

PV ARRAY CONNECTED T-TYPE MULTILEVEL INVERTER WITH AN IMPROVED PWM TECHNIQUE

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ABSTRACT-Solar energy generation has become an emerging area for years now but the integration of the generated energy into the grids have been an issue. In recent times, reduced switch count multilevel inverter (RSC-MLI) has become popular in power electronic converters. The integration of the solar array output with the help of these RSC-MLI provides a new method for the utilization of solar energy. To control this RSC-MLI topology with PV array, a novel modulation scheme is suggested here. Multireference scheme is one of such modulation scheme reported for various RSC-MLI topologies, such as T-type. However, the performance of this conventional scheme results in high total harmonic distortion (THD) in line voltages, when compared with the conventional level shifted pulse-width modulation scheme. To overcome this problem, a modified multi-reference dual-carrier modulation technique with multiple references and two carriers is proposed for the RSC-MLI with PV array. To implement this proposed modulation technique, an alternate carrier and modulation signals arrangement with multiple carriers and single reference is also presented. A comparative analysis of THD values of the proposed RSC-MLI with PV and conventional modulation schemes is carried out on a five-level T-type MLI. The validation of the proposed techniques are done using SIMULINK software.

Keywords: Total Harmonic Distortion (THD), Reduced Switch Count Multilevel Inverter (RSC-MLI),

1 INTRODUCTION

Multilevel inverters (MLIs) use the concept of addition of small multiple voltage levels and possess various advantages like reduction in dv/dt , electro-magnetic interference and total harmonic distortion (THD) [1, 2]. In literature, cascaded H-bridge (CHB), diode clamped and flying capacitor are the widely accepted classical MLI topologies, and are reported with various modulation strategies, such as sinusoidal pulse-width modulation (SPWM), selective harmonic elimination (SHE), third harmonic injection and space vector modulation (SVM) [3–8].

Among these conventional schemes, SPWM is very popular due to its easiness in implementation and is further classified into level shifted pulse width modulation (LSPWM) and phase shifted pulse-width modulation (PSPWM) [9]. LSPWM is sub-classified into in phase disposition (IPD), opposite phase

disposition (OPD) and alternate phase disposition (APD). It is well reported that LSPWM-IPD results in better line THD performance compared with LSPWM OPD, LSPWM-APD and PSPWM [9]. In practice, MLIs are limited to lower levels, because of its increased switch count at higher levels. This increase in switch count not only turns the topology complex but also raises its overall cost. From past two decades, there is an extreme exploration carried out to evolve newer topologies with reduced switch count (RSC). T-type is one of the recently reported RSC MLI, which gathered much attention. T-type possesses most feasible and generalized configuration with 37.5% reduction in switch count compared with classical topologies [10–12].

Extreme reduction in switch count of RSC-MLI's created diversified effects on switching states such that, most popular conventional SPWM schemes are insufficient to implement them [13, 14]. In literature, few of such RSC configurations are reported with SHE and SVM methods. However, these schemes involve complex mathematical calculations, which turn more complicated at higher levels [23]. Recently, few RSC topologies are reported with multi-carrier modulation schemes involving logical expressions. However, these logical expressions are not generalized, and vary with variation in number of levels and topological arrangement [15]. A novel multi reference modulation scheme for T-type MLI is reported, and a seven-level T-type with multi-reference modulation for grid connected systems is reported in [16, 17].

This scheme is accepted widely, due to its generalized nature which can be applicable to any RSC configuration [18–21]. However, this scheme suffers from high THD in line voltages when compared with the conventional LSPWM scheme. In [22], a phase shifted multi-reference modulation scheme is reported for cascaded T-type topologies. In this method, the number of carriers is equal to the number of modules that are connected in cascade and moreover, when considering a single module its performance is identical to a conventional multi-reference modulation scheme. From the keen literature review of various multi-reference and multi-carrier modulation schemes reported for

various RSC-MLI topologies, it is observed that, most of these schemes either result in high THD in line voltages or suffers from generalisation of switching scheme at higher levels.

This observation is clearly discussed in this paper and simple generalised modulation schemes are proposed, which obtain satisfactory line voltage THD performance on any RSC-MLI topology. The structure of this paper is as follows. In Section 2, performance of conventional multi-reference modulation scheme on a five-level T-type MLI is discussed and the reason for its poor THD performance is analyzed. In Section 3, modifications in the conventional multi-reference modulation scheme to improve its THD performance are suggested and a modified multi-reference dual-carrier modulation scheme is proposed. In addition, to implement the proposed scheme an alternative carrier and modulating signal arrangement is presented and generalisation of this scheme to higher levels is discussed with the help of a flowchart. Performance of the proposed scheme is investigated on a five-level T-type topology and their superior harmonic performance over conventional multi-reference modulation can be observed. Section 4 presents simulation results of the proposed and conventional modulation schemes on a five-level T-type MLI.

Obtained simulation results are validated experimentally with dSPACE-1104 R&D control board. Finally, a comparative performance of the proposed and conventional modulation schemes, for a five-level MLI, at various modulation indices is carried out.

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Obtained simulation results are validated experimentally with dSPACE-1104 R&D control board. Finally, a comparative performance of the proposed and conventional modulation schemes, for a five-level MLI, at various modulation indices is carried out.

2 T-TYPE CONFIGURATION AND MULTI-REFERENCE MODULATION SCHEME

2.1 T-type configuration

T-type topology is the congregation of bidirectional and unidirectional switches. To obtain five levels in phase voltage, four unidirectional switches (S_1, S_2, S_3 and S_4), one bidirectional switch and two dc sources are required per phase as shown in Fig. 1. Considered bidirectional switch is represented with two back-to-back connected unidirectional switches (S_5 and S_6).

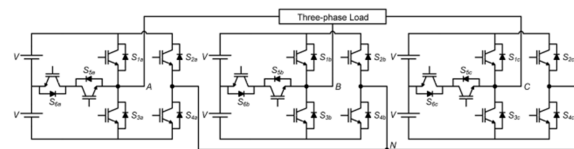


Fig. 1 Five-level T-type topology

The four unidirectional switches form an H-bridge and the isolated dc supplies are connected to H-bridge through the bidirectional switch. As the level increases, requirement of bidirectional switches and dc sources increases, but the switches in the H-bridge remains unaltered. To obtain 'n' levels in phase voltage and '2n-1' levels in line, '4 + (n-3)

switches are required per phase. Here, four indicate number of switches in H-bridge and ‘n-3’ indicate additional unidirectional switches required.

2.1.1 Operation of the T-type MLI for five levels in phase: To obtain five levels in phase voltage, i.e. 2V, V, 0, -V and -2V, two dc sources (of each V volts) in each phase are required. In every phase, switching S4 – S2 and S1 – S3 obtains 2V, -2V levels, respectively. Similarly, switching S5 – S4 and S6 – S3 obtains + V and -V levels, respectively. Switching states to obtain desired voltage levels per phase are shown in Table 1.

Table 1

Operating switches to obtain respective voltage levels in each phase

Switches in conduction	Voltage level
S ₅ and S ₄	V
S ₁ and S ₄	2V
(S ₁ and S ₂) or (S ₃ and S ₄)	0
S ₆ and S ₂	-V
S ₃ and S ₂	-2V

2.2 Conventional multi-reference modulation – performance analysis Conventional multi-reference modulation involves single carrier and (n-1)/2 shifted dc references to obtain ‘n’ levels in phase voltage [16]. In literature, this scheme is well reported for T-type topologies.

2.2.1 Observation: Performance analysis of conventional multi reference scheme on a five-level T-type topology with 2 kW, 0.9 pf RL load is carried out, at 1500 Hz carrier frequency (fc). Obtained phase voltage, line voltage and load currents are shown in Fig. 2a with their respective harmonic spectra in Fig. 2b. From the harmonic spectra shown in Fig. 2b, the following conclusions can be drawn.

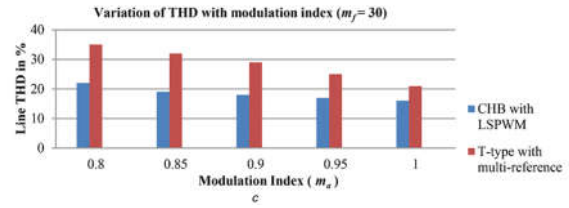
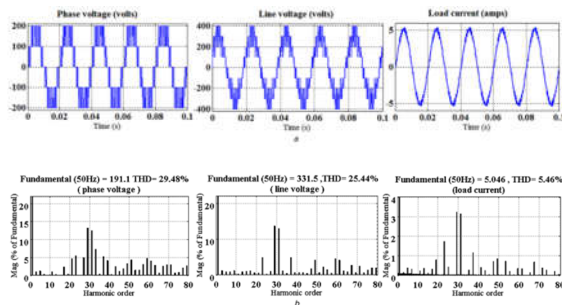


Fig. 2 Performance analysis of multi-reference modulation scheme on five-level T-type configuration with ma = 0.95 and fc = 1500 Hz (a) Phase voltage, line voltage and load current, (b) Respective harmonic spectra, (c) Comparative harmonic performance of conventional multi-reference modulation scheme for five-level T-type MLI and LSPWM for five-level CHB

- i. Amplitude of harmonic component at integer multiples of carrier frequency is zero.
- ii. Odd order harmonics appear in the side band centred at integer multiples of carrier frequency.

Harmonic performance of conventional multi-reference modulation is compared with most popular LSPWM (IPD) modulation on a five-level CHB. Comparative line THD performance of both the schemes for various amplitude modulation indices (ma) is carried out and is observed that conventional multi-reference modulation results in high THD in line voltages compared with LSPWM modulation. This observation is clearly presented in Fig. 2c.

2.2.2 Reason analysis: Reason for poor THD performance of conventional multi-reference scheme can be understood, by referring to Fig. 3. Position of references and carrier for obtaining five levels in phase voltage is provided in Fig. 3a, where Reference1 is the modulus of modulating signal and Reference2 is obtained by shifting Reference1 by its carrier peak. From Fig. 3b, it can be stated that referring a unipolar carrier with respect to the modified (unipolar) modulating signal (Reference1) is similar to referring a unipolar carrier to the positive half, and its mirror image to the negative half of the modulating signal, respectively.

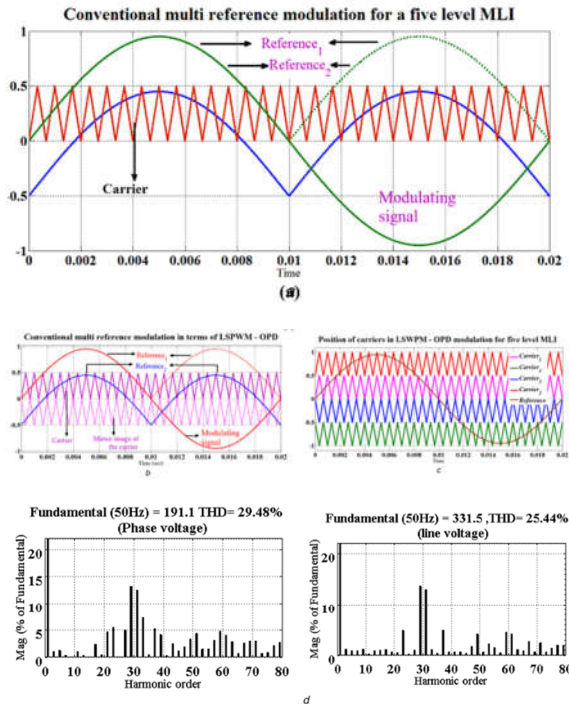


Fig. 3 Comparison of LSPWM-OPD and multi-reference modulation scheme with $m_a = 0.95$ and $f_c = 1500$ Hz (a) Conventional multi-reference modulation scheme for a five-level T-type, (b) Comparison of position of carriers in multi-reference modulation in terms of LSPWM-OPD scheme, (c) Position of carriers in LSPWM-OPD modulation scheme, (d) Phase and line harmonic spectra of LSPWM-OPD for a five-level CHB

The position of carrier and its mirror image with respect to the modulating signal is shown in Fig. 3b, and resembles the position of carriers in LSPWM-OPD scheme, i.e. is shown in Fig. 3c. Careful examination of Figs. 3b and c verifies that position of carrier in multi-reference modulation and LSPWM-OPD are identical. Further this can be confirmed by comparing phase and line harmonic spectra of both these conventional schemes. Harmonic spectra of phase and line voltages of LSPWM-OPD for a five-level CHB are depicted in Fig. 3d. Appearance of harmonic content in the sidebands centered at integer multiples of carrier frequency is reported in [9] and the same can be observed from Fig. 3d.

It is to be noted that conclusions drawn from harmonic spectra of multi-reference modulation scheme (Section 2.2.1) are similar to side-band harmonics of LSPWM-OPD spectra. From this analysis, it can be concluded that inherent switching action of conventional multi-reference modulation is

similar to LSPWM-OPD modulation. In literature, LSPWM-OPD is not preferred for three-phase MLI, due to its poor line THD performance [9]. Therefore, by referring conventional multi-reference modulation scheme to any typical RSC configuration also results in poor line THD performance.

Therefore, few modifications in carrier arrangements of conventional schemes are necessary to improve its harmonic performance [15, 16]. In this paper, a modified modulation scheme is proposed which serves as a better alternative to conventional modulation schemes.

MODULATION SCHEMES WITH IMPROVED THD PERFORMANCE

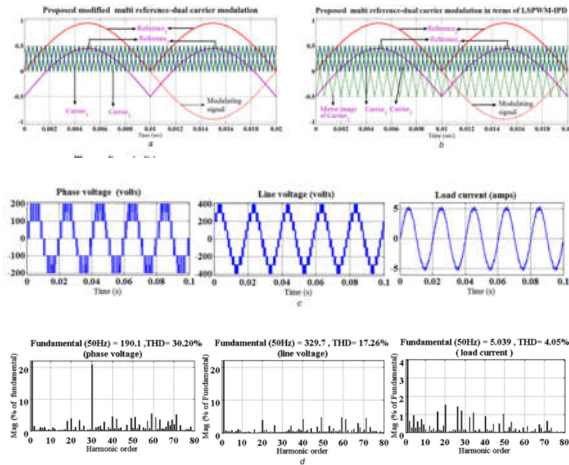
3.1 Multi-reference dual-carrier modulation scheme

One possible approach to improve THD performance of the conventional multi-reference modulation scheme is to change its carrier's position, such that its inherent switching scheme becomes similar to LSPWM-IPD. Therefore, a modified multi-reference dual-carrier modulation scheme is proposed by using two carriers and '(n-1)/2' shifted dc references to obtain 'n' levels in phase voltage. Arrangement of carriers and reference signals in the proposed scheme for a five-level MLI is shown in Fig. 4a. For a normalized modulating signal, carrier peak is decided by phase voltage levels in (1). Formula to calculate amplitude modulation index (m_a) is given in (2)

$$V_c = \frac{2}{n-1} \quad (1)$$

$$m_a = \frac{V_m}{(n-1)V_c} \quad (2)$$

V_m is the peak of the modulating signal, V_c is the peak of the carrier signal and n is the level in phase voltage. The basic constraint of switching logic in modified multi reference dual-carrier modulation is similar to the conventional multi-reference modulation. However, this conventional scheme involves only one carrier, i.e. Carrier1, where the proposed scheme involves two carriers, i.e. Carrier1 and Carrier2. Both these carriers are of the same polarity and magnitude, but opposite in phase, as shown in Fig. 4a. Carrier1 is used to obtain positive levels in phase voltage, by comparing with Reference1 and Reference2, for the positive half of the modulating signal.



Similarly Carrier2 is involved in obtaining negative voltage levels. The main intension behind using an additional carrier, i.e. Carrier2, is to make its inherent switching action similar to LSPWM-IPD. This can be understood by referring to Fig. 4b, where the position of Carrier1 and mirror image of Carrier2, together resemble the position of the carriers in LSPWM-IPD modulation scheme [9]. This statement can be further verified by observing harmonic performance of proposed multi-reference dual-carrier modulation. Performance of the proposed scheme is investigated on a five level T-type topology with 2 kW, 0.9 PF load. Obtained phase voltage, line voltage and load currents are shown in Fig. 4c. By its respective harmonic spectra shown in Fig. 4d, two observations can be drawn. i. Amplitude of harmonic content at even multiples of carrier frequency is zero, but dominant harmonics appear at odd multiples of carrier frequency. ii. Even-order harmonic components appear in the side-bands centred at odd multiples of carrier frequency. Similarly odd order harmonic components appear in the side-bands centred at even multiples of carrier frequency.

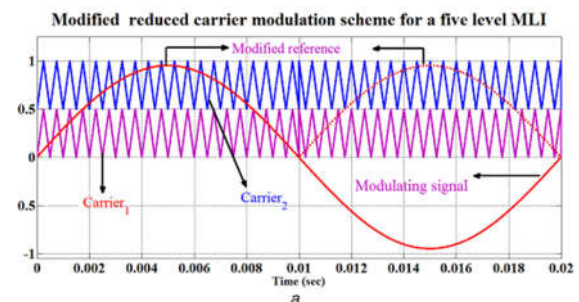
From these observations it can be concluded that harmonic spectrum of the proposed scheme is identical to LSPWM-IPD reported in [9]. Hence, it verifies that modified multi-reference dual-carrier modulation inherent switching action is similar to LSPWM-IPD. It is to be noted that, even though the phase voltage THD in Figs. 2b and 4d are almost same but the order of harmonics presented in these two spectra are different. However, there is a large difference in line voltage THD and this can be observed from Figs. 2b and 4d.

This is because, in modified multi-reference dual carrier modulation (and LSPWM-IPD) scheme, harmonics injected at odd multiples of mf in consecutive phases are co-phasal in nature. Hence,

they cancel out in line voltages, resulting in huge reduction in line voltage THD [9]. Therefore, in modified multi reference dual-carrier modulation scheme the line voltage THD is less compared with conventional multi-reference modulation scheme. Further, the modified multi-reference dual-carrier modulation requires multiple shifted dc references which will increase its complexity for closed-loop applications. To alleviate this problem, an alternate carrier and modulation signals arrangement with multiple carriers and single reference is presented in below section.

3.2 Modified reduced carrier modulation scheme (alternate carrier and modulation signals arrangement of the proposed PWM scheme)

An alternate carrier and modulation signals arrangement with multiple carriers and single reference is presented in this section and is identical to the proposed modified multi-reference dual carrier modulation scheme. This alternate method can be easily realisable on digital platforms. In this scheme, $(n-1)/2$ carriers are required to obtain 'n' levels in phase voltage. Carrier and modulation signal arrangement for a five-level converter is shown in Fig. 5a. If the modified reference (unipolar modulating signal) is less than Carrier1 peak, then a voltage band of 0–V is obtained in phase voltage. If modified reference is greater than Carrier1 peak, then V–2V band is obtained. Polarity of these voltage bands is decided by polarity of the modulating signal such that + 2V, + V, 0, –V and –2V levels are obtained in phase voltage.



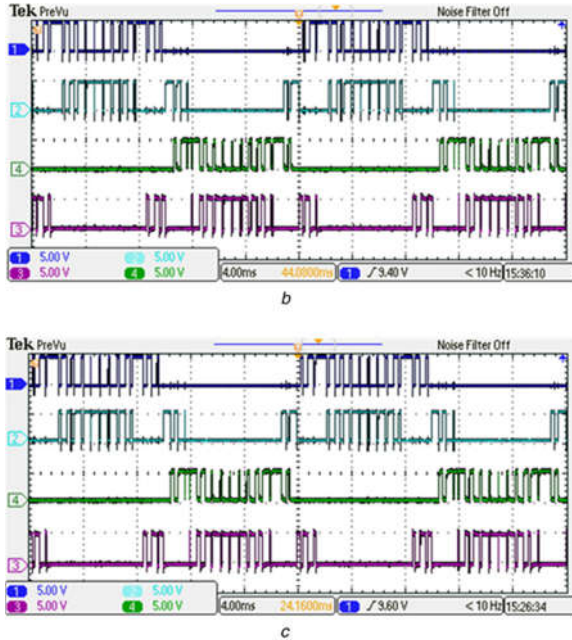


Fig. 5 Five-level T-type MLI PWM (a) Carrier arrangement of reduced carrier scheme for five levels in phase, (b) Switching pulses of modified multi-reference dual-carrier modulation, (c) Switching pulses of modified reduced carrier modulation. Trace 1: switching pulse to S5; trace 2: switching pulse to S1; trace 3: switching pulse to S3; and trace 4: switching pulse to S6

The difference in carrier position for the positive and negative half of the modulating signal can be noticed from Fig. 5a. It should be noted that arrangement of each carrier in this modified scheme is the effective way of representing Carrier1 and Carrier2 of the proposed scheme shown in Fig. 4a. This makes the inherent switching of this modified scheme identical to the proposed scheme (in Section 3.1). This can be further verified by observing the switching pattern of both these proposed and modified schemes on a five-level T-type topology, which is shown in Figs. 5b and c, respectively.

These switching pulses are observed for 1500 Hz carrier frequency for $m_a = 0.95$. The carrier and modulating signal arrangement for any number of levels and a flowchart to implement this method is shown in Fig. 6.

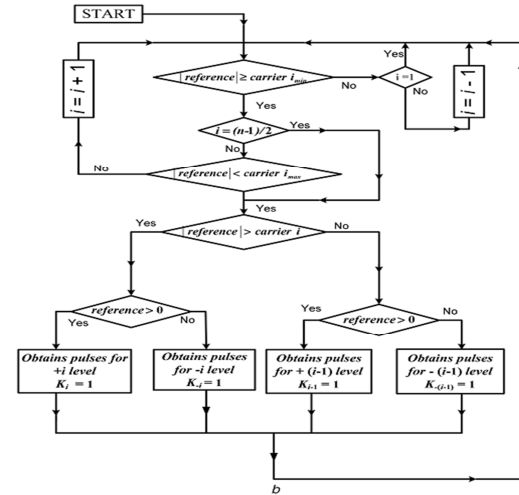
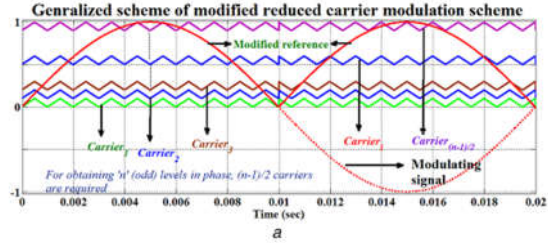


Fig. 6 Generalisation of modified reduced carrier modulation scheme (a) Carrier arrangement, (b) Flowchart of its switching scheme

Fig. 6a depicts carrier and modulating signal arrangement for any number of levels, where Carrier 1,2,3,4,5,...,(n-1)/2 are responsible for obtaining 0–V, V–2V, 2V–3V... (((n-1)/2)–1)V to ((n-1)/2)V bands, respectively. The maximum and minimum value of each carrier can be calculated from (3) and (4). The amplitude modulation index (m_a) and frequency modulation index (m_f) are defined in (5) and (6)

$$carrier\ i_{max} = \frac{2}{(n-1)}i \quad (3)$$

$$carrier\ i_{min} = \frac{2}{(n-1)}(i-1) \quad (4)$$

where i is the carrier number and n is the levels in phase voltage

$$m_a = \frac{2V_m}{(n-1)V_c} \quad (5)$$

$$m_f = \frac{f_c}{f_m} \quad (6)$$

where V_m is the peak of the modulating signal, V_c is the peak of the carrier signal, f_c is the frequency of carrier signal, f_m is the frequency of the modulating signal and n is the levels in phase voltage. Fig. 6b depicts a flowchart for the implementation of generalised switching logic for any number of levels. Here, 'i' indicates carrier number, 'n' is the number of levels in phase voltage, P_i is the switching pulse to obtain i th level in phase voltage and S_i indicates the switching path for obtaining i th level. Initially 'i' is assumed to be 1, and it varies from 1 to $(n-1)/2$. If the modified reference is greater than $carrier_{i-min}$ and less than $carrier_{i-max}$, then 'carrier_i' is compared with modified reference.

This obtains a logic 'Pi' and it is high, if the modified reference is greater than 'carrier_i', else Pi is low. This pulse Pi is responsible for obtaining a voltage band of i to $(i-1)$, and polarity of this band is same as to polarity of the modulating signal. In this voltage band i to $(i-1)$, to obtain i th level, pulse P_i is applied to the switching devices in S_i path and, to obtain $(i-1)$ th level, pulse $(1-P_i)$ is applied to the devices in S_{i-1} path. In case, if the modified reference is more than the $carrier_{i-max}$, then 'i' value is incremented by 1. In case if the modified reference turns less than $carrier_{i-min}$, then i is decremented by one. This logic continues as shown in Fig. 6b. It should be noted that, verifying maximum condition for $carrier_{(n-1)/2}$ should be avoided. Since, it is the carrier with peak magnitude, involving maximum condition to this carrier will limit the switching logic to under modulation. Performance of this modified reduced carrier modulation scheme on a five-level T-type MLI for 2 kW, 0.9 PF load is shown in Fig. 7. Results are shown for $m_a = 0.95$ at 1500 Hz carrier frequency.

The phase voltage, line voltage and load current are shown in Fig. 7a and their corresponding harmonic spectra are shown in Fig. 7b. By comparing Figs. 7a and 4c it can be observed that the shape of phase and line voltage waveforms are identical. It can be further observed that the harmonic spectra in Figs. 7b and 4d are identical and verify the identical performance of this method with proposed multi-reference dual-carrier modulation scheme. Finally comparative line THD performance of the conventional schemes (LSPWM-IPD, OPD and multi-reference) with the proposed and alternative carrier arrangement of proposed schemes with various modulation indices for a five-level MLI is shown in Fig. 7c. From this figure it can be concluded that the proposed modified multi-reference dual-carrier modulation and alternative carrier

arrangement of the proposed schemes are identical to LSPWM-IPD. Fig. 7c also verifies the superior performance of proposed schemes over conventional modulation schemes.

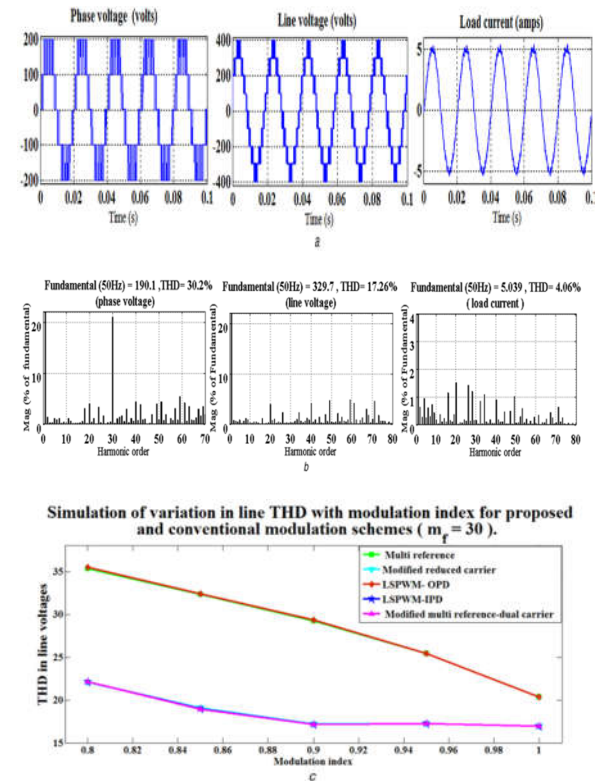


Fig. 7 Performance of reduced carrier modulation on a five-level T-type MLI (a) Phase voltage, line voltage and load currents, (b) Respective harmonic spectra, (c) Simulink comparison of line THD among proposed and conventional schemes at various modulation indices

SIMULATION RESULTS

To validate the performance of the proposed modulation schemes, a prototype of a five-level T-type topology is developed. The various components used for simulation set-up are given in Table 2. Control pulses for power circuit switching devices (IGBTs) are obtained from dSPACE-1104 R&D controller followed by driver circuit. Initially, an simulation set-up of a five-level CHB is developed. To control the voltage, a various conventional LSPWM schemes are implemented to CHB inverter. Fig. 8 shows the simulation results obtained with conventional LSPWM techniques for $f_c = 1500$ Hz and $m_a = 0.95$. Fig. 8a shows the simulation results of phase and line voltage waveforms and their corresponding harmonic spectra with LSPWM-IPD

technique.

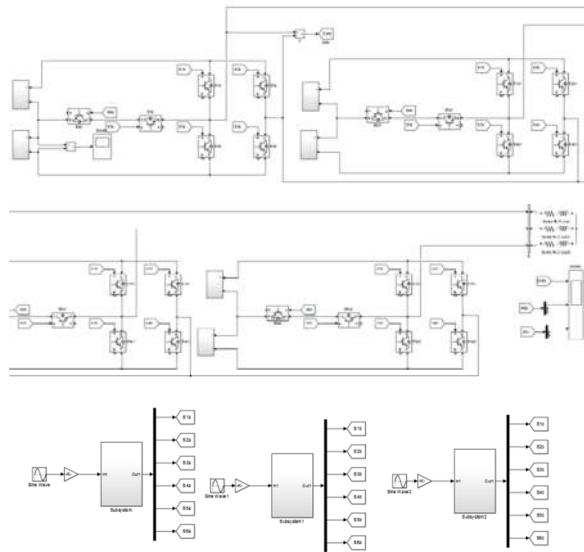


Table 2
parameters

Circuit	Component	Specification – type
100 V isolated dc power supplies	bridge rectifier (IC)	KBPC3510
	filter capacitor	450 V, 2250 μ F
	voltage regulator	LM5008
power circuit	switching device (IGBT) anti-parallel diode	XPT™ –600 V - IXGH30N60E3
driver circuit	ICs	DPH 30 IS 600 HI HEX 4010, IC 4081BC, HCPL 3120 / TLP 250
controller	dSPACE	DS1104 R&D controller board
THD measurement	sampling time	50 μ s
	power quality analyser	fluke 435 series II

Similarly, Fig. 8b shows the simulation results of phase and line voltage waveforms and their corresponding harmonic spectra with LSPWM-OPD technique. The side-band harmonics of simulation recorded harmonic spectra of Figs. 8a and b matches with literature [9]. This justifies the improved line THD performance of LSPWM-IPD (7.0%) over LSPWM-OPD (20.3%). An simulation set-up of a five-level T-type MLI is developed, and its performance with conventional, proposed and alternative implementation of proposed scheme is evaluated. Fig. 9 shows the simulation results obtained with various modulation techniques for $f_c = 1500$ Hz and $m_a = 0.95$. Fig. 9a shows the simulation results of phase and line voltage waveforms and their corresponding harmonic spectra with conventional multi-reference modulation technique.

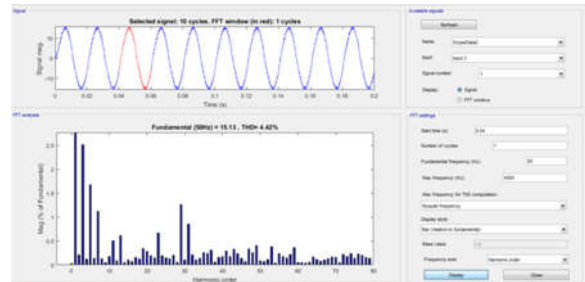
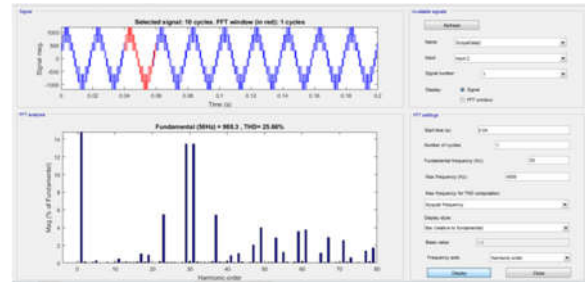
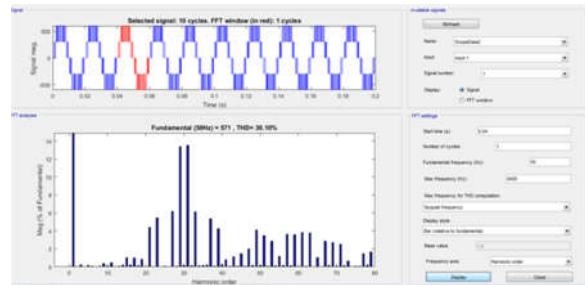
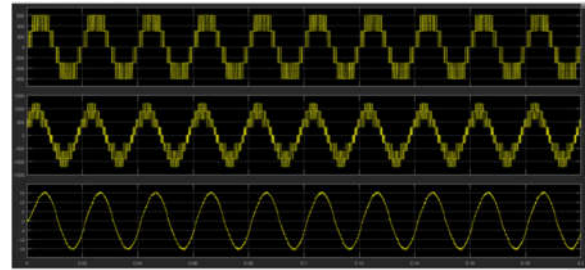
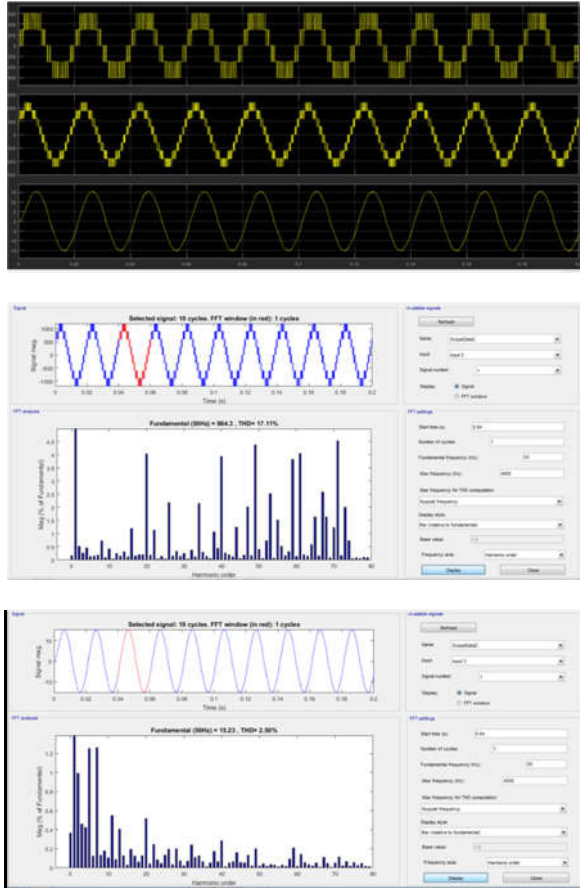


Fig. 8 Simulation performance of LSPWM modulation scheme for a five-level CHB (a) Phase voltage and line voltage with its respective harmonic spectra of LSPWM-IPD scheme, (b) Phase and line voltages with its respective harmonic spectra of LSPWM-OPD scheme. (Scale: trace 1: line voltage, volts/div = 200 V, time/div = 10 ms and trace 2: phase voltage, volts/div = 200 V, time/div = 10 ms)



Figs. 9b and c show the simulation results of phase and line voltage waveforms and their corresponding harmonic spectra with proposed modulation and alternate carrier arrangement of proposed multi-reference dual-carrier scheme, respectively. From Figs. 9a and 8b, it is observed that phase and line THD of conventional multi-reference (23.3 and 20.3%) and LSPWM-OPD (23.4 and 20.3%) are similar.

Fig. 9 Simulation performance of conventional and modified modulation schemes for a five-level T-type topology (a) Phase and line voltages with its respective harmonic spectra of conventional multi-reference modulation, (b) Phase and line voltages with its respective harmonic spectra of modified multi-reference dual-carrier modulation, (c) Phase and line voltages with its respective harmonic spectra of alternate carrier arrangement of proposed multi-reference dual carrier scheme, (d) Simulation line THD comparison of proposed and conventional modulation schemes at various modulation indices for a five-level topology. (Scale: trace 1: line voltage, volts/div = 200 V, time/div = 10 ms and trace 2: phase voltage, volts/div = 200 V, time/div = 10 ms)

This is validated with simulation results too, where the phase and line THD performance of conventional multi-reference (29.4 and 25.4%) depicted in Fig 2b matches with LSPWM-OPD (29.4 and 25.4%) depicted in Fig. 3d. Comparison of Figs. 9b and c with Fig. 8a verifies that phase and line THD performance of the proposed multi-reference dual-carrier modulation scheme (23.2 and 7.3%) and modified reduced carrier modulation (23.3 and 7.1%) are identical to phase (23.3%) and line (7.0%) THD performance of LSPWM-IPD. Finally, simulation line voltage THD performance of the conventional schemes (LSPWM-IPD, OPD and multi-reference) with the proposed and alternative carrier arrangement of proposed scheme with various modulation indices on a five-level MLI is shown in Fig. 9d.

From this figure it can be concluded that the proposed multi-reference dual-carrier modulation and alternative carrier arrangement of the proposed schemes are identical to LSPWM-IPD. Fig. 9d also verifies the superior performance of proposed schemes over conventional modulation schemes. Fig. 9d is also in good agreement with Fig. 7c which is obtained with simulation. However, there is a variation in THD recorded in simulation and simulation case (Figs. 7c and 9d). This is due to the MATLAB simulator, which measures the THD until Nyquist frequency (up to 499th order harmonics), where fluke meter used to measure simulation THD measures up to 49th order harmonics. However, minimizing measurable THD frequency limit to 49th order in MATLAB simulator makes the simulation THD equal to simulation THD recorded. However, this is not opted in simulation because it is necessary to observe the complete harmonic spectrum of inverter output voltages.

CONCLUSION

In this report, the poor harmonic performance of the conventional multi-reference modulation method for T-type MLI topology is analyzed. To address this problem, a modified multi-reference dual-carrier modulation is proposed. The performance of the proposed modulation scheme is identical to LSPWM-IPD technique which is the best PWM technique with lowest THD value available. Further, to implement the proposed PWM scheme, an alternate carrier and modulation signals arrangement is also proposed which can be easily realizable on digital platforms. The performance of the proposed modulation schemes is evaluated with simulation and simulation studies on a five-level T-type MLI topology. The simulation studies are in good agreement with simulation studies and also verify the

superior performance of the proposed schemes over conventional modulation schemes. A generalization of the modified reduced carrier modulation to implement any number of levels for a T-type is presented with the help of a flowchart.

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