Semi Active Rectifier for High Output Voltage Applications in Boost Mode

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Abstract— A method for developing isolated buck boost converter in boost mode is projected in this paper. This method is more efficient because of soft switching operation, low voltage stress on active switches and also a single stage power conversion. Low voltage stress on the components is accomplished. From this efficiency of the converter also improves. On the basis of two switch non isolated buck boost converter, isolated buck boost converter in boost mode is proposed. Semi active rectifier (SAR) is also proposed in this paper. It acts as a secondary rectification circuit for isolated buck boost converter. It improves the converter voltage gain and reduces the voltage stress on the devices in the rectification circuit. By choosing a transformer with a smaller turn's ratio and reduced parasitic parameters, efficiency can be improved. Primary side of transformer is taken as full bridge isolated buck boost converter. To obtain isolated buck boost conversion, phase shift control strategy is applied to the full bridge. Over a wide load and voltage range, soft-switching performance of all active switches and diode can be achieved.

Key words: Isolated Buck-Boost Converter, Semi-Active Rectifier, Soft-Switching, High Step-Up

I. Introduction

Isolated DC-DC converters are extensively used to provide the input/output voltage range and also galvanic isolation desires in the inexhaustible energy and battery discharging applications. Usually, isolated converters can be characterized into three kinds: boost converters buck converters and also buck-boost converters. From the angle of conversion efficiency, the isolated buck-boost (IBB) converter is a hopeful approach. Flyback converter is a classic IBB converter, even though its efficiency residues small since the high voltage/current stresses on the apparatuses and the hard-switching of an active switch and also rectifying diode. Furthermore, a flyback converter is applicable to small power applications. A two switch non isolated buck boost converter, which is composed of buck unit, DC-link inductor and boost unit. This converter is useful since it can gather both voltage step up and step down conversion and also can realize high efficiency over a wide voltage range Nevertheless, it cannot provide galvanic isolation. Isolated buck boost converter is established by swapping a non-isolated buck unit in a non-isolated two-switch buck boost converter with isolated buck-unit. A wide voltage gain range with flexible control has accomplished with these converters, and also conversion efficiency is delayed by cascaded two step conversion construction.

Active switches and also rectifying diodes in secondary-side of this converters are endangered to hard-switching, it has a destructive impact on the conversion efficiency. From the angle of an efficiency, accomplishing IBB conversion with a single-stage and a soft-switching action is of excessive concern and signifies a possibly appreciated research subject. Moreover to IBB conversion, additional substantial task is the capable conversion of small output voltage of inexhaustible energy supply and batteries to greater voltage, which is essential since the voltage output of PV arrays, a fuel units and a batteries working in inexhaustible power systems are much lesser than the input DC voltage of a grid coupled inverter. For improving the efficiency of high voltage conversion uses, it is necessary to diminish a voltage stresses taking place in power devices, specifically on the active switches for example MOSFETs, since ON resistance and a switching losses of MOSFET increases when voltage-rating rises.

In this paper, the notion of a semi-active rectifier (SAR) is familiarized to assuage the limitations reviewed above. These SAR are resultant by reunion of a half-bridge path and a switched-capacitor path. The key grant of this project is to come up with novel IBB converters by take on the semi-active rectifier as boost unit. Smaller current stresses and isolated buck or boost conversion have been attained for the anticipated SAR established converters linked with those of passive rectifier. Due to a phase shift modulation and capacitive output step of a SAR, single-step power conversion, soft-switching operation and small voltage stresses on all the active switches and diodes perhaps done with the offered converters. High switching frequency is taken on to create the input current ripple with high frequency and is accessible to eradicate in real systems.

II. Proposed Topology

Fig. 1 shows two-switch non-isolated buck-boost converter. It is composed of DC buck unit, DC link inductor and Boost unit.

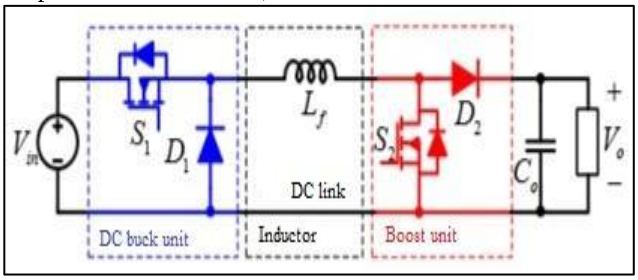

Fig. 1: Two Switch Non Isolated Buck Boost Converter

To generate an IBB converter, a high frequency transformer is employed to produce galvanic isolation, and DC-link inductor is swapped with AC-link inductor. To interface with AC-link inductor and the high-frequency transformer, the DC buck-unit and the DC boost-unit in the non-isolated two-switch buck-boost converter can be swapped with an AC buck-unit and an AC boost-unit, respectively. General structure of IBB converter is shown in Fig. 2.

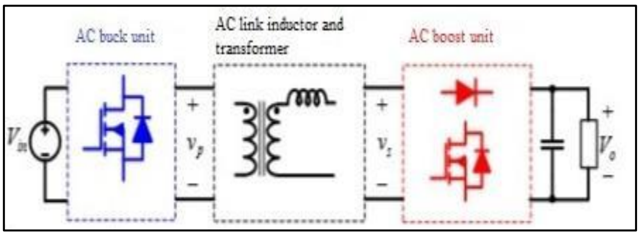

Fig. 2 General Structure of IBB Converter

AC buck-unit exhibited in Fig. 2 is capable of creating high frequency AC voltage v_p, which can be realized by half-bridge, full-bridge and three-level half bridge switching units. In this paper full-bridge is used as a buck unit. The AC boost-unit displayed in Fig. 2 is capable of producing high frequency AC voltage v_s. There are various executions for AC boost-unit. To reduce the voltage stress on the devices in AC boost-unit, SAR is projected in this paper.

As shown in Fig. 3 the SAR is generated by merging a symmetrical half-bridge circuit with a boost switched-capacitor circuit with the shared active switches.

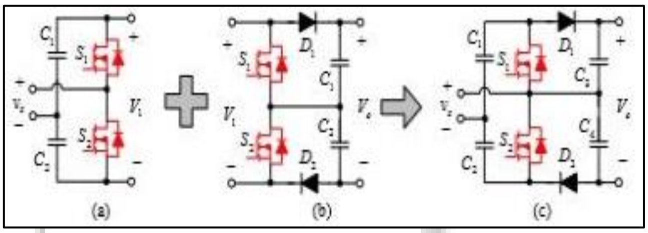

Fig. 3 Derivation of the semi-active rectifier, (a) symmetrical half-bridge circuit, (b) Boost switched-capacitor circuit, (c) semi-active rectifier.

As shown in Fig. 3(c), the proposed SAR is involved of two active switches S1&S2, two diodes D1&D2, and four capacitors C1~C4. In SAR, C1 and C2 are the capacitors which are in series, C3 and C4 are output capacitors. High frequency AC voltage vs can be obtained by turning ON/OFF of S1 and S2 switches complementarily. The voltage output Vo can be upto four times of the peak value of vs, and voltage stresses on the diodes and switches in the SAR is only half of the voltage output Vo. Another two kinds of SAR can be established by merger of a symmetrical half-bridge unit and boost switched-capacitor unit also can be developed.

Proposed topology is shown in Fig. 4, where NP is winding of primary side and NS winding of secondary of transformer. Inductor Lf is realized either by leakage inductance of a transformer or through external inductor towards to accomplish preferred value.

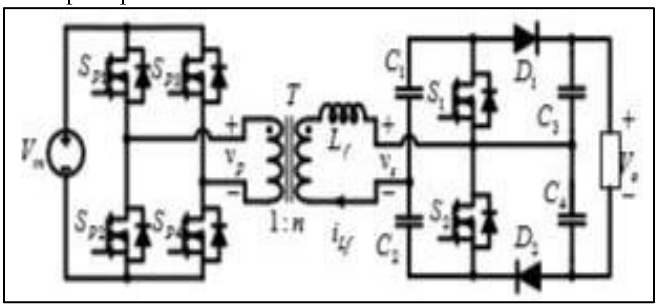

Fig. 4: Proposed FB-IBB Converter

Normalized gain voltage G is well-defined as,

$$G=\frac{V_O}{4nV_O} \qquad (1)$$

Where n=Ns:Np and n is ratio turns of the transformer.

Converter works in boost mode while G≥1. Subsequently, six active switches are used in FB-IBB converter, control to a converter is very flexible, and anyways PWM, phase-shift or PWM plus phase-shift control can be applicable. To accomplish soft switching, phase-shift control approach is applied to FB-IBB converter. As demonstrated in Fig. 4, primary-side of FB-IBB converter remains active full-bridge, and secondary-side of converter is Hybrid Bridge poised by two diodes and two active switches. Every active switch at primary-side and secondary-side is of constant duty cycle 0.5. The switches SP1 and SP2, SP3 and SP4, and S1 and S2 are driven complementary, respectively. Primary-side angle of phase shift φP is defined as difference of phases between gate signals of switches SP1 and SP3, and the secondary-side angle of phase shift φS is defined as difference of phases between gate signals of switches SP4 and S1. Meanwhile primary-side and secondary-side angles of phase shift works as the same function as duty cycles of a buck-unit and boost-unit in two-switch non-isolated buck-boost converter, respectively.

The primary-side and secondary-side duty cycles are demarcated as,

$$\begin{cases} D_P = \frac{\varphi_P}{\pi} \\ D_S = \frac{\varphi_S}{\pi} \end{cases} \qquad (2)$$

A. *Operation of Proposed Converter in Boost Mode*

When the converter works in boost mode, duty-cycle of primary-side is fixed to a maximum value DP=1 which is like as two-switch non-isolated buck-boost converter. So, flow of power is controlled by fluctuating the duty cycle of secondary-side Ds. Full-bridge primary-side switches products square voltage wave designated as VP in Fig. 4, although voltage square waveform formed by SAR secondary-side is designated as VS in Fig. 4. Fig. 5 displays the operational waveforms of FB-IBB converter in the boost mode, where fs is a switching frequency.

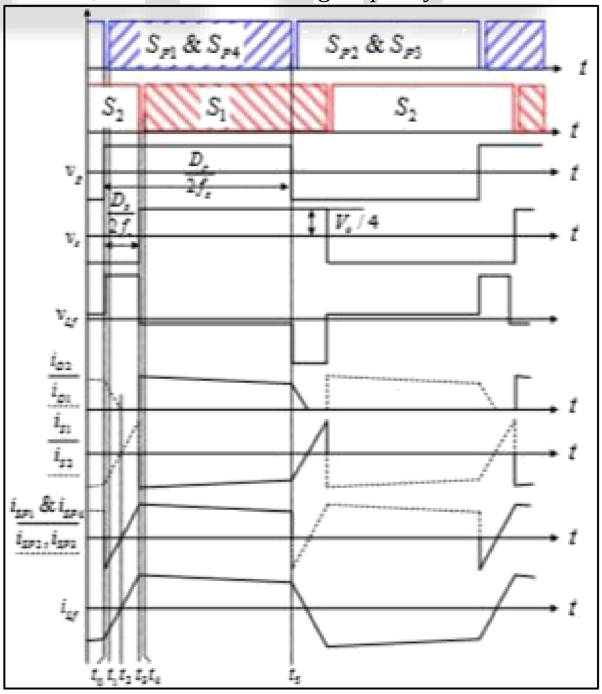

Fig. 5: Switching Waveforms of FB-IBB Converter in The Boost Mode

To simplify the exploration, MOSFET's parasitic capacitances are ignored and assumed to be ideal transformer. In one switching period, ten switching states are there. Due to circuit symmetry, five states are only examined now and corresponding circuit equivalents for every switching state are presented in Fig. 6.

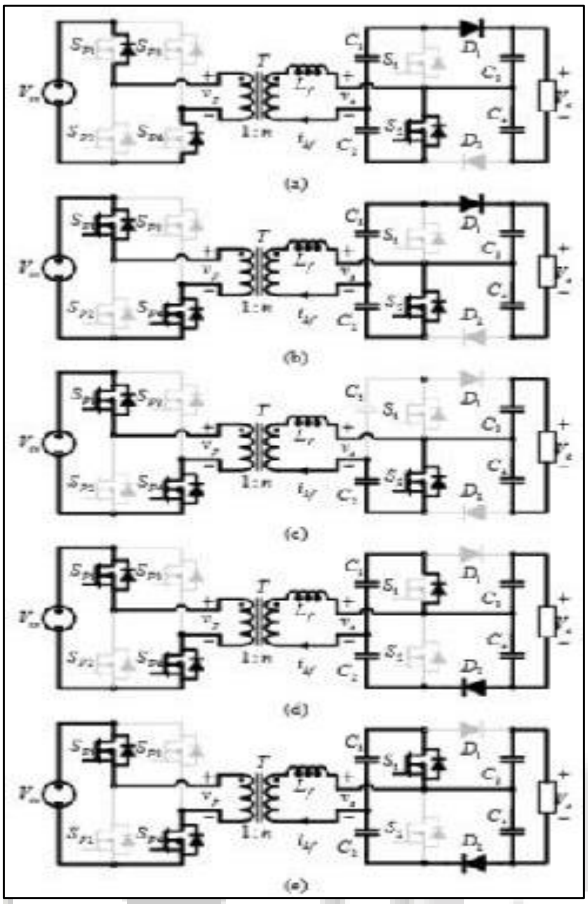

Fig. 6: Equivalent Circuits For Each Switching State In Boost Mode: (A) State 1 [T0, T1], (B) State 2 [T1, T2], (C) State 3 [T2, T3], (D) State 4 [T3, T4] And (E) State 5 [T4, T5]

State 1 [t0, t1] in Fig. 6(a): Before time t0, switches SP2, SP3, S2 and D1 are ON, and current of inductor iLf<0. Source of input and stored energy in a inductor Lf delivered to the load. Charging of C2 and C3 capacitors takes place while C1 and C4 capacitors are discharged. At t0, SP2 and SP3 switches are turned OFF. The body-diodes of switches SP1 and SP4 conduct because of energy stored in Lf..

State 2 [t1, t2] in Fig. 6(b): At t1, with zero voltage switching (ZVS) switches SP1 and SP4 are turned ON. This state finishes when iLf recovers to zero, and D1 is OFF certainly without reverse-recovery loss and with zero current.

State 3 [t2, t3] in Fig. 6(c): At t2, iLf recovers to zero, input voltage and the voltage of the capacitor C2 charges Lf.

State 4 [t3, t4] in Fig. 6(d): At t3, switch S2 turns OFF. Meanwhile iLf is positive, body-diode of switch S1 and diode D2 start to conduct. Hence, source input and stored energy in inductor Lf are supplied to the load. At this state, charging of C1 and C4 capacitors occur, while discharging of C2 and C3 capacitor takes place.

State 5 [t4, t5] in Fig. 6(e): At t4, with ZVS switch S1 turns ON. Transferring of power from source to load continuously at this state. An identical operation occurs in rest states of switching period.

Avoiding the loss of power in conversion of power, power output can be obtained as

$$P_o = \frac{D_S(1-D) n V_o V_{in}}{8 f_S L_f} \quad (3)$$

Substituting (1) into (3), below equation is obtained,

$$P_o = \frac{D_S(1-D_S) V_o^2}{32 f_S L_f G} \quad (4)$$

III. EXPERIMENTAL RESULTS & DISCUSSION

The hardware model for proposed topology is shown in figure 7. The circuit consists of six MOSFETs. Four switches in primary side and two switches in secondary side of the transformer. Inductor of 15µH is used. The proposed hardware successfully converts 12Vdc input battery (scaled to least half from 48V DC input) to 95V. UCC3895 analog controller is used. From Fig. 8, it is clear that the output voltage of the proposed converter dc voltage.

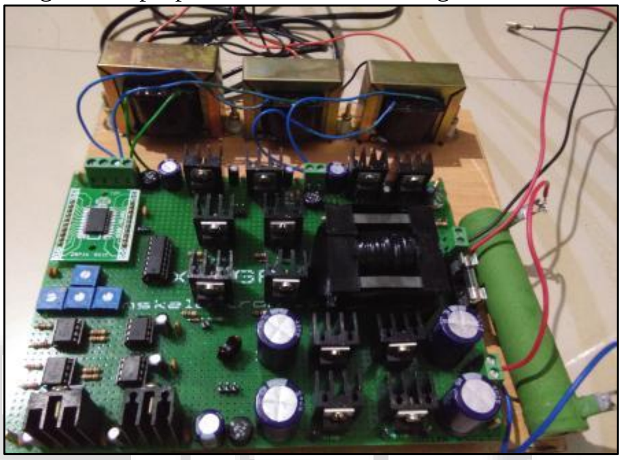

Fig. 7: Hardware Prototype of the Proposed Semi Active Rectifier for High Output Voltage Applications in Boost Mode

IV. SIMULATION RESULTS

The proposed converter is simulated in MATLAB 2013a version. The simulation output waveform of a proposed system is shown in Fig. 8. In this paper phase shift control strategy is used. Input DC voltage of 48V is supplied and output DC voltage of 395V is obtained.

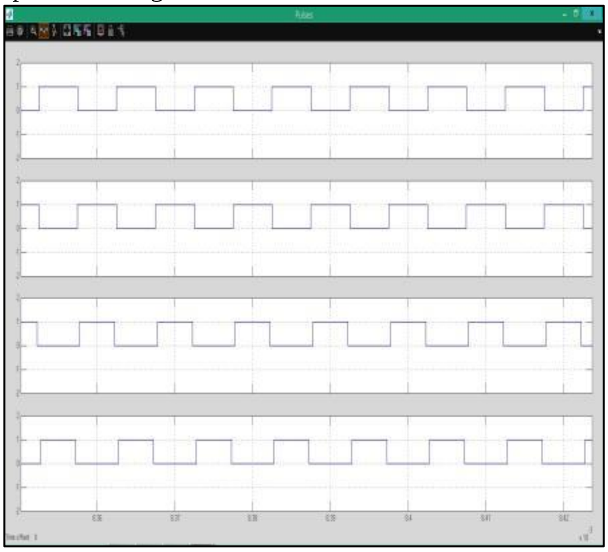

Fig. 8(a): Gate pulses to the switches

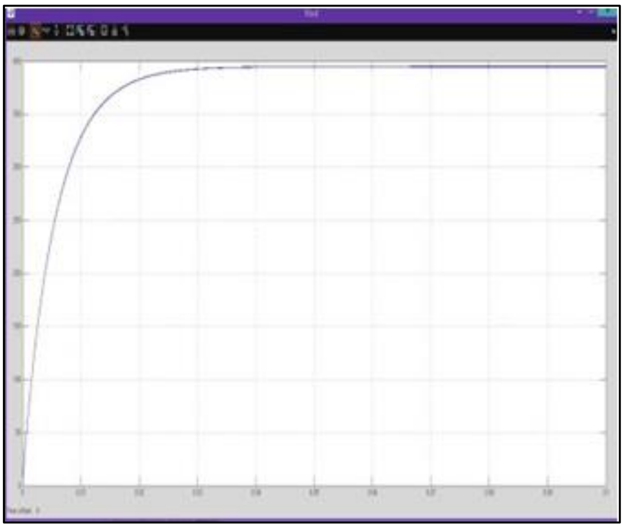

Fig. 8(b): Output voltage waveform
Fig. 8: Output waveforms

V. CONCLUSION

This paper has proposed a semi active rectifier (SAR) for high output voltage applications in boost mode. Phase shift control strategy is used. Soft switching operation of diodes and switches over a wide range of voltage and load is obtained. Single stage power conversion is accomplished. The voltage stresses on the devices in the SAR are reduced significantly, and hence, low-voltage rating devices with better conduction and switching performance have been used to improve efficiency.

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