International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 02 Issue: 09 | Dec-2015 www.irjet.net p-ISSN: 2395-0072

Voltage mode control of soft-switched single switch Isolated DC-DC Converter

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Abstract - ***The high switching frequencies in power converters increases the switching losses, and electromagnetic interferences. These losses can be overcome by employing soft switching techniques. The paper introduces a soft switched single switch isolated DC-DC Converter where Switching losses, current and voltage stress can be reduced. The presented converter can be Zero current Switching (ZCS) turn on and Zero-Voltage Switching (ZVS) turn off of diodes and switches, regardless of load variation. Low rated lossless snubber used in the paper can reduce the transformer volume due to low magnetizing current. In the presented voltage mode control topology makes the output voltage constant and also switching stress is reduced even for load variations. The simulation of the circuit with 28V input, 380V/0.65A output is done using MATLAB***

Key Words: *Isolated step up dc-dc converter, single switch, soft switching*

1. INTRODUCTION

Isolated step up dc-dc converters are used in many applications, such as photovoltaic module–integrated converter (MIC) systems, portable fuel cell systems, and vehicle inverters where high efficiency, high power density, and low cost are required [2]. Isolated DC-DC Converters are used to provide galvanic isolation to regulate the output in telecom DC/DC converters. The non isolated switching regulators are mainly classified as Buck, Boost, and Buck Boost. Isolated DC DC Converters are derived from these non isolated DC-DC Converters by adding an isolating transformer and various other components.

The isolated boost converter topology was conceived by Davidson on June 15, 1982 at Varian Canada micro wave division. Isolated boost converters have some inherent advantages when used in fuel cell applications. With storage inductor placed at the input side, ripple current is inherently low. The drawback of boost topologies is need for the clamping of voltage spikes on primary switches caused by parasitic inductors. Thus various topologies have been analyzed to overcome these drawbacks.[4] . The Fly back

current fed push pull DC-DC converter shown in fig 1 is composed of a push pull transformer and a two winding transformer. These converters have several advantages over conventional current fed push pull transformers. In this topology [5] , there is no output inductor and has only a single input which makes the topology best suited for multiple output power supply.

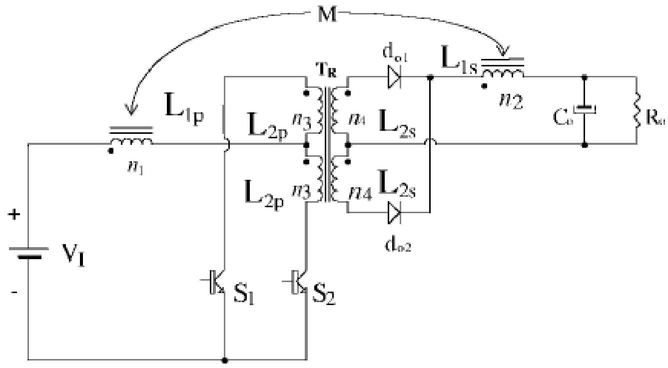

Fig 1 new flyback-current-fed push–pull dc–dc converter

In order to miniaturize a converter it is preferred to use high switching frequency. Increasing the switching frequencies helps to reduce the volume of power supplies. In medium power applications where isolation is required, which can be achieved by transformers, fly-back [6] and forward converters [7].

Current fed push pull DC-DC Converters [8] features good regulation. The main drawbacks of this topology are severe voltage over shoot, and the practical implementation of the circuits becomes unfeasible. The two possible techniques to solve such problems are passive clamping and active clamping techniques. The passive clamping techniques reduces the voltage over shoot problem, however diminishes the converter's efficiency, since energy is wasted through the clamping resistor. The active clamping techniques [9] promote the complete devolution of the energy stored in the leakage inductances.

During turn OFF of ZVT Converters [10], a snubber circuit is added across the switch to achieve turn off at Zero

Voltage. . The snubbers are of mainly two types, namely dissipative snubber and Non dissipative snubbers [11]. Dissipative snubber composed of resistors, capacitors and diode. These snubbers can be easily designed and adopted. But they can degrade the overall efficiency of the converter Whereas Non dissipative snubber consists of inductor, capacitor and diode which have high efficiency.
Isolated boost converters suffers from a problem at switch turn off due to energy stored in the transformer leakage inductance. At switch turn off, energy redistributes into the parasitic capacitance of the switches, causing a voltage over shoot capable of destroying the switches. In PWM DC DC converter [13], ON time 'T_{on}' is varied but chopping frequency 'f' is kept constant. PWM converters suffer from switching loss and electromagnetic interference. These losses can be overcome by resonant and soft switching converters. Resonant and quasi resonant converters [14] provides soft switching using resonant tank consisting of capacitors and inductors. In these converters energy is transferred through L-C tank circuit. Switching is performed when voltage and current is reduced to zero during resonance [15]. Switch On time and off time is limited by resonance period. Transformer and output filter design are optimum at constant switching frequency. Switch voltage and current are increased in resonant Converters [16] in comparison with PWM converters.

Conventional Fly back converters [17] as shown in fig 2 are with high magnetizing current which will result in large magnetizing inductance. Fly back suffers from voltage stress across the switches because of the energy stored in the leakage inductance of the transformer. The main drawback of Fly back converter [18] is the hard switched at both turn on and turn off instants.

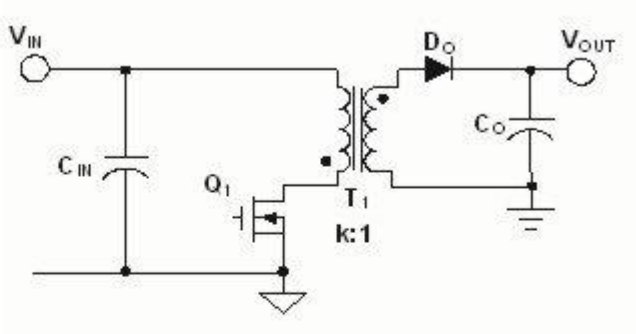

Fig 2.Conventional Fly back Converter

Z- source converters [19] are also hard switched at turn OFF and turn ON instants. Transformer volume of the fly back converter is large compared with the Z source converters. Magnetizing inductor is used in fly back converter for energy transfer. In hybrid Frequency Modulation for PWM integrated Converters [20] is hybridizing the constant ON and constant OFF time .Fixed frequency control is used only on depending the required duty cycle. In [21], Core loss and conduction losses are reduced by reducing the applied volt-sec balance at the transformer .In hybrid frequency control; the circuit also maintains zero current switching for output diode, thus minimizes switching loss and eliminates circulating energy.
The gain of non isolated boost and buck boost DC DC converter is limited because of the internal resistance of inductors even at high duty cycles [22]. Also switches in these topologies have to block output voltage. In Isolated Boost DC-DC converter for high power low-voltage fuel cell [23] has a storage inductor at the input side thus input ripple current is inherently low. Output diodes ensure minimum voltage stress and effective voltage clamping. [24].
ZVS techniques [25] are now frequently employed to reduce switching losses. Turn OFF or ON of a high capacitance switching device takes place only at zero voltage across that device for low switching losses. Similarly turn ON or OFF of a low capacitance switching device takes place only at zero current across that device for low switching losses [26]. Resonant converters use smaller value resonant inductors [27] and capacitors to resonant only during transitions of switching devices for achieving ZVS and ZCS [28].
Quasi resonant converters [29] employ a single switch and provide soft switching condition without any extra switch but suffer from the mentioned disadvantages of their hard switching counter parts namely the fly back transformer and forward output inductor.

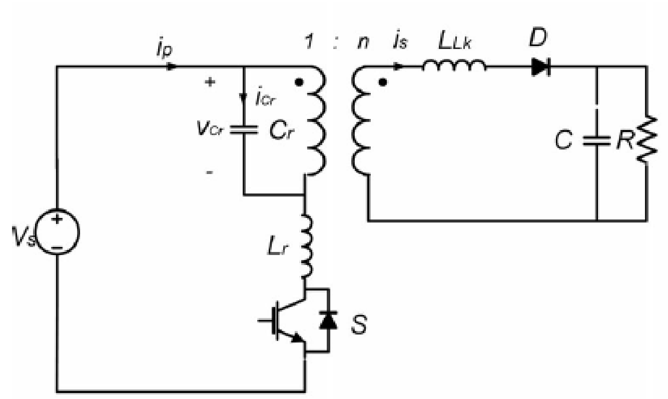

Fig3. Single switch soft switched isolated DC-DC Converter

The soft switched single switch isolated DC-DC Converter is the new converter topology introduced in the paper. The introduced converter has several features like ZCS turn on and ZVS turn off of switch regardless of voltage and load variation. ZCS turn off of all diodes leading to negligible voltage surge. More over small input current ripple due to CCM operation. Transformer volume is also reduced due to low magnetizing current. A low rated lossless snubber is used to achieve high efficiency.

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1. NEW ISOLATED SOFT SWITCHED SINGLE SWITCH CONVERTER

The Fig 4.Shows the circuit diagram of new converter. Converter includes a input filter L_i, switch S_1, a lossless snubber which have capacitor C_s , inductor Ls, and diodes

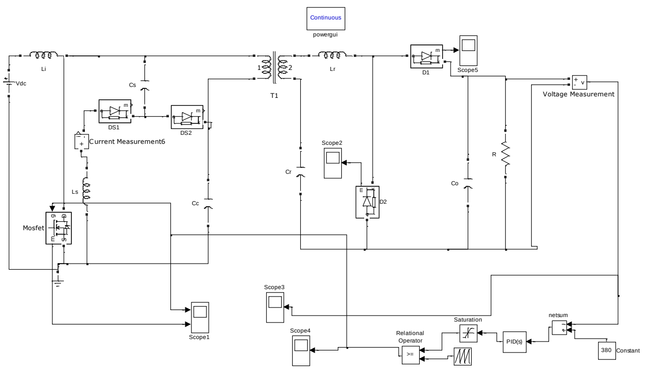

Fig 4 New isolated single switch ZCS-ZVS Converter

D_{S1}, D_{S2} and clamp capacitor C_c in the primary side. L_r, C_r series resonant circuit and diodes D_1 and D_2 in secondary side. The lossless snubber circuit with Ls, Cs resonates which traverses the voltage across the switch from zero to its peak and back down to zero , at this point switch is activated. Thus ZVS is achieved. Similarly in the secondary side of transformer L_r, Cr resonates to traverses the energy thus ZCS can be achieved to turn off the diodes.

1.1.Operating Principles

The input filter and magnetizing inductance are large and they are assumed to be constant current sources during a switching period. Output capacitance and clamp capacitance are treated as large so that they can be treated as constant voltage sources. Thus V_{Cc} is treated as the same as the input voltage.

When switch S_1 is turned ON. L_s and C_s starts resonating and resonant current I_{ls} flows through L_s, D_{s1}, C_s, and S_1. The current through the switch increases resulting in ZCS turn –on of S_1. When the current through the diode is zero, thus diode D_1 is turned OFF under ZCS. In the next instant, the current through L_r changes its direction. L_r, C_r start resonating and resonant current flows through L_r, C_r, and D_2. Thus D_{S2} is turned ON . Diodes D_{S1} and D_{S2} are turned OFF under ZCS condition which is obtained when the current through snubber L_s reaches Zero. The L_r-C_r resonance keeps ON and current through L_r reaches zero. Thus D_2 is turned OFF under ZCS condition

In the next instant, A constant current flows through S_1 which has the value of input current and magnetizing current. Thus S_1 is turned OFF, Then magnetizing current and input current flows through C_s, D_{s2} and C_c. Due to this diode D_1 is turned ON. L_r and C_s start resonating and resonant current flows through Cs, D_{s2}, L_r, D_1 and C_r.

In the next instant diode D_{S1} is turned ON. Ls , Cs , L_r and C_r start resonating and resonant current flows through L_s, D_{S1} ,C_s, C_c, L_r, D_1 under this condition Switch S_1 is in the turn –off state , sum of input current and magnetizing current is being transferred to the secondary. Thus switch S_1 is turned ON.

Voltage mode control is imparted in the presented converter. In voltage mode control, there is a single voltage feedback path in which PWM is performed by comparing the error signal with a constant triangular waveform. In voltage mode control, the difference between the desired and actual output voltages controls the applied voltage across the inductor. Since voltage mode control needs to monitor the output voltage only one feedback path is required, thus simplifies the design of the converter.

2. DESIGN PROCEDURE

A specification for the design is given as follows: output power P_o = 250 W, output voltage V_o = 380, input voltage V_i = 28-38V, and switching frequency f_s = 100KHz.

To obtain Voltage gain of the proposed converter, it is assumed that voltage across C_c is constant and magnetizing current is ignored during switching period T_s. By applying volt-sec balance The gain equation obtained as follows.

$$\frac{V_0}{V_I} = \frac{n}{1-D}$$

The minimum duty cycle for the below resonance operation can be obtained as

$$D_{\min} = \pi f_s \sqrt{L_r C_r}$$

Since resonant inductance L_r should be greater than $3t_{rr1}$, which can be expressed as

$$3t_{rr1} = \frac{(I_i + I_{Lm})L_r}{nV_0\left(1+\frac{1}{2C_r f_s R_0}\right)}$$

From the above equations L_r, C_r are determined by 5μH, 560nF.

Maximum voltage of the resonant capacitor $V_{cr.mini}$ and Maximum capacitor voltage can be $V_{cs,max.}$ are follows.

$$V_{cr,\max} = nV_{cc} + \frac{V_o}{2C_r f_s Ro}$$

$$V_{cs,\max} = \frac{I_i + I_{Lm}}{n}\sqrt{\frac{L_r}{C_s}} + \frac{V_0 - V_{cr,\max}}{n}$$

The $t_{rr2,}$ which can be expresses as the reverse recovery time of diodes D_{S1},D_{S2} .

$$3trr_2 = \frac{V_{cs}(to)L_s \sin(\cos^{-1}(\frac{-v_i}{V_{cs}(t_o)}))}{V_i}\sqrt{\frac{C_s}{L_s}}$$

From the above equations L_s is calculated as 5μH. Similarly C_s can be also calculated as 16nF.

3. SIMULATION RESULTS

The simulation of the converter single switch soft switched isolated Boost DC-DC Converter has been carried. An input voltage of 28V and switching frequency of 100 kHz is chosen and an output of 380V/0.65A is obtained. The duty ratio is equal to 0.653 and the corresponding parameters are listed in Table I.

Table 1

COMPONENTS RATINGS

NO	Components	Ratings
1	Switch S_1	110V
2	Snubber diodes D_{s1}, D_{s2}	94V
3	Output diodes D_1, D_2	380V
4	Filter inductor L_i	100μH
5	Snubber inductor L_s	5μH
6	Snubber capacitor C_s	16nF
7	Clamp capacitor C_c	82μF
8	Resonant Capacitor C_r	560nF

Fig5. Shows the output voltage and output current waveforms. The fig 6 and fig 7 shows the voltage stress of the diodes are approximately 380 V ie, the voltage stress of the semi-conductor devices are equal to the input voltage there by shows the ZCS turn on of the diodes. The fig 8 shows the voltage and current stress of switch which implies ZCS turn ON of the switch and ZVS turn OFF.

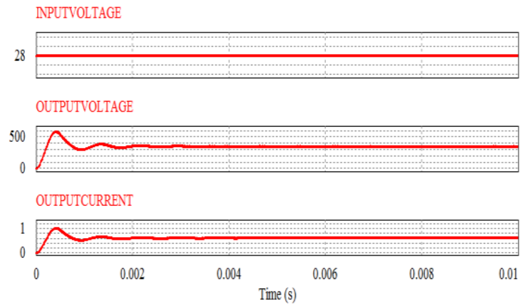

Fig 5. output voltage , input voltage and current

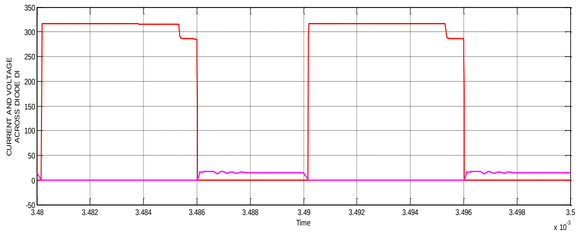

Fig 6. voltage and current across diode D_1

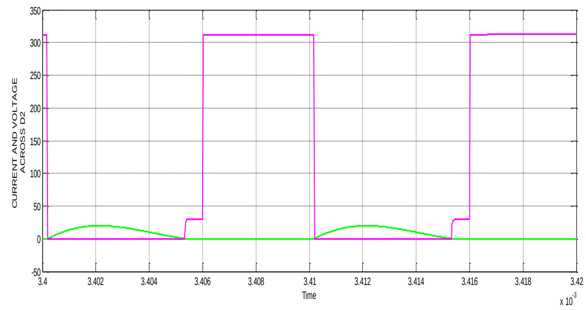

Fig 7. Voltage and current stress in the diode D_2

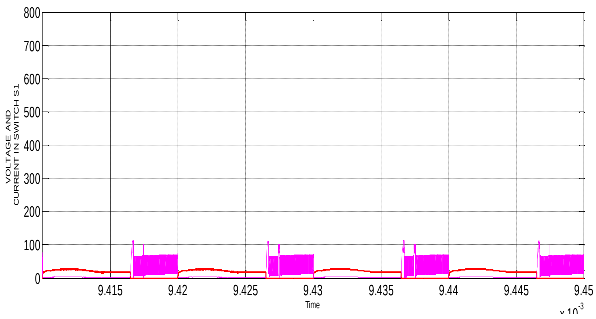

Fig 8 Voltage and current stress across the switch S_1

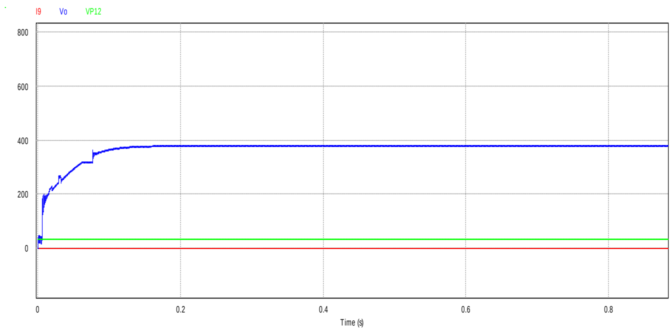

Fig 9 Line regulation at 35 V

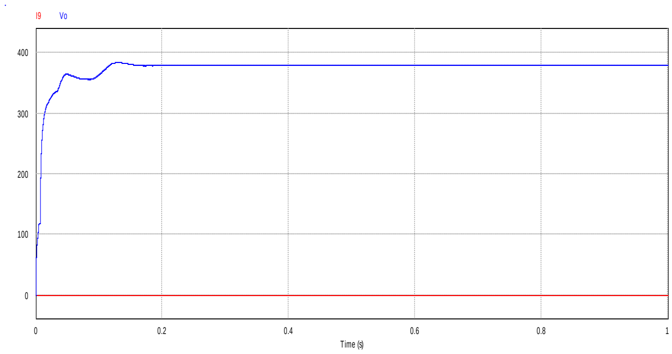

Fig 10 Load regulation at 10000ohm

4. CONCLUSION

A single switch isolated converter is presented for step up applications. In the presented voltage mode control topology, the actual output voltage is compared to the desired output voltage and the difference (error) is used to adjust the PWM duty cycle to control the voltage across the inductor. The main advantages of the converter includes 1) ZCS turn on and ZVS turn off of switch. 2) ZVS turn off of diodes regardless of voltage and load variations 3) Low rated lossless snubber is used for reducing magnetizing current. Converter is validated through MATLAB simulations

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