International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 04, April-2021

Analysis and Design of Multilevel Boost Inverter for High frequency with Reduced Components

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***Abstract*: This work explores the use of the flying-capacitor multilevel (FCML) topology in high step-up conversion. Compared to the conventional two-level boost converter, the FCML topology utilizes high energy density capacitors to facilitate inductors with storing and transferring energy during the conversion process. This contains more features such as lower voltage stress on the switches, reduced voltage stress on the inductor and high effective switching frequency at the switching node. As a result, the total volume of the passive components in the converter is greatly reduced, while maintaining high efficiency at high voltage gain. To demonstrate the potential of high power density and high efficiency, a hardware prototype that converts 100 V to 1 kV with 820 W maximum output power is built. Such specifications require careful optimizations in many aspects of the converter to ensure a high power density and efficiency design. The implemented solutions and associate design process are presented in detail, with comparison with other state-of-the-art solutions. The hardware prototype has successfully demonstrated a peak efficiency of 94.1%, and 329 W/in3 (20 W/cm3) overall power density.**

Key words: High step-up converter, flying-capacitor multilevel, high voltage, GaN

1. INTRODUCTION

A power supply is an electrical device that supplies electric power to an electrical device. The primary function of a power supply is to convert electric current from a source to the correct voltage, current, and frequency to energize the load. Therefore, these power supplies are sometimes referred to as electric power converters. Some power supplies are made as separate standalone pieces of equipment, while others are built inside the appliances that they power. Examples of the latter include power supplies found in desktop computers and electronics devices.

The electrical power is almost exclusively generated, transmitted and distributed in the form of ac because of economical consideration but for operation of most of the electronic devices and circuits, dc supply is required. Dry cells and batteries can be used for this purpose. No doubt, they have the advantages of being portable and ripple free but their voltages are low, they need frequent replacement and are expensive in comparison to conventional dc power supplies. Now a days, almost all electronic equipment include a circuit that converts ac supply into dc supply. The part of equipment that converts ac into dc is called DC power supply. In general at the input of the power supply there is a power transformer. It is followed by a rectifier (a diode circuit)a smoothing filter and then by a *voltage* regulator circuit.

The block diagram of the DC power supply is shown in figure 1. The basic power supply is constituted by four elements namely, a *transformer*, a *rectifier*, a *filter* and a *regulator*. The output of the DC power supply is used to provide a constant DC voltage to the load. Let us briefly outline the function of each of the elements of the DC power supply.

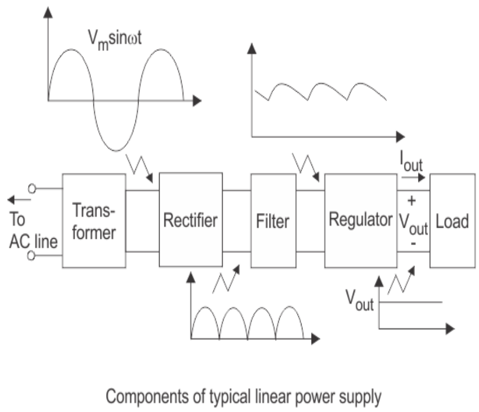

Figure 1. Block diagram of DC power supply

Transformer is used to step-up or step-down (usually to step-down) the-supply voltage as per need of the solid-state electronic devices and circuits to be connected. It can isolate the device from the supply line, which is an important safety consideration. It may also include internal shielding to prevent unwanted electrical noise signal on the power line from getting into the power supply and possibly disturbing the load.

Rectifier is a device, which converts the sinusoidal AC voltage into either positive or negative pulsating DC. P-N junction diodes, can be used for rectification *i.e.* for conversion of AC into DC. The rectifier typically needs one, two or four diodes. Rectifiers may be either **half-wave rectifiers** or full-wave rectifiers (**centre-tap** or **bridge**) type. The output voltage from a rectifier circuit has a pulsating character i.e., it contains unwanted AC components (components of supply frequency *f* and its harmonics) along with the DC component. Most of the electronic devices work with the pure constant DC voltage than that furnished by a rectifier. Therefore to eliminate the AC components from the rectifier a *filter circuit is required.*

Filter is a device, which passes DC component to the load and blocks the AC components of the rectifier output. Filter is typically constructed from reactive circuit elements such as capacitors and/or inductors and resistors. The magnitude of output DC voltage may vary with the variation of either the input AC voltage or the magnitude of load current. So at the output of a rectifier filter combination a voltage regulator is required, to provide an almost constant DC voltage at the output of the regulator. The voltage regulator may be constructed from a Zener diode, and or discrete transistors, and/or integrated circuits (ICs). Its main function is to maintain a constant DC output voltage. However, it also rejects any AC ripple voltage that is not removed by the filter. The regulator may also include protective devices such as short-circuit protection, current limiting, thermal shutdown, or over-voltage protection.

High-voltage power supply is one that outputs hundreds or thousands of volts. A special output connector is used that prevents arcing, insulation breakdown and accidental human contact. Federal Standard connectors are typically used for applications above 20 kV, though other types of connectors (e.g., SHV connector) may be used at lower voltages. Some high-voltage power supplies provide an analog input or digital communication interface that can be used to control the output voltage. High-voltage power supplies are commonly used to accelerate and manipulate electron and ion beams in equipment such as x-ray generators, electron microscopes, and focused ion beam columns, and in a variety of other applications, including electrophoresis and electrostatics.

High-voltage power supplies typically apply the bulk of their input energy to a power inverter, which in turn drives a voltage multiplier or a high turns ratio, high-voltage transformer, or both (usually a transformer followed by a multiplier) to produce high voltage. The high voltage is passed out of the power supply through the special connector and is also applied to a voltage divider that converts it to a low-voltage metering signal compatible with low-voltage circuitry. The metering signal is used by a closed-loop controller that regulates the high voltage by controlling inverter input power, and it may also be conveyed out of the power supply to allow external circuitry to monitor the high-voltage output.

High step-up DC to DC converters deliver high voltage DC output which is required for the DC power systems such as photovoltaic grid-connected power systems [1], very big wind mill farms [2] [3], power generators used for medical electronics used in hospitals such as X-ray [4], satellite ion trusters [5], and Pulse Electric Field (PEF) related applications [6] [7]. In these applications, high step-up converters are usually required to generate DC voltage at kilovolt levels from sources at hundreds of volts, with rated power ranging from hundreds of watts to few kilowatts.

There are many limitations with the traditional boost converter in simultaneously achieving high voltage gain with high power density and efficiency. Some of the major limitations with these system are high voltage stress on switches and diodes, high conduction and switching losses [8] and large magnetic volume due to the low frequency switching of the required high voltage switches [2]. The switched-capacitor (SC) converter is another type of converter that can attain large step-up ratios. It utilizes the high energy density of capacitors [9] to transfer energy, resulting in much higher power density than conventional switched-inductor DC – DC buck or boost converters. However, SC converters have their own issues such as charge redistribution loss and no ability for lossless output load regulation [10].

In this paper we have proposed the use of the FCML converter in high voltage step-up operation. A hardware prototype is implemented, which can convert 100 V to 1000 V with 820 W maximum output power and 94.1% peak efficiency. Comparing to state-of-the-art solutions, the proposed converter has demonstrated a significant improvement on the power density and efficiency, with the inherent advantages of the FCML topology that allow the use of smaller inductors, low voltage switches and high energy density capacitors in designing the circuit.

2. LITERATURE SURVEY

In [11] Serban et al., have proposed a system for solar inverters. Solar plants based on single-stage conversion photovoltaic (PV) inverters have gained popularity due to their simplicity, high efficiency, and cost effectiveness. Existing PV plants mostly operate under 1000 V and are subject to wide dc-bus voltage variations due to the effect of PV cell temperature and the voltage of the maximum power point. This paper investigates 1500 V solar inverters with a focus on dc-bus voltage range extension capabilities through novel modulation and power devices utilization. A comparative analysis with the existing 1000 V solar inverters is presented to illustrate the significant advantages of the wide dc-bus range in 1500 V systems.

A non-isolated multilevel step-up dc-dc converter suitable for high power and high output voltage application is proposed by LF Costa et al [12]. The main features of proposed converter are: reduced voltage across the semiconductors, low switching losses and reduced volume of input inductor. This paper focuses on the five-level structure of the proposed converter, in which the theoretical analysis is carried out and discussed. The five-level proposed DC-DC converter has four capacitors and their voltages should be balanced for its correct operation. In [13] G. Lefevre et al., have proposed a multilevel flying-capacitor boost converter. It is analyzed for asymmetric voltage operation-this permits loss optimization that takes advantage of different voltage class MOSFETs. A cost-motivated design of a suitable zero-voltage zero-current switching snubber is then developed that permits a great reduction of the inductor size. With the proposed snubber, synchronous rectification operation is compared to that of diode boost, with a particular attention to the contribution of nonlinear MOSFET parasites.

Barth C et al. have proposed a model [14], "Experimental evaluation of capacitors for power buffering in singlephase power converters". Variable or adjustable speed drives generate pulse width modulated waveforms with risetimes

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below 100 ns. These very rapid transitions can cause large turn-to-turn voltages in inductive devices such as random wound motors, resulting in partial discharge and premature failure. One way to mitigate this problem is to absorb high frequency energy in the cable between the drive electronics and the motor. This contribution analyses design considerations for optimization of such a cable. Y. Lei and R. Pilawa-Podgurski have proposed a method [15], which shows that resonant and soft-charging operations of SC converters are closely related, and a technique is proposed, which achieves either operation by adding a single inductor to existing SC topologies. In addition, since most preexisting resonant or soft-charging SC converters were devised in an ad-hoc manner, this paper formulates an analytical method that can determine whether an existing conventional SC converter topology is compatible with the proposed approach. A number of common SC topologies are analyzed, including Dickson, series-parallel, ladder, Fibonacci, and doubler configurations. Through comparison to simulated results, as well as experimental work, the proposed method is validated and a family of high-performance SC converters is obtained.

Y.Lei et al. [16] have designed a 2-kW, 60-Hz, 450-VDC-to-240-VAC power inverter, and tested subject to the specifications of the Google/IEEE Little Box Challenge. The inverter features a seven-level flying capacitor multilevel converter, with low-voltage GaN switches operating at 120 kHz. The inverter also includes an active buffer for twice-line-frequency power pulsation decoupling, which reduces the required capacitance by a factor of 8 compared to conventional passive decoupling capacitors, while maintaining an efficiency above 99%. E. Babaei et al.[17] have proposed "A Single-Phase Cascaded Multilevel Inverter Based on a New Basic Unit With Reduced Number of Power Switches", In this paper, a new single-phase cascaded multilevel inverter is proposed. This inverter is comprised of a series connection of the proposed basic unit and is able to only generate positive levels at the output. Therefore, an H-bridge is added to the proposed inverter. This inverter is called the developed cascaded multilevel inverter. In order to generate all voltage levels (even and odd) at the output, four different algorithms are proposed to determine the magnitude of dc voltage sources.

3. PROPOSED METHOD

Pulse Width Modulation (PWM) is the simplest technique that can be implemented in multilevel inverters. A nine-level inverter employing one voltage source and two capacitors is proposed for power system. Compared With the existing topologies, the proposed inverter has more voltage levels with fewer components. Lower THD of output voltage is obtained and the voltage stress on the power switches in the backstage is relatively relieved. More importantly, the inherent self-voltage balancing ability of the two capacitors has simplified the modulation algorithm. The main advantage of pulse width modulation (PWM) control strategies is to reduce the total harmonic distortion (THD) of the output voltage. The switching frequency of the inverter is the frequency of the carrier signal. Multiple carriers PWM techniques are used always in multilevel applications.

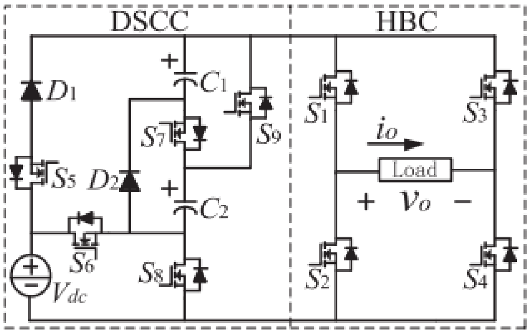


Figure 2. Functioning model of the nine-level inverter

3.1 Functioning of the proposed model

The functioning model of the proposed system is shown in figure 2. This figure shows the proposed nine-level inverter, which consists of two stages. The circuit in the frontend is a developed switched capacitor circuit (DSCC), which is different from the basic SC cells in that it can output more voltage levels with relatively fewer components.

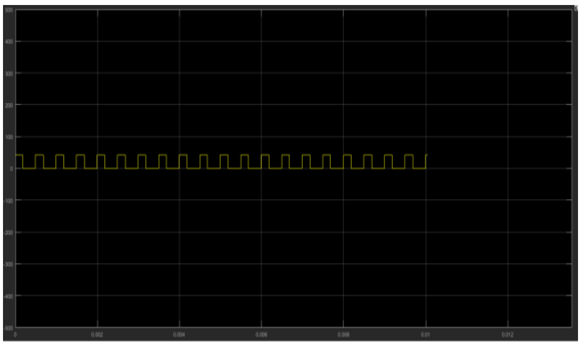
An H-bridge circuit (HBC) is used in the backend to change the polarity of the frontend output. In ideal circumstance, the proposed inverter has nine output voltage levels and to achieve this goal, only one dc voltage source, two capacitors, two diodes, and nine power switches are needed.

3.2 Advantages and applications of the proposed system

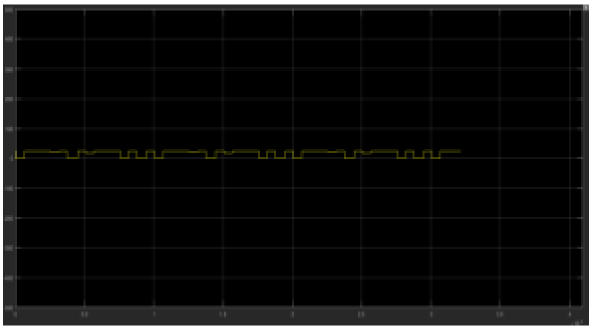
- The proposed HF inverter can output nine levels using only one voltage source and fewer components.
- Less harmonics,
- Thus the switching loss is decreased greatly.
- High power conversion applications.

4. SIMULATION RESULTS

Matlab simulation is conducted to verify the performance of the proposed nine-level inverter, and the detailed simulation process are shown in below. The output frequency is set to 1 kHz. The simulation waveforms of different output voltages are shown in figure 3, the waveforms for different load currents are shown in figure 4 when supplying for different types of loads. Figure 5 shows the waveform of output voltage.



(a)



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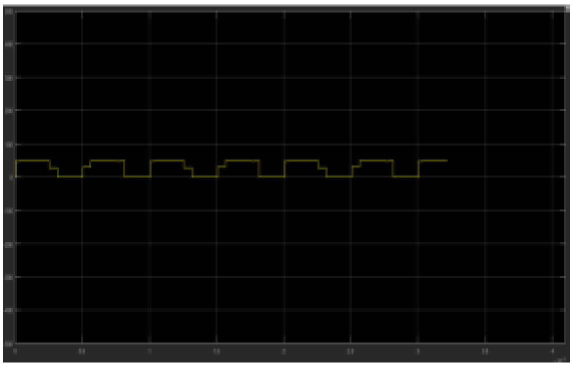

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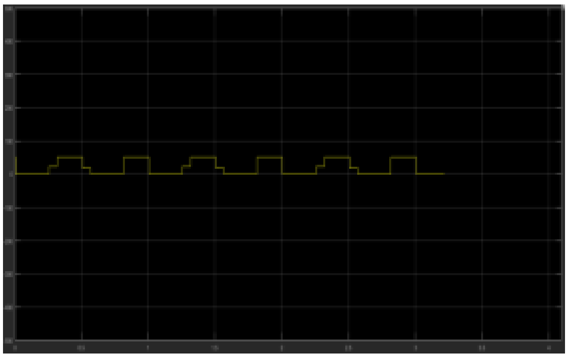
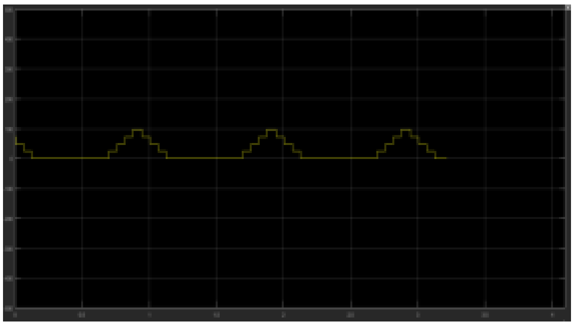
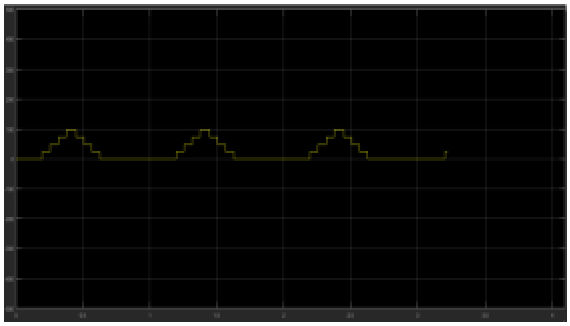


(d)

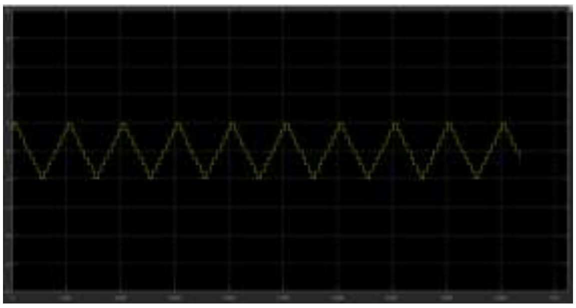


(e)

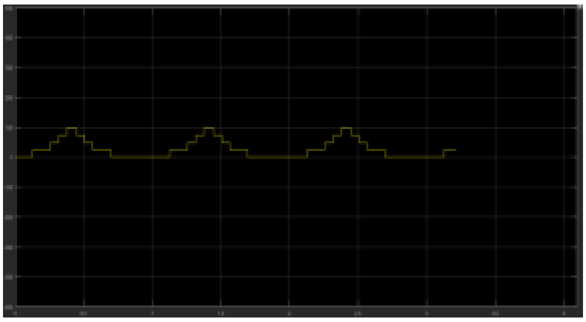


(f)

Figure 3 (a), (b), (c), (d), (e), and (f) simulation waveforms of different voltage levels



(a)



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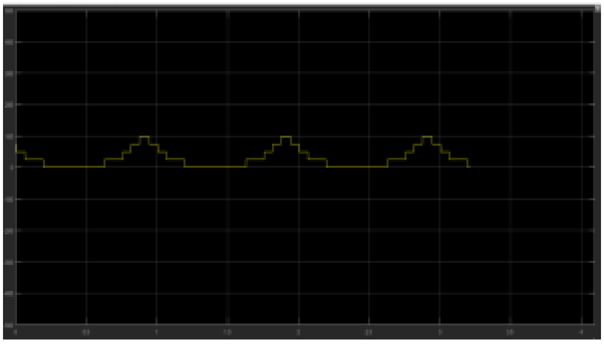

(c)

Figure 4 (a), (b) and (c) shows the wave forms of load current for different voltage levels

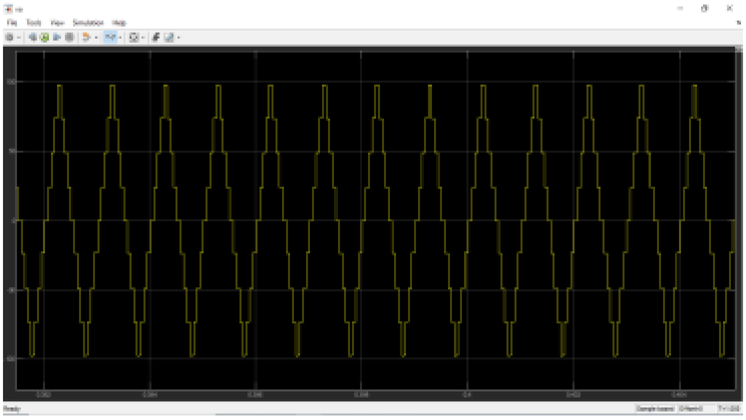

Figure 5 Wave form of the output voltage

5. CONCLUSION

In this paper, a multilevel inverter is proposed for high frequency power distribution system. Compared with the existing topology, the proposed topology can achieve nine-level staircase output with only one voltage source, fewer power devices and relatively less voltage stress. All these have enlarged its application scopes. Voltage balance problem is avoided by the inherent self-voltage balancing ability, which has simplified the modulation technique is used for this proposed topology of capacitor multilevel inverter are Pulse Width Modulation.

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