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A NINE-LEVEL CASCADED MULTILEVEL INVERTER WITH REDUCED SWITCH COUNT AND LOWER HARMONICS

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ABSTRACT

Increasing demands for power supplies have contributed to the population of high frequency ac (HFAC) power distribution system (PDS), and in order to increase the power capacity, multilevel inverters (MLIs) frequently serving as the high-frequency (HF) source-stage have obtained a prominent development. Existing MLIs commonly use more than one voltage source or a great number of power devices to enlarge the level numbers, and HF modulation (HFM) methods are usually adopted to decrease the total harmonic distortion (THD). All of these have increased the complexity and decreased the efficiency for the conversion from dc to HF ac. In this paper, a nine-level inverter employing only one input source and fewer components is proposed for HFAC PDS. It makes full use of the conversion of series and parallel connections of one voltage source and two capacitors to realize nine output levels, thus lower THD can be obtained without HFM methods. The voltage stress on power devices is relatively relieved, which has broadened its range of applications as well. Moreover, proposed nine-level inverter is equipped with the inherent self-voltage balancing ability, thus the modulation algorithm gets simplified. The circuit structure, modulation method, capacitor calculation, loss analysis and performance comparisons are presented in this paper, and all the superior performances of proposed nine-level inverter are verified by simulation and experimental prototypes with rated output power of 200W. The accordance of theoretical analysis, simulation and experimental results confirms the feasibility of proposed nine-level inverter.

INTRODUCTION

With the increasing demands for power supplies in computer, telecom, electric vehicle, and other similar areas where low voltage and high current are needed, the traditional dc power distribution system (DC PDS) is gradually unable to meet the requirements due to its insufficiencies such as more conversion stages, low efficiency and poor transient response. High frequency ac power distribution system (HFAC PDS) proposed in [1] has become an alternative [2-5] because of its merits such as fewer conversion stages, higher efficiency, faster response, high power density, distributed heat profile and potential for connector-less power transfer.

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HFAC PDS is usually composed of two stages: a high frequency (HF) multilevel inverter (MLI) or a resonant inverter as the source side and several ac/ac or ac/dc voltage regulation modules (VRMs) as the load side. In order to raise the power capacity, one of the most popular methods of the source side is to connect multiple resonant inverters in series or in parallel [6], while the control for the HF synchronizations of both amplitudes and phases will become extremely complicated. In contrast, using a HF MLI as the power source is a preferable solution with larger power capacity and lower switch stress. In HFAC PDS as shown in Fig.1, a HF MLI is employed to transform the dc voltage source from the batteries, fuel cells or photovoltaic cells into a HF staircase output, and the more number of voltage levels is significant to decrease the total harmonic distortion (THD) and electromagnetic interference (EMI), thus simplifying the design of output filters. However, the level number is restricted by the complexity of the MLI. The output frequency of the HF inverter usually ranges from 400 Hz to 50 kHz [4], [7-8]. As a result, the HF modulation (HFM) methods represented by multicarrier phase disposition [9] are no longer suitable, as the excessively high switching frequency and so-caused switching loss are unbearable for HF applications. In other words, the fundamental-frequency modulation (FFM) methods will have to be adopted in HF fields, and the further discussions are necessary to customize a HF MLI that can output sufficient number of voltage levels with a simplified structure to increase the efficiency and decrease the THD for HF applications. Traditional MLIs include the neutral-point-clamped (NPC) inverter [10], flying-capacitor (FC) inverter [11] and cascade H-Bridge (CHB) inverter. The NPC and FC inverters respectively use diodes and capacitors to clamp the voltage levels, and more levels can be obtained by increasing the number of power devices. However, both the circuit configurations and their controls will become extremely complicated along with the increasing number of voltage levels. Additionally, the capacitors' imbalance is another problem needed to be solved. The CHB inverter increases the output voltage levels and simplifies the modulation by the combination of H-bridge cells. However, the number of power devices and input dc sources multiplies when outputting more voltage levels. Several simplified topologies have been proposed in recently years to overcome the shortcomings of the traditional ones. However, they have the common disadvantage that symmetric or asymmetric dc inputs are needed [12-17].

A single phase grid-connected inverter was proposed in [18]. However, the limited five output levels will lead to more output harmonics. A seven-level PWM inverter was proposed in [19], in which three capacitors are connected in series and then paralleled with the dc source to obtain extra $\pm 1/3V_{dc}$ and $\pm 2/3V_{dc}$ voltage levels. However, the capacitor voltages are in unbalancing conditions, thus increasing the control complexity. Meanwhile, both topologies in [18] and [19] adopt the multicarrier modulation method to decrease the THD of the staircase outputs. The high switching frequency makes them unsuitable for HFAC PDS. A grid-connected converter topology was proposed with only one voltage source, a flying capacitor and eight switches [20]. It can output nine levels exactly when the HF modulation strategy keeps the capacitor voltage at a desired level such as $1/3V_{dc}$, which is indeed difficult to be realized without any auxiliary charging circuit, and the literature [20] merely presents the experimental results from a seven-level prototype. Moreover, the HF modulation has limited the proposed topology to low frequency (LF) occasions only. A series of step-up multilevel topologies was

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proposed based on switched-capacitor (SC) techniques [21-24]. They can be used as HF power sources. However, more dc sources or more components are required to accomplish higher number of output voltage levels. The power switches in the backend H-bridges bear the sharply cumulative voltage levels from the SC frontends, and the extremely high voltage stress has limited their applicability to low input occasions only.In this paper, a nine-level inverter employing one voltage source and two capacitors is proposed for HFAC PDS. Compared with the aforementioned topologies, 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 back-stage is relatively relieved. More importantly, the inherent self-voltage balancing ability of the two capacitors has simplified the modulation algorithm.

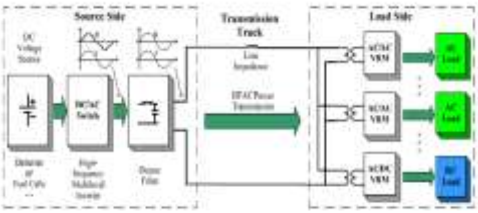

Fig. 1. Structure of HFAC PDS using a MLI as the source side.

INVERETER:

The main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable. According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled ac output is a voltage waveform. These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications, such as adjustable speed drives(ASDs), which are the most popular application of inverters; see Fig. 14.1a. Similarly, these topologies can be found as current source inverters (CSIs), where the independently controlled ac output is a current waveform. These structures are still widely used in medium-voltage industrial applications, where high-quality voltage waveforms are required.

DISTRIBUTED GENERATION

Distributed generation, also called on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy generates electricity from many small energy sources. Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel (coal, gas powered) nuclear or hydropower plants. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment. Most plants are built this way due to a number of economic, health & safety, logistical,environmental, geographical and geological f actors. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water flow. Most power plants are often considered to be too far away for their waste heat to be used for heating buildings. Low pollution is a crucial advantage of combined cycle plants that burn natural gas. The low pollution permits the plants to be near enough to a city to be used for district heating and cooling. Distributed generation is another

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approach. It reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed. Typical distributed power sources in a Feed-in Tariff (FIT) scheme have low maintenance, low pollution and high efficiencies. In the past, these traits required dedicated operating engineers and large complex plants to reduce pollution. However, modern embedded systems can provide these traits with automated operation and renewables, such as sunlight, wind and geothermal. This reduces the size of power plant that can show a profit.

ELECTRICAL GRID:

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

Power stations may be located near a fuel source, at a dam site, or to take advantage of renewable energy sources, and are often located away from heavily populated areas. They are usually quite large to take advantage of the economies of scale. The electric power which is generated is stepped up to a higher voltage at which it connects to the electric power transmission network.

The bulk power transmission network will move the power long distances, sometimes across international boundaries, until it reaches its wholesale customer (usually the company that owns the local electric power distribution network).

On arrival at a substation, the power will be stepped down from a transmission level voltage to a distribution level voltage. As it exits the substation, it enters the distribution wiring. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage(s).

RESULTS

Simulation circuit with R-Load

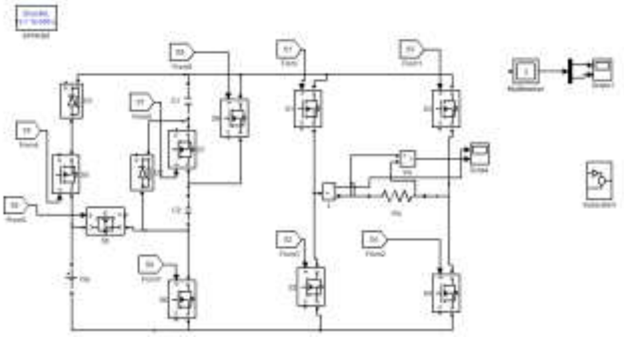


Fig 6.1 Proposed circuit with R-Load

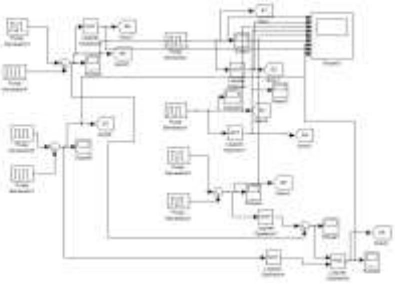


Fig 6.2 Control circuit of proposed model

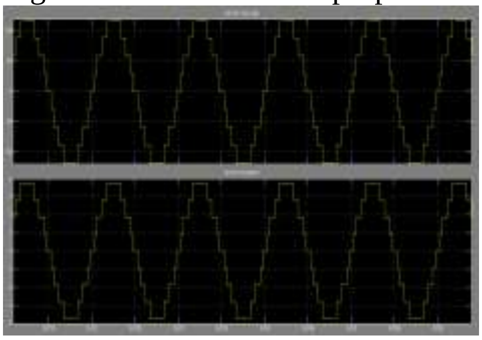
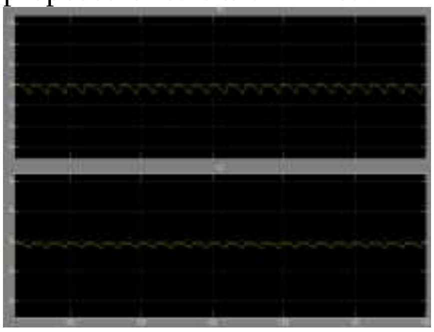


Fig 6.3 output voltage & current of the proposed circuit with R-Load



-Fig 6.4 Capacitor voltages of VC1 & VC2

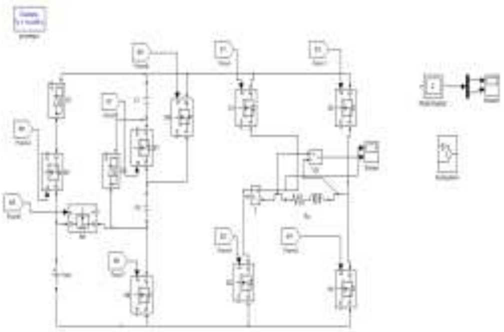


Fig 6.5 Proposed circuit with R L-Load

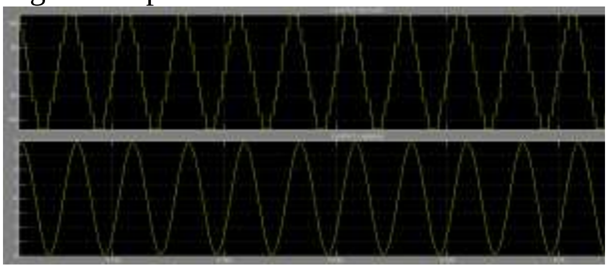


Fig 6.6 output voltage & current of the proposed circuit with R L-Load

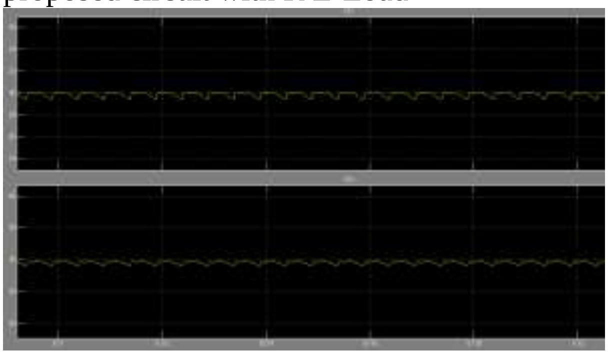


Fig 6.7 Capacitor voltages of VC1 & VC2

CONCLUSION

In this paper, a novel nine-level inverter is proposed for HFAC PDS. Compared with the existing topologies, 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 circuits or algorithms, and the lower THD of 3.13% is realized without using HFM methods. As a result, the switching loss is significantly reduced. The capacitor calculation and power loss analysis are conducted in this paper, and the comparisons with existing topologies further testify the superiority of proposed HF inverter. All the merits and the feasibility of proposed topology are evaluated by a simulation model and an experimental prototype with rate power of 200W, and their results illustrate that proposed inverter is a preferable topology to implement HF power source for HFAC PDS.

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