ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Cascaded H-Bridge Multi Level Inverters for DTC Induction Motor Drives

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ABSTRACT:

In olden days conventional inverters have some limitations i.e.) in high voltage and high power applications. Nowadays multi level inverters are extensively used in high power applications due to their improved harmonic profile and increased power ratings. Several investigations have been focused on the multi level inverter topologies and control techniques and their applications. Some of the studies discussed about the induction motor drives associated with the three phase multi level inverter. In this paper firstly symmetrical cascaded H-Bridge multi level inverter has been studied. To overcome the losses in the symmetrical arrangement asymmetrical cascaded H-Bridge multi level inverter has been studied. Asymmetrical cascaded H-Bridge multi level inverter affordsalmost sinusoidal voltages with extremelylittle distortion and with less switching devices, and torque ripples are significantlycondensed.

Index terms:

Direct torque control (DTC),Induction motor (IM), Multi level inverter (MLI).

I.INTRODUCTION:

Multi level voltage source inverters are broadly used for high power applications [1], and also for medium voltage industrial applications [2], [3]. rising in the number of output voltage levels the waveform will synthesize with a superior harmonic spectrum and reduce the motor winding stress. More number of devices will reduce the power converter overall reliability and system efficiency. While reducing the number of levels it will need a huge and high-priced LC output filter for limiting themotor winding insulation stress or designed motors to resist such type of stress. Various voltages could be elected after taking into account the real power input of the main voltage stage. Maximum power supplied by the highest voltage stage is preservedbeneath the load power.Several investigations have been conducted for recovering the multi level inverter. Some of the studies dealt with innovative methods such as cascaded H-Bridge multi level inverter, and asymmetrical multi level inverter for recovering the output voltage resolution. Former work mainly implemented on either advanced control strategies or improving voltage source inverter techniques for multi level inverter [4], [5]. In symmetrical multi level inverter voltages will be given to the all H-Bridge cells are equal and each arm cell generatesanalogous output voltage steps. And unequal voltages will be given to the H-Bridge cells it will be a asymmetrical multi level inverter. In this inverter each arm cell will create a different output voltage. Other methods are also possible such as unbiased point clamped fed by unequal capacitors.

Asymmetrical multi level inverter has been recently developed [6]. After studying all these techniques H-Bridge topology has been considered and cascade cell numbers and DC source ratios have been implemented [6]. The required pulse width modulation strategy maintains at high voltage stage and Operate at little frequency limits. The Method that hasbeen utilized for a major multi level manufacturer is direct torque control. Direct torque controller today recognised as a high characteristics control strategy for ac drives [7]-[9]. A number of authors have reported that strengthening the performance of DTC ac motors especially dropping the torque ripples. Various methods have been projected and these are appropriate for the traditional two level inverters [10]. However extension to the more numbers of levels is not easy. In this paper Cascaded H-Bridge multi level inverter are considered and symmetrical and asymmetrical configurations are implemented. Experimental results will be acquired for an asymmetrical level inverter fed induction motor. It shows that the elevated dynamic presentation of the previous method and presents good performance and little torque ripples.

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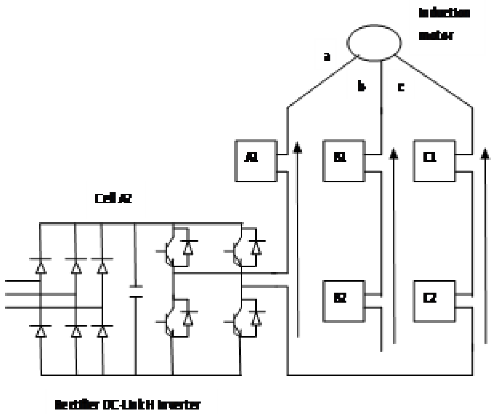

Fig.1 Structure of cascade multi level inverter for two cells

II.STRUCTURE AND OPERATION OF THE CASCADE H-BRIDGES:

Cascade H-Bridge inverter comprises of power conversion cells. The voltage supplied to every cell is from the DC source on the DC side i.e.) from batteries or fuel cells or ultra capacitors[11]-[12], and series connection on the ac side. This topology will have the some advantages that are modulation control and safeguard requirements for every bridge are modular.

In cascade H-Bridge inverter inaccessible DC source will be required in every cell in every phase not similar to the diode clamped and flying capacitor topologies. Fig I shows a three phase topology of the cascade inverter with inaccessible DC sources. Output phase voltage waveform is achieved from summing of the bridge output voltages

$$V_0(t) = V_{0,1}(t)+V_{0,2}(t)+...+V_{0,N}(t) \qquad (1)$$

Where N is number of cascade bridges
The inverter output voltage may be acquired from the individual cells switching states

$$V_0(t)\sum_{j=1}^{N}(uj-1)V_{dc,j}, \quad \mu_j=0,1,....(2)$$

Equal DC voltages will be given in fig I then it will be the symmetrical multi level inverter. The efficient number of output voltage levels is represented as

$$N=1+2N \qquad (3)$$

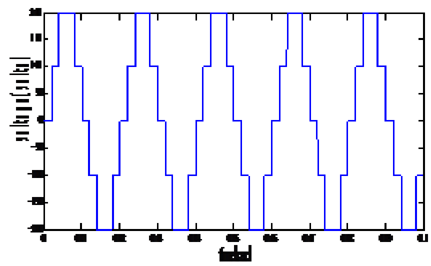

Fig.2 Five level output voltage synthesis for symmetrical multi level inverter

Fig 2 shows a typical waveforms of multi level inverter showed in the fig 1 with two DC sources that is five level output. The maximum output voltage V0,Max is

$$V_0, MAX=N\ V_{dc} \qquad (4)$$

The number of output levels can be augmented without increasing the number of inverters so that the asymmetrical multi level inverter must be used. DC voltage sources could be chosen according to geometric progression. For N cascade inverters the different voltage levels are

{n=2N+1-1, if V dc, j=2j-1Vdc, j=1,2.., N
{n= 3N, if V dc,j = 3j−1Vdc, j= 1, 2..,N(5)

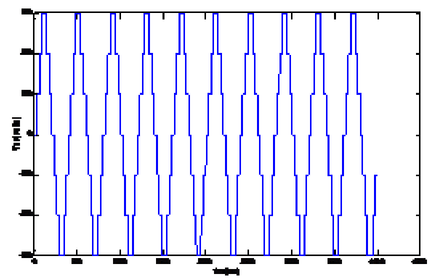

Fig.3 Seven level output voltage synthesis for asymmetrical multi level inverter

Fig 3 shows typical waveforms for fig 1 multi level inverter in accordance with the two dc sources V dc and 2Vdc sources for 5 levels output And seven levels output.

The maximum output voltage of the N cascaded multi level inverter is

$$V0, MAX=\sum^{N}_{j=1}Vdc,j \qquad (6)$$

Equation 6 can also be written as

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{V0,MAX=(2^N-1)V dc,

If V dc, j=2^{j-1} Vdc, j=1,2….,N

{V0, MAX =(3^N – 1)/2Vdc,

{If V dc,j = 3^{j-1} V dc, j= 1, 2….., N

TABLE I:COMPARISON OF MULTI LEVEL INVERTERS

	Symmetrical inverter	Asymmetrical inverter	
		Binary	Ternary
N	2N+1	2^{N+1}-1	3N
DC Sources number	N	N	N
Switches number	4N	4N	4N
	N	2^N-1	(3^N-1)/2
$V_{o,MAX}$ [pu]			

While comparing to (3) and (7) it represents that asymmetrical multi level inverter can generate more voltages levels and maximum output voltage with the same number of bridges.Table I shows that the number of levels,switches and dc sources and output voltage levels for cascade multi level inverter. While raising the number of levels the steps of the waveform will be increased. The resolution of the output voltage waveform will be higher and the output voltage of the sinusoidal will achieved better. In n level inverter there are n3 switching states and there are n zero states where zero output voltages are formed. There are distinctive states and mutual states in the non-zero remaining states (n3-n). The exceptional state provides the voltage vectors and this voltage vectors cannot be obtained from any other states. While the mutual states provides the set of output voltages and this can be acquired from some other mutual states. The corresponding mutual states have the equivalent voltage vectors.

The n level inverter has [(n-1)3-(n-1)] non-zero mutual states.The number of voltage vectors attained from n level inverter is [(n-1)3-(n-1)]. The corresponding mutual states can condense the switching losses. While the equivalent mutual states can be substituted that means the other states can be considered as redundant. In n level symmetrical H-Bridge inverter there are (n-1)3 redundant states.

III.INDUCTION MOTOR DIRECT TORQUE CONTROLLER:

DTC is an alternative method to the flux vector control method [8]. The torque ripples are observed greatly in the high frequencies in the benchmark version. The inverter switching frequency is varied and depends on the shaft speed and torque. While varying the frequency torque harmonics are produced and the noise disturbances will be accustomed. With the aim to minimize these drawbacks multi level inverter provide some control strategies that is space vector and phase configuration etc... [4].

A .NOMENCLATURE:

VSStator Voltage Vector
Φs(φr) Stator (rotor) flux vector
Te Electromagnetic Torque
Rs Stator resistance
Ls (Lr) Stator (rotor) inductance
Lm Magnetizing inductance
σTotal leakage coefficient
σ = 1− L2m/ Ls Lr
θsr Angle between stator and rotor flux vectors
P Pole Pair number

B.TORQUEAND FLUX ESTIMATION:

The stator flux vector of an induction motor depends upon the stator voltage and current vectors by

$$d\varphi s(t)/ dt = Vs (t) − Rs\ is (t)...... \quad (8)$$

Vsis constant at the sample time interval and neglecting the stator resistance

$$\Delta \varphi s(t) = \varphi s(t) − \varphi s(t − \Delta t) =\int(t-\Delta t)tVs\Delta t \ ..... (9)$$

Equation 9 states that Stator flux vector is varied directly by the stator voltage vector.

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International Journal & Magazine of Engineering, Technology, Management and Research
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On the converse,the authority of Vsagainst the rotor flux is strained by means of the rotor and stator leakage inductance [13], and is therefore not relevant to a short time horizon. If the rotor flux rotates slower thenthe stator can be changed quickly. The angle between the both vectors can be openly controlled by the stator voltage vector that is Vs.The detaileddemonstration of both the stator and rotor flux of the dynamic performance is depicted below

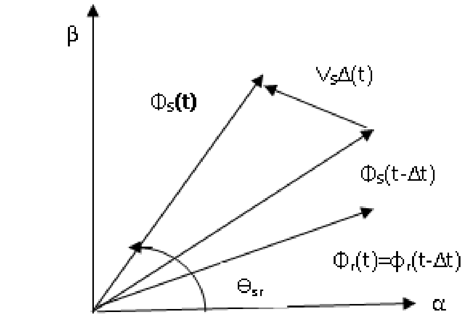

Fig.5 Influence of Vs over φsduring a simple interval Δt

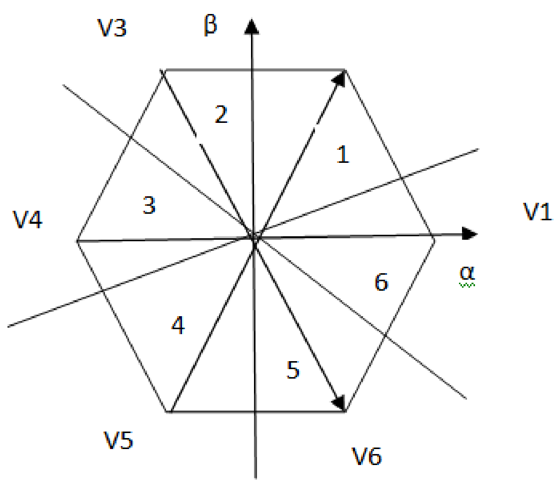

Fig.6 Possible voltage changes ΔVksthat can be applied from certain Vk

The relationship between the stator and rotor flux in fig 6 shows that φs constant will generate a constant flux φr [14]. The electromagnetic torque of an induction motor is expressed by [15]

Te= (3/2)p(Lm/σLsLr)(φsφrsin θsr) .....(10)

φsrwill change because of the action of vs. Due to this direct and fast change will occurs in the developed torque. By using the DTC principle required torquereaction will be achieved in the induction motor by using the stator voltage vector to accurate the flux trajectory.

C.VOLTAGE VECTOR SELECTION:

Fig 7 demonstrates one of the 127 Voltage vectors produced by the inverter at instant t=k, i.e.) vsk. The subsequent voltage vector will be applied to the load is vsk+1, can be articulated as

Vsk+1 = Vsk +Δ Vsk

Where ΔVsk= {Vi |i= 1...., 6}.

Each vector is in contact to the one corner of the elemental hexagon.Vsk+1 will spot the torque and flux responses knowing the actual voltage vector Vsk and the torque and flux errors. And stator flux vector arrangement is calculated by an angle θs. The next voltage vector will be in one of the six adjoining vectors. Due to hugevariation in the reference it will reduce the high dynamics in torque response.

TABLE II:VOLTAGE VECTOR SELECTION LOOK UP TABLE

Sector	Signal($e\varphi^k$,eT^K)			
	(+,+)	(+,-)	(-,+)	(-,-)
1	V_2	V_6	V_3	V_5
2	V_3	V_1	V_4	V_6
3	V_4	V_2	V_5	V_1
4	V_5	V_3	V_6	V_2
5	V_6	V_4	V_1	V_3
6	V_1	V_5	V_2	V_4

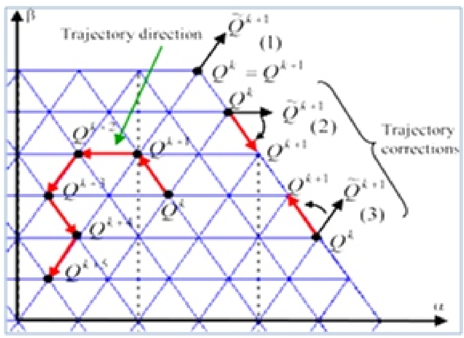

Fig.7 Optimal space vector tracking and trajectory correction in the stationary α–β frame.

Table 2 shows that vector selections of the different sectors. DTC of the induction motor is fed to the multi level inverter onevery sampling period, the inverter states is a purpose of torque and flux values for space vector selection in the α-β frame[16]. The proposed technique was separated in to two tasks i.e.) not dependent and executed in cascade.

FIRST ONE:

It controls the electromagnetic state of induction motor. For the space Vector Selection in the α-β frame torque and flux values and their variations will be considered. If the space is chosen phase level sequence can be selected. To perform this tasks space vector position can be detected in the α-β frame (Qk at sampling time k). Next position Qk+1 to be accomplishedprior to the next sampling instant k+1 (see in fig 8) and it will be Chosen to diminish the voltage steps magnitude. For each sampling period single step displacement is allowed in α-β frame. In the absence of inverter saturation Qk+1 it must be selected within the six corners of the hexagonal centred at Qk. The same procedure will be repeated to determine the next period i.e.) Qk+2Trajectory correction is necessary (see in fig 8) in the inverter saturation. In cases 2& 3 closest displacement direction is selected. No switching should takes place since the nearest reachable trajectory goes roughly toward the opposite sense of the favoured one given by the lookup table (see table II).

SECOND ONE:

Multi level topology chooses the phase levels that produce the voltage vector selected earlier. There are many phase levels sequences that generate thesimilar voltage vector. The voltage steps magnitude can be reduced in accordance with 1) the commutation number per period can be minimized. 2) The commutations will be distributed for three phases per period. 3) By selecting the vector which minimizes the homo polar voltage. This one will reduce the losses and torque ripples. The phase levels will be generated by selecting the configuration of each phase.

IV.SIMULATION RESULTS:

For the validation of earlier discussion control approach simulations has been carried out. Fig 9-18 shows simulation results for five and seven level H bridge multi level inverter.

The motor ratings are given in the appendix. The output voltage waveforms for seven level multi level inverter can be appreciated. The motor currents can be stated the presentation of the drive, and it will be completely sinusoidal ,since the low pass nature of the load has filtered the high frequency substance of the applied voltage. The stator flux with steady amplitude forced by the flux controller authenticates the good dynamic characteristics of the drive. The most important thing is torque ripple has been eliminated in the five level classic DTC.

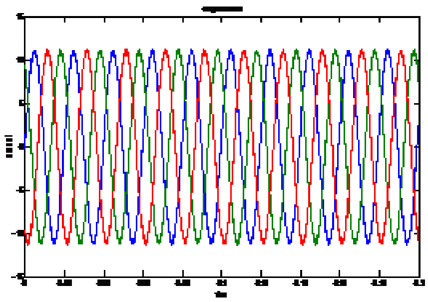

Fig.8 Five levels cascaded H-Bridge inverter output current waveform

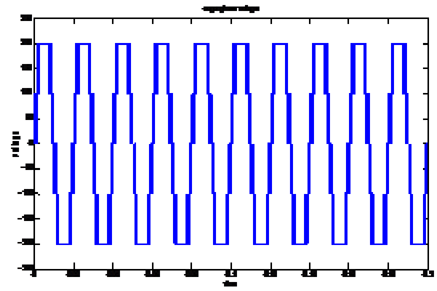

Fig.9 Five levels cascaded H-Bridge inverter output phase voltage waveform

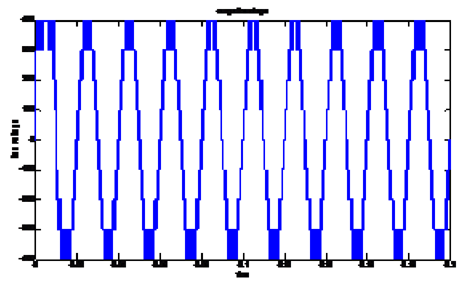

Fig.10 Five levels cascaded H-Bridge inverter output line voltage waveform

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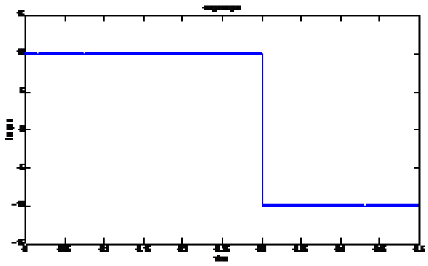

Fig.11 Five levels cascaded H-Bridge inverter estimated torque waveform

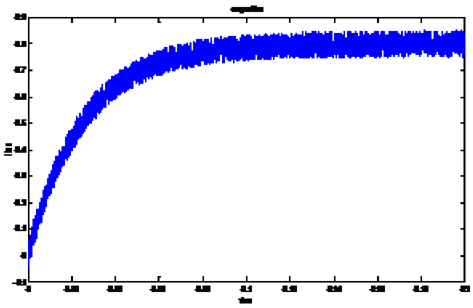

Fig.12 Five levels cascaded H-Bridge inverter stator flux waveform

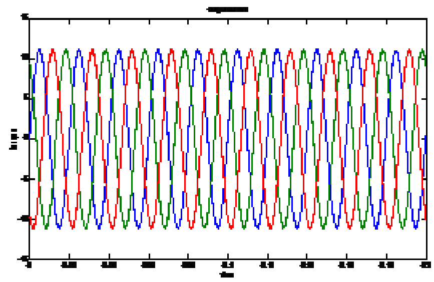

Fig.13 Seven levels cascaded H-Bridge inverter output current waveform

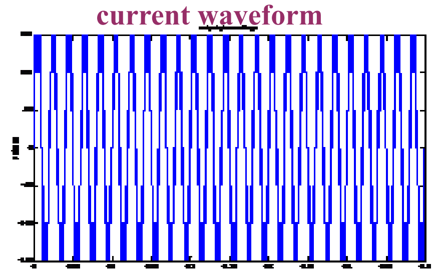

Fig.14 Seven levels cascaded H-Bridge inverter phase voltage waveform

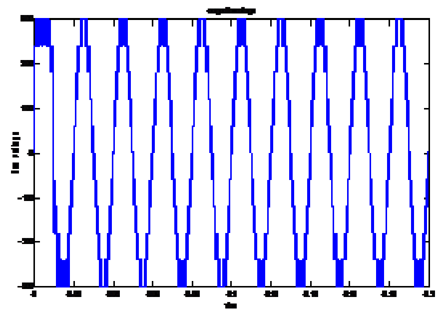

Fig.15 Seven levels cascaded H-Bridge inverter line voltage waveform

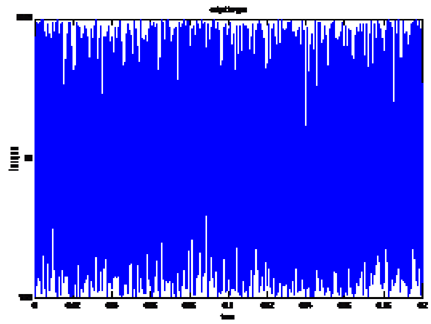

Fig.16 Seven levels cascaded H-Bridge inverter estimated torque waveform

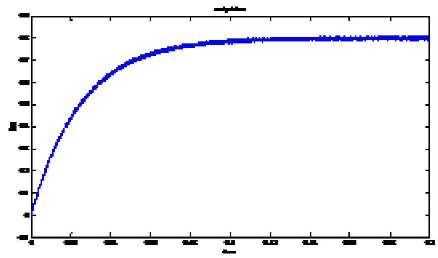

Fig.17 Seven levels cascaded H-Bridge inverter stator flux waveform

V. CONCLUSION:

This paper deals with the study of symmetrical and asymmetrical pattern of cascade H-Bridge inverter. Here five level and seven level H-Bridge inverters are evaluatedwith the intention that the optimum arrangement with lower switching losses and optimised output voltage superiority. Simulation results shows that asymmetrical configuration presents nearly sinusoidal voltages with a reduced distortion with very less switches and torque ripples are enormously reduced. Asymmetrical inverter enables DTC solution for high power induction motor drives for reducing the switching losses and improving the output voltage eminence and improving the sinusoidal currents without output filter.

APPENDIX:

Rated data of the simulated and tested induction motor 1kw, 50 Hz, 400/230 v, 3.4/5.9 A, 1420 rpm Rs=4.67ohm, Rr=8 ohm ,Ls=Lr =0.347 H, m=0.366 H j=0.06 kg m2 ,β=0.042Nm-sec

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