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A High Step up DC-DC Converter using Cascade Cockcroft Walton Voltage Multiplier

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Abstract: *This project proposes an improved transformer less high step-up dc-dc converter using Cockcroft Walton voltage multiplier. The low input DC voltage is boost up by a boost inductor in DC-DC converter and the proposed circuit performs the inverter operation. The n-stage CW-voltage multiplier is applying low input AC voltage to high output DC voltage. It provides continuous input current with low ripple, high voltage gain, reduced switching losses, low voltage stress on the switches, diodes and capacitors and also improving efficiency of the converter. The power switches having 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. Voltage ripples produced during the motor operation is reduced in this proposed method. The main advantage of this project is that it increases the given input voltage by multiplying it without any use of transformer but just with the few switches, diodes and capacitor. The proposed converter can be applied to various applications like solar energy, fuel cells, hybrid vehicle.*

Keywords -*Cockcroft–Walton (CW) voltage multiplier, voltage gain step-up dc–dc converter*

I. Introduction

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. Among these high step-up dc-dc converters, voltage-fed type sustains high input current ripple. Thus, providing low input current ripple and high voltage ratio, current-fed converters are generally superior to their counterparts. However, in order to achieve high voltage gain, the leakage inductance of the transformer is relatively increased due to the high number of winding turns. Consequently, the switch is burdened with high voltage spikes across the switch at the turn-off instant. Thus, higher voltage-rating switches are required. 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 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.

II. Proposed High Step Up Dc-Dc Converter Using Cascade Cockcroft Walton Voltage Multiplier

The proposed converter block diagram is shown in Fig. 1 consists of several components in it such as DC source, improved boost converter, stacked Cockcroft Walton voltage multiplier, controller. The low dc source is provided to the improved boost converter where the low voltage is boosted to a certain amount according to the input voltage. The boosted voltage is given to the voltage multiplier and the voltage multiplier is stacked to improve the output voltage.

Due to the stacking of the voltage multiplier the low input voltage is multiplied to obtain a high output voltage without a transformer. The high output voltage is given to a load due to which the output voltage get voltage ripples which is controlled by the parallel inductor in the boost converter. The control circuit of the proposed converter is implemented using PIC microcontroller as PWM generator for gate supply.

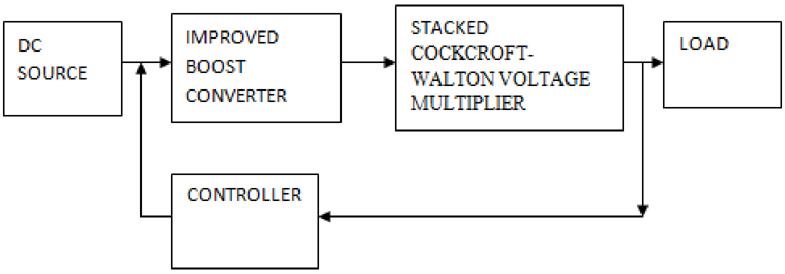

Fig 1 Proposed Converter Block Diagram

1.1 Circuit Diagram of Proposed Converter

Replacing the step-up transformer with the conventional CW voltage multiplier structure, the proposed converter provides higher voltage ratio.Fig. 2 shows the proposed converter, which is supplied by a low-level dc source, such as battery, PV module, or fuel cell sources.

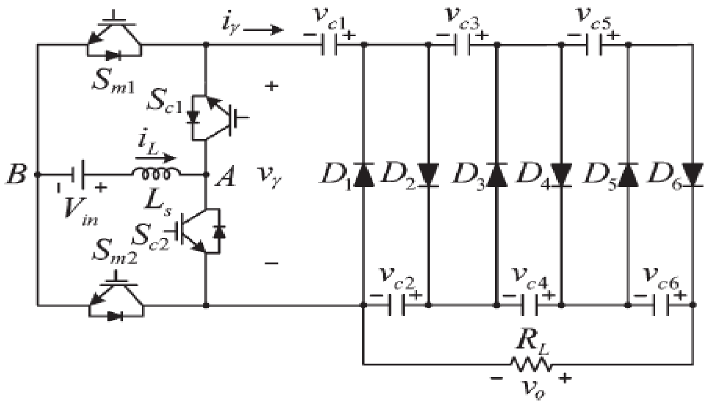

Fig. 2 Proposed converter with three-stage CW voltage multiplier.

The proposed converter consists of one boost inductor *Ls*, four switches (*Sm*1, *Sm*2, *Sc*1, and *Sc*2), and 3-stage CW voltage multiplier. *Sm*1(*Sc*1) and *Sm*2(*Sc*2) operate in complementary mode, and the operating frequencies of *Sm*1 and *Sc*1 are defined as *f*sm and *f*sc, respectively. For convenience, *f*sm is denoted as modulation frequency, and *f*sc is denoted as alternating frequency. Theoretically, these two frequencies should be as high as possible so that smaller inductor and capacitors can be used in this circuit. In this paper, *f*sm is set much higher than *f*sc, and the output voltage is regulated by controlling the duty cycle of *Sm*1 and *Sm*2, while the output voltage ripple can be adjusted by *f*sc. As shown in Fig. 2, the well-known CW voltage multiplier is constructed by a cascade of stages with each stage containing two capacitors and two diodes. In an *n*-stage CW voltage multiplier, there are $N(= 2n)$ capacitors and *N* diodes.

1.2 Operating Principles of the Proposed Converter

The circuit operation of the proposed converter is analyzed with a three-stage stacked CW voltage multiplier. Fig. 3 shows the theoretical waveforms of the proposed converter, including switching signals, inductor current, $v\gamma$, $i\gamma$, and diode currents. The circuit operation principle of the proposed converter and the characteristic behaviour of each mode in both positive and negative-half cycles are presented as follows:

According to the polarity of $i\gamma$, the operation of the proposed converter can be divided into two parts: positive conducting interval $[t_0, t_1]$ for $i\gamma>0$ and negative conducting interval $[t_1, t_2]$ for $i\gamma<0$. 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 $D_5-D_3-D_1$. The circuit operation principle of the proposed converter is described in detail as follows.

1) State I: During state 1, switches Sm_1 and Sc_1 are turned on, and Sm_2, Sc_2, and all CW diodes are turned off. 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.

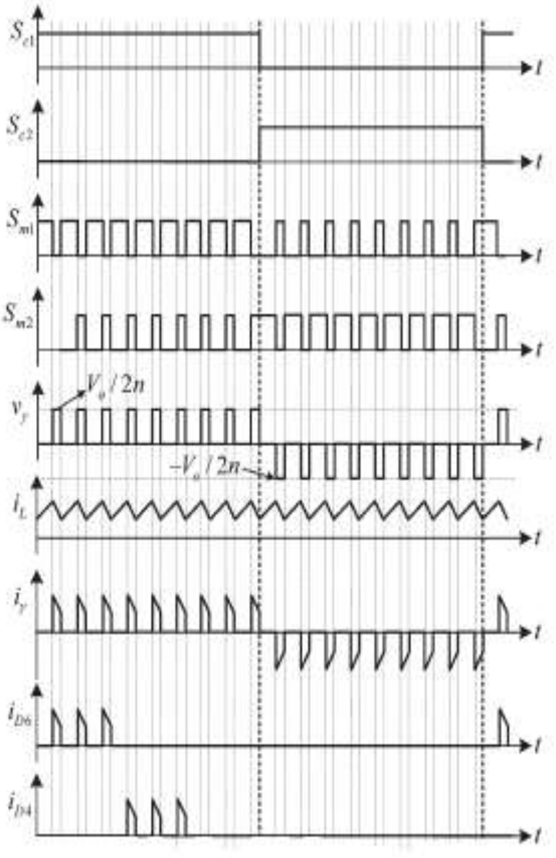

Fig.3 Ideal waveforms of the proposed converter in CCM.

2) State II: During this state the switches, Sm_2 and $Sc1$ are turned on, Sm_1 and Sc_2 are turned off, and the current $i\gamma$is positive. The boost inductor and input dc source transfer energy to the CW voltage multiplier through different even diodes as described below.

2.a) In 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 $i\gamma$.

2.b), In state II-b, D_4 is conducting. Thus, C_4 and C_2 are charged, C_3 and C_1 are discharged by $i\gamma$, C_6 supplies load current, and C_5 is floating.

2.c) In state II-b, D_2 is conducting. Thus, C_2 is charged, C_1 is discharged by $i\gamma$, C_6 and C_4 supply load current, and C_5 and C_3 are floating.

.3) State III: During this state the switches, Sm_2 and Sc_2 are turned on, and Sm_1, Sc_1, and all CW diodes are turned off. 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.

4) State IV: During this state the switches, Sm_1 and Sc_2 are turned on, Sm_2 and Sc_1 are turned off, and the current $i\gamma$is negative. The boost inductor and input dc source transfer energy to the CW voltage multiplier through different odd diodes.

4.a) In state IV-a, D_5 is conducting. 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 $i\gamma$.

4.b) In state IV-b, D_3 is conducting. Thus, C_2 is discharged, C_3 and C_1 are charged by $i\gamma$, C_6 and C_4 supply load current, and C_5 is floating.

4.c) In state IV-c, D_1 is conducting. Thus, C_1 is charged by $i\gamma$, all even capacitors supply load current, and C_5 and C_3 are floating.

III. Design Procedure

The main equations to design the high step up dc-dc converter using CW voltage multiplier are given below.

The boost inductor $L_s$is given by

$$Ls = \frac{DTsm}{KI\ Ipk} \qquad (1)$$

where 'D' is the duty ratio, 'T_{sm}' is modulation switching time period $K_I$is the expecting percentage of the maximum peak to peak current ripple in the inductor.

The Voltage of the k'th Capacitor, V_{ck}isgiven by

$$Vck=\frac{2Vin}{1-D} \quad (2)$$

Where 'V_{in}' is the input voltage

IV. Result And Discussions

A prototype with following specifications was built to verify the validity of the proposed converter. The parameters and the component specifications of the proposed converter are described in table I and II.

TABLE I: Prototype Parameters

PARAMETER	PROPOSED CONVERTER
Output voltage,V_0	120V
Input dc voltage,V_{in}	10-15V
Modulation frequency,f_{sm}	60kHz
Alternating frequency,f_{sc}	1kHz
Resistive load, R_L	1kΩ
Stage no,n	3

TABLE IIPrototype Components

COMPONEMT DISCRIPTION	SPECIFICATION
Control IC	PIC16F877A
Boost Inductor ,Ls	1.5mH
Power Switches, S_{m1},S_{m2},S_{c1},S_{c2}	P55
Capacitors, C_1-C_6	470µF/400V
Diodes, D_1-D_6	IN5408

The circuit diagram of the proposed converter is shown in figure 4. The converter module consist of four switches using is P55. The diodes used are IN5408.

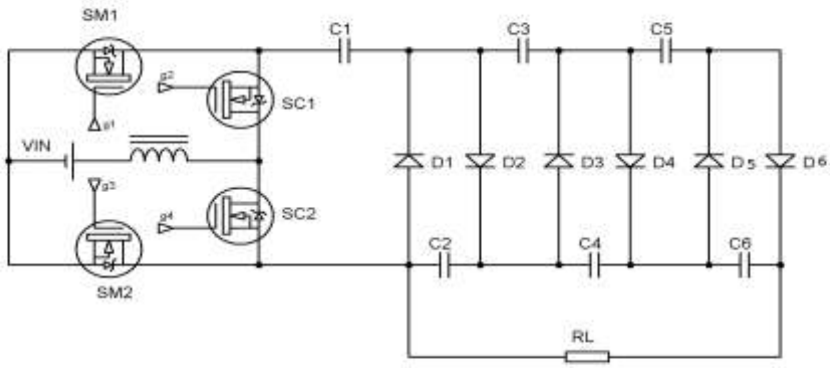

Fig: 4 proposed converter

The gate control circuit is implemented with PIC16F877A and optocouplers are provided for isolation purposes as shown in fig 5.

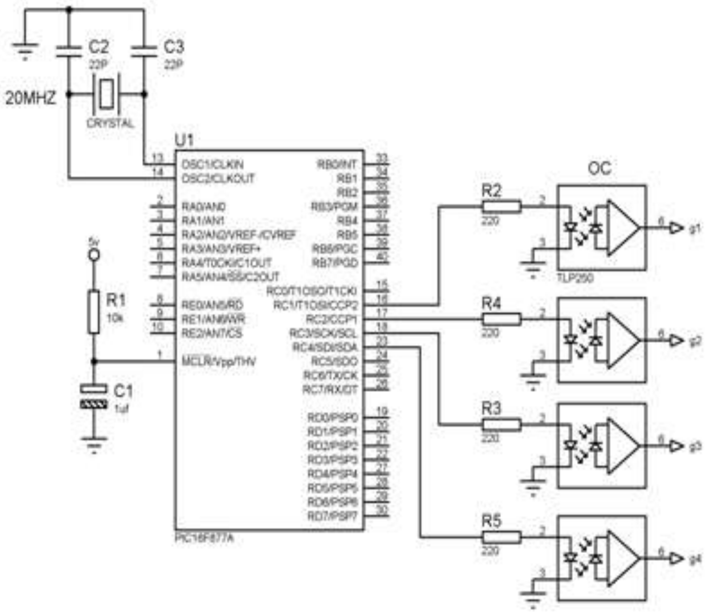

Fig. 5. Control circuit of proposed converter

The photograph of the proposed converter is shown in figure 6.It consists of a converter module and a PWM control circuit. Here we are using four switches.

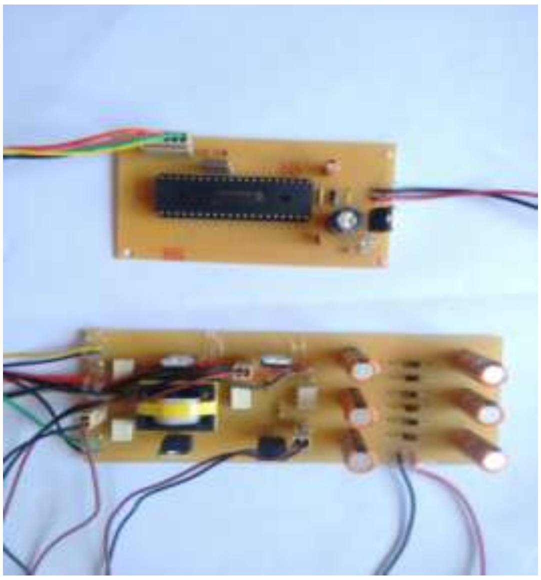

Fig. 6 Prototype of Proposed Converter.

The results obtained with the proposed converter with CW voltage multiplier are presented from Figs. 7 to 9 operating with a resistive load equal to 100 W.

The gate signal of the switch, S_{m1} is shown in the fig.7

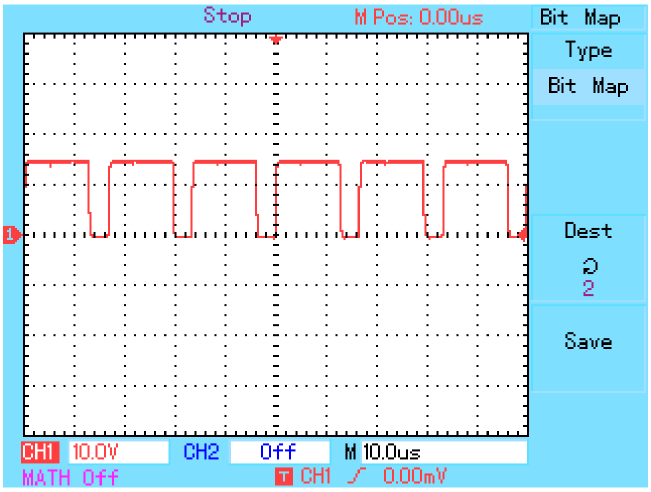

Fig: 7 Experimental Waveform , S_{M1}-V_{GS}

The gate signal of the switch, S_{m2} is shown in the fig. 8

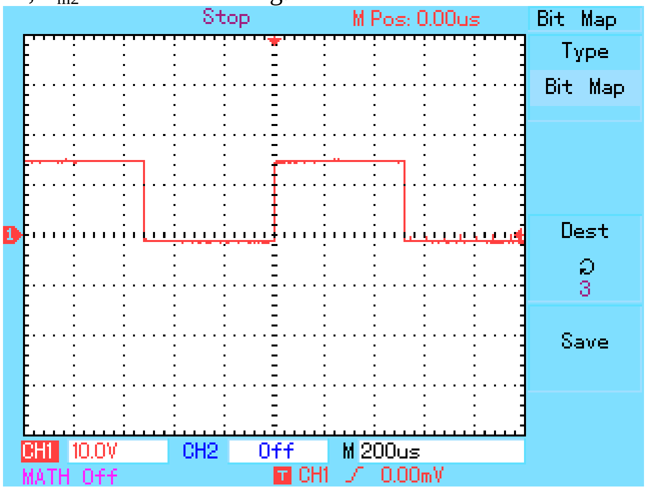

Fig: 8 Experimental Waveform, S_{M2}-V_{GS}

The output voltage is shown in fig. 9 and is equal to 120V Here the gain is 10.

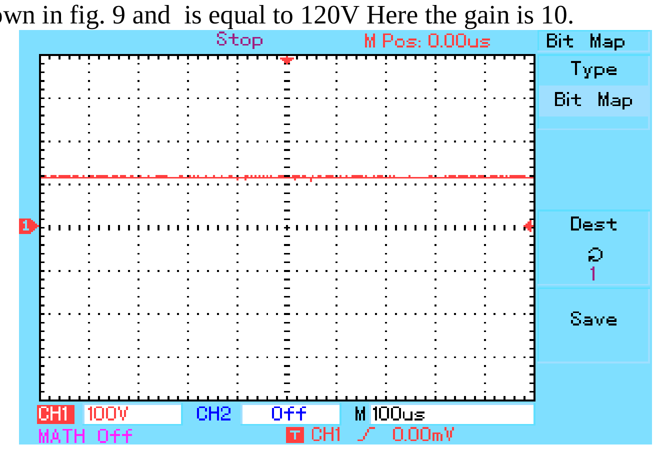

Fig:9 Experimental Waveform,V_{OUT}=120V

The experimental results are similar to the theoretical waveforms presented in Fig. 3.

V. CONCLUSION AND FUTURE SCOPE

Conclusion

In this project the operation of the improved transformerless high step-up dc–dc converter using stacked Cockcroft Walton voltage multiplier is explained, the design of the converter was discussed, and experimental results obtained. The proposed converter can produce a high output voltage with a low input voltage. The main advantage of this paper is that it increases the given input voltage by multiplying it without any use of transformer but just with the few switches, diodes and capacitor. The ripples, distortion present in the output voltage have been reduced and a high output voltage is obtained with a low input voltage. Here the use of the Stacked Cascaded Voltage Multiplier increases the output voltage and the parallel capacitor to the switch increases the efficiency and helps in increases the voltage too. The proposed converter can be applied to various applications like renewable energy, fuel cells, hybrid vehicle.

Future Scope

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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