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Research Paper

HYBRID ENERGY PUMPING USING STEP-UP CONVERTERS

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Hybrid energy pumping using step-up converters are presented. The voltage conversion ratios of step-up converters are higher than the traditional boost converter or some existing voltage-boosting converters. Upon these, by changing the circuit connection or turn-on types of switches, there are three voltage conversion ratios to be generated. Thus, three types of step-up converters to be presented herein. In addition, for any type, isolated gate driver are not used instead of one half-bridge gate driver and one low-side gate driver, and the voltage stress on the low-side switch to magnetise the inductor and the voltage stress on the output diode can be reduced as compared to the traditional boost converter. Furthermore, the basic operating principles of these converters are easy to describe and analyse along with mathematical deductions. The proposed step-up converters circuit is simulated using Matlab/Simulink tool and the results are obtained.

Keywords: Step-up converter, Half-bridge and isolated gate drivers, MATLAB/Simulink

INTRODUCTION

Power for step-up converter can be generated from many sources like rectifiers, batteries, dc generators. DC-DC conversion is a process that changes one DC voltage to another DC voltage. The step-up converter is a DC-to-DC power converter with an output voltage greater than its input voltage. The step-up converter is also known as voltage boost converter. For many applications of the power supply using the low voltage battery, such as Radio Frequency (RF) amplifier, audio amplifier, and so on, often need high voltage to obtain required output power and voltage amplitude. This high voltage is obtained by boost converter [1-2]. Traditional boost converters offer high voltage but have some drawbacks such as reduced voltage conversion ratio, increased voltage and current spikes [3-5]. Similarly, in [5-7] different voltage converters are presented. Voltage conversion ratio can be increased by coupling inductor or transformers, but voltage spikes are introduced by leakage inductance [6]. In [9], even though the operating principle is very simple, the voltage conversion ratio is limited to some extent.

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Based on that analysis, voltage boosting converters with hybrid energy pumping are proposed herein. Any one of the proposed converters described in this paper pumps the energy stored in the capacitor and inductor plus the input voltage into the output during the turn-off period of the switch driven from the PWM control signal created from the controller, so as to increase the voltage conversion ratios. Hence, three types of converters are to be presented in this paper and the PWM control strategy. Hence, the corresponding voltage conversion ratios are no less than that for the traditional boost converter or any other converter [3, 8].

Thus, the voltage stress on the low-side switch to magnetise the inductor and the voltage stress on the output diode can be decreased as compared to the traditional boost converter. Upon this, by changing circuit connection or changing the turn-on types of switches, there are three voltage conversion ratios to be yielded. That is, there are three types of voltage-boosting converters. In addition, no isolated gate driver is needed instead of one half-bridge gate driver and one low-side gate driver. The detailed illustration of the basic operating principles of such converters is given, along with some experimental results offered to demonstrate the effectiveness of the proposed topologies. This topology is simulated using MATLAB/ Simulink simulation software and simulation results prove that, the design ideas work as expected.

CIRCUIT OF NEW PROPOSED TOPOLOGY

Three types of voltage conversion ratios are proposed by two step-up converter structures in this paper. Figure 1 shows type 1 converter whereas Figure 2 shows type 2 and type 3 converters. All these three converters are generated by different PWM converter strategies. These converters consist of three MOSFET's switches S_1, S_2, S_3, three diodes D_1, D_2, D_3, two large energy transfer capacitors C_{b1}, C_{b2} to keep constant voltage across them, two charge pump diode D_{b1}, D_{b2}, one output diode D_0, one output capacitor C_0, one inductor L and one output resistor R_0.

Figure 1: Circuit of Type 1 Topology

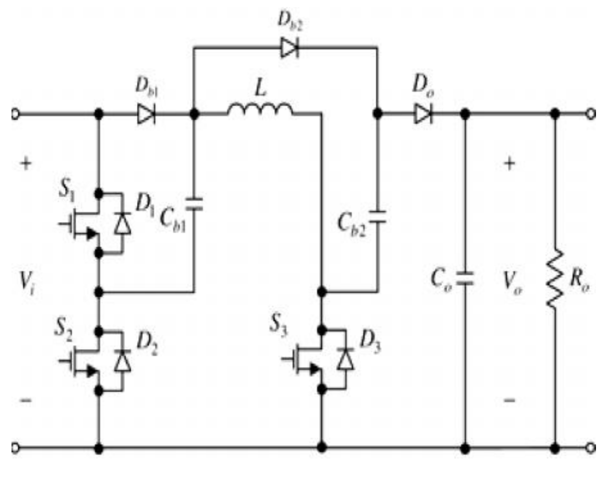
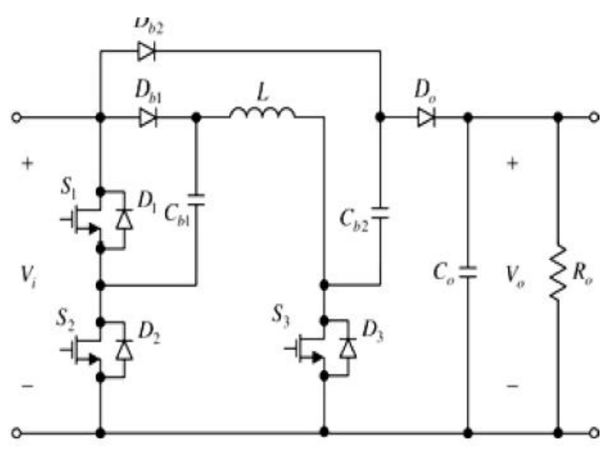


Figure 2: Circuit of Type 1 and Type 3 Topology



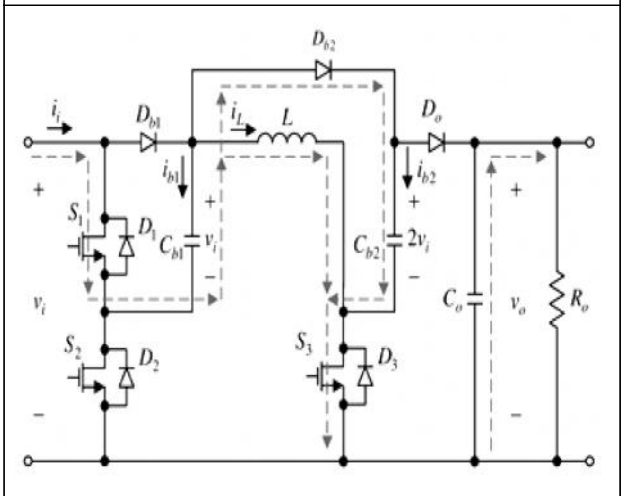
OPERATION OF NEW PROPOSED TOPOLOGY

There are some assumptions given as follows: (i) The dead-band time between switches are omitted; (ii) During turn on period, the voltage drop across diodes and switches are neglected; (iii) C_1, and C_{b2} are suddenly charged up to some voltage in short interval of time since it is operated based on charge pump principle, the voltage across C_{b1} and C_{b2} is v_i and $2v_i$ respectively for type 1 and for type 2 and 3 the voltage across both capacitor remains same, i.e., v_i; (iv) input voltage is v_i and input current is i_i; (v)output voltage is represented as v_o; (vi) three converters are operated under Continuous Conduction Mode (CCM).

Type 1 Converter

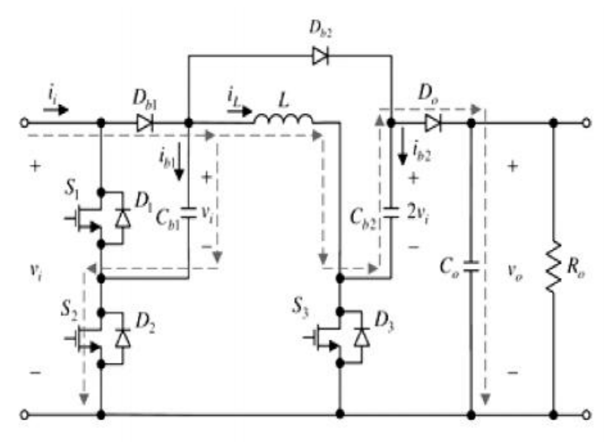
Mode 1: Figure 3a shows mode 1 operation of type 1 converter. Switches S_1 and S_3 are turned on and S_2 is off. Since D_o is reverse biased and D_{b2} is forward biased capacitor C_{b2} suddenly charges to $2v_i$. When switch S_1 turned on diode D_{b1} is reverse biased which results in discharging of capacitor C_{b1}. At the same time voltage across inductor L is $2v_i$. Thereby C_o releases energy to the output.

Figure 3a: Circuit of Type 1 in Mode 1



Mode 2: Figure 3b shows mode 2 operation of type 1 converter. Switches S_1 and S_3 are turned off and S_2 is on. Since D_o is reverse biased C_{b2} suddenly discharges. When switch S_1 turned off diode D_{b1} is forward biased which results in charging of capacitor C_{b1} to v_i. At the same time voltage across inductor L is $3v_i$-v_o and get demagnetised. Thereby C_o is energised.

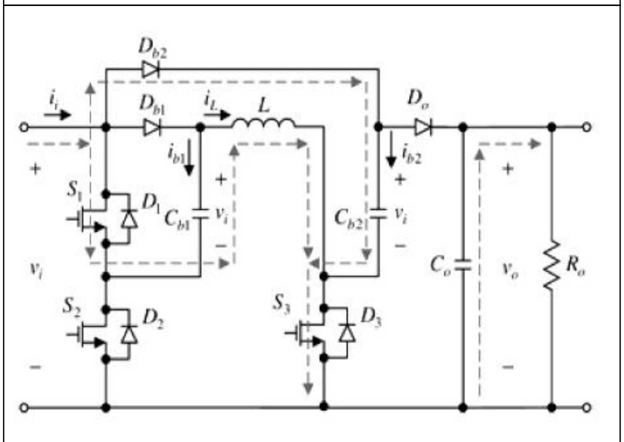
Figure 3b: Circuit of Type 1 in Mode 2



Type 2 Converter

Mode 1: Figure 4a shows mode 1 operation of type converter. Switches S_1 and S_3 are

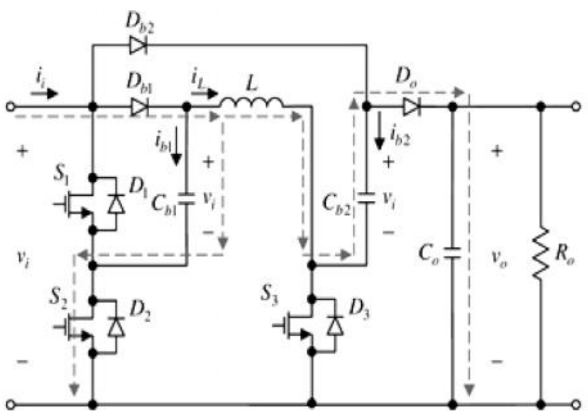
Figure 4a: Circuit of Type 2 in Mode 1



turned on and S_2 is off. Since D_{b2} is forward biased capacitor C_{b2} suddenly charges to $2v_i$. When switch S_1 turned on diode D_{b1} is reverse biased which results in discharging of capacitor C_{b1}. At the same time voltage across inductor L is $2v_i$. Thereby C_o releases energy to the output.

Mode 2: Figure 4b shows mode 2 operation of type 2 converter. Switches S_1 and S_3 are turned off and S_2 is on. Since D_o is reverse biased C_{b2} suddenly discharges. When switch S_1 turned off diode D_{b1} is forward biased which results in charging of capacitor C_{b1} to v_i. At the same time voltage across inductor L is $2v_i$-v_o and get demagnetised. Thereby C_o is energised.

Figure 4b: Circuit of Type 2 in Mode 2



Type 3 Converter

Mode 1: Figure 5a shows mode 1 operation of type 3 converter. Switches S_2 and S_3 are turned on and S_1 is off. Since D_{b1} and D_{b2} is forward biased capacitor, C_{b1} and C_{b2} suddenly charges to vi in very short period. At the same time voltage across inductor L is v_i. Thereby C_o releases energy to the output.

Mode 2: Figure 5b shows mode 2 operation of type 3 converter. Switches S_2 and S_3 are turned off and S_1 is on. Since S_3 is turned off D_o is forward biased, C_{b2} suddenly discharges. When switch S_1 turned on diode D_{b1} is reverse biased which results in discharging of capacitor C_{b1}. At the same time voltage across inductor L is $3v_i$-v_o and get demagnetised. Thereby C_o is energised.

Figure 5a: Circuit of Type 3 in Mode 1

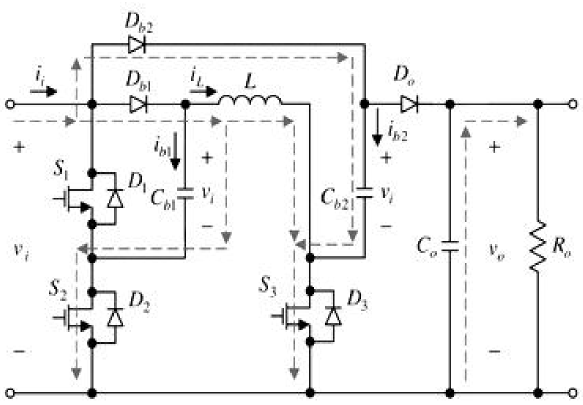
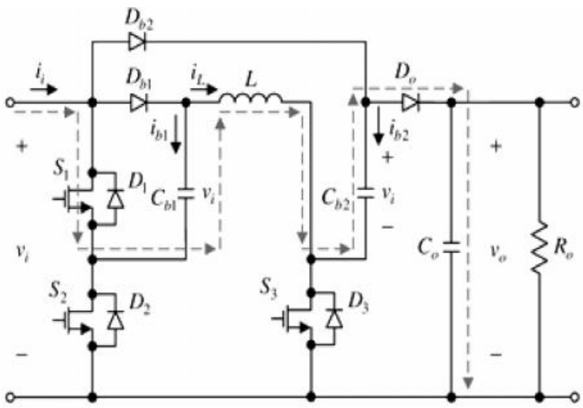


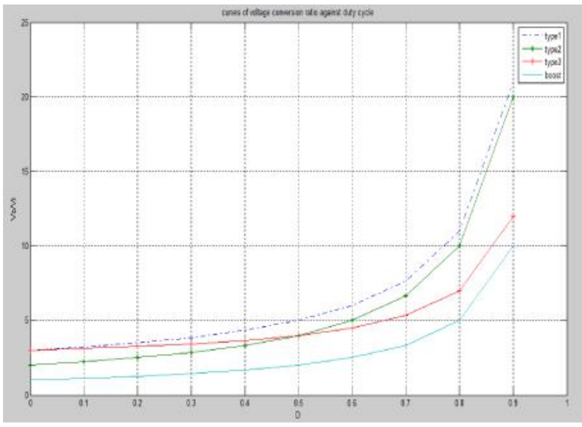
Figure 5b: Circuit of Type 3 in Mode 2



Curve of Voltage Conversion Ratios Against Duty Cycle

Figure 6 shows the curve of voltage conversion ratio against duty cycle for proposed converters and traditional boost converter. It can be seen that proposed converters have high voltage conversion

Figure 6: Curve of Voltage Conversion Ratio Against Duty Cycle

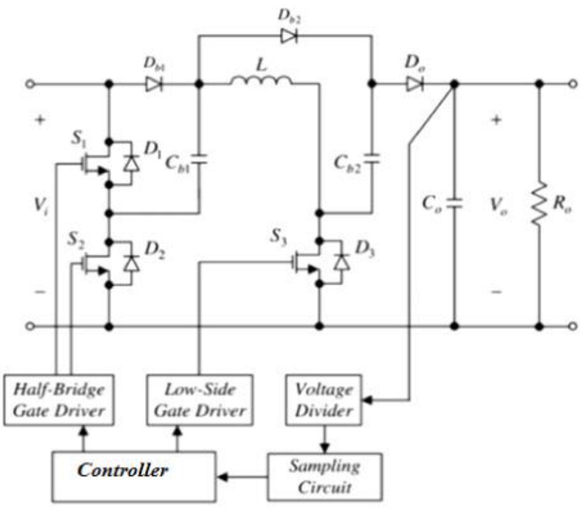


ratios compared to traditional boost converter and derived KY converter [3, 4].

Small Signal ac Model

Figure 7 shows the block diagram simple voltage boosting converter with hybrid energy pumping. The converter pumps the energy stored in the capacitor and inductor plus the input voltage into the output during the turn-off period of the switch driven from the PWM

Figure 7: Small Signal Model of Proposed Converter and Overall System Block Diagram



control signal created from the controller. Thus, the voltage conversion ratios can be increased. Hence, three types of converters are presented and the PWM control strategy. This is the Field Programmable Gate Array (FPGA)-based PWM control strategy based on the one-comparator counter-based sampling. The output voltage information after the voltage divider is obtained through the sampling circuit, and then sent to FPGA to create the desired PWM control signals to drive the MOSFET switches after the gate drivers.

1. Half bridge gate drive: It is a power amplifier that accepts a low power from a controller and produces a high current drive input for the gate of MOSFET.
2. Voltage divider: It is a passive linear circuit that produces an output voltage i,e fraction of input voltage.
3. Sampling circuit: Sample and hold circuit is an analog device that sample the voltage of a continuously varying analog signal and holds it value at a constant level for a minimum period of time.

Simulation Results

The simulation of three proposed converters topology is carried out using a computer-aided

Figure 8a: Simulated Output of Type 1 Converter

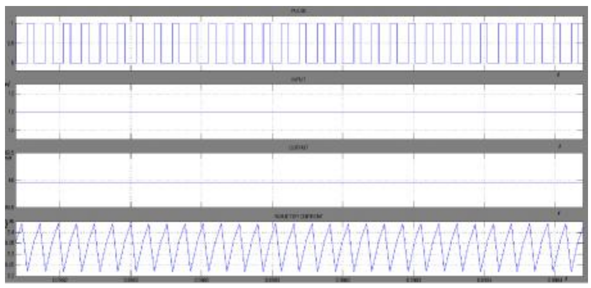


Figure 8b: Simulated Output of Type 2 Converter

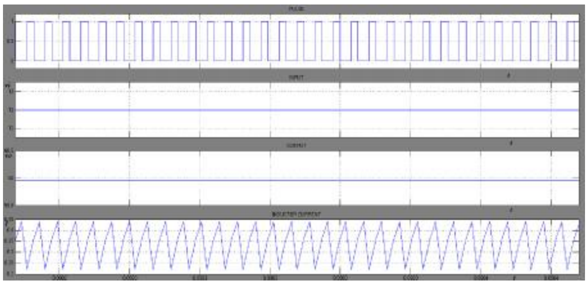
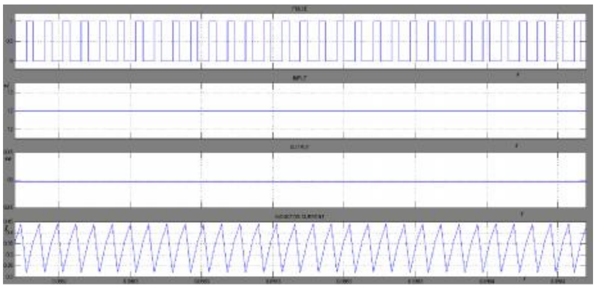


Figure 8c: Simulated Output of Type 3 Converter



simulation tool to verify the validity of the circuit. The simulation is done using Matlab/Simulink. The circuit is simulated with an input DC voltage of 12 V. Figure 8 shows the simulation output window obtained from the Matlab.

CONCLUSION

In this paper, three types of step-up converters are presented. The voltage conversion ratio of these three converters is higher than traditional boost converter. These converters have good steady state and transient state performance. The voltage stresses on the switch magnetise the inductor and voltage stress on output diode can be reduced compared to boost converter.

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