An Extensive Review on Voltage THD Reduction for Open-End Load with Isolated DC Sources

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Abstract - The common-mode voltage generated by the power converter with respect to ground has been modelled as a switching voltage source. Apart from the issue of common-mode voltage switching, conventional drive systems utilize bulky electrolytic capacitors in the power converters. These have limited lifetime as compared to the rest of the components and add to the system size and weight, ultimately affecting cost. Presently industries acquire low-voltage high-current ac motor drives with megawatt power level utility requirements. For medium voltage grid, troublesome to connect only one power semiconductor switch directly. The number of clamping diodes required is quadratically related to the number of levels. Fundamental frequency switching will cause an increment on voltage and current THD. A brief survey of literature on THD reduction has been given in this work.

Keywords- Voltage THD Reduction, VSI, Isolated DC Sources, Dual-Inverter, Open-End Load. PWM.

I. INTRODUCTION

Electric machines are critical to modern industry. They are utilized in almost all facets of industry: from factories to power generation. Variable speed drives utilize power electronic converters to control electric machines. Combined, these systems are termed electric drive systems. In almost all industrial applications, power converters drive three phase electric machines. Power converters enable efficient and flexible operation of electric machines. These machines may be induction machines, permanent magnet machines or other derived machine architectures. Invariably, power converters utilize semiconductor switches which are operated in a pulse-width modulated (PWM) fashion to precisely control the voltages applied to the machines in a fast and efficient manner. A vast majority of PWM converters utilize the now mature two-level inverter. These inverters are composed of three phase legs, each with two semiconductor switches. These are usually Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) or Insulated Gate Bipolar Transistors (IGBTs). High power topologies utilize different topologies such as the three-level inverter, cycloconverter or current-source inverter. Modern semiconductor switches offer extremely fast switching with switching times as low as hundreds of nanoseconds. Fast semiconductors have enabled precise control of electric machines which in turn has enabled their use in sophisticated applications examples of which include robotics, wind power generation and electric vehicles.

The quality of the power is affected if there is any deviation in the voltage and frequency values at which the power is being supplied. This affects the performance and life time of the end user equipment. Whereas, the continuity of the power supplied is affected by the faults which occur in the power system. So to maintain the continuity of the power being supplied, the faults should be cleared at a faster rate and for this the power system switchgear should be designed to operate without any time lag.

The power quality is affected many problems which occur in transmission system and distribution system. Some of them are like- harmonics, transients, sudden switching operations, voltage fluctuations, frequency variations etc. These problems are also responsible in deteriorating the consumer appliances. In order to enhance the behavior of the power system, these all problems should be eliminated.

Now-a-days with the advancement in technology there is a drastic improvement in the semi-conductor devices. With this development and advantages, the semi-conductor devices got a permanent place in the power sector helping to ease the control of overall system. Moreover, most of the loads are also semi-conductor based equipment. But the semi-conductor devices are non-linear in nature and draws non-linear current from the source. And also the semi-conductor devices are involved in power conversion, which is either AC to DC or from DC to AC. This power conversion contains lot of switching operations which may introduce discontinuity in the current. Due to this discontinuity and non-linearity, harmonics are present which affect the power quality delivered to the end user. In order to maintain the power quality delivered, the harmonics should be filtered out. Thus, a device named Filter is used which serves this purpose.

Harmonic distortion: when non-linear loads are connected to the electrical grid, the current that flows through the lines contains harmonics, and the resulting voltage drops

caused by the harmonics on the lines impedances causes distortion on the feeding voltages.

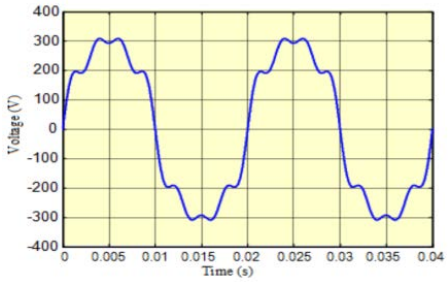


Figure 1.1 Harmonic distortions.

Increasing phase becomes more predominant factor to have additional degree of freedom. On another hand multilevel inverter widely replaces the conventional two-level three-phase voltage source inverter (VSI) by their performance toward lower THD and lower dv/dt (leakage current) stresses in output. Combing multiphase motor with multilevel inverter technologies could be good solution for low-voltage high-current application more suitable for industries. Several power conversion structures addressing towards multiphase-multilevel ac motors are proposed last decades for its reliability and performance.

II. MODULATION STRATEGIES FOR OPEN-END WINDING

Pulse-width modulated (PWM) inverters are widely used in variable frequency drives. However, conventional PWM inverters cause switching common-mode voltages at the terminals of ac machines. These switching common-mode voltages are known to cause undesirable bearing currents which may damage the machine bearings. EMI issues also arise due to these common-mode voltages. Methods have been proposed in literature which addresses this problem. Extra hardware or special modulation strategies are employed to reduce common-mode voltages.

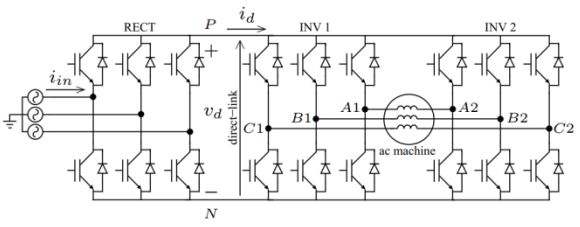
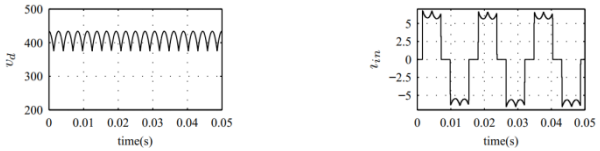


Figure 2.1 Direct- link drives for open-end winding ac machines.

The circuit configuration of the direct-link drive is shown in Fig. 2.1. The front-end rectifier is denoted by ‘RECT’. Its operation is similar to that of a three-phase diode bridge rectifier. Switches (e.g. IGBT’s) with bidirectional current carrying capability are used instead of diodes to allow operation in the generating mode. The top-switch of a phase leg is turned ON when the corresponding phase voltage is maximum. Similarly, the bottom switch is turned ON when the corresponding phase voltage is minimum. The direct-link voltage (vd in Fig. 2.1) is a three-phase line-rectified voltage. This is shown in Fig. 2.2. Also, the input current of the direct-link drive (iin) is a 120◦-conduction waveform with unity displacement power factor. The input power factor of the drive is uncontrollable and the input current has considerable total harmonic distortion (THD ≈ 30%).

The two inverters, shown as ‘INV1’ and ‘INV2’ in Fig. 2.1, are modulated in synchronism to generate three-phase sinusoidal voltages across the machine phase windings.



(a) (b)

Figure 2.2 (a) Direct- link voltage for direct- link drive (b) Input current for direct- link.

III. LITERATURE SURVEY

A. D. Kiadehi, K. E. K. Drissi and C. Pasquier, [1] In this work, the near-state pulse width modulation (NSPWM), adapted to be used in dual-voltage source inverter (VSI) fed open-end load, is introduced primarily aiming to appreciably minimize the voltage total harmonic distortion (THD). Within the framework of the proposed method, the active time of pulses at the second inverter is relatively adjusted within switching interval (compared to the first VSI). The phase voltage harmonics are formulated for dual-inverter modulated by NSPWM; then, optimal adjustment is identified via a three-dimensional curve of phase voltage THD versus modulation index (MI) and phase angle displacement (PAD). Due to the limitation of MI in NSPWM, the desired output voltage is synthesized with modifying not only MI but also PAD between references of two VSIs. Furthermore, NSPWM inherently takes advantage of better efficiency compared to conventional space vector modulation due to switching only two phases within an interval (by clamping one phase to positive/negative dc-rail). The dual-VSI supplied by two isolated dc sources is assembled in the laboratory to experimentally evaluate the THD reduction feature of the proposed method; also, the simulation results obtained by means of a MATLAB/Simulink environment show close agreement with experimental data.

A. D. Kiadehi, K. El Khamlichi Drissi and C. Pasquier, [2] In this exploration, the near-state pulsewidth modulation (NSPWM), adapted to be implemented in dual-voltage-source inverter (VSI) fed open-end motor, is proposed with

the aim of mitigating low-order harmonics (which lead to current total harmonic distortion (THD) minimization). The following two proposed methods are studied in detail: 1) fixing phase angle displacement (PAD) between two VSIs to 120° while adjusting the modulation index (MI); and 2) fixing MI to the predetermined value (wherein low-order harmonics are highly mitigated) while adjusting PAD. Furthermore, the proposed approaches enhance efficiency by limiting the number of commutations within the switching interval. The investigation also presents the mathematical approaches to accurately determine low-order harmonic components and switching losses for dual-VSI structure. The experimental setup, including dual-VSI and open-end induction motor, is assembled in the laboratory to evaluate performance of the proposed method. Finally, the simulation results, carried out in the MATLAB/Simulink environment, are found to be in close agreement with experimental data.

Table 1: Summary of Literature Survey

SR. NO.	TITLE	AUTHORS	YEAR	APPROACH
1	Voltage THD Reduction for Dual-Inverter Fed Open-End Load With Isolated DC Sources	A. D. Kiadehi, K. E. K. Drissi and C. Pasquier,	2017	The near-state pulse width modulation (NSPWM), adapted to be used in dual-voltage source inverter (VSI) fed open-end load,
2	Adapted NSPWM for Single DC-Link Dual-Inverter Fed Open-End Motor With Negligible Low-Order Harmonics and Efficiency Enhancement	A. D. Kiadehi, K. El Khamlichi Drissi and C. Pasquier,	2016	the near-state pulsewidth modulation (NSPWM), adapted to be implemented in dual-voltage-source inverter (VSI)
3	Angular Modulation of Dual-Inverter Fed Open-End Motor for Electrical Vehicle Applications	A. Dehghani kiadehi, K. El Khamlichi Drissi and C. Pasquier,	2016	angular modulation index (AMI) implemented through a modified space vector modulation for the dual voltage source inverters (VSI)
4	An Open-End Winding Four-Level Five-Phase Drive,	M. Darijevic, M. Jones and E. Levi,	2016	A four-level five-phase open-end winding (OeW) drive topology is introduced
5	Hybrid Modulation of Dual Inverter for Open-End Permanent Magnet Synchronous Motor,	Y. Lee and J. I. Ha,	2015	analyzes the dual inverter driven open-end permanent magnet synchronous motor (PMSM) system
6	Charging Method for the Secondary Battery in Dual-Inverter Drive Systems for Electric Vehicles	J. Hong, H. Lee and K. Nam,	2015	The inverter voltage margin remaining after motor torque production determines the charging capacity
7	A Near-State Three-Dimensional Space Vector Modulation for a Three-Phase Four-Leg Voltage Source Inverter,	M. Zhang, D. J. Atkinson, B. Ji, M. Armstrong and M. Ma,	2014	A near-state three-dimensional space-vector modulation (NS 3-D SVM) switching scheme
8	Discontinuous Decoupled PWMs for Reduced Current Ripple in a Dual Two-Level Inverter Fed Open-End Winding Induction Motor Drive	K. R. Sekhar and S. Srinivas,	2013	presents investigations on current ripple in a dual 2-level inverter feeding an open-end winding induction motor drive

A. Dehghani kiadehi, K. El Khamlichi Drissi and C. Pasquier, [3] In this research work, angular modulation index (AMI) implemented through a modified space vector modulation for the dual voltage source inverters (VSI) is proposed with the primarily aiming to reduce switching losses. The desired voltage across the load is synthesized by applying appropriate phase-angle displacement between space vector references. The proposed approach avoids the use of a dc/dc boost converter (which imposes loss and weight/price penalty to duplicate the dc-link voltage) and results to be particularly suitable for electrical/hybrid vehicle applications. Namely, the application of saving energy to keep driving has been identified as major concern. Hence, this work focuses on the strategy to enhance efficiency. The principles of the proposed controlling method and switching loss, which is reduced at

least by 50%, are theoretically evaluated. This work proposes a pioneering mathematical approach to correctly determine total harmonic distortion (THD) value of the voltage/current for the dual-VSI structure. Furthermore, simulation and experimental results prove that the proposed method insures benefits in terms of common-mode voltage, THD of the voltage, and switching loss reduction. The dual-VSI prototype supplying 1.5-kW induction motor is assembled in the laboratory to experimentally evaluate performance of the proposed method. Also, the simulation results carried out through MATLAB/Simulink environment are given to confirm performance of this easy-to-implement and high-efficient method.

M. Darijevic, M. Jones and E. Levi, [4] A four-level five-phase open-end winding (OeW) drive topology is introduced in this exploration. The drive comprises a five-phase induction machine with open-end stator windings, supplied using two two-level voltage-source inverters with isolated and unequal dc-link voltages, in the ratio 2 : 1. The topology offers the advantages of a modular structure with fewer semiconductor components and has a greater potential for fault tolerance, as compared with an equivalent single-sided four-level drive. Due to the large number of switching states, development of a suitable space vector pulsewidth-modulation (PWM) method can be challenging. Hence, this work examines the implementation of two-level-shifted carrier-based PWM methods. The effect of dead time on the drive performance is discussed, and it is shown that simultaneous PWM switching of both inverters can lead to degraded output phase voltage waveforms. Detailed analysis of this phenomenon is presented, a solution is proposed, and the modified modulation techniques are incorporated in an experimental setup, at first in conjunction with V/f control. Once the proof of concept has been provided, full field-oriented control is implemented in this OeW drive topology for the first time; detailed experimental testing is conducted, and results are reported.

Y. Lee and J. I. Ha, [5] This work analyzes the dual inverter driven open-end permanent magnet synchronous motor (PMSM) system and proposes control method which can generate maximum output power in overall speed range for integrated starter/alternator. Dual inverter driven open-end machine system consists of two inverters which are connected to the both ends of the machine winding. By disconnecting one inverter from the power source, the dc-link voltage of flying capacitor can be boosted through the machine. Because one inverter is connected to the only power source, output power of the machine is regulated by the source connected inverter. In this inverstigation, modulation method for maximizing output power of inverter and motor with reduced harmonic and loss is proposed. It is a hybrid modulation combining six-step and pulse width modulations. With proposed method, efficiency and operation area are improved and cost of entire driving system is also decreased due to the removing of dc-dc converter. Analyses, strategies, control method, and simulation results are descripted. The experiments with PMSM are accomplished to verify the feasibility of proposed method.

J. Hong, H. Lee and K. Nam,[6] A dual-inverter with an open-end winding motor configuration is an attractive method to supply a higher voltage to a motor for electric vehicle (EV) applications. A topology utilizing two isolated dc sources is considered to reap the advantages of reliability and high voltage. Although this design may require two battery chargers, in this study, the use of only one charger to a main battery was considered. The central issue is to charge the secondary battery from the main battery via the motor, whether it is at a standstill or running. The inverter voltage margin remaining after motor torque production determines the charging capacity. The unity-power-factor operation is shown to be useful to maximize the charging power. Simulations and experiments are presented that show the validity of the proposed scheme.

M. Zhang, D. J. Atkinson, B. Ji, M. Armstrong and M. Ma, [7] A near-state three-dimensional space-vector modulation (NS 3-D SVM) switching scheme, which aims to reduce the common-mode noise in a three-phase four-leg voltage source inverter, is proposed. The impact of common-mode noise, which is related to electromagnetic interference issues for a high-voltage level four-leg system, is investigated first. Identification of the section in a 3-D space, selection of the near-state switching vectors, and sequence of the selected switching vectors are then introduced in steps to describe the proposed switching scheme. The proposed switching scheme is based on classical 3-D SVM, producing higher dc-link utilization, less harmonic content, and reduced switching loss compared to sinusoidal PWM. Theory, simulation, and experimental results show that the near-state 3-D SVM can work under both balanced and unbalanced load conditions.

K. R. Sekhar and S. Srinivas, [8] This work presents investigations on current ripple in a dual 2-level inverter feeding an open-end winding induction motor drive. Pulsewidth modulations (PWMs) for the independently controlled inverters are implemented using a simple effective time placement affected by offset-time concept, thus, eliminating the use of sector identification and lookup tables. Analytical expressions for ripple content in the motor phase current are developed and a current trajectory is theoretically obtained directly from the switching states of the dual inverter in a stationary

reference frame. In addition, this work also describes a current ripple trajectory in the motor by exploring the freedom of independently operating the individual inverters with different PWMs. Based on the analysis, discontinuous PWMs are employed for the individually inverters that not only offer the advantage of reducing the total switching commutations in the inverters but also reduces the current ripple. Analytical expression for the RMS ripple current and variation in RMS ripple current in one cycle of operation for different PWMs are also presented for the entire speed range of the dual-inverter drive. The performance of the dual-inverter drive with the proposed PWM variants is first studied analytically and then verified by performing suitable experiments on a 1-kW open-end winding induction motor drive.

IV. PROBLEM STATEMENT

The quality of electric power delivered is characterized by two factors namely- “continuity” of supply and the “quality” of voltage. The idea of controlling and establishing the touchy supplies in a manner that is suitable for the operation of the gear. There are many reasons by which the power quality is affected. The occurrence of such problems in the power system network is almost indispensable. Therefore, to maintain the quality of power care must be taken that suitable devices are kept in operation to prevent the consequences of these problems. Harmonic production is an inherent property of any power electronic converter. The traditional approach of harmonic reduction is by means of passive filters. The design data and the ratings of passive filters are dependent on the harmonic frequency and impedances of a particular utility system. As a consequence, the passive filters do not prepare themselves to an evaluation and therefore are not very useful. Performance evaluation of a VSI from previous research work consists of analysis based on total harmonic diction (THD), crest factor, conduction switching loss.

I. CONCLUSION

In this work presented an extensive survey on performance of voltage THD reduction for dual-inverter fed open-end load. Power generated from renewable resources is either connected to the grid or to the local loads through inverters. A voltage source inverter can guarantee a balanced output even when the load is unbalanced and nonlinear. A VSI therefore is mostly seen in applications such as standalone power generation system or a three-phase UPS system. Analysis based on different switching schemes has been carried out and comparison has been made for a variable speed drive system. Open-end winding drive configurations offer certain advantages in terms of increased voltage capability and common-mode voltage and current suppression. By selectively switching voltage vectors across machine terminals, common-mode voltage can be reduced as compared to conventional two-level or three-level drive systems

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