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Performance of Induction Motor Drive by Using Modular Multilevel Converter with Battery Energy Sources

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ABSTRACT:

In this paper a new topology is proposed for energy storage and the power distribution using Battery energy source in cascaded multilevel inverters. This consists of hybrid cascaded multilevel inverter (HCMI) topologies and corresponding control strategies are applied to motor drive, interfacing both dc sources and capacitor energy storage elements. For high power motor drive application this proposed topology has a capability to produce high voltage at fundamental switching frequency makes it possible to use switches with low voltage and current ratings. The major advantages of this proposed control method are reduced switching loss, improved efficiency with less number of dc sources, elimination of harmonics and the ability of the capacitor voltage to be successfully maintained at the desired value when the machine is in transient state. In this paper a 7-level cascaded multilevel inverter with motor drive is considered. Finally, the simulation results validate the concept of this topology.

Keywords: ***Multilevel Converters, Three Phase Induction Motor, Voltage Control, Current Control, Power Control, sensor less Control and PWM Control.***

I.INTRODUCTION

A Modular Multilevel Converter (MMC) with focus on high-power medium voltage AC motor drives is presented [1]-[10]. The use of the MMC makes it possible to save bulky reactive components in a medium-voltage motor drive application such as a line-transformer, harmonic filter, and DC-link reactor. Compared to conventional medium voltage source converters, the MMC has a modular structure made up of identical converter cells. Because it can easily provide higher number of voltage level for medium voltage applications, the quality of the output voltage waveform is better. Also, because of the modular structure it has advantages such as easy maintenance and assembly. Fig. 1 shows the circuit configuration of an MMC. This topology needs to be controlled by extra balancing strategies. As shown in Fig. 1, since the upper and lower arm currents flow through cells in each arm, the corresponding arm currents cause fundamental periodic pulsations of cell capacitor voltages. The voltage pulsation of each cell's capacitor is mostly affected by the output phase current and output frequency. Theoretically, the magnitude of the cell voltage fluctuation is proportional to magnitude of the output phase current and inversely proportional to operating frequency [6]. For this reason, special effort is demanded to drive the AC machine through MMC, which requires considerable starting torque and low speed steady state operation. In recent studies of [7]-[9] and [16], the principles and algorithms for AC motor drives with the MMC have been introduced. However, they did not address the actual control strategies such as changing output frequency including standstill and covering load torquedisturbance. The energy balancing control is one of the main issues of an MMC system. In many literatures [6]-[10], the energy balancing controls of an MMC that uses circulating current control and modulation scheme has been introduced. The leg offset voltage is used to regulate the circulating current and has little effect on AC and DC terminal voltages. The conventional

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balancing controls need the circulating current controller that produces the leg offset voltage reference from the input of circulating current references using the proportional and integral (PI) or the proportional and resonant (PR) controller. The performance of the circulating current controller has detrimental effects on the dynamics and complexity of the balancing control. Therefore, in order to improve the balancing performance by increasing bandwidth of the balancing controller, this paper proposes a balancing control method without the circulating current controller. Therefore, in the view point of capacitor voltage balancing, the leg offset voltage can be directly obtained with no phase delay due to the circulating current controller. So, the bandwidth of balancing controller based on the direct voltage injection method can be extended more than that based on the circulating current controller. In addition, the difference between the cell voltages can be reduced faster. As a result, from the perspective of the control dynamics and control complexity, the proposed leg offset voltage injection method is better and simpler than the conventional circulating current injection method. Furthermore, the injecting frequency of leg offset voltage injection method can be increased more than that of current injection method, because of the extended bandwidth of the proposed method. So, owing to the high frequency injection with the proposed method, the fluctuation of cell capacitor voltage can be minimized compared to circulating current injection method. The goal of this paper is to propose a control strategy of the entire frequency range operation including standstill for variable speed AC motor drive. The proposed method reduces the control performance degradation of the MMC when the load torque abruptly changes. The control scheme introduces two operation modes. One is a low frequency mode for start-up and low speed operation, and the other is a normal frequency mode from medium to higher speed operation. The strategy in the low frequency mode exploits leg offset voltage and common mode voltage with the high frequency component to suppress the cell capacitor voltage ripple. The square wave voltage is used as the leg offset voltage, which shows that the circulating current peak is reduced when compared to sinusoidal waveform of the voltage [7]. A switchover tactic between two operation modes is described to drive the AC machine in the overall speed region To prove the effectiveness of the proposed control strategies, a 12kV 24MVA MMC based adjustable motor drive system was designed by using the PSIM software. The simulation results could offer the feasibility and advantage of the devised method for high power medium voltage drives with MMC. And then, experiments for variable-speed AC motor drives by a 10kVA prototype MMC emulating fans, blowers, or pump drive system were performed to verify the feasibility of the proposed balancing strategy. The experiments were conducted for comparing features of the sinusoidal and square wave leg offset voltage. The stable operation at 1Hz, which is less than 2% of the rated speed, is shown under an abrupt step load torque disturbance from 0% to 40% in order to demonstrate the dynamic performance. The experimental respectively. The common mode voltage, rsn , is the results show that all control strategies was well incorporated in the variable-speed AC motor drive system with a load where the torque varies in proportional to the square of the speed, like fans, blowers, or pumps.

II.CONFIGURATION AND BASIC PRINCIP LEOF THE MMC

Fig. 1(a) shows the circuit configuration of the MMC. The three-phase MMC is composed of three legs andeach leg has two arms and two arm inductors. Each arm has cascaded N-identical half-bridge circuit based cells, and each cell consists of one DC capacitor and two active in Fig. 1(b) in detail. In Fig. 1(a), isu and is1 are the upper and lower arm currents, respectively, and iss is the output phase current where ‘x’ represents the u, r, or w phase. The output phase current, iss , and circulating current, iso, are calculated from the upper and lower arm currents described in (1)-(2). Therefore, the arm currents can be deduced as (3)-(4), according to the decoupled control scheme.

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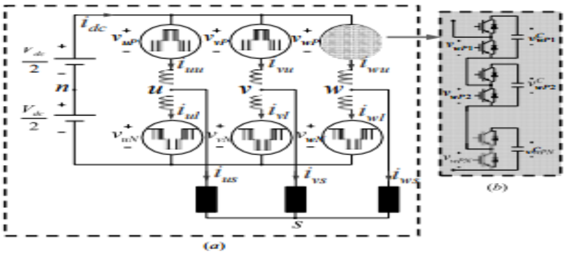

Fig. 1. Circuit configuration of the MMC

$$i_{xs} = i_{xu} - i_{xl}. \tag{1}$$

$$i_{xo} = (i_{xu} + i_{xl})/2 . \tag{2}$$

$$i_{xu} = \frac{1}{2} i_{xs} + i_{xo}. \tag{3}$$

$$i_{xl} = -\frac{1}{2} i_{xs} + i_{xo}. \tag{4}$$

The leg offset voltage, rso , produces a circulating current defined as (5), where R and L stand for the resistance and inductance of an arminductor when all arm inductors in MMC are assumed to be identical. From the voltage relationships along the x-phase loop, the upper and lower arm voltage references are denoted as (6) and (7), respectively, where Vdc is the DC-link voltage, and rsP and rsN are the upper and lower arm voltage difference between nodes ‘s’ and ‘n’, and rss is the phase voltage, which is rss = Vmcos(mst).

$$v_{xo} = \left(R + L\frac{d}{dt}\right) i_{xo}. \tag{5}$$

$$v_{xP}^{*} = \frac{V_{dc}}{2} - v_{xs}^{*} - v_{sn}^{*} - v_{xo}^{*} . \tag{6}$$

$$v_{xN}^{*} = \frac{V_{dc}}{2} + v_{xs}^{*} + v_{sn}^{*} - v_{xo}^{*} . \tag{7}$$

III. PROPOSED BALANCING CONTROL SCHEME

A.Start-up and Low Frequency Mode The capacitor power difference between the upper and lower arm, which is derived as (12) from (8) and (9), affects the cell capacitor voltage balance of the arms. The first two terms on the right-hand side in (12), 0.5Vdciss — 2r∗ i , have considerable DC or very low frequency components. Thus, when the output frequency is DC or very low, the voltage difference between the arms will diverge due to this low frequency term. To balance the power difference between arms, a control strategy exploiting the common mode voltage, rsn, was used in this paper. The common mode voltage can be regarded as an additional degree of freedom for controllability since the common mode voltage does not affect the line-to-line output voltage. It is natural to select the frequency of the common mode voltage as a high frequency to minimize the cell capacitor voltage fluctuations. In addition, since the circulating current, iso, is also a controllable element that does not affect the output phase current, a high frequency component can be superimposed on the circulating current. Hence, the third term on the right-hand side in (12), 2rsniso can be used to balance the power of arms with the high frequency components in rsn and iso . For convenience, the low and high frequency elements can be segregated from iso and rsn as (13) and (14), where “∼” and “^” refer to the low and high frequency components, respectively To nullify the low frequency as in(15) the low frequency component of 2vsnŝso should be controlled thus vsn and isn should be regulated as the same frequency same high frequency to make the power term of 2rˆsnŝso have DC or low frequency component. In the case of the sinusoidal leg offset voltage injection ∗ ∗ method, rˆsn and rˆso can be defined as (16)-(17), and mh refers to the angular speed of the high frequency component, Vsn for the effective value of common mode voltage and the magnitudfe of high frequency leg offset voltage which may have dc and several low frequency components.

B. Normal Frequency Mode Since the output frequency is high enough in the normal frequency mode, the voltage fluctuation of the cell capacitor is tolerable. In this mode, the circulating current is controlled to have only DC component to minimize the Practical MMC systems may have an inherent unbalance due to slight asymmetries in cells, structural errors, and other issues. In normal frequency mode, therefore, it should be performed just to eliminate the achieved by using the circulating current as 2vxsixo in (12). By regulating the leg offset voltage for circulating current to have fundamental frequency component, this DC unbalance can be suppressed.

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IV.OVERALL CONTROL SCHEME FOR ENTI RE FREQUENCY OPERATION

The overall controller for the entire frequency operation from standstill to normal frequency mode. Firstly, the averaging controller carries out regulating the leg power, which is the difference between DC-link input power and AC output power. The leg power is calculated as (25) by adding (8) and (9).control.

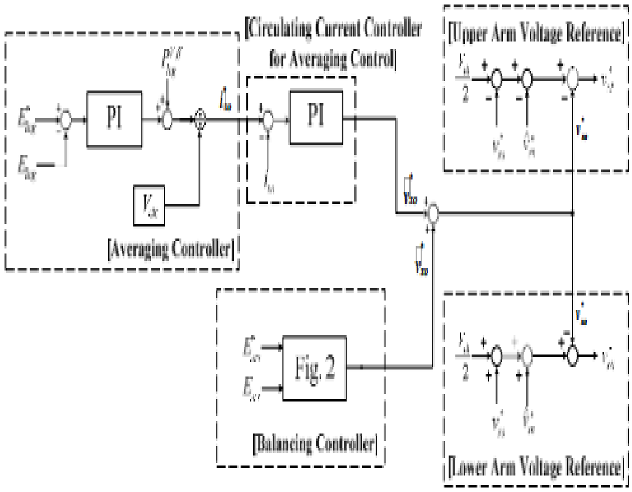

Fig. 2. Proposed overall control scheme for variable-speed drives.

V. 3-PHASE INDUCTION MOTOR

This section covers 3-phase asynchronous motors, the most commonly used motors for driving machinery. The use of this type of motor has become the norm in a large number of applications because of its numerous advantages: it is standardized, rugged, easy to maintain and use, and inexpensive Stator This is the altered piece of the engine. A cast iron or light combination casing encompasses a ring of dainty overlays (around 0.5 mm thick) made of silicon steel. The covers are protected from each other by oxidation or a protecting varnish. The "overlay" of the attractive circuit diminishes misfortunes by means of hysteresis and whirlpool streams. The overlays have openings in them for holding the stator windings that create the pivoting field (three windings for a 3-stage engine). Every winding is comprised of various loops. The way these curls are joined to each other characterizes the quantity of sets of posts of the engine, and accordingly the pace of turn. Rotor This is the moving piece of the engine. Like the attractive circuit of the stator, it is comprised of a heap of dainty covers protected from each other, framing a keyed barrel on the engine shaft. Two distinct innovations can be utilized for this part, which isolate offbeat engines into two unmistakable families: those with a "squirrel confine" rotor and those with an injury rotor which are alluded to as "slip-ring".

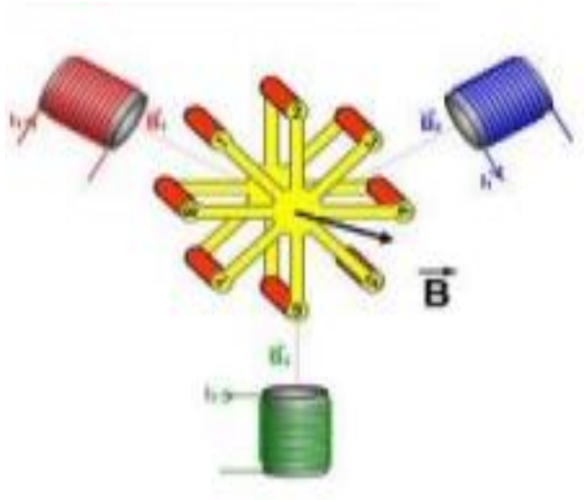

Fig.3-phase squirrel cage induction motor

VI. PRINCIPLE AND WORKING

At the point when 3 stage supply is given to the engine, the subsequent current produces an attractive flux "Ø". Due to the exchanging succession of 3 stage current in R, Y and B, the created flux pivots around the rotor conductor As showed by Faraday's law which communicates that –"an emf influenced in any close circuit is a direct result of the rate of advancement of appealing flux through the circuit". Emf is provoked in the Copper bar and on account of this, present streams in the rotor. The course of rotor can be given by Lenz law which communicates that –"the orientation of actuated current will be in the converse of the development bringing on it" Here the relative speed between the turning flux and static rotor conductor is the explanation behind current time; subsequently the rotor will rotate in the same going to abatement the reason i.e. the relative rate, subsequently turning the rotor of the insincerity motor.

POWER SUPPLY

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The stator is connected with a 3-stage aerating and cooling power supply. In the going hand in hand with blueprint organize An is joined with stage An of the power supply. Stage B and C would similarly be connected with stages B and C of the power supply individual associated with stages B and C of the force supply individual Stage windings (A, B, and C) are put 120° separated. In this sample, a second arrangement of three-stage windings is introduced. The quantity of shafts is dictated by how often a stage winding shows up. In this sample, every stage winding seems two times. This is a two-shaft stator. In the event that every stage winding seemed four times it would be a four-shaft stator

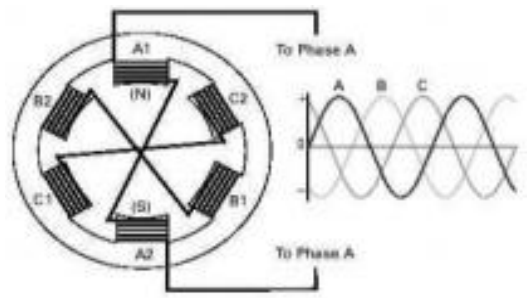

Fig.4 power supply to motor

At the point when air conditioning voltage is connected to the stator, current courses through the windings. The attractive field grew in a stage twisting relies on upon the bearing of current move through that winding. The accompanying outline is utilized here for clarification just. It will be utilized as a part of the following couple of outlines to show how a pivoting attractive field is created. It accept that a positive current stream in the A1, B1 and C1 windings bring about a north post.

VII. SIMULATION RESULTS

To verify the effectiveness of the proposed control strategy, an adjustable speed drive system based on 12kV applied to high power medium voltage adjustable drive system based on MMC. From the dynamic comparison between circulating current injection with the inner current loop and the proposed leg offset voltage injection method, it can be concluded that the proposed method might be an acceptable solution for high power medium voltage drives based on MMC under requirements of considerable torque disturbance and steady state operation down to a few percent of the rated frequency. Fig. 5 shows the low frequency operation at 1Hz (6r/min, less than 2% of the rated frequency) with an abrupt step load torque from 50kN-m (10%) to 200kN-m (40%) at 4s. Fig. 5(a) shows the simulation result of the sinusoidal wave leg offset voltage method, and Fig. 5(b) shows that of the square wave leg offset voltage method. The high frequency (100Hz) voltage is used to balance the arm in low the frequency mode in both sinusoidal and square wave cases. Before 4s, the PMSM is controlled to be 6r/min with 10% load torque. At the time point 4s, the 40% load torque is abruptly applied to the PMSM. Regardless of the impact of step load torque, MMC systems with both sinusoidal and square wave cases have successfully kept the stable operation. Meanwhile, comparing the waveforms between Fig. 5(a) and Fig. 5(b), the square waveform method can save the magnitude of the circulating current. Additionally, it has better balancing ability than the sinusoidal waveform method, from the view of the u-phase upper and lower cell capacitor voltage fluctuations. Meanwhile, In Fig. 6, the simulation results with the conventional circulating current injection method based on the inner current regulating loop is shown. All operating conditions are identical to those in Fig. 5 except for the magnitude of the step load torque. For fair comparison between the conventional current injection and proposed leg offset voltage injection methods, the bandwidth for the balancing controller of the two methods is set as the same, and the frequency of the injected component was also set as the same, 100Hz. The magnitude of the step load torque applied at the conventional current injection method is 36% of the rated torque, which is less than the proposed method test in Fig. 5. As shown in Fig. 6, the system based on the conventional method becomes unstable and stalls in a moment at the end. After the abrupt step load torque is applied at 4s, the cell capacitor voltage fluctuations

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are larger than the fluctuations when using the leg offset voltage injection method in Fig. 5.

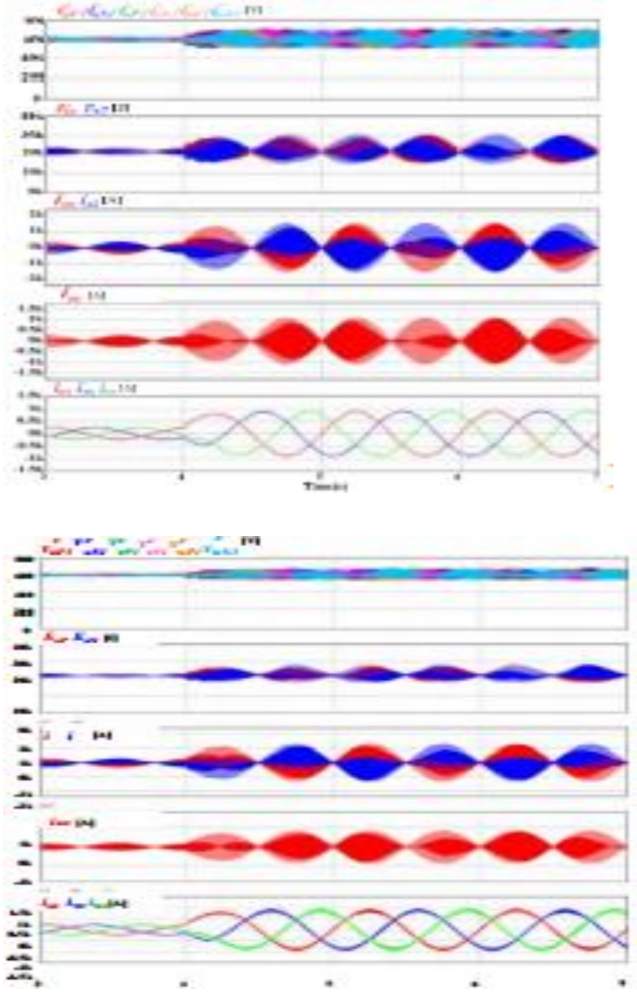

Fig. 5. The simulation waveform when applying the proposed leg offset voltage injection method with 6r/min speed and step load torque from 10% to 40% of the rated torque: (a) sinusoidal waveform offset voltage injection, (b) square waveform offset voltage injection.

VIII. CONCLUSIONS

In this paper, a control strategy for variable-speed AC motor drives based on MMC has been presented. To overcome the difficulties of the power balance between cells and arms of MMC over wide operation speed ranges, a direct leg offset voltage injection method has been devised. Utilizing the proposed method, the ripple voltage of each cell of MMC has been kept within allowable bounds under the sudden application of 40% of rated load torque at the extremely low frequency, 1Hz, which is less than 2% of rated frequency. Based on the simulation and experimental results, it can be noted that the control performance of the upper and lower arm energy ripple by the proposed leg offset voltage injection method is better than that by the conventional circulating current injection method with the inner loop. In addition, the variable speed AC motor drive has been proven to work based on the switchover tactic by testing the overall speed including standstill.

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