Vd^2)} \quad (11)$$

4) Mode 4: (T4: t3<t<t4): By conduction of diode D3 the inductor current flows through the load side. The inductor current linearly decreases to zero as shown in (12)

$$iLr = -\left(\frac{Vcd}{Lr}\right)t + I3 \quad (12)$$

This mode ends when iLr=0. The time duration T4 can be obtained as

$$T4 = \left(\frac{Lr}{Vcd}\right)I3 \quad (13)$$

IV. SIMULATION RESULTS

The proposed converter was analysed using PSIM software. The specifications for the elements used in the proposed converter are calculated in order to achieve a partial resonant condition for the switching devices. The output voltage Vcd was regulated to 200V by using frequency control for the proposed converter. Fig 4 shows the waveforms of the simulation results for one switching cycle of the proposed converter, in order to verify the soft switching operation of the control devices.

In fig 4 the controlling switches of duty factor 46%`are simultaneously turned on at T1. The waveforms of simulation are showing soft switching for the switches S1 and S2.

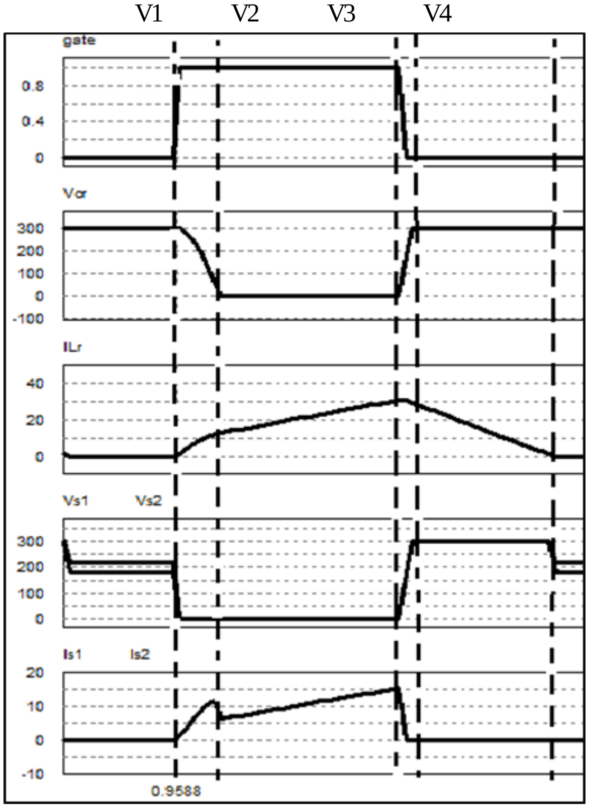

Fig 4 simulation results of proposed converter showing soft switching

When the switches are given pulses at start of time T1, the capacitor Cr starts discharging until the capacitor voltage Vcr becomes zero at the end of time duration T1.here, the inductor current starts rising linearly until the switches are turned off at T3. The voltage is zero hence ZVS is occurring at turn off. After end of T3, inductor current decreases linearly until it reaches zero and remains zero til the next pulse is given. This duration is the DCM duration. And at the next pulse, the turn is occurring at zero current showing ZCS at turn on.

The output voltage of the proposed converter is a function of the load resistance, frequency and duty cycle of operation. So, to maintain a regulated output voltage maximum efficiency the frequency of operation is varied. For a variable load, with a regulated output voltage efficiency of the proposed converter was observed. And it is seen that a higher efficiency is obtained as compared to the conventional converter of the same rating. Fig 5 shows the graph of output power vs. efficiency for the proposed converter.

Thus a regulated output voltage with high efficiency was obtained using the proposed converter.

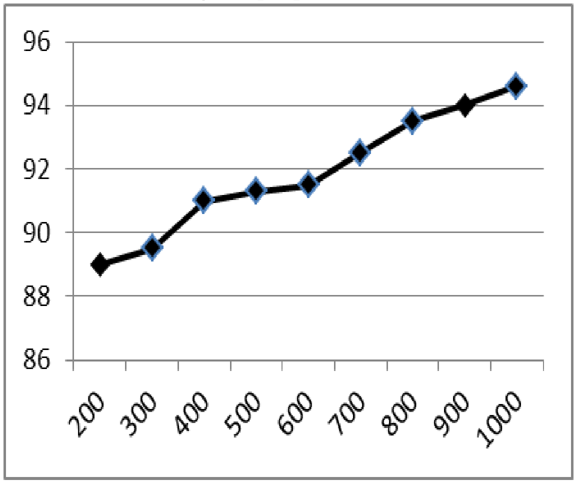

Fig 5 Graph showing efficiency vs. output power for the proposed converter

V. CONCLUSION

A new buck boost converter with high efficiency has been presented in this paper. The switching losses are being reduced using a partial resonant circuit in place of the conventional snubber circuit to improve the efficiency. A loss less capacitor along with series connected switch diode pair, and an inductor was used as the partial resonant circuit. The proposed converter was operated in DCM. The output voltage was regulated by controlling the frequency of operation for the prposed converter. In this way a highly efficient dc-dc converter was studied and analysed.

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