

Open-end Winding Induction Motor Drive Using Decoupled Algorithm

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Abstract

In now a days modern multi level inverters have emerged to overcome the drawbacks due to the conventional inverters. In various industries inverters with different PWM techniques have been employed to achieve good performance in the context of variable speed drives. But due to multilevel inverters the switching losses are more and the cost of the equipment is also more because of the number of devices is increased in multilevel inverters. These are some drawbacks due to the usage of conventional multilevel inverters in industries. In this proposed work a decoupled algorithm is proposed to overcome the drawbacks due to conventional inverter have been presented. The cascaded connection of asynchronous motor and two 2-level inverters at both ends of motor constitutes to open end winding induction motor drive. The characteristics of dual inverter fed open end winding induction motor drive resembles to those of conventional three level inverter. In this proposed work the performance characteristics of Induction motor with different PWM techniques like CSVPWM, DPWMMAX, DPWMMIN have been analysed using MATLAB/SIMULINK environment and to validate the results the harmonic spectra values has been listed out.

Keywords: Bearing currents; CSVPWM; Decoupled algorithm; Open end winding induction motor drive; Modulation index

Introduction

Conventional two level inverters are extensively used in medium voltage and high power variable speed drive systems because of their inherent switching operation but however have some limitations in operating at high frequency mainly due to switching losses and constraints of device rating. These switching converters can also provokes high dv/dt caused due to the switching transients [1-2]. These zero sequence voltages results into various adverse effects on motors named as bearing currents, conducted electromagnetic interference, ground currents through stray capacitors. In consequence to this premature motor bearing failures will occur [3]. The clear indication of flowing of hazardous bearing currents in the context of motors inside the motors can be shown in the Figure 1.

So concerning to this the hazardous common mode voltages in the context of variable speed motors has to be mitigated [4,10].

The numerous methods for mitigating common mode voltage in inverters can be classified as [4]:

- a. Using isolation transformers, Common mode choke, using hybrid active and passive filters, Using dual inverter fed open end winding induction motor drive, Using four phase inverter.
- b. Using some advanced modulation techniques like carrier based SVPWM scheme for dual inverter fed open end winding IM drive.

The methods proposed in [a] above increases the system cost as it employs some extra hardware circuitary and complexity in control. So this is mainly focused on the implementation of SVPWM technique for dual inverter fed open end winding induction motor. A schematic of dual inverter fed open end winding induction motor can be represented as shown in the Figure 2.

As dual inverter fed open end winding induction motor drive resembles the performance of three level inverter thus we can achieve multilevel inverter operation using this configuration. Hence the harmonic content of the output voltage waveform decreases significantly, dv/dt stresses are reduced, produces smaller zero sequence voltages therefore stress in the bearings of motor can be reduced, Provides low switching losses and higher efficiency [5-8].

Multi Level Inverter Operation with Open End Winding Induction Motor

A remedy for the production of flowing of bearing currents inside the motors is open end winding induction motor. In this configuration Induction motor is faded by two inverters from either side which are operated be isolated power supplies. A schematic diagram of dual inverter fed induction motor is represented as shown in Figure 3.

Here S₁, S₂, S₃, S₄, S₅, S₆ are the switches of inverter 1 and S₁', S₂', S₃', S₄', S₅', S₆' are the switches of inverter 2. The two inverters are supplied with isolated DC links, If the isolated DC link voltages are equal (i.e., $Vs_1=V_{DC}/2$ and $Vs_2=V_{DC}/2$) then the configuration resembles to that of three level inverter drive. If the Isolated DC link voltages are unequal (i.e., $Vs_1=2V_{DC}/3$ and $Vs_2=V_{DC}/3$) then the configuration resembles to that of four level inverter. In this 1 and 0 represents on states of switches of inverter 1, 1' and 0' represents on states of switches of inverter 2. For the three level inverter the levels of voltage in the output voltage are $+V_{dc}/2$, $0, -V_{dc}/2$. For the four level inverter the levels of $-V_{dc}/2$ (Figure 4).

Here first space vector corresponds to Inverter-1 and the reference vector is switched in sector-1 between first two active vectors V₁ and V₂, at an angle α w.r.t first active vector V₁. And the second space vector corresponds to Inverter-2 and the reference vector is switched in sector-4 between V₄ and V₅ at an angle α i.e., 180°+ α w.r.t V₁, the reference vector of first space vector and reference vector of second space vector are 180° apart. But the supply voltages for the two inverters are same i.e., V₄/2 for dual inverter (three level operation).

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Here V_{A0} , V_{B0} , V_{C0} are the pole voltages of inverter 1, V_{A0} , V_{B0} , V_{C0} are the pole voltages of inverter 2. V_{AA} , V_{BB} , V_{CC} are the Phase voltages of the inverter which are supplied to the three phase induction motor but here the sum of all these phase voltages is not equal to zero, which results as zero sequence component in motor due this the bearing currents will flow inside the motor. But here carrier based SVPWM algorithm is proposed to mitigate this Common mode voltage. The three phase voltages of dual inverter fed induction motor drive is given by

$$V_{AA} = V_{A0} - V_{A0},$$

$$V_{BB} = V_{B0} - V_{B0},$$

$$V_{CC} = V_{C0} - V_{C0},$$
(1)

Where V_{A0} , V_{B0} , V_{C0} are the pole voltages of inverter 1,

 V_{A0} , V_{B0} , V_{C0} are the pole voltages of inverter 2

and V_{AA} , V_{BB} , V_{CC} are the Phase voltages of the inverter

The common mode voltage or Zero sequence voltage is given by

$$CMV \text{ or } V_{ZS} = \frac{V_{AA}' + V_{BB}' + V_{CC}'}{2}$$
(2)

The reference voltage in SVPWM modulation technique will be obtained as represented in equation

$$V_{ref} = V_{AA} + V_{BB} e^{j2\pi/3} + V_{CC} e^{j4\pi/3}$$
(3)

Hence by employing this open end winding configuration multilevel inverter operation can be achieved and the problems due to conventional inverters like common mode voltages can be overcome.

Decoupled PWM technique

The procedure described in [6] uses the instantaneous reference voltages and is based on the concept of 'effective Time'. The effective time is expressed as the time "For which the motor is supplied by the inverter voltage and is designated as Teff. The sampling time period is designated as Ts. The instantaneous phase reference voltages are acquired by projecting the tip of the reference vector Vsr on to the corresponding phase axes and these projections have to be multiplied with a factor of (2/3). The factor (2/3) is multiplied to the projections because of the 'Two to Three phase' transformation. These instantaneous phase reference voltages are indicated as Va*, Vb* and Vc*. The symbols Tga, Tgb and Tgc respectively signifies the time spell for which a given motor phase is connected to the positive rail of the input DC power supply of the inverter in the given sampling time period Ts. The timings Tga, Tgb and Tgc are labelled as the phase switching times. The procedure to generate the gating pulses for the individual devices using this algorithm is elaborately explained in [10].

For a dual inverter system, there would be two sets of phase switching times, one for each inverter. The phase switching

timings of inverter-1 are represented by the symbols Tga, Tgb and Tgc. while the symbols T'ga, T'gb and T'gc denote the same for inverter-2.

There are two distinct PWM strategies:

- (1) Decoupled PWM strategy
- (2) The alternative inverter switching strategy.

For achieving three level inverter operation with dual inverter configuration the space vector corresponds to the inverter-2 is overlaid

Page 2 of 9

on the space vector of inverter 1. After superimposing space vector of inverter-2 on space vector of inverter-1 there exists a centre hexagon (ABCDEF) with a centre named as O, covered by six sub hexagons signified as OBHGSF, OCJIHA, ODLKJB, OENMLC, OFQPND and OASRQE having centres at A, B, C, D, E, F respectively as shown in the Figure 5.

This Decoupled PWM strategy mainly focusses on the concept that the reference voltage space vector Vsr can be formulated with two opposite components Vsr/2 and -Vsr/2. Subtraction of the second component from the first component achieves the anticipated reconstruction of the reference vector. In other words, it is based on the observation that the effect of applying a vector with inverter-1 while inverter-2 assumes a null state is twice as that of applying the opposite vector with inverter-2 while inverter-1 assumes a null state [11,12]. The decoupled PWM strategy is as shown in the Figures 5 and 6.

It is worth noting that the phase axes of the motor viewed with reference to individual inverters are in phase opposition. In Figure 5 and 6, the vector OT signifies the actual reference voltage space vector, and it has to be synthesized from the dual-inverter system and is specified by $|Vsr| \angle \alpha$. This vector is resolved into two opposite components OT1 is $(|Vsr/2| \angle \alpha)$ and O'T2 is $(|Vsr/2| \angle 1800 + \alpha)$. The vector OT1 is synthesized by inverter-1 by switching among the states (8 1 2 7) while the vector O'T2 is reconstructed by inverter-2 by switching among the states (8' 5' 4' 7'). The advantage with the recommended decoupled control is that the inverter switching timings of both the inverters need not be computed. However, in this strategy, both the inverters have to be switched (Figure 8).

Simulation Results

For single inverter Fed IM drive with SVPWM control

A two level inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation(SVPWM) control technique with Modulation index=0.8(Under modulation) and the Modulated waveform, output pole voltage, Line voltage, phase voltages and the common mode voltage of the inverter are shown in Figure 7.

The performance characteristics of Induction motor drive i.e., Stator currents, Torque response, Speed response at no load are as shown in Figure 7. The motor achieves steady state at 0.3 sec. The Total Harmonic Distortion (THD) for the stator currents is 7.26% for this model.

For dual inverter Fed IM drive (three level inverter operation) with CSVPWM, DPWMMAX, DPWMMIN control

A dual inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation (CSVPWM) control technique and the Modulated waveform, output pole voltage, Line voltage, phase voltage and the common mode voltage of the inverter which resembles the characteristics of three level inverter characteristics are shown in Figure 9.

The performance characteristics of Induction motor drive i.e., Stator currents, Torque response, Speed response at no load are as shown in Figure 10. The motor achieves steady state at 0.25 sec. The Total Harmonic Distortion (THD) for the stator currents is 4.77% for this model and the common mode voltage is mitigated compared to single inverter fed IM drive.

A dual inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation (DPWMMAX) control technique and the Modulated waveform, output pole voltage, Line voltage, phase voltages and the common mode voltage of the inverter which resembles the characteristics of three level inverter characteristics are shown in Figure 11.

The performance characteristics of of dual inverter fed Induction motor drive(three level inverter operation)with DPWMMAX control i.e., Stator currents, Torque response, Speed response at no load is as shown in Figure 12. The motor achieves steady state at 0.25 sec and the Total Harmonic Distorsion (THD) for the stator currents is 3.97% for this model and the common mode voltage is mitigated compared to single inverter fed IM drive.

A dual inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation (DPWMMIN) control technique and the Modulated waveform, output







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Page 4 of 9







pole, Line voltage, phase voltages and the common mode voltage of the inverter which resembles the characteristics of three level inverter characteristics are shown in Figure 13.

The performance characteristics of of dual inverter fed Induction motor drive(three level inverter operation)with DPWMMIN control i.e., Stator currents, Torque response, Speed response at no load are as shown in Figure 14. The motor achieves steady state at 0.25 sec. The Total Harmonic Distortion (THD) for the stator currents is 3.85% for this model and the common mode voltage is mitigated compared to single inverter fed IM drive.

For dual inverter Fed IM drive(Four level inverter operation) with CSVPWM, DPWMMAX, DPWMMIN control

A dual inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation(CSVPWM) control technique and the Modulated waveform, output pole voltage, Line voltage, phase voltage and the common mode voltage of the inverter which resembles the characteristics of four level inverter characteristics are as shown in Figure 15. The performance characteristics of of dual inverter fed Induction motor drive(four level inverter operation)with CSVPWM control i.e., Stator currents, Torque response, Speed response at no load are as shown in Figure 16. The motor achieves steady state at 0.25 sec. The Total Harmonic Distortion (THD) for the stator currents is 4.77% for this model and the common mode voltage is mitigated compared to dual inverter fed IM drive with three level inverter operation.

A dual inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation (DPWMAX) control technique and the Modulated waveform, output pole voltage, Line voltage, phase voltage and the common mode voltage of the inverter which resembles the characteristics of four level inverter characteristics are as shown in Figure 17.

The performance characteristics of dual inverter fed Induction motor drive (four level inverter operation) with DPWMMAX control i.e., Stator currents, Torque response, Speed response at no load are as shown in Figure 18. The motor achieves steady state at 0.25 sec. The Total Harmonic Distorsion (THD) for the stator currents is 3.85% for





Figure 13: Modulating Wave, Pole voltage, Phase Voltage, common mode voltage for dual inverter (Three level inverter operations) with DPWMMIN control technique.



J Electr Electron Syst ISSN: 2332-0796 JEES an open access journal Page 6 of 9





Figure 15: Modulated wave, Pole voltage, Line voltage, Phase voltage, Common mode voltage for dual inverter (Four level inverter operation with CSVPWM control).





this model and the common mode voltage is mitigated compared to dual inverter fed IM drive with three level inverter operation.

A dual inverter fed induction motor drive is modelled and is simulated by employing space vector pulse width modulation(DPWMMIN) control technique and the Modulated waveform, output pole voltage, Line voltage, phase voltages and the common mode voltage of the inverter which resembles the characteristics of four level inverter characteristics are as shown in Figure 19.

The performance characteristics of of dual inverter fed Induction motor drive(four level inverter operation)with DPWMMIN control i.e., Stator currents, Torque response, Speed response at no load are as shown in Figure 20. The motor achieves steady state at 0.25 sec. The Total Harmonic Distortion (THD) for the stator currents is 3.43% for this model and the common mode voltage is mitigated compared to dual inverter fed IM drive with three level inverter operation.

THD Comparison

The THDs for stator currents of IM drive is listed out as shown in the Table 1.

Conclusion

In this paper the implementation of dual inverter fed induction motor drive has been done. With the implementation of triangular based SVPWM the machine performance will be improved in the context of harmonic spectra and effective DC bus utilization over the conventional sinusoidal pulse width modulation technique. And the zero sequence voltage problems is also mitigated at a greater level compared to other mitigating techniques. This work can be





Figure 19: Modulated wave, Pole voltage, Line voltage Phase voltage, Common mode voltage for dual inverter (Four level inverter operation with DPWMMIN control).



Figure 20: Performance characteristics of dual inverter (Four level inverter operation (DPWMIN control)) fed IM drive at steady state.

Invert-er Type	Control technique	THD of stator currents of the Motor (I_{THD})	THD of inverter voltage (V _{line} THD) In under modulation(M.I=0.8) region	THD of inverter voltage (V _{line} THD) In over modulation (M.I=1.154) region
2 level	SVPWM	7.26%	77.27%	44.11%
3 level	CSVPWM	4.77%	64.97%	22.37%
	DPWMMAX	3.97%	70.09%	24.57%
	DPWMMIN	3.85%	69.99%	23.75%
	CSVPWM	4.51%	63.65%	25.16%
4 level	DPWMMAX	3.85%	72.15%	26.99%
	DPWMMIN	3.43%	71.48%	25.55%

Table 1: Comparison of stator currents THDs for various control techniques.

extended with the implementation of SVPWM for higher level (5-7 levels) for dual inverter fed open end winding induction motor.

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Page 9 of 9