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Advanced PWM Techniques for Control of Power Electronic Converters in PV and Motor Drive Systems

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Abstract

The occurrence of common mode voltage (CMV) leads to flow leakage current between PV panel and earth surface in photovoltaic(PV) systems interfaced with semiconductor devices. Similarly, electromagnetic interface and bearing failure in motor drive systems. These are the major drawbacks in their respective systems with less efficiency and more losses. A review of this study makes us focus on the system loss reduction by suppressing the CMV with various PWM techniques to different power electronic circuits (Inverter/ Converter) for application of PV systems. By reducing the CMV and switching losses, improved performance for various applications is presented.

***Key Words*:**PWM methods, Inverter, Converter, SVPWM, AZSPWM, RSPWM, NSPWM.

1 Introduction

Pulse in terms of power electronics, sudden change of rise for ON condition and sudden change of decay for OFF condition in a specified interval of time by the user or by the automated system. Rise or decay is the electromagnetic field, voltage or current parameters of electric power leads to generate a pulse.

Pulse density modulation(PDM), Pulse width modulation (PWM), pulse frequency modulation (PFM), amplitude modulation (AM), pulse code modulation (PCM) are introduced by the researchers to operate the various electronic, communication and power electronic systems. In this paper, we are presenting a review based on various PWM methods, their operation, and utilization for the area of power electronics. The arrangement of power electronic switches in a specified design to build the inverter. To operate the inverter for the required outs, it has to switch ON and switch OFF the arranged switches in a sequential order. To ON or OFF the switch, the pulse is needed. Based on the parameters of the pulse, the switches are performing the required needs. Generation of the pulse is done by various methods. These methods are called pulse generation methods[1][4]. The control of switches in the inverter is done by varying the width of the pulse have been called pulse width modulation(PWM). We have many types of PWM method swhich are popularly exists listed in the presentation.

In the proposed work, section II gives the basic parameters of PWM methods and their analysis. Section III presents types of PWM methods. Section IV highlights with the analysis of various PWM methods with various Power Electronic converters and a comparative table is presented.

2 PARAMETERS OF PWM

To analyse the operation of the various PWM methods, we have to follow some of the basic parameters to obtain efficient proper outcome. In such, modulation index (Mi), modulation ratio (Mf) and zero sequence signal (Vz) are the key points of the PWM methods. In this section we briefly presenting these parameters.

2.1 *Modulation Index (Mi)*

Among various pulse width modulation strategies, many are introduced by the various researchers and scientists. Based on the carrier signal and modulation signal the important parameter is described as modulation index Mi. Mi gives the relation of the carrier signal and modulation signal as the ratio of amplitudes of the modulation signal to the carrier signal. Various modulation signals and carrier signals are presented and first published by schonumg in 1964 with SPWM. Holtz and Busesgive the concept of SVPWM [5].

$$Mi = \frac{(Peakamplitudeofmodulatingsignal(Vm))}{(Amplitudeofcarriersignal(Vf))}$$

Value of the modulation index is preferably in the range of 0 to 1(0¡Mi¡1), if Mi increases to 1, then the overmodulation will cause and reduces the number of pulses and losses the linearity of the system. To overcome the issue of linearity a zero sequence component is added to the modulating signal which increases the fundamental component [6], [7].

2.2 *Modulation Ratio (Mf)*

The occurrence of modulation index is happened due to the modulation ratio of the two signals. It is defined as theratio between switching frequency of the carrier signal to the fundamental frequency of modulating signal [5].

$$Mf = \frac{(Frequencyofcarriersignal)}{(frequencyofmodulatingsignal)}$$

Different values of modulation ratio are preferred for the generation of the new modulation wave for the PWM operations of carrier-based systems [8].

2.3 *Zero Sequence Signal(ZSS), (Vz)*

A reference modulation signal based on zero sequences of the actual modulating signal is injected to improve the linearity and the fundamental of theoutput voltage by 15.5 %. The new wave is obtained with the third harmonic injected modulation wave. The new modulated signal is generated as nonsinusoidal signal further used for the PWM methods leads to nonsinusoidal PWM techniques newly called modified PWM methods, Third-harmonic injection PWM(THIPWM) methods, and advanced SVPWM methods [5], [9][12].An equivalent representation of the modified modulated signal is given by the following equation.

V*no = V*n + Vz

Where V*no is the new modulated one phase signal as a nonsinusoidal signal, V*n is reference sinusoidal signal of one phase and Vz is the zero sequence signal (n = name of phase, a,b,c). Zero sequence carrier signal injection based sensorless control method is proposed based on the distribution ratio of thecarrier signal for the induction motor application [13]. A new algorithm for the optimal selection of the zero sequence signal for the various PWM operations to multilevel neutral point clamped(NPC) converter[14][16].The different frequency range of zero sequence carrier signal is injected for the reference modulation signal for the application of various motors, based on SVPWM without interacting the controller [17], [18]. Implicit zero sequence signal discontinuous PWM(IZDPWM), Discontinuous zero sequence component(DZSC) are proposed for a balanced and unbalanced load with standard three phase two level VSI and NPC three-phase inverter for the improvement of efficiency and linearity of the system [19], [20]. Double zero sequence injection PWM(DZIPWM) with analysis of four-dimensional 24 sector SVPWM method is proposed for the operation of the split phase induction motor for harmonic performance improvement [21].

3 TYPES OF PWM

Simple PWM methods
• Single PWM,
• Multiple PWM,
• Sinusoidal PWM.

Advanced PWM methods
• Conventional methods (Space vector PWM (SVPWM) as continuous PWM, Level Shifted PWM(LSPWM), Phase Shifted PWM (PSPWM)),
• Discontinuous PWM (DPWM),
• Reduced common mode voltage PWM (RCMV-PWM).

3.1 Conventional Methods (Space vector PWM (SVPWM) as continuous PWM)

A two-axis PWM control methodwith four voltage vectors and not having any zero state vectors is proposed by the author for the control of three-phase inverter designed by four power electronic switches[22]. Improved techniques by many researchers lead to SVPWM. Analysis of the vectors is presented in figure 1. Specifying ON with 1 and OFF with 0 of eight possible switching conditions for the power electronic converter or inverter in table 1.

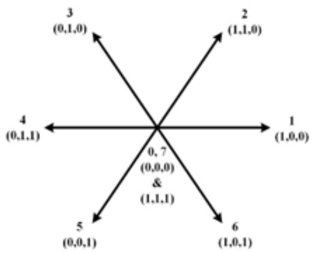

Fig. 1. Three Phase VSI Voltage Vectors

Based on the number of voltage vectors selection the PWM methods are categorized as type I with 3 vectors and type II with 4 vectors [22]. Interconnection of renewables for the three-phase micro grid is proposed with the four switches based three-phase inverter. The control of four switchesthree-phase inverter has been proposed with a simple sine PWM method with the help of Lyapunov functions for the current of inverter under the a-b-c frame. The cost of theinverter with highly reliable and efficiency is achieved with the proposed control modulation [23].

TABLE 1. position of switches and state of thevector of three-phase VSI.

Vector number	Switching Condition	Zero vector (ZV)/ Active vector(AV)
0	0,0,0	ZV
1	1,0,0	AV
2	1,1,0	AV
3	0,1,0	AV
4	0,1,1	AV
5	0,0,1	AV
6	1,0,1	AV
7	1,1,1	ZV

Various conventional modulation methods are presented for the operation of the cascaded H bridge (CHB) converter, CHB electronic power transformer (CHB-EPT), modular multilevel converters (MMC), neutral point coupling inverters and multilevel inverters. Depending on the carrier based modulation methods level shifted PWM (LSPWM), phase shifted PWM (PSPWM) and preprogrammed PWM method. Under vector based modulation operation,space vector modulation methods with the zero sequence signal injection methods and the digital control method. A Hybrid PWM method and pseudo modulation technique are also presented for the control of the various multilevel inverters operating as acentral inverter for the renewable energy applications [24], [25]. Phase disposition (PDPWM) and phase opposition disposition (PODPWM) pulse width modulation methods are used for the analysis of the neutral point potential diode clamped 3 level inverter [26]. For the operation of hybrid ML inverter in the application of PV systems, PDPWM, PODPWM and VFPDPWM methods are investigated which suits perfectly for the system proposed [27], [28].

Harmonic elimination pulse width modulation (HEPWM) method is proposed for the reduction of circulating currents caused due to the parallel operation of inverters in various applications. Reduction of harmonics isobtained by the specified selection of the switching angle within the quarter symmetrical region (00 to 900). Null vectors are the major keys for the common mode voltage operation. This null voltage vectors selection is designed by a field programmable gate array (FPGA) circuit [29]. A three-phase inverter with neutral point clamped (NPC) is used with the novel modulation method of SVPWM by 18 voltage vectors to reduce the leakage currents. Selection of three medium voltage vectors or two active vectors and one zero vector for the modulation method to control the NPC inverter fed with the photovoltaic system [30]. With the combination of carrier-based conventional PWM method and CMV reduction, a scalar PWM method is proposed for the easy implementation of motor drive control [31]. A novel SVPWM is proposed by using dq frame, the reference voltage is obtained by the stationary frame voltages and is obtained by the effective voltage of each switching state. Obtained voltages are directly transformed to the phase voltages with the necessary equations depends on the switching time. A simple three sorting algorithm is used to calculate the effective time and recombination without sector selection [32]. The SVPWM based dq reference frames for the application of grid-connected PV systems is presented in [33]. 27 switching states are possible for the proposed Space vector modulation method for the three-level Neutral point potential(NPP) inverter for the regulation of CMV and to reduce the losses due to switching operation and temperature at NPC [34].

3.2 Saddle Space Vector Pulse Width Modulation (SAPWM)

Modified SVPWM results to the three-level saddle SVPWM based on the two-level SVPWM for the neutral point clamped three level inverter (NPC). Based on the switching state optimization, duration of the selected phase under on condition is equal to the other selected phases of thecycle. Effectiveness and the output harmonic performances are better in NPC three level inverter and results are presented based on the performance of thedigital signal processor and complex programmable logic device (DSP-CPLD). Based on the value of the modulation ratio Mf the modulation wave is proposed for the SAPWM. Mf is given as follows in the proposed work [8].SAPWM is one of the optimized methods with 15% greater the value of maximum output voltage as compared to the SPWM, further results in a reduction of harmonic currents and torque fluctuations [35].

0 Mf 1.15

3.3 Conventional Methods (Reduced Common Mode Voltage PWM(RCMV-PWM))

RCMV-PWM has been presented withits various methods like Active zero state PWM(AZS-PWM), Remote state PWM(RSPWM), Near state PWM (NSPWM). Common mode voltage is a major issue in the area of adjustable speed drives which makes to flow the circulating currents through stray capacitance between the stator winding, rotor winding,and frame of the machine which leads to electromagnetic interface and bearing failures [36][38]. Similar to the condition of the dynamic machines of speed control, thestray capacitance between the PV panel and the ground as dominating factor leads to cause of electromagnetic interfaces, grid current distortion and additional power losses[39], [40] focus towards CMV and CMC. To achieve the advantages by reducing the common mode voltage (CMV) and common mode current (CMC) occurred due to the switching operations of the inverter, three RCMV-PWM methods are used with only active vector states. Generally, the common mode voltage of thethree-phase inverter is presented below as VCM. Among the various RCMV-PWM methods NSPWM gives the better practical results under comparison [41]. VCM = (Vao+ Vbo + Vco)/3

Based on the selection of the zero state vectors 0(0,0,0) and 7(1,1,1), for the digital PWM method is equals to the selection of the zero-sequence signal to carrier wave for the intersection of PWM method. The performance characteristics of the PWM technique of desired output voltage is depending on the modulation index. The modulation index is defined by the ratio of the magnitude of the line to neutral output voltage V1m to the six-step mode voltage V1m6step of their fundamental components and expressed as Mi below[42], [43]. Mi = V1m / V1m6step

Depends on the harmonic distortion factor(HDF) and the quality factor of the DC link current are deciding the value of the filters. If the HDF is small then the size of the filter is small for the less ripple content. For every method of RCMV-PWM, the HDF and DC link current quality factor are presented which are depends on the displacement power angle and the modulation index of the PWM technique. The quality of the output voltage can be analyzed by harmonic flux vector of Nth order PWM cycle of an arbitrary plane [41], [42].

An application of open-end winding induction motor connected to the asymmetrical dual inverter at both winding ends is controlled by the continuous pulse width modulation(CPWM) and discontinuous pulse width modulation(DPWM) techniques, instead of the AZSPWM and NSPWM for the reduction of common mode voltage without changing thequality of the power [44]. Stray capacitance of PV system leads to cause of leakage currents. This leakage current can be reduced by the CMV model and the modulation methods. Based on the voltage vectors and the operation of the CMV AZSPWM and RSPWM are considered for the analysis of the converter operation [45].

A novel algorithm for the reduction of CMV with common mode voltage reduction pulse width modulation(CMVRPWM). Symmetrical switching pattern without simultaneous switching problem is categorized in the algorithm of CMVRPWM. Application of the carrier phase shift CMVRPWM is depended on the modulation index value less than 0.4 to 0.6[46], [47]. A novel AZSPWM1-3 method is proposed for reduced switches and number of switching to the next sector of the voltage sector plane [48].By reducing the magnitude of the modulating reference signal to 50%, based on the original PV output voltage depends on modulation index ma which is given in comparison table for cascaded five level MLI [39], [40]. Proposed modulation method results in the reduction of CMV in considered PV systems with high reliability and efficiency. In the study of Matrix converter, CMV isfocused and reduced with various modulation methods [49], [50].

3.4 Conventional Methods (Active Zero State PWM (AZS-PWM))

The author used active vector instead of zero vector for the reduction of CMV of the inverter and to improve the power quality of the system[41]. Based on the selection of voltage space vectors and the sequence of switching operation AZSPWM is differentiated as AZSPWM1, AZSPWM2, and AZSPWM3 [46], [51]. AZSPWM1 and AZSPWM3 are used for the space vector dependent alternating carrier signals of the PWM method [31].1/3rd of CMV is reduced with the AZSPWM novel algorithm with less number of switches as compared to conventional space vector PWM. A comparative analysis is proposed with various AZSPWM 1-3 and conventional space vector PWM method for the BLAC application[48]. CMV reduction methods based on SVPWM and AZSPWM for the application of the autonomous microgrid is presented with $\frac{v}{f}$ control algorithm[52].

TABLE 2. switching sequence comparison between SVPWM and AZSPWM

SVPWM (0,1,2,7)	AZSPWM (6,1,2,3)
0,0,0	1,0,1
1,0,0	1,0,0
1,1,0	1,1,0
1,1,1	0,1,0

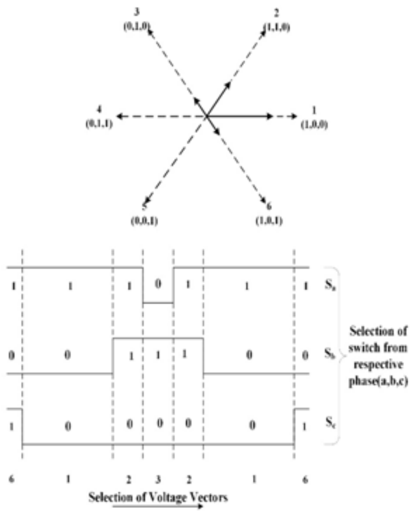

Fig. 2. Illustration of AZSPWM operation.

From the analysis of various research work, the presentation of the AZSPWM conditions is mentioned. Instead of using zero vector, use an active vector. i.e. instead of using vectors 0 and 7 use the opposite active vectors of the required operation like 1,2,3,4,5,6.Forexample, a comparison switching pattern operation of SVPWM and AZSPWM is presented in table 2.Illustration of AZSPWM operation which gives a clear view of the change of ON and OFF condition of theswitch when changes from one vector to other without violating the basic condition.

3.5 Conventional Methods Remote State PWM (RSPWM)

In this PWM method the selection of the vectors is chosen from the same group (vectors 1, 3, 5 or vectors 2, 4, 6). With the same group vectors the sequence of vector operation is done in three modes as RSPWM1 as fixed order sequence, RSPWM2 as variable sequence and RSPWM3 as variable sequence selection with every 600 spans for the alternative vectors[41].The author proposed RSPWM3 with odd or even active voltage vectors for the range of -300 to 300 and 300 to 900 respectively, for the elimination of leakage currents[45]. Two-stage converter design with the combination of theDC-DC boost converter and VSI for the CMV reduction by the operation of RSPWM1[53],whichresults in efficiency improvement. Two parallel connected VSI control and study is observed by RSPWM application for the reduction of CMC [54].

TABLE 2. switching sequence operation for RSPWM methods.

RSPWM1	RSPWM2		RSPWM3
Fixed order sequence 1,3,5 3,5,1 5,1,3	Variable sequence		Variable sequence selection with every 60^0spans for both alternative vector 3,1,5,1,3
	1,3,5 3,5,1 5,1,3	5,3,1 1,5,3 3,1,5	

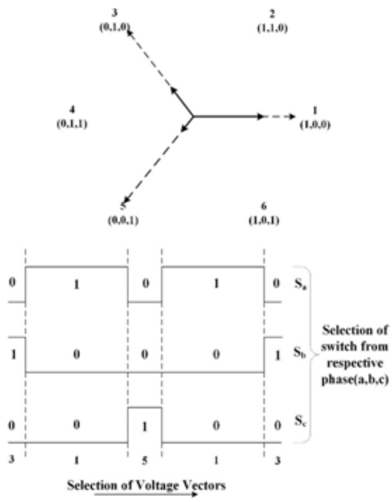

Fig. 3. Illustration of RSPWM operation.

In ananalysis of the RSPWM, selection of the vectors is from thesame side of inverter switching voltages. i.e. 1,3,5 from the upper side of inverter and 2,4,6 are from the lower side of theinverter. Illustration of RSPWM is clearly observed from the table 3 and figure 3,which is given with various RSPWM methods decides the output voltage of theinverter.

3.6 Near State PWM (NSPWM)

In the NSPWM the selection of the three active vectors is closest toneighbor voltage vectors. Selected vectors can change their sequence for every 600 spans of the vector plane to achieve desired output voltage[41]. Illustration of NSPWM operation is presented in figure 4.

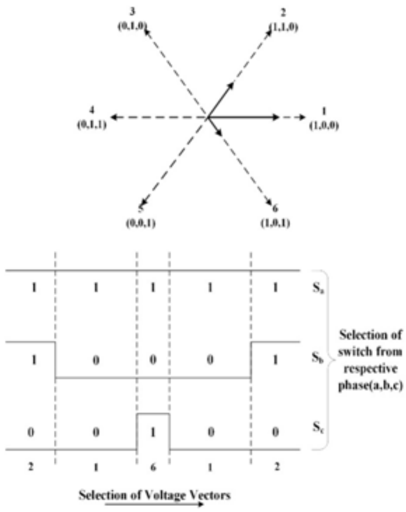

Fig. 4. Illustration of NSPWM operation.

TABLE 4. Comparative analysis of various PWM techniques for various application based on the author'sproposal.

S.No	Author and Year	Formula for Modulation Index (Mi) and Value	Type of Power Electronic Circuit.	Type of PWM technique used.	Analysis of the work presented.
1	S. Umashankar et al in 2018[34]	Proposed Mi should be high value.	Three Level NPC Inverter	CMV, SVPWM	Reduced switching losses and losses due to a junction temperature of NPC inverter.
2	T.M. Parreiras et al in 2018[12]	Not Described	Three Level NPC Medium Voltage Converter	ZSS, Carrier Based PWM	Application to high-frequency motor drives in mining sites to maintain the voltage level in the specified range. Where the motor is connected to the transformerless medium voltage VSC.
3	Bharatiraja et al in 2018[16]	Mi = 0.8	NPC Multi-Level Inverter	Multi-Carrier PWM, SVPWM	To suppress the bearing currents of the IM without affecting THD profile of inverter voltage. A fourth arm is Implemented for the successful operation in NPC MLI.
4	Tian Jie et al in 2017[25]	0<Mi<1 and Modulation Ratio Mf = 0.9	Cascaded H Bridge – Electronic Power Transformer	PSPWM, unipolar PWM	The minor effect of the SPWM on the CMV and for the application of Cascaded converters are presented.
5	Ji-Yoon Yoo et al in 2017[48]	Mi = (3Vref)/(2Vdc)	Voltage Source Inverter	AZSPWM	Less number of switching for AC drive with heat characteristics by various AZSPWM techniques.
6	S.M. Mohiuddin et al in 2017[9]	Mi<1	Three phase Voltage Source Converter	THIPWM	Grid-connectedUltracapacitor energy storage system (UCESS) for the linearization of active and reactive power during integration and to maintain voltage requirements.
7	Sachin Jain et al in 2017[40]	Mi depends on PV sources and their MPPT algorithm, Mi = 0.8125	Cascaded Five Level Multi-Level Inverter	Proposed PWM based on PV voltage	Switching losses are reduced and the condition of each MLI is studied for a2.5kW system with switching frequency of 2.5kHz and Vdc of 400V. circulating currents are minimized with less switching operations in PV connected system.
8	M. H. Hedayati et al in 2017[38]	Not Described	Symmetrical H Bridge Single Phase Inverter	Unipolar PWM with carrier opposite phase shift	7.5kW Parallel single phase PWM rectifier is experimentally used under various conditions of interleaving angle like 0^0, 90^0, 180^0 for the effectiveness and to suppress the harmonics. By this method, a THD of 1.23% is achieved.
9	V. Padhee et al in 2017[49]	Mi = (Vo/Vdc) for VSI. Mi = (Ii/Idc) for CSR.	Indirect Matrix Converter (IMC)	SVPWM	High modulation index range (HMIR) and low modulation index range (LMIR) are analyzed for the operation of IMC for the effective operation of CMV reduction. Experimental results are presented with Mi = 0.7 for HMIR and Mi = 0.4 for LMIR by a grid voltage of $120V_{LL}$,50kW, switching frequency of 5kHz, the output frequency of 30Hz with a power factor of 0.8.where HMIR as 0.577<Mi<0.866 and LMIR as 0<Mi<0.577.
10	Khaliqur Rahman et al in 2017[50]	0<Mi<1 Mi = 0.5	Three to Three Phase Indirect Matrix Converter	SVPWM	Improved SVPWM method is proposed to reduce peak of CMV by 48% without effecting voltage magnitude for the proposed three to three phase IMC connected to three phase IM.
11	Y. Lian et al in 2017[47]	Mi<0.4	Current Source Rectifier(CSR)- Current Source Inverter(CSI)	RCMVPWM, Average Value Reduction SVM(AVR SVM)	3 segment SVM, 3 Segment AVR SVM, and 4 Segment AVR SVM are proposed with the experimental setup with the preferred frequencies. Among these 3 segment, AVR SVM and 4 segment AVR SVM are preferable for the reduction of the CMV and CMC for current source drives at low Mi
12	J. Lyu et al in 2016[8]	0<Mi<1.15 Mf= 0.8	NPC Three Level Inverter	saddle SVPWM	DC bus of 200V, switching frequency of 20kHz, the range of output power is 0-200W are presented with the Saddle SVPWM method and compared with the conventional methods. Proposed modulation method gives the better output harmonics and ripples in neutral point voltage.
13	K. Ren et al in 2016[20]	0.4<Mi<1	NPC Three Level Converter	DZSC for DPWM	A 20kW, three-levelgrid-connected inverter is used to reduce switching losses and NP voltage control. These results are achieved by the CBDPWM formed by injecting DZSC.
14	G. Tan et al in 2016[46]	Mi = (2Vm)/Vdc 0.8<Mi<1.15	Three phase Two level Inverter	CMVRPWM	22kW, 380V, 50Hz, 1470RPM Induction motor with v/f control is analyzed for the elimination of spikes in CMV with the proposed algorithm based on current ripple losses optimization (CRLO) and switching losses optimization (SLO) CMVRPWM.
15	N. Prabaharan et al in 2016[27]	0.86<Mi<1	Hybrid Multilevel Inverter	PDPWM, VFPDPWM	Presents different phase dispositions for the suitable operation of hybrid MLI with PV based grid-connected systems.
16	M. Harsha Vardhan Reddy et al in 2015[44]	Mi=0.8	Asymmetrical Dual Inverter	DPWM	1Hp, 415V, 1.8A, 50Hz three phase induction motor is fed from 9.2 kVA PWM inverters under asymmetrical condition. A switching frequency of 1kHz is preferred for the reduction of CMV by 40%.
17	T. Ahmad et al in 2015[52]	Mi = 0.7	Voltage Source Inverter	AZSPWM	CMV is reduced by 17% by AZSPWM method instead of SVPWM. Switching frequency is of 6kHz and an induction motor is considered as the load in the autonomous micro grid.
18	S. Alireza et al in 2015[19]	0<Mi<1.15	Voltage Source Inverter, Two level	Implicit ZSDPWM (IZDPWM)	To improve the output quality and to the linearity of the output voltage control, IZDPWM is presented with the line to line voltage as reference wave and compared with the carrier wave. Quality of output voltage is increased by 15%.
19	F. Bradaschia et al in 2015[11]	$M_{bot} + M_{top} = 1$. If $M_{bot} = 0.5$ Then $M_{top} = 0.5$. If $M_{bot} = 0.3$ Then $M_{top} = 0.7$	Nine Switch Dual Bridge Back to Back Converter (Top and Bottom)	Scalar PWM with ZSS Injection	40kW, 1200V, 50A nine switch inverter prototype is presented for the experimental analysis. With novel nine switchesthree-phase inverter the power losses of the operation are reduced by the less number of switches and clamping the output voltage by preferred PWM technique.
20	R. Maheshwari et al in 2015[54]	0.5<Mi<1	Parallel Connected Voltage Source Inverter	SVPWM, DPWM, RSPWM	Parallel inverters are operated with the DC link voltage of 500V, switching frequency of 2.5kHz, thereference frequency of 50Hz is considered for the experimental analysis with a phase shift between carrier waves of parallel inverters. By DPWM technique they achieved small peak and RMS values of leakage currents with avoidance of low-frequency harmonic content.
21	M.C. Cavalcanti et al in 2014[53]	Mi = (2Vac)/Vo 0<Mi<1.15	Boost Converter (DC-DC) + Voltage Source Inverter	RSPWM1	87.88% efficiency is obtained with the experimental results by proposed PWM method operated for the prototype of 10A/2kW PV system with thetwo-stage converter.
22	M.C. Cavalcanti et al in 2012[30]	Mi = √(3) Vkn* / Vpn Mi=0.6	Neutral Point Clamped Inverter	3medium vectors, and 2 medium vectors and 1 zero vector SVPWM	A switching period of 200μs, source frequency of 60Hz, DC link voltage of 240V and preferred LC filter is used in simulation analysis to present the current harmonic spectrum. The performance of the NPC is increased and obtained a constant CMV to transformless PV system.
23	Ahmet.M.Hava et al in 2011[31]	0<Mi<0.907	Voltage Source Inverter	AZSPWM, DPWM, NSPWM	Enhanced PWM module of DSP make of Texas instrument is used in experimental setup for the various operations of PWM methods. A 4kW, 1440 rpm, IM drove from VSI to 176.7V, 50Hz with constant v/f control. Preferred switching frequency is 6.6kHz for CPWM and 10kHz for DPWM to maintain a better interfacing performance between VSI and IM.
24	Ahmet.M.Hava et al in 2009[43]	Mi = V1m/(V1m 6step) Mi varies, depends on type of inverter	Three phase Inverter driven by diode rectifier front end	RCMVPWM	A comparative analysis is performed on various RCMVPWM methods with various Mi values to achieve the better performance characteristics of CMV and CMC for a DC voltage of 500V. based on the comparison NSPWM is well suitable for the driver application.
25	X. Yuan et al in 2009[14]	Not Described	Multi-Level Neutral Point Clamped Inverter	Carrier-based PWM, ZSS	1kW three level NPC prototype is operated with switching frequency of 6kHz, the line voltage of 170V, line frequency of 60Hz, DC link reference voltage value of 245V for the steady state operations of the system. With the proposed algorithm, reduction of CMV is obtained for 1kW DSP controlled inverter system.
26	P. K. Chaturvedi et al in 2008[26]	Amplitude modulation index Mi = √(Vd^2 + Vq^2)	Three level Diode Clamped Inverter	SPWM, PDSPWM, PODSPWM	With PDSPWM the % THD value reduced to 2% from 29% and increased fundamental voltage from 173.2V to 181.2V with switching frequency operation of 2kHz. CMV is reduced to 34V from 60V. This experimental operation is verified with dSPACE DS1104. Parameters for the analysis is 500kW, 400V, 50Hz.
27	P. Garcia et al in 2007[13]	Not Described	Voltage Source Inverter	ZSSPWM	Application to induction motor control leads to add components like sensors and cabling are reduced with the proposed application of negative sequence carrier signal and zero sequence carrier signal. Along with this, the accuracy of the system is increased.
28	J. Rodriguez et al in 2004[37]	Mi = √(3) Vref / (2 Vcc Cn) Cn is cell number in phase. Mi=0.9	Cascaded Multilevel converter and Inverter	MLSPWM	A comparative analysis is presented between 7 level and 11 level inverter with the reduced CMV and improved efficiency of the system. The proposed modulation method is suitable for the 7 level or more of it. The %THD comparison is presented with respect to the modulation index range from 0 to 1.
29	H. Zhang et al in 2000[36]	Mi = V1m/(Vdc/2) Mi = 1 for SPWM Mi = 1.15 for SVPWM	Three phase Multilevel Inverter, Neutral Point Clamped Inverter	SPWM, SVPWM	15Hp, 150rpm, 460V, 5Hz, synchronous motor fed from 3 level inverter with switching frequency of 500Hz and 1000Hz with a modulation index of 0.175 and 0.58 respectively for comparative analysis under SVPWM method. The proposed method of SVPWM and SPWM are suitable for medium voltage applications to reduce the CMV and to improve the reliability of the system.

NSPWM is proposed as one of the methods for the carrier phase shift CMVRPWM with the selection of near state non zero voltage space vector for the elimination of voltage spikes [46]. NSPWM is considered for the alternating carrier waveform of the CMVR-PWM method [31]. Novel vector selection based on the nearest three vector strategy based SVM (NTV-SVM) is proposed with zero sequence voltage injection for the modulation signal to form a new modulated signal. Based on the carrier sequence NTV-SVM is presented for the NPC converter [10].

4 ANALYSIS OF PWM METHODS WITH VARIOUS POWER ELECTRONIC CIRCUITS

More attention towards the PWM methods and their applications to the various inverter and converter circuits under drives and grid-connected operations made us present the comparative analysis of the selected research work from citations. From comparative table 4, readers can easily understand the method of PWM, type of power electronic converter or inverter, application and presented modulation index from researchers work.

5 Conclusion

Brief comparative experimental analysis of various power electronic circuits with different PWM techniques for their control to reduce the CMV and switching losses is presented with THD analysis. Based on the considered parameters of various systems RCMVPWM, which consist of AZSPWM, RSPWM, NSPWM are the most efficient modulation methods for the existence to improve the performance of the system. A well suitable inverter design is neutral point clamped (NPC) inverter with various level output voltages based on the application of the system. For PV based system operations, NSPWM is the preferable modulation technique to achieve the required output parameters with favorable efficiency. In motor drive applications, AZSPWM and DPWM are preferable for the operation of dual inverter.

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