

Multiple Input DC-DC Converters with Input Boost Stages

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Abstract— A high voltage gain DC-DC converter is proposed. This converter is capable of stepping up voltages as low as 20V to 400V. The proposed converter can draw power from four independent sources which makes it suitable for applications like solar panels. The proposed converter finds its application in integration of individual solar panels onto the 400V distribution bus in DC micro grids. The proposed converter consists of Diode-Capacitor voltage multiplier stages. The converters achieve a high voltage gain by charging and discharging of the voltage multiplier capacitors. The design and component selection procedures are presented. The simulation of converter is done using MATLAB/SimulinkR2014 software. A 2W, 10kHz hardware prototype of the base circuit with $V_{in}=1V$ and $V_{out}=20V$ is also implemented in the laboratory. PIC16F877A is used for generating the control pulse. mikroC software is used for programming the PIC.

Keywords —DC-DC Converter, Multi Port Converter, Boost Converter.

I. INTRODUCTION

A four input DC-DC converter is proposed for renewable energy applications where several renewable sources are employed. The versatility multiple input converters topologies gives us the advantage of a large variety of connection. Furthermore, the multiport structures extend the opportunity of making the entire system more simple and compact. Multi-port converters have less component count and less conversion stage than the traditional power processing solution which adopts several independent two-port converters. Due to their advantages multi-port converters recently have attracted much attention in academia, resulting in many topologies for applications like integration of low voltage sources to 400V DC microgrid system.

The step-up stage normally is the critical point for the design of high efficiency converters due to the operation with high input current and high output voltage, thus a careful study must be done in order to define the topology for a high step-up application. Theoretically, the conventional boost DC-DC converter can provide a very high voltage gain by

using an extremely high duty cycle. Large duty cycles result in high current stress in the boost switch. Due to large duty ratio parasitic elements has to be considered and their effects reduce the theoretical voltage gain

Some converters can easily achieve high step-up voltage gain. However, transformer volume is a concern. Transformer leakage inductance can produce high voltage stress, increases the switching losses and the electromagnetic interference problems, thus reducing the efficiency of converter. In order to reduce the voltage stress certain measures, have to be considered. Thus, the weight, volume and losses of the power transformer are limiting factors for the isolated DC-DC converters used in embedded applications.

Some other alternative step-up DC-DC converters without step-up transformers and coupled inductors were presented in [2] – [6]. By cascading diode-capacitor or diode-inductor modules, these kinds of DC-DC converters can provide high voltage gain. But the passive elements and switch were under high voltage stress in this cascaded converter.

Non-isolated DC-DC converter topologies using capacitor-diode voltage multiplier cells can be used to, obtain high static gain, low voltage stress and low losses, improving the performance with relation the classical topologies. A high voltage gain dual input converter used voltage multiplier cells integrated with a classical boost converter is proposed as proposed [1]. Several multiplier cells are connected together to boost up the output voltage without compromising the voltage stresses across the components. The main advantage is that voltage gain can be increased by adding of diode capacitor stages.

The proposed converter can draw current from four independent sources. So in place of four different converters we can use a single converter. Thus making the process of energy harvesting a very efficient.

II. MULTIPLE INPUT DC-DC CONVERTER WITH INPUT BOOST STAGES

The working of the proposed converter is inspired from the Dickson charge pump [7]. Diode-capacitor voltage multiplier (VM) stages are integrated with

boost stages at the input. The VM stages are used to help the boost stage achieve a higher overall voltage gain. The voltage conversion ratio depends on the number of VM stages and the switch duty ratios of the input boost stages. This converter is capable of stepping up voltages as low as 20V to 400V. The proposed converter offers continuous input current and low voltage stress ($1/4^{\text{th}}$ of its output voltage) on its switches. Thus offering a gain of 20.

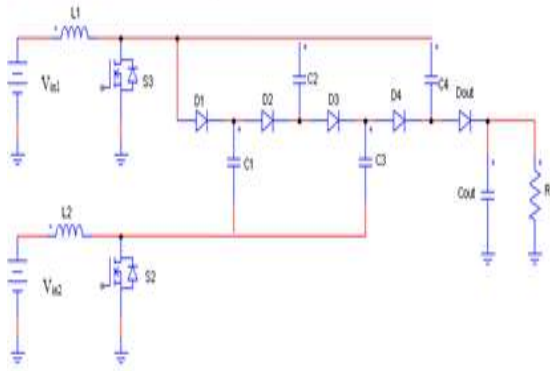


Fig. 1: High-voltage-gain DC-DC converter proposed in [1].

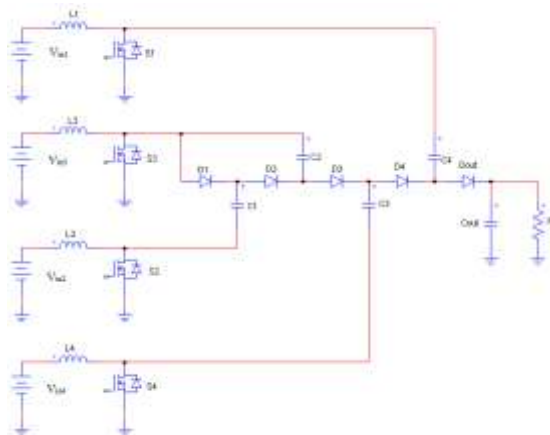


Fig. 2: Proposed multiple input DC-DC converter with input boost stages

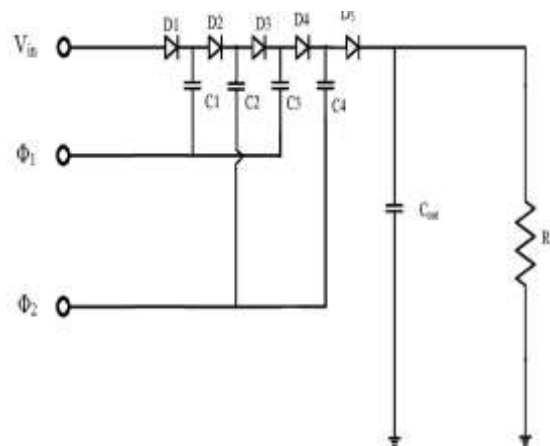


Fig. III: A Dickson Charge Pump

III. OPERATING PRINCIPLE

The proposed converter provides a high voltage gain using the modified Dickson charge pump voltage multiplier circuit (See Fig. 3). On a closer look, it can be seen that the converter is made up of two stages. The odd numbered upper stages, which have same mode of operation and the even numbered lower stages, which have same mode of operation.

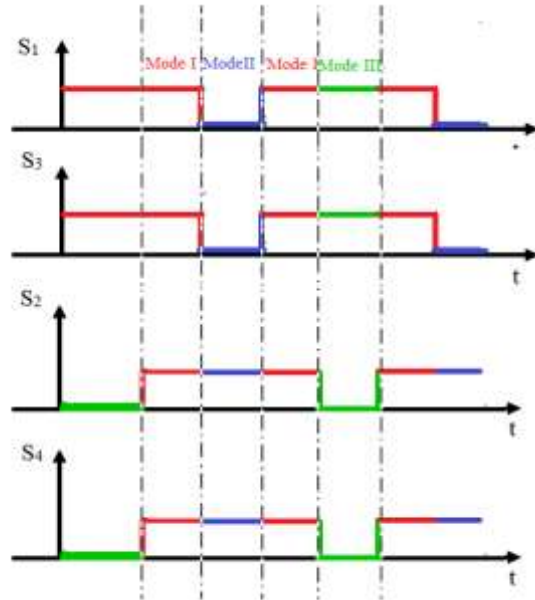


Fig. 3: The switching sequence

For normal operation of the proposed converter, there should be some overlapping time when both the switches are ON and also one of the switches should be ON at any given Therefore, the converter has three modes of operation. The proposed converter can operate when the switch duty ratios are small and there is no overlap time between the conduction of the switches. However, this mode of operation is not of interest as it leads to smaller voltage gains.

A. Mode I

In this mode all the switches are ON. All the inductors are charged from their input sources. The current in the inductors rise linearly. The diodes in different VM stages are reverse biased and do not conduct. The VM capacitor voltages remain unchanged and the output diode D_{out} is reverse biased Fig. V. Thus the load is supplied by the output capacitor C_{out} .

B. Mode II

In this mode switch S_1 and S_3 is ON. All the odd numbered diodes are forward biased and the inductor current flows through the VM stage capacitors charging the odd (C_1, C_3) and discharging the even numbered capacitors (C_2, C_4) shown in Fig. 6.

C. Mode III

In this mode switch S₂ and S₄ ON. Now the even numbered diodes are forward biased and the inductor current flows through the VM stage capacitors charging the even numbered capacitors and discharging the odd numbered capacitors as shown in Fig.7.

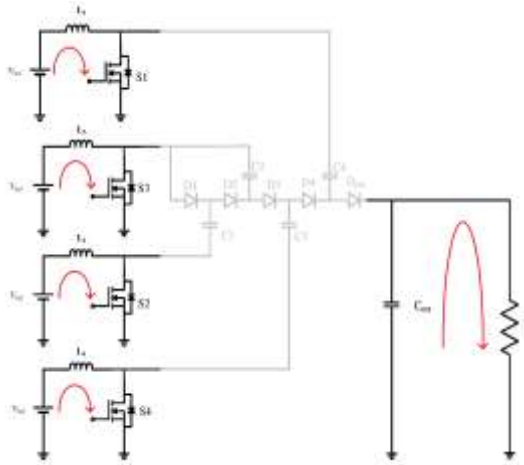


Fig. 5: Mode I Operation

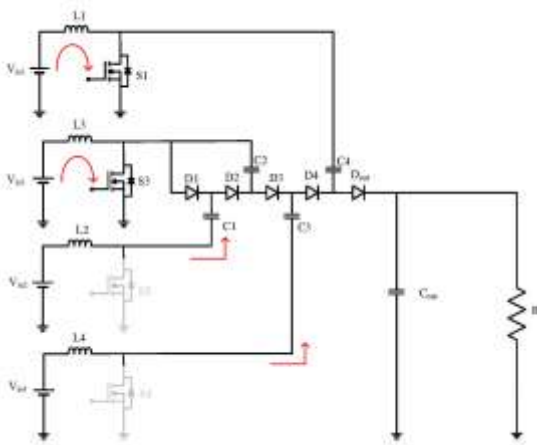


Fig. 6: Mode II Operation

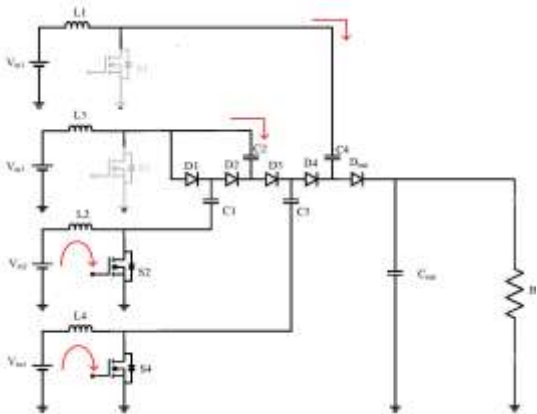


Fig. 7: Mode III Operation

IV. VOLTAGE GAIN

The charge is transferred progressively from input to the output by charging the VM stage capacitors. Here V_{in1} = V_{in2} = V_{in3} = V_{in4} = V = 20V. And duty ratio of all switches are same and equal to 0.75. From the working of Dickson charge pump.

$$\frac{V_{out}}{V_{in}} = \frac{5}{1-d} \quad (1)$$

V. DESIGN OF COMPONENTS

The simulation of a converter rated at 400 W with V_{in1} = V_{in2} = V_{in3} = V_{in4} = 20 V and V_o = 400 V is simulated. So the Output current I_o = 1A. Switching frequency f_{sw} = 100kHz. Number of voltage multiplier (VM) stages, N = 4. Duty ratio is given by

$$d_1 = d_3 = d_4 = d_4 = \frac{V_0 - V_{in} * (N + 1)}{V_0} = 0.75 \quad (2)$$

A. Inductor Design

The inductor currents in the boost stages depend on the number of VM stages connected to each leg. The inductor design is similar to that of the normal boost converter. The inductor value is selected such that the boost stages operate in continuous conduction mode (CCM). The minimum inductor value for the CCM operation of the boost stages is given by,

$$L_{1min} = \frac{d_1 * (1 - d_1) * V_{in1}}{I_{out} * f_{sw} * (N + 1)} \quad (3)$$

$$L_{3min} = \frac{d_3 * (1 - d_3) * V_{in3}}{I_{out} * f_{sw} * (N + 1)} \quad (4)$$

$$L_{2min} = \frac{d_2 * (1 - d_2) * V_{in2}}{I_{out} * f_{sw} * N} \quad (5)$$

$$L_{4min} = \frac{d_4 * (1 - d_4) * V_{in4}}{I_{out} * f_{sw} * N} \quad (6)$$

B. Capacitor Design

The output capacitor is selected based on the amount of charge that is transferred to the output for a desired output voltage ripple. Assuming a voltage ripple of 0.02% of output voltage, the required capacitance is given by,

$$C_{out} = \frac{I_0 * (1 - d)}{f_{sw} * \Delta V_0} \quad (7)$$

The VM stage capacitors are selected such that the equivalent series resistance due to charging/discharging of the capacitors is low keeping the total capacitance to reasonable levels, thus improving the efficiency and output voltage regulation. It is important to select VM stage

capacitors with low *ESR* to minimize the losses, for that purpose thin film capacitors are selected as they have low *ESR* values.

VI. SIMULATION PARAMETERS

The simulation parameters used for multiple input DC-DC converter are shown in Table I. The duty ratio and input voltage for all the branches are taken same.

TABLE I
Simulation parameters

Components	Rating
Input Voltage	20V
Output Voltage	400V
Load Resistance	400Ω
Duty Ratio	75%
Inductors	100μH
VM stage capacitors	20μF
Output Capacitor	22μF

VII. SIMULATION MODEL AND RESULT

A 400W model of converter is simulated in MATLAB/ SIMULINK environment.

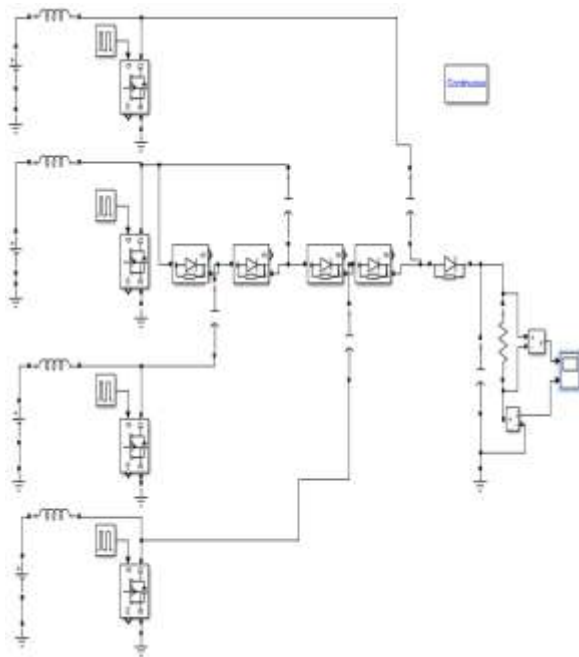


Fig. 8: Simulation model of the proposed converter

The switching sequence for S_1, S_3 are same and switching sequence of S_2, S_4 are same.

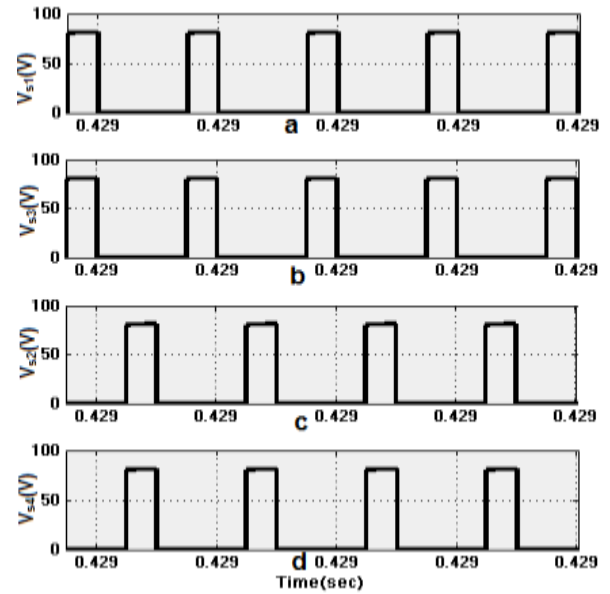


Fig. 9: Voltage Stress across switch (a) S_1 (b) S_3 (c) S_2 (d) S_4

Fig. 9 shows the voltage stress across the switches. A voltage stress of 80V is experienced by the switches. Compared to the output voltage of 400V the value is small (25%). So the switching stress is low.

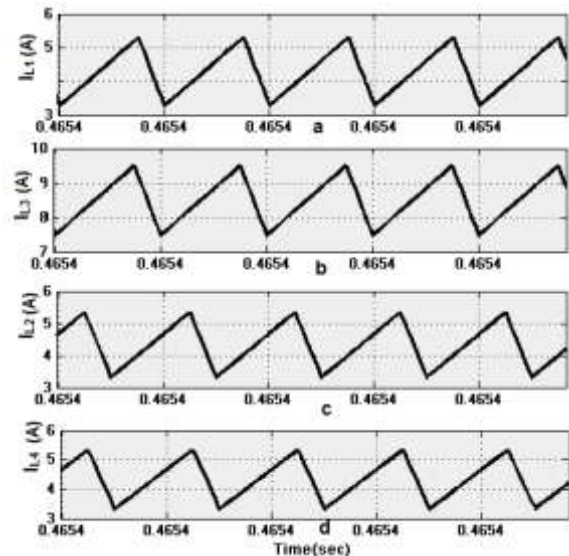


Fig. 10: Current through inductor (a) L_1 (b) L_3 (c) L_2 (d) L_4

The inductor current and the input current are the same. The current through inductor 3 is slightly higher than other inductors, this anomaly is contributed by the voltage imbalance between the VM stage capacitors.

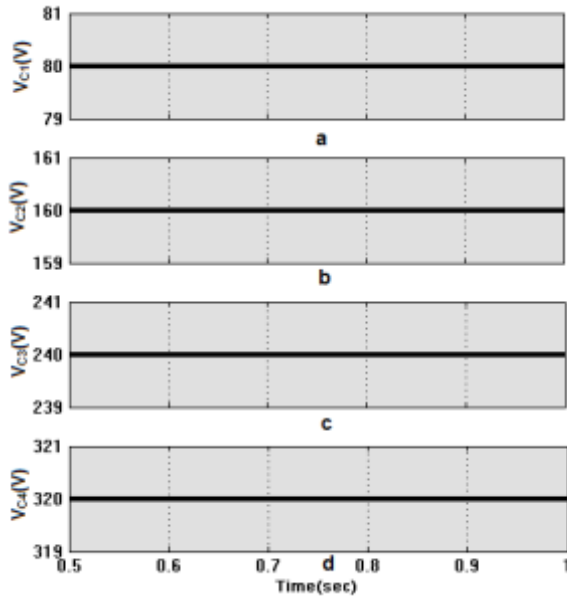


Fig. 11: Voltage across capacitor (a) C₁ (b) C₃ (c) C₂ (d) C₄

Fig. 11 shows the voltage across each voltage multiplier stage capacitors. The voltage across each capacitor will be a multiple of 80V. The output of each boost stages will be 80V. Similar to the working of Dickson charge pump [7] the voltage across each capacitor will increase by 80V.

Fig 12 shows the output waveforms of obtained in the simulation. Output voltage is 400V and the output current is 400A. The simulation model is rated for 400W.

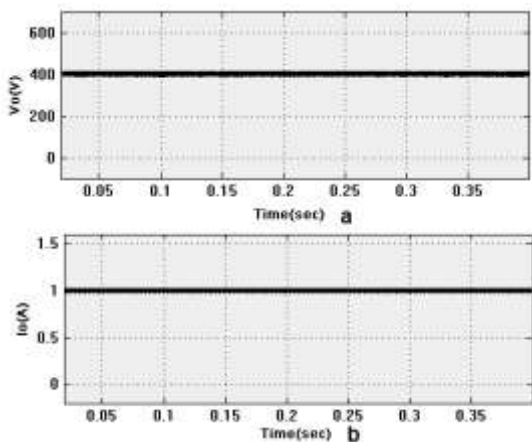


Fig. 12: Output (a) Voltage and (b) Current

VIII. EXPERIMENTAL SETUP AND RESULTS

A 2 W, 10kHz prototype of the DC-DC converter with high voltage gain and two input boost stages with input 1V is implemented. Table 2 shows the specification.

TABLE II

Components used for prototype

Components	Rating
Inductors	30 μ H
Capacitor	22 μ F
Diode	IN5819
Controller	PIC16F877A
MOSFET	IRF540
Driver IC	TLP250



Fig. 13: Experimental setup

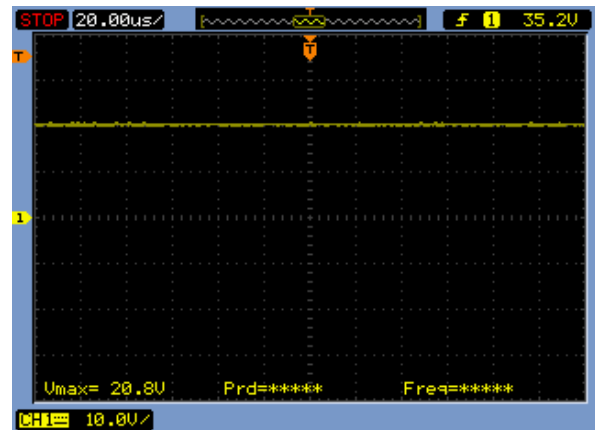


Fig. 14: Output voltage waveform

The power supply consist of a step down transformer, full bridge diode rectifier, filter capacitor and a regulator IC (7812). IRF540 MOSFET is used as the switches. TLP250 driver is used to drive the MOSFET. To generate the switching signal PIC16F8771A was programmed in the laboratory and necessary waveforms were obtained. The Switches are working in 10kHz

frequency and have a duty ratio of 0.75.

IX. CONCLUSION

A high voltage gain DC-DC converter is introduced that can offer a voltage gain of 20, i.e., to step up a 20V input to 400V output. The output voltage, switching stress, inductor current and capacitor voltage are observed. Output voltage of 400V was obtained during the simulation. The observed values from the simulation are similar to the calculated values. Compared to the classical DC-DC converters the voltage stress across switches is low. The voltage across the switch was 80V which is a small value compared to the output voltage. The current through S_2 shows a spike because of the voltage imbalance between different voltage multiplier stages. The size of the converter would be less because high frequency operation and absence of winding transformer. On comparing with resonant converter the absence coupled inductor makes this converter superior, since leakage flux and stray magnetic field loss is not present. Since it is a multi-port converter with a high voltage gain, independent sources can be connected and power sharing, MPPT algorithms can be implemented independently at each input port. The main problem associated with the proposed converter is that, as the stages increases the size of capacitor becomes large. Thus making the circuit bulky. The converter finds its application in integration of individual solar panels onto the 400V distribution bus in data centers, telecom centers, DC buildings and microgrids. Hardware prototype of 2W, 10 kHz of the base circuit [1] was implemented.

REFERENCES

- [1] V. A. K. Prabhala, P. Fajri, V. S. P. Gouribhatla, B. P. Baddipadiga, and M. Ferdowsi, "A DC-DC Converter With High Voltage Gain and Two Input Boost Stages," *IEEE Trans. on Power Electronics*, volume 31, pp. 4206- 4215, 2016.
- [2] Zhao and F. C. Lee, "High-efficiency, high step-up dc-dc converters," *IEEE Trans. Power Electronics*, vol. 18, no. 1, pp. 65-73, Jan.2003.
- [3] R.-J. Wai and R.-Y. Duan, "High step-up converter with coupled-inductor", *IEEE Transactions Power Electronics*, vol. 20, no. 5, pp. 1025- 1035, Sep. 2005.
- [4] R.-J. Wai and R.-Y. Duan, "High-efficiency power conversion for low power fuel cell generation system," *IEEE Transactions on Power Electronics*, vol.20, no. 4, pp. 847-856, Jul. 2005.
- [5] Y. Jang and M. M. Jovanovic, "Interleaved boost converter with intrinsic voltage-doubler characteristic for universal-line PFC front end," *IEEE Transactions Power Electron.*, vol. 22, no. 4, pp. 1394-1401, Jul. 2007.
- [6] A. Z. Rehman, I. Al-Bahadly, and S. Mukhopadhyay, "Multi input DC-DC converters in renewable energy applications: An overview", *Renewable and Sustainable Energy Reviews*, Vol. 41, pp. 521-539, 2015.
- [7] John F. Dickson, "On-chip high-voltage generation in MNOS integrated circuits using an improved voltage multiplier technique," *IEEE Journal of Solid-State Circuits*, vol. 11, Issue: 3, pp. 374-378, Jun. 1976.
- [8] Marcos Prudente, Luciano L. Pfitscher, Gustavo Emmendoerfer, Eduardo F. Romaneli, and Roger Gules, "Voltage Multiplier Cells Applied to Non-Isolated DC-DC Converters," *IEEE Transactions on Power Electronics*, vol. 23, no. 2, pp. 871-887, Mar. 2008.
- [9] Kuo-Ching Tseng, and Chi-Chih Huang, "High step-up high-efficiency interleaved converter with voltage multiplier module for renewable energy system," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 3, pp. 1311-1319, Mar. 2014.
- [10] Chung-Ming Young, Ming-Hui Chen, Tsun-An Chang, Chun-Cho Ko, and Kuo-Kuang Jen, "Cascade Cockcroft-Walton Voltage Multiplier Applied to Transformerless High Step-Up DC-DC Converter," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 2, pp. 523-537, Feb. 2013.