



Multiple output dc-dc converter derived from Cock-Croft Walton voltage multiplier and SIMO converter

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Abstract

This paper proposes a high step-up dc-dc converter based on the Cockcroft-Walton (CW) voltage multiplier without a step-up transformer with a high-efficiency single-input multiple-output (SIMO) dc-dc converter. Increased voltage dependent on number of stages is obtained using Cockcroft Walton voltage multiplier, which acts as an input voltage source for SIMO converter. Providing continuous input current with low ripple, high voltage ratio, and low voltage stress on the switches, diodes, and capacitors, this converter is quite suitable for applying to low-input-level dc generation systems plus this converter can boost the voltage of a low-voltage input power source to a controllable high-voltage dc bus and middle-voltage output terminals. The high-voltage dc bus can take as the main power for a high-voltage dc load or the front terminal of a dc-ac inverter. Moreover, middle-voltage output terminals can supply powers for individual middle-voltage dc loads or for charging auxiliary power sources (e.g., battery modules). Moreover, based on the n-stage CW voltage multiplier, this converter can provide a suitable dc source for an n + 1-level inverter. The Cockcroft-Walton voltage multiplier circuit is designed from a series of rectifiers to obtain high DC voltage. In the presented model, the DC voltage, which is generated in the present stage, contributes to a higher value in the next stage. Every stage produces a higher DC output voltage Cockcroft-Walton multiplier constructed by ladder network of capacitor and diode for generation of high voltage. When number of stages of multiplier increases output of the Cockcroft-Walton Multiplier also increases. In this paper 3 stages Cockcroft-Walton multiplier are used for simulation purpose and for practical implementation to generate high voltage. Also in this paper transformer method are eliminated therefore cost and size of propose converter are reduced. The control strategy employs three 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. In this study, a coupled-inductor based dc-dc converter scheme utilizes only one power switch with the properties of voltage clamping and soft switching, and the corresponding device specifications are adequately designed. As a result, the objectives of high-efficiency power conversion, high step up ratio, and various output voltages with different levels can be obtained. This converter does not require any other circuit components in order to achieve good cross regulation. So that it again reduces the cost which will be an attractive feature in modern market. In order to check the behavior of the converter simulation is carried out in MATLAB environment. The simulation results validate the operation of the converter.

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Keywords: Converter, Multiplier, DC output, load.

1. Introduction

The motivation of this study is to design a multiple-output converter for increasing the conversion efficiency and voltage gain, reducing the control complexity, and saving the manufacturing cost. 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. 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, without extra arrangements, the output voltages generated from both of them are with rather low level. Thus, a

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<https://doi.org/10.36037/IJREI.2020.4303>

high step up dc-dc converter is desired in the power conversion systems corresponding to these two energy sources
 This converter uses one power switch to achieve the objectives of high-efficiency power conversion, high step-up ratio, and different output voltage levels. In the SIMO converter, the techniques of soft switching and voltage clamping are adopted to reduce the switching and conduction losses via the utilization of a low-voltage-rated power switch with a small RDS (on). The voltage gain can be substantially increased by using a coupled inductor. The stray energy can be recycled by a clamped capacitor into the auxiliary battery module or high-voltage dc bus to ensure the property of voltage clamping. An auxiliary inductor is designed for providing the charge power to the auxiliary battery module and assisting the switch turned ON under the condition of ZCS. The switch voltage stress is not related to the input voltage so that it is more suitable for a dc power conversion mechanism with different input voltage levels. This converter operates in continuous conduction mode (CCM), so the switch stresses, the switching losses, and EMI noise can be reduced as well.

1.1 Cascade cockcroft –walton voltage multiplier

Fig.1 shows an n-stage cascade boost converter for obtaining a high voltage gain i.e. the converter, which is supplied by a low-level dc source, such as battery, PV module, or fuel cell sources. The converter consists of one boost inductor L_s , four switches (S_{m1} , S_{m2} , S_{c1} , and S_{c2}), and one n-stage CW voltage multiplier. S_{m1} (S_{c1}) and S_{m2} (S_{c2}) operate in complementary mode, and the operating frequencies of S_{m1} and S_{c1} 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 S_{m1} and S_{m2} , while the output voltage ripple can be adjusted by f_{sc} . As shown in Fig.1, the well-known CW voltage multiplier is constructed by a cascade of stages with each stage containing two capacitors and two diodes.

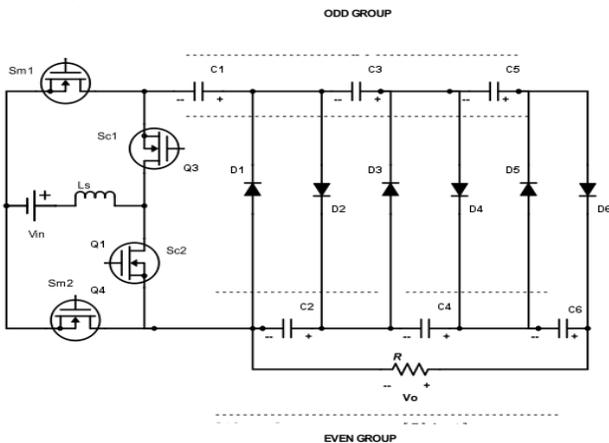


Figure 1: dc-dc converter with n-stage CW voltage multiplier

In an n-stage CW voltage multiplier, there are $N = 2n$ capacitors and N diodes. For convenience, both capacitors and diodes are

divided into odd group and even group according to their suffixes.

1.2 Mathematical model

For analysis, the equivalent circuit of the converter can be divided into source-side and load-side parts as shown in Fig.2 (a) and (b), respectively. For the source-side part, the conducting states d_{sc} and d_{sm} are defined in Table 1, where strategy I does not include safe commutation and strategy II includes safe commutation.

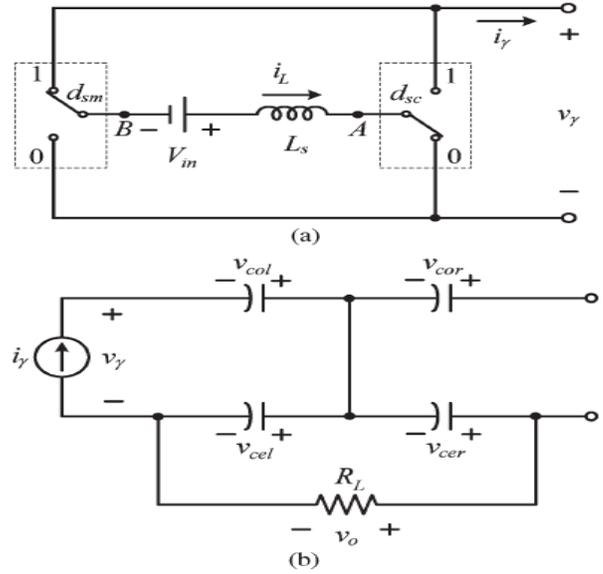


Figure 2: Equivalent ckt of converter a) source side part b) load side part

According to the conducting states d_{sc} and d_{sm} , the differential equation of the inductor current is given by

$$\frac{di_L}{dt} = \frac{1}{L_s} [V_{in} - (d_{sc} - d_{sm}) \cdot V_y]$$

Where V_{in} is the input voltage, i_L is the input current, and v_y is the terminal voltage of the CW voltage multiplier. Assuming that the converter operates in CCM.

Table 1: Conducting states of four switches

| Conducting States | | Strategy I | Strategy Ii |
|-------------------|----------|----------------------------------|-------------|
| d_{sc} | d_{sm} | $S_{c1}, S_{c2}, S_{m1}, S_{m2}$ | |
| 0 | 0 | 0101 | 0111 |
| 0 | 1 | 0110 | 0110 |
| 1 | 1 | 1010 | 1011 |
| 1 | 0 | 1001 | 1001 |
| 1 | 1 | - | - |
| Or | Or | - | 1111 |
| 0 | 0 | - | - |

The current i_y flowing into the CW voltage multiplier depends on d_{sm} and d_{sc} and can be expressed as

$$I_y = (d_{sc} - d_{sm}) \cdot i_L$$

Where the current i_y can be deemed a pulse-form current source.

1.3 Modes of operation of CW voltage multiplier

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.3(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.3 (b)–(d). In Fig.3 (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.3(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.3 (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.3(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.3 (f)–(h). In Fig. 3(f), 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_γ . In Fig.3 (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.3 (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.

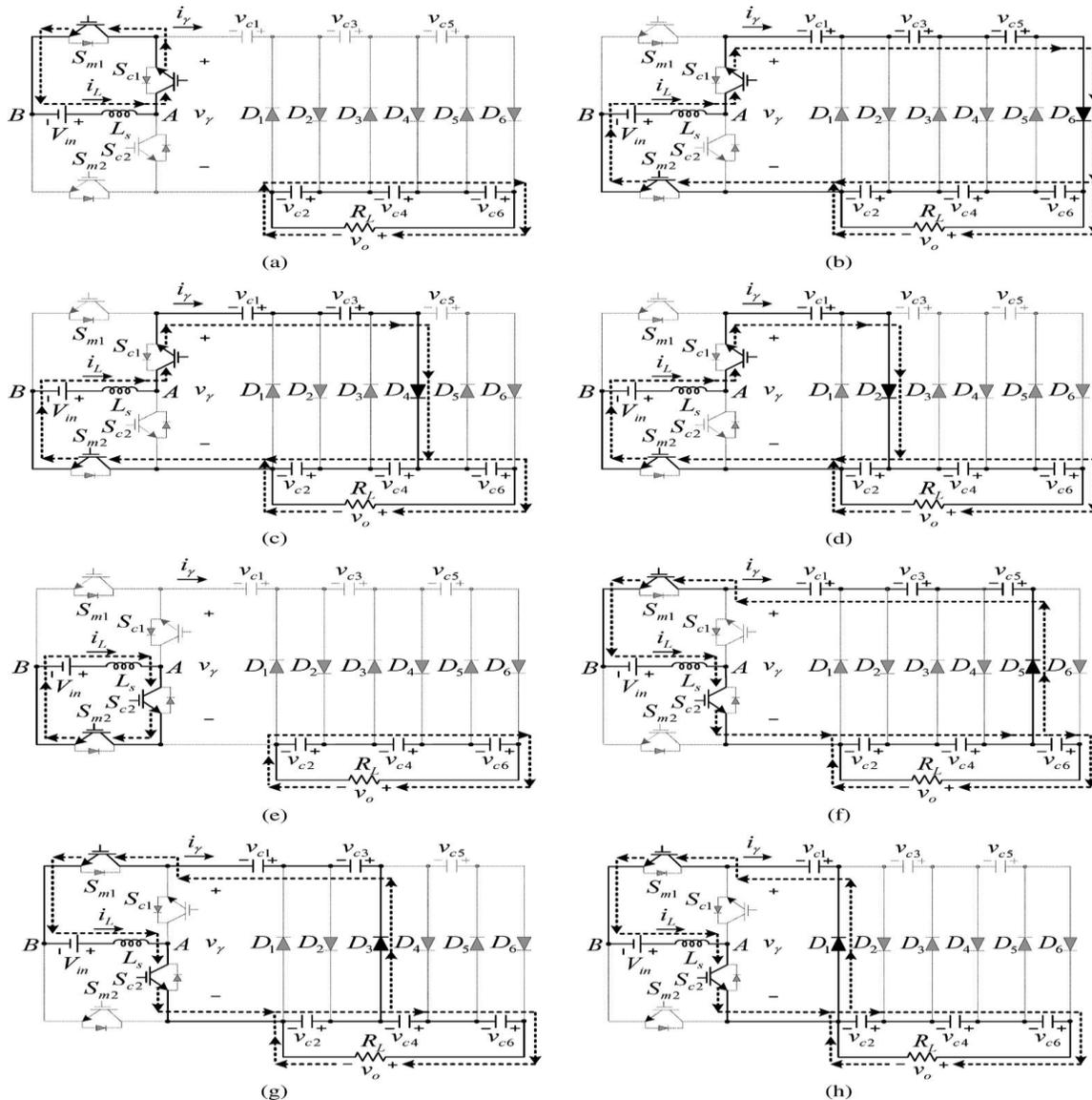


Figure 3: Modes of operation

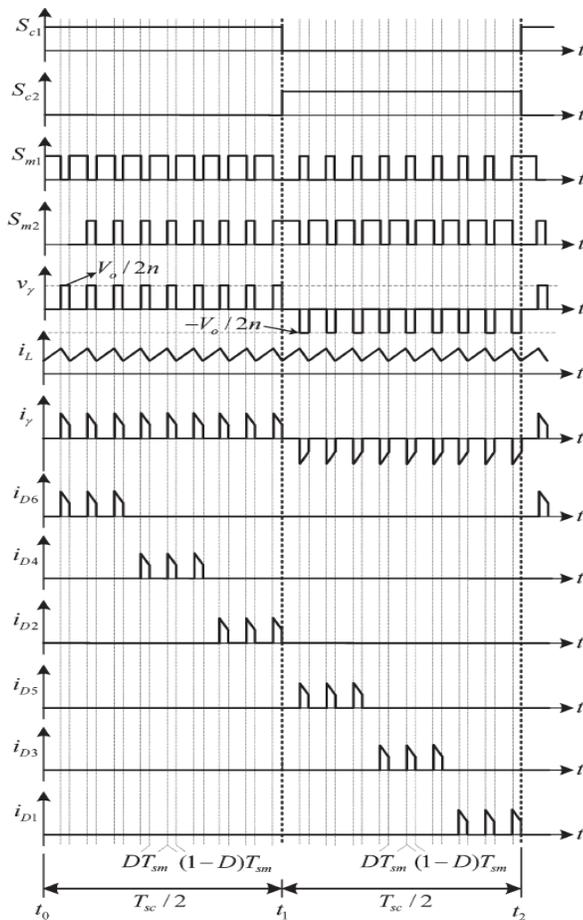


Figure 4: Ideal waveforms of CW voltage multiplier in CCM

1.4 SIMO converter

This converter can boost the voltage of a low-voltage input power source to a controllable high-voltage dc bus and middle-voltage output terminals. The high-voltage dc bus can take as the main power for a high-voltage dc load or the front terminal of a dc-ac inverter. Moreover, middle-voltage output terminals can supply powers for individual middle-voltage dc loads or for charging auxiliary power sources (e.g., battery modules).

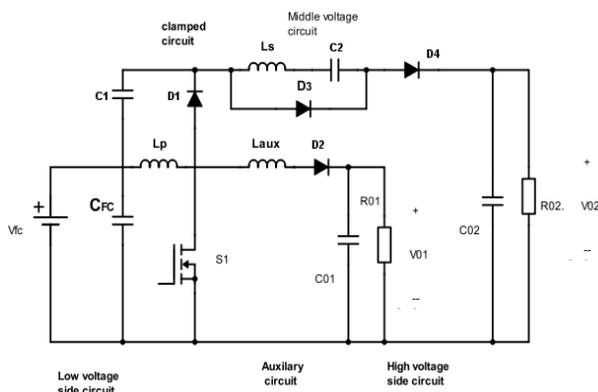


Figure 5: System configuration of single input multiple output converter

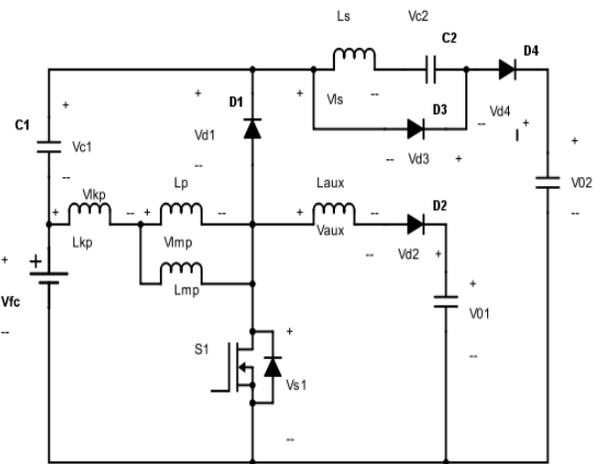


Figure 6: Equivalent circuit of SIMO converter

Single Input Multiple- Output (SIMO) converter can boost the voltage of a low-voltage input power source to a controllable high-voltage dc bus and middle-voltage output terminals. The high-voltage dc bus can take as the main power for a high-voltage dc load or the front terminal of a dc-ac inverter. Moreover, middle-voltage output terminals can supply powers for individual middle-voltage dc loads or for charging auxiliary power sources (e.g., battery modules). In this study, a coupled-inductor based dc-dc converter scheme utilizes only one power switch with the properties of voltage clamping and soft switching, and the corresponding device specifications are adequately designed. As a result, the objectives of high-efficiency power conversion, high step up ratio, and various output voltages with different levels can be obtained.

The system configuration of the high-efficiency SIMO converter topology to generate two different voltage levels from a single-input power source is depicted in Fig.6. This SIMO converter contains five parts including a low-voltage-side circuit (LVSC), a clamped circuit, a middle-voltage circuit, an auxiliary circuit, and a high-voltage-side circuit (HVSC). The major symbol representations are summarized as follows. V_{FC} (i_{FC}) and V_{O1} (i_{O1}) denote the voltages (currents) of the input power source T_r and the output load at the LVSC and the auxiliary circuit, respectively; V_{O2} and i_{O2} are the output voltage and current in the HVSC. C_{FC} , C_{O1} , and C_{O2} are the filter capacitors at the LVSC, the auxiliary circuit, and the HVSC, respectively; C_1 and C_2 are the clamped and middle-voltage capacitors in the clamped and middle-voltage circuits, respectively. L_p and L_s represent individual inductors in the primary and secondary sides of the coupled inductor, respectively, where the primary side is connected to the input power source; L_{aux} is the auxiliary circuit inductor. The main switch is expressed as S_1 in the LVSC; the equivalent load in the auxiliary circuit is represented as R_{O1} , and the output load is represented as R_{O2} in the HVSC.

The corresponding equivalent circuit given in Fig.6 is used to define the voltage polarities and current directions. The coupled inductor can be modeled as an ideal transformer including the magnetizing inductor L_{mp} and the leakage inductor L_{kp} in Fig.6. The turns ratio N and coupling coefficient k of this ideal transformer are defined as,

$$N = N_2 / N_1$$

$$k = \left[\frac{L_{mp}}{L_{kp} + L_{mp}} \right] = L_{mp} / L_p$$

Where, N_1 and N_2 are the winding turns in the primary and secondary sides of the coupled inductor T_r .

2. MATLAB Simulink

Simulation model of both Cascade Cockcroft Walton voltage multiplier and single input multiple output converter is performed separated in MATLAB 2015 and results obtained as explained earlier.

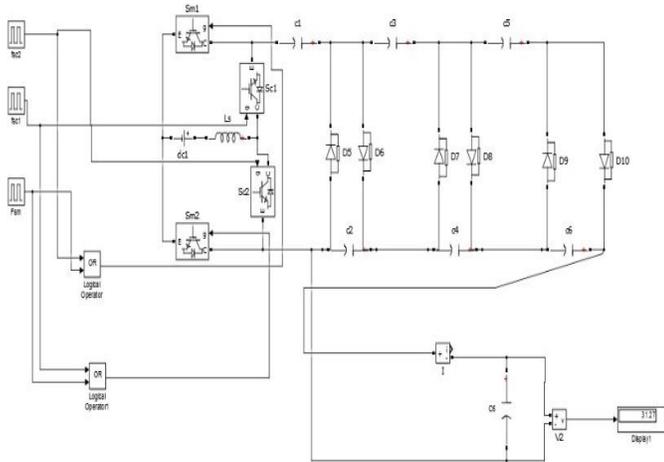


Figure 7: System Simulink model for CW voltage multiplier converter

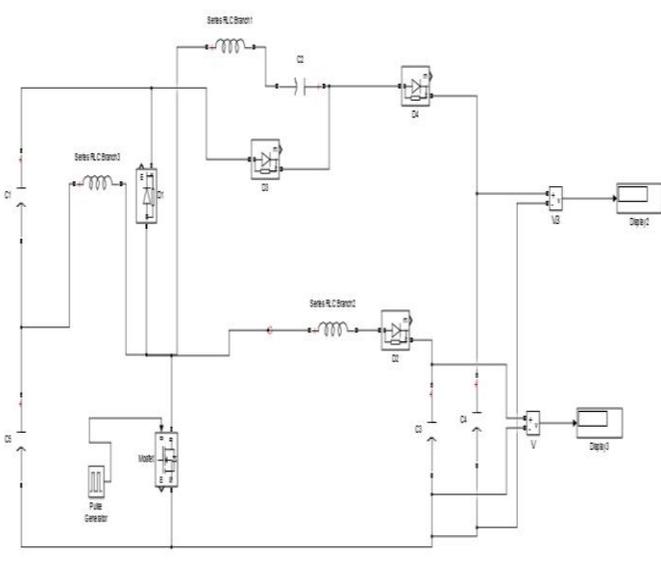


Figure 8: System Simulink model for SIMO converter.

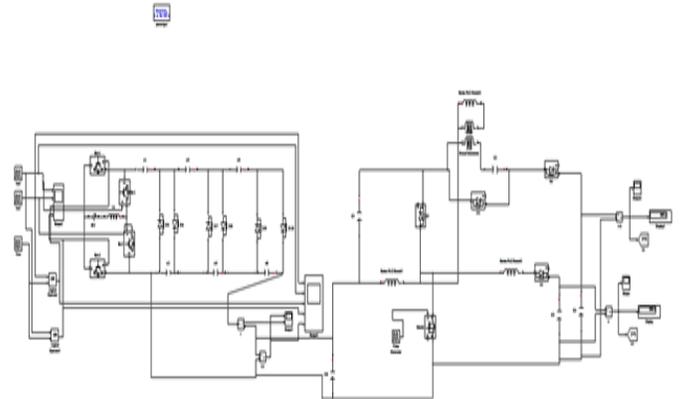


Figure 9: Simulink model of DC-DC converter

As shown in fig.9 i.e. Simulink model of dc-dc converter when CW voltage multiplier and SIMO converter are combined we get required outputs from 12 volts dc input source which is battery as shown.

3. Simulation Results

When 12 volts is given as input to cascade Cockcroft Walton voltage multiplier then depending on number of three stages output required must be 36. When this verified using mathematical model we get nearly 36 volts which is shown in fig.10.

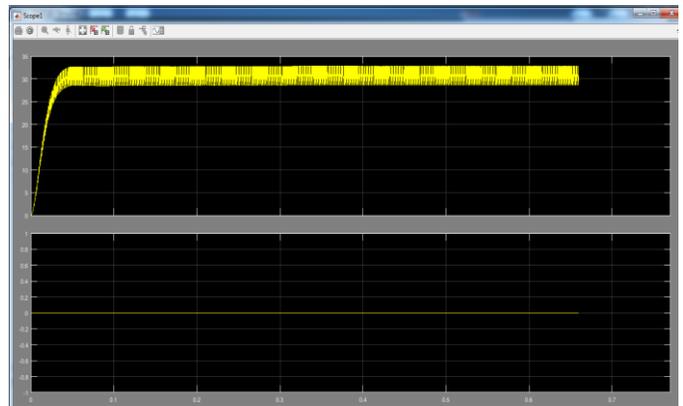


Figure 10: Output of Cockcroft Walton voltage multiplier

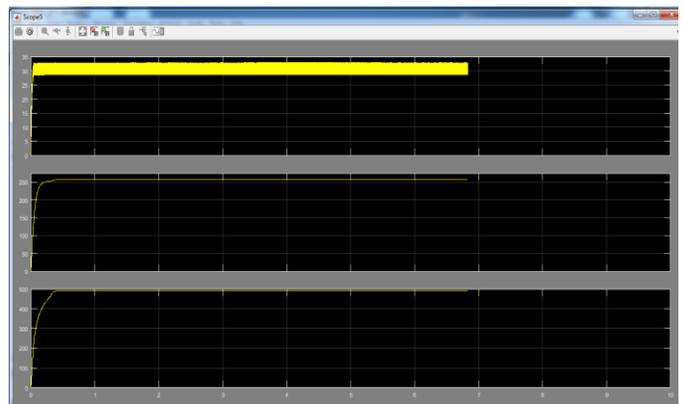


Figure 11: Output of proposed DC-DC converter

Output of dc-dc converter are shown in fig.11. First waveform indicates output of CW voltage multiplier and next two waveforms shows outputs of dc-dc converter.

4. Hardware Results

When 12volt input is given to the cascade Cockcroft Walton voltage multiplier it gives 30volt output voltage which is dc voltage as we have selected three stages for the same. Next as per our objective, when output of CW voltage multiplier given to the SIMO converter we get 50 volts and 170 volt DC output voltages. So finally from 12 volt dc input we achieve two dc outputs having higher magnitudes.



Figure 12: Hardware set up

5. Conclusions

This study has successfully developed a high-efficiency dc-dc converter which is derived from combination of Cascade Cockcroft Walton voltage multiplier and single input multiple output converter. So we can create multiple dc outputs from one

dc source. 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 which gets applied to SIMO dc-dc converter, and this coupled-inductor-based converter was applied well to a single-input power source plus two output terminals composed of an auxiliary battery module and a high-voltage dc bus. The 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. The converter is suitable for the application required one common ground, which is preferred in most applications. This topology adopts only one power switch to achieve the objective of high-efficiency multiple output power conversion. The voltage gain can be substantially increased by using a coupled inductor. The auxiliary battery module used in this study also can be extended easily to other dc loads, even for different voltage demands, via the manipulation of circuit components design.

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Cite this article as: Abhishek Kanchan Shiwalkar, Shilpa Ravindra Shinde, Multiple output dc-dc converter derived from Cock-Croft Walton voltage multiplier and SIMO converter, *International Journal of Research in Engineering and Innovation* Vol-4, Issue-3 (2020), 137-142. <https://doi.org/10.36037/IJREI.2020.4303>.