A New Soft Switching ZCS and ZVS High Frequency Boost Converter with an HI-Bridge Auxiliary Resonant Circuit to Drive a BLDC Motor

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Abstract- This paper presents a novel low-cost, highly efficient, reliable and compact motor drive topology for residential and commercial application. The Brushless DC (BLDC) motor is a simple robust machine which has found application over a wide power and speed of ranges in different shapes and geometry. This paper briefly reviews the fundamentals behind the motor and also the different types of BLDC motors with different geometries and then presents a new configuration for BLDC motor/generator, which does not use a permanent magnet in the rotor. A new soft-switching boost converter is proposed in this paper. The conventional boost converter generates switching losses at turn ON and OFF, and this causes a reduction in the whole system's efficiency. The proposed boost converter utilizes a soft- switching method using an auxiliary circuit with a resonant inductor and capacitor, auxiliary switch, and diodes. Therefore, the proposed soft-switching boost converter reduces switching losses more than the conventional hard-switching converter. The efficiency, which is about 91% in hard switching, increases to about 96% in the proposed soft-switching converter. In this paper, the performance of the proposed soft-switching boost converter is verified through the theoretical analysis, simulation, and experimental results.

Index Terms- Hybrid BLDC Motor, Auxiliary resonant circuit, boost converter, soft-switching boost converter, zero-current switching (ZCS), zero-voltage switching (ZVS).

I. INTRODUCTION

This paper discusses about the usage of Soft Switching Boost Converter to power up the vehicle or BLDC Motor. In order to achieve the required voltage, the Soft Switching Boost Converter are boost the power and voltage at the desire level. Thus to make it cost effective; power converters and batteries are been used. The electrical charge is consolidated from the PV panel and directed to the output terminals to produce low voltage (Direct Current). The charge controllers direct this power acquired from the solar panel to the batteries. According to the state of the battery, the charging is done, so as to avoid overcharging and deep discharge. The voltage is then boosted up using the boost power converter, ultimately running the BLDC motor which is used as the drive motor for our vehicle application. In the course work, the characteristic features of the components; input dc either solar PV, battery, power Boost converter and BLDC motor required for the vehicle application were studied in real time and also were modelled.

In a conventional boost converter, the duty ratio increases as the output to input voltage ratio increases. But applications like HEV and EV require high step-up ratio and high efficiency power conversion. In such applications it becomes a major challenge to maintain high efficiency using conventional boost converter due to the required large duty ratio. For the high output voltage, the boost switch has to block a large voltage. At the same time for high power application like electric vehicle, the low input voltage causes large input current too low. Also with low duty cycle operation the rms ripple current through the boost converter diode and output capacitor becomes very high. These increase the losses enormously.

A new soft-switching boost converter with an auxiliary switch and resonant circuit is proposed in this paper. The resonant circuit consists of a resonant inductor, two resonant capacitors, two diodes, and an auxiliary switch. The resonant capacitor is discharged before the main switch is turned ON and the cur- rent flows through the body diode. These resonant components make a partial resonant path for the main switch to perform soft switching under the zero-voltage condition using the resonant circuit. Compared with other soft-switching converters, the proposed converter improves the whole system's efficiency by reducing switching losses better than other converters at the same frequency. The efficiency is improved due to reduction in switching losses. MATLAB simulations are performed to verify the theoretical analysis.

II. OVERVIEW OF BLDC MOTOR

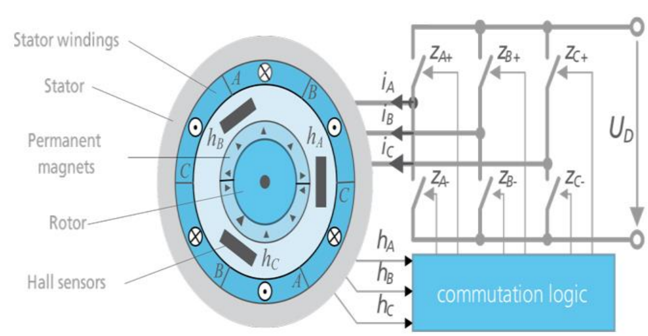


Fig-1. Input inverting stage of BLDC motor.

The control of PMBLDC motors can be accomplished by various control techniques using conventional six pulse inverters which can be classified in two broad categories as voltage source inverter (VSI) and current source inverter (CSI) based topologies. The controllers can further be divided on the basis of solid state switches and control strategies. The BLDCM needs rotor-position sensing only at the commutation points, e.g., every 60°electrical in the three-phases; therefore, a comparatively simple controller is required for commutation and current control. The commutation sequence is generated by the controller according to the rotor position which is sensed using Hall sensors, resolvers or optical encoders. These sensors increase the cost and the size of the motor and a special mechanical arrangement is required for mounting the sensors.

The components are DC-AC inverter, DC-DC converter, battery, and electric BLDC motor. DC-AC inverters supply voltage to the electric motor from the battery and also supply utility loads such as air conditioning and AC power outlet. DC-DC converters supply voltage to various vehicular loads set to operate at different voltages. In the near future, high power DC-DC converters will be needed for EVs since the vehicular power requirements are continuously increasing due to which the present day 12- V/14-V electrical system will be replaced by 42-V/300-V architecture. DC-DC converters are well developed for low and medium power applications, whereas development of highly efficient and cost effective high power DC-DC converters for vehicular applications is in continuous progress. This is partly due to the stringent Electromagnetic Interference (EMI) standards and also due to temperature related issues. The boost dc voltage is the input of the BLDC motor.

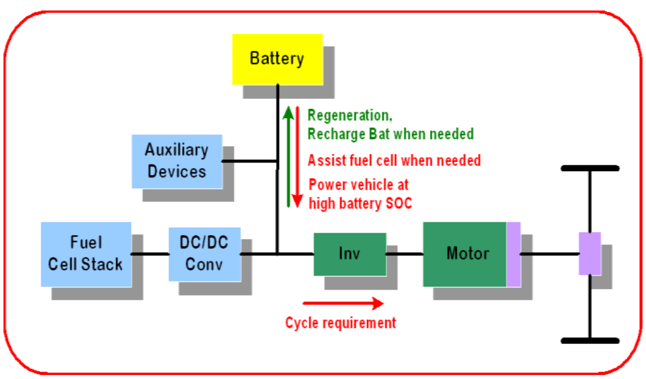


Fig-2. Driving process of high voltage BLDC motor.

III. Hard Switching Vs Soft Switching.

Recently, switch-mode power supplies have become smaller and lighter due to higher switching frequency. However, higher switching frequency causes lots of periodic losses at turn ON and turn OFF, resulting in increasing losses of whole system.

Semiconductors utilised in Static Power Converters operate in the switching mode to maximise efficiency. Switching frequencies vary from 50 Hz in a SCR based AC-DC Phase Angle Controller to over 1.0 MHz in a MOSFET based power supply. The switching or dynamic behaviour of Power Semiconductor devices thus attracts attention specially for the faster ones for a number of reasons: optimum drive, power dissipation, EMI/RFI issues and switching-aid- networks.

Present day fast converters operate at much higher switching frequencies chiefly to reduce weight and size of the filter components. As a consequence, switching losses now tend to predominate, causing the junction temperatures to rise. Special techniques are employed to obtain clean turn-on and turn-off of the devices. This, along with optimal control strategies and improved evacuation of the heat generated, permit utilisation of the devices with a minimum of deration.

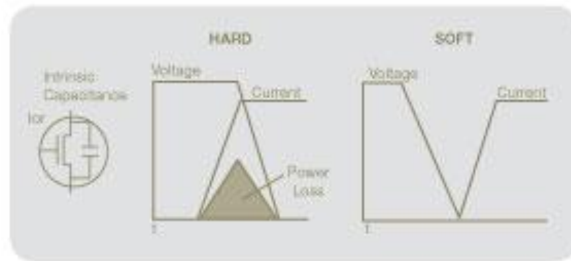


Fig-3. Hard and Soft Switching Waveform

IV. METHODS OF SOFT SWITCHING.

A. *Design a High Frequency PWM Subsystem.*

The carrier waveform used is Saw tooth waveform instead of Triangular waveform. When the reference value is more than the carrier waveform the output PWM signal is HIGH. The switching turn ON points is determined by the saw tooth waveform used.

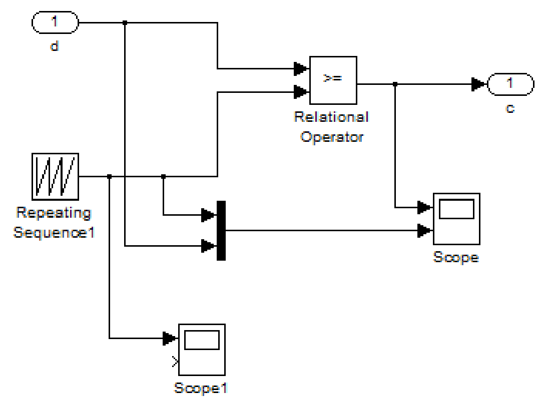
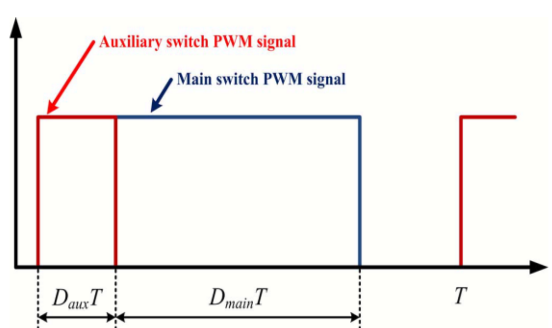


Fig-4. PWM subsystem.

Fig-5. PWM signals of the main and auxiliary switch



The proposed Boost Converter has two switches namely main switch and auxiliary switch. The main switch has a duty ratio of 0.61 while that of auxiliary switch is 0.21. The main switch duty ratio determines the average output voltage. The function of auxiliary switch is to enable the main switch to operate soft switching. First the auxiliary switch is turned ON then the main switch in turned ON after some time delay. The resonant loop of the resonant inductor (Lr) and resonant capacitor (Cr) is completed by the turning ON of the auxiliary switch. By the help of resonance the auxiliary switch is made to operate at ZCS. As the snubber capacitor is discharged the current of the resonant loop flows through the anti-parallel diode of the main switch. By turning ON the main switch the ZVS is assured. As the resonant capacitor is fully discharged the auxiliary switch is turned OFF.

The PWM signal of the main switch is given some delay compared to auxiliary switch. The phase difference is obtained by delaying the carrier waveform. The main switch is turned ON while the auxiliary switch is still in the ON state.

B. Configuration of the proposed HI-Bridge Boost converter.

The proposed converter is shown in Fig. 6. The main switch (IGBT) and the auxiliary switch (IGBT1) of the proposed circuit enable soft switching through an auxiliary switching block, consisting of an auxiliary switch, two resonant capacitors (Cr and Cr2), a resonant inductor (Lr), and two diodes (D1 and D2).

The following assumptions are made
1) All switching devices and passive elements are ideal.
2) The input voltage (Vin) is constant.
3) The output voltage (Vo) is constant. (Output capacitor Co is large enough).
4) The recovery time of all diodes is ignored.

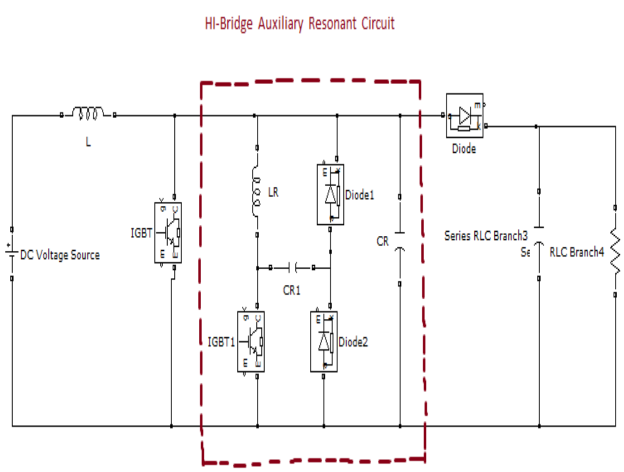


Fig-6. Schematic of the proposed soft-switching boost converter.

The main switch and auxiliary switch.

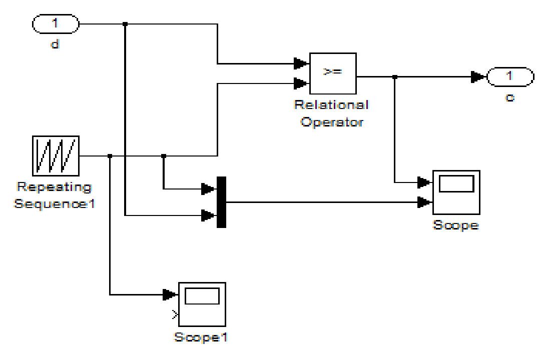
There are two switches in this paper. One is the main switch deal with a duty ratio and the other one is the auxiliary switch enables the main switch to operate with a soft switching. The carrier, reference and pulse width modulation(PWM) waveforms of the main switch and auxiliary switch are illustrated in Fig. 4. After the auxiliary switch is turned on, the main switch is turned on. If the auxiliary switch is turned on, the resonant loop of the resonant inductor(Lr) and resonant capacitor(Cr) is made. The auxiliary switch operates with ZCS using the resonance. The current of the resonant loop flows across the anti-parallel diode of the main switch after the snubber capacitor is discharged. Thus, ZVS area is guaranteed by turning on the auxiliary switch. A point the auxiliary switch is turned off is the time the energy of the resonant capacitor(Cr) is fully discharged. The main switch set a voltage gain. A transfer function of the proposed soft switching boost converter is same to the conventional boost converter and that is given by the equation (1) .

$$Gv = (Vout/Vin) = 1/(1-D) \qquad \text{----------} \qquad (1)$$

Where Gv is a voltage gain and D is a duty ratio. The PWM has to be made with a delay between the main switch and auxiliary switch. A phase difference can be obtained by delaying the carrier waveform. The main switch always has to be turned on during the auxiliary switch turns on. Points which switches turn on at have to be fixed to realize a soft switching without resonance failure. A Sawtooth waveform is used as a carrier waveform instead of a triangular one. If a reference value is upper than a carrier one, the PWM output signal becomes high. Thus, switching turn on points can be fixed by using the sawtooth waveform.

V. SIMULATION AND OUTPUT.

A. PWM subsystem output waveform.



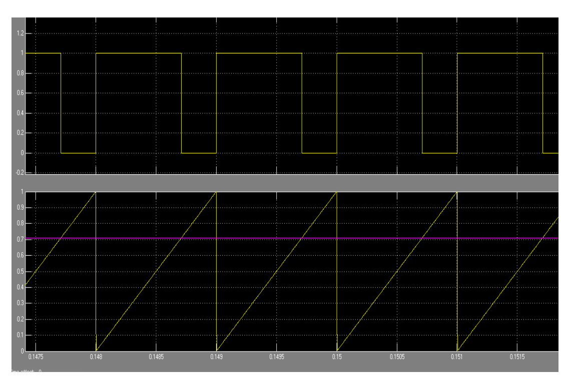


Fig-7. PWM subsystem and output waveform in MATLAB.

B. Simulation of HI-bridge soft-switching boost converter output waveform.

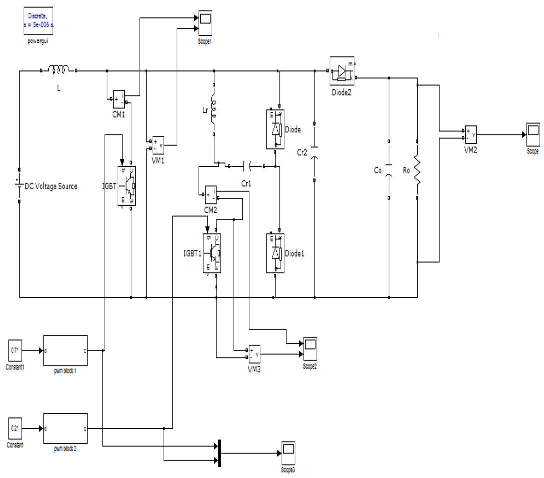


Fig-8. Simulink model of HI-bridge boost converter using auxiliary boost converter.

The above proposed boost converter with auxiliary resonant circuit is simulated in MATLAB-SIMULINK. The values of the circuit parameters are given below:

TABLE-1
KEY DATA

Parameters	Values
Input voltage (Vin)	130-170[V]
Output voltage (Vo)	400[V]
Switching Freq.(fsw)	30[]KHz]
Resonant Cap. (Cr)	3.3[nF]
Resonant Cap. (Cr2)	30[nF]
Resonant Ind. (Lr)	20[µH]
Main Inductor (L1)	560[µH]

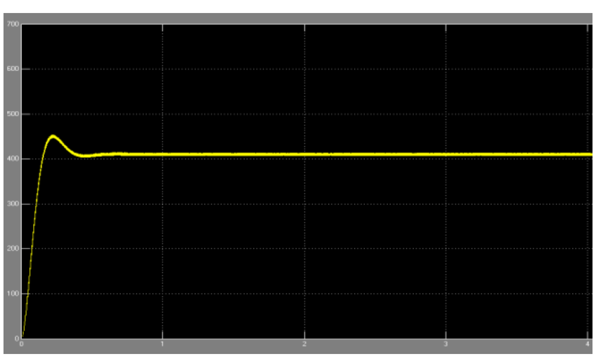


Fig-9. Output Voltage Vs Time Waveform.

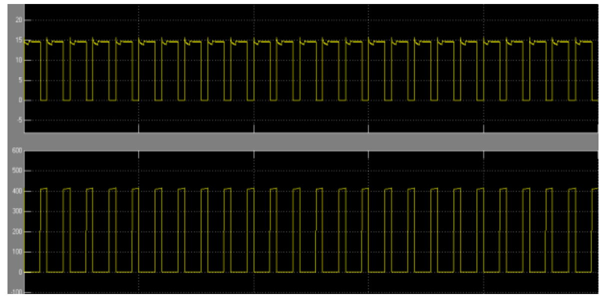


Fig-10. Main switch Current and Voltage

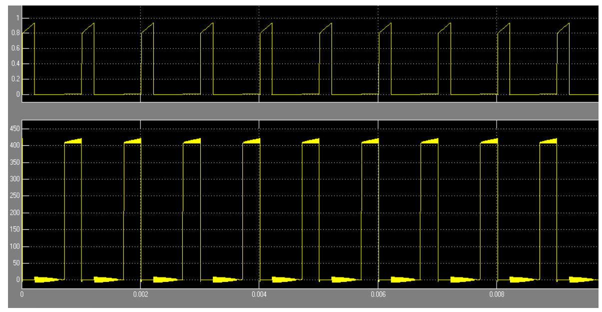


Fig-11. Auxiliary switch Current and Voltage

VI. DESIGN PROCEDURE

The following design procedure is based on the soft-switching turn-ON and turn-OFF requirements of the main switch, the main diode, and the auxiliary switch.

A. Resonant Capacitor (Cr)

The resonant capacitor (Cr) is selected to allow ZVS of the main switch. The charging time of the resonant capacitor (Cr) must be longer for ZVS of the main switch. Thus, for the resonant capacitor (Cr), it is more than ten times the output capacitance of the main switch.

Assume that the maximum current of the resonant inductor is ILmax, and the sum of the two inductor currents is the charging current of the resonant capacitor (Cr). In this case, the minimum resonant capacitor (Cr) is equal to 20 times the output capacitance of the main switch.

B. Parameters Design

D = 1- (Vin (min) * η)/ Vout
D= Duty Cycle.
Vin (min) = Minimum input voltage.
Vout = Desired output voltage.
Ƞ = Efficiency of Converter
L = (Vin/ΔIL) * (Vout – Vin) * (1/Vout) * (1/fs)
L = Inductance of main Inductor.
fs = Switching frequency.
ΔIL = Estimated Inductor ripple current.
ΔIL = (0.2 - 0.4) * Iout (max) * (Vout/Vin).
Iout (max) = Maximum output current.
Cout (min) = (Iout (max)/fs) * D/ΔVout.
Cout (min) = Minimum output Capacitance.

VII. SIMULATION RESULTS

The simulation parameters are shown in Table II. This paper simulated the proposed converter by MATLAB software. The simulation was performed under a 30-kHz switching frequency and a 130∼170-V input voltage. Figs. 10 and 11show the simulation waveforms of the main and auxiliary switch voltage and current, respectively. Before the main switch is turned ON, the body diode is turned ON. As a result, the main switch enables zero-voltage switching and the auxiliary switch performs soft switching. The resonant capacitor (Cr2) is charged and discharged in the manner of a sine wave- form. At an input voltage of 130∼170 V, the output voltage is adjusted to 400 V.

VIII. CONCLUSION

In this paper, a new soft-switching boost converter has been proposed that uses an auxiliary switch and resonant circuit. The main switch performs soft switching under the zero-voltage condition by using a resonant capacitor and inductor, as does the auxiliary switch. The efficiency, which is about 91% in hard switching, increases to about 96% in the proposed soft-switching converter.

A comparative study of CSI fed BLDC motor using Boost Converter are presented in this paper. Both the strategy significantly reduces the switching loss and cost thereby increasing the speed and efficiency of the BLDC motor drive system. The study is verified with the simulation results using MATLAB software. The results of the simulation model gives help in building hardware with expected results. The simulation saves time and manpower in making hardware models at initial stages and reduces the costing of research work.

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