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Retraction

Retracted: Improved Quadratic Boost High-Gain DC-DC Converter Based on Constant Off-Time Control Mode

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] J. Fan and M. Kang, "Improved Quadratic Boost High-Gain DC-DC Converter Based on Constant Off-Time Control Mode," *Mobile Information Systems*, vol. 2022, Article ID 4214275, 7 pages, 2022.

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Research Article

Improved Quadratic Boost High-Gain DC-DC Converter Based on Constant Off-Time Control Mode

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A non-isolated modified quadratic boost high-gain DC-DC converter is proposed to overcome the problems of limited boost capability and high switching stress in quadratic boost converters. The proposed converter has two topologies. The operating principles of the two topologies are analyzed, and the voltage gain and switching stress of the circuit topologies are theoretically derived and compared with existing converters. The proposed converter increases the output gain while reducing switching stress and improving conversion efficiency. A simulation model is built in MATLAB/Simulink, and the simulation results verify the correctness of the theoretical calculations. A prototype was built, and the feasibility of the converter design was verified by comparing the theoretical derivation and the prototype test results.

1. Introduction

The rapid development of integrated circuit technology and the huge demand in the consumer market are driving the development of all kinds of electronic products towards intelligence, multifunctionality, and efficiency [1]. A wide range of portable electronic lifestyle products such as smartphones, tablets, personal digital assistants (PDAs), and handheld electronic devices have become part of people's working life, and the working duration of these electronic devices is directly determined by the power supply. Most of the portable electronic products on the market today are powered by a single lithium battery, which has the disadvantage of an unstable charge/discharge characteristic curve [2]. To ensure that the drive voltage of the sub-circuit modules in the system is constant, a regulated power supply module needs to be added between the sub-circuit and the lithium battery [3]. In order to meet these needs, small, highly efficient switching power supplies with voltage stabilisation have been developed, which are widely used in various fields such as remote and data communications, computers, industrial instrumentation, aerospace, and military. Since their introduction at the end of the last century, switching power converters have attracted widespread interest at home and abroad [4].

Currently, the main switching converters are DC-DC converters, AC-DC converters, DC-AC converters, and AC-AC converters. DC-DC converters have the fastest increase in switching frequency of all converters. Compared to the low-dropout regulator (LDO), DC-DC converters have the advantage of low energy loss, high conversion efficiency, light weight, high power density ratio, and wide voltage regulation range. Converters can provide large drive currents and can maintain a very low quiescent current [4]. The renewal of electronic devices has also put forward higher requirements for power management chips, and high-performance DC-DC converters have become a research hotspot and an inevitable trend in the development of power management chips. At the same time, in the context of encouraging independent R&D and design, there is still a large gap between the design level of domestic switching power supplies and that of developed countries in Europe and the US [5]. Therefore, the study of DC-DC converters is of great importance.

In terms of control mode, as the CFT control mode and COT control mode are pairwise control, the control architecture is basically the same, they have better transient characteristics than the traditional voltage or current mode, and their system structure is simpler and more efficient; many domestic and foreign research teams have conducted research for these two PFM control modes. In [6], a small-signal model of the current-mode CFT architecture was proposed to describe the system loop model in the CFT control mode.

In recent years, green energy is developing rapidly and the use of new renewable fuel cells such as direct methanol fuel cells and proton exchange membrane fuel cells to replace conventional batteries is a major trend for the future. However, most green energy sources and new fuel cells only provide very low voltages, making it difficult to power circuit systems directly from a single battery, requiring a boost converter to increase the input voltage [7]. LED backlighting is widely used in LCDs such as mobile phones, cameras, and laptops due to its environmental friendliness, low power consumption, good dimming capability, and rich colour expression. The voltage required for LED backlighting of electronic products is higher than the battery voltage [8]. Therefore, the study of boost converters is of great importance in saving energy, promoting the development of solid state lighting industry, greening the environment, and so on. To achieve stable and efficient operation, electronic devices need their power supply to have high conversion efficiency and fast transient response performance [9, 10]. Compared to PWM control, CFT control does not require a ramp compensation circuit and has the advantages of low audio sensitivity, wide output voltage range, fast transient response, simple system design, low power consumption, and high efficiency [11, 12].

2. Related Work

In terms of boost converter topology, the phase margin as well as the closed-loop bandwidth of the system is affected due to the presence of the right half-plane zero. In order to improve the effect of the right half-plane zero, researchers have proposed various methods, such as current injection control [13], Smith's predictor [14], and so on, but these methods do not eliminate the right half-plane zero of the conventional boost converter. A new current control technique was proposed in [15] based on the three-state boost converter structure. Al-Saffar and Ismail [16] proposed an embedded boost converter with near lossless expansion, where the expansion branch consists of small inductors and half-bridge switching units that require parallel additional synchronous phases. However, the expansion branch is only activated during the recovery of the large signal, thus achieving high efficiency.

To address the problem of non-constant switching frequency, Alonge et al. [17] proposed an adaptive on-time method to represent the on-time of the system as a quantity related to the input voltage and output voltage, which theoretically maintains a constant switching frequency in the continuous on-time mode, but the actual simulation results still have less than 10% variation in the switching frequency. In [18], a boost-type DC-DC converter based on a fixed-off-time control mode was implemented with a two-way output voltage feedback. A new frequency control circuit was proposed in [19], which sets the threshold voltage of the comparator and the charging current of the timing capacitor with respect to the input and output voltages and adds a phase frequency detector to form a feedback loop, which detects in real time the voltage signal generated by the error between the switching frequency and the target frequency and adjusts the off time by superimposing the input voltage with this voltage signal. The input voltage is superimposed on this signal to regulate the off-time TOFF and thus stabilise the switching frequency. A timer for the COT modulation mode was invented in [20]. Based on the previously existing timer circuit, a second switch, a third switch unit, and an inverter are added. The soft-start process of the circuit is completed by regulating the third switch unit, so that the converter is regulated by the feedback of the output voltage. There is still a certain frequency variation when the load is changed. A constant frequency-fixed off-time control technique based on feedback regulation of the input and output voltages was proposed in [13].

Ahmad et al. [14] proposed a constant on-time capacitor current control technique (CC-COT). This technique uses the capacitor current instead of the output voltage as the inner loop modulation signal, and the outer loop comparison signal is generated by the output voltage and the reference voltage through the error amplifier. The inner and outer loop signals simultaneously control the switch-off of the switching tube, eliminating the influence of the capacitor voltage phase lagging the inductor current phase on the stability of the converter, so that the stability of the converter is not affected by the value of the output capacitor ESR. In the same year, Fan et al. [15] also studied the CC-COT control technique and found that although this technique improved the output voltage steady-state accuracy, it had the problem of slow transient response when the input voltage changed abruptly.

3. Topology and Working Principle

3.1. Secondary Boost Converters. The secondary boost converter consists of inductors L_1 and L_2, capacitors R_1 and R_2, and diodes C_{R_X}, R_X, and R_L and uses a switching tube to cascade two boost converters with a voltage gain that is quadratic to the conventional boost converter. Figure 1 shows the quadratic boost converter topology. Buck converter and boost converter are the most basic topologies. The other four are derived from these two topologies. If negative power output is to be realized, buck boost converter can be realized. It is a buck or boost circuit. The output voltage is larger or smaller than the input voltage, but the polarity is opposite.

3.2. Non-Isolated Modified Quadratic Boost Converter Topology. The non-isolated modified quadratic boost converter is based on the topology of the quadratic boost converter with the addition of capacitors O_1 and O_2 and diodes C_{T_X} and C_{R_X}. The proposed converter has two topologies, as shown in Figures 2 and 3, which are referred to in this paper as Type-1 and Type-2 converter topologies. The boost converter or step-up converter is a common switching

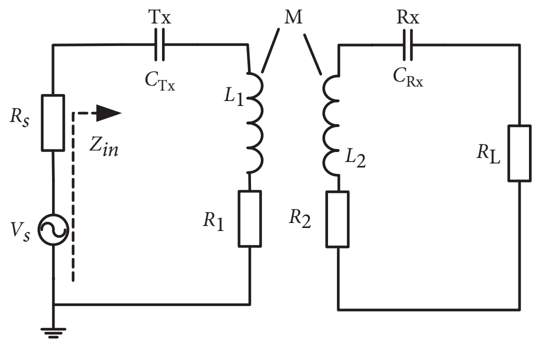

FIGURE 1: Quadratic boost converter topology.

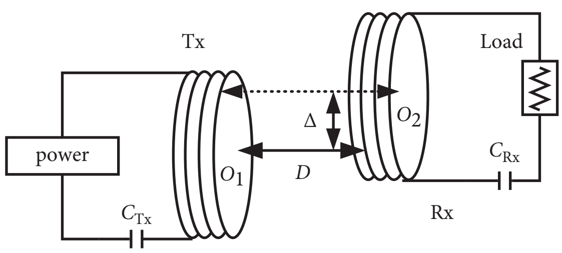

FIGURE 2: Type-1 converter topology.

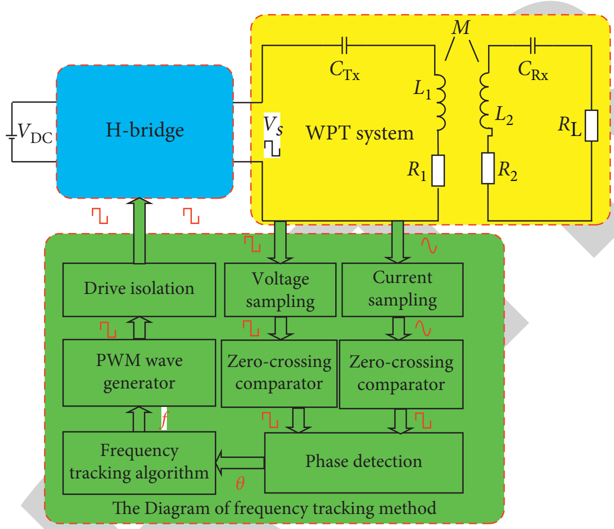

FIGURE 3: Type-2 converter topology.

DC boost circuit. It controls the inductor to store and release energy by turning on and off the switch tube, so that the output voltage is higher than the input voltage.

Working Process. The working process can be divided into charging and discharging (controlled by PWM).

3.3. Working Principle. To simplify the analysis, it is assumed that the current flowing through inductors L_1 and L_2 is continuous.

Type-1 converter has two modes when operating in continuous mode. Operating mode 1 (t0 to t1): switching tube S_1 and diodes V_{D_0} and V_{D_3} are on; diodes V_{D_1}, V_{D_2}, and V_{D4} are switched off in the opposite direction. The input voltage V_i charges the inductor L_1; the capacitor C_2 charges the inductor L_2 via S_1, while V_i is connected in series with capacitors C_1 and C_3 to supply the load. In this mode of operation, there is

$$\begin{cases} -V_i + V_{L_1} = 0, \\ -V_{C_2} + V_{L_2} = 0, \\ -V_i - V_{C_1} + V_{C_0} - V_{C_3} = 0. \end{cases} \quad (1)$$

Operating mode 2 (t_1 to t_2): switching tube S_1 and diodes V_{D0} and V_{D3} are switched off, V_{D_1}, V_{D_2}, and V_{D4} are switched on, V_i series inductor L_1 charges C_2 via diode V_{D_2}, inductor L_1 charges C_1, V_i series inductors L_1 and L_2 charge C_2 via V_{D4}, and capacitor C_0 discharges the load. In this mode, there is

$$\begin{cases} -V_i + V_{L_1} + V_{C_2} = 0, \\ V_{C_1} + V_{L_1} = 0, \\ -V_i - V_{C_1} + V_{L_2} + V_{C_3} = 0, \\ V_{C_0} - V_0 = 0, \end{cases} \quad (2)$$

where V_0 is the load voltage.

4. Performance Analysis

4.1. Type-1 Converter Performance Analysis. Based on the modal analysis of the converter and the principle of inductive volt-seconds balance, consider the relationship between the physical quantities for L_1 and L_2 for Type-1 converter in steady state:

$$\begin{cases} D \cdot V_i + (1-D)\left(V_i - V_{C_2}\right) = 0, \\ D \cdot V_i - (1-D).V_{C_1} = 0, \\ D \cdot V_{C_2} + (1-D)\left(V_i + V_{C_1} - V_{C_3}\right) = 0, \end{cases} \quad (3)$$

where D is the PWM duty cycle.

Simplifying equation (4), the capacitor voltages V_{C_1}, V_{C_2}, and V_{C_3} can be obtained as

$$\begin{cases} V_{C_1} = \dfrac{D}{1-D} V_i, \\ V_{C_2} = \dfrac{1}{1-D} V_i, \\ V_{C_3} = \dfrac{1}{(1-D)^2} V_i. \end{cases} \quad (4)$$

This gives the voltage gain of Type-1 converter as

$$G = \frac{V_0}{V_i} = \frac{2-D}{(1-D)^2}. \quad (5)$$

4.2. Type-1 Switching Tube Voltage Stress. Analyzing the operating principle of the converter, when the switching tube S_1 is switched off, the voltage stress across S_1 is

$$V_{S1} = V_{C_3} = \frac{1}{(1-D)^2} V_i. \quad (6)$$

Using Kirchhoff's law for capacitors C_1, C_2, C_3, C_0, the current flowing through the capacitor in a single cycle is equal to 0:

$$\begin{cases} \int_0^{DT} \left(i_{L_1\_on} - i_{in_o n}\right) dt + \int_{DT}^{T} \left(i_{L_1\_off} - i_{in_o ff}\right) dt = 0, \\ \int_0^{DT} \left(-i_{L_2\_on}\right) dt + \int_{DT}^{T} \left(i_{in_o ff} - i_{L_2\_on}\right) dt = 0, \\ \int_0^{DT} \left(i_{L_1\_on} - i_{in_o n}\right) dt + \int_{DT}^{T} iL_{2-off} dt = 0, \\ \int_0^{DT} \left(i_{in_o n} - i_{L_1\_on} - I_0\right) dt + \int_{DT}^{T} (-I_0) dt = 0. \end{cases} \quad (7)$$

Assuming that the inductance is large enough and the inductor current is continuous, the average current flowing through the inductor can be expressed by the following equation:

$$I_L = \frac{1}{DT} \int_0^{DT} i_{L\_on} dt = \frac{1}{(1-D)T} \int_{DT}^{T} i_{L\_off} dt. \quad (8)$$

According to (7), (8) can be obtained:

$$\begin{cases} I_{L_1} = \frac{2-D}{(1-D)^2} I_0, \\ I_{L_2} = \frac{1}{1-D} I_0, \end{cases} \quad (9)$$

where I_{L_1}, I_{L_2} represent the average current flowing through inductors L_1, L_2, respectively. When the switch is closed, the current flowing through the switching tube S_1 is

$$i_{S1} = \frac{1 + D - D^2}{D(1-D)^2} I_0. \quad (10)$$

In turn, the flow through the switching tube can be obtained:

$$I_{S1} = \frac{1 + D - D^2}{2-D} I_{in}. \quad (11)$$

4.3. Type-2 Converter Performance Analysis. Based on the volt-seconds balance principle for inductors, consider the relationship between the physical quantities for L1 and L2 for Type-2 converter at steady state:

$$\begin{cases} D \cdot V_i + (1-D)\left(V_i - V_{C_1}\right) = 0, \\ D \cdot V_{C_1} + (1-D)\left(V_{C_1} - V_{C_2}\right) = 0, \\ D \cdot V_{C_1} + (1+D)\left(V_{C_1} - V_{C_3}\right) = 0. \end{cases} \quad (12)$$

Simplifying equation (14) gives the capacitance voltageV_{C_1}, V_{C_2}, V_{C_3}, respectively:

$$\begin{cases} V_{C_1} = \frac{1}{1-D} V_i, \\ V_{C_2} = \frac{1}{(1-D)^2} V_i, \\ V_{C_3} = \frac{1}{(1-D)^2} V_i. \end{cases} \quad (13)$$

This leads to the voltage gain of Type-2 converter:

$$G = \frac{V_0}{V_i} = \frac{2}{(1-D)^2}. \quad (14)$$

5. Simulation and Testing

To verify the correctness of the theoretical analysis and topology of the non-isolated modified quadratic boost high-gain DC-DC converter, a simulation model of the converter was built in MATLAB and a Type-2 converter prototype was fabricated. $V_{in} = 10$ V, $L_1 = 220\,\mu$H (20 mΩ), $L_2 = 1$ mH (0.15Ω), $C_1 = 22\,\mu$F (20 mΩ)$C_2 = C_3 = 4.7\mu$F (20 mΩ), $C_0 = 100\mu$F (20 mΩ),$C_0 = 100\,\mu$F (20 mΩ),MOSFET ($r_s = 12$ mΩ, $t_r = 31$ ns) Diode VD0 to VD4 forward voltage drop VF = 0.7 V, $R = 100\ \Omega$, $D = 0.6$, and switching frequency $f = 50$ kHz.

5.1. Simulation Results. Taking into account the internal resistance of each component, the simulation results in MATLAB are shown in Figures 4 and 5.

From Figures 4 and 5, it can be seen that with input Vin = 10 V and duty cycle $D = 0.6$, the voltage stress on switching tube S1 is 60 V and the output voltage is 103 V.

5.2. Test Results. The test results are shown in Figures 6–8. It can be seen that when the input Vin = 10 V and $D = 0.6$, the output voltage is 103 V and the voltage stress on switch S1 is 59 V, which is basically the same as the simulation results. Many concepts in buck converter, such as duty cycle, pwm/pfm, efficiency, ripple, loss, synchronous rectification, and so on (including the volt second rule mentioned later) are common to boost converter (that is, the concepts are suitable for other converters). Because there are too many concepts of switching power supply, it is not suitable to be described in one section. Therefore, if the description is not particularly necessary, it will not be reintroduced to avoid taking up space.

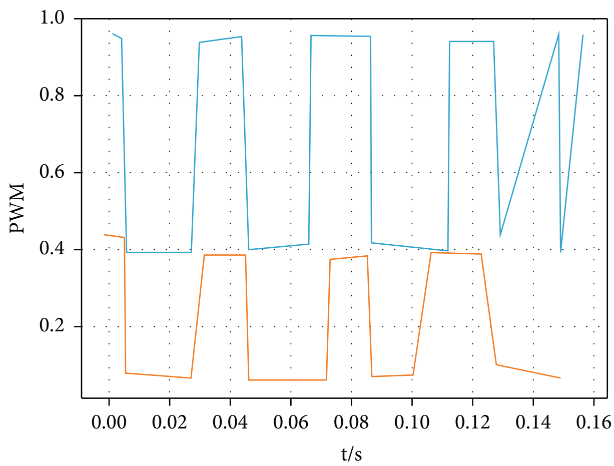

FIGURE 4: PWM drive signal and voltage stress of the switching tube (simulation).

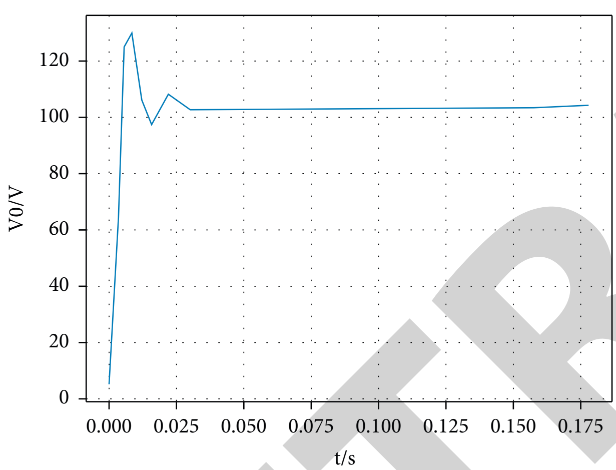

FIGURE 5: Output voltage of the converter (simulation).

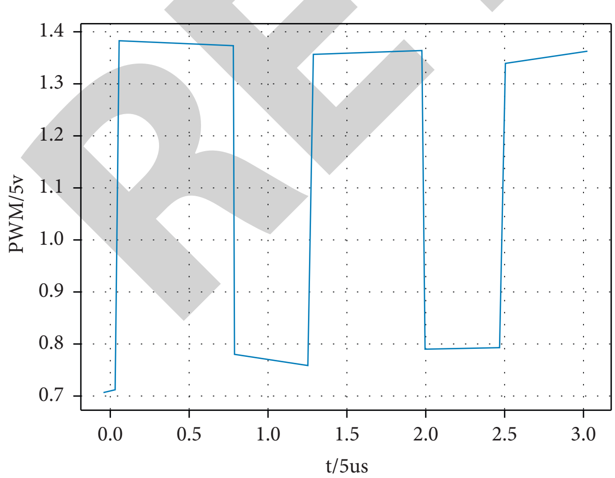

FIGURE 6: PWM drive signal for switching tubes (test).

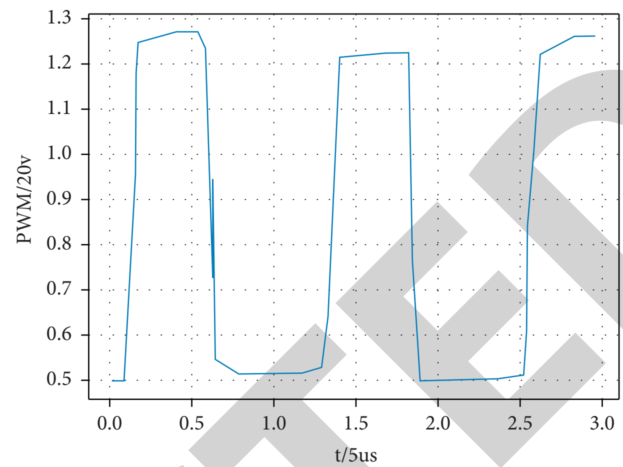

FIGURE 7: Voltage stress on the switching tube (test).

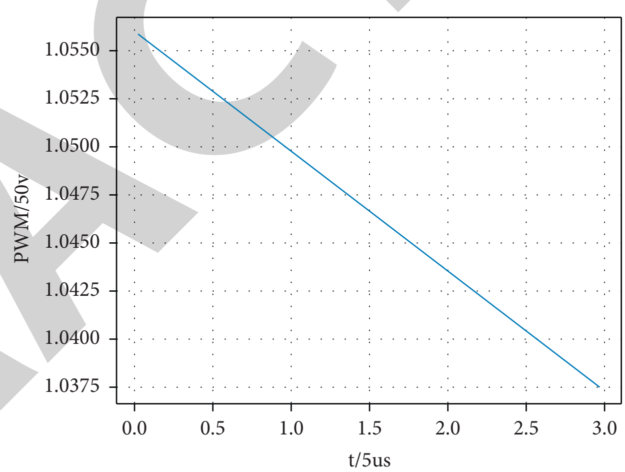

FIGURE 8: Output voltage of the converter (test).

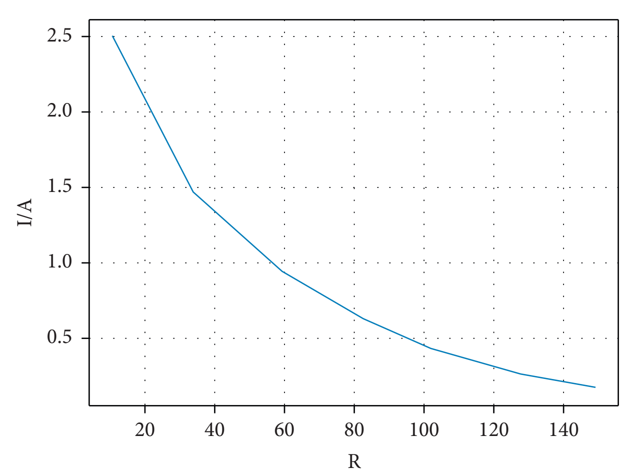

FIGURE 9: $I_0 - R$ curve of the transducer.

The actual output voltage is slightly lower than the theoretical value (125 V) due to the conduction losses of the components. With a constant input voltage of Vin = 10 V and varying the load resistance of the converter, the I_0-R curve of Type-2 converter is shown in Figure 9. Here we can know that the result has changed

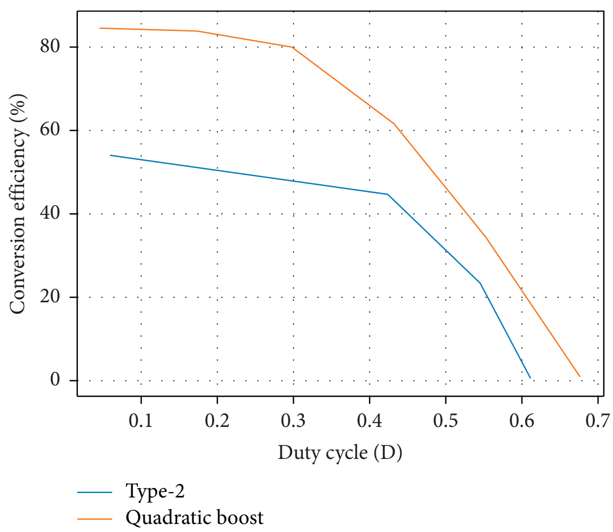

FIGURE 10: Efficiency curve of the converter.

from time-varying to non-time-varying. This second-order non-linear device has to be eliminated. It is called averaging in the book, which eliminates the time difference in the dynamic characteristics of the power stage, but it brings non-linearity to the average model of the power stage. Those who have studied automatic control know that we can introduce small-signal disturbance (take a small part of the curve as a straight line) and then separate variables to obtain a linear model.

As can be seen from Figure 9, the output voltage of the converter is relatively stable when the input voltage is constant and does not change with the load resistance.

When $\mathrm{Vin} = 10\,\mathrm{V}$ and $R = 100\,\Omega$, the curves of the conversion efficiency of Type-2 converter and the secondary boost converter with duty cycle are shown in Figure 10.

As can be seen from Figure 10, the conversion efficiency of Type-2 converter is significantly higher than that of the secondary boost converter under the same input conditions, and the conversion efficiency of both converters decreases with increasing duty cycle because the conduction losses on each component increase with increasing duty cycle, with diode conduction losses accounting for a larger proportion.

6. Conclusions

In order to achieve higher gain and lower switching stress, a non-isolated modified quadratic boost high-gain DC-DC converter is proposed, and two topologies of the converter are obtained. The proposed converter is analyzed in continuous mode, and the voltage gain, switching stress, voltage stress, and current stress on the diodes of the two topologies are derived, and the performance of Type-2 converter is found to be better than that of Type-1 converter. Finally, the theoretical analysis was verified by simulation and test, and the high gain and low stress characteristics of Type-2 converter were confirmed.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding this work.

Acknowledgments

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