Soft switched DC-DC converter

To cite this article: K Subramanian *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **263** 052008

IOP Conf. Series: Materials Science and Engineering **263** (2017) 052008 doi:10.1088/1757-899X/263/5/052008

Soft switched DC-DC converter

K Subramanian[1], K V N Kavitha[2] and K Saravanan[2]

[1] School of Electrical Engineering, VIT University, Vellore - 632014, Tamil Nadu, India

[2] School of Electronics Engineering, VIT University, Vellore - 632014, Tamil Nadu, India

E-mail: kvnkavitha@yahoo.co.in

Abstract. A soft switched single switch isolated dc-dc conveys proposed in this paper. This converter works on the principle of zero current switching (zcs) and zero voltage switching (zvs). The circuit comprises lossless snubber with low rating. The switch works on zcs during turn on and zvs during turnoff. The diodes are based on zcs turn on and turnoff conditions. This paper presents the concept of soft switching and its applications to dc-dc converter. The losses due to soft switching and hard switching are compared.

1. Introduction

In recent years soft switched isolated step up dc-dc converters have undergone a vigorous development. It is being used in enumerous application such as photo voltaic systems, fuel cell systems, vehicle inverters etc., [1-2] This present converter is the advancement of many older topologies. Initially current fed isolated converter was used for step-up applications. This was of two types. They are passive clamped and active clamped. The drawback in passive clamped was that considerable power loss in the snubber due to hard switching of main switch. This drawback was overcome by active clamped converter [2]. This used zvs turn on of switches which clamps the voltage spikes caused by the leakage inductance of the transformer[3]. But still the drawback in it was it required more number of switches and driver circuits for gate. The next topology was Z source converter and flyback converter[4]. But the switches in these topologies were hard switched both during turn on and turn off. Overcoming this disadvantage, isolated dc-dc converter with two switches was introduced, Turn on was based on zvs but turnoff was based on hard switching. Then fly back converter evolved which involved zcs turn on and during turn off it remained hard switched[5]. Finally it ended in the proposed converter here.

The converter combines both zcs turn on and zvs turn off of switches, zcs turn on and turn off of diodes, a snubber with low power rating and transformer of low power density. All these features make it possible to achieve high efficiency with reduced losses.

2. Working

The converter consists of a single switch. The transformer separates the supply from the load. On the primary side a lossless snubber is present. It consists of Cs , two diodes, inductor Ls and clamp capacitor Cc . This snubber will help to achieve zvs turn off of switch and clamp the spikes in voltage. The input filter is inductor Li . On the secondary side Lr-Cr resonant circuit will help in achieving zcs turn on and turn off of diodes. Co is the output capacitor to filter out the ripples.

Condition for step up operation

1. DTs < 0.5Tr1 is the above resonance operation.
2. DTs = 0.5Tr1 is the resonance operation.
3. DTs > 0.5Tr1 is the below resonance operation.

For below resonance operation, only the turn off current and diode current are less. Hence, total switching losses are less. So below resonance condition is chosen for step up operation of proposed converter.

Assumptions:

1. The input filter and magnetizing inductances are very large so they can be represented by constant current sources.
2. The output capacitor and clamp capacitors are very large values. So they can be represented by constant voltage source.
3. The voltage across clamp capacitor is same as input voltage.

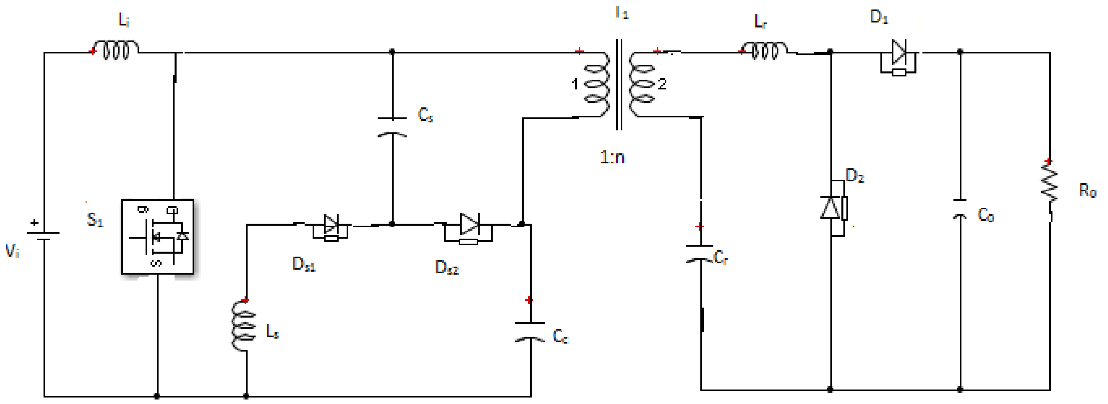


Figure 1. Proposed ZCS-ZVS Converter

3. Modes of Operation:

3.1 Mode1:

In this mode, the switch is turned on at t=0. Then the current iLs flows through Ls, Ds, Cs and S1. Since Li acts as constant current source that current also flows through the switch. During this interval from t0 to t1 the current iLs and voltage Vcs starts decreasing.

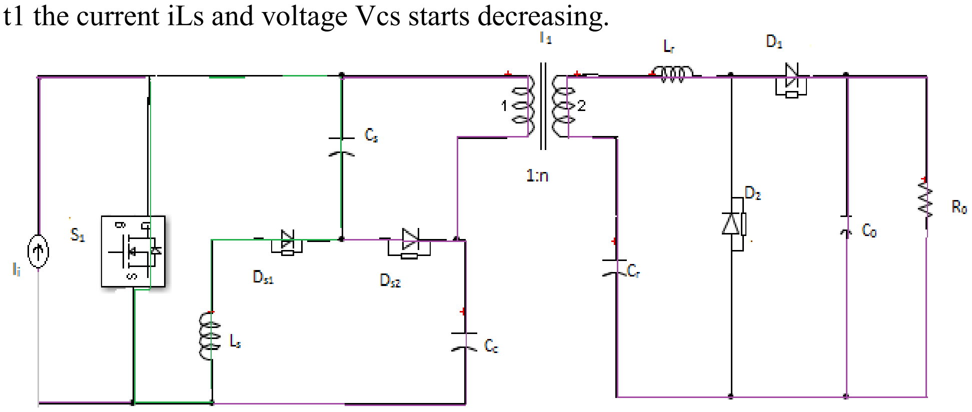


Figure 2. Mode 1 Operation

On the secondary side, iLr flows through Lr, D1, C0 and Cr. At t=t1, iLr will become zero. The diode D1 is turned off. Here the switch is turned on at zcs condition. The loss due to MOSFET's output capacitance is negligible as input is very low. This operation is given in Figure 2.

3.2. Mode 2

The current through iLr now flows through Cr, D2 and Lr. The D2 is turned on at zero current instant. The iLr starts to decrease and Vcr starts to increase. The Cs charges to –Vcc. Ls- Cs resonance ends and this operation model is given in Figure 3.

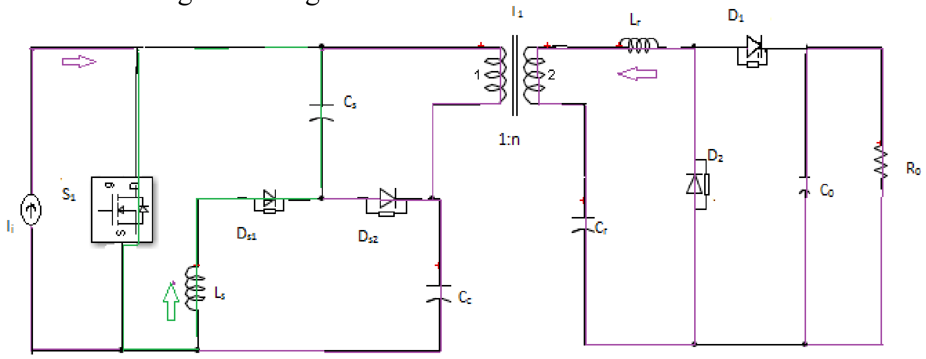


Figure 3. Mode 2 Operation

3.3. Mode 3

In this mode, Ds2 will be turned on and now iLs flows through Ls, Ds1, Ds2 and Cc. The current iLs decreases and reaches zero. Ds1 and Ds2 are turned off under zcs condition.

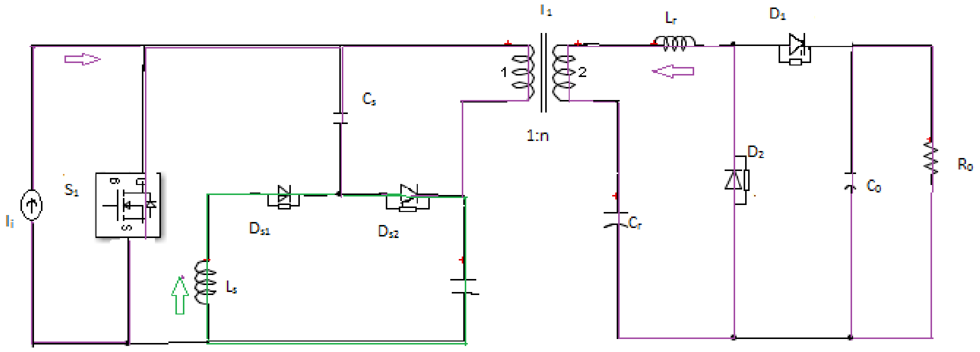


Figure 4. Mode 3 Operation

3.4. Mode 4

On the secondary side, Lr-Cr resonates. The inductor current iLr becomes 0A. The diode D2 is turned off under zcs condition.

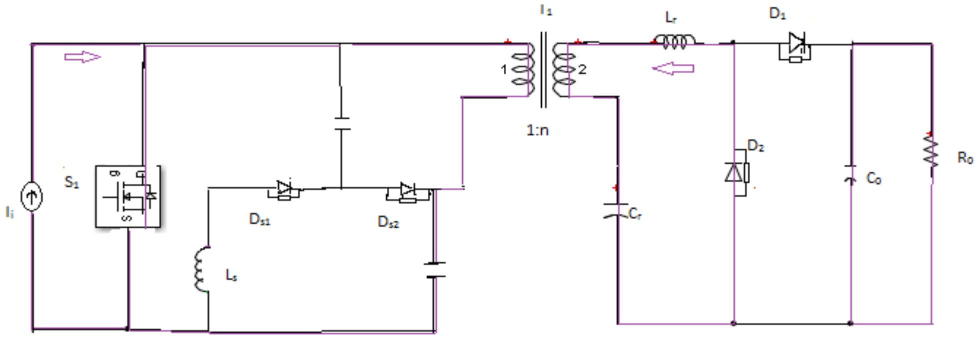


Figure 5. Mode 4 Operation

IOP Conf. Series: Materials Science and Engineering **263** (2017) 052008 doi:10.1088/1757-899X/263/5/052008

3.5. Mode 5
Now, here Ds1 is off so iLs=0.The current which flows through the switch is Ii and ILm which is constant because both the currents are flowing from constant current sources.

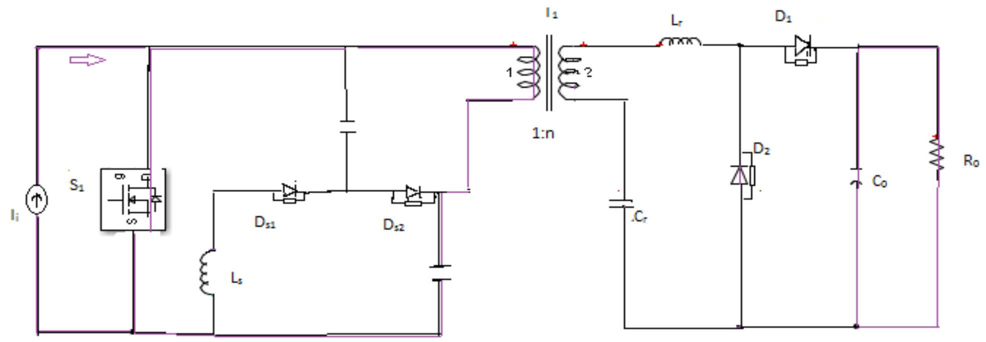


Figure 6. Mode 5 Operation

3.6. Mode 6
In this mode, s1 turned off at zvs condition i.e., Vcs is charged to –Vcc and Cc is charged to +Vcc. The voltage is zero hence voltage across switch is also zero. Now, the current Ii and Ilm flows through Cs , Ds2 and Cc.

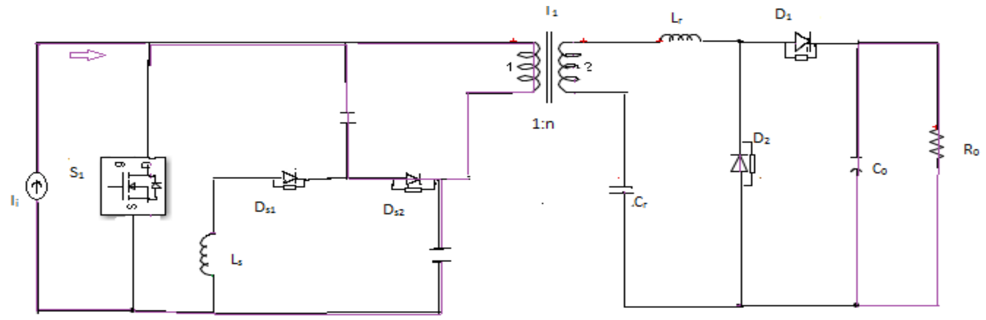


Figure 7. Mode 6 Operation

3.7. Mode 7
In this mode, the resonant current iLr flows through Cs, Ds2, Lr, D1 and Cr as per the equivalent circuit.

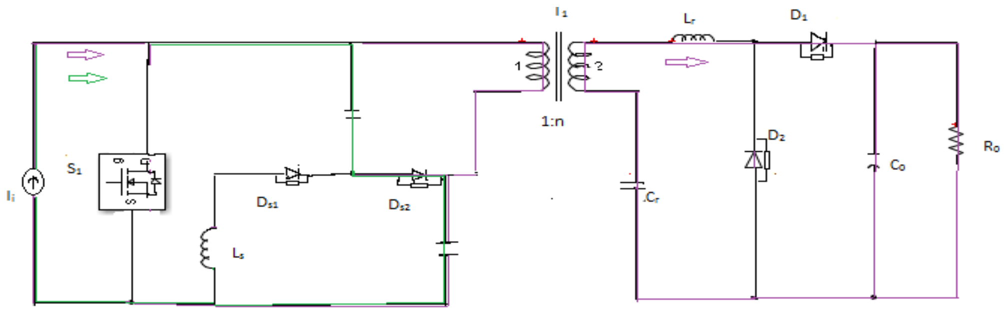


Figure 8. Mode 7 Operation

3.8. Mode 8

In this mode, capacitor Cs charges to Vcc and diode Ds1 is forward biased. Now Ls-Cs, Lr-Cr starts to resonate. Now the current iLr flows through Ls, Ds1, Cs, Cc, Lr, D1 and Cr. After sometime iLs reaches 0A.

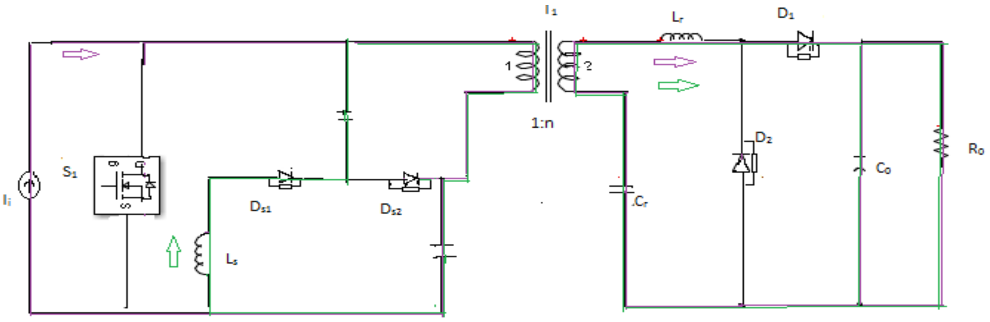


Figure 9. Mode 8 Operation

3.9. Mode 9

Now the current flowing through the primary is transferred to the secondary until the switch S1 is turned on again.

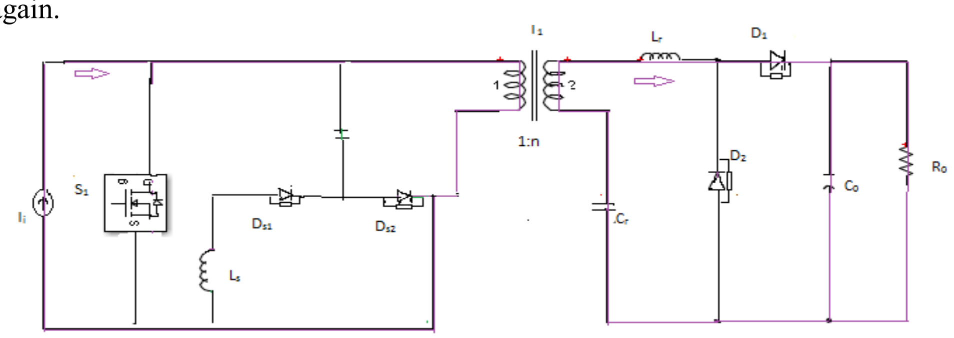


Figure 10. Mode 9 Operation

4. Design Methodology

The design procedure is presented by means of taking an example. Output power P0 = 275W, output voltage V0 = 400V, input voltage Vi = 35V and switching frequency fs = 100kHz.

4.1. Selection of ILs, avg

For minimizing losses due to conduction of snubber componenets and magnetizing current ILs,avg should be as small as possible. Based on conduction losses of switch and snubber components the value of ILs, avg is selected to be around 3% of average input current [2].

$$\text{ILs,avg} = 0.03\ \text{Ii,avg} = 0.27\text{A} \quad (1)$$

4.2. Values of n, Lr and Cr

The voltage gain of the below resonant operation approximately is

$$\frac{V_0}{V_i} \approx \frac{n}{1-D} \quad (2)$$

For the below resonance operation, the minimum duty cycle is

$$Dmin = \pi fs \sqrt{LrCr} \quad (3)$$

For minimizing the reverse recovery diode D1, the inductance Lr should be minimum.

$$3trr1 = \frac{(Ii + ILm)Lr}{nV0\left(1+\frac{1}{2CrfsRo}\right)} \quad (4)$$

Where trr1 is reverse recovery time of diode D1.
The RMS current and turn on voltage is,

$$Is1,rms = \sqrt{DIi} + \frac{n\pi I0}{2\sqrt{2Dmin}} \quad (5)$$

$$Vs1,on = Vs1(t0) = \frac{V0 - VCr,min}{n} + Vcc \quad (6)$$

Choosing the turns ratio of the transformer to be n = 7 and considering the above equations Lr is found to be 7.57µH and Cr is determined as 200.73nF.

4.3. Value of Cs
The value of the snubber capacitor Cs can be found as follows.

$$I_{Ls\,avera} = C_s/T_s\,[v_{Cs}(t_0) + 3V_{cc} - 2V_{Csmax} + 2(V_0 - V_{Crmax})/n + 0.5v_{Cs}(t_0)\sin(\cos^{-1}(-V_{cc}/v_{Cs}(t_0)))\cos^{-1}(-V_{cc}/v_{Cs}(t_0))] \quad (7)$$

Where VCs(t0) is obtained by,

$$VCs(t0) = 2\left(Vcc + \frac{V0 - Vcr,max}{n}\right) - Vcs,max \quad (8)$$

Where Vcs,max is given by the formula,

$$Vcs,max = \left(\frac{Ii+ILm}{n}\right)\sqrt{\frac{Lr}{Cs}} + \frac{V0 - Vcr,max}{n} \quad (9)$$

By using n, Lr,Cr the snubber capacitance is calculated as 17.17nF.

4.4. Value of Ls
Ls can be calculated from the following equation,

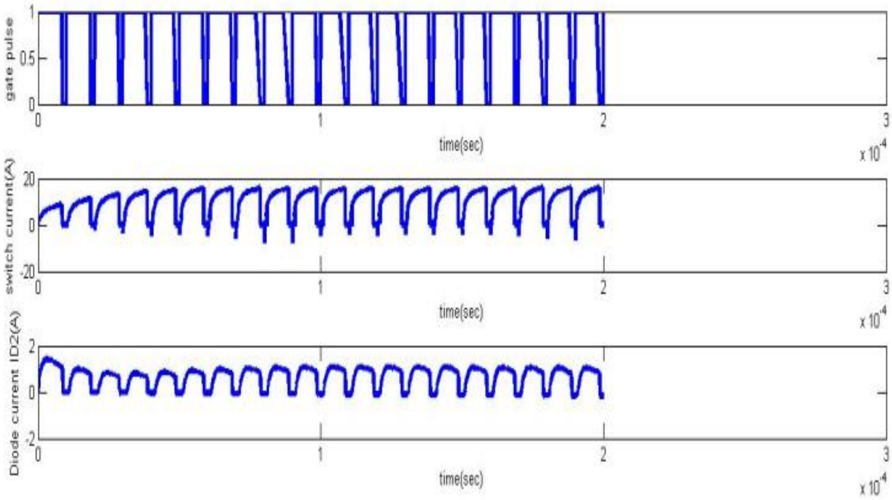
$$3trr = \frac{v_{Cs}(t_0)L_s\sin\left(\cos^{-1}\left(\frac{V_1}{v_{Cs}(t_0)}\right)\right)}{V_1}\sqrt{\frac{C_s}{L_s}} \quad (10)$$

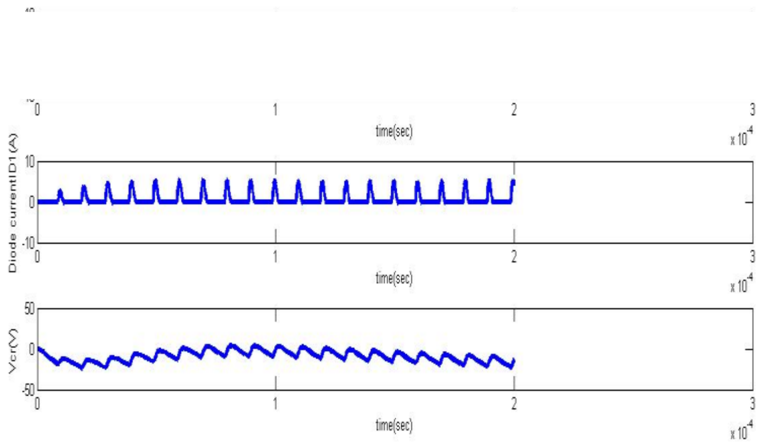
Where, trr1 recovery time of diodes Ds1 and Ds2. Snubber capacitance is calculated as 1.049µH.

IOP Conf. Series: Materials Science and Engineering **263** (2017) 052008 doi:10.1088/1757-899X/263/5/052008

5. Simulation Results

Simulation results are given below.





6. Conclusion

The isolated single switch DC-DC converter is proposed and results are presented in this paper. The conditions of zero current and zero voltage are verified. The efficiency is proved to be increased by soft switching.

References

[1] P S Bimbhra 2012 *Power Electronics* 5th Edition (Khanna Publications New Delhi)
[2] Ned Mohan 2001 Power *Electronics* 2nd Edition (NewYork)
[3] Minjae Kim and Sewan Choi 2015 A Fully Soft Switched Single Switch Isolated DC-DC Converter *IEEE transactions on power electronics* **9 (30**)
[4] D A Ruiz-Caballero and I Barbi 1999 A new fly back-current-fed push-pull DC-DC

converter *IEEE transactions on power electronics* **14(6)** 1056–1064
[5] M Nymand and M A E Andersen 2010 High-efficiency isolated boost DC converter for high-power low-voltage fuel-cell applications *IEEE transactions on industrial electronics* **57 (2)**