Middle-East Journal of Scientific Research 19 (7): 913-918, 2014
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2014.19.7.1476

# Design and Analysis of Resonant Soft Switching Chopper

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**Abstract:** This paper presents a easy way to achieve soft switching in the chopper circuit. A near Zero Voltage switching is realized by adding a simple auxiliary resonant branch to a given chopper circuit. The turn off loss is reduced by connecting snubber capacitors in across the main switches. The design which is carried out is to realize ZVS at the rated load and near ZVS under all other load conditions. In this design on chopper, there is no additional voltage or current stress on the main switches and freewheeling diodes. Also, the auxiliary switch and auxiliary diode is subjected to allowable voltage and current levels. The operating principle and theoretical design analysis has been carried out for this chopper circuit using IGBT as main switches and this has been verified experimentally for 15 volts, 0.75 A at switching frequency of 45 K Hz.Under ZVS condition, the switching loss and dv/dt of the power device can be significantly reduced and the reverse recovery problem of diodes can be avoided as compared with hard-switching case.Keywards: achieve soft switching, chopper circuit, connecting snubber capacitors, current stress, Under ZVS condition, compared with hard-switching case.

**Key words:** Achieve soft switching · Chopper circuit · Connecting snubber capacitors · Current stress · Under ZVS condition · Compared with hard-switching case

## INTRODUCTION

There has been an increasing interest in the soft-switching power conversion technologies in order to overcome the limitations of the hard-switching technologies. Soft- switching converters had many advantages over hard- switching converters. For example, SS converts have lower switching losses, reduce voltage/current stress, reduce EMI noise and allow a greater high switching frequency in high power applications. Despite the advantages of SS converters, its applications have been so far limited due to complexity in the design of SS circuits and difficult in control realization. There has been growing demand for a simple design that provides reliable control in a wide range of operational condition [1].

Several SS techniques have been developed such as the auxiliary resonant snubber inverter(RSI), auxiliary resonant commutated pole inverter (ARCP), the inductor coupled zero voltage transition inverter and the resonant dc link inverter(RDCL). This study found that the RSI can easily be extended to two quadrant chopper applications, but it must use a variable boost current to meet different load current condition. In TQSS converter, there is no switches available for current boosting because it uses diodes in the current return path. Therefore, a simple control timing scheme is given in this converter with the only one auxiliary branch to achieve near zero voltage switching under all load conditions [2].

The ZVS-Soft switching has become more and more popular in the power electronics industry. The main aim of this soft switching is to achieve reduction in switching losses and noises across the switches during their operation present in the chopper circuit. There are many methods to achieve this soft-switching but they are not adapting wide range of load variations and to achieve this, they have to go for variable timing control which is very complicated and it requires number of iterations and tunings. In this paper [3], fixed timing control is used with the auxiliary resonant snubber to achieve ZVS-soft switching chopper.

**Principle of Operation:** The soft switching chopper circuit with auxiliary resonant snubber is for two-quadrant chopper which operate in first and fourth quadrant. The chopper bridge circuit consists of two synchronously

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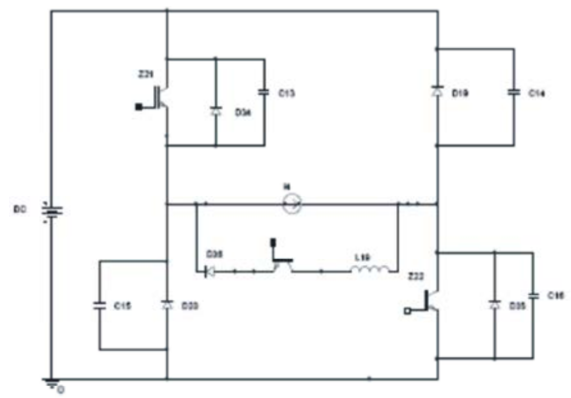


Fig 1.2: The Soft Switching Chopper Circuit

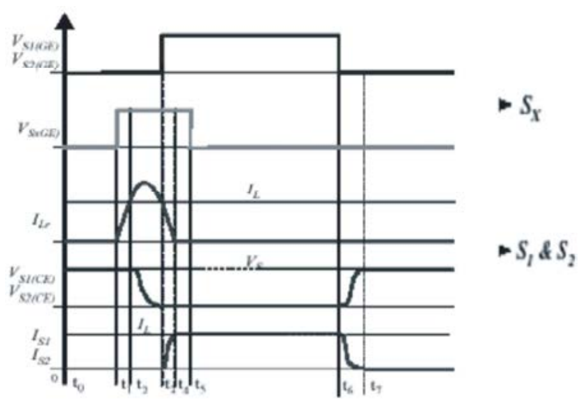



Fig 2.2: Key Waveforms

switching pairs S1 and S2 and two freewheeling diodes D1 and D2 respectively [4-8]. The diodes provides a freewheeling path and a reverse voltage across the load for two quadrant operation.

The loss less snubber capacitors are added across the main devices and the auxiliary branch is added in between the two phase-legs of the chopper circuit. The auxiliary branch consist of one auxiliary switch [4], one fast reverse recovery diode and one resonating inductor. Since the load current flows in uni-direction, only one auxiliary branch is needed to achieve soft switching.

The basic control is to turn on the auxiliary switch Saux, before turning on the main switches S1 and S2. The auxiliary branch takes over the current from the freewheeling diode and resonates with the capacitors in parallel with the main switches. The main switch is turned on while the voltage across the main switches drops to zero voltage after resonance. Although only near zero voltage switching can be achieved with the proposed fixed timing control, the diode reverse recovery and dv/dt problems of the circuit are effectively solved. The proposed circuit diagram and the respective key waveforms are shown in the fig 2.1 and fig.2.2

Initially at time t = to, all the switches are off and load current is freewheeling through D1 and D2 and the modes of operation is as follows,

**Mode A ( to-t1):** Assume that the load current is positive when diode D1 and D2 are conducting and the main switches are in the off state.

**Mode B ( t1-t2 ):** [9-12] By applying the PWM command, the auxiliary switch Saux is made to turn on at t1, then the current through the resonating inductor starts increasing linearly and the current through the diodes starts decreasing linearly. Therefore the auxiliary branch diverts the current from the freewheeling diode gradually.

**Mode C ( t2-t3 ):** After the auxiliary branch current is larger then the load current at t2, then automatically the two diodes D1 and D2 will be turned off naturally. Then all the four snubber capacitors resonates with the auxiliary inductor. The capacitor across the switches discharges with a finite rate to allow the switch voltage drop to zero.

**Mode D ( t3-t4 ):** At the end of the resonant stage, the snubber capacitors are discharged to zero voltage at t3. At this moment, the main switches can be turned on at zero voltage condition by giving the gating pulse by PWM technique. After the main switches are turned on the inductor current decreases linearly due to reverse polarity.

**Mode E ( t4-t5 ):** After the resonant current decreases to zero at t4, the auxiliary switch gate signal can be turned off at t4. The main switches then conduct the load current and the auxiliary switch is turned off under zero current condition.

**Mode F ( t6-t7 ):** The main switches are turned off with loss less snubber capacitors.Once the capacitors C1 and C4 are charged to Vdc and C2 and C3 are discharged to zero, the load current is transferred to diodes D1 and D2 and the circuit operation continues and returns to Mode A.

**Design:** The main aim of the design is to catch the zero- voltage instant and turn on the main switch exactly or nearer to the zero voltage at that time ie, t3. From the

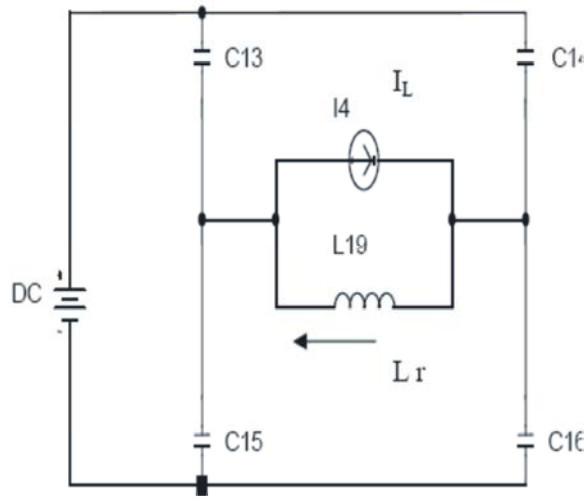



Fig 3.1: Equivalent Circuit of the Resonant Stage

proposed circuit operation, at the end of the resonant stage ( t2-t3 ), the voltage across the main switch should be fully discharged so that the main switches can be turned on under zero voltage. The following design analysis will focus on this particular resonant stage to ensure proper resonant operation. Once the resonant stage is well designed, the components value and control timing can be determined. As long as the resonant inductor current reaches the load current at t2, it will resonant with the capacitors. The equivalent circuit during the resonant period can be shown in the fig 3.1.

To simplify the circuit, C1 is flipped down and C4 is flipped up. Finally, a very simple circuit can be draws as shown in the fig 3.2. In this figure, Cr* and Lr * are the equivalent capacitor and inductor during the resonant stage, ie.,

$$Cr^* = (C1 + C2)(C3 + C4) / (C1 + C2 + C3 + C4)$$

$$Lr^* = Lr$$

In case of C1 = C2 = C3 = C4, we can have Cr * = Cr = C1

Finally the equivalent circuit is a very simple LC resonant tank with zero initial condition. Here we can notice two important points,

- The resonant stage is independent of load current condition.
- The duration of the resonant stage is fixed at half of the natural resonant cycle of the resonant tank Tr.

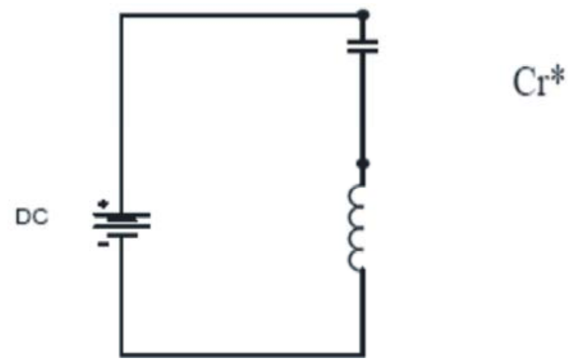



Fig 3.2: Simplified Final Equivalent Circuit

The resonant capacitor voltage and inductor current can be expressed as follows,

$$Vcr(t) = Vdc\,(1-\cos(wt))$$

$$I\,Lr(t) = I\,L + Vdc / Z \sin(wt)$$

Where

$$Z = \sqrt{Lr^*} / Cr^*$$
$$w = 1 / .\sqrt{Lr^*\,Cr^*}$$
$$Tr = 2.\,\Pi\sqrt{Lr^*..Cr^*}$$

The current stress on the auxiliary branch can be obtained as

$$I\max(Z) = I\,load + Vdc / Z$$

The auxiliary switch pre-turn on time T pre is the interval from t1 to t3, which is the sum of inductor charging time T1 and the resonant stage duration T2. A quality factor Q(Z) is defined as the ratio of T2 to T1.

$$T1 = Lr^*\,I\,Load / Vdc$$
$$T2 = .\pi\sqrt{Lr^*\,Cr^*}$$
$$Q(Z) = T2 / T1 = Vdc.\,\Pi / I\,Load.\,Z$$

If the main switch is turned on precisely with T1+T2 delay after the auxiliary switch and the circuit components are loss less, the exact ZVT condition can be achieved. I t should be noted that according to the expression for the T1, it is load current dependent and it is necessary to adjust the pre-turn on time of the auxiliary switch to meet different load current condition if an exact ZVT is desired. To implement this it is necessary to use variable timing control to change Tpre according to the load current condition.

However, such a variable timing control requires current sensing and additional complicated control circuitry. [10]It is desirable to look for a simple solution with fixed timing control but without losing ZVT. It can be done as follows.

- Select the value of Cr and Lr such that T2 >> T1 (or) Q (Z) is large enough with a fixed pre-turn on time, Tpre = T1 (normal) + T2where T1(normal) is the charging time under normal load condition., the near ZVT can then be obtained. Since T2 is much larger than T1, even if the main switch is turned on a little earlier or later due to the load current variation, the voltage will only swing back to a finite amplitude, but very close enough to zero-voltage condition.
- To reduce the peak resonating current so as to reduce the circulating energy, it is desirable to have large Lr and small Cr However, for a wide range of near ZVT operation, it is desirable to have a large Cr and a small Lr so that T2 >> T1 condition is satisfied [11-15]. Therefore, a small tank impedance is desirable in most of the cases and thus the tank impedance Z becomes an important design factor.
- The capacitor value can be selected based upon the dv/dt requirement and turn-off loss test.
- The resonant inductor value can be calculated with the predetermined Z and the pre-turn on time of the auxiliary switch which is optimized at the rated load condition. That is let Tpre = T1 + T2 under the rated load condition. As a result, the worse case happens under no-load and heavily load conditions.

**Theoritically Designed Values of the Circuit:** The theoretical values are obtained as per the formulation is presented below:

- DC Supply voltage Vdc : 15 volts
- Constant Load Current I Load : 0.75 amps
- Resonating Capacitor Cr * : 50nF
- Resonating Inductor Lr* : 10u H
- Resonant Tank impedance Z : 14.142 ohms
- Maximum Current Stress I max : 1.2 amps
- Inductor Charging Time T1 : 0.8 uS
- Resonant stage duration T2 : 2.4 uS
- Quality factor Q (Z) : 3.0
- Pre-turn ON Time Tpre : 3.2 uS
- Auxiliary Switch Turn On Time Taux : 4.0 uS

**LIST OF COMPONENTS:**

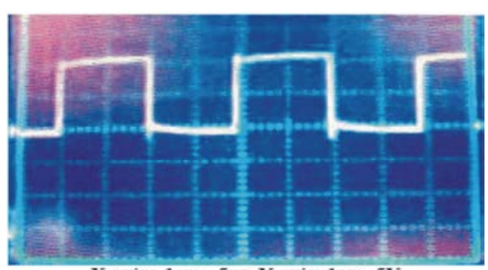
| S.No | Name of the Component | Quantity (Nos) |
|---|---|---|
| 1. | Transformer 230 / 15 V | 1 |
| 2. | Transformer 230 / 5 V | 1 |
| 3. | Bridge Rectifier (IN4007) | 4 |
| 4. | Positive Voltage Regulator(L7815CV) | 2 |
| 5. | Capacitor Filter 4700uF | 2 |
| 6. | Capacitor Filter 1000uF | 2 |
| 7. | IGBT (G4BC20S) | 3 |
| 8. | PWM control IC (TL494CN) | 1 |
| 9. | Fast recovery diode (FR107) | 1 |
| 10. | High and Low Driver IC (IR2110) | 3 |
| 11. | Opto-couplers(6N137) | 3 |
| 12. | Ceramic Capacitance ( 10nF) | 20 |
| 13. | Load Inductance | 4 |
| 14. | Auxiliary Inductance (10uH) | 1 |

**Practical Output Values:**

- DC Supply voltage Vdc : 15 volts
- Constant Load Current I Load : 0.65 amps
- Resonating Capacitor Cr * : 50nF
- Resonating Inductor Lr* : 10u H
- Resonant Tank impedance Z : 14.142 ohms
- Maximum Current Stress I max : 1.0 amps
- Inductor Charging Time T1 : 0.6 us
- Resonant stage duration T2 : 2.6 us
- Quality factor Q (Z) : 4.33
- Pre-turn ON Time Tpre : 3.2 us
- Auxiliary Switch Turn On Time Taux : 3.8 us

**Practical Output Waveforms:**

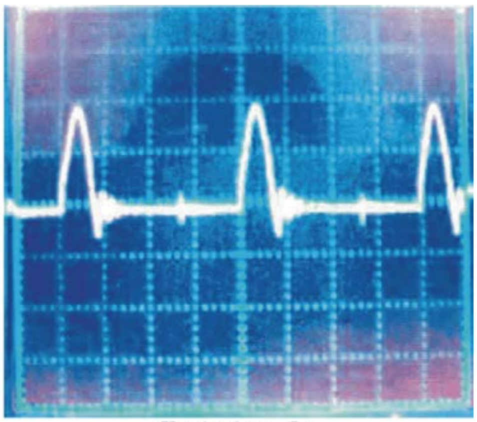
**Pulse to the Main Switch:** This is the gate pulse generated for the switches (IGBT) used in the project. It is generated at a frequency of 45 KHz with a duty cycle of 52%. This has been generated using Switched mode pulse width modulated IC ie. TL494CN and given to the gate terminal of the switches through the driver Circuit. In this project we use IR2110 IC as the high and low side driver.



X-axis : 1cm =5us, Y-axis: 1cm=5V

Gating Pulse of the Main IGBT

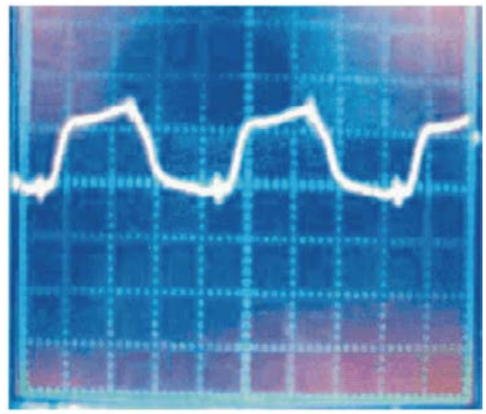
**Current Through the Resonating Inductor:** This is the resonating current through the inductor present in the auxiliary branch.The maximum value of current through the auxiliary branch is noted as 1.0 A. The inductor charging time to reach the load current is noted as T1 = 0.6us and the resonant duration is noted as T2 = 2.6 us. When the resonating current reaches zero, it has got few oscillations and its tolerable when compared to hard switching and it has been much reduced in this project.



X-axis : 1cm = 5us
Y-axis : 1cm =0.5 V

Current Through the Resonating Inductor

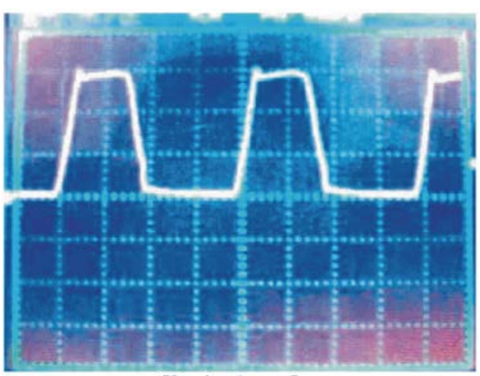
**Current Through the Main Switches:** This is the current waveform obtained throughthe main switches. It is found from the output that during switching on and off of the switches, very small current spikes are noted and it does not affect the main switches when compared to the hard switching so the size of the heat sink is reduced and switching losses are reduced.. The value of current is 0.65 A



X-axis : 1cm= 5us
Y-axis : 1cm = 0.5 V

Current Through the Main Switches

**Voltages Across the Main Switches:** This is the voltage waveform obtained across the switches of the circuit. It is found from the output that during the switch off condition, a very small voltage spike is noted and it is comparably very less when compared with the hard switching. Similarly, it is found that during switching on condition, the voltage across the goes to zero with out any negative spikes due to the presence of snubber circuit across the switches. Therefore the voltage stress on the switches are reduced.



X-axis : 1cm= 5us
Y-axis : 1cm = 5V

Voltage Across the Main Switches

**Complete Experimental Setup of the Preject:**

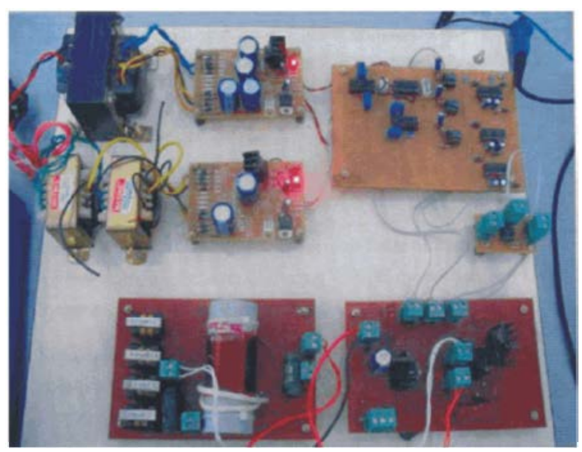


Fig 4.8: Experimental Setup

Thus the theoretical values are compared with the practical values of the proposed circuit.

| Mode | Load Current | Max. Current | 2T1 + T2 |
|---|---|---|---|
| Theoretical | 0.75 A | 1.2 A | 4.0us |
| Practical | 0.5 A | 1.0 A | 3.8us |

## CONCLUSION

In the present paper, the design criteria of a ZVS soft switching chopper is presented with verification both theoretical and practically. In this paper, a soft switching converter topology with a simple resonant snubber circuit is given and it is verified fully for working conditions with an inductive load. The proposed simple fixed timing control scheme is proved to effective to achieve ZVS for a wide range of load conditions. The propose converter achieved in reducing the switching losses during turn ON and OFF conditions and also the turn ON noise. Apart from this considerable reduction in voltage and current spike is achieved across the main switches. So the heat sink temperature rise is reduced. The result shows that the proposed converter not only saved weight and space but also reduced the cost of the converter while improving the performance.

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