# Simulation Study Based on a Novel High-Gain Boost Converter (Postprint)

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**Date:** 2018-10-26T00:00:00+00:00

## Abstract

High-gain DC/DC converters have found extensive applications in photovoltaic systems, new energy sources, and aerospace fields. To improve the reliability of Boost circuits in high-gain applications, a novel high-gain Boost converter is proposed. This new topology integrates a switched-capacitor unit and a coupled-inductor boost unit into the conventional Boost circuit, allowing high output voltage to be achieved with a relatively moderate duty ratio while simultaneously reducing the voltage stress on the switching devices and the input current ripple, thus enhancing the converter efficiency. The operating principle and steady-state characteristics of the circuit are analyzed in detail, and the corresponding control strategy is presented. Experimental verification is subsequently performed using PSIM simulation software. The simulation results confirm that the proposed novel high-gain Boost converter is theoretically correct and feasible.

## Full Text

## Preamble

**Volume 13, Issue 10**
**DOI: 10.11985/2018.10.003**
**JOURNAL OF ELECTRICAL ENGINEERING**

**Simulation Research Based on a New High Gain Boost Converter**

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## Abstract

High gain DC/DC converters have been widely used in photovoltaic systems, new energy applications, and aerospace power systems. To improve the reliability of Boost converters in high-gain applications, this paper proposes a novel high-gain Boost converter. The proposed converter incorporates a switched-capacitor unit and a coupled-inductor voltage multiplier unit into the traditional Boost topology, enabling high output voltage with a reasonable duty cycle while reducing the voltage stress on the switching device and input current ripple, thereby improving converter efficiency. The operating principle and steady-state characteristics are analyzed in detail, and the control strategy is presented. Experimental verification is performed using PSIM simulation software. The simulation results demonstrate that the proposed high-gain Boost converter is theoretically correct and feasible.

**Keywords:** High gain Boost circuits, coupled inductor, simulation

## 1 Introduction

Energy shortage is a pressing global issue. With the emergence of new energy sources such as photovoltaic, wind power, and fuel cells, grid-connected renewable energy systems require DC power converters with higher voltage transfer ratios. Non-isolated power topologies are favored by researchers due to their compact size. The main non-isolated step-up circuits include Boost, Buck-Boost, and various derived topologies. However, Buck-Boost circuits can only achieve voltage step-up when the steady-state duty cycle $D > 0.5$, and the output voltage polarity is inverted. Therefore, the Boost circuit, which can achieve step-up operation across the entire range $0 < D < 1$, is the preferred choice for increasing output voltage in grid-connected systems.

The voltage gain of a traditional Boost converter is $1/(1 - D)$. While theoretically the output voltage can approach infinity as D approaches 1, practical limitations in voltage and current ratings of components such as capacitors and inductors prevent the use of extremely high duty cycles to increase gain. Several methods have been proposed in the literature to enhance Boost converter gain.

Reference [1] proposes a single-switch dual-inductor high-gain Boost converter utilizing the characteristic of parallel charging and series discharging of inductors and capacitors. This converter features a simple structure and easy control. Compared with the circuit proposed in this paper, the topology in [1] uses fewer components, which can reduce converter volume, weight, and cost, but its gain improvement is limited—only twice that of the conventional Boost converter. Reference [2] presents an interleaved high-gain Boost converter with a switched-capacitor network, which reduces input current ripple and increases voltage gain. However, compared with the traditional Boost converter, the gain improvement is only $2(1 + D)$ times, and the additional switches in the parallel structure increase switching losses, which is detrimental to efficiency improvement. Reference [3] combines voltage self-lifting technology with quadratic converter characteristics to propose a novel high-gain converter, but the bootstrap voltage unit provides limited gain improvement. Reference [4] integrates switched-inductor, switched-capacitor, and bootstrap voltage techniques to achieve a high-gain, high-efficiency Boost converter, though the input current ripple remains significant. Reference [5] introduces a coupled-inductor voltage multiplier unit and a zero input current ripple unit to improve conversion gain and reduce input current ripple, but the complex topology and tedious parameter design make control difficult.

[Figure 1: see original paper] Traditional Boost converter topology

The traditional Boost converter has limited voltage step-up capability. To achieve higher output voltage at the same duty cycle, this paper proposes a novel high-gain Boost circuit, as shown in [Figure 2: see original paper]. The new Boost circuit incorporates switched-capacitor and coupled-inductor voltage multiplier units into the traditional Boost topology to increase circuit gain, reduce switching device stress, minimize input current ripple, and improve efficiency. The circuit consists of coupled inductors L1 and L2, diodes VD1–VD4, capacitors C1–C5, input voltage source Vin, switch Q, and load resistor R.

[Figure 2: see original paper] New high gain Boost converter

## 2 Converter Topology and Operating Principle

### 2.1 Converter Topology

To simplify analysis, the following assumptions are made: (1) The circuit operates in Continuous Conduction Mode (CCM); (2) All circuit components are ideal; (3) The switching frequency is much higher than the characteristic frequency; (4) The load is purely resistive; (5) The coupling coefficient of inductors L1 and L2 is 1.

### 2.2 Operating Principle

When the circuit operates in steady state, there are two operating modes during one switching period T based on the switching state of the power switch.

(1) **Mode 1 (t0 t t0 + dT):** Switch Q is turned on, diodes VD1 and VD3 are reverse-biased and cut off, while VD2 and VD4 conduct forward. As shown in [Figure 3: see original paper] (solid lines indicate on-state, dashed lines indicate off-state), the input voltage Vin charges L1, causing the inductor current to rise linearly. Due to the coupled inductor, L2 charges C2 through VD2. Meanwhile, C4 charges C5 through VD4, and C4 and C3 supply power to the load.

[Figure 3: see original paper] Mode 1

Applying Kirchhoff' s voltage law, the voltage across each component and the relationship of the input inductor current can be expressed as:

$$i_{L1}(t) = I_{L1}(t_0) + \frac{(t - t_0)}{L_1} V_{in}$$

$$V_{C2}(t) = \frac{V_{in}}{N}$$

where d is the duty cycle of any switching period, iL1(t) is the current through inductor L1 at time t (similar notation applies to other variables), and N is the turns ratio of inductor L1 to inductor L2.

(2) **Mode 2 (t0 + dT t t0 + T):** Switch Q is turned off, diodes VD2 and VD4 are reverse-biased and cut off, while VD1 and VD3 conduct forward. The voltage polarity of inductor L1 reverses, and its current decreases linearly. As shown in [Figure 4: see original paper], L2 charges C1, while C3 and C4 supply power to the load. The voltage relationships and inductor L1 current in this mode are:

$$i_{L1}(t) = I_{L1}(t_0 + dT) - \frac{V_{C5}(t) + V_0 - V_{in}}{L_1}(t - t_0 - dT)$$

[Figure 4: see original paper] Mode 2

The main operating waveforms of the proposed high-gain Boost circuit in CCM are shown in [Figure 5: see original paper].

[Figure 5: see original paper] The main waveforms of new high gain Boost converter

## 3 Steady-State Characteristics and Analysis

### 3.1 Steady-State Characteristics

In steady state, inductors are treated as short circuits and capacitors as open circuits. Based on equations (2)-(9) and applying the volt-second balance principle, we obtain:

$$DV_{in} = (1 - D)\frac{V_{in}}{1 + N^2}$$

Therefore, the voltage gain M of the circuit is:

$$M = \frac{V_0}{V_{in}} = 2\left[\frac{N^2}{1 - D} + 1\right]$$

Equation (11) shows that the circuit gain is at least twice that of the traditional Boost converter.

### 3.2 Voltage Stress Analysis

Voltage stress analysis is crucial for schematic parameter design and component selection. In DC/DC switching circuits, most losses come from switching and conduction losses of the power switch, which becomes particularly significant in high-frequency applications. The voltage stress on switch Q is:

$$V_Q = V_0 - V_{C5}$$

where VQ is the voltage across switch Q.

The voltage stresses on each diode are:

$$V_{VD1} = V_{VD2} = V_{C1}$$

$$V_{VD3} = V_0 - V_{C4}$$

$$V_{VD4} = V_{C3}$$

### 3.3 Voltage Gain Comparison Analysis

A comparison of several gain enhancement methods proposed in existing literature is presented in .

Voltage gain comparison

| Gain Enhancement Method | Circuit Gain M |
|---|---|
| Based on switched-capacitor network with interleaved parallel structure | 3/(1 - D) |
| Bootstrap voltage combined with quadratic conversion | 1 + 1/(1 - D) |
| Switched-inductor, switched-capacitor combined with bootstrap voltage | 3(1 + D)/(1 - D) |
| Method proposed in this paper | $2[1/N^2 + 1/(1 - D)]$ |

According to , when D (2 - N)/(2 + 3N), the gain enhancement method proposed in this paper provides more significant improvement compared with the switched-inductor, switched-capacitor, and bootstrap voltage combination method at the same duty cycle.

## 4 Circuit Control Strategy

The circuit employs peak current mode PWM control with a classical PI controller. The control block diagram is shown in [Figure 6: see original paper]. In the dual-loop control scheme, the inner current loop improves response speed, while the outer voltage loop ensures steady-state accuracy. The PI controller transfer function is:

$$G(s) = K\left(1 + \frac{1}{s\tau}\right)$$

where K is the proportional coefficient,   is the time constant, and s is the complex frequency domain variable.

For stable and reliable system operation, the voltage loop parameters are set to K = 0.01,   = 5 ms, and the current loop parameters to K = 10,   = 10 ms.

In [Figure 6: see original paper], Gc is the voltage compensator transfer function of the high-gain Boost circuit (i.e., the PI controller transfer function); Hv is the voltage sampling function; Hc is the current sampling function; Fg, Fm, and Fv are disturbance coefficients related to steady-state duty cycle, switching period, and slope compensation; Gvg, Gvd, Gig, and Gid are the transfer functions from output-to-input, output-to-control, inductor current-to-input, and inductor current-to-control, respectively.

[Figure 6: see original paper] Control block diagram

## 5 Simulation Verification and Analysis

### 5.1 PSIM Simulation Verification

PSIM (Power Simulation) is a simulation package oriented toward power electronics and motor control applications, consisting primarily of SIMCAD and SIMVIEM. It offers fast simulation speed, a user-friendly interface, and waveform analysis capabilities. This study uses the PSIM simulation environment. The experimental parameters for the high-gain Boost circuit are listed in prior to verification.

Experimental parameters and indexes

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Input voltage Vin (V) | 12 | Energy storage capacitor C3 ( F) | 470 |
| Output voltage V0 (V) | 80 | Energy storage capacitor C4 ( F) | 470 |
| Output power P0 (W) | 200 | Switching frequency f (kHz) | 50 |

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Energy storage capacitor C1 ( F) | 470 | Energy storage capacitor C2 ( F) | 470 |
| Energy storage capacitor C5 ( F) | 470 | Energy storage inductor L1 (mH) | 1 |
| Energy storage inductor L2 (mH) | 1 | Load resistor R (Ω) | 32 |

The steady-state duty cycle is 0.5, sampling time is set to 0.6 s, and sampling step size is 1  s. The simulation waveforms of the proposed high-gain Boost circuit are shown in [Figure 7: see original paper].

[Figure 7: see original paper] Simulation waveforms of new high gain Boost converter

Figure 7a shows the input and output voltage waveforms. When the input voltage is 12 V, the output reaches 80 V in steady state. Figure 7b shows the output voltage and switch Q voltage stress waveform, demonstrating that the switch voltage stress is half of the output voltage, reducing the voltage stress and allowing the selection of lower voltage-rated switches to minimize switching and conduction losses. Figure 7c shows the voltage stress waveforms of capacitor C5 and diode VD1; the voltage across C5 is half of the output voltage, which matches equation (12) and improves circuit reliability. Figure 7d shows the dynamic response when the output voltage suddenly increases by 10 V at 0.3 s. The response time is approximately 15 ms, with a steady-state voltage of 80.04 V, indicating good steady-state performance and effective control strategy. Figure 7e shows the input current ripple, which is small, demonstrating that the circuit effectively suppresses input current ripple.

These experimental results verify the correctness of the theoretical analysis.

### 5.2 Efficiency Analysis

The simulated efficiency of the proposed high-gain Boost converter at rated output power is 82.16%. The efficiency variation trend from no-load to full-load conditions is shown in [Figure 8: see original paper].

[Figure 8: see original paper] Efficiency change curve

The efficiency curve shows that system efficiency first increases and then decreases with output power, reaching its maximum of 82.16% at rated load. The relatively low efficiency in simulation is due to the long complete turn-off time of the switch in the simulation model (approximately 0.3(1 - D)T, as shown in [Figure 7b: see original paper]), which results in significant turn-off losses and reduces overall system efficiency. In practical circuit implementation, the switch turn-on and turn-off times are much shorter, yielding higher efficiency than in simulation.

## 6 Conclusion

This paper proposes a high-gain DC/DC Boost converter for renewable energy grid-connected power systems. By combining a coupled-inductor voltage multiplier unit and a switched-capacitor boost unit, the converter achieves continuous inductor current and high voltage gain, producing higher DC steady-state voltage at the same duty cycle while reducing voltage stress on both the switch and diodes. This allows selection of power switches with lower on-resistance to decrease switching and conduction losses. The operating principle is introduced, steady-state characteristics are derived, and the system demonstrates good dynamic performance and stability under closed-loop control. Efficiency analysis shows that proper circuit design can achieve optimal operating efficiency. Simulation results confirm the feasibility of the proposed converter.

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*Note: Figure translations are in progress. See original paper for figures.*