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A 21 Level Cascaded MLI with Reduced Switch Count

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ABSTRACT

A new single-phase cascaded multilevel inverter is analyzed. This inverter is comprised of series connection of the proposed basic unit and is able to generate only positive levels at the output. Therefore, an H-bridge is added to the proposed inverter. This inverter is called developed cascaded multilevel inverter. In order to generate all voltage levels (even and odd) at the output of the developed topology, four different algorithms are proposed to determine the magnitude of dc voltage sources. Reduction in the number of power switches, driver circuits and dc voltage sources are advantages of the developed single-phase cascaded multilevel inverter. As a result, the installation space and cost of the inverter are reduced. These features are obtained by the comparison of the conventional cascaded multilevel inverters with the proposed cascaded topology. The ability of the proposed inverter in generation all voltage levels (even and odd) is reconfirmed by using the results based on simulation studies of a 15-level inverter.

I. INTRODUCTION

Offshore wind farms are growing rapidly because of their comparatively more stable wind conditions than onshore and land-based wind farms. Offshore 5-10 MW marine turbines are becoming more attractive for the wind power industry. In particular, they increase the efficiency and reduce generation cost, compared to previous wind turbine technologies. The power capacities of these offshore behemoths result in an increase in the size of each component. Therefore, offshore wind turbine manufacturers are attempting to create an optimal design for large marine turbines. The optimized design of offshore wind turbines should cope with the following challenges to make high power conversion systems a feasible alternative. Bulky and huge electrical components have high investment costs because of the more difficult erection and the equipment transportation from the shore to the installation sites. In addition, there is a greater need for high reliability due to the inherent lack of turbine access at sea, which makes operation and maintenance more difficult. Therefore, an optimal power conversion system should feature high power density, high efficiency, high reliability, and low costs for high power offshore wind energy applications.

On the other hand, the longer transmission distances from offshore wind turbines to the load center lead to higher energy losses due to the low output voltage of wind turbines. In this regard, high voltage DC (HVDC) transmission promises a very flexible and efficient technology for offshore wind farms that requires power conversion systems to step-up and control the wind turbine output. A conventional HVDC system uses an AC line frequency (50/60 Hz) transformer to boost the voltage and AC/DC converters for rectification and power flow control. This technology is robust and reliable, but it causes a considerable increase in weight and volume, which leads to higher installation cost. A high-power density can be obtained by replacing the bulky 50/60 Hz transformers with high frequency transformers. Unfortunately, high frequency transformers with large turn ratios are difficult to design at high voltages and mega power levels because of the enormous expense of the magnetic material, core and dialectic losses. One of the key-enabling components for HVDC is the high-power DC/DC conversion system because it has a rigid structure, is easy to control system and more compact.

To overcome the increasing power losses and maintain a high-power density, it is expected that large marine turbines will require a higher voltage with high voltage gain DC/DC conversion systems to interface with the power transmission networks. Single-module DC/DC boost converters can theoretically achieve infinite voltage conversion ratios but practically, the maximum gain is limited by circuit imperfections, such as parasitic elements and switch commutation times . Multiple-module boost converters have been proposed to achieve high conversion ratios for applications to offshore wind farms . Nevertheless, because the duty ratio of the main switch is large to achieve high-voltage gain, the switching frequency is relatively low to reduce the losses and also allows sufficient turn-off time for the switches. Therefore, increasing the size of passive elements, such as boost inductors and filter capacitors, is inevitable due to the low switching frequency.

Recently, the common types of switched-capacitor (SC) converters are considered as an attractive solution for meeting the requirements, such as high power density and control simplicity. In , a resonant SC (RSC) converter was investigated, where an extra inductor was added to form a sinusoidal manner with the capacitors to perform a soft switching. In , a multilevel RSC topology was proposed with significant benefits, including a modular structure, low voltage stress of the switches, and reduced switching loss. On the other hand, the large number of capacitors, high passive component losses, and inevitably large physical size of the converters have limited the use of these topologies in high voltage gain offshore wind energy systems. A 55 kW 3 x (the output voltage is three times the input voltage) flying-capacitor DC/DC converter was introduced for hybrid electric vehicles . The major drawbacks are the non-modular structure, complicated switching scheme, and low voltage gain. An RSC voltage tripler with interleaving capability and high efficiency was presented in . Nevertheless, it still has several problems including the passive component counts when a high voltage gain is required for high power applications due to the low voltage conversion ratio of the circuit. To solve the problems listed previously, this project presents a new high-gain RSC DC/DC converter for offshore wind energy systems. The proposed converter combines the output of two modular cells to reduce the device count, output capacitance requirements, and total capacitor power rating. The principle of a soft-switching operation and output voltage analysis of the proposed converter are described in detail. The output capacitors are charged and discharged continuously by a 180° phase shift with respect to each other to eliminate the output voltage ripples without adding extra components. In this project, the series-modular and cascade RSC configurations are introduced to increase the reliability and reduce the control complexity. These configurations are verified by a simulation and their efficiency, volume, weight, and device count are compared with a counterpart to highlight its advantages for high voltage and high power offshore winds applications. A comprehensive collection of the experiments is carried out to evaluate the feasibility of the proposed converter.

II. Multilevel Inverter Structure

A voltage level of three is considered to be the smallest number in multilevel converter topologies. Due to the bi-directional switches, the multilevel VSC can work in both rectifier and inverter modes. This is why most of the time it is referred to as a converter instead of an inverter in this dissertation.

A multilevel converter can switch either its input or output nodes (or both) between multiple (more than two) levels of voltage or current. As the number of levels reaches infinity, the output THD approaches zero. The number of the achievable voltage levels, however, is limited by voltage-imbalance problems, voltage clamping requirements, circuit layout and packaging constraints complexity of the controller, and, of course, capital and maintenance costs.

Three different major multilevel converter structures have been applied in industrial applications: cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. The multilevel inverter structures are the main focus of discussion in this chapter; however, the illustrated structures can be implemented for rectifying operation as well.

Although each type of multilevel converters share the advantages of multilevel voltage source inverters, they may be suitable for specific application due to their structures and drawbacks. Operation and structure of some important type of multilevel converters are discussed in the following sections.

In a multilevel VSI, the dc-link voltage V_{dc} is obtained from any equipment which can yield stable dc source. Series connected capacitors constitute energy tank for the inverter providing some nodes to which multilevel inverter can be connected. Primarily, the series connected capacitors will be assumed to be any voltage sources of the same value. Each capacitor voltage V_c is given by $V_c=V_{dc}/ (n-1)$, where n denotes the number of level.

Fig. 2.1 shows a schematic diagram of one phase leg of inverters with different number of levels, for which the action of the power semiconductors is represented by an ideal switch with several positions. A two-level inverter generates an output voltage with two values (levels) with respect to the negative terminal of the capacitor, while the three-level inverter generates three voltages, and so on.

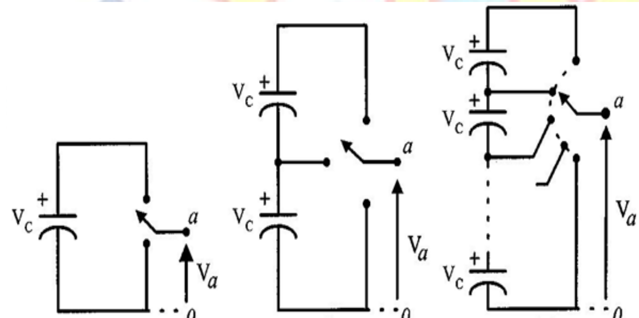

Fig. 2.1 One phase leg of an inverter with (a) two levels, (b) three levels, and (c) n levels.

Diode-Clamped Multilevel Inverter

The most commonly used multilevel topology is the diode clamped inverter, in which the diode is used as the clamping device to clamp the dc bus voltage so as to achieve steps in the output voltage. The neutral point converter proposed by Nabae, Takahashi, and Akagi in 1981 was essentially a three-level diode-clamped inverter [15]. A three-level diode clamped inverter consists of two pairs of switches and two diodes. Each switch pairs works in complimentary mode and the diodes used to provide access to mid-point voltage. In a three-level inverter each of the three phases of the inverter shares a common dc bus, which has been subdivided by two capacitors into three levels. The DC bus voltage is split into three voltage levels by using two series connections of DC capacitors, C1 and C2. The voltage stress across each switching device is limited to V_{dc} through the clamping diodes Dc1 and Dc2. It is assumed that the total dc link voltage is V_{dc} and mid-point is regulated at half of the dc link voltage, the voltage across each capacitor is $V_{dc}/2$ ($Vc1=Vc2=V_{dc}/2$). In a three-level diode clamped inverter, there are three different possible switching states which apply the stair case voltage on output voltage relating to DC link capacitor voltage rate. For a three-level inverter, a set of two switches is on at any given time and in a five-level inverter, a set of four switches is on at any given time and so on. Fig-2.2 shows the circuit for a diode clamped inverter for a three-level and a five-level inverter. Switching states of the three-level inverter are summarized in table-1.

Table-2.1. Switching states in one leg of the three-level diode clamped inverter

Switch Status	State	Pole Voltage
S_1=ON, S_2=ON $S_{1'}$=OFF, $S_{2'}$=OFF	S=+ve	V_{ao}=Vdc/2
S_1=OFF, S_2=ON $S_{1'}$=ON, $S_{2'}$=OFF	S=0	V_{ao}=0
S_1=OFF, S_2=OFF $S_{1'}$=ON, S_2=ON	S=-ve	V_{ao}=-Vdc/2

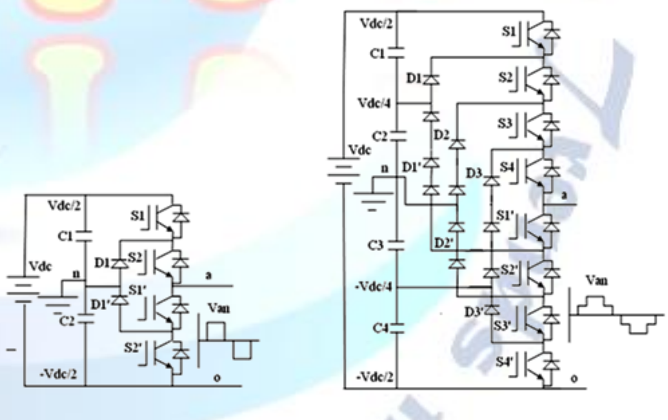

Fig 2.2: Topology of the diode-clamped inverter (a) three-level inverter, (b) five -level inverter

Fig 2.3 shows the phase voltage and line voltage of the three-level inverter in the balanced condition. The line voltage V_{ab} consists of a phase-leg *a* voltage and a phase-leg *b* voltage. The resulting line voltage is a 5-level staircase waveform for three-level inverter and 9-level staircase waveform for a five-level inverter. This means that an N-level diode-clamped inverter has an N-level output phase voltage and a (2N-1)-level output line voltage. In general the voltage across each capacitor for an N level diode clamped inverter at steady state is $V_{dc}/$ (N-1). Although each active switching device is required to block only a voltage level of V_{dc}, the clamping diodes require different ratings for reverse voltage blocking.

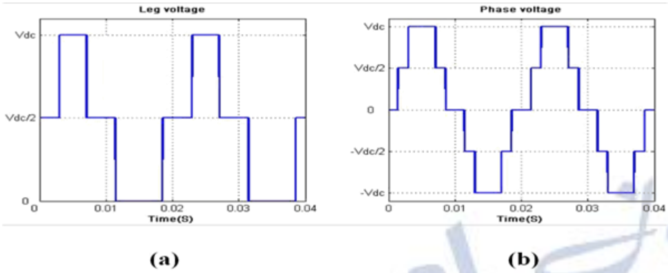

Fig:2.3. Output voltage in three-level diode- clamped inverter (a) leg voltage, (b) output phase voltage

In general for an N level diode clamped inverter, for each leg 2(N -1) switching devices, (N-1) * (N-2) clamping diodes and (N-1) dc link capacitors are required. By increasing the number of voltage levels the quality of the output voltage is improved and the voltage waveform becomes closer to sinusoidal waveform. However, capacitor voltage balancing will be the critical issue in high level inverters. When N is sufficiently high, the number of diodes and the number of switching devices will increase and make the system impracticable to implement. If the inverter runs under pulse width modulation (PWM), the diode reverse recovery of these clamping diodes becomes the major design challenge.

Though the structure is more complicated than the two-level inverter, the operation is straightforward.

III. Model Simulation and Results

MATLAB based Schematic of Hybrid multilevel inverter based converter is shown in Fig. 5.1. The model is controlled with the help of a pulse width modulation with proper time intervals. All the switches that were used are modeled with the help of IGBT switches. Polarity generator is shown in Fig 5.2. Basic unit of inversion is shown in Fig.5.3. Power Circuit used for level generation is shown in Fig. 5.4. The load voltage is shown in Fig 5.4. Voltage across load is shown in Fig.5.5, Current through load is in Fig.5.6, Voltage across the first basic unit is shown in Fig.5.7, Voltage across the second basic unit is shown in Fig.5.8, Voltage across the Switches S1, S2 is presented in Fig.5.9, Ouput across the level generator is shown in Fig. 5.10.

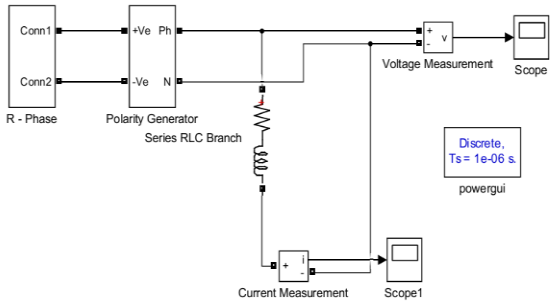

Fig.5.1: MATLAB Schematic of Hybrid Multilevel inverter under analysis

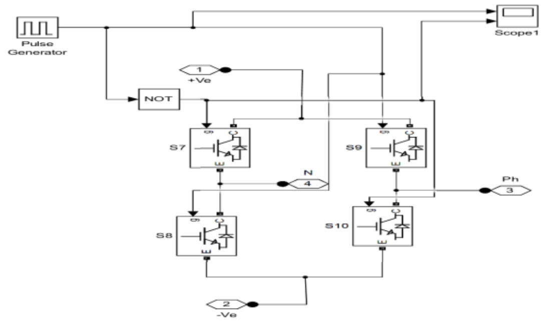

Fig 5.2: Polarity Generator

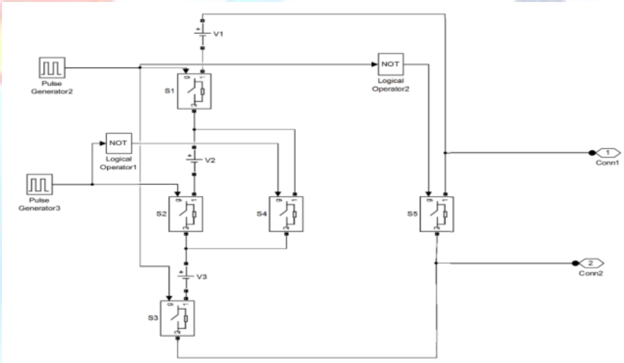

Fig.5.3: Basic level Generator Unit

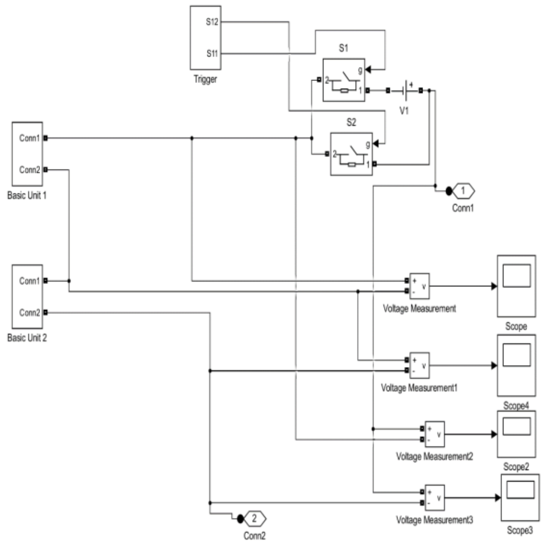

Fig.5.4: Level Generator Unit

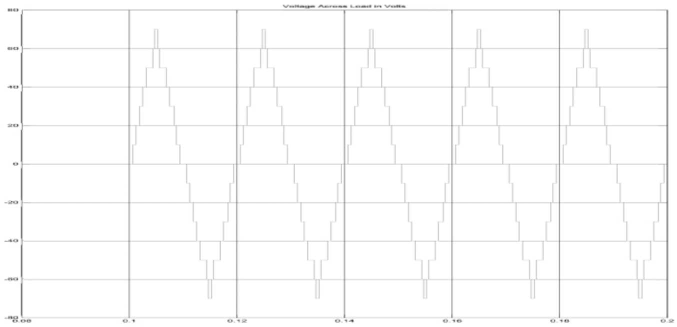

Fig.5.5: Voltage across load in Volts

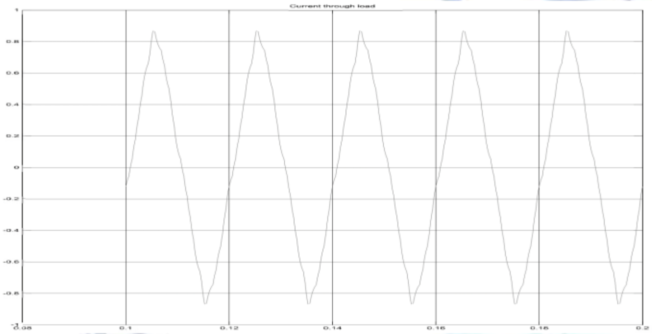

Fig.5.6: Current load in Amps

Fig.5.7: Output of First basic unit in Volts

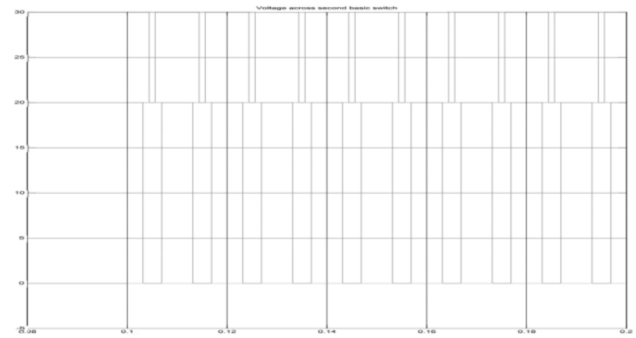

Fig.5.8: Output of Second basic unit in Volts

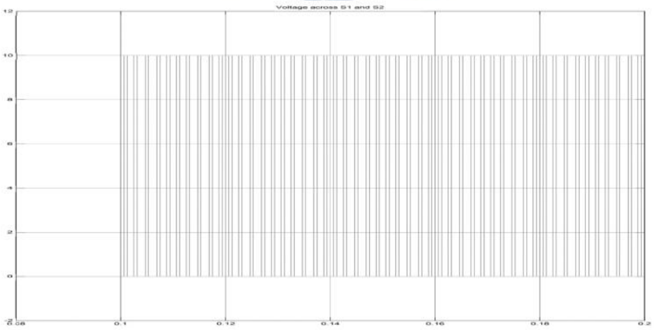

Fig.5.9: Voltage across the Switches S1, S2 Volts

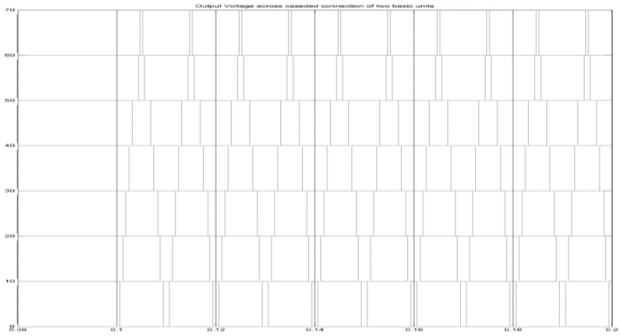

Fig.5.10: Ouput across the level generator

IV. Conclusion

A Hybrid multilevel inverter based on basic level generation units is modeled with the help of MATLAB SIMULINK. A new basic unit for cascaded multilevel inverter is analyzed. By series connection of several basic units, a cascaded multilevel inverter is proposed that only generates positive levels at the output. Therefore, a H- bridge is added to the proposed inverter to generate all voltage levels. This inverter is called developed cascaded multilevel inverter. In order to generate even and odd voltage levels at the output, four different algorithms are proposed to determine the magnitude of dc voltage sources. Therefore, the developed proposed inverter has better performance and needs minimum number of power electronic devices that lead to reduction the installation space and total cost of the inverter. Finally, the accuracy performance of the developed proposed single-phase cascaded multilevel inverter in generation all voltage levels is verified by using the simulation results on a 15-level inverter

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