An Improved Transformerless High Step-Up DC-DC Converter Using a 4 Level Stacked Voltage Multiplier

[#1]U.Sam Richards,

#Department of EEE, Paavai Engineering College, Namakkal.

[1]samlikers@gmail.com

[#2]C.Saravanan,

#Department of EEE, Paavai Engineering College, Namakkal.

[2] saravananchinnusamypec@paavai.edu.in

*Abstract-***This paper proposes animproved Transformerless high step-up dc-dc converterusing a 4 level stacked voltage multiplier. The multiplying of voltage is done using stacked voltage multiplier; the low DC voltage has been multiplied to obtain high DC voltage. The Stacked cascaded voltage multiplier is a two 4 stage voltage multiplier which is designed and implemented based upon the Cockcroft Walton voltage multiplier. Two independent frequencies are used for the control strategy, one high frequency is used to minimize the size of the inductor and one low frequency is used according to the desired output voltage. The high voltage is obtained from a very low DC voltage. The obtained output is given to a DC motor. The voltage ripples produced during the motor operation is reduced in this proposed method. The Simulated motor output of the proposed converter is compared with the conventional converter, the results illustrates that the stacked cascaded voltage multiplier gives better dynamic performance and it can be used for high voltage industrial applications.**

*Keywords:*Stacked cascaded voltage multiplier, voltage multiplier, DC motor, Transformerless, High DC voltage, step up dc–dc converter, Cockcroft Walton (CW).

I. INTRODUCTION

In recent years, the need and demand for electrical energy has increased due to the extensive use of electrical equipment and the technology development, and this trend is constantly growing. Consequently, researchers and governments worldwide have realized that the future relies on renewable energy due to the environmental concerns as the non-renewable energy sources are getting depleting [1], [2]. Among various renewable energy sources, the photovoltaic (PV) cell and fuel cell have been considered attractive choices [3]–[5]. However, without extra arrangements, the output voltages generated from both of them are with rather low level [6], [7]. A high step up dc-dc converter is used in the power conversion systems corresponding to these two energy sources for various applications [8].

In addition to the mentioned applications, a high step-up dc-dc converter is also required by many industrial applications, such as high-intensity discharge lamp ballasts for automobile headlamps and battery backup systems for

uninterruptible power supplies [9]. 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 [10]. The proposed circuit, which focused on improving efficiency and reducing voltage stress, were presented to achieve high ripple free voltage without extremely high duty cycle.

The first section gives the introduction about the paper. The second section of the paper discuss about the Improved Transformerless High Step-Up DC–DC Converter using Stacked Cockcroft-Walton Voltage Multiplier. Ripple reduction and output voltage gain is discussed in the third section. The fourth section deal with the proposed system simulation output using MATLAB. The fifth section is about the results, discussions and the conclusion.

II. PROPOSED CONVERTER BLOCK DIAGRAM

The proposed converter shown in Fig.1 consists of several components in it such as DC source, improved boost converter, stacked Cockcroft Walton voltage multiplier, pi 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.
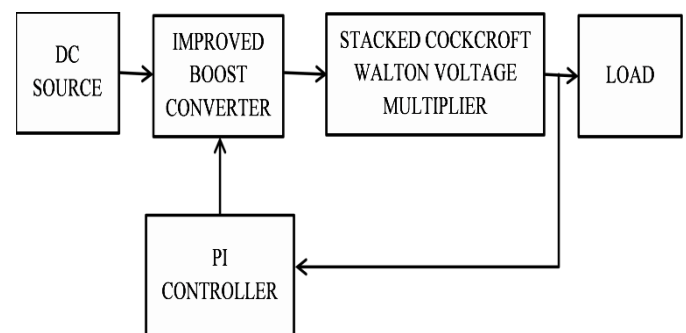

Fig.1 Proposed Converter Block Diagram

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 output voltage is controlled by using a pi controller by varying the gate pulse given to the switching devices present in the boost converter. The proposed converter can be used in renewable energy systems where usually low input voltages (12Vdc to 48Vdc) are involved or in uninterrupted power supply systems to avoid going for a step-up transformer.

III. PROPOSED CONVERTER CIRCUIT DIAGRAM

The proposed converter shown in Fig.2 consists of four switches in the boost converter named as switches Sm_1, Sm_2, Sc_1, and Sc_2, in which switches Sc_1 and Sc_2 are used to produce an ac source to provide for the stacked cockcroft walton voltage multiplier and the switch Sm_1 and Sm_2 are used to obtain a boost performance by controlling the inductors energy. The proposed converter is supplied by a low-level dc source. The proposed converter consists of one boost inductor Ls and one parallel inductor Lp, four and stacked Cockcroft Walton voltage multiplier.
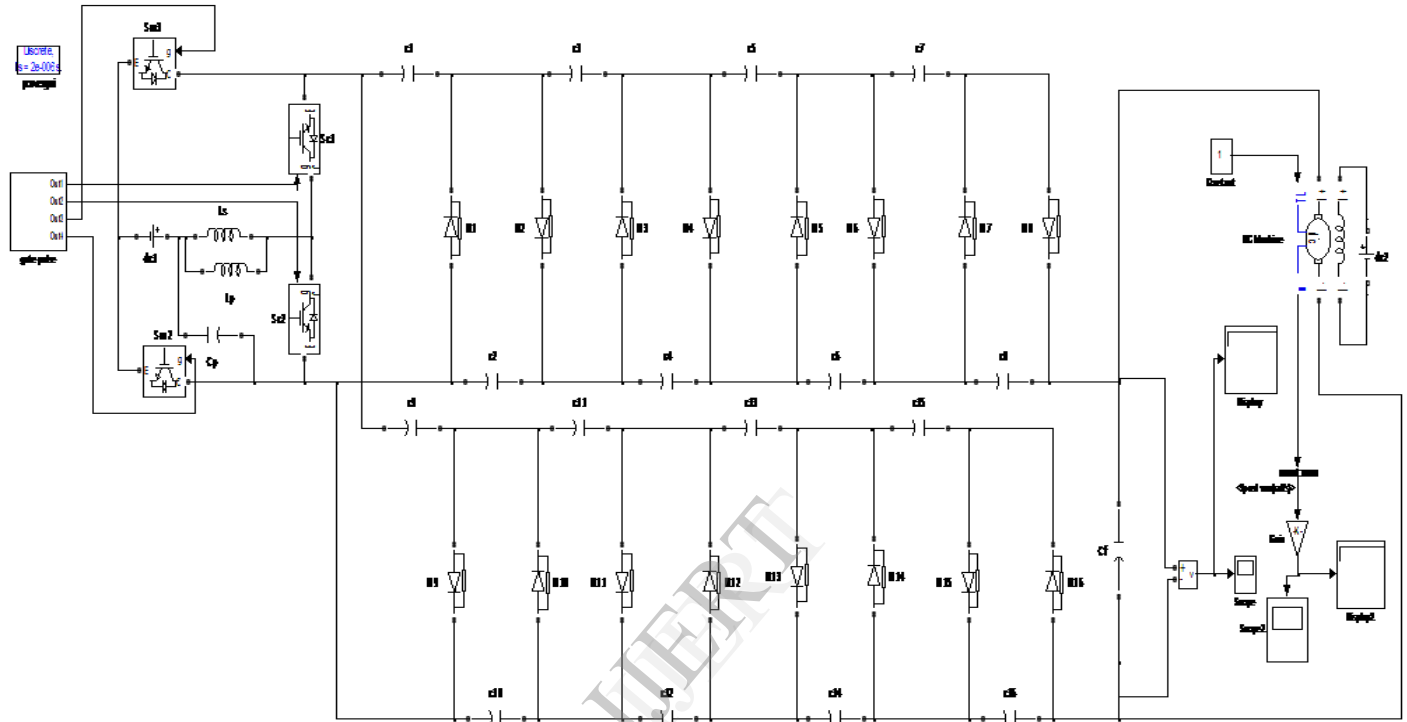

Fig.2 Circuit Diagram of the Proposed Converter

The stacked CW voltage multiplier is constructed using capacitors and diodes by a cascade of stages with each stage containing two capacitors and two diodes and stacked to create stacked CW voltage multiplier. In the stacked CW voltage multiplier both capacitors and diodes are divided into odd group and even group according to their suffixes. Switches Sm_1 (Sc_1) and Sm_2 (Sc_2) operate in opposite mode, and the operating frequencies of switches Sm_1 and Sc_1 are defined as fsm and fsc, respectively. For ease, fsm is denoted as modulation frequency, and fsc is denoted as alternating frequency. In theory, these two frequencies should be as high as possible so that smaller inductor and capacitors can be used in this circuit. The fsm is set much higher than fsc, and the output voltage is controlled by controlling the duty cycle of Sm_1 and Sm_2, while the output voltage ripple is controlled by the capacitor filter and the parallel inductor and can also be adjusted by fsc.

A. Operation

The circuit operation of the proposed converter as shown in Fig.2 is analysed with a three-stage stacked CW voltage multiplier. The operation of the proposed converter can be separated into two parts depending on the polarity of

operation as positive conducting interval [t_0, t_1] for $i_\gamma \geq 0$ and negative conducting interval [t_1, t_2] for $i_\gamma \leq 0$. At some point in positive conducting period, only one of the even diodes can conduct with the sequence D_8-D_6-D_4-D_2 and D_{16}-D_{14}-D_{12}-D_{10}, at some point in negative conducting period, only one of the odd diodes can conduct with the sequence D_7-D_5-D_3-D_1 and D_{15}-D_{13}-D_{11}-D_9. Some assumptions are made as follows.

1) All the circuit elements present are ideal so there is no power loss in the system.
2) The proposed converter is operating in CCM and in the steady-state condition.
3) Some safe commutation states are ignored.
4) When the inductor transfers the storage energy to the stacked CW circuit, only one of the diodes in the stacked CW circuit will be conducting.

According to the polarity the operation of the proposed converter can be divided into two parts as positive conducting interval [t_0, t_1] for $i_\gamma \geq 0$ and negative conducting interval [t_1, t_2] for $i_\gamma \leq 0$. The circuit operation of the proposed converter is explained using Fig.2. During positive conducting interval, only one of the even diodes can conduct with the sequence D_8−D_6−D_4−D_2-D_{16}−D_{14}-D_{12}-D_{10},

while during negative conducting interval, only one of the odd diodes can conduct with the sequence $D_7-D_5-D_3-D_1-D_{15}-D_{13}-D_{11}-D_9$. Moreover, during positive conducting interval, there are four circuit states.

1) State I: Sm_1 and $Sc1$ are turned on, and Sm_2, Sc_2, and all stacked CW diodes are turned off. The boost inductor is charged by the input dc source, the even group capacitors C_6, C_4, C_2, C_{12}, C_{10} and C_8 supply the load, and the odd-group capacitors C_5, C_3, C_1, C_{11}, C_9 and C_7 are floating.

2) State II: Sm_2 and Sc_1 are turned on, Sm_1 and Sc_2 are turned off, and the current i_γ is positive. The boost inductor and input dc source transfer energy to the stacked CW voltage multiplier through different even diodes. State II-A, D_6 is conducting; thus, the even-group capacitors C_6, C_4, C_2, C_{12}, C_{10} and C_8 are charged, and the odd-group capacitors C_5, C_3, C_1, C_{11}, C_9 and C_7 are discharged by i_γ. 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. 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.

3) State III: Sm_2 and Sc_2 are turned on, and Sm_1, Sc_1, and all stacked CW diodes are turned off. The boost inductor is charged by the input dc source, the even group capacitors C_6, C_4, C_2, C_{12}, C_{10} and C_8 supply the load, and the odd group capacitors C_5, C_3, C_1, C_{11}, C_9 and C_7 are floating.

4) State IV: Sm_1 and Sc_2 are turned on, Sm_2 and Sc_1 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. 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, C_1, C_{11}, C_9 and C_7 are charged by i_γ. 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. 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.

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

$$\frac{di_L}{dt} = \frac{1}{L_s}\left[V_{in} - (d_{sc} - d_{sm})v_\gamma\right] \qquad (1)$$

Where V_{in} is the input voltage, i_L is the input current, and v_γ is the terminal voltage of the stacked Cockcroft Walton voltage multiplier. In the proposed converter switches Sc_1 and Sc_2 are used to generate an alternating supply to feed into the CW voltage multiplier and switches Sm_1 and Sm_2 are used to control the inductor energy to obtain a boost performance. The diodes and capacitors are connected in cascaded connection to form a voltage multiplier. This is connected to the switches with a source

and to parallel inductors. These form a two loop with two switches at both sides with a common inductor to boost the initial supply or source. The parallel inductors have mutual inductance due to which it helps in reducing the sudden increase in the output value. Here a capacitor is connected across a switch and the source. This will increase the system efficiency and increase the initial supply voltage to a certain amount. The Cockcroft Walton voltage multiplier is formed and another cascaded voltage multiplier is stacked to it and the output is taken from the D_8cathode and D_{16} anode. The converter operates in continuous conduction mode, so the switch stresses, the switching losses, and EMI noise can be reduced as well.
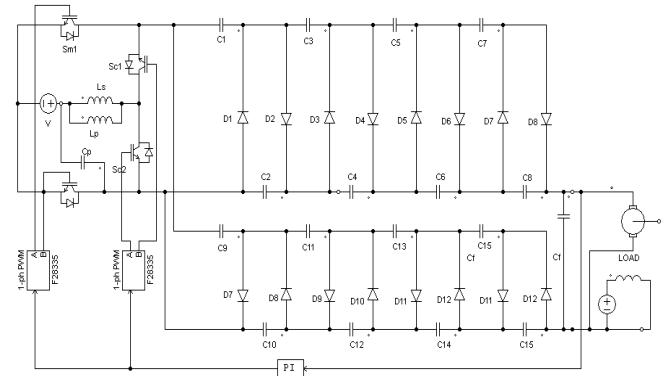

Fig.3 Circuit Diagram of the Proposed Converter for 4 levels for Closed Loop

The stacked Cockcroft Walton voltage multiplier is provided by a sinusoidal ac source with line frequency is used to analyse the behaviour of the stacked CW circuit through simulation using Fig.3. One inductor is connected between the ac source and the stacked CW voltage multiplier for smoothing the current iγ. During positive half cycle, that only one of the even diodes is conducted with the sequence $D_8-D_6-D_4-D_2-D_{16}-D_{14}-D_{12}-D_{10}$and with the aim of the even and odd capacitors are charged discharged through the conducting diodes. Similar behaviour occurs during the negative half cycle, while the odd diodes are conducted with the sequence $D_7-D_5-D_3-D_1-D_{15}-D_{13}-D_{11}-D_9$and the odd and even capacitors are charged and discharged.

The DC voltage gives the required initial voltage for the circuit to operate; the inductor stores the energy and boosts the voltage and this voltage has to be passed through the switches. The IGBT switches starts to operate as soon as it gets the gate pulse from the pulse generator and due to the varying in operation for individual IGBT the output gets increased slightly. Thus this part produces a voltage little higher than the input voltage. The parallel inductor helps in reducing the sudden rise of voltage at output side during the initial stage of the system. The capacitor connected across to the source and the switch increases the output and the system efficiency.

This voltage is given to the stacked voltage multiplier; the voltage multiplier multiplies the give voltage to certain times according to the number of stages used in the circuit. Then the output voltage is given to load after filtering it with a capacitive filter. The output voltage is taken as

feedback and compared with a reference voltage and the resultant value is given to a PI controller and the pulse generation for the IGBT switches is automatically adjusted and the reference value can be set according to the load or according to the requirement. The desired output is obtained without any ripples and distortion with improved output voltage, thus a high voltage is obtained using a low voltage source.

IV. SIMULATION & EXPERIMENTAL RESULTS

The conventional converter is compared to the proposed converter by producing the output by both converters. Both the converters are simulated with and without load, when the load is applied the conventional converter showed more distortion in the output and the output voltage of the converter too got reduced but the proposed converter removed those distortion and produced a distortion free output and the output voltage too increased and maintained at a certain level.

A. Comparison of Proposed Output with Conventional Converter Output

When the nonlinear load is applied to the conventional converter Fig.4 the ripples obtained are too high and the distortion is too high, it produces nearly 310v, but the simulation output of the proposed converter Fig.5 shows that it does not have too much ripples and distortion when a nonlinear load is applied and it also obtains a voltage of 810v approximately.
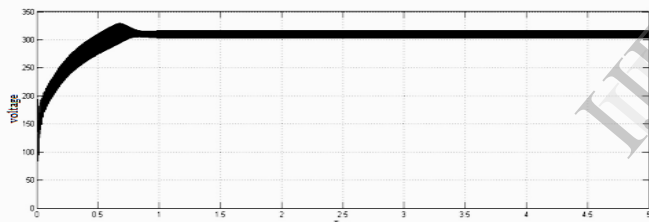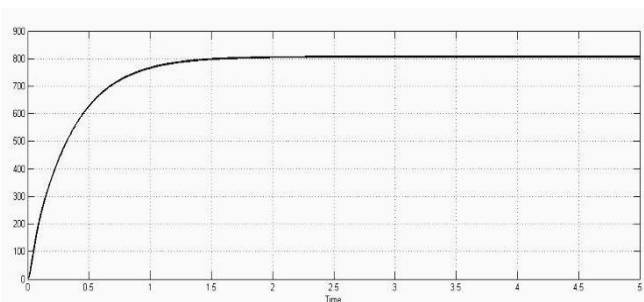
Fig.4 Conventional Converter Output for 42v with Load

Fig.5 Proposed Converter Output for 42v with Load

V. RESULTS

The comparison chart of existing and proposed system output voltagesis shown Fig.6. The table 1 is the comparison tables of the output voltage of proposed and existing system. The Comparison gives us a clear idea about the proposed converter which can produce large output without too much distortion, ripples and much more efficient than the conventional converter. This is obtained

due to the addition of capacitor and the stacking of the circuit resulted in increase of voltage and the inductor and capacitor acts as a filter and produces a stable output. Thus the analysis of both converters shows that the proposed converter is more efficient and can be used in all fields.
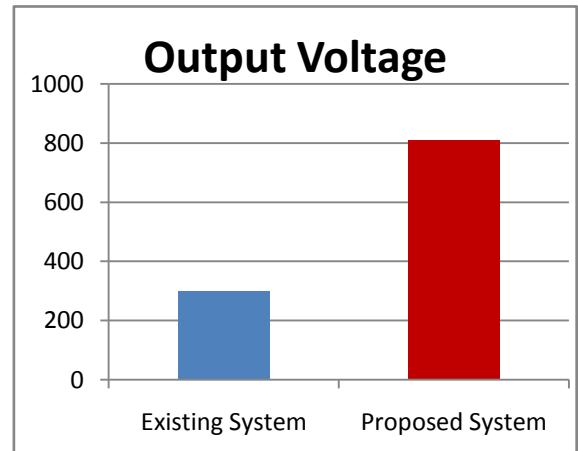
Fig.6 Comparison Chart of Existing and Proposed System

Table.1 Comparison of Proposed and Existing Method

INPUTVOLTAGE	EXISTING METHOD	PROPOSED METHOD
10 V	70 V	176 V
42 V	300 V	810 V

The Comparison gives us a clear idea about the proposed converter which is can produce large output without too much distortion, ripples and much more efficient than the conventional converter.

REFERENCES

[1] B. K. Bose (2000), "Energy, environment, and advances in power electronics," IEEE Trans. Power Electron., vol. 15, no. 4, pp. 688–701.

[2] F. Blaabjerg, Z. Chen, and S. B. Kjaer (2004), "Power electronics as efficient interface in dispersed power generation systems," IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1184–1194.

[3] Q. Li and P. Wolfs (2008), "A review of the single phase photovoltaic module integrated converter topologies with three different dc link configurations," IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1320–1333.

[4] W. Li and X. He (2011), "Review of nonisolated high-step-up dc/dc converters in photovoltaic grid-connected applications," IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1239–1250.

[5] M. W. Ellis, M. R. Von Spakovsky, and D. J. Nelson (2001), "Fuel cell systems: Efficient, flexible energy

conversion for the 21st century," Proc. IEEE, vol. 89, no. 12, pp. 1808–1817.

[6] G. R. Walker and P. C. Sernia (2004), "Cascaded dc-dc converter connection of photovoltaic modules," IEEE Trans. Power Electron., vol. 19, no. 4, pp. 1130–1139.

[7] J. Wang, F. Z. Peng, J. Anderson, A. Joseph, and R. Buffenbarger (2004), "Low cost fuel cell converter system for residential power generation," IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1315–1322.

[8] L. S. Yang, T. J. Liang, and J. F. Chen (2009), "Transformerless dc-dc converters with high step-up voltage gain," IEEE Trans. Ind. Electron., vol. 56, no. 8, pp. 3144–3152.

[9] N. Mohan, T. M. Undeland, and W. P. Robbins (1995), Power Electronics, 2^{nd}ed. New York: Wiley, pp. 172–178.

[10] A. L. Rabello, M. A. Co, D. S. L. Simonetti, and J. L. F. Vieira (1997), "An isolated dc-dc boost converter using two cascade control loops," in Proc.IEEE ISIE, vol. 2, pp. 452–456.