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Dual-Inverter-Fed Open-End Winding InductionMotor based Bearing Currents and Shaft Voltage Reduction

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ABSTRACT: Connection of two 2-stage inverters on the two ends of anopen end winding induction motor with equal DC-hyperlink voltages isidentical to a traditional 3-level inverter. Better fault toleranceand adaptability in controlling is received in open-finish windingdesktop configuration in comparison with a traditional threephase neutral related electric motor. Two voltage entities, particularly, fashioned-mode voltage (CMV) and differential modevoltage are identified within the twin inverter, and all hybrid PWMs are envisaged aimed toward decreasing and likewise eliminatingthe CMV in it. The consequences of such attempts on motor shaft voltage and likewise the motor bearing currents are offeredin detail. Additionally, bearing present profiles of an open-finish winding induction motor are additionally presented with bothconventional and hybrid PWMs proposed in this paper. Electrical discharge machining discharge currents arewholly eradicated with the use of all hybrid PWM ways proposed in this paper. Moreover, implications offully disposing of the CMV are also awarded on this paper.

KEYWORDS-Bearing current, common-mode voltage(CMV), differential-mode voltage (DMV), dual inverter, electric discharge machining (EDM) current.

I. INTRODUCTION

Inverter-driven ac motors have become common in variable speed applications due to increased energyconservation. The use of high-frequency PWM methods and also multilevel inverters make the output voltage ofthe inverters more sinusoidal but also generate high common-mode voltage (CMV). From the studies on PWMinverter-fed drives in the last few decades, it is found that high-frequency CMV of the inverters causes voltagedrop across the bearings and this may cause bearing currents leading to premature bearing failures [1]–[6].Owing to increased cost of maintenance and downtime, attention on protecting the motor bearings has increased[2]. Among the known solutions such as the use of brushes, insulated bearings, and electrostatic shielding, theuse of appropriate filters is reported in [7]–[10]. Also, new PWM methods are proposed for the two-levelinverters that only reduce the CMV generated by them since complete elimination is not possible [11]. Toinvestigate the impact of CMV generated by PWM inverters on bearing currents, a simplified measurementsetup is proposed in [12] that enables the measurement of motor shaft voltage and motor bearing current in aninduction motor driven from a two-level inverter. Multilevel inverters can also offer excellent solutions inreducing the CMV and the related problems.

Reducing the motor shaft voltage and bearing currents using multilevel inverters is reported. Of many multilevel inverter topologies, the dual-inverter topology employing open-end windinginduction motor drive has slowly gaining popularity ever since it was introduced as it inherits many advantagescompared to its counterparts . In literature a dual inverter fed from two isolated dc sources and also a single dcsource is presented. However, arresting circulating zero sequence currents in the motor phase windings is addressed using zero sequence chokes in single-dc-source-driven dual inverter. Later, many PWM methods arereported for the dual inverter for achieving improved performance..

The available literature on dual-inverter-fed motor drives suggests that the voltage that is responsiblefor circulating zero sequence current in it is termed as zero sequence voltages (ZSVs) by few researchers andCMV by some works, and the focus has been only to reduce and/or eliminate such voltage usingnew PWM methods that arrests the circulating current flow, thus leading to deriving the advantage of dualinverter that can be fed from a single dc power source. In literature, it is demonstrated that ZSV in the dual invertercan be forced to zero in the average sense in every sampling time interval by suitably placing the effective-timeperiods of the individual inverters.

Recently, it has been shown that the effective-time periods of the individualinverters can be independently controlled to control the ripple content in the load current .From the knowledge of motor shaft voltage which is found to be replica of the CMV output of theinverter, the equivalent voltage in the dual inverter that is responsible for motor shaft voltage is clearlyidentified, and analytical expression for the same is first presented. In literature, four new hybrid PWMs areproposed that successfully reduce the motor shaft voltage by following the reduced CMV principles reported forthe two level inverter'.

Exploiting the rich switching redundancy of the dual two level inverter, newhybrid PWM methods are proposed in this paper for the dual inverter, which are aimed at reducing and alsoeliminating the CMV output. Bearing current profiles composed of capacitive bearing currents (dv/dt) and theelectric discharge machining (EDM) discharge currents are presented for the open-end winding induction motordrive fed from dual inverter with conventional and also hybrid PWM methods proposed in this paper. Theeffects of reducing and eliminating CMV in the dual inverter on motor shaft voltage and bearing currents arealso presented in this paper. The proposed hybrid PWMs succeed in reducing the motor shaft voltage to such anextent that they manage to completely keep the EDM discharge currents away in the open-end windinginduction motor that are known to be dominant in low-power-rating motors [2]. The envisaged propositions arefirst simulated using MATLAB and are validated experimentally.

II. DUAL INVERTER FED OPEN END WINDINGINDUCTION MOTOR DRIVE

The open-end winding configuration of the induction motordrive is obtained by opening the neutral point of the statorwinding in a three phase induction motor. The Individualwindings of each phase will be kept open and the eachwinding terminals a, b, c and a', b', c' are fed with individualinverter. It is best suited for high-power applications. Thisopen-end winding induction motor (OEWIM) configurationhas a better operation compared to all other multilevel inverterconfigurations [4].

Advantages of OEWIM configuration are:

By using the conventional two-level inverter as itsbasic block multilevel inversion is achieved.

- Absence of neutral point fluctuations.
- Reduced THD value and low dv/dt (leakagecurrents) at output voltages.
- Fault tolerance capability
- Additional zero-sequence compensator circuits arenot required as zero-sequence components are notcirculated, when DC links are isolated.
- It has freedom to have two different singleinverter's combination.
- The issues of capacitor voltage unbalance areabsent
- Clamping diodes or any additional capacitor banksare not required in OEWIM configuration as inflying capacitor multilevel inverter topology.

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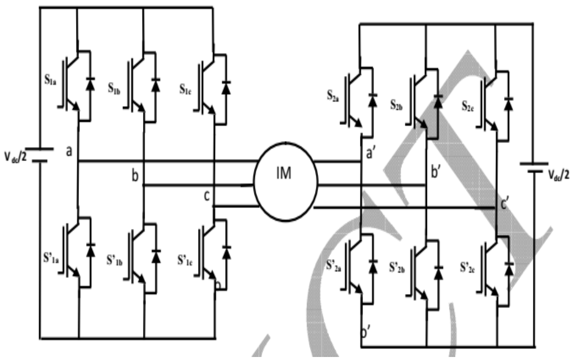

Fig 1 : Dual inverter fed open end winding induction motor drive

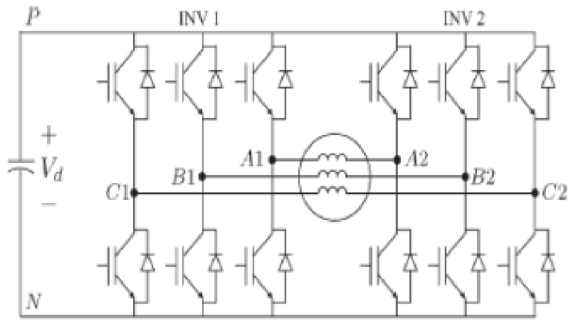

Fig.2 Dual Two-Level Inverter fed open-end windinginduction motor with single DC source

The OEWIM drive which is fed by two 2-level inverters withequal DC link voltage is shown in the Fig-1.Vao, VboandVcoare the pole voltages of inverter-1 and Va'o, Vb'o and Vc'o arethe pole voltages of inverter-2.Each two level inverter iscapable of producing two pole voltages Vdc/2 and 0independently. The effective pole voltage of the combinedinverter system is obtained by the difference of the polevoltages of the two inverters which produces three voltagevalues resulting in the three level induction motor driveconfiguration.

Open-end winding induction machine is obtained byopening the neutral point of conventional starconnected induction machine which results in sixterminals instead of three and requires two standardtwo-level inverter on either sides of the machine asshown in Fig.2. The common-mode voltages at thetwo sets of machine terminals are defined as theaverage of the pole voltages as

Vcm1 = (VA1O+VB1O+VC1O)/3
Vcm2 = (VA2O+VB2O+VC2O)/3

The combined space vector diagram of Dual-inverterfed open-end configuration is similar to a three-levelNPC inverter with 19 distinct voltage vectors out ofthe total 27 switching states. Among these 19 voltagevectors 7 of them does not contribute any CMVacross the machine phase windings as shown inFig.3.The two inverters are modulated using SVPWMstrategy such that CMV of both inverters are equaland CMV across machine windings (Vcm) is zero.

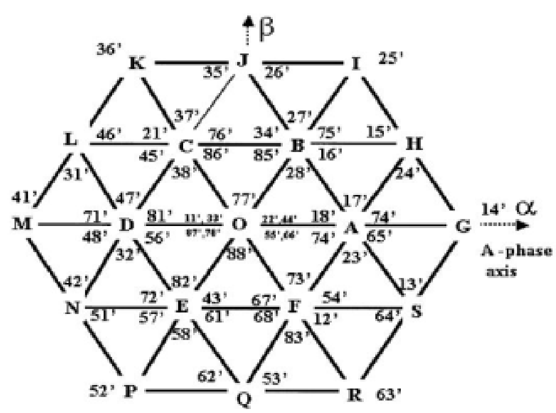

Fig.3 Combined Space vector diagram of Dual inverter

Space phasor locations S, H, J, L, N, Q and O asshown in Fig.3 do not produce any CMV across themachine phase. To eliminate switching or alternatingCMV of individual inverters, SVPWM for Dualinverter is modified in such a manner that inverter 1will switch in states 1, 3 and 5 or (2, 4 and

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6) andinverter 2 will switch through 1’, 3’ and 5’ or (2’, 4’and 6’. In the proposed work, space phasor locationswith zero CMV across machine windings as shown inTab.I are taken for CMV elimination.

Tab.I Voltage space vectors without alternatingCMV and Zero CMV across machine windings

Space Vector Locations	Space vector combination	Vcm1	Vcm2	Vcm
S	13’	Vdc/6	Vdc/6	0
H	15’	Vdc/6	Vdc/6	0
J	35’	Vdc/6	Vdc/6	0
L	31’	Vdc/6	Vdc/6	0
N	51’	Vdc/6	Vdc/6	0
Q	53’	Vdc/6	Vdc/6	0
O	11’,33’,55’	Vdc/6	Vdc/6	0

From Tab.I, it can be observed that there is noalternating or switching CMV for individual invertersas the CMV for individual inverters are always sameand equal to Vdc/6 and CMV across machinewindings is obtained by taking the difference of CMVof individual inverters.

Vcm = Vcm1 – Vcm2 = 0

To achieve the proposed PWM scheme, the voltagespace vectors OS, OH, OJ, OL, ON, OQ are chosenamong the various voltage vectors of combined spacevector diagram to obtain the space vector diagramwithout triplen contribution as shown in Fig.4.

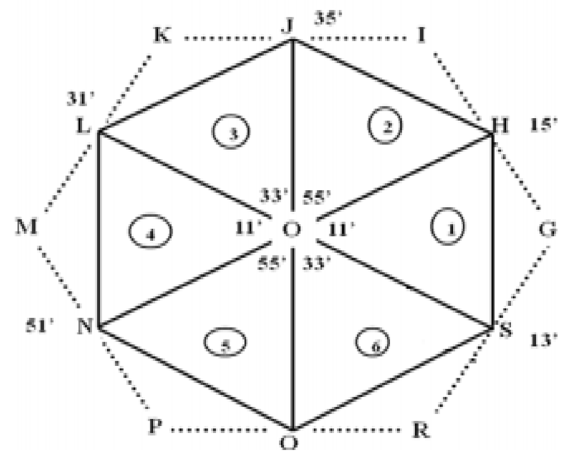

Fig.4 Space vector diagram of proposed PWM scheme

III. SIMULATION RESULTS

The experimental setup consists of a 4-kVA dual two-levelinverter fed from two isolated dc power sources, a 1.1-kW415-V 2.5-A 50-Hz 3-φ open-end winding induction motor.All hybrid PWMs proposed in this paper for the dual inverterinvolving reducing and eliminating the CMV are first simulatedusing MATLAB/Simulink and then experimentally verified tovalidate them. In order to examine the impact of the hybridPWMs proposed in this paper on the motor load, the motor shaftvoltage and also the motor bearing current are also presented.