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Soft Switching Isolated Bidirectional DC-DC Converter Associated With Flyback and Passive Snubbers

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Abstract – An Isolated bidirectional full bridge DC–DC converter used for battery charging and discharging with soft switching features is proposed in this paper. The proposed converter is outfitted with an active fly back snubber and passive capacitor diode snubbers configured such that it can decrease voltage and current spikes and diminish voltage and current stresses. With the switching frequency of 25KHz the proposed bidirectional converter for soft switching is simulated using MATLAB/SIMULINK software. The hardware setup with low voltages is proposed to exhibit step up and step down conversion. The corresponding results are obtained and discussed.

Keywords— Soft Switching, Active Snubber, Battery Charging/Discharging.

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INTRODUCTION

Bidirectional DC-DC converters are applicable in battery chargers and dischargers, uninterruptible power supply, hybrid electric vehicle driving systems etc. [1]-[4]. These converters are used to interface the energy storing device with the renewable sources as solar cell, fuel cell etc. [5]-[6]. During switching in the converters the component stress, electromagnetic interference (EMI), switching losses are increased due to MOSFET drain–source voltage and diode-reverse-recovery current, resulting in low reliability [7]. A more extreme issue which causes high voltage spike during switching transition is because of the leakage inductance of the isolation transformer.

A conceivable arrangement is to pre-energize the leakage inductance to increase its current level till that of the current fed inductor. This can reduce their current distinction and in turn diminish voltage spikes. On the other hand, to match these two currents it is quite difficult to tune the switching timing. Thus, an active or passive snubber circuits are needed. An ordinary passive methodology is employing a resistor–capacitor–diode snubber to clamp the voltage, and the energy obtained by the buffer capacitor is being dissipated on the resistor, this gives low efficiency.

A simple active clamping circuit was proposed as shown in Fig.1. Here, the resonant current will conduct through the main switches, thus increases the current stress significantly.

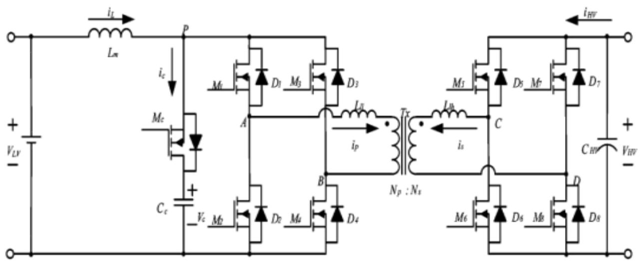

Fig.1. Isolated Bidirectional full bridge DC–DC converter with an active clamp snubber

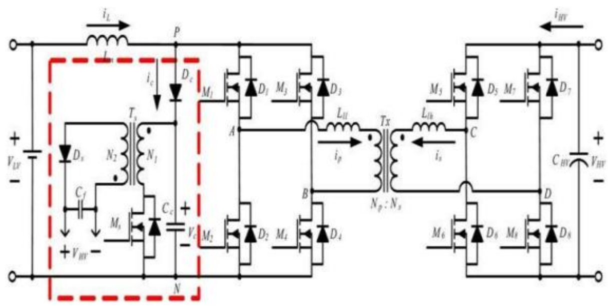

Fig.2. Isolated Bidirectional full bridge DC–DC converter with a flyback snubber

An isolated bidirectional converter associated with a flyback snubber was hence proposed [9], which is shown in Fig.2. The absorbed energy stored in the clamping capacitor CC is recycled by the flyback snubber, while without making the current to flow through the main switches. The voltage is also clamped to the desired value slightly greater than low side of transformer by the flyback snubber. As the snubber current does not conducts through the main switches, under heavy-load conditions current stress can be widely decreased. In these cases, the switches on the low and high sides are worked with hard switching turnoff. This results in high-voltage spikes.

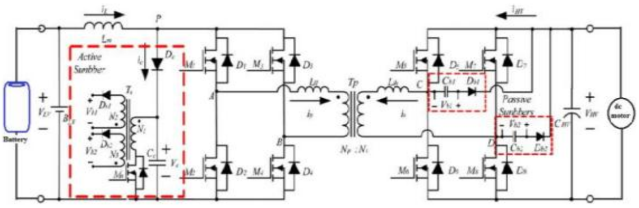

Fig.3.Proposed soft-switching isolated bidirectional full-bridge converter with an active and passive capacitor–diode snubbers.

The proposed isolated bidirectional full bridge converter comprising with soft switching is shown Fig.3. The battery is made to charge and discharge as per the power flow in the converter. To achieve soft switching features the isolated bidirectional converter consists of active flyback snubber on low voltage side and two passive capacitor diode snubbers [8] on high voltage side. The two passive capacitor–diode snubbers are proposed to supplement the active flyback snubber The MOSFET switches arranged as current fed switch bridge and voltage fed switch bridge on both low voltage and high voltage sides respectively.

II. CONFIGURATION AND OPERATION

The proposed converter is configured with Inductor Lm which is on the low voltage side does output filtering when power flows from high voltage side to low voltage side. It helps for boosting the voltage when the power flows from low voltage side to high voltage side. Diode Dc and snubber capacitor Cc are utilized to absorb the current distinction between current fed inductor current iL and leakage inductance current iP of the isolation transformer Tp during switching commutation. The switch Ms is made to operate with flyback snubber to transfer the energy stored to buffer capacitors Cb1 and Cb2 from the snubber capacitor Cc , and the voltage across the Cc will drop to zero. So the voltage stresses of switches M1 to M4 can be reduced to lower level, accomplishing near ZCS turn off.

The proposed converter configuration can limit the voltage spike caused by the current distinction between the current fed inductor and leakage inductance currents and can also mitigate the drawbacks of high voltage and high current stresses imposed on the main switches during turn off and turn on transitions. Moreover, it can accomplish close ZCS and ZVS for the switches which are on both sides of the transformer.

III. MODES OF CONVERSION

The converter can be operated with two types of conversions:

- *Step up conversion*
- *Step down conversion*

In the step-up conversion the switches M1 – M4 which are on low voltage side are controlled, and the corresponding body diodes of switches M5 -M8 which are on high voltage side serve as a rectifier. In the step down conversion, the switches M5 –M8 are being controlled, and the corresponding body diodes of switches M1 - M4 operate as a rectifier.

A. Step up Conversion

In the step-up conversion the switches M1 – M4 are worked as a boost converter, where switch sets (M1, M2) and (M3, M4) operate to store energy in inductance Lm. On the high voltage side the body diodes D5 - D8 of switches M5 - M8 present on high voltage side will lead the transfer of power to the CHV. At the point when switch sets are switched to (M2, M3) or (M1, M4), then the current difference iC (iC= iL − iP) will make capacitor CC to charge until iP ascends to iL, and clamps the capacitor voltage VC to VHV ·(NP /NS), accomplishing near ZCS turnoff for M4 or M2. Meanwhile, the high voltage side current iS will be conducting through one of the two passive capacitor diode snubbers, and before the diode D5 or D7 conducts, either Cb2 or Cb1 will be fully discharged. As the switch set (M2, M3) or (M1, M4) is switched back to (M3, M4) and (M1, M2), ZCS turn on feature can be achieved in switch M2 or M4 due to leakage inductance Lll constraining the di/dt of reverse recovery current of diodes which are on high voltage side. Simultaneously the discharge of the snubber capacitor CC and transfer of the stored energy to the buffer capacitors Cb1 and Cb2 from CC is performed by the flyback snubber. As the energy is absorbed in CC, hence no spike current flow through switches M1 - M4, which can decrease the current stresses drastically when there is a significance of a leakage inductance of the isolation transformer.

B. Step down Conversion

In the inspection, at the low voltage side of the transformer the leakage inductance is reflected on the high voltage side in which equivalent inductance L*eq equals to the $(L_{lh} + L_{ll} \cdot N_s^2/N_p^2)$.

In the step-down conversion the switches M5 - M8 are worked like a buck converter in which switch sets (M6, M7) and (M5, M8) alternate leading to transfer power to battery BLV from capacitor CHV. Switches M5 - M8 are operated for mitigating leakage inductance impact on voltage spike with achieving ZVS turn on features. The capacitor CC clamps the voltage ringing due to parasitic capacitance of M1 - M4 and L*eq as there is no need to incorporate the current distinction between iL and iP. The switches M8 and M6 can accomplish near ZCS turn off with the assist of two passive capacitor diode snubbers.

IV. DESIGN OF PRACTICAL SNUBBERS

The reason for utilizing an active flyback snubber is to transfer energy to buffer capacitors Cb1 and Cb2 from snubber capacitor CC, which can attain a near ZCS soft switching feature. The flyback snubber is operated in discontinuous conduction mode to decrease high voltage spike occurring on switch MS. The key segments of the proposed snubbers [8] are designed as follows.

A. Snubber Capacitor CC

To clamp the switch voltage at the low voltage side, snubber capacitor CC needs to fulfill the accompanying disparity:

$$C_c \geq \frac{L_{eq}(i_L - i_P)^2}{V_c^2} \qquad \text{................ (4.1)}$$

where $L_{eq} = L_{ll} + L_{lh}.N_p^2/N_s^2$.

B. Leakage Inductance

The leakage inductance of the transformer can limit diode reverse recovery current and also can accomplish ZVS turn on with a phase shift operation manner. The leakage inductance needs to fulfill is > 2$Leqh$ 43$CmosVin$2+12$CTRVin$2

$$i_s > \sqrt{\frac{2}{L_{eqh}}\left(\frac{4}{3}C_{mos}V_{in}^2 + \frac{1}{2}C_{TR}V_{in}^2\right)} \qquad \text{............... (4.2)}$$

where, $L_{eqh} = L_{lh} + L_{ll} \cdot N_s^2/N_p^2$. But, large leakage inductance will bring about high current distinction during the step up conversion, and here the flyback snubber is obliged to process a high power level.

C. Flyback Snubber

A large transient voltage takes place under the step up conversion because of the current distinction between the current fed inductor and leakage inductance currents during the time interval of t0 - t2. This transient voltage can be suppressed by the diode DC and capacitor CC. The flyback snubber transfers the energy to buffer capacitors Cb1 and Cb2 which is stored in capacitor CC. The rating of power of the flyback snubber can be demonstrated as

$$P_{FB} = 0.5C_c.V^2 f_s \qquad \text{.............. (4.3)}$$

where f_s is the switching frequency.

D. Magnetizing Inductance of Flyback Snubber

The snubber capacitor CC can be completely discharged by the flyback snubber if the turn on time of MS that is the TON is not larger than 1/4 resonant cycle of the magnetizing inductance and capacitor CC . Accordingly, the magnetizing inductance due to the flyback snubber should fulfill the following disparity:

$$L_{mf} > \frac{4T_{on}^2}{\pi^2 C_C} \qquad \text{................. (4.4)}$$

where TON is the conduction time of switches M1 - M4 in the step up conversion.

E. Buffer Capacitors Cb1 and Cb2

At the point when the converter is operated in the step down conversion the capacitors Cb1 and Cb2 shares the current iS. The voltage Vds of switch M6 and voltage Vds of switch M8 will ascend with a lower incline at switches M6 and M8 turnoff transition, which minimizes the switching losses. Buffer capacitors Cb1 and Cb2 can be developed to accomplish close ZCS turnoff if the power rating becomes higher. Then again when the converter is being operated in the step up conversion, the snubber capacitor CC will be completely discharged by the proposed operation strategy. When switches M1-M4 are switched to either (M2, M3) or (M1, M4) conducting then the current difference iC (= iL − iP) will first charge capacitor CC.. In the meantime the current iP can begin to rise up on account of Cb1 and Cb2 holding voltage VHV, where the duty loss can be reduced. As buffer capacitors Cb1 and Cb2 being energized to VHV by the flyback snubber, they fulfill the accompanying disparity:

$$C_{b1}C_{b2} \leq \frac{C_c V_c^2}{V_{HV}^2} \qquad \text{................ (4.5)}$$

F. Snubber Diodes Db1 and Db2

If the capacitors Cb1 and Cb2 are associated in parallel with the upper legs of the voltage fed bridge straight forwardly, then these capacitors will resonate with the leakage inductance at the time of switching transition in step down conversion. This increases switching losses. Hence the two snubber diodes Db1 and Db2 are made to connect with the capacitors Cb1 and Cb2 in series, respectively, Thus the ringing current which is through the high voltage side switches can be blocked successfully.

V. SIMULATION RESULTS

A. Step up Conversion

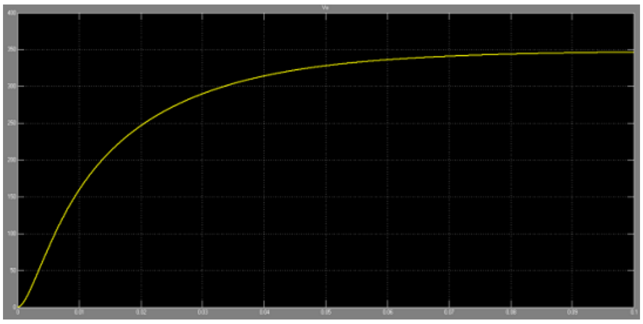

Fig.4. Output Voltage waveform (Vo= 350V)

We can see in Fig.4. the output voltage is stepped up from input 48V to 350V. Thus, the converter successfully operates for step up conversion.

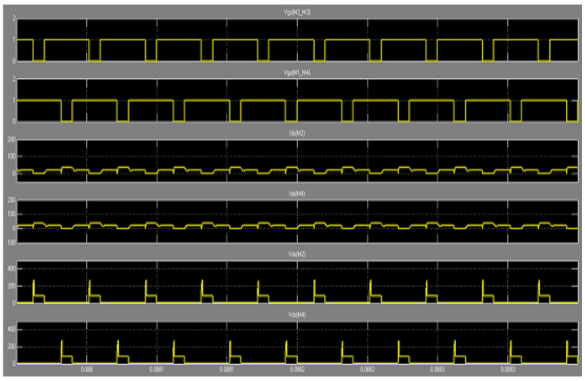

Fig.5. Key voltage and current waveforms

$V_{gs}(M_2,M_3)$, $V_{gs}(M_1,M_4)$, $i_{ds}(M_2)$, $i_{ds}(M_4)$, $V_{ds}(M_2)$, $V_{ds}(M_4)$

The voltage spikes are reduced due to an active and passive snubbers used in the converter. Thus, soft switching features are accomplished.

B. Comparison with the Pre-Existing Method

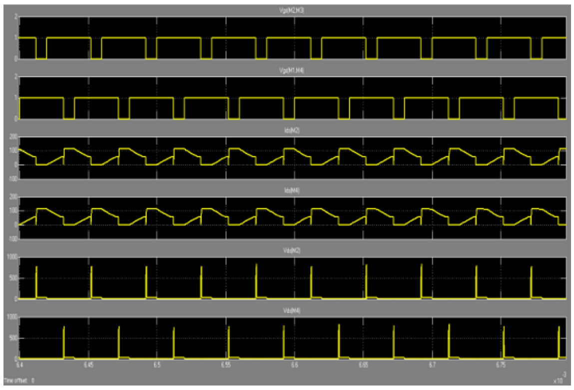

Fig.6. Key voltage and current waveforms of isolated bidirectional converter with flyback snubber

$V_{gs}(M_2,M_3)$, $V_{gs}(M_1,M_4)$, $i_{ds}(M_2)$, $i_{ds}(M_4)$, $V_{ds}(M_2)$, $V_{ds}(M_4)$

In the preexisting converter[9] shown in Fig.1, we get voltage spikes about 700volts across the switches as shown in Fig.6, but for the same circuit input voltages the voltage spikes are about 300volts for the proposed converter shown in Fig.5. This confirms us that the proposed converter configuration and circuit topology can reduce the switching losses better than the preexisting converters configuration.

C. Step Down Conversion

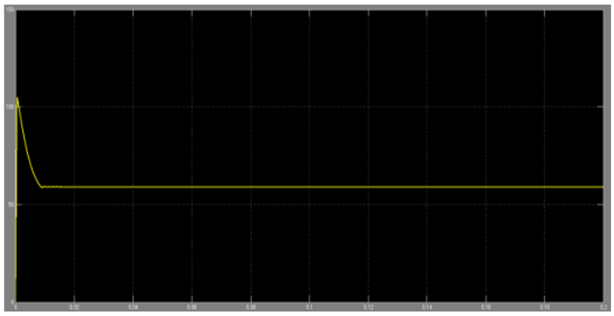

Fig.7. Output Voltage waveform (Vo= 60V)

We can see in Fig.7. the output voltage is stepped down from input 350V to 60V.Depending of the switches conducting the converter works now as a step down converter. Key voltage and current waveforms during the step down conversion is shown in Fig.8.

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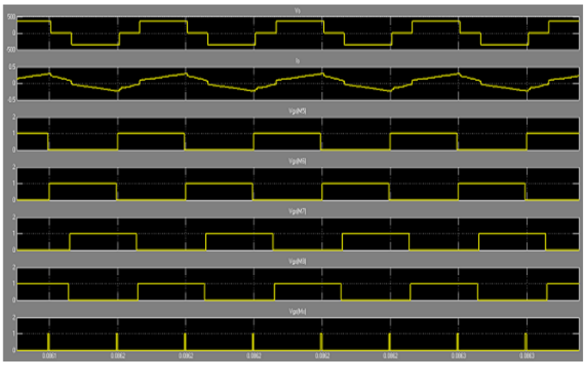

Fig.8. Key voltage and current waveforms

V_S, i_S, $V_{gs}(M_5)$, $V_{gs}(M_6)$, $V_{gs}(M_7)$, $V_{gs}(M_8)$, $V_{gs}(M_S)$

D. Proposed Converter with Application

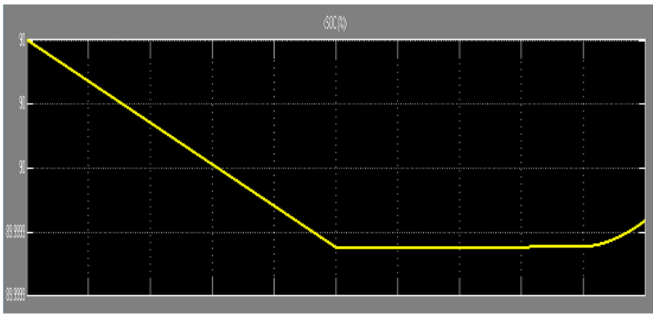

Fig.9. State of Charging

The fig.9 shows the state of battery charging and discharging waveform of the proposed converter. For 0.5 seconds the battery is discharging to form step up conversion. And for next 0.5 seconds battery is charging which forms step down conversion.

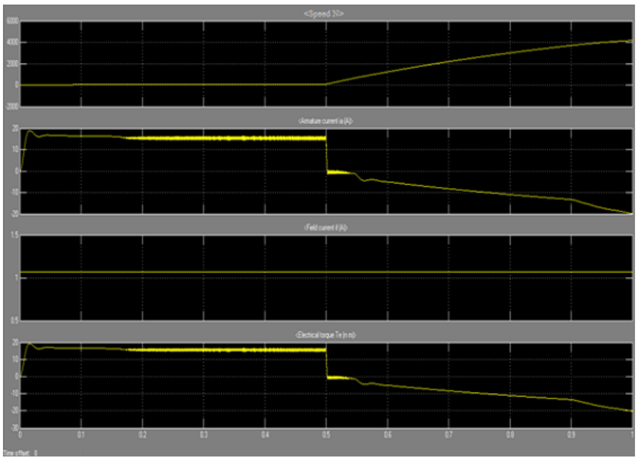

Fig.10. Speed, Armature current, Field current, Electrical torque waveforms

The waveforms of the Speed, Armature current, Field current, Electrical torque of the proposed converter is shown in Fig.10. The converter operates in step up conversion mode from 0 to 0.5 seconds, which makes the motor to run with positive torque and the battery is made to discharge. From 0.5 to 1 seconds the converter operates in step down conversion mode, where the motor runs with negative torque with charging the battery.

VI. EXPERIMENTAL SETUP

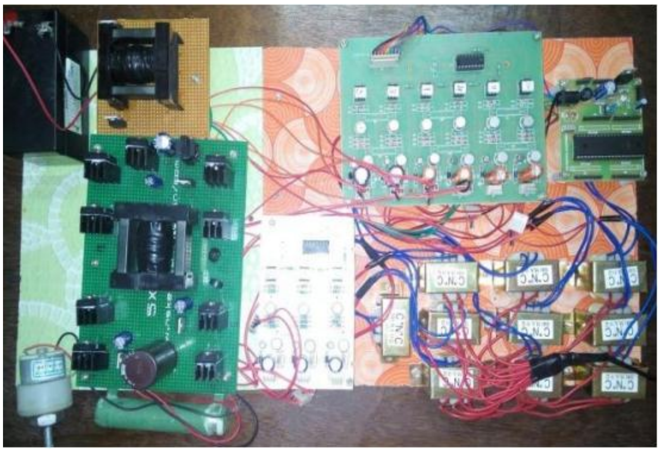

Fig.11. Experimental Setup

The prototype experimental setup of the proposed converter is shown in Fig.11.

The 230V power supply is step down to 12V by the step down transformers is supplied to each base drive circuit. As per the given voltage signals from the microcontroller, the base drive circuits operate to generate gate pulses which are fed to switches of the proposed converter. Thus, the converter operates as per the requirement. The switches M1-M4 are operated for step up conversion and switches M5-M6 are operated for step down conversion. Here the bidirectional flow of power can be performed by changing the pulses to the switches.

VII. HARDWARE RESULTS

Fig.12. Input voltage waveform (Vin=12V)

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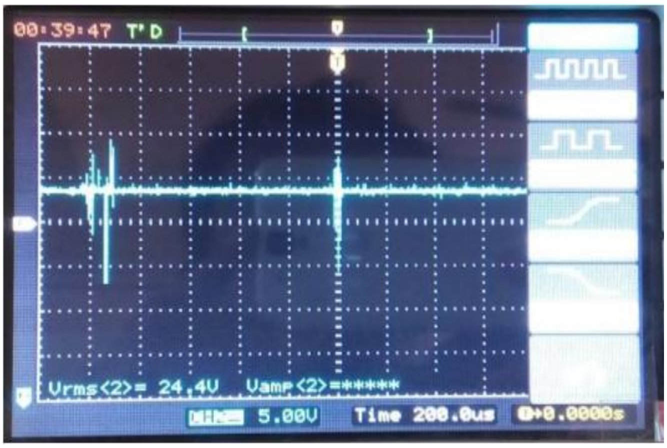

Fig.13.Output waveform during step up conversion (Vo=25V)

Fig.14Output waveform during step down conversion (Vo=3V)

During the step up conversion the voltage is stepped up from 12V shown in Fig.12 to about 25V which is shown in Fig13. During the step down conversion the input voltage 12V is stepped down to about 3V which is shown in Fig.14. The snubber configuration introduced in the proposed converter reduces switching losses.

VIII. CONCLUSION

This paper describes Soft Switching Isolated Bidirectional Converter Associated with Snubbers. The active flyback and passive snubber configuration used in the proposed converter reduces the voltage and current spikes, voltage and current stresses and EMI noise. Thus, switching losses are eliminated. As compared to the preexisting configuration of bidirectional converter, the proposed converter achieves soft switching features and gives high efficiency. The bidirectional flow of power is represented by battery charging/discharging.

The experimental setup of bidirectional flow of power can be made by making motor load to work in motoring and braking mode which discharges and charges the battery. The circuit of the proposed converter consists of number of capacitors, transformers and switches which forms a complex configuration.

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