How to Improve the Step-up Ratio of DC Converter by Coupling Inductance and Switching Capacitance

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Abstract. In grid-connected power generation system, the output voltage of single photovoltaic module and fuel cell is generally low. In order to meet the requirements of the latter grid-connected inverters, DC converters need to have a high boost ratio to raise the output voltage of photovoltaic cells or fuel cells to a higher voltage. A high boost ratio DC/DC converter based on switched capacitor and coupled inductance is proposed in this paper. Coupled inductance is introduced on the basis of switched capacitor high boost ratio DC/DC converter. The voltage stress of power devices is reduced, and the conduction loss and switching loss are also reduced, which can effectively improve the conversion efficiency. Finally, the experimental results verify that using the coupled inductance could make the DC converter have higher conversion efficiency.

Keywords: High Step-Up Ratio, Switching Capacitance, Coupling Inductance, DC Converter Introduction

1. Introduction
In the grid-connected photovoltaic or fuel cell power generation system, a DC converter is usually used to raise the output voltage of photovoltaic or fuel cell to a higher voltage to meet the requirements of the latter grid-connected inverter [1][2]. Because the output voltage of single photovoltaic module and fuel cell is generally lower, and the DC voltage of the latter grid-connected inverter is higher, the DC converter needs a high boost ratio [3]. In this article, aiming at the situation without the requirement of electrical isolation, the method to improve the boost ratio of DC converter is studied, and these data obtained by the prototype are verified.

2. High Boost Ratio Converter with Composite Switched Capacitor
According to the principle of switching capacitance’s parallel charging and switching capacitance’s series discharge, switched capacitor converters may achieve high boost ratio, but it cannot adjust the output voltage and the boost ratio is constrained by the circuit structure [4][5]. The first circuit designed in this paper is based on Boost converter [6], which combines switched converter and switched capacitor. It is called high boost ratio converter with composite switching capacitance, as shown in Fig. 1.
When the inductance current is continuous, the converter has two working modes. When the switch Q is on, the energy of inductance L can be stored by the input voltage source. At the same time, C2 is connected in series with the input voltage source by the switch Q and C3, and then supplies power to the load through the diode D0. When Q is off, the inductance C3 is charged, while C2 is charged by the input voltage source in series, and the load is supplied by the output filter capacitor Cf. The voltage ratio of converter with composite switching capacitance is higher than Boost converter, and the voltage ratio of the converter with composite switching capacitance can be improved by increasing the number of switched capacitors in series, which can supply power to the load. And increasing inductance in series with the input source can supply power to the load, as shown in Fig. 2.

**Figure 1.** High boost ratio converter with composite switching capacitance

**Figure 2.** Multi-inductance energy storage unit composite switched capacitor high boost ratio converter
3. Composite Switching Capacitance DC Converter with High Boost Ratio Using Coupling Inductance

The first method is to increase the step-up ratio by means of increasing the number of switching capacitors in series [7][8]. This method needs more passive components such as inductance and capacitance, and has complex structure and high cost [9]. Therefore, the coupling inductance can be introduced and used in combination with the switched capacitor [10]. While the switch Q is turned off, the switching capacitor can be charged by the original side of the coupling inductance which is connected in series, and the turn ratio is used to increase the switching capacitor voltage. When the switch is on, the power of the load can be supplied by the switching capacitor and the secondary side of the coupling inductance which are connected in series, which further improves the step-up ratio of the converter, as shown in Fig. 3.

![Figure 3. A high Step-up ratio DC/DC converter with a coupling inductance and a composite switching capacitance](image)

4. Experimental Results

Based on the circuit principle mentioned above, the experimental comparison between the composite switching capacitance high step-up ratio DC converter with coupling inductance and the composite switching capacitor high step-up ratio DC converter with single inductance energy storage unit is carried out.

The experimental results include two aspects: (1) Fig. 4 shows the simulation waveform of these two circuits. Among them, $V_{ds}$ is the switch voltage between the drain pole and the source pole, $V_{D2}$ and $V_{D3}$ are the voltage of diode $D_2$ and $D_3$ respectively. If turn off the switch, because the leakage inductance of the coupling inductance will oscillate with the junction capacitance of the switch, the $V_{ds}$ waveform is slightly higher at the moment of the switch is turned off, but it is still far less than the voltage stress of the switch with high boost ratio of the switching capacitor, which greatly reduces the switching loss and it is beneficial to the improvement of the efficiency of the converter. (2) Fig. 5 shows the efficiency comparison between the composite switched capacitor high step-up ratio DC converter and the composite switching capacitance high step-up ratio DC converter with coupling inductance. After using the coupling inductance, the efficiency of the converter in the full load range is improved, up to 96.5%, because the voltage stress of the switch is greatly reduced and the switching loss is reduced.
(a) Voltage waveform at $V_g=36V$ High Step-up Ratio DC Converter with Coupling Inductance Composite Switching Capacitance

(b) Voltage waveform at $V_g=36V$ Compound Switched Capacitor DC Convert with High Boost Ratio

(c) Voltage waveform at $V_g=45V$ High Step-up Ratio DC Converter with Coupling Inductance Composite Switched Capacitor

(d) Voltage waveform at $V_g=45V$ Compound Switched Capacitor DC Convert with High Boost Ratio

**Figure 4.** Comparison of voltage waveform of high step-up ratio DC converters with coupling inductance and composite switching capacitors

Efficiency of Coupled Inductance Composite Switched Capacitor DC Converter with High Sep-up Ratio

Efficiency of Compound Switched Capacitor DC Converter with High Boost Ratio

**Figure 5.** Comparison of measure efficiency of composite switched capacitor and coupled inductance composite switched capacitor converter
5. Conclusion

On the basis of switched capacitor DC converter with high step-up ratio, coupling inductance is introduced. When the switch is turned off, the original side is connected in series to supply energy to the switched capacitor to increase the switched capacitor voltage; if turned on the switch, the energy of the load can be supplied by the switching capacitance and the coupling inductance sides are connected in series, which further improves the boost ratio of the converter. By comparing the conversion efficiency of these two DC converters, the results show that the coupled inductance composite switched capacitor DC converter designed in this paper has higher boost ratio.

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