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A Hybrid Cascaded Multilevel Inverter Applied To Induction Machine Drive

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Abstract- Cascade multilevel inverter is a power electronic device built to synthesize a desired ac voltage from several levels of dc voltages. Such inverters have been received increasing attention in the past few years for high power application. A small total harmonic distortion is the most important feature of these inverters. Basically cascade multilevel inverter is used in this work with proposed control circuit to control the output voltage using sinusoidal pulse width modulation (SPWM). The objective of this paper is to propose an alternative topology of hybrid cascaded multilevel inverter applications. The modified PWM technique is also developed to reduce switching losses. Also, the proposed topology can reduce the number of required power switches compared to a traditional cascaded multilevel inverter. And Hybrid cascaded multilevel inverter is applied to induction machine drive for evaluate the performance of the drive. MATLAB/SIMULINK platform are used to simulate the circuit operation and control signal. The reduced switching losses of the proposed multilevel inverter are also discussed. The results show that this alternative multilevel inverter topology can be applied to interface with renewable energy resources.

Keywords- Cascaded Multilevel Inverter, Mathematical Model of Induction Machine Drive, Hybrid Multilevel Inverter, Modified PWM Technique.

I. INTRODUCTION

Power electronic inverters are widely used in various industrial drive applications. To overcome the problems of the limited voltage and current ratings of power semiconductors devices, some kinds of series and/or parallel connections are necessary. Recently, the multilevel inverters have received more attention in literature due to their ability to synthesize waveforms with a better harmonic spectrum and to attain higher voltages. They are applied in many industrial applications such as ac power supplies, static VAr compensators, and drive system, etc

Various converter topologies have been developed for renewable energy sources or distributed energy resources

(DER's) [1] that demonstrate effective power flow control performance whether in grid-connected or stand-alone operation. Among them, solutions that employ high-frequency transformers or make no use of transformers at all have been investigated to reduce size, weight, and expense.

Therefore, multilevel inverters are suitable for this application because a multilevel inverter can possibly provide the high volt ampere ratings; more specially, in adjustable speed drive applications, Generally, three different major multilevel converter structures have been reported in the literature: cascaded H-bridges converter with separate dc sources (SDCS), diode clamped (neutral clamped), and flying capacitors (capacitor clamped). As explained in [2], a cascaded multilevel inverter may have more potential than others since input SDCS (Photovoltaic and Fuel cell) could be naturally interfaced to the multilevel inverter to provide higher output voltages. Moreover, a cascaded configuration would provide a possibility to connect a higher SDCS for getting higher the output voltages. However, a cascaded multilevel inverter contains a lot of power switches and this number of power switches will be depended upon a number of required output voltage levels. Consequently, higher switching losses will be traded off with output voltage quality.

Multilevel inverters have very important development for high power medium voltage AC drives. Quite a lot of topologies have found industrial approval; Neutral Point Clamped, flying capacitor, H-bridge, cascaded with separated DC source, several control and modulation strategies have been developed Pulse Width Modulation (PWM), Sinusoidal PWM, Space Vector PWM and

Selective harmonic eliminations. A cascaded hybrid multilevel inverter has been developed from a conventional cascaded multilevel inverter as illustrated in Fig.1. An IGBT H-Bridge inverter and an IGCT H-Bridge inverter are used as a hybrid multilevel inverter as proposed in [3]. The IGCT inverter can be used at higher volt ampere rating than the IGBT inverter; however, the IGBT inverter can be operated at higher switching frequency than the IGCT inverter. This illustrates that the hybrid inverter can operate at higher volt ampere rating with lower switching losses than a conventional cascaded multilevel inverter. The IGCT inverter can operate at fundamental switching frequency (square wave) and the IGBT inverter can operate at PWM switching mode as clearly explained. The hybrid inverter proposed has the same number of power switches compared to a conventional cascaded multilevel inverter. It would be better if we could reduce a number of power switches in a hybrid inverter with the same functionality. The application of hybrid multilevel inverter with a single SDCS can be also applied in vehicle applications as proposed in [4]. Therefore, an alternative hybrid multilevel inverter (HMI) is developed as shown in Fig. 2. The HMI consists of two types of inverter: a conventional three phase six switches inverter and a single phase four switches H-bridge inverter. The objective of this proposed HMI is to apply with the renewable energy resources for a high power application; thereupon, two SDCS is used to supply both inverters. The switching paradigm of both inverters will be developed with low switching losses.

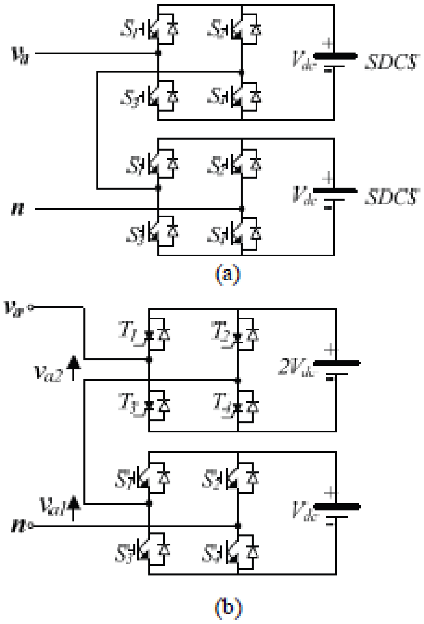

Fig. 1. Single phase cascaded multilevel inverter configuration (a) a conventional multilevel inverter (b) hybrid multilevel inverter using IGCTs and IGBTs.

II. PROPOSED CONCEPT AND PWM SCHEME

The topology of the proposed hybrid multilevel inverter is shown in Figure 1, which includes a complete and a simplified single-phase topology. The bottom is one leg of a standard 3- leg inverter with a dc power source. The top is an H-bridge in series with each standard inverter leg. The H-bridge can use a capacitor, battery or other dc power source [5].

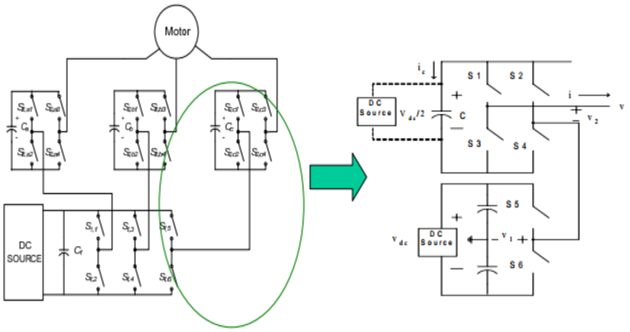

Fig. 2. Proposed three phase cascaded hybrid multilevel inverter and Simplified circuit

The output voltage v1 of this leg (with respect to the ground) is either +Vdc/2 (S5 closed) or −Vdc/2 (S6 closed). This leg is connected in series with a full H-bridge, which in turn is supplied by a capacitor voltage. If the capacitor is used and kept charged to Vdc /2, then the output voltage of the H-bridge can take on the values +Vdc/2 (S1, S4 closed), 0 (S1, S2 closed or S3, S4 closed), or −Vdc/2 (S2, S3 closed). Fig.3 shows an output voltage example. The capacitor's voltage regulation control method consists of monitoring the output current and the capacitor voltage so that during periods of zero voltage output, either the switches S1, S4, and S6 are closed or the switches S2, S3, S5 are closed depending on whether it is necessary to charge or discharge the capacitor. This method depends on the voltage and current not being in phase. That means one needs positive (or negative) current when the voltage is passing through zero in order to charge or discharge the capacitor. Consequently, the amount of capacitor voltage the scheme can regulate depends on the phase angle difference of output voltage and current.

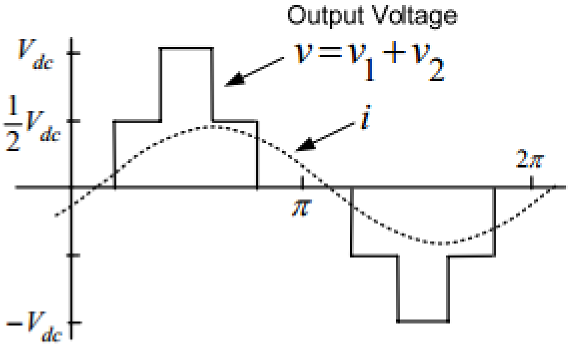

Fig. 3. Five level output waveform

A. PWM Scheme:

Before continuing discussion in this paper, it should be noted that the word *main inverter* is used to refer to the six-switch three phase inverter and the word auxiliary inverter is referred to four-switch H-bridge inverter. Since the low switching losses during PWM operation is required, the main inverter will operate on square wave mode and auxiliary inverter will operate on PWM mode as depicted in Figure 4. In practical, if a single chip is used to generate the PWM signals, it normally has only one carrier signal with six PWM channels; nevertheless, the HMI requires 12 PWM channels for both main and auxiliary inverter. Thereafter, the referent signal of sinusoidal PWM (SPWM) used for the auxiliary inverter is modified by using equation (1)-(4).

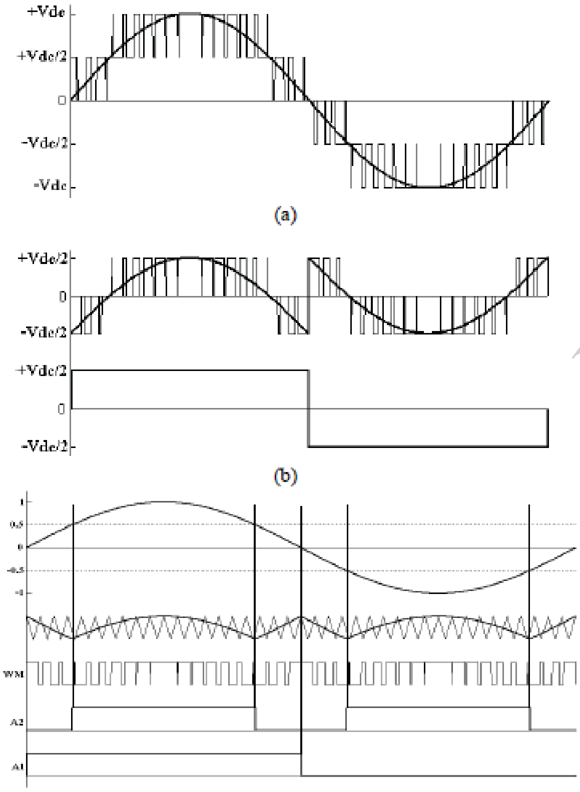

Fig.4. Proposed PWM paradigm: (a) output phase voltage, (b) auxiliary and main inverter output voltages and (c) modulation signals of both main and auxiliary inverter.

$$f\ (t)\ m\ Sin\ (\ t) \qquad (1)$$

$$\frac{T_P}{T_C} = \begin{cases} 2\left(f(t)-\frac{1}{2}\right) ; \frac{1}{2} \le f(t) \le 1 \\ 2\left(\frac{1}{2}-f(t)\right) ; 0 \le f(t) \le \frac{1}{2} \end{cases} \qquad (2)$$

$$A_1 = \begin{cases} 1 \ ; f(t) \ge 0 \\ 0 \ ; f(t) < 0 \end{cases} \qquad (3)$$

$$A_2 = \begin{cases} 1 \ ; \left|f(t)\right| \ge \frac{1}{2} \\ 0 \ ; \left|f(t)\right| < \frac{1}{2} \end{cases} \qquad (4)$$

where $f(t)$ is a referent signal,
m_a is modulation Index (0.0/1.0-1.0/1.0),
A_1 is a multiplexing signal #1,
A_2 is a multiplexing signals #2,
$\frac{T_P}{T_C}$ is pulse width of PWM (0.0–1.0).

III. MATHEMATICAL MODEL INDUCTION MACHINE DRIVE

The induction machine d-q or dynamic equivalent circuit is shown in Fig. 5 and 6. One of the most popular induction motor models derived from this equivalent circuit is Krause's model detailed in [5]. According to his model, the modeling equations in flux linkage form are as follows:

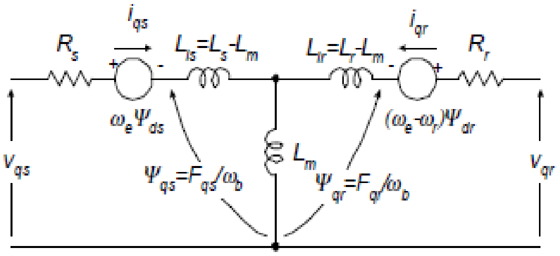

Fig. 5. Dynamic q-axis model

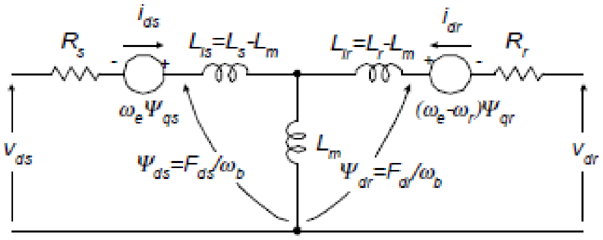

Fig. 6. Dynamic d-axis model

$$\frac{dF_{qs}}{dt}=\omega_b\left[v_{qs}-\frac{\omega_e}{\omega_b}F_{ds}+\frac{R_s}{x_{ls}}\left(F_{mq}+F_{qs}\right)\right] \tag{5}$$

$$\frac{dF_{ds}}{dt}=\omega_b\left[v_{ds}+\frac{\omega_e}{\omega_b}F_{qs}+\frac{R_s}{x_{ls}}\left(F_{md}+F_{ds}\right)\right] \tag{6}$$

$$\frac{dF_{qr}}{dt}=\omega_b\left[v_{qr}-\frac{\left(\omega_e-\omega_r\right)}{\omega_b}F_{dr}+\frac{R_r}{x_{lr}}\left(F_{mq}-F_{qr}\right)\right] \tag{7}$$

$$\frac{dF_{dr}}{dt}=\omega_b\left[v_{dr}+\frac{\left(\omega_e-\omega_r\right)}{\omega_b}F_{qr}+\frac{R_r}{x_{lr}}\left(F_{md}-F_{dr}\right)\right] \tag{8}$$

$$F_{mq}=x_{ml}^{*}\left[\frac{F_{qs}}{x_{ls}}+\frac{F_{qr}}{x_{lr}}\right] \tag{9}$$

$$F_{md}=x_{ml}^{*}\left[\frac{F_{ds}}{x_{ls}}+\frac{F_{dr}}{x_{lr}}\right] \tag{10}$$

$$i_{qs}=\frac{1}{x_{ls}}\left(F_{qs}-F_{mq}\right) \tag{11}$$

$$i_{ds}=\frac{1}{x_{ls}}\left(F_{ds}-F_{md}\right) \tag{12}$$

$$i_{qr}=\frac{1}{x_{lr}}\left(F_{qr}-F_{mq}\right) \tag{13}$$

$$i_{dr}=\frac{1}{x_{lr}}\left(F_{dr}-F_{md}\right) \tag{14}$$

$$T_e=\frac{3}{2}\left(\frac{p}{2}\right)\frac{1}{\omega_b}\left(F_{ds}i_{qs}-F_{qs}i_{ds}\right) \tag{15}$$

$$T_e-T_L=J\left(\frac{2}{p}\right)\frac{d\omega_r}{dt} \tag{16}$$

where d : direct axis,
q : quadrature axis,
s : stator variable,
r : rotor variable,
F_{ij} is the flux linkage (i=q or d and j=s or r),
v_{qs}, v_{ds} : q and d–axis stator voltages,
v_{qr}, v_{dr} : q and d–axis rotor voltages,
F_{mq}, F_{md} : q and d axis magnetizing flux linkages,
Rr : rotor resistance,
Rs : stator resistance,
X_{ls} : stator leakage reactance ($\omega_e L_{ls}$),
X_{lr} : rotor leakage reactance ($\omega_e L_{lr}$),
X_{ml}^{*} : $1\Big/\left(\frac{1}{x_m}+\frac{1}{x_{ls}}+\frac{1}{x_{lr}}\right)$,
i_{qs}, i_{ds} : q and d–axis stator currents,
i_{qr}, i_{dr} : q and d–axis rotor currents,
p : number of poles,
J : moment of inertia,
T_e : electrical output torque,
T_L(or T_l) : load torque,
ω_e : stator angular electrical frequency,
ω_b : motor angular electrical base frequency,
ω_r : rotor angular electrical speed.

$$\frac{dF_{qs}}{dt}=\omega_b\left[v_{qs}-\frac{\omega_e}{\omega_b}F_{ds}+\frac{R_s}{x_{ls}}\left(\frac{x_{ml}^{*}}{x_{lr}}F_{qr}+\left(\frac{x_{ml}^{*}}{x_{ls}}-1\right)F_{qs}\right)\right] \tag{17}$$

$$\frac{dF_{ds}}{dt}=\omega_b\left[v_{ds}+\frac{\omega_e}{\omega_b}F_{qs}+\frac{R_s}{x_{ls}}\left(\frac{x_{ml}^{*}}{x_{lr}}F_{dr}+\left(\frac{x_{ml}^{*}}{x_{ls}}-1\right)F_{ds}\right)\right] \tag{18}$$

$$\frac{dF_{qr}}{dt}=\omega_b\left[-\frac{\left(\omega_e-\omega_r\right)}{\omega_b}F_{dr}+\frac{R_r}{x_{lr}}\left(\frac{x_{ml}^{*}}{x_{ls}}F_{qs}+\left(\frac{x_{ml}^{*}}{x_{lr}}-1\right)F_{qr}\right)\right] \tag{19}$$

$$\frac{dF_{dr}}{dt}=\omega_b\left[\frac{\left(\omega_e-\omega_r\right)}{\omega_b}F_{qr}+\frac{R_r}{x_{lr}}\left(\frac{x_{ml}^{*}}{x_{ls}}F_{ds}+\left(\frac{x_{ml}^{*}}{x_{lr}}-1\right)F_{dr}\right)\right] \tag{20}$$

$$\frac{d\omega_r}{dt}=\left(\frac{p}{2J}\right)\left(T_e-T_L\right) \tag{21}$$

IV. MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS

Here the simulation is carried out by two cases 1. Three Phase Cascaded Hybrid Multilevel Inverter. 2. Three Phase Cascaded Hybrid Multilevel Inverter Applied to Induction Motor Drive.

Case 1: Three Phase Cascaded Hybrid Multilevel Inverter:

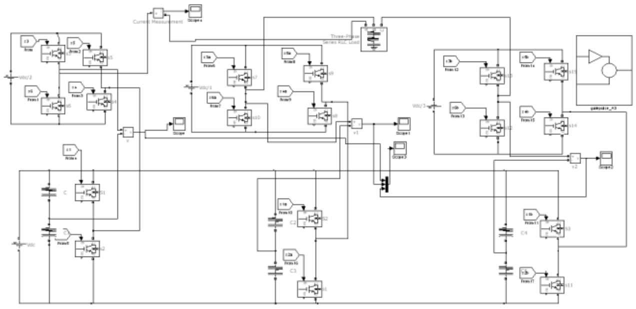

Fig. 7. Matlab/Simulink model of Three Phase Cascaded Hybrid Multilevel Inverter

Fig.7. shows the Matlab/Simulink model of Three phase Cascaded Hybrid Multilevel inverter.

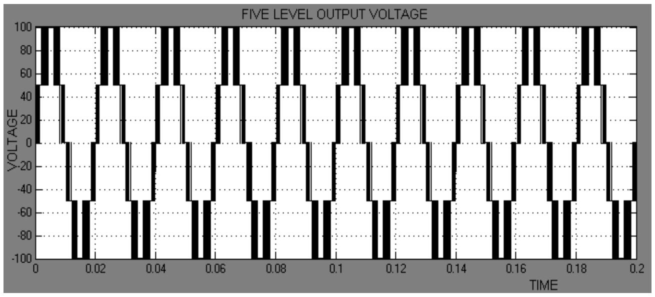

Fig. 8. Five Level Output Voltage

Case 2 : Three Phase Cascaded Hybrid Multilevel Inverter Applied to Induction Motor Drive:

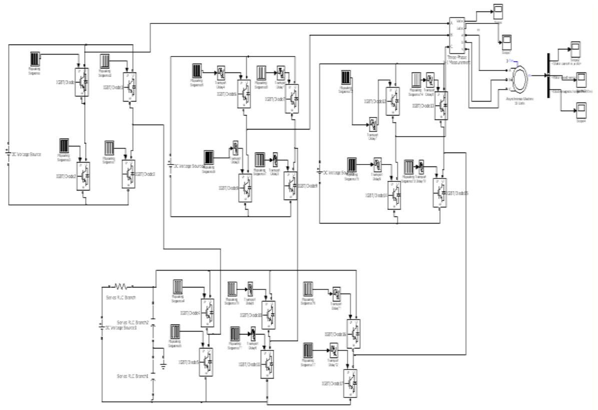

Fig. 9. Matlab/Simulink Model of Three Phase Cascaded Hybrid Multilevel Inverter Applied to Induction Motor Drive

Fig.9 shows the matlab/simulink model of three phase cascaded hybrid multilevel inverter applied to induction motor drive, for evaluating motor characteristics.

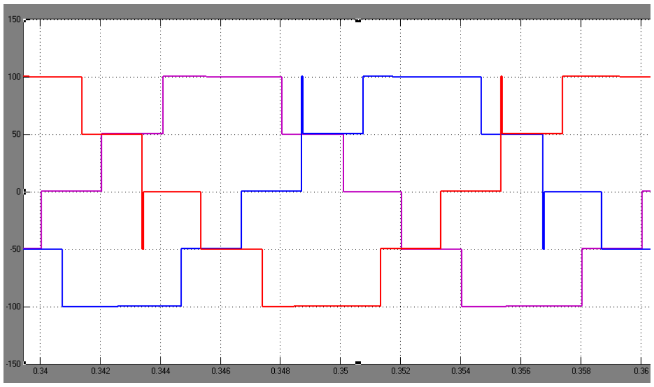

Fig .10. Five level Output Voltage

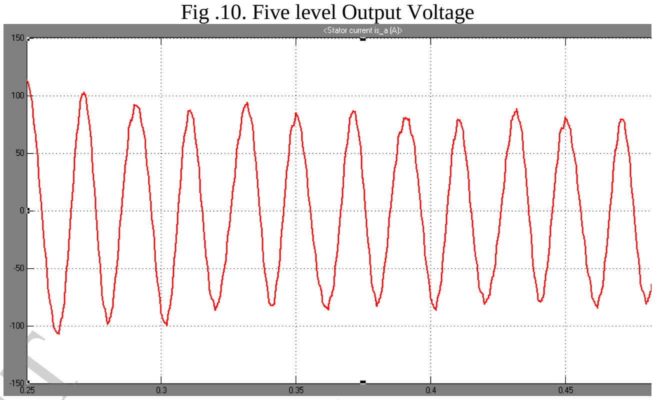

Fig. 11. Stator current of inductor motor Drive

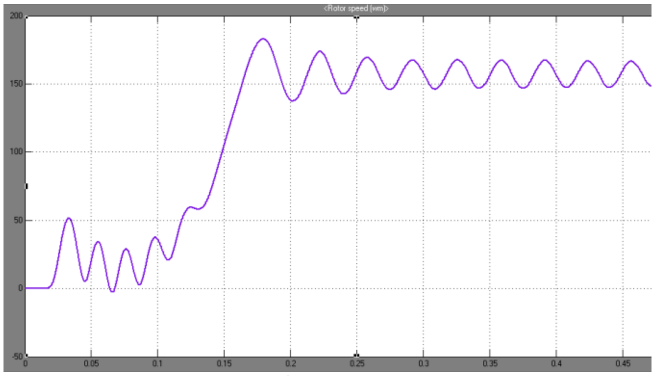

Fig .12. Speed of the induction motor drive

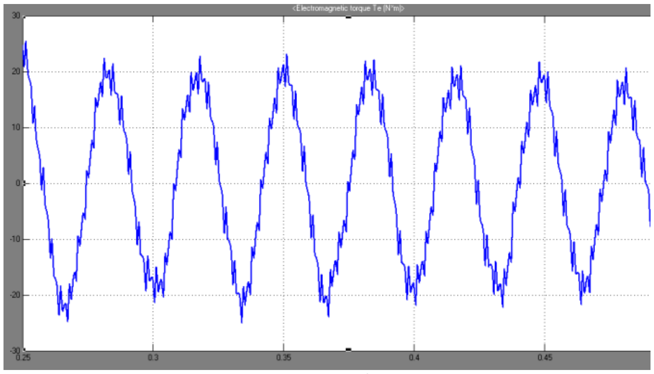

Fig. 13: Electro magnetic torque of the induction motor drive

Fig 11, 12,13 Shows the Stator current and Speed and Electro magnetic Torque respectively, of the Three phase cascaded hybrid multilevel inverter Applied to induction motor drive.

V CONCLUSION

The hybrid cascaded multilevel inverter is applied to induction motor drive and see the drive characteristics. The modified PWM technique has also been developed to reduce switching losses. Also, the proposed topology can reduce the number of required power switches compared to a traditional cascaded multilevel inverter. Simulation results have been performed. The switching losses of the HMI are less than the conventional multilevel inverter; consequently, the system efficiency would be improved by utilizing the HMI. In addition, inverter efficiency has been achieved based on this particular load condition. The results show that this alternative cascaded hybrid multilevel inverter topology can be applied for high power applications as a multilevel inverter and can be used to interface with renewable energy resources and induction motor drive.

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