

A Novel DC-DC Boost Converter for Piezoelectric Actuators in Automotive Applications

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Abstract: In this paper, a novel high step-up converter is presented for piezoelectric actuators, which uses one coupled inductor with small turn's ratio. This converter produces an output with high voltage gain with small component design. The switches used here are operated at zero voltage switching, hence efficiency is improved. Aside from this the converter produces a non-pulsating current, which reduces the current stress across the output capacitor and also output voltage ripple. The simulation is done in PSIM software which produces 110 V output voltage and 120 W output power. The input supply is 12 V and the switching frequency is 5 KHz. The simulation results are provided which highlights the merits of the proposed work.

Keywords: Boost converter, Zero voltage switching, coupled inductor, and piezoelectric actuators.

1. Introduction

Recent emerging application of power electronics is the driving of piezoelectric actuators used in automotive applications. The use of piezoelectric actuators (used as injectors) allows less response time with respect to traditional magnetic actuators but requires high driving voltages in order to be driven in a smaller time. This is a big concern in automotive environment, where the battery voltage is still the main power source available.

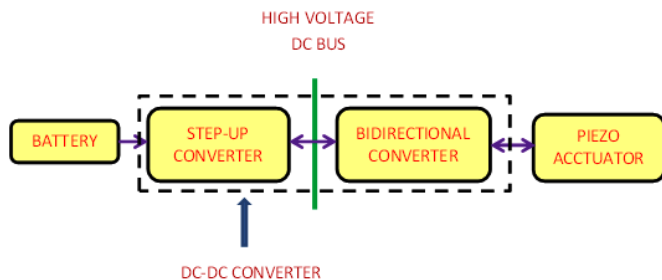


Figure 1: Block Diagram

Figure 1 shows the block diagram of power source for piezoelectric actuator. It consists of two main components. A unidirectional DC/DC converter with a small input power loads and large buffer capacitor and, a second bidirectional DC/DC converter that controls the energy exchanged between the buffer capacitor and the reactive load.

The requirements on the unidirectional DC/DC converter are few. It only needs to compensate the power losses of the two stages plus the energy dissipated in the actuator and the connected mechanical system. Second stage presents more problems, because it must be designed for full system power.

Conventional DC/DC boost converter [1, 2] is not the best solution in piezoelectric based applications where high step-up ratio and high efficiency power conversion is required.

Up to now, many kinds of voltage-boosting techniques have been presented [3,4], including several inductors which are magnetized and then pump the stored energy into the output with all inductors connected in series. In these converters there are too many components, thereby making the converters relatively complicated. The step-up converter combining KY and buck-boost converters [5] produces an

output voltage of 48 V, which uses coupled inductor but it has low voltage gain and to increase voltage gain, the duty cycle is also increased.

The boost converter with proposed control circuit meets the demanding requirements of these applications, including high reliability, relative low cost, safe operation and high performance, therefore an excellent choice for interfacing the battery with the high voltage DC bus used for piezoelectric actuator system. This converter has high voltage gain with constant duty cycle when compared to traditional converter and also the output current is non-pulsating. Furthermore, part of the leakage inductance energy can be recycled.

2. Proposed DC-DC converter

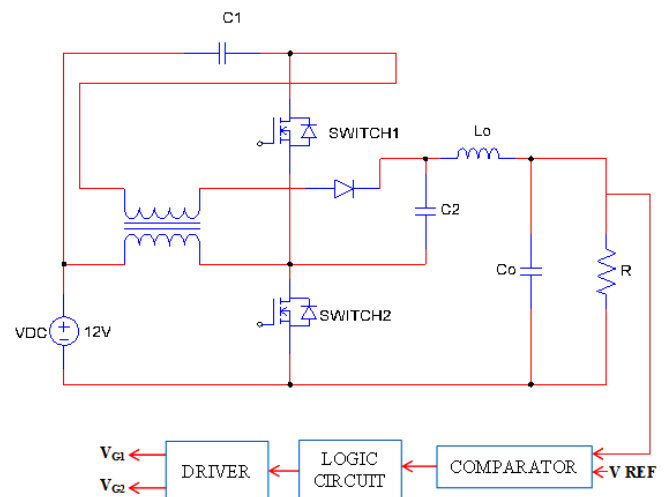


Figure 2: Circuit Diagram

Figure 2 shows the circuit diagram of boost converter. It consists of transformer with turn's ratio of 1:3, one energy transferring capacitor $C1$, one charge pump capacitor $C2$, one diode $D1$, one output inductor L_o , and one output capacitor C_o . The switches are turned on and off at zero voltage switching. The firing pulses for switches are generated by comparing the output voltage with the required DC voltage and this error signal is given to logic circuit. The logic circuit along with driver generates the gate pulses and which is given to switches.

The operating principles of the circuit can be explained in two modes.

2.1 Mode A

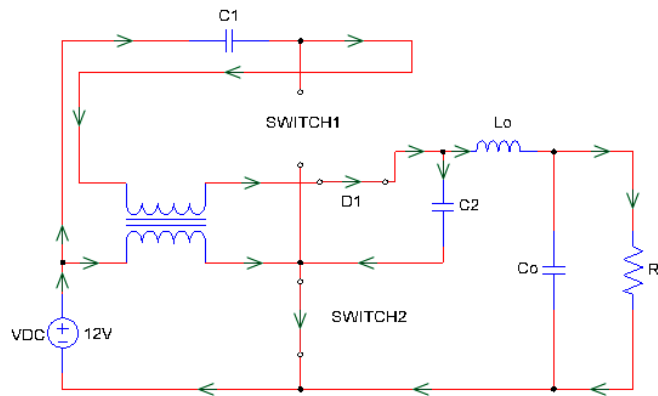


Figure 3: Power flow in mode A

Figure 3 shows the power flow diagram during mode A operation. In this mode gate pulse is given to switch 2, hence it will be turned on. The supply will appear across primary winding and hence a voltage is induced in the secondary which forward bias diode D_1 . The capacitor C_2 starts charging and inductor L_0 starts discharging. Figure 5 shows the waveform of gate pulse given to the switches, inductor voltage and inductor current during this mode of operation. The voltage across the inductor L_0 is given as

$$V_{L0} = V_{C2} - V_O \quad (1)$$

2.2 Mode B

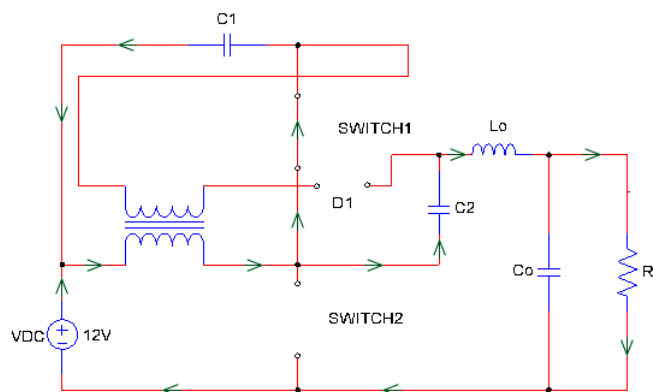


Figure 4: Power flow in mode B

Figure 4 shows the power flow diagram during mode B operation. In this mode gate pulse is given to switch 1, hence it will be turned on. The capacitor C_1 imposes a negative voltage on primary winding and hence a voltage is induced in the secondary which reverse bias diode D_1 . The inductor L_0 now starts charging. Figure 5 shows the waveform of gate pulse given to the switches, inductor voltage and inductor current during this mode of operation. The voltage across the inductor L_0 is given as

$$V_{L0} = V_i + V_{C1} + V_{C2} - V_O \quad (2)$$

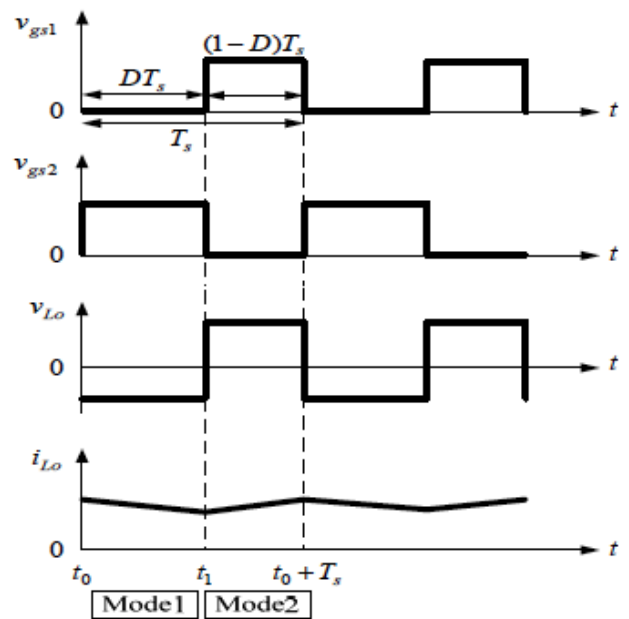


Figure 5: Operating waveform

2.3 Design

The value of the output inductor is calculated from the below equation and is given as

$$L_0 = \frac{V_{L0} \Delta t}{\Delta i_{L0}} = \frac{(V_{C1} + V_i + V_{C2} - V_o) (1-D) T_s}{\Delta i_{L0}} \quad (3)$$

The value of the energy transferring capacitor C_1 is calculated from the below equation and is given as

$$C_1 = \frac{i_{c1} \Delta t}{\Delta V_{C1}} = \frac{(I_{i \text{ rated}} - I_{o \text{ rated}}) (1-D) T_s}{\Delta V_{C1}} \quad (4)$$

3. Simulation and Result

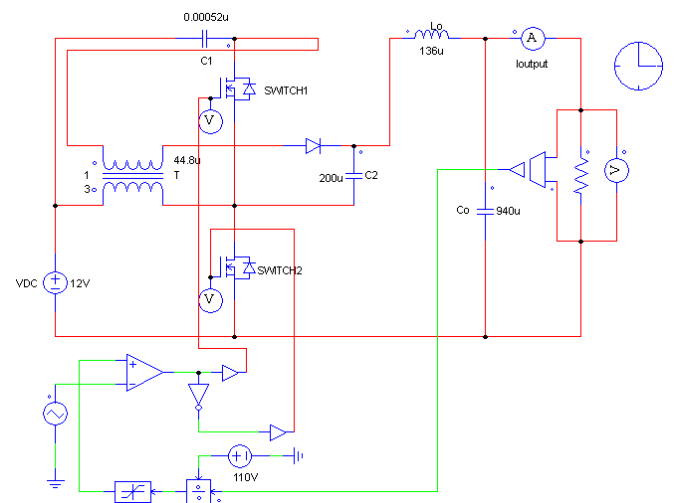


Figure 6: PSIM simulation circuit

Figure 6 shows the simulation circuit diagram of proposed circuit done in PSIM software.

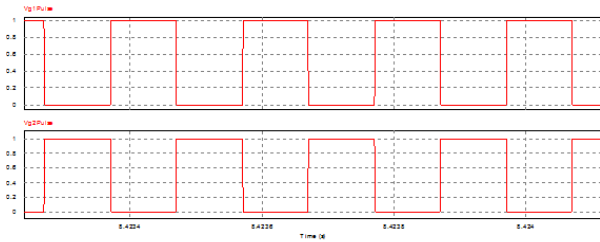


Figure 7: Gate pulse waveform

Figure 7 shows the gate pulse waveform generated for the switches. The switching frequency is 5 KHz and the duty cycle of operation is 0.5.

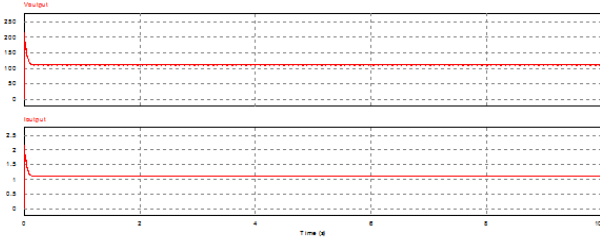


Figure 8: Output voltage and current waveform

Figure 8 shows the output voltage and current waveform of the converter. It produces an output voltage of 110 V and current of 1.1 A. The load current is not pulsating.

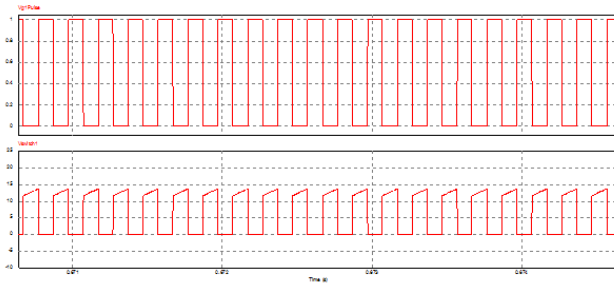


Figure 9: Gate pulse and Switch voltage

Figure 9 shows the gate pulse and switch voltage waveform of the switch 1. The switches are turned on and off at zero voltage, therefore the switching losses are reduced and thereby increasing the efficiency. The maximum voltage stress across the switch is only 12 V. hence the cost and size is also reduced.

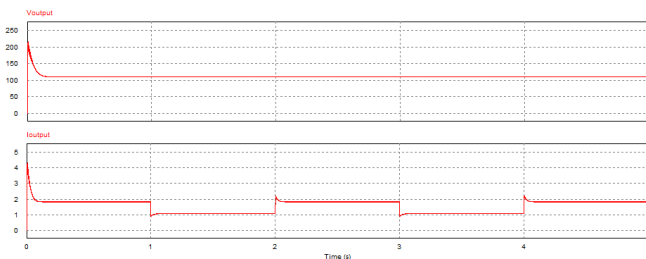


Figure 10: Transient load current waveform

Figure10 shows the load current waveform during transient operation. It is clear that the output voltage of the converter is stable when the load current changes from 1.1 A to 1.8 A and vice versa.

4. Conclusion

A high voltage gain converter with high efficiency for piezoelectric actuators in automotive applications has been presented in this paper. Here the switches are turned on and off at zero voltage. Therefore switching losses are reduced and hence efficiency is improved when compared to traditional converters. The maximum voltage stress across the switch is small thereby reducing the size of the switches used. The duty ratio is maintained constant and is 0.5. Hence heat generated is reduced. The output voltage remains in constant voltage when there is a transient in load.

References

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