A Transformer Less High Step up DC-DC Converter Based on Cockcroft Walton Voltage Multiplier for Inverter fed Three Phase Induction Motor

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Abstract

In this paper, the proposed work focused on Cockcroft Walton Voltage multiplier for step up DC-DC converter without a transformer. For renewable energy applications, the proposed converter gives high voltage gain and less voltage stress across 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. The proposed work is carried out using MATLAB Simulink. The simulation results are presented to validate the proposed work.

Key words: High Voltage DC-DC Conversion, transformer less, non-isolated, voltage multiplier, induction motor.

I. INTRODUCTION

The consumption of electrical energy was increased from past few years, so that the demand for the renewable energy source also increased. The electric energy produced by renewable energy sources is not stable in nature; resulting utility grid will be badly effected [1]. So that the researches worldwide focused on the active-power flow on the utility grid. In the group of different renewable energy sources, the photo voltaic cell and fuel cell and fuel cell are considered as an attractive choice [2]. And from the past few decades the solar energy demand was increased. However, the output voltages from these sources are very low [3]. Therefore, in the power conversion system, an extra arrangement is needed. A high voltage DC-DC step-up converter is needed in the power conversion system. To make an energy storage system more compact and flexible the transformer is replaced with a DC-DC converter [4].

There are different bidirectional isolated DC-DC converters interfaced with the energy storage devices, which concentrates on fuel cell application. The main aim of this paper is to get high voltage gain, and it can be done by conventional boost converter with an extreme high duty cycle. But the effect of parasitic elements associated with the inductor, capacitor, diode and switch can reduce the voltage gain [5]. A high voltage ratio can be possible with the step up DC-DC converter by using coupled inductors or isolated...
Transformers without high duty cycle. For this the transformer leakage inductance should be increased, resulting high voltage spikes at turn off instant, so that the switch is burdened. Therefore, high voltage rating switches are required [6]. The current fed converters are providing low input current ripple and high voltage ratio. Without extreme high duty cycle, to accomplish high voltage gain with efficiency improvement and voltage stress reduction, some alternative current fed converters with step up transformers or coupled inductors are there. The main drawback to use these converters are, the high-frequency transformers, coupled inductors or resonant components design is complex [7].

To overcome this design complexity, the transformer in the converter should be removed. And transformers less step up DC-DC converters are in existence to achieve high voltage gain. These types of converters consist of cascaded diode inductor modules or diode capacitor modules. This type of converters is simple and robust structure [8]. Among high voltage DC applications, a Cockcroft Walton Voltage Multiplier is very popular. To provide high voltage ratio than the CW Voltage Multiplier, the proposed converter uses boost type structure instead of step up transformer. The applications of the DC power supplies over past few years are, industries, sciences, military, medicine, and especially in testing equipment, like X-ray systems, dust-filtering, insulating test and electronic coating [9].

To reduce the switch stress, switching losses and EMI Noise, the continuous conduction mode of operation is considered in this paper. 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 clearly in this paper.

II. PROPOSED METHODOLOGY:

Fig 1: Architecture for Proposed System

The block diagram of a PV power conversion system is shown in fig. 1. Among various renewable energy sources, the solar photo voltaic source plays a major role, and a PV cell generates voltage around 0.5 to 0.8 volts, this voltage is very low, and tens of PV cells are connected to in series to form a module. These modules are interconnected in series or parallel to form a pv panel[10]. Thus a high step up DC-DC converter is connected across the PV panel. The High DC voltage is converted into AC voltage to drive a motor. A multilevel inverter can be used for the conversion of high DC voltage to AC voltage. The number of levels of the multilevel inverter is based on the CW voltage multiplier levels. For an N stage CW voltage multiplier, N+1 level inverter can be used.

With the high voltage multilevel inverters, high power can be produced, because the voltage stresses developed in the devices are controlled. Without using higher rating components in the inverter, it may be
possible of getting high power rating by increasing the number of levels in the multilevel inverter. It is possible of getting high voltages with low harmonics, by using a transformer less multilevel voltage source inverter. The harmonic content of the output voltage waveform can be reduced with increasing the number of levels in the inverter. Therefore, the total harmonic distortion (THD) for output voltages, high efficiency, and power factor of multilevel inverter is low.

In this paper, a control strategy has been developed for PV enter faced high gain DC-DC converter for inverter fed three phase induction motor. The performance of the proposed work has been carried under MATLAB/Simulink software.

II. DESCRIPTION OF THREE-STAGE CW VOLTAGE MULTIPLIER CONVERTER:

A three stage CW circuit applied to a transformer less step up converter is depicted in fig 2. It consists of four switches, from those four, two switches Sc1 and Sc2 are used to feed CW circuit with an alternating source. Sm1 and Sm2 are used to obtain the boost performance. And the switches Sm1 and Sm2 operated in complementary modes with the same frequency $f_{sm}$ and is defined as modulating frequency. Similarly, Sc1 and Sc2 are operated in complementary modes with the frequency of $f_{sc}$ which is defined as alternating frequency. Fig. 2 shows the proposed converter, which consists of a PV module as a source and 3 stage CW voltage multiplier. And also one boost inductor $L_s$.

![Fig 2: Proposed converter with 3-stage CW voltage multiplier.](image)

The follows are assumptions to simplify the circuit operation.

1. For the analysis all components in the converter assumed to be ideal.
2. Assuming, in the Continuous Conduction the proposed converter analyzed during steady state.
3. During transfer of storage energy in the boost inductor only one of the diodes of CW circuit conductors.

The proposed converter operation can be divided into two modes. Positive conduction mode and negative conduction mode. Four conduction states in positive conduction mode, states I, II, III, and IV. $S_{m1}$ turns on in State I; thus, the boost inductor charges. $S_{m2}$ turns on in states II, III and IV, and the inductor transfers energy to the CW circuit through even diodes $D_6$, $D_4$, and $D_2$, respectively. Similarly, four circuit states are there in the negative conduction mode, states IA, IIA, IIIA and IVA. Each state behavior is explained as follows.

**State I:** This interval starts with switching on of $S_{m1}$ and $S_{m2}$ and Switching off $S_{m2}$ and Sc2 along with all the CW diodes made turned
off as depicted in fig 3a. In this interval charging of boost inductor done by PV input and the power flow from source to load is supplied by already charged capacitors C6, C4, and C2, which are even capacitors and the odd pair of capacitors C5, C3 and C1 are floating.

**Fig 3a: Mode-1 Circuit Configuration**

**State II:** This interval starts with switching on of Sm2 and Sc1 and Switching off Sm1 and Sc2 and the current $i_γ$ is positive. In this interval the input PV source and boost inductor supplies the CW circuit. And it is depicted in fig 3b, in this state the load is supplied by even capacitors C6, C4, C2. And the odd pair of capacitors C5, C3 and C1 are discharged by $i_γ$. Moreover, in the CW voltage multiplier only D6 is conducting. The conducting condition of D6 is ($vc_5 > vc_6$) and ($vc_3 > vc_4$).

**Fig 3b: Mode-2 Circuit Configuration**

**State III:** This interval starts with Switching on of Sm2 and Sc1 and Switching off of Sm1 and Sc2 and the current $i_γ$ is positive. In this interval the input PV source and boost inductor supplies the CW circuit. And it is depicted in fig 3c, in this state the load is supplied by even capacitor C6 and remaining even capacitors C4 and C2 are charged. And the odd pair of capacitors C3 and C1 are discharged. And C5 is in open condition. Moreover, in the CW voltage multiplier only D4 is conducting. The conducting condition of D4 is ($vc_5 \leq vc_6$) and ($vc_3 > vc_4$).

**Fig 3c: Mode-3 Circuit Configuration**

**State IV:** This interval starts with switching on of Sm2 and Sc1 and switching off Sm1 and Sc2, and the current $i_γ$ is positive. In this interval the input PV source and boost inductor supplies the CW circuit. $C_2$ is charged and the $C_1$ is discharged by $i_γ$, the load is supplied by the $C_6$ and $C_4$ which are even capacitors, and the odd pair of capacitors $C_5$ and $C_3$ are floating. Moreover, in the CW voltage multiplier only D2 is conducting. The conducting condition of D2 is ($i_γ > 0$) and ($vc_5 \leq vc_6$) and ($vc_3 \leq vc_4$).

**Fig 3d: Mode-4 Circuit Configuration**
The switching cycle of next half is similar to that of above discussed four modes.

**IV. DESIGN CONSIDERATIONS**

The voltage gain of the proposed converter, under steady state condition, can be defined as $M_v$, where $M_v$ represents the static voltage gain of the proposed converter.

$$M_v = \frac{V_o}{V_{in}} = \frac{2n}{1 - D}$$

**VOLTAGE STRESS**

**capacitor voltage stress** Assuming that all the capacitors are sufficiently huge in the CW circuit. The drop and ripple of each capacitor voltage are ignored, when a high frequency periodic alternating current is fed into the circuit. Thus, the voltages across all capacitors equal except the first capacitor. The first capacitor voltage is one half of the other, resulting, because of transformer less topology, the voltage rating of the capacitor dependent on duty modulation and the supplied voltage which makes the voltage stress on each capacitor is reduced to maximum of $V_o. pk/n$, where as in previous case discussed it is $V_o. pk/2n$. where $V_o. pk$ is peak value of output voltage.

**Switch and diode voltage stresses** For the proposed converter, the maximum voltage stress on the switches is $V_o. pk/2n$.

The maximum voltage stress on the diode in the proposed converter is $V_o. pk/n$. The switch voltage stress is half of the diode voltage stress.

**Input inductance** The boost inductor value can be calculated as

$$L_s = V_{in} \frac{D T_{sm}}{K1 I_{pk}}$$

Where $K1$ is the inductor maximum peak to peak ripple (expecting percentage). $I_{pk}$ is the current stress.

**V. SIMULATION RESULTS**

The specifications and parameters of the proposed converter are listed below.

**TABLE I**

<table>
<thead>
<tr>
<th>Proposed converter specifications</th>
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<tbody>
<tr>
<td>Output power, $P_o$</td>
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<tr>
<td>Output voltage, $V_o$</td>
</tr>
<tr>
<td>PV output voltage, $V_{in}$</td>
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<tr>
<td>Modulation frequency, $f_{sm}$</td>
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<tr>
<td>Alternating frequency, $f_{sc}$</td>
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<tr>
<td>Resistive load, $R_L$</td>
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<td>Stage number, $n$</td>
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**TABLE II**

<table>
<thead>
<tr>
<th>Component List for The Proposed converter</th>
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<tbody>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Boost inductor</td>
</tr>
<tr>
<td>Power switches Sm1, Sm2, Sc1, Sc2</td>
</tr>
<tr>
<td>Capacitor</td>
</tr>
<tr>
<td>Diodes</td>
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**TABLE III**

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<tr>
<th>Induction Motor Specifications</th>
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<tr>
<td>Output Power</td>
</tr>
<tr>
<td>Nominal Voltage</td>
</tr>
<tr>
<td>Nominal Frequency</td>
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<tr>
<td>Speed</td>
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Simulation results for the proposed converter with ratings of $P_o=300\text{W}$, $V_{in}=48\text{V}$, $V_o=580\text{V}$ are shown in fig 4. The switching signals of the four switches $S_{c1}$, $S_{c2}$, $S_{m1}$, $S_{m2}$, output voltage of the solar panel $V_{in}$, output voltage of the DC-DC converter $V_o$, inductor current $I_L$, terminal voltage $V_γ$ and current $i_γ$, line voltages of the three phase inverter, rotor speed and torque are presented to validate the proposed method.

Fig 4a represents the output of the PV panel which is given as input for the DC-DC converter. Fig 4b represents the gate pulses for the proposed converter, top two figures in the fig 4b are the gate pulses of $S_{c1}$ and $S_{c2}$ which are operated at a frequency, $f_{sc}$. Fig 4b shows pwm pulses which are given to the switches $S_{m1}$ and $S_{m2}$ with the frequency of $f_{sm}$. Fig 4c and 4d represents DC output voltage which is given to the inverter and inductor current respectively. Fig 4e and 4f are...
the terminal voltage and currents of the proposed converter. Fig 4g represents the line voltages of inverter. Fig 4h and 4i are the angular speed and electromagnetic torque of the three phase induction motor.

VI. CONCLUSION

A transformer less high step up DC–DC converter based on CW voltage multiplier is designed with a PV panel. Power components with the same rating are selected while the number of cascaded stages doesn’t affect the voltage stress on the switches, diodes, and capacitors. The block diagram, circuit operation and design considerations are discussed. Simulation results proved that the validity of the proposed converter.

VII. REFERENCES


