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Different Control Strategies Adopted by Dual Inverter Fed Open End Winding Induction Motor Drive

Kavya Venugopalan, Jegathesan V

Abstract**:** ***An open end winding induction motor (OEWIM) drive fed by dual inverter is now being studied for high power application. It is simple in design, operation and it does not have any capacitor balancing issues. A dual inverter circuit can either have an isolated dc sources or a single dc source. Different PWM methods are used to control dual inverter fed OEWIM drive. A review of different control strategies applied for dual inverter fed OEWIM drives are given in this paper.***

Keywords **:** ***Asymmetrical dual inverter, Common mode voltage (CMV), Discontinuous decoupled PWM, Space vector pulse width modulation(SVPWM), Modulation Index (MI).***

I. INTRODUCTION

A device which converts direct current DC into an alternating current AC is called an inverter. There are different types of inverters which vary in price, power, efficiency and purpose. Two level inverter fed induction motor drive with vector control strategies have output voltage with poor quality and high common mode voltage and it can be only used for low power applications. Various multilevel inverter configuration like H Bridge, diode clamped, capacitor clamped multilevel inverters and dual inverter configuration provide output voltage of good quality and low common mode voltage [1]. The advantages of multilevel inverter over pulse width modulated inverters are (1) Lower dV /dT per switching at higher operating voltages (2) Lower EMI (3) higher efficiency. Hence they can be used for high power applications like utility supply and large motor drives [2]. In multilevel inverters when the number of level increases, power circuit complexity increases which increases the system cost. Another topology called OEWIM are now under study for high power applications. At each end of the star or delta connected load, two power inverters are connected to form the dual inverter topology. These two inverters can either be supplied by isolated DC sources or by a single DC source. Open ended load connection has the following advantage over star or delta connections [3].

1. Both sides of the load are given equal power input, so each inverter have a load power rating of half the rated value.
2. Both the loads can be controlled independently.
3. Based on the modulation methods the switching frequency can be increased upto two times.
4. A reduced CMV.
5. Multiphase loads can be used if a reduction in current is required.

The OEWIM drive fed by a dual inverter have advantages like simple design and operation and free from capacitor balancing issue.

Dual inverter circuits are categorized into symmetrical and asymmetrical dual inverter based on how the input DC voltage to the inverter is applied. Assymmetrical and symmetrical dual inverter fed OEWIM drives are shown in Fig1 and Fig 2 [4].

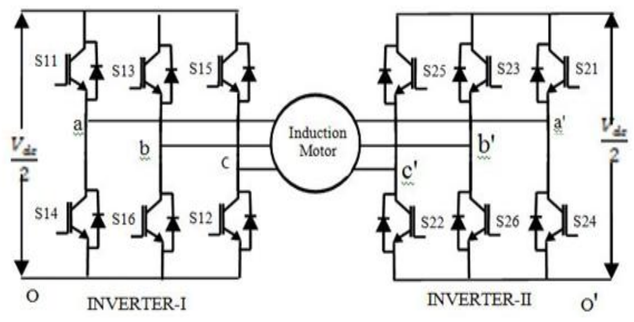

Fig.1 Symmetrical dual inverter fed OEWIM drive configuration

In symmetrical configuration the DC input voltage is Vdc/2, Vdc/2 at both ends. In asymmetric topology input voltage of 2Vdc/3 is applied to inverter 1 and Vdc/3 it is applied to inverter 2. For control of dual inverter which feeds OEWIM drive different PWM methods are used. These methods are categorized into scalar carrier and space vector approach. In space vector based PWM the voltage vectors can be selected without any restriction [5].

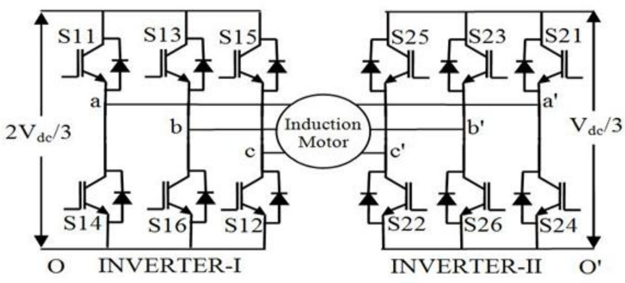

Fig.2 Asymmetrical dual inverter fed OEWIM drive configuration.

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* Correspondence Author
Kavya venugopalan,Electrical and Electronics, Karunya University, Coimbatore, India.
Dr Jegathesan V, *,Electrical and Electronics, Karunya University, Coimbatore, India.

II. SPACE VECTOR BASED PWM CONTROL

A. Control of Symmetrical dual inverter

Using SVPWM technique PWM pulses for the dual inverters are produced. Many papers has been published based on the different PWM signals generated, harmonic elimination, common mode voltage reduction etc.

In the paper [6] by shivakumar et.al a 2 level inverter with three phase OEWIM is considered. Such a combination causes formation of in 64 switching state vectors which is used for generating PWM signals with a lesser switching frequency. In this method during a switching transition all the 64 space phasor combinations are available for controlling the entire speed range using PWM control and only one inverter is switched. Fig.3 shows the power circuit used for this method and Fig.4 shows the phasor locations of the two inverters.

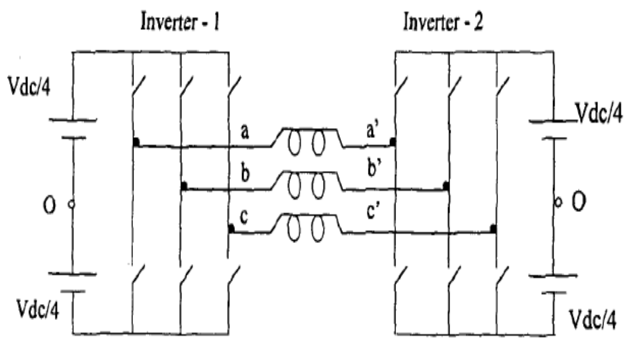


Fig.3 3 phase OEWIM drive fed by dual inverter fed

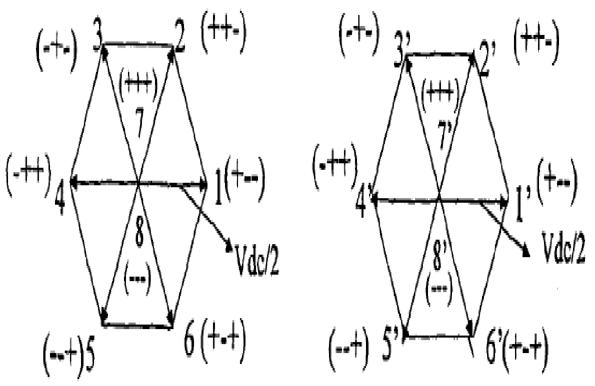


Fig.4 Inverter-1 and Inverter -2 space phasor locations

A switching strategy with a switched neutral was proposed by Somasekhar et.al.[7]. Fig 5 shows the power circuit. In this method the zero sequence current is suppressed by eliminating the bulky harmonic filters and isolation transformers. For some space phasor combinations switched neutrals are created using an auxillary bidirectional switch which will block the triplen harmonic currents. The inverter switching is done in such a way that only one leg of an inverter is turned ON during a sub interval which have sampling period T_s

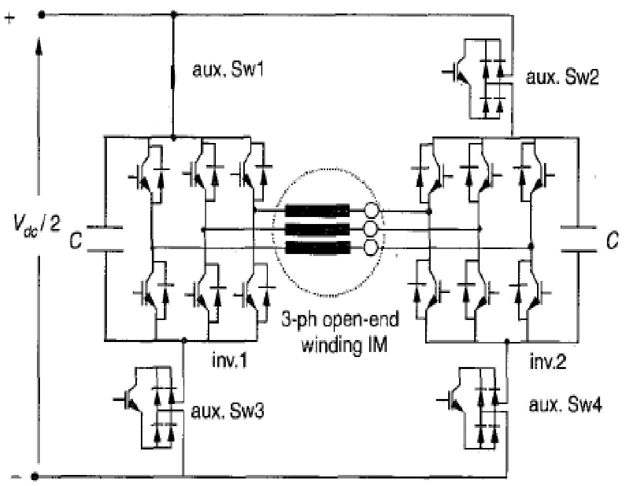
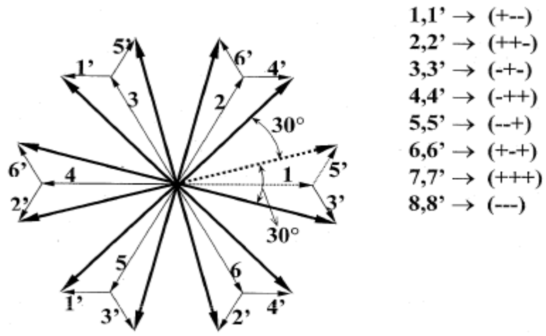
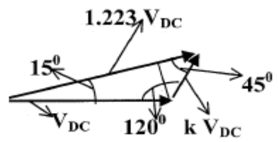


Fig.5 Auxiliary switch assisted neutral generation

5th and 7th harmonic elimination and 11th and 13th order harmonic suppression was proposed in [8]. For this, two inverters having symmetrical dc-link voltage of ratio of 1:0.366 are selected. For the entire speed range a carrier wave with frequency of 12 times that of the modulating waves was used for v/f control. Fig 6 shows the positional combinations selected from inverter-I and inverter II



(a)



$V_{DC}\sin 15^0 = k\, V_{DC}\sin 45^0$

So $k = \sin 15^0 / \sin 45^0 = 0.366$

(b)

Fig.6 (a) Combinations of the positions selected from inverter-1and inverter-2 (b) DC-link voltage ratio calculation for inverter-1and inverter-2

The CMV is a major issue in case of induction motor drive because it generates bearing current and leakage currents. [9]. In this paper switching strategy is proposed that does not result in any alternating CMV. When compared to traditional neutral point clamped three level inverter, this type of drive is devoid of neutral point fluctuation. Here the voltage of the single DC link is only half the voltage that has been used in common mode elimination method.

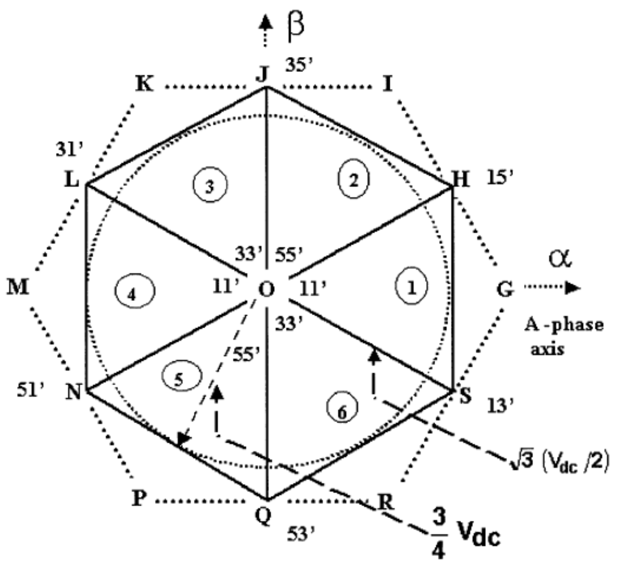


Fig.7 Combinations of space phasor for zero vectors and active vectors in common mode elimination[9]

A single DC power supply with switching scheme that uses all the combinations of space phasor from the dual inverter scheme is proposed [10]. Bulky harmonic filters isolation transformers that are needed to suppress triplen harmonic components are eliminated. The bidirectional switches present in the above method is rearranged so that full DC link utilization is achieved. The dc bus utilization factor is found to be enhanced by 15%.

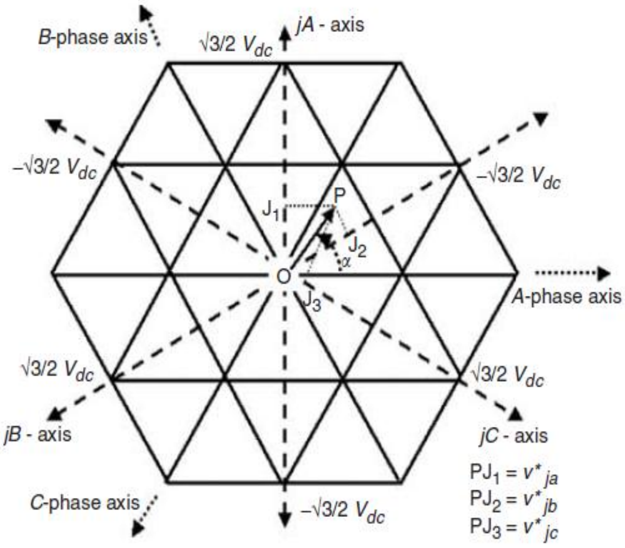


Fig.8 Sector identification [10]

When compared to the work in [6] the CMV was decreased by reducing the modulation index in [11]. The PWM scheme proposed works only with instantaneous phase reference voltages and therefore look up tables and sector identification are not needed. Fig.9 shows the principle behind alternate sub-hexagonal centre switching scheme. Switching duty for each inverter is equally provided in this PWM scheme.

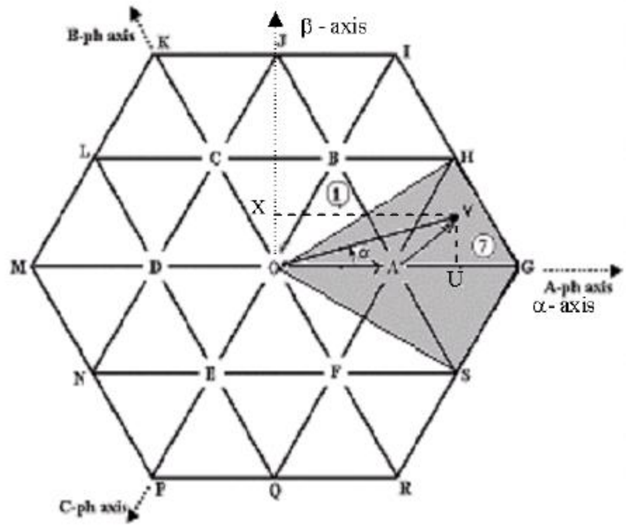


Fig.9 Principle behind Alternate-Sub-Hexagonal centre switching

[12]In this paper it is shown that placement of zero vector affects the zero sequence voltage distribution. Both discontinuous and continuous PWM methods are analysed. In the discontinuous PWM approach the number of switching is decreased by 33% as a result the switching losses are also reduced. Electrical isolation is mandatory because of the significant values of zero sequence voltage.

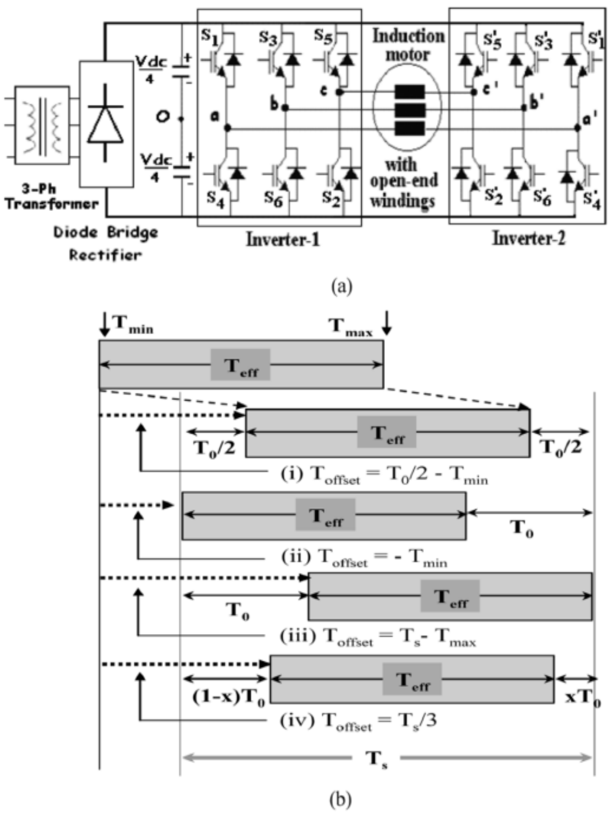


Fig.10 (a)Power circuitry of dual inverter drive with offset time period $T_s/3$ (b) T_{eff} of each inverter placed within the sampling time interval

The above disadvantage was resolved in the paper proposed by somashekar et al. [13]. It is shown in this paper that by doing certain engineering adjustments a single DC power supply can be used instead of 2 isolated dc power supplies. A new decoupled SVPWM is used to achieve this. In this method the zero sequence voltage is to suppress by forcing it to a value of zero in each sampling interval.

As the switching frequency increases the losses also increases. A PWM scheme with reduced switching and its variants for a 2 level dual inverter is proposed in this paper [14] which can synthesise 3 level voltage space vector. The instantaneous values of the 3 phase reference voltages corelated to the reference space vector are only required by the controller. There was a significant reduction in switching losses by using this scheme.

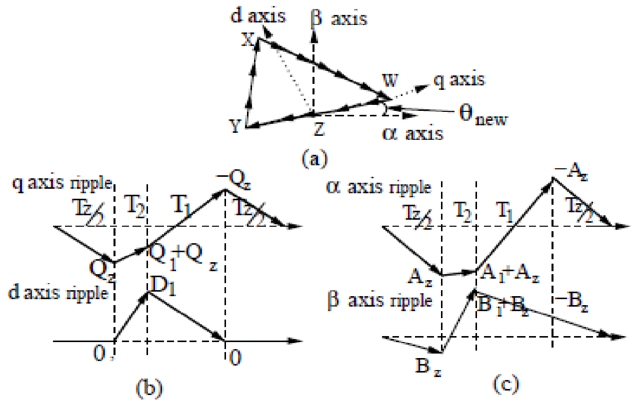


Fig.11 (a) Center placed PWM with its current trajectory (b) Projection of current ripples on d-q axes (c) Projection of current ripples on α-β axes

The current trajectories were predicted and the ripple content in it was estimated. Centre placed PWM with its current trajectory, projection of current ripples on d-q axes and on α-β axes are shown in fig. 11 According to this paper SVPWM produces minimum current ripple when compared to other cases. A random PWM (RPWM) which is based on space vector approach is proposed in [15]. In every switching period the effective vectors are placed randomly. The RPWM technique for a two level inverter can be used to generate switching pulses for a three level inverter. This technique is called mapping technique. Usually in SVPWM the energy is concentrated at the switching frequencies. This is reduced in RPWM method.

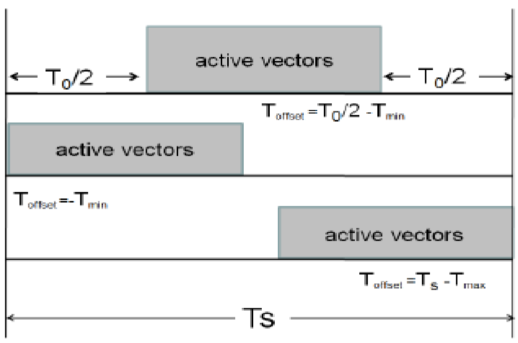


Fig.12 Active vectors placed for middle, minimum and maximum offset values

The above prescribed work is used for an OEWIM drive in [16]. The instantaneous values of the three phase reference voltages are used to generate the switching vectors. The randomness of the switching frequencies introduced in this method helps to eliminate the unwanted spectral harmonics which was present in SVPWM.

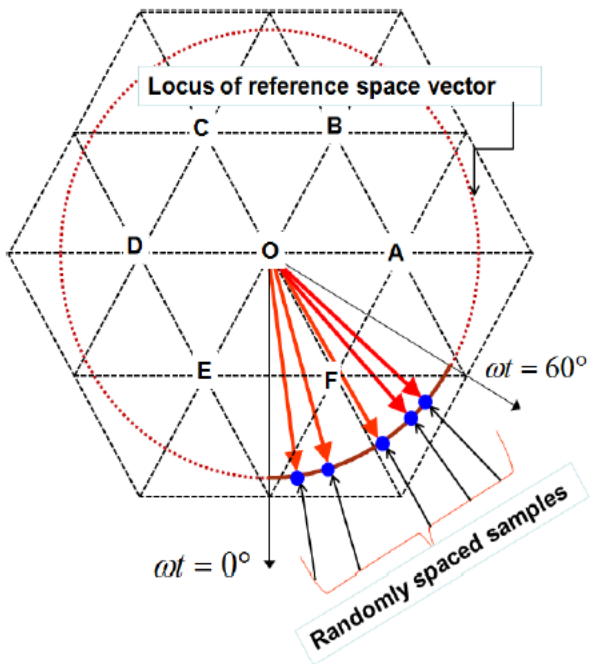


Fig.13 Reference space vector sampled randomly

B. Control of Asymmetrical dual inverter

In the scheme proposed by Shivakumar et.al.[17],a 64 voltage space vector combinations in 37 space locations are produced. A two level inverter with dc link voltage of $(2/3)V_{dc}$ and $(1/3)V_{dc}$ are used. This will produce step voltage waveforms in different speed ranges. In this type of inverter drive switching frequency can be reduced by increasing the speed which increases the phase voltage steps. Control of isolated dc link should be provided for this scheme.

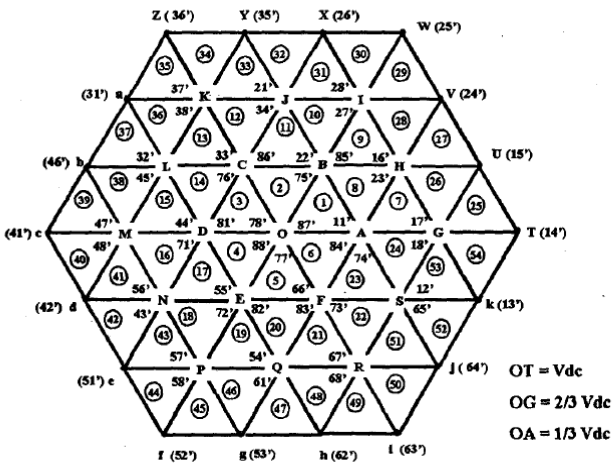


Fig.14 Combinations of space phasor for a dual inverter drive with asymmetrical voltage

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Equal duty and proportional duty SVPWM are described in this paper [18]. A four level wave form from an OEWIM configuration is synthesized using this method. Sector identification and look up tables are not needed while implementing these PWM strategies. Among these two a good spectral performance and reduced switching losses are exhibited by proportional duty SVPWM. When compared to equal duty SVPWM the energy saving is almost10%.

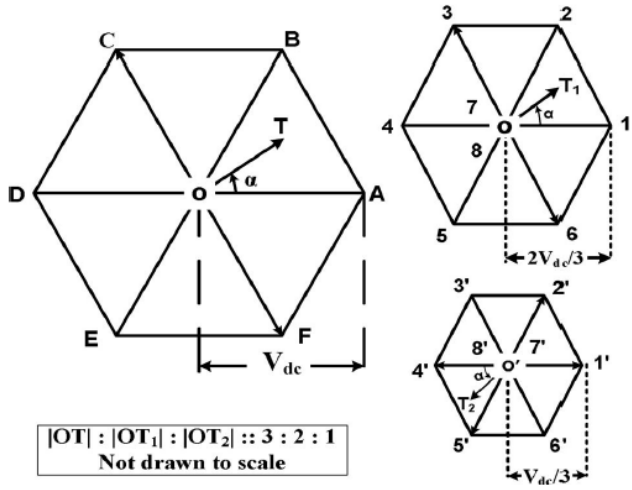

Fig.15 A four level inverter with decoupled PWM strategy

In [19] a PWM method which uses space vector concept is proposed. Look up tables and sector identification are needed since this method uses only instantaneous reference voltages. Inverter that is having a greater dc link voltage works at a lower frequency which is made possible with this PWM method. In this paper a hysteresis current controlled front end converter is described to prevent the overcharging of dc link capacitor.

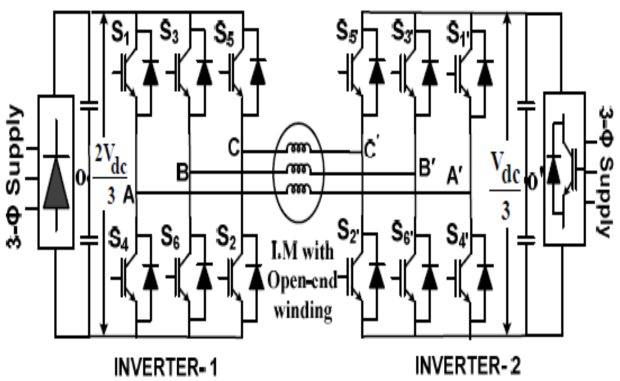

Fig.16 An OEWIM drive fed by four-level dual inverter with front-end converter

A conventional 2 level inverter topology is nested with a rectifier-inverter configuration in this paper [20]. One end of the OEWIM is fed by the output of a traditional 2 level inverter and a nested rectifier inverter circuit feeds the other end. (Fig.17). To avoid zero sequence currents decoupled SVPWM scheme is adopted.

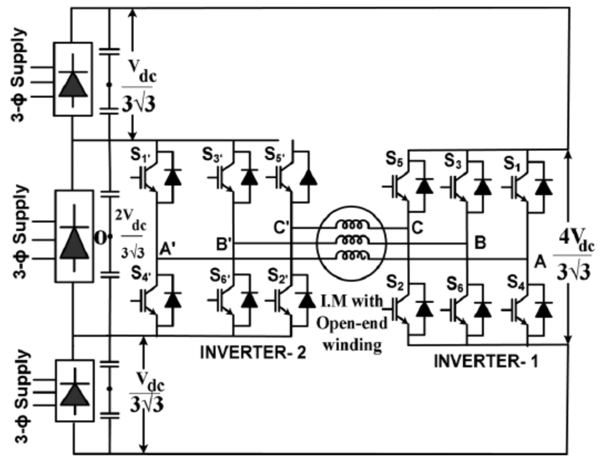

Fig.17 Open-end winding induction motor drive fed by four-level dual inverter with V_{dc}=0.77V

To decrease the current ripple a discontinuous decoupled PWM strategy is described in [21]. Ripples in the current of dual 2 level inverter is investigated in this paper using simple effective time placement affected by offset time concept. Using different PWM techniques for individual inverters the current ripple trajectory is also described. It is found that by applying discontinuous PWM scheme to each of the inverter, a dual inverter helps to reduce the inverter phase switching combination of two level inverter and also the motor phase current has the lowest ripple content.

III. SCALAR CARRIER BASED PWM CONTROL

A. Control of Symmetrical dual inverter

In this paper [22] 2 PWM algorithms which were used for VSI are extended to dual inverter. The 2 algorithms are AZSPWM (Active Zero State PWM) and NSPWM (Near State PWM). These 2 scalar approaches reduce the complications present in SVPWM approach. The AZSPWM decreases the CMV and NSPWM provides reduced CMV and switching losses.

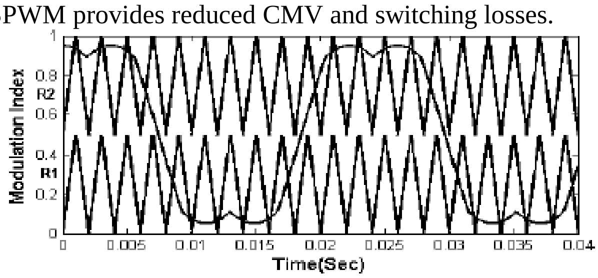

Fig.18 Scalar method for dual inverter configuration

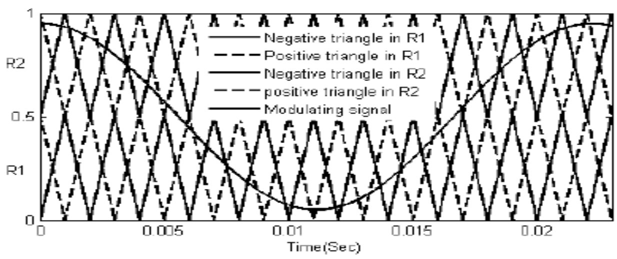

Fig.19 A region with triangular pattern

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In the method proposed in [23] vector controller dual inverter circuit is able to work as 3 level inverter when modulation index is high and as 2 level inverter when modulation index is less. Block diagram is shown in Fig.20. Here carrier based SVPWM approach has been used to generate control signal of dual inverter. As per this method switching losses are less. A reduced CMV and current ripple is obtained.

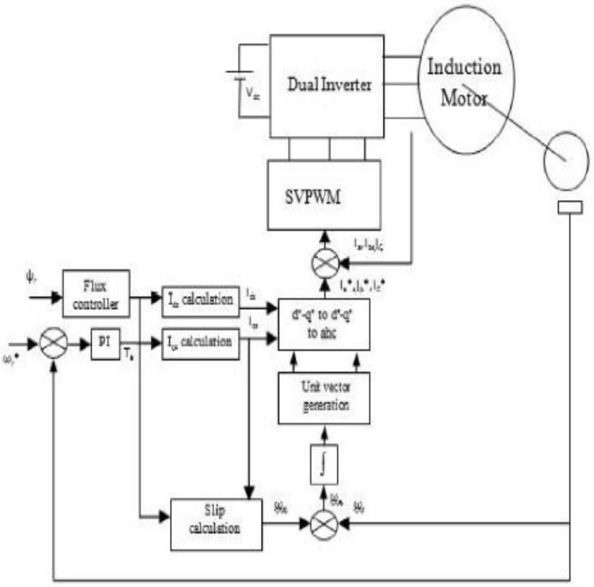

Fig.20 Induction motor drive fed by dual inverter with vector control

B. Control of Asymmetrical dual inverter

A random PWM technique to spread the energy spectrum which is usually concentrated around the harmonic of switching frequencies is presented in this paper [4] (Fig. 21). Here a dual inverter with asymmetrical configuration that feeds vector controlled IM drive is considered. A decoupled control is put forwarded in this paper. The harmonics near the switching frequency is reduced as per this method.

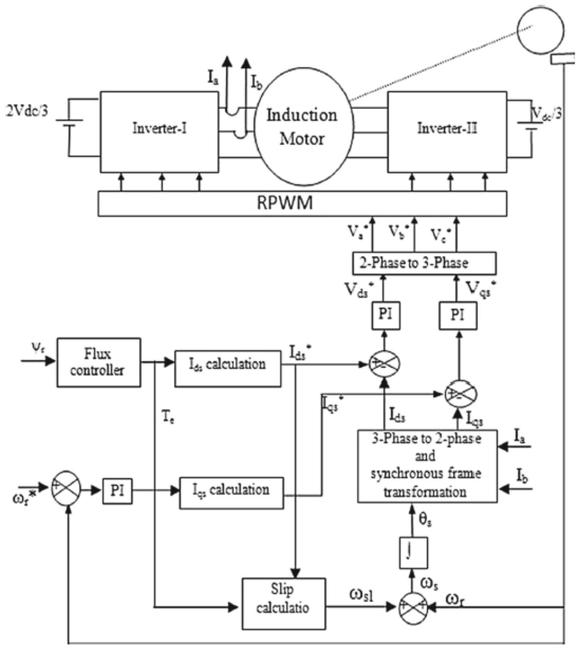

Fig.21 Proposed open-end winding induction motor drive fed by dual inverter with vector control

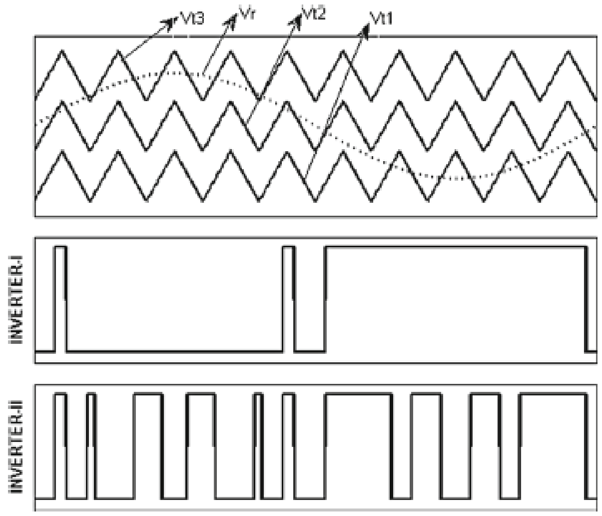

Fig.22 An asymmetrical dual inverter configuration realized with scalar PWM method

A decoupled random PWM technique for OEWIM fed by a dual inverter is proposed in [24]. In this scheme switching signal for individual inverter are derived separately. Here the decoupled reference voltage of each inverter is compared with a random carrier wave and switching sequence is generated. Fig 23 and Fig. 24 shows the same. A performance comparison of the dual inverter with present PWM technique and sine triangle PWM technique is also done in this paper.

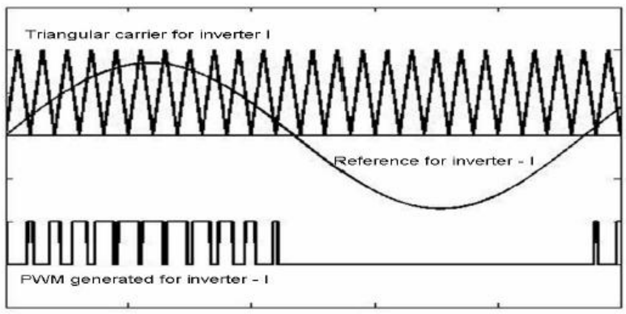

Fig.23 PWM signal generated for phase A of inverter I with level shifted reference signal using decoupled method

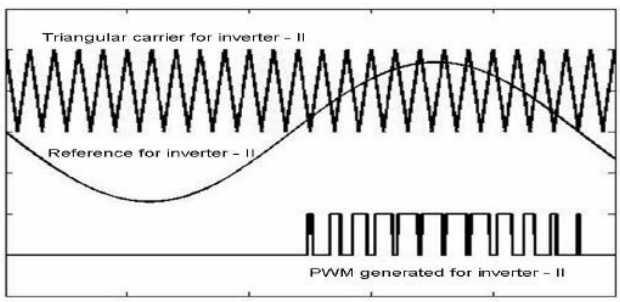

Fig.1 PWM signal generated for phase A of inverter II with level shifted reference signal using decoupled method

In the proposed PWM method one inverter operates at lower modulation indices and the other inverter will be clamped to dc bus [25].

When the modulation index is between 0.33 and 0.66 both the inverters will work and for higher modulation index it works as conventional methods but with reduced common mode voltage.

A modified control method for a four level asymmetrical dual inverter fed OEWIM with is proposed [26]. A scalar control method is proposed. The drive is made to work with lowest switching losses when it is operated with a modulation index below 0.3. When the MI takes a value that is greater than 0.3 and less than 0.6 CMV decreases and when modulation index is higher than 0.6 there is similarities in the control strategies. Since the continuous modulating signal based PWM (CPWM) overcharges the dc link capacitor which makes the wide range speed control impossible. A PWM with discontinuous modulating signal for an asymmetric dual inverter configuration is proposed [27]. This not only improve the output quality but also help in control of speed in wide range. In this technique zero sequence voltage is reduced. Since this is scalar approach the complexity is reduced when compared to SVPWM. During the entire modulation index (0-1.154) overcharging of dc link capacitor was eliminated using DPWM and it could operate the drive with low output voltage quality which was impossible using CPWM technique. When the modulation index is higher DPWM showed better performance.

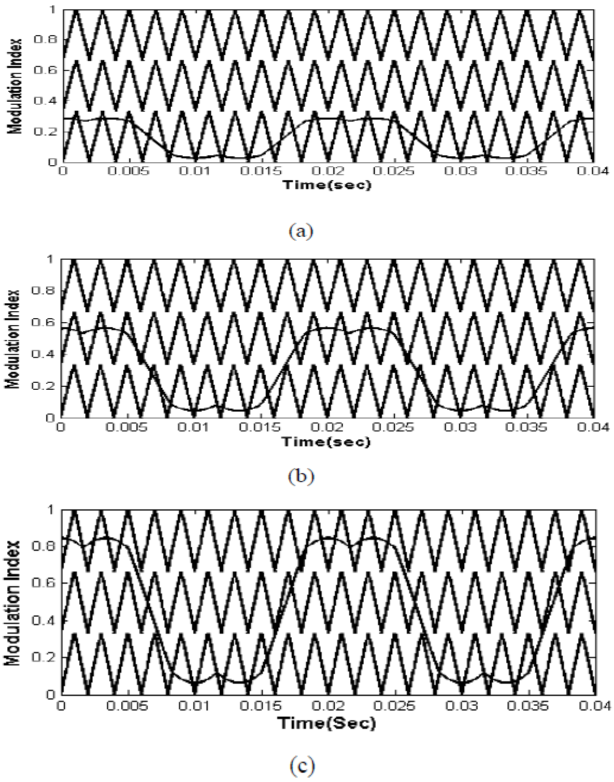

Fig.2 Carrier based approach (a) when MI is low (b) when MI is medium (c) when MI is high

A switching scheme with hybrid PWM for each of the 2 level inverters of the dual inverter configuration are carried out and the CMV that is the reason for shaft voltage is identified. The shaft voltage was found reduced in case of hybrid PWM scheme[28].

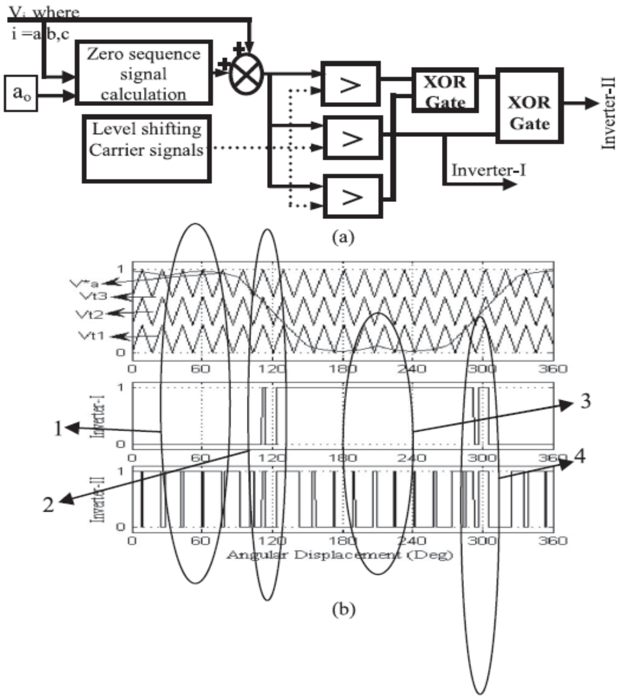

Fig.3 (a) Asymmetrical dual inverter configuration realised using scalar PWM technique (b) pulse pattern generated for top switches in A phase of first and second inverter respectively.

IV. CONCLUSION

Different control methods adopted by dual inverter fed OEWIM drive have been discussed in this paper. Space vector control and carrier based scalar control are adopted for both asymmetrical and symmetrical dual inverter fed OEWIM drive.

REFERENCES

1. Syed Munavar Ali, V.Vijaya kumar Reddy, M. Surya Kalavathi, “Coupled random PWM technique for dual inverter fed induction motor drive”, IJPEDS, Vol.10,No.1,pp 58-65,March 2019
2. Komal Satose, S.N Deshpande, Rahul Bhujabal, Priya Tiwari, Jeetendra Tiwari, “Analysis of Different Topologies of Multilevel Inverters”,IJIRST,Vol.2,No.09,pp 304-309,February 2016.
3. Javier Riedemann Aros, Ruben Pena Guinez, Ramon Blasco Gimenez,”Recent Development on power Inverters”, Chapter 5, Dual-Inverter Circuit Topologies for Supplying Open Ended Loads, pp 103-134, 2017
4. M. Harsha Vardhan Reddy, T. Brahmananda Reddy, B. Ravindranath Reddy, M. Suryakalavati, "Random PWM technique for Dual-Inverter-fed Vector-Controlled Induction Motor Drive," Journal of control automation and electrical systems (Springer publisher), vol. 27, no. 1, pp 60-68, 2016.
5. Jose Rodriguez, Jih-Sheng Lai. "Multilevel Inverters: A Survey of Topologies ,Controls, and Applications"I EEE Trans.Ind. Ele. , Vol. 49, no. 4, pp 724-737,Aug 2002.
6. Shivakumar, E. G., Gopakumar, K., Sinha, S. K., Pittet, A., & Ranganathan. V. T. (2001). Space vector PWM for dual inverter fed open-end winding induction drive. In *IEEE-APEC*, pp. 399–405.
7. V. T. Somasekhar, K. Gopakumar,A. Pittet, andV. T.Ranganathan, “PWM inverter switching strategy for a dual two-level inverter fed open-end winding induction motor drive with a switched neutral,” *Proc. Inst. Elect. Eng., Electr. Power Appl.*, vol. 149, no. 2, pp. 152–160, Mar. 2002.
8. K. K. Mohapatra, K. Gopakumar, V. T. Somasekhar, and L. Umanand, “A harmonic elimination and suppression scheme for an open-end winding induction motor drive,” *IEEE Trans. Ind. Electron.*, vol. 50, no. 6, pp. 1187–1198, Dec. 2003.

9. M. R. Baiju, K. K. Mohapatra, R. S. Kanchan, and K. Gopakumar "A dual two-level inverter scheme with common mode voltage elimination for an induction motor drive," *IEEE Trans. Power Electron.*, vol. 19, no. 3, pp. 794–805, May 2004.
10. V. T. Somasekhar, M. R. Baiju, and K. Gopakumar, "Dual two-level inverter scheme for an open-end winding induction motor drive with a single dc power supply and improved dc bus utilisation," *IEE Proc. Electr. Power Appl.*, vol. 151, no. 2, pp. 230–238, Mar. 2004.
11. V. T. Somasekhar, S. Srinivas, and K. Gopakumar, "A space vector based PWM switching scheme for the reduction of common-mode voltages for a dual inverter fed open-end winding induction motor drive," in *Proc. IEEE PESC*, Recife, Brazil, 2005, pp. 816–821.
12. V. T. Somasekhar, S. Srinivas, and K. K. Kumar, "Effect of zero-vector placement in a dual-inverter fed open-end winding induction motor drive with alternate sub-hexagonal center pwm switching scheme," *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1584–1591, May 2008.
13. V. T. Somasekhar, S. Srinivas, and K. K. Kumar, "Effect of zero-vector placement in a dual-inverter fed open-end winding induction-motor drive with a decoupled space-vector PWMstrategy," *IEEE Trans. Ind. Electron.*, vol. 55, no. 6, pp. 2497–2505, Jun. 2008.
14. S. Srinivas and K. Ramachandra Sekhar, "Theoretical and experimental analysis for current in a dual-inverter-fed open-end winding induction motor drive with reduced switching PWM," *IEEE Trans. Ind. Electron.*, vol. 60, no. 10, pp. 4318–4328, Oct. 2013.
15. D. S. George, M. R. Baiju. "Random PWM scheme for 3-level inverter using offset time randomization", 37th Annual Conference on IEEE Industrial Electronics Society, pp. 1989-1994, 2011 D. S. George, M. R. Baiju. "Random PWM scheme for 3-level inverter using offset time randomization", 37th Annual Conference on IEEE Industrial Electronics Society, pp. 1989-1994, 2011.
16. George, D. S., & Baiju,M. R. (2012). Space vector based random pulse width modulation scheme for a 3-level inverter in open-end winding induction motor configuration. In *ISIE-2012*, pp. 742–747.
17. V. T. Somasekhar, K. Gopakumar, E. G. Shivakumar, and A. Pittet, "A multilevel voltage space vector generation for an open-end winding induction motor drive using a dual-inverter scheme with asymmetrical D.C. – Link voltages," *EPE J.*, Vol. 12, No. 3, pp. 21-29, Aug. 2002.
18. B. V. Reddy, V. T. Somasekhar, and Y. Kalyan, "Decoupled space-vector PWM strategies for a four-level asymmetrical open-end winding induction motor drive with waveform symmetries," *IEEE Trans. Ind. Electron.*, vol. 58, no. 11, pp. 5130–5141, Nov. 2011.
19. B. Venugopal Reddy and V. T. Somasekhar, "A SVM based four-level open-end winding-induction motor drive with voltage balancing of dclink capacitors using SVM based HCC front-end converter," in *Proc. Annu. IEEE India Conf.*, 2011, pp. 1–5.
20. B. Venugopal Reddy and V. T. Somasekhar, "A dual inverter fed four-level open-end winding induction motor drive with a nested rectifier-inverter," *IEEE Trans. Ind. Informat.*, vol. 9, no. 2, pp. 938–946, May 2013.
21. K. R. Sekhar and S. Srinivas, "Discontinuous decoupled PWMs for reduced current ripple in a dual two-level inverter fed open-end winding induction motor drive," *IEEE Trans. Power Electron.*, vol. 28, no. 5, pp. 2493–2502, May 2013.
22. Vardhan Reddy,M. Harsha, Reddy, T. Brahmananda, Reddy, B. Ravindranath,&Suryakalavati,M "Reduced Common Mode Voltage PWM Techniques for Dual Inverter Configuration," in *Proc. IEEE, ICRAIE*, Jaipur, 2014.
23. Vardhan Reddy,M. Harsha, Reddy, T. Brahmananda, Reddy, B. Ravindranath,&Suryakalavati,M "Control strategies for dual inverter fed vector controlled induction motor drive," IJEHV, Vol. 6, No.3, pp. 195-214,2014.
24. David Solomon George, M. R. Baiju," Decoupled Random modulation technique for an open-end winding induction motor based 3-level Inverter*", IEEE Symposium on Industrial Electronics and Applications (ISIEA)* pp 1022-1027, 2009.
25. Vardhan Reddy,M. Harsha, Reddy, T. Brahmananda, Reddy, B. Ravindranath,&Suryakalavati,M. (2014).Novel scalarPWMalgorithm for four-level asymmetrical dual inverter fed inductionmotor drive. *Asian Power Electronics Journal*, *8*(1), 30–36.
26. M. Harshavardhan Reddy, T. Brahmananda Reddy, B. Ravindranath Reddy, M. Suryakalavati, "Efficient control strategy for four level asymmetrical dual inverter fed induction motor drive", IEEE PESTSE 2014, pp 1-6.
27. M. H. V. Reddy, T. B. Reddy, B. R. Reddy and M. S. Kalavathi, "Discontinuous PWM Technique for the Asymmetrical Dual Inverter Configuration to Eliminate the Overcharging of DCLink Capacitor," in IEEE Transactions on Industrial Electronics, 65 (2018) 156 (DOI: 10.1109/TIE.2017.2716858)
28. J. Kalaiselvi and S. Srinivas, "Hybrid PWMs for shaft voltage reduction in a dual inverter fed induction motor drive," in *Proc IEEE ICIT*, Feb. 25–28, 2013, pp. 539–544.

AUTHORS PROFILE

Kavya Venugopalan received the B.E. degree in Electrical and Electronics Engineering from Avinashiligam University, Coimbatore, India, in 2008 and the M.Tech degree in Power Electronics and Drives from Karunya University, Coimbatote, India, in 2012. She is currently working toward the Ph.D. degree in Electrical Engineering at Karunya University.

Dr. V. Jegathesan is Currently working as Associate Professor, Department of Electrical and Electronics Engineering, Karunya University, India. He has successfully completed his Administrative responsibilities as Professor. His research has included Static Power Converters, Inverters, AC Motor Drives, Power Quality Enhancement by eliminating the lower order harmonics in Voltage Source Inverter.