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A Transformer Less High Step up DC-DC Converter Based on Cockcroft Walton Voltage Multiplier for Grid Tied System

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Abstract : *In this project, a transformer less high step-up DC-DC converter based on Cockcroft Walton voltage multiplier is proposed. Normally batteries, fuel stacks, solar cells are operated at low voltages. In order to connect grid tied systems, there should be a high voltage gain and low voltage stress on the switches, diodes and capacitors. For an n-stage Cockcroft Walton voltage multiplier, the proposed converter can provide suitable dc source for n+1 level multi-level inverter. In this project, the proposed control strategy employs two different frequencies; one is operated at high frequency in order to reduce size of the inductor, while the other is operated at low frequency according to the desired output voltage.*
Keywords: *Multiplier, Walton voltage, Converter, Tied system, Control system*

I. Introduction

The extensive use of electrical equipment has imposed severe demands for electrical energy and this trend is constantly growing. The conventional boost DC-DC converter can provide a very high voltage gain by using an extreme high duty cycle. The step-up dc-dc converters have been proposed to obtain high voltage ratios without extreme high duty cycle by using isolated transformers or coupled inductors. The current fed converters are providing low input current ripple and high voltage ratio. Modified current-fed converters integrated with step-up transformers or coupled-inductors which focused on improving efficiency and reducing voltage stress, were presented to achieve high voltage gain without extreme high duty cycle. The design of the high-frequency transformers, coupled inductors or resonant components for these converters are relatively complex compared with the conventional boost DC-DC converter. The step-up DC-DC converters without step-up transformers and coupled inductors were presented. By cascading diode-capacitor or diode-inductor modules, these kinds of DC-DC converters provide not only high voltage gain but also simple and robust structures. The conventional Cockcroft-Walton voltage multiplier is very popular among high voltage DC applications. Replacing the step-up transformer with the boost type structure, the proposed converter provides higher voltage ratio than that of the conventional CW voltage multiplier. The proposed converter operates in continuous conduction mode, so that switch stresses, the switching loss, and EMI noise can be reduced.

The various components that are required for the construction of the high step up DC-DC converter using Cockcroft Walton voltage multiplier have been described. The AC source is supplied to diode bridge rectifier and its output is connected with DC filter to produce pure DC voltage from pulsating DC voltage. Then the DC voltage is applied to boost converter with voltage multiplier. The conventional boost DC-DC converter can provide a very high voltage gain by using an extreme high duty cycle. The step-up DC-DC converters have been proposed to obtain high voltage ratios without extreme high duty cycle by using isolated transformers or coupled inductors. The simulation details of the DC-DC boost converter using n-stage Cockcroft Walton voltage multiplier. The simulation is done by using MATLAB Simulink software.

II. DC DC Converters

Theoretically, the conventional boost dc-dc converter can provide a very high voltage gain by using an extremely high duty cycle. However, practically, parasitic elements associated with the inductor, capacitor, switch, and diode cannot be ignored, and their effects reduce the theoretical voltage gain. Up to now, many step-up dc-dc converters have been proposed to obtain high voltage ratios without extremely high duty cycle by using isolated transformers or coupled inductors.

However, the design of the high-frequency transformers, coupled inductors, or resonant components for these converters is relatively complex compared with the conventional boost dc-dc converter.

Some other alternative step-up dc-dc converters without step-up transformers and coupled inductors were presented in. By cascading diode–capacitor or diode-inductor modules, these kinds of dc-dc converters provide not only high voltage gain but also simple and robust structures. Moreover, the control methods for conventional dc-dc converters can easily adapt to them. However, for most of these cascaded structures, the voltage stress on each individual switch and passive element depends on the number of stages. Fig. 2.1 shows an *n*-stage cascade boost converter proposed in for obtaining a high voltage gain.

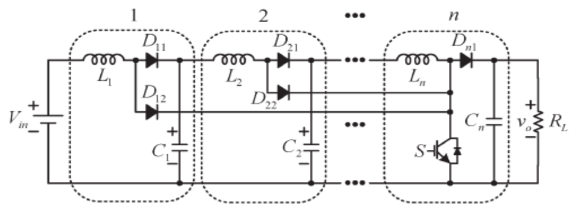

Fig 1: n cascade boost converter

Fig. 2.2 shows one of these topologies in, which consists of a conventional boost converter and an *n*-stage diode–capacitor multiplier. The main advantage of this topology is that higher voltage gain can easily be obtained by adding the stages of the diode-capacitor multipliers without modifying the main switch circuit. Nevertheless, the voltage across each capacitor in each switched-capacitor stage goes higher when a higher stage converter is used.

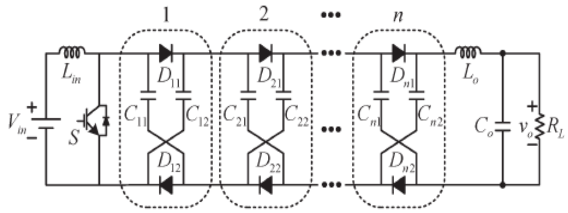

Fig 2:Diode-capacitor *n*-stage step-up multiplier

In this paper, a high step-up converter based on the CW volt-age multiplier is proposed. Replacing the step-up transformer with the boost-type structure, the proposed converter provides higher voltage ratio than that of the conventional CW voltage multiplier. Thus, the proposed converter is suitable for power conversion applications where high voltage gains are desired. Moreover, the proposed converter operates in continuous conduction mode (CCM), so the switch stresses, the switching losses, and EMI noise can be reduced as well. The proposed converter deploys four switches, in which S_{c1} and S_{c2} are used to generate an alternating source to feed into the CW voltage multiplier and S_{m1} and S_{m2} are used to control the inductor energy to obtain a boost performance.

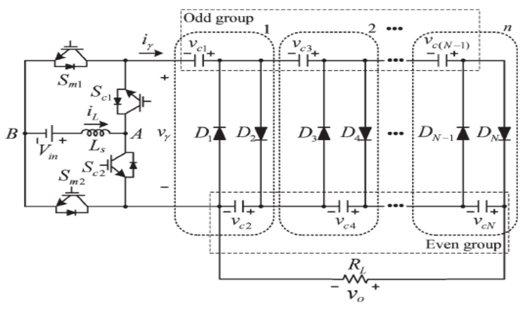

Fig 3: Proposed n-stage Cockcroft Walton multiplier

Nevertheless, the proposed converter still demonstrates some special features:

1) The four switches operate at two independent frequencies, which provide coordination between the output ripple and system efficiency.

2) With same voltage level, the number of semiconductors in the proposed converter is competing with some cascaded dc-dc converters.

III. Modeling For Proposed Circuit

In order to simplify the analysis of circuit operation, the proposed converter with a three-stage CW voltage multiplier, as shown in Fig 4, is used. Before analyzing, some assumptions are made as follows

1. All of the circuit elements are ideal, and there is no power loss in the system.
2. The proposed converter is operating in CCM and in the steady-state condition.

When the inductor transfers the storage energy to the CW circuit, only one of the diodes in the CW circuit will be conducted

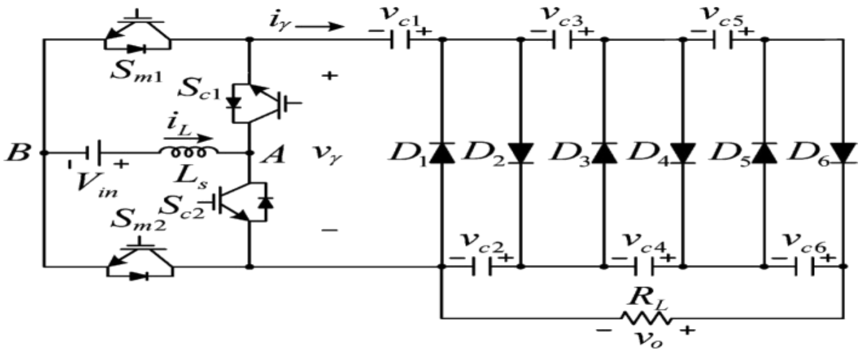

Fig 4: Proposed converter with 3-stage CW voltage multiplier

For an n-stage CW voltage multiplier, the output voltage is equal to the total voltage of all even capacitors, which can be expressed as

$$V_o = nV_c.$$

Fig. 5 shows the theoretical waveforms of the proposed converter, including switching signals, inductor current, v_γ , i_γ , and diode currents. According to the polarity of i_γ , the operation of the proposed converter can be divided into two parts: positive conducting interval $[t_0, t_1]$ for i_γ 0 and negative con-ducting interval $[t_1, t_2]$ for i_γ 0. During positive conducting interval, only one of the even diodes can conduct with the sequence $D_6-D_4-D_2$, while during negative conducting interval, only one of the odd diodes can conduct with the sequence $D_5-D_3-D_1$.

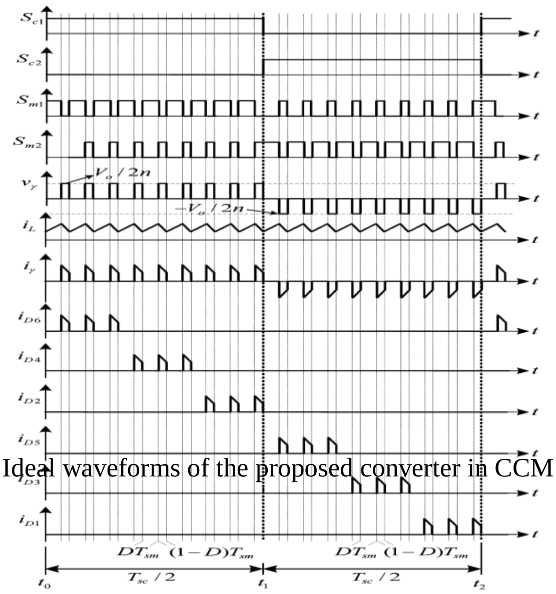

Fig 5: Ideal waveforms of the proposed converter in CCM.

Moreover, during positive conducting interval, there are four circuit states, as shown in Fig. 6(a)–(d), denoted as states I, II-A, II-B, and II-C. In state I, S_{m1} turns on; thus, the energy stored in the inductor increases. In states II-A, II-B, and II-C, S_{m2} turns on, and the inductor transfers energy to the CW circuit through D_6, D_4, and D_2, respectively. Similarly, there are four circuit states in the negative conducting interval, as shown in Fig. 6(e)–(h), denoted as states III, IV-A, IV-B, and IV-C.

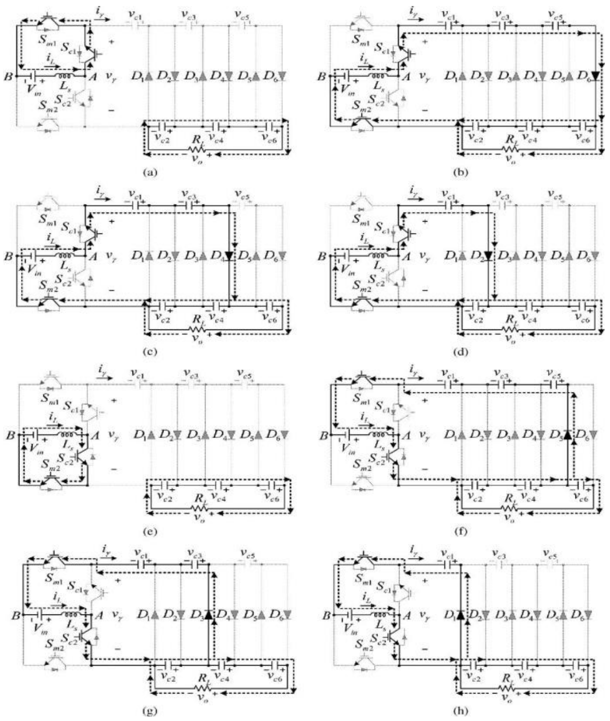

Fig 6: Conducting paths of proposed converter.

(a) State I. (b) State II-A. (c) State II-B. (d) State II-C. (e) State III. (f) State IV-A. (g) State IV-B. (h) State IV-C.

State I: S_{m1} and S_{c1} are turned on, and S_{m2}, S_{c2}, and all CW diodes are turned off, as shown in Fig. 6(a). The boost inductor is charged by the input dc source, the even-group capacitors C_6, C_4, and C_2 supply the load, and the odd-group capacitors C_5, C_3, and C_1 are floating.

State II: S_{m2} and S_{c1} are turned on, S_{m1} and S_{c2} are turned off, and the current i_γ is positive. The boost inductor and input dc source transfer energy to the CW voltage multiplier through different even diodes, as shown in Fig. 6(b)–(d).In fig 6(b) state II-A, D_6 is conducting; thus, the even-group capacitors C_6, C_4, and C_2 are charged, and the odd-group capacitors C_5, C_3, and C_1 are discharged by i_γ . In Fig. 6(c), state II-B, D_4 is conducting. Thus, C_4 and C_2 are charged, C_3 and C_1 are discharged by i_γ , C_6 supplies load current, and C_5 is floating. In Fig. 6(d), state II-C, D_2 is conducting. Thus, C_2 is charged, C_1 is discharged by i_γ , C_6 and C_4 supply load current, and C_5 and C_3 are floating.

State III: S_{m2} and S_{c2} are turned on, and S_{m1}, S_{c1}, and all CW diodes are turned off, as shown in Fig. 6(e). The boost inductor is charged by the input dc source, the even- group capacitors C_6, C_4, and C_2 supply the load, and the odd-group capacitors C_5, C_3, and C_1 are floating

State IV: S_{m1} and S_{c2} are turned on, S_{m2} and S_{c1} are turned off, and the current i_γ is negative. The boost inductor and input dc source transfer energy to the CW voltage multiplier through different odd diodes, as shown in Fig. 6(f)–(h). In Fig. 6(f), state IV-A, D_5 is conduct-ing. Thus, the even-group capacitors, except C_6 which supplies load current, are discharged, and the odd-group capacitors C_5, C_3, and C_1 are charged by i_γ . In Fig. 6(g), state IV-B, D_3 is conducting. Thus, C_2 is discharged, C_3 and C_1 are charged by i_γ , C_6 and C_4 supply load current, and C_5 is floating. In Fig. 6(h), state IV-C, D_1 is conducting. Thus, C_1 is charged by i_γ , all even capacitors supply load current, and C_5 and C_3 are floating.

IV. Control Strategy

In this paper, an average-current mode control will be used to design the PWM modulator in order to achieve the proposed converter in CCM. For facilitating design, this paper deploys ICE1PCS01 as the main controller for the PWM modulator, which adopts the quasi-steady-state approach by using one-cycle control technique on leading-edge modulation, as shown in Fig.7, in which the protective control devices are left out [34]. For the quasi-steady-state approach [35], the control aim is to provide a resistor emulator, making the input current i_L to be proportional to the input voltage V_{in}. Define the emulated resistance R_e as

$$R_e = \frac{v_{in}}{i_L}$$

Using one-cycle control technology on leading-edge modulation, the PWM modulator, as shown in Fig.7, is constructed by a constant time clock generator, a voltage comparator, an SR flip-flop, and a ramp waveform generator with reset. For practical applications, the average inductor current can be approximately equal to the instant inductor when the current ripple in the inductor is negligible during one modulation period

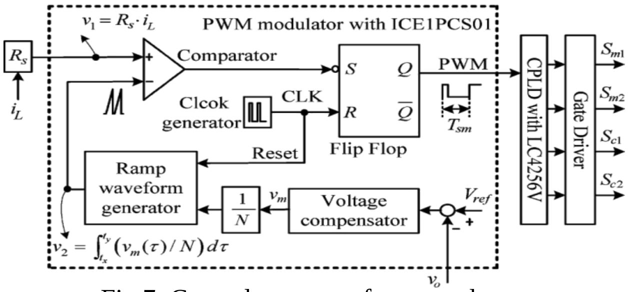

Fig 7: Control strategy of proposed converter

V. Simulation Diagram and Results

Moreover, Mat lab/ Simulink is applied to simulate the mathematic model and control strategy of the proposed converter. Some selected waveforms of the proposed converter at P_o = 200 W, V_{in} = 48 V, and V_o = 450 V for both simulation and experiment are shown in given Figures

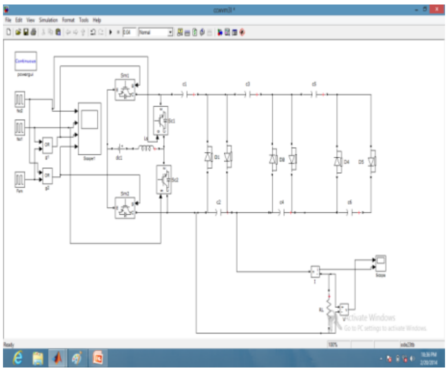

Fig 8: CW circuit

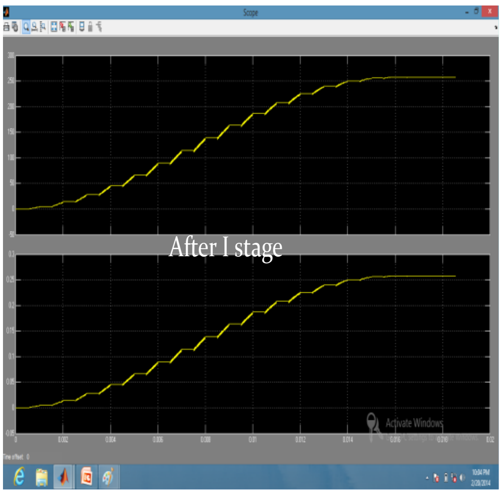

Fig 9: Voltage and current wave forms for CW I stage

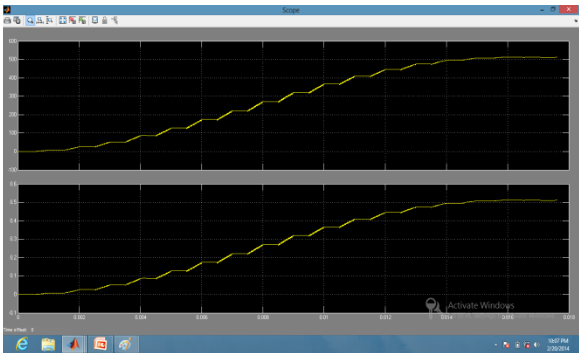

Fig 10: Voltage and current wave forms for CW II stage

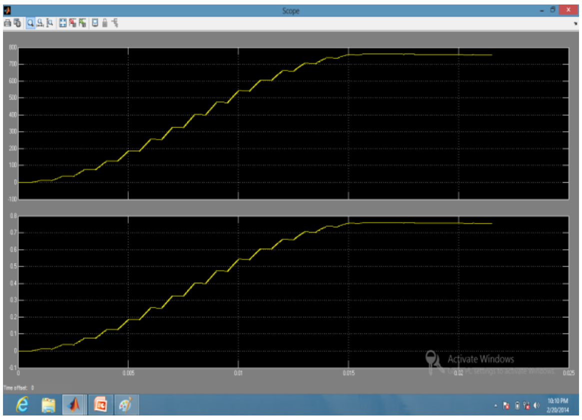

Fig 11: Voltage and current wave forms for CW III stage

VI. Conclusion

In this paper, a high step-up dc-dc converter based on the CW voltage multiplier without a line- or high-frequency step-up transformer has been presented to obtain a high voltage gain. Since the voltage stress on the active switches, diodes, and capacitors is not affected by the number of cascaded stages, power components with the same voltage ratings can be selected. The mathematical modeling, circuit operation, design considerations, and control strategy were discussed. The control strategy of the proposed converter can be easily implemented with a commercial average-current-control CCM IC with adding a programmed CPLD. The proposed control strategy employs two independent frequencies, one of which operates at high frequency to minimize the size of the inductor while the other one operates at relatively low frequency according to the desired output voltage ripple. Finally, the simulation and experimental results proved the validity of theoretical analysis and the feasibility of the proposed converter. In future work, the influence of loading on the output voltage of the proposed converter will be derived for completing the steady-state analysis.

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