Modified Resonant Transition Switching for Buck Converter

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***Abstract*-**A modified resonant transition switching technique for Buck converter using coupled inductor is proposed in this paper. The principle of operation of this converter is analysed in detail. An additional winding is added on the same core of the main inductor for the purpose of commutation. By using current control, Zero Voltage Switching (ZVS) conditions are ensured over wide load range. The main inductor current is kept in continuous conduction mode (CCM) with small ripple, which allows high output power and small filter parameters. Also, the switching frequency is kept constant when load changes. The simulation results are presented and they verify theanalysis.

***Index Terms*-**ZVSPWM converters, Coupled inductor, current control, continuous conduction mode

I. INTRODUCTION

Switched Mode Power Supplies [SMPS], have become the natural choice for most of the power supply problems, owing to their higher efficiency, they are widely used in industrial, residential and aerospace environments. The basic requirements are small size and high efficiency.

'Frequency goes up, size comes down', is a belief that has been the main motivating factor for switching a thigh frequencies so high switching frequency is necessary to achieve small size. Most of the present commercial SMPS, operate with a switching frequency of around 50 kHz, using Hard Switching PWM topologies. Consider a step down converter in fig1

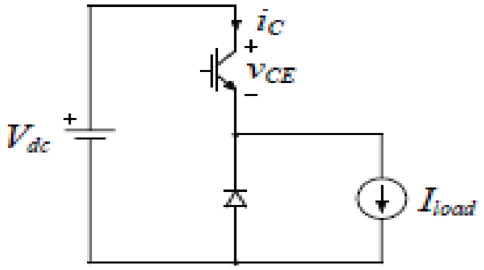
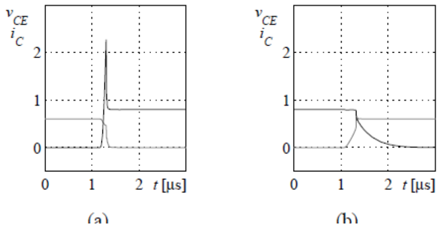


Fig.1step down converter

If we use hard pulse width technique then IGBT have to sustain high power during transition as shown in fig2



(a) (b)

Fig.2transient response

To solve this problem soft switching technique need to be used. soft switching must satisfy two conditions,
(a) switch transitions should occur only when either the device current or device voltage is zero. (b) energy stored in parasitic elements are fully recovered.

They can be broadly classified as Zero Current Switching [ZCS] Converters and Zero Voltage Switching [ZVS] converters. In the ZCS converters, the Current through the device is brought to zero by external means, just prior to turn-off. Thus the turn-off losses as will as the voltage spikes due to stray inductance are totally eliminated. During the turn- on process, the current rise is slowed down, again by external means, so that the device voltage falls to zero before the current becomes appreciable. In the ZVS converters, the device voltage is brought to zero just prior to turn-on, thus totally eliminating the turn-on losses. During turn-off, the rate of voltage rise is limited, so that the device current falls to zero before the voltage rises substantially.

Some soft switching techniques are (a) snubber circuit (b) Resonant switch(c) Resonant Transition converter
In snubber circuit: are effective, to a limited extent, in reducing the device stress during switching transitions. However, they do not appreciably reduce the switching losses, as they only shift the power loss from the switches to the snubber resistors.
In resonant switch: The Resonant Switch Converters are obtained by simply replacing the controllable switch (es) in PWM converters, with the Resonant Switch. The Resonant Switch is a sub circuit consisting of semiconductor switches and resonant LC elements. The resonant elements shape The device current/voltage waveforms, so that the switching's can be done under favourable conditions But This type has some limitation peak current and peak voltage stress, conduction losses is high .

In Resonant Transition converter as in fig3

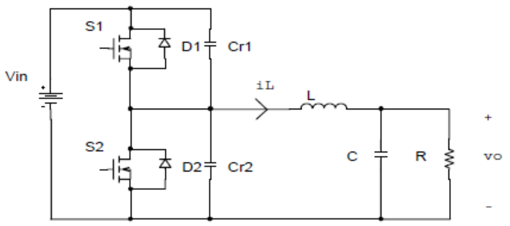


Fig.3 ZVS Buck converter using coupled inductor

The drawback of ZVRT converters is large ripple in the inductor current, which makes the conduction loss higher compared with the conventional PWM converters. Also, it needs large filter parameters. Since all output filter capacitors have Equivalent Series Resistor (ESR), large ripple current will generate high loss in the capacitors. High ripple current will also cause high magnetic core loss. For the sake of efficiency, the inductor current should have small ripple. This technique is only suitable in low power applications.

In the modified ZVRT converters, the switching current can still be bi-directional so that ZVS conditions are retained and at the same time, the main inductor current is in continuous conduction mode with small ripple. The proposed technique helps to overcome the drawbacks of the ZVRT converter discussed above.

In this paper, the operational modes of the proposed Buck converter is analysed in detail. To achieve ZVS conditions in the switches and fast response, hysteresis current control is used in this converter. By using this method, the bi-directional current has the average value determined by the output of the voltage loop, hence by output power while its minimum value is always less than zero to achieve ZVS conditions. Also, the switching frequency is kept constant when the load changes.

II. PRINCIPLES OF OPERATION OF THE PROPOSED SOFT SWITCHING TECHNIQUE

The proposed ZVS-Buck converter is shown in fig.4 Inductor *L* 2 and *L*1 are tightly coupled on the same ferrite core. The polarities of the inductor *L* 2 and *L*1 are marked as in the schematic circuits to ensure that the voltage across the coupled inductor (*L* 2) can be used as the commutation source for soft switching for MOSFETs. The inductor *Lr* is small while the main inductor *L*1 is comparatively large. Current *ir* is controlled to be bidirectional (positive and negative) while the output current *i*1 has small ripple. The waveforms for *i*1 and *ir* for Buck converter are shown in Fig.4

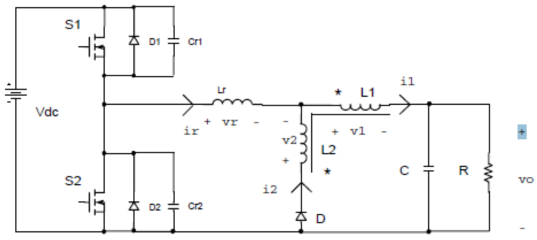


Fig.4 ZVS Buck converter using coupled inductor

Current *ir* is controlled to be bidirectional (positive and negative) while the output current *i*1 has small ripple. The waveforms for *i*1 and *ir* for Buck converter are shown in Fig 5

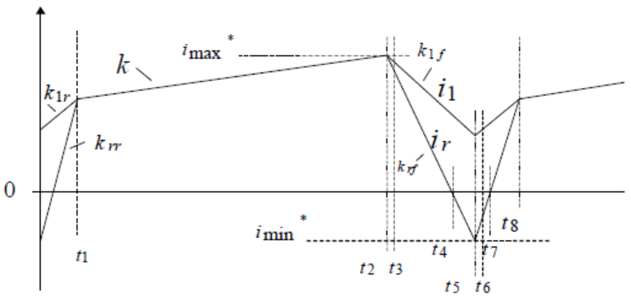
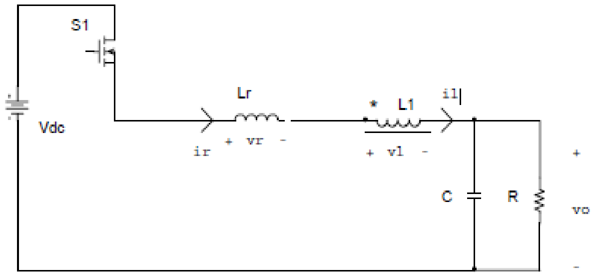


Fig.5 Waveforms of *ir* and *i*1

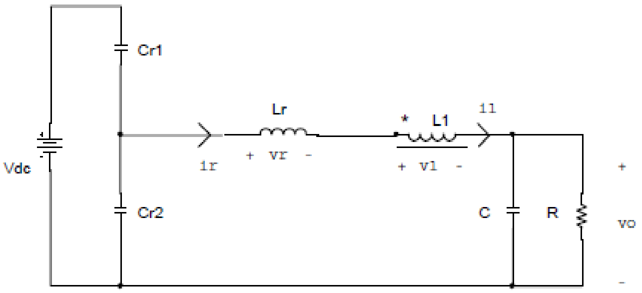
The current *ir* is bi-directional, which ensures ZVS conditions for the two MOSFETs. Small ripple current in *L*1 allows higher output power and lower requirements of the output filter capacitors. As an example, the Buck converter is analysed. There are seven modes in one switching cycle. The equivalent circuits for these modes are shown in Figure.

Mode 1 [*t*1- *t*2]: at time *t*1, *S*1 is turned on and *D* is off. Inductor *Lr* is in series with *L*1 . The current i_r will rise linearly. When the current reaches the current reference $i_{\max}$ that is determined by the output of voltage regulation loop, *S*1 is turned off.



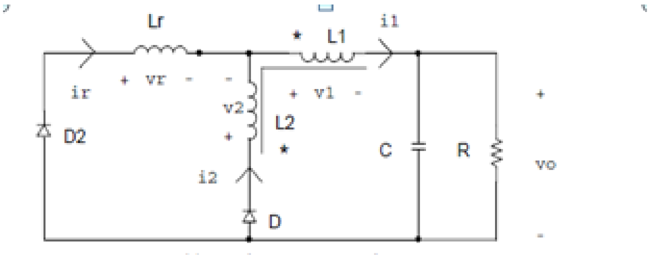
(a) Mode 1: S_1 conducts

Mode 2 [*t*2 - *t*3]: When *S*1 is turned off at *t*2 , resonance occurs between the inductor *Lr* and snubber capacitors (*Cr*1 , *Cr*2). During this interval, *Cr*1 is charged and *Cr*2 is discharged. At time *t*3 , the voltage across *Cr*2 becomes zero and *D*2 begins to conduct.



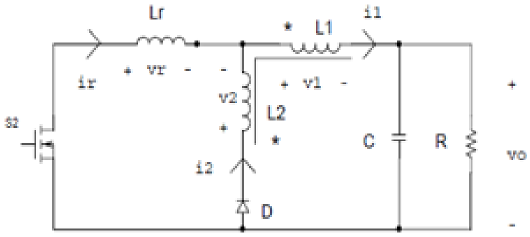
(b) Mode 2: L_r, C_{r1} and C_{r2} resonant

Mode 3 [$t3 - t4$]: When $D2$ conducts, the voltage across the output inductor ($v1$) changes its polarity. Because inductors $L2$ and $L1$ are tightly coupled, $v2$ is negative. The current in Lr begins to decrease due to the voltage across $L2$. Because Lr is comparatively small, its current will decrease much faster than that of $L1$. As long as $D2$ is on, the gate signal can be applied to $S\,2$ so that $S\,2$ can be turned on at zero voltage.



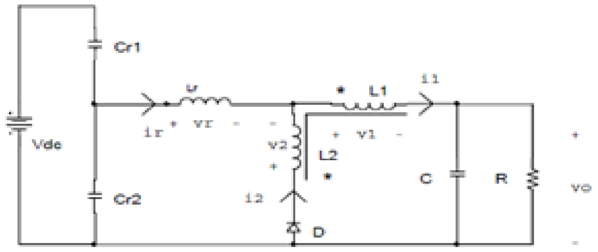
(c) Mode 3: D_2 conducts

Mode 4 [$t4 - t5$]: at time $t4$, ir reduces to zero and $S2$ begins to carry current. The current ir rises in opposite direction. When ir reaches the current reference $i$min at time $t5$, $S2$ is turned off. The value of $i$min is set by controller to make sure that the energy stored in Lr is large enough to charge and discharge the snubber capacitors thoroughly so that ZVS conditions can be satisfied.



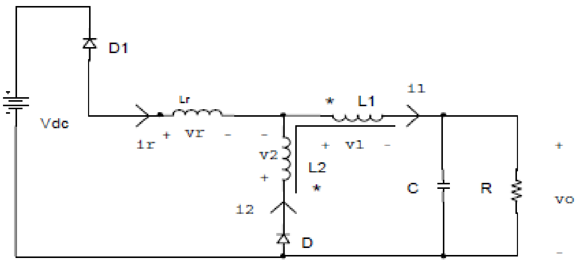
(d) Mode 4: S_2 conducts

Mode 5 [$t5 - t6$]: When $S2$ is turned off, resonance occurs between the inductor Lr and the snubber capacitors ($Cr1$ and $Cr2$). This mode is similar to ***Mode 2.*** Capacitor $Cr1$ is discharged while $Cr2$ is charged. At time $t6$, the voltage across $Cr1$ becomes zero.



(e) Mode 5: L_r, C_{r1} and C_{r2} resonant

Mode 6 [$t6 - t7$]:$D1$ begins to conduct. During this duration, ir and $i1$ begin to increase. The conduction of $D1$ makes itpossible for $S1$ to be turned on at zero voltage. At time $t7$, ir will be equal to zero.



(f) Mode 6: D_1 conducts

Mode 7 [$t7 - t8$]: ir and $i1$ continue to increase. At time $t8$, the current ir will be equal to $i1$ so that current in inductor $L2$ becomes zero.

III. CONTROL STRATEGY

As discussed above, to achieve ZVS conditions, the current ir should be bi-directional. Since the voltage mode control has low response it can’t be used in this case. So inductor current control method is used here.

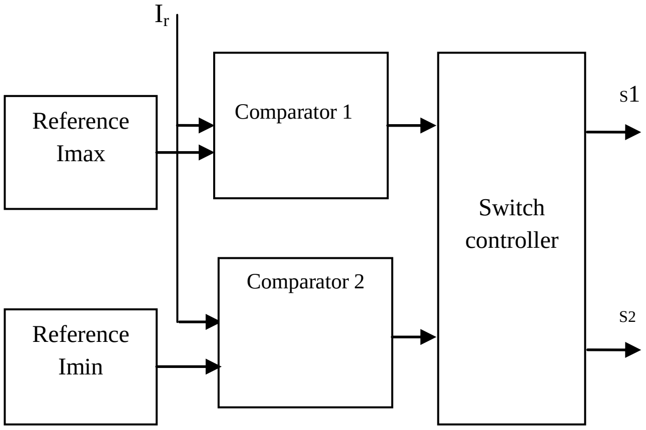


Fig.6 Block diagram for circuit diagram

The current Ir, through the inductor Lr is compared with the reference values Imax and Imin. When Ir ≥ Imax then S1 is turned OFF and S2 is turned ON. When Ir ≤ Imin then S2 is turned OFF and S1 is turned ON. Thus controls for the MOSFETs are achieved in an easier way than the existing control schemes by this method as in fig6.

IV. SIMULATION RESULTS

The converter is simulated using simulation software MATLAB version 7.10.0.

Components	**Simulation value**
Switches, S1,S2	Ideal
Diode	Ideal
Capacitance, C	$10^{-10}\mu F$
Resonant inductor, Lr	4.2 μH
Inductor, L2	10 μH
Main inductor, L1	100 μH

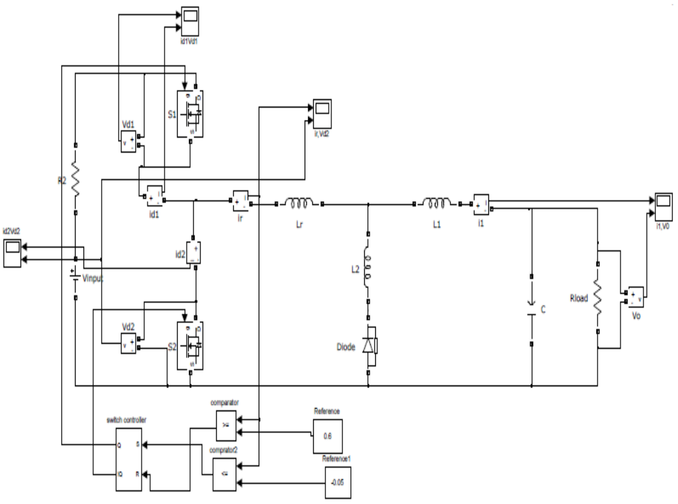


Fig.7 Matlab simulation model

Output Waveforms

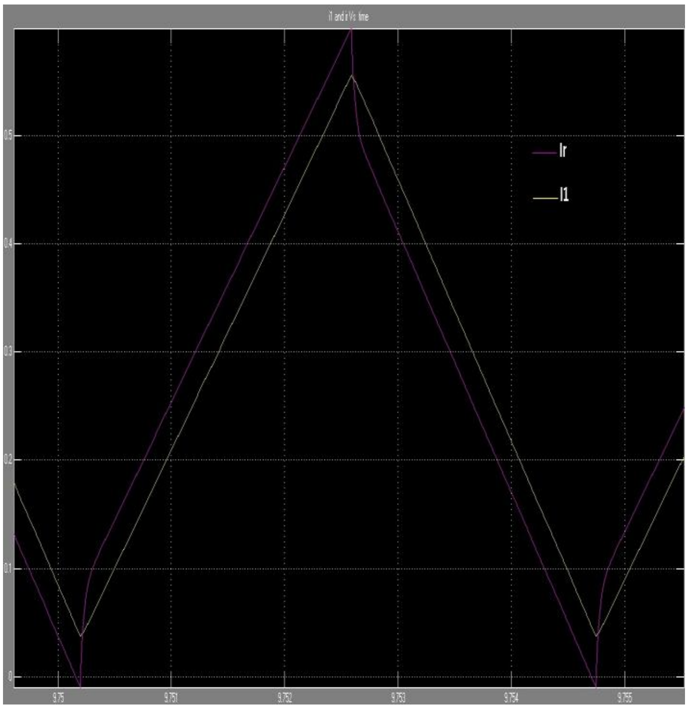


Fig :8 Waveforms of *ir* and *i*1

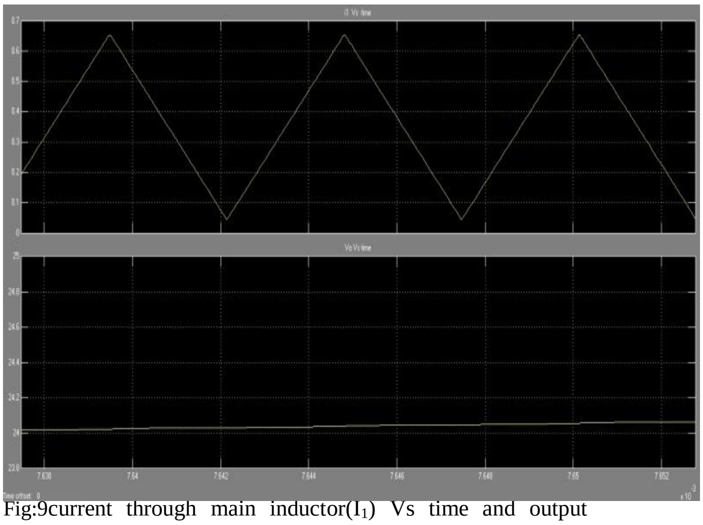


Fig:9current through main inductor(I_1) Vs time and output voltage(V_0) Vs time

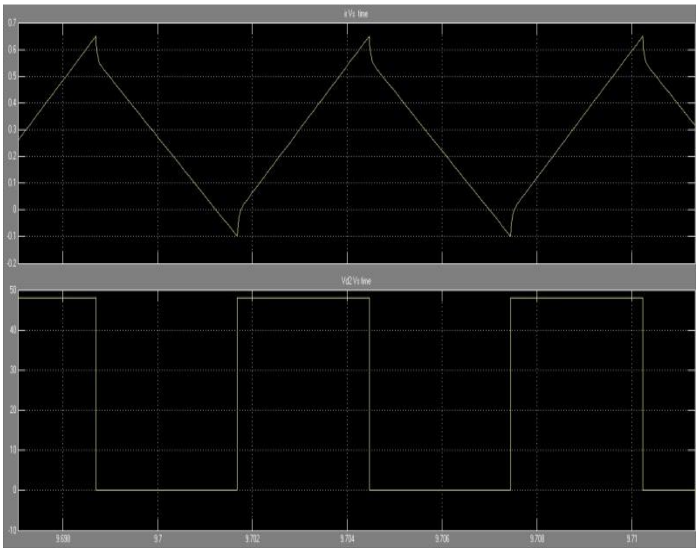


Fig:10current through resonant inductor(I_r) Vs time and voltage across switch,S2 (V_{d2}) Vs time

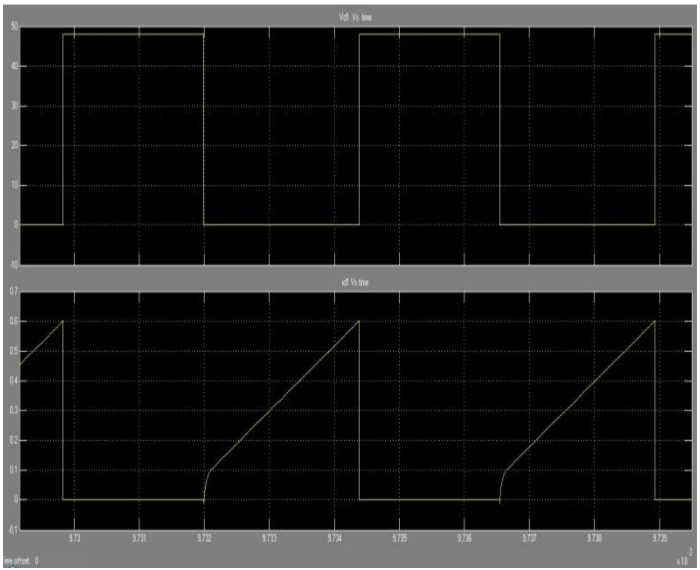


Fig :11voltage across switch,S1 (V_{d1}) Vs time and current through switch S1(I_{d1}) Vs time

V. CONCLUSION

In this paper a soft switching technique for buck converter is proposed. This technique allows the main inductor current to operate in continues condution mode (CCM) with small ripple current and at the same time ensures ZVS conditions of the switch. A modified current control is used in this converter to achieve ZVS condition. The modes of operation are analyzed in detail. MATLAB results(fig8,9,10,11) of the converter is presented in the paper, they agree with the analysis. Because of soft switching conditions high efficiency could be obtained in this converter. Continues main inductor current will allow high power application and reduced filter size. Feauture investigation is underway for boost converter.

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