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The Modular Multilevel Converter for High Step-Up Ratio DC-DC Conversion

Abhijith Narayanan[1], Eldhose K.A[2], Honey Soosan Eldhose[3]

PG Scholar [PE], Dept. of EEE, MACE, Kothamangalam, Kerala, India[1]

Assistant Professor, Dept. of EEE, MACE, Kothamangalam, Kerala, India[2]

Assistant Professor, Dept. of EEE, MACE, Kothamangalam, Kerala, India[3]

ABSTRACT:High step-up ratio DC-DC converters with megawatt ratings are of interest in wind turbine interfaces and high-voltage direct-current systems. The modular multilevel DC-DC converter based on the standard boost converter topology but with the normal single switches replaced by a number of capacitor-clamped sub-modules. The converter is operated in resonant mode with resonance between sub-module capacitors and the arm inductor. A phase-shifted switching arrangement is applied such that there is a constant number, i.e., N, of sub-modules supporting the high voltage at a time. In this operationmode, the step-up ratio is dependent on the number of sub-modules and the inductor charging ratio. The converter exhibits scalability without using a transformer and is capable of bidirectional power flow. The output is simulated using MATLAB R2014a. The experimental verification of the concept using a lab-scale prototype is provided.

KEYWORDS: Modular multilevel converters (MMCs), resonant conversion, step-up dc–dc conversion.

I. INTRODUCTION

Multilevel converters used for medium-voltage and high-voltage applications significantly reduce the harmonic content of the output voltage as compared with the traditional two-level converters [1]. The modular multilevel converter (MMC) is found to have more attractive features than the others. Diode-clamped converters have a large number of diodes required, and with the unbalancing issue, making the system impractical to implement. Conventional flying capacitor converters require many capacitors connected in series. The total series capacitance is much smaller than that of a single one. Therefore, the total volume of capacitors required is quite high. Generalized multilevel converters can be used for step-up DC-DC conversion but topology results in a large size when the step ratio is high. Other topologies such as input-parallel output-series (IPOS) converters and switched capacitor converters have been proposed and developed for step-up DC-DC conversion. Switched capacitor converters with series-parallel topologies are subject to incremental voltage stress either on the module switch or on the module capacitor. The highestvoltage stress is close to the output (high-side) dc voltage. The switched capacitor converters are also subject to high charge losses and overshoot currents. This problem canbe mitigated by driving metaloxidesemiconductor field-effect transistors (MOSFETs)with very high switching frequency. Therefore, switched capacitor converters are onlyused under a low-voltage condition. A power-electronics-based Cockcroft-Walton multiplier has been demonstrated in. This is a light and cheap solution for high-voltage dc experiments when only unidirectional step-up conversion is required. A bidirectionalmediumvoltage ladder-shaped DC-DC converter is proposed in, which can achieve ahigh step ratio. The advantage is that the converter does not require synchronizationof switching between sub-modules.

In medium and high-voltage applications, MMCs used for DC-DC conversion are emerging technologies. These converters are based on conventional MMCs. MMCs usually require a complicated balancing control scheme to maintain the voltage levels. However, they provide more than two levels and good waveform quality.Cells with fault can also be bypassed while keeping the system operational. High modularity and redundancy are the main advantages of MMCs. Until now, there has been no direct andsimple solution for large step-up ratio DC-DC conversion using the MMC approach. Thispaper presents a new topology and control scheme of a modular multilevel bidirectional DC-DC converter with high step-up ratio. It is based on the conventional boost converterwith groups of sub-modules placed in both the diode and switch positions. The converter can achieve a high step up ratio. Phase-shifted pulse width

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modulation (PWM) is used to achieve a high effective operating frequency for a given sub-module switching frequency.

II.THE MODULAR MULTILEVEL CONVERTER FOR HIGH STEP-UP RATIO DC-DC CONVERSION

The configuration of the step-up conversion is provided to demonstrate the concept.The most commonly used boost converter topology with a single IGBT and a single diode is shown in Fig. 1(a). The IGBT in the lower position is used forcharging the input inductor L. The diode in the upper position of the circuit is automatically commutated on when the inductor is discharging current to the high-voltage capacitor. Applying active clamping to the two switches, the modular multilevelunidirectional step-up converter with two stacks of sub-modules is obtained as shown in Fig. 1(b). The number of the half-bridge (clamped IGBT) sub-modules in thelower position is M. The number of the chopper (clamped diode) sub-modules in theupper position is N.

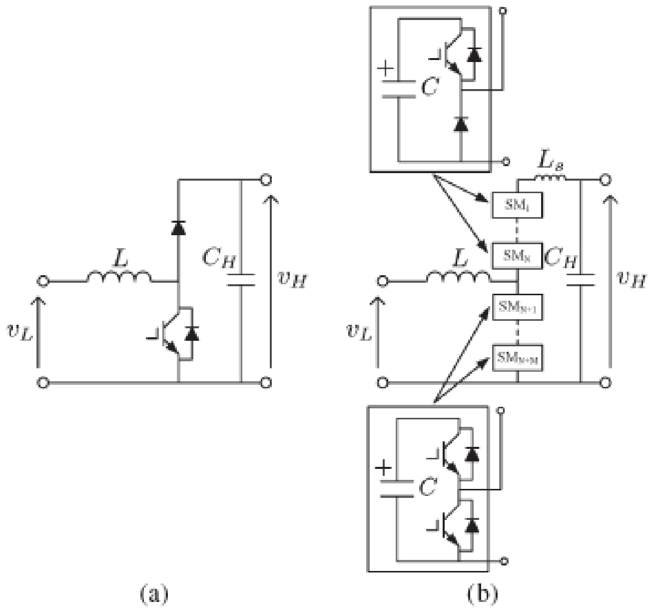

Fig. 1: Bidirectional DC-DC converters. (a) Conventional two-level DC-DC converter.
(b) Novel modular multilevel DC-DC converter.

The output (high-side) voltage is approximately equal to the sumof capacitor voltages of the stack of sub-modules once duty cycles are accounted for. There will be small differences between the instantaneous voltage across the stack (assub-modules switch) and the voltage across, and this is accommodated by includingthe small inductor LS. A large capacitor would normally be present at the input(low voltage) side. The step-down conversion can be configured using the similar concept.

III. MODES OF OPERATION

The converter has various operating modes resulting in different operating features and step up ratios.Apart from the high step-up ratio operation mode, whichis the focus of this paper, the converter can also be used for high step down

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ratio DC-DC conversion providing power for an auxiliary electronic circuit in medium-voltage systems.

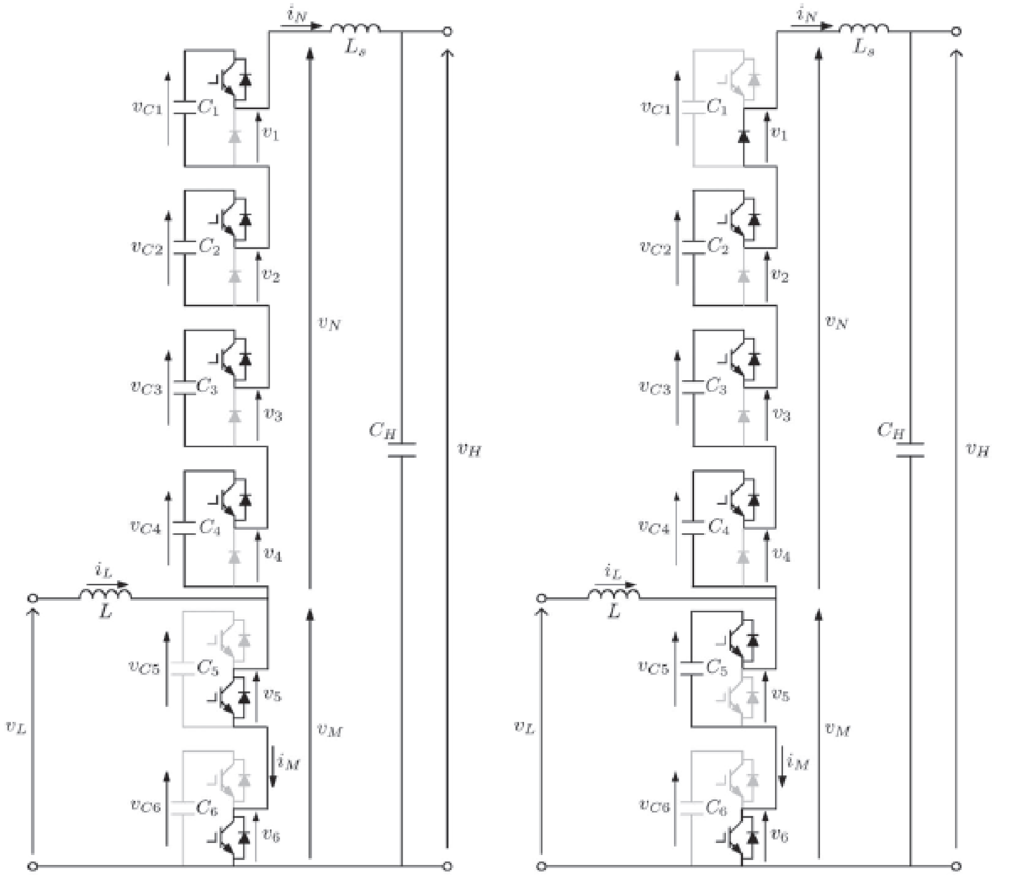

Fig .2(a) Mode 1. (b) Mode 2.

Mode 1 starts when theIGBT in Cell 4 is switched on and ends when the IGBT in Cell 1switches off [see Figure. 2(a)]. The IGBT in Cell 1 switches offwhen the lower IGBT in Cell 5 switches off, and this definesthe beginning of Mode 2 [see Figure. 2(b)]. Mode 2 ends whenthe IGBT of Cell 1 is switched on again. Modes 1 and 2 areanalogous to the on- and off-states of the simple boost converterbut with the difference that current can flow in both paths inboth modes. The current flowing through the input inductor,upper cells (clamped diodes), and lower cells (clamped IGBTs)are defined as i_L, i_N, and i_M, respectively.

IV.DESIGN OF CONVERTER

The capacitors C_1, C_2, C_3, and C_4 are in series with the inductor L and the high-side (output) capacitor C_H, and together, they form a resonant tank. Therefore, theresonant frequency is:

$$f_S = \frac{1}{2\pi\sqrt{\frac{LC}{N}}} \quad \text{.............................(1)}$$

From the above equation, we can find the cell capacitor values and inductance. We get C = 50µF and L= 5.02µH. Under ideal conditions, the capacitor voltages are balanced and equal to V_C. Thevoltage conversion ratio can be derived by:

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$$\frac{v_H}{v_L} = \frac{N}{1-d}$$

Where, d = 0.6.

Components	Specification
Cell capacitors	50µF
Series Inductor	5.02µH
Output Capacitor	180µF
MOSFET	IRF540

Table 1 Components Specification.

V. SIMULINK MODEL AND RESULTS

Using the designed values a Simulink model for the proposed converter is created. Table.1 shows the values used for simulation. Simulation was done using MATLAB/SIMULINK. The converter is simulated for an input voltage of 5V DC and gives outputs of 33V. Figure 5 shows the voltage gate pulses to the switches and figure 6 shows the output waveform.

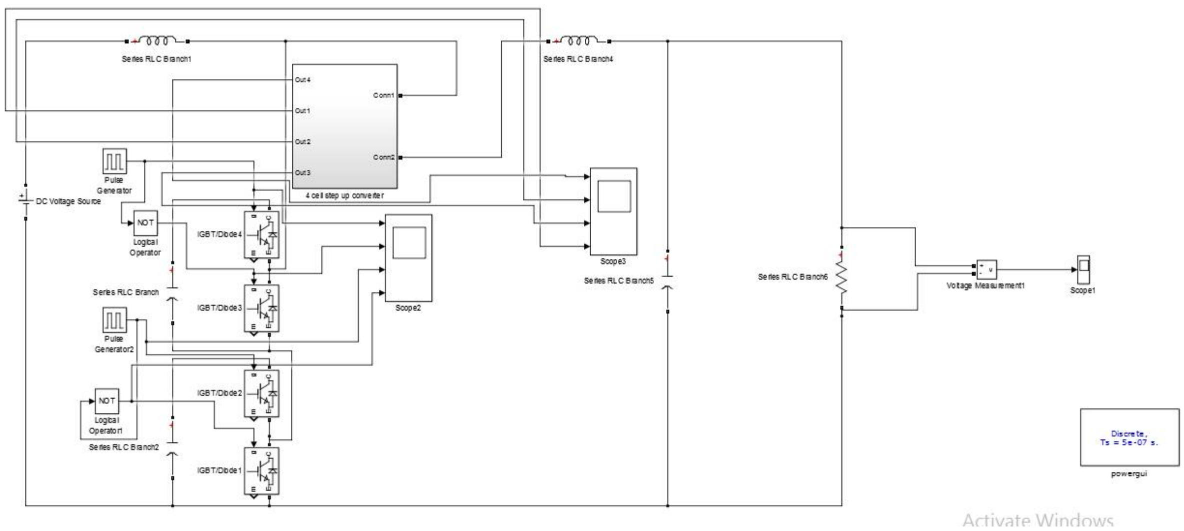

Fig. 3 Simulink model

The figure. 3 shows the Simulink model of MMC with four sub-modules. Simulation was done using MATLAB/SIMULINK.

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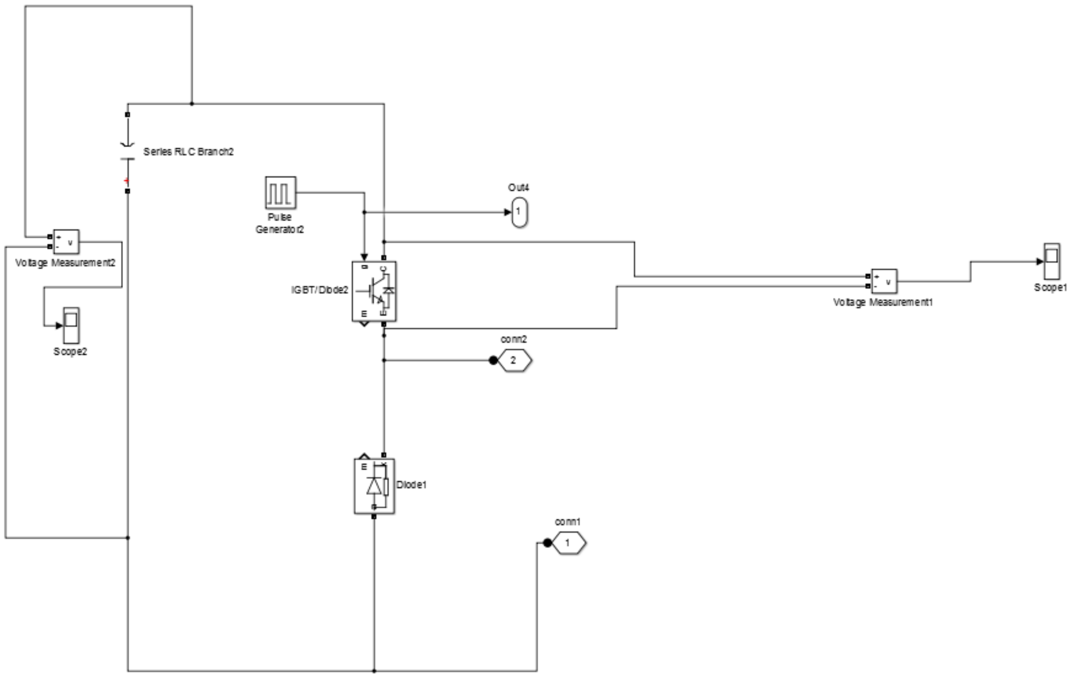

Fig. 2. Simulink model of converter sub-module

The figure. 3 shows the Simulink model of a single unit of converter subsystem. Simulation was done using MATLAB/SIMULINK.

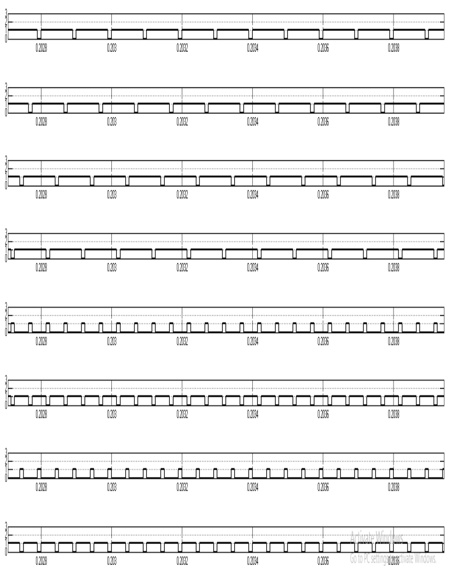

Fig. 5 Voltage Waveforms

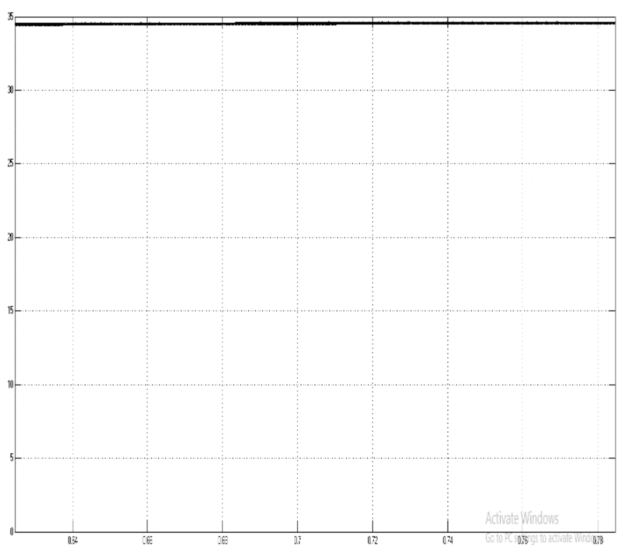

Fig. 6 Output Waveforms.

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In the fig 5, it shows the graph of gate pulses to each switches. The switches in the upper sub-modules are given a time period of 100 µs, where the lower sub-modules are triggered with a time period of 50µs. In the fig 5, it shows the graph of output voltage waveform of the converter for a input voltage of 5 V.

VI.EXPERIMENTAL SETUP

A prototype is designed and the simulation of prototype is also done using MATLAB. The control pulse are generated using a PIC 16F877A microcontroller and to drive the power electronic switches TLP250 is used. The outputs are

Fig. 7. Experimental Setup

observed using a DSO. Figure 7. Shows the experimental setup for the converter. Figure 9. Shows the voltage across the converter switches and Figure 8. Shows the gate pulses.

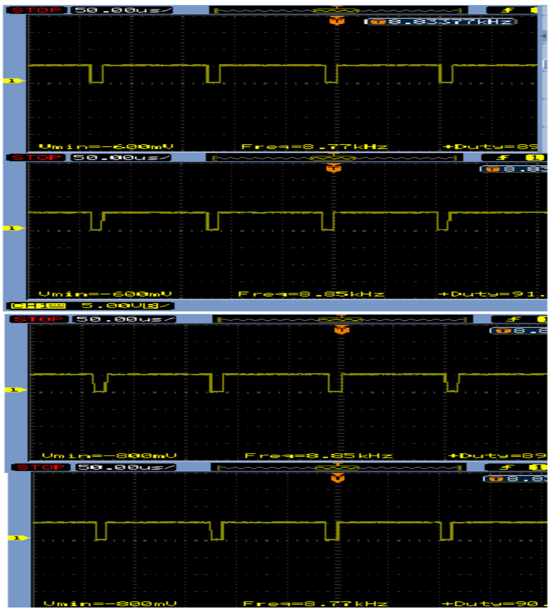

Fig. 8Gate pulses

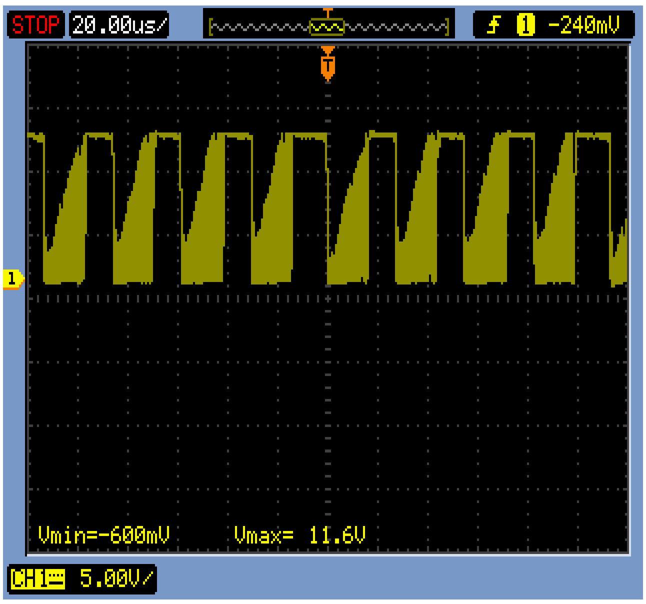

Figure 9. Voltage across the Switches.

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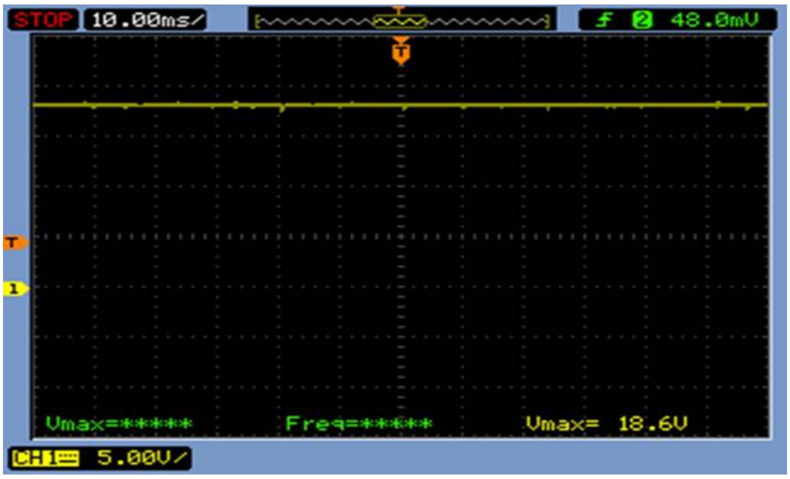

Figure 10. Output Voltage

Figure 10.Shows the output voltage of the converter for a input voltage if 5V.

VII.CONCLUSION

The new transformer less MMC DC-DC converter has been presented and analysed. Two stacks of sub modules in series arrangement support the high voltage. The dc capacitors of the sub-modules are used also for resonant operation. The proposed converter hasa bidirectional conversion ability. The step-up operation and the step-down operation are demonstrated. This converter is capable of operating under open-loop control as adc transformer with good linearity. Alternatively, closed-loop control can be applied for trimming of the output voltage. The operating principle was verified through a bench-scale experimental prototype. The proposed converter may exhibit relativelyhigh losses because of the high ac current that resonates in the sub modules, but reasonably high efficiency was shownto be possible in high-voltage application

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