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Multi-Carrier PWM Techniques Applied to Cascaded H-Bridge Inverter

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Abstract: **This manuscript presents a three-phase five-level cascaded H-bridge inverter. The Multi-carrier PWM technique is classified into phase as well as level-shifted PWM techniques. Again level-shifted PWM technique is classified into PD, POD, and APOD. In literature, many researchers used PD, POD, and APOD techniques for controlling three-phase five-level inverter. This paper applied the phase-shift PWM technique to a three-phase five-level inverter. The presented technique has many advantages compared to conventional SPWM, single pulse PWM, multiple pulse PWM, third harmonic injecting method. The advantages are low THD value, low switching losses, and better yield voltage along with current waveforms. The anticipated topology result is established in MATLAB Simulink.**

Keywords: Multilevel inverter, PWM techniques, Voltage, Switches, THD, Current

I INTRODUCTION

Authors in [1] reviewed different single-phase symmetrical and unsymmetrical inverter topologies and discussed their merits and demerits. Different inverter control pulse width modulation techniques and different advanced PWM techniques, however, different algorithms were reviewed in [2]. Three-phase three-level inverter used in [3] for power quality improvement in distribution as well as reviewed different robust control techniques for controlling inverter. The redundancy SVM method is implemented inside [4]. The presented technique determines switching sequence, minimizes switching losses, and improved THD in output voltage. A reduced device count five-level inverter is presented in [5].
The presented inverter has a single DC source and four semiconductor devices. The presented topology output current results maintained IEEE 519 standards. Model predictive controller proposed for five-level ANPC inverter [6]. The proposed controller reduced computation time, reduce the number of switching states and it reaches the reference value with less time. Reference [7] presented a five-level grid-connected inverter. The presented topology is linked to a grid without a power converter. The usage of the proposed inverter is low cost, fewer switching devices, and low switching losses. Z-source inverter [8] implemented for photovoltaic applications. The presented technique has High gain, low voltage, and sources it supplies continuous current**.** The advantages of the converter are more efficiency and good steady-state output.
Z-Source three-phase two-level inverter implemented [9]. The proposed topology results are compared to the conventional three-level inverter. Transformerless five-level inverter is implemented for renewable energy source applications [10]-[11]. The proposed technique is connected to a grid without a neutral point. Series resonant five-level inverter is analyzed in [12]. The proposed inverter is suitable for hybrid energy DC sources. This paper [13] compared two inverter topologies**.** the proposed technique increases the efficiency of FPTL VSI. To decrease common-mode voltage and AC ripples implemented a parallel three-level inverter [14]. In the conventional method, the DC side voltage is improved proposed method reduces the voltage to Vdc/12. In [15]-[16] three-phase three-level inverter is used for power quality improvement.

II CASCADED H-BRIDGE INVERTER

Fig.1 shows 3 Phase 5 Stage Cascade H-bridge Inverter. The presented inverter has 3-legs, each leg has two H-bridges.

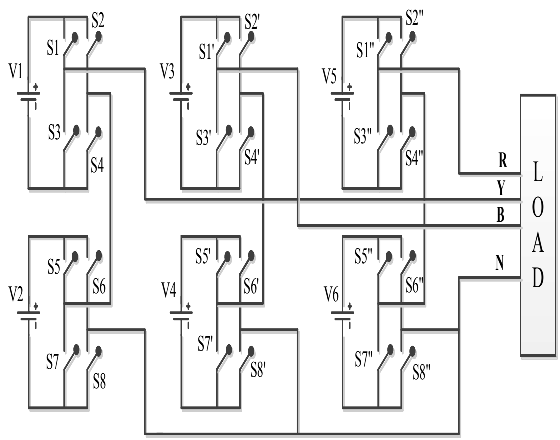

Fig.1. 3-phase 5-stage cascaded H- bridge inverter.

This inverter S1 and S3 switches are complementary, these switches are controlled by carrier wave one. S2 and S4 switches are complementary; these switches are controlled by carrier 4. S5 and S7 switches are complementary; these switches are controlled by carrier wave three. S6 and S8 switches are complementary.
3 Phase 5 Stage Cascade H-bridge Inverter has 6 DC sources and a total of 24 switches. Each leg has two DC sources and 8 switches. One leg is assumed as R phase, the second leg is assumed as Y phase and the third leg is assumed as B phase. This three R, Y, and B phases are connected to balance Load.

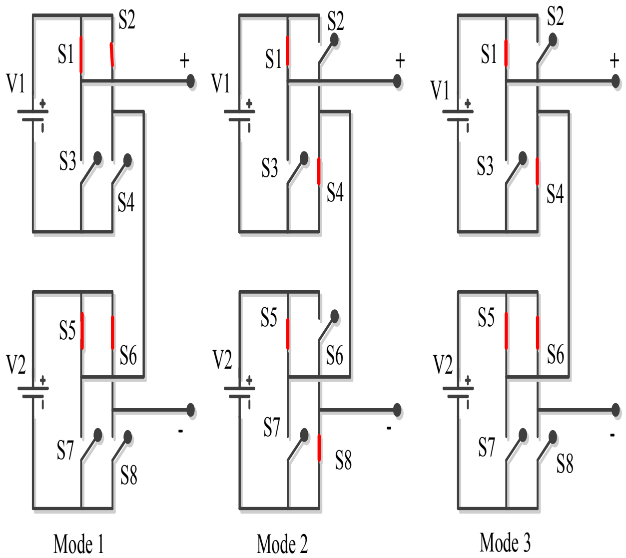

Fig.2. MLI Mode I, II, and III of operation

Figure 2 shows the three operating modes of a multilevel inverter. In mode, I, the operating switch upper H-Bridge two upper switches ON, lower Switches are OFF. So it produces an output voltage level of zero.
In mode II, the operating switches, upper H-bridge two switches are ON, those switches are one and four remaining two switches are off. Lower H-bridge operation is also the same as upper H-bridge. So it produces a production voltage level at Vdc.

In mode III operation switches S1, S4, S5, and S6 turn ON in leg 1 and outstanding switches S2, S3, S7, and S8 turn OFF. So it produces an output voltage level at Vdc/2.

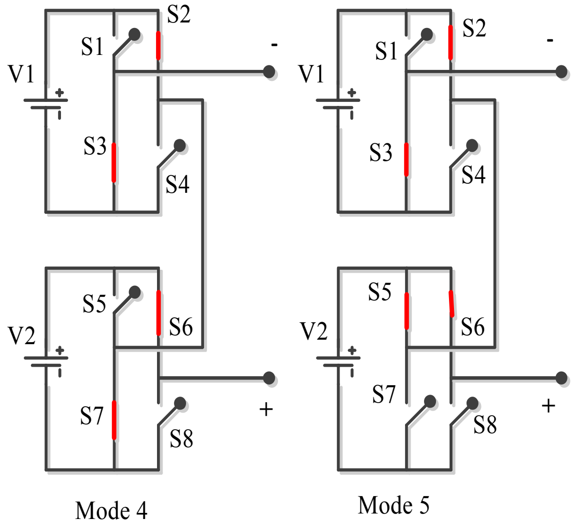

Fig.3. MLI Mode IV and V operation

Figure 3. Operating two modes of operation, those two modes are negative supply generation. Mode of operating circuit red color indicates switch close and switch open indicates switch off. The total one to five modes operation switches operation explained clearly in a table.

TABLE 1: SWITCHING SEQUENCE

Output Voltage	S1	S2	S3	S4	S5	S6	S7	S8
0	1	1	0	0	1	1	0	0
Vdc	1	0	0	1	1	0	0	1
Vdc/2	1	0	0	1	1	1	0	0
-Vdc	0	1	1	0	0	1	1	0
-Vdc/2	0	1	1	0	1	1	0	0

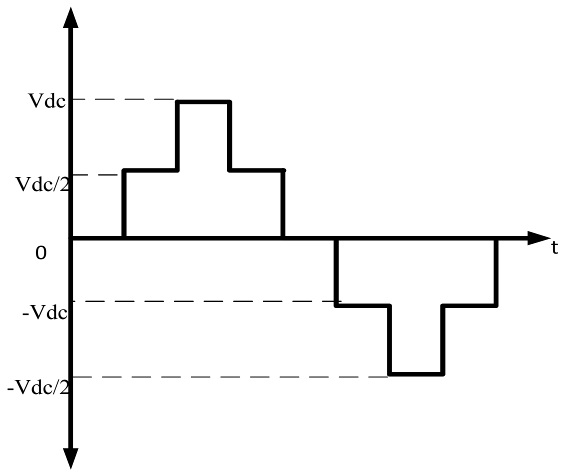

Fig.4. Model Waveforms of 5- level inverter

III MULTI-CARRIER PWM TECHNIQUES

This section presents how to control multilevel inverter output voltage using different PWM techniques. SPWM, single pulse PWM, multi-pulse modulation, selective harmonic elimination, and SVPWM. These techniques are used for controlling the single-phase and three-phase two-level as well as three-level inverters.

Different algorithms are used for controlling multilevel inverters. Space vector-based algorithm is a vector-based algorithm and it controls all in group .voltage levels based algorithm it is the time-based algorithm and it controls each phase individually.

The magnitude depends algorithms are classified into multicarrier PWM, hybrid modulation, SHE, and NLC. The hybrid modulation technique is used for asymmetric-type multilevel inverters. Selective harmonic elimination technique used for eliminating selected harmonics. Nearest level control technique used for when several levels high inverter.

Multicarrier PWM is an extension of the SPWM technique. Multicarrier PWM is classified into phase and level-shifted PWM. In the Phase shifted PWM technique, you need a multi-level inverter with a voltage level of "m" (ml) on the triangular carrier. "M" all carrier waves are the same amplitude (from 1 to -1).

Phase Shift PWM Technology - With a transport delay two neighboring carrier signals,

$$\varphi_{cr} = \frac{360^0}{(m-1)} \quad (1)$$

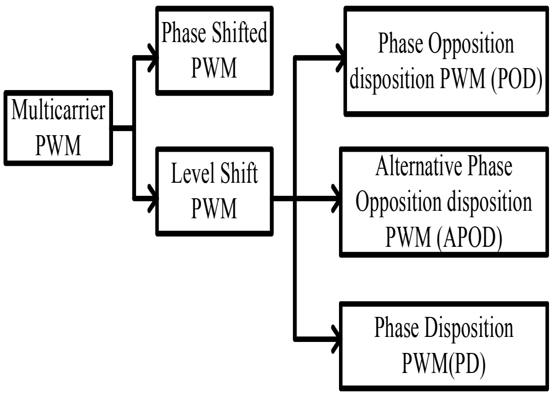

Fig.5. multicarrier PWM technique

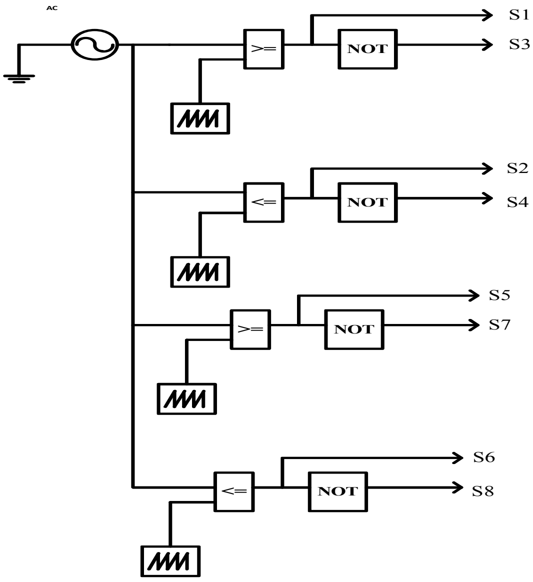

Fig.6. Multicarrier PWM technique logic

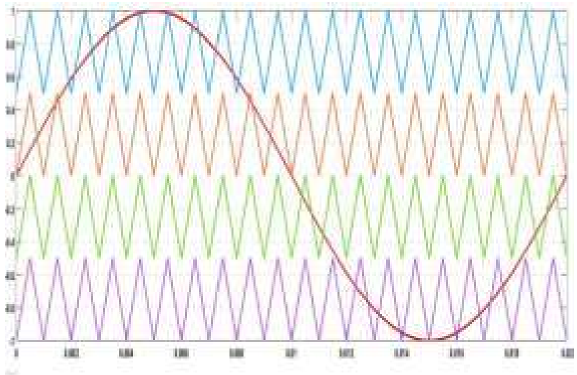

Fig.7. Phase Disposition PWM

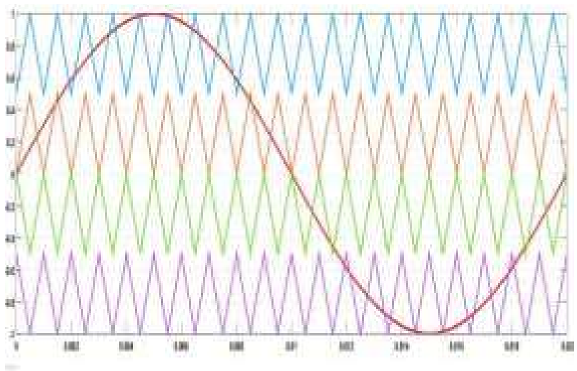

Fig.8.Phase Opposition Disposition PWM

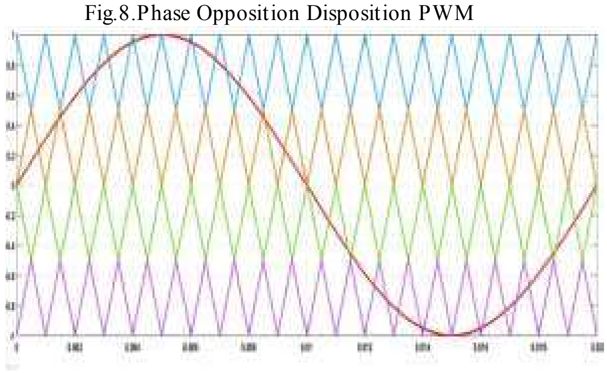

Fig.9.Alternate Phase Opposition Disposition PWM

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Fig.7 represents the PD PWM technique. In this procedure, four transporter signals are in phase with the same magnitude and same frequency.

Fig.8 represents the POD PWM technique. In this method 1 and 2 transporter signal is in phase and 3 and 4 are in phase with the same magnitude and same frequency. Carrier signals 1, 3 and 2, 4 are 180 degrees out of phase.

Fig.9 represents the APOD PWM method. In this technique 1, 2, and 3, 4 carrier signals are 180 degrees out of phase with the same magnitude and frequency.

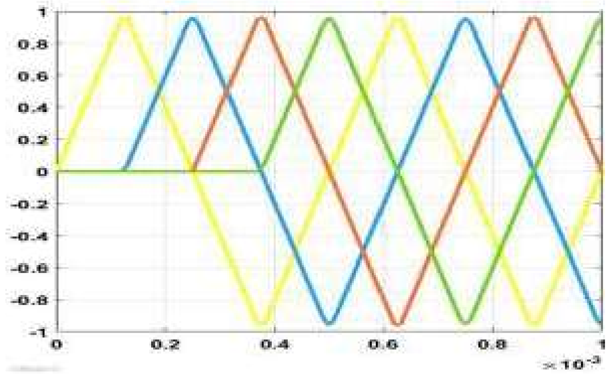

Fig.10 Phase-shift PWM technique

Fig.10 represents the Phase-shift PWM technique. In this technique, four transporter signals are having identical magnitude and frequency but any two carrier signals differ by 90 degrees phase shift.

S.No	Conventional PWM	Multi-carrier PWM
1.	Conventional PWM techniques are SPWM, single pulse PWM, Multiple pulses PWM, and third harmonic injecting method.	Multi-carrier PWM techniques are level shift and phase shift PWM techniques.
2	These methods are suitable for the two-level inverter.	These methods are suitable for multilevel inverters and higher-level inverters.
3	This method switching losses and power loss are more.	This method switches losses are less.

IV SIMULATION RESULTS

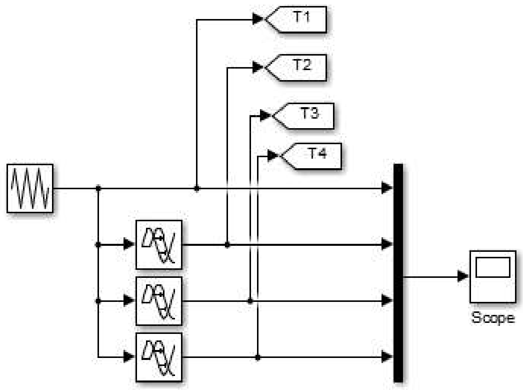

Fig.11 phase shift PWM carrier signal generator

Fig.11 represents the time shift PWM carrier signal generator. This circuit generates one triangular signal and three transport delay signals. Carrier signal starts at 0, transport delay 1 starts at 90 Degrees, transport delay 2 starts at 180 degrees, and transport delay 3 starts at 270 degrees.

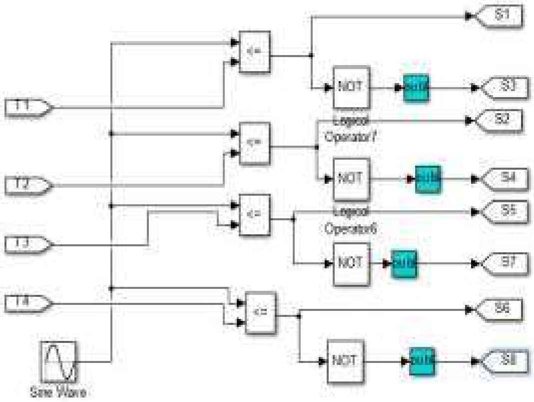

Fig.12 phase shift PWM technique Matlab diagram

Fig.12 represents the time shift PWM method. This circuit has four carrier signals T1, T2, T3, and T4 that are compared with a sine wave. The connected logic operator compared one carrier signal and one sine wave and generates a Pulse.

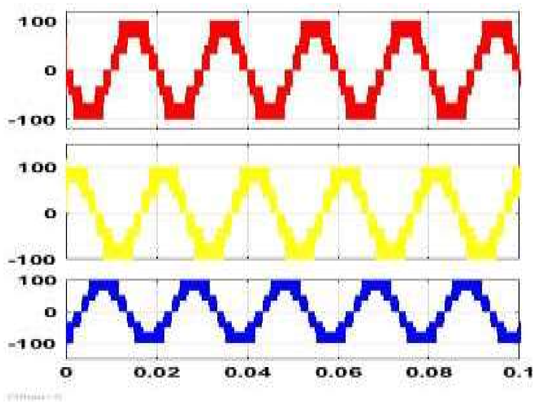

Fig.13. multilevel inverter three-phase output voltages

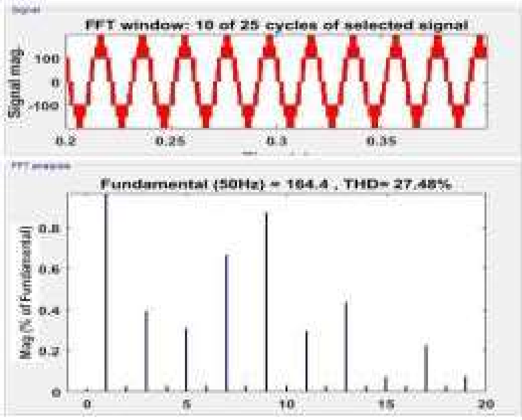

Fig.14. MLI output voltage and THD value

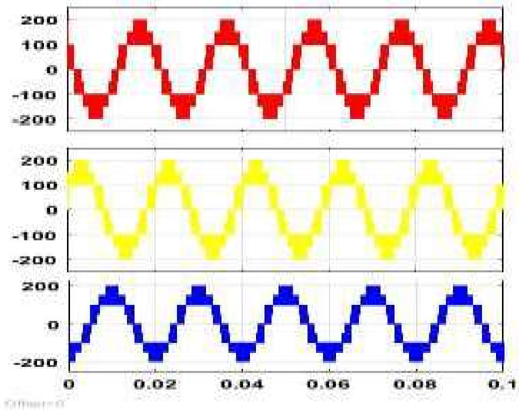

Fig.15. multilevel inverter three-phase line-line voltages

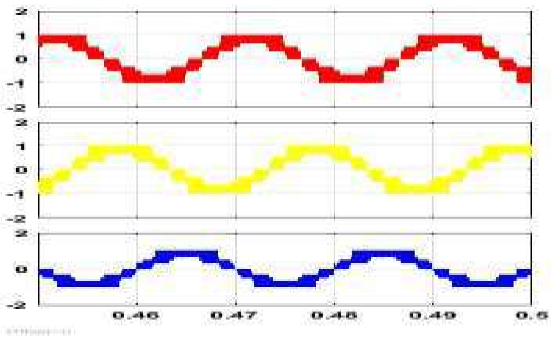

Fig.16. multilevel inverter three-phase current waveforms

Fig.13 shows the multilevel inverter three-phase output phase-phase voltages. The magnitude of peak to peak value is 100V. Fig.14 shows the multilevel inverter R phase output voltage and THD value. The THD value is 27.48%. Fig.15 shows the multilevel inverter three-phase line-line voltage. The magnitude of peak to peak voltage is 200V. Fig.16 shows multilevel inverter three-phase current waveforms. The magnitude of peak to peak current value is 1A. I conclude that the presented topology is very suitable for renewable energy sources, PV to grid integration, wind to the grid, and standalone applications. In literature, many researchers implemented three-phase inverter and five-level inverter separately but in this combined topology was implemented.

IV CONCLUSION

This paper presented a 3-phase five-stage cascaded H-bridge inverter. The proposed topology is controlled by the phase-shift PWM technique. The presented technique has many advantages compared to conventional PWM techniques like SPWM, single pulse PWM, multiple pulses PWM, third harmonic injecting method. The advantages are low THD in output voltage, low switching losses, and better production voltage and current waveforms. The planned topology result is demonstrated in MATLAB Simulink.

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