Seven-Level Hybrid Cascaded H-Bridge Multilevel Inverter Fed Single Phase Induction Motor Drive

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Abstract— The poor quality of voltage and current of a conventional inverter fed induction machine is due to the presence of harmonics and hence there is significant level of energy losses. The Multilevel inverter is used to reduce the harmonics. The inverters with a large number of steps can generate high quality voltage waveforms. The higher levels can follow a voltage refer-ence with accuracy and with the advantage that the generated voltage can be modulated in amplitude instead of pulse-width modulation. An active harmonic elimination method is applied to eliminate any number of specific higher order harmonics of multilevel converters with unequal dc voltages. a cascaded H-bridge multilevel inverter that can be implemented using only a single dc power source and capacitors. Standard cascaded multilevel inverters require 'n' dc sources for '2n + 1' levels. Without requiring transformers, the scheme proposed here allows the use of a single dc power source with the remaining'n-1' dc sources being capacitors, which is referred to as hybrid cascaded H-bridge multilevel inverter (HCMLI). HCMLI using only a single dc source for each phase is promising for high-power motor drive applications as it significantly decreases the number of required dc power supplies, provides high-quality output power due to its high number of output levels, and results in high conversion efficiency and low thermal stress as it uses a fundamental frequency switching scheme.

Keywords: Fundamental Frequency Modulation Control, Hybrid Cascaded H-Bridge Multilevel Inverter, Multilevel Inverter, Fuel Cell

I. INTRODUCTION

In recent years, industry has begun to demand higher power equipment, which now reaches the megawatt level. Controlled ac drives in the megawatt range are usually connected to the medium-voltage network. Today, it is hard to connect a single power semiconductor switch directly to medium voltage grids (2.3, 3.3, 4.16, or 6.9 kV). For these reasons, a new family of multilevel inverters has emerged as the solution for working with higher voltage levels. Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generate voltages with stepped waveforms.

Unlike the diode clamp or flying capacitors inverter, the cascaded inverter does not require any voltage clamping diodes or voltage balancing capacitors. This configuration is useful for constant frequency applications such as active front-end rectifiers, active power filters, and reactive power compensation. Choosing appropriate conducting angles for the H-bridges can eliminate a specific harmonic in the output waveform. The required conduction angles can be calculated by analyzing the output phase voltage of cascade inverter assuming that four H-bridges have been used.

There are several types of multilevel inverters but the one considered in this paper is the cascaded multilevel inverter (CMI). The structure of the CMI is not only simple and modular but also requires the least number of components compared to other types of multilevel inverters. This in turn, provides the flexibility in extending the CMI to higher number of levels without increase in circuit complexity as well as facilitates packaging.

II. MULTILEVEL INVERTER ARCHITECTURE

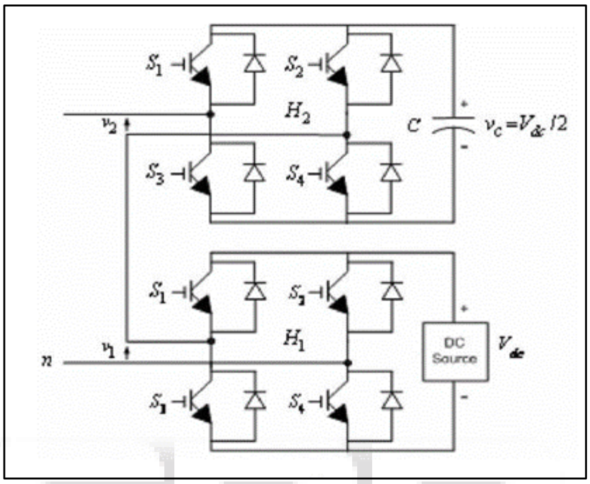

Fig. 1: Single-phase structure of a multilevel cascaded H-bridges inverter.

Each phase of a cascaded multilevel inverter requires n dc sources for 2n + 1 levels. For many applications, obtaining so many separate dc sources may preclude the use of such an inverter. To reduce the number of dc sources required when the cascaded H-bridge multilevel inverter is applied to a motor drive, a scheme is proposed in this paper that allows the use of a single dc source (such as battery or fuel cell) as the first dc source with the remaining n-1 dc sources being capacitor in the cascaded H-bridges multilevel inverter, which is referred to as the hybrid cascaded H-bridge multilevel inverter (HCMLI). the proposed HCMLI has a low number of dc sources and retains the low switching-frequency advantage. The control goal of the HCMLI needs to maintain the balance of the dc voltage level of the capacitors while producing a nearly sinusoidal three-phase output voltage using a low-switching frequency harmonic elimination method.

III. WORKING PRINCIPLE OF HCLMI

Multilevel voltage-source inverter topologies, including diode-clamped, flying capacitor, and cascaded H-bridge structures, are intensively studied for high-power applications, and standard drives for medium-voltage industrial applications have become available. Solutions with a higher number of output voltage levels have the ability to synthesize waveforms with a better harmonic spectrum and to limit the motor-winding insulation stress. However, their increasing number of devices tends to reduce the overall reliability and efficiency of the power converter.

The advantages of such symmetric multilevel converters are modularity and control simplicity. Hybrid multilevel inverters use different types of voltage sources in various parts of the inverter. These sources, which can be batteries, ultracapacitors, or fuel cell, allow this structure to be narrowly well adapted to electric vehicles (EVs) and hybrid EVs (HEVs). By addition and subtraction of these voltages, more different output voltage levels can be generated with the same number of components, compared to a symmetric multilevel inverter. Higher output quality can be obtained with fewer cascaded cells and control complexity, and output filters can be remarkably shrunk or even eliminated cascaded multilevel inverter using a single dc source, ca-pacitors are used as the dc sources for all, but the first source The dc source for the first H-bridge (H1) is a battery or fuel cell with an output voltage of Vdc, while the dc source for the second H-bridge (H2) is a capacitor whose voltage is to be held at Vc. The output voltage of the first H-bridge is denoted by V1 and the output of the second H-bridge is denoted by V2 so that the output voltage of the cascaded multilevel inverter is

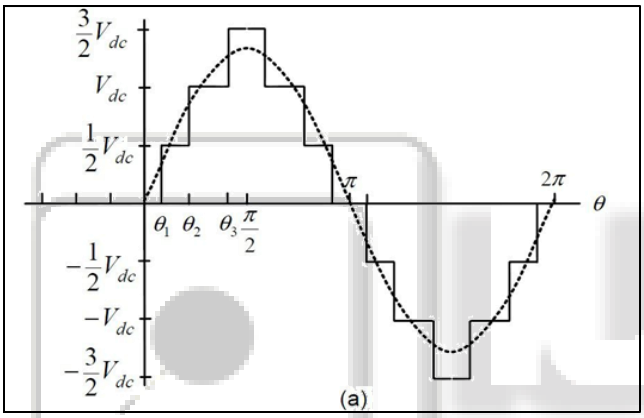

Fig. 2: Output waveform of an 7-level cascade multilevel inverter.

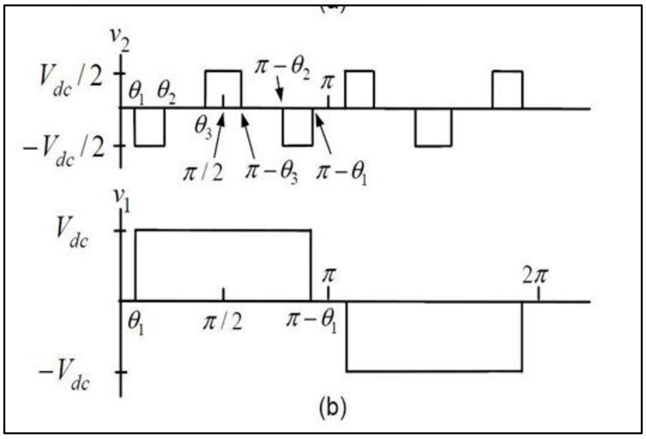

Fig. 3: H-bridge voltages V1 and V2 which achieve the same output voltage waveform V = V1 + V2.

V (t) = V1(t) + V2(t) (1)

By opening and closing the switches of H1 appropriately, the output voltage V1 can be made equal to +Vdc, 0, and Vdc while the output voltage of H2 can be made equal to +Vdc=2, 0, and Vdc=2 by opening and closing its switches appropriately. Therefore, the output voltage of the inverter can have the values -(Vdc+Vc), -Vdc, -(Vdc-Vc), 0, (Vdc-Vc), Vdc, (Vdc+Vc) , which is seven levels.

Fig. 3(b) shows how the waveform of Fig. 2(a) is generated if, For 1< 2, V1 = Vdc and V2= Vdc=2 are chosen. Similarly, Fig. 4(c) shows how the waveform of Fig. 2(a) is generated if, For 1< 2, V1 = 0 and V2= Vdc=2 are chosen. The fact that the output voltage level Vdc=2 can be achieved in two different ways is exploited to keep the capacitor voltage regulated. The criteria required for this capacitor regulating scheme is that (1) the desired capacitor voltage is less than the DC power source voltage, (2) the capacitance value is chosen large enough so that the variation of its voltage around its nominal value is small, and (3) the capacitor charging cycle is greater than the capacitor discharge cycle. For three-phase systems, the triplen harmonics in each phase need not be canceled as they automatically cancel in the line-to-line voltages. In this case where there are 3 DC sources, the desire is to cancel the 5th and 7th order harmonics as they tend to dominate the total harmonic distortion.

IV. INDUCTION MOTOR DRIVE

Synchronous speed of Induction Motor is directly pro-portional to the supply frequency. therefor, by changing the frequency, the synchronous speed and the motor speed can be controlled below and above the normal full load speed. The voltage induced in the stator, E is proportional to the product of slip frequency and air gap flux. if the stator voltage was neglected. Any reduction in the supply frequency without a change in the terminal voltage causes an increase in the air gap flux. Induction motors are designed to operate at the knee point of the magnetization characteristic to make full use of the magnetic material. Therefore the increase in flux will saturate the motor. This will increase the magnetizing current, distort the line current and voltage, increase the core loss and the stator copper loss, and produce a high pitch acoustic noise. While any increase in flux beyond rated value is undesirable due to the of saturation effects, a decrease in flux was also avoided to retain the torque capability of the motor. Therefore, the variable frequency control below the rated frequency is generally carried out by reducing the machine phase voltage, V, along with the frequency in such a manner that the flux is maintained constant. Above the rated frequency, the motor is operated at a constant voltage in order to the limitation imposed by stator insulation or by supply voltage limitations.

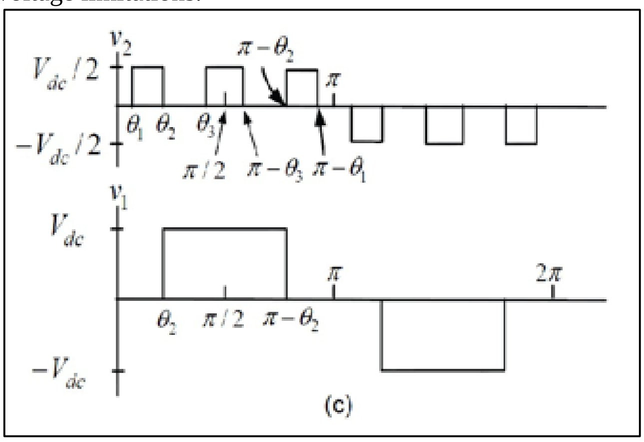

Fig. 4: H-bridge voltages V1 and V2 which achieve the same output voltage waveform V = V1 + V2.

θ	v_1	v_2	$v = v_1 + v_2$
$0 \leq \theta \leq \theta_1$	0	0	0
$\theta_1 \leq \theta \leq \theta_2$	0	$V_{dc}/2$	$V_{dc}/2$
$\theta_1 \leq \theta \leq \theta_2$	V_{dc}	$-V_{dc}/2$	$V_{dc}/2$
$\theta_2 \leq \theta \leq \theta_3$	V_{dc}	0	V_{dc}
$\theta_3 \leq \theta \leq \pi/2$	V_{dc}	$V_{dc}/2$	$3V_{dc}/2$

Table 1: Output Voltages for a 7-Level Inverter.

V. EXTENDED THREE PHASE TOPOLOGY OF HCMLI FOR DRIVING INDUCTION MOTORS

Cascaded multilevel inverters consisting of two H-bridges are connected to all the three phases of an induction motor, for extending the single phase topology in to three phase H-bridge 7 level inverter. Thus high and medium voltage drives can also easily driven with reduced harmonics, less thermal stresses, and reduced number of components using this extended topology.

In three phase cascaded H-bridge MLI Each single dc source is connected to an inverter. The other sources are capacitors. Each inverter level can generate three different voltage outputs, +Vdc, 0, and Vdc using various combinations of the four switches. The ac outputs of the different full bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs.

System State	v_1	v_2	$v = v_1 + v_2$
$v_c < V_{dc}/2, i > 0$	V_{dc}	$-V_{dc}/2$	$V_{dc}/2$
$v_c < V_{dc}/2, i < 0$	0	$V_{dc}/2$	$V_{dc}/2$
$v_c > V_{dc}/2, i > 0$	0	$V_{dc}/2$	$V_{dc}/2$
$v_c > V_{dc}/2, i < 0$	V_{dc}	$-V_{dc}/2$	$V_{dc}/2$

Table 2: Controller for Capacitor Voltage Level

Phase voltage waveform of three phase cascaded H-bridge MLI is obtained as a combination of three single phase H-bridge MLI inputs. The usage of transformers can be avoided by this method. Also the range of induction motors using MLI can be improved. The usage of battery or fuel cells are also limited by using this topology.

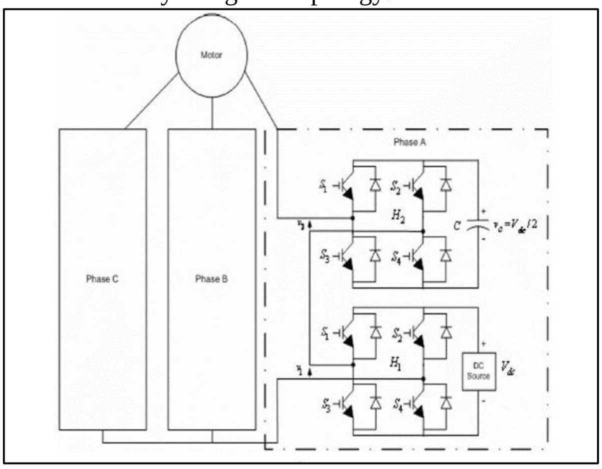

Fig. 5: Three phase topology of seven level HCMLI for Induction motor drives

VI. CONCLUSION

Cascade multilevel inverter topology here proposed, requires only a single DC power source. All others are capacitors. The voltage level of the capacitors can be controlled. The requirement of transformers can be eliminated. Choosing the switching angles we have to achieve a specified modulation index. Harmonics in the output waveform can also be eliminated by using this method. The components used in this HCMLI method is less than the previous MLI topologies. Hence it is a cost effective method to produce reduced harmonics output waveform.

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