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Hybrid Carrier-Based Pulse Width Modulation Techniques for Leakage Current Suppression in Five Level Cascaded H-Bridge Solar Inverter: A comparative Study

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Abstract

Multilevel inverters have gained increasing popularity in the field of medium voltage and high-power applications. Among the three most favored configurations of multilevel inverters, cascaded H-bridge multilevel inverter has been considered as the most suitable topology to integrate photovoltaic system with the utility grid. However, transformer-less PV system suffers from leakage current problem. This paper investigates the adoption of hybrid switching frequency approaches in carrier based PWM for leakage current suppression. To evaluate the effectiveness of using this strategy in minimization of this current, a comparative study between all standard and proposed hybrid carrier-based pulse width modulation methods is carried out using MATLAB/ Simulink environment for single-phase five-level cascaded H-bridge multilevel inverter. Both standard and hybrid level shifted and phase shifted are compared. The results demonstrate the ability of the proposed hybrid CB-PWM to minimize the leakage current and comply effectively with the VDE-0126-1-1 (German standard) in term of both rms and peak values of leakage current. The results are also show that the best leakage current rms value of (3.129 mA) is achieved when applying the hybrid phase and level shifted pulse width modulation (HPALS-PWM) approach, while the best leakage current peak value of (4.952 mA) is obtained when using hybrid phase shift pulse width modulation (HPS-PWM) approach. Therefore, the hybrid approach can be considered an appropriate PWM strategy for grid connection of transformer-less multilevel inverters for PV applications.

Keywords: Cascaded H–Bridges multilevel inverter, Carrier based pulse width modulation, Hybrid switching frequency carrier-based pulse width modulation, Transformer-less multilevel, Leakage current suppression.

1.Introduction

In recent years, global warming has been considered as a significant concern due to its dangerous environmental impact. Therefore, a replacement to fossil fuels electrical generation systems with less carbon footprint energy systems are crucial. The most dependable approach to reduce carbon emissions is the adoption of renewable energy sources. Currently, the application of renewable energy sources such as solar panels, wind turbines, biomass, biogas, fuel cells and hydroelectric power has seen a notable increase in both domestic and industrial settings. The employment of Photovoltaic (PV) energy systems increased significantly due to the reduced cost of PV panel and increased PV modules efficiency [1]. Multilevel inverters (MLIs) are increasingly employed as a replacement to two-level inverters for PV panel integration with a utility grid. Since, two-level inverters suffer from inability to handle high voltages level, power quality problems, and high levels of voltage stress across semiconductor switches which reduce the efficiency of solar photovoltaic (PV) systems. This leads to urgent need for replacement with MLIs [2]. MLIs are characterized by reduced power switches voltage ratings, multiple redundant states, even load distribution between input sources, seamless integration of sustainable sources, and produce nearly sinusoidal staircase waveform in its output. This enhances the power quality and harmonic profile, allowing for a significant reduction in filter size or no filter if total harmonic distortion (THD) falls within the regulatory limit of IEEE 519 [3]. The main topologies of multilevel inverters can be categorized into: Diode clamped multilevel inverter (DCMLI), Flying capacitor multilevel inverter (FCMLI), and Cascaded H-bridge multilevel inverter (CHBMLI) [4]. In PV applications, CHBMLI inverter is widely preferred due to its simplicity in structure, reliability, modularity, reduced number of components, and high level of fault tolerance [4], [5], [6]. The modular design of the H-bridge inverter allows for the stacking and cascading of inverters, making it suitable for applications requiring high power and high voltage. In addition, CHBMLI is able to operate at lower power levels even when one cells may fail [7]. A single stage transformer-less PV inverters are increasingly employed in Solar applications to avoid the bulky transformer required for galvanic isolation and reduces the system losses by lowering system's components and rating [8]. In such systems, removing the bulky and expensive transformer and employing the solid-state switching device exposes to lower voltage stress related to low rate of voltage change (dv/dt), resulting in a reduction in the overall size and cost of the inverter. This reduction in the stress across the switching devices can extend the lifespan of the load and minimize electromagnetic compatibility issues. In essence, the output voltage of an inverter is regulated via Pulse Width Modulation (PWM) techniques. Various PWM techniques have been presented in the literatures to control MLI which can be classified based on switching frequencies as fundamental switching and high switching frequencies [9]. This paper focuses on modulation strategies applied to five level cascaded H-Bridge inverter (5L-CHBI). Conventional Carrier based pulse width modulation (CCB-PWM) which operate at high switching frequency, has been successfully employed to regulate the output of PV inverter. However, in transformer-less (TRL) grid connected CHB-MLI PV systems, the leakage current problem has been emerged due to lack of galvanic isolation is considered as a serious issue [10]. According to the VDE-0126-1-1 (German standard), in only 0.3 seconds, the PV systems should be disconnected from the grid if the leakage current's value peak or RMS exceeds 300mA or 30mA, respectively. Pulse width modulation strategies are among the strategies used to reduce the leakage current in such system. Conventional CB-PWM is classified to Level Shifted (LS) and Phase Shifted (PS) pulse width modulation [11]. Three configurations of LS-PWM are existing based on the carrier arrangements including Phase-Disposition PWM (PD-PWM), Phase-Opposition-Disposition PWM (POD-PWM), and Alternative-Phase-Opposition-Disposition PWM (APOD-PWM) [12]. However, the high switching frequency of the carriers leads to increase the losses and reduce the overall efficiency of PV system.

This paper proposes for the first time a hybrid frequency level shifted pulse width modulation (HLS-PWM) for CHBMLI. A comparison between standard, modified and hybrid frequency CB-PWM strategies in terms of leakage current suppression in a MATLAB/SIMULINK environment is presented. Moreover, it evaluates the effectiveness of hybrid frequency carrier-based pulse width modulation (HFCB-PWM) to suppress leakage current in open loop system which has not been reported before. The rest of the paper is structured as follows: Section 2 describes 5L CHB MLI. Section 3 demonstrates the common mode voltage in TRL- PV system. Various PWM strategies are explored in Section 4 including standard, modified and hybrid frequency CB-PWM strategies for 5L CHBMLI. Section 5 demonstrates a comparative assessment via MATLAB/Simulink to evaluate the effectiveness of all types of CB-PWM in minimizing leakage current. Conclusions are presented in Section 6.

2 Five Level Cascaded H-Bridge Multilevel Inverter

A 5L CHBMLI is created by serially connecting two single-phase H-bridge inverters with separate (DC) sources [13], [14], [15]. As shown in Fig. 1, each HB (cell) contained one (DC) source and four unidirectional power switches. There are three voltage outputs set up for each H-bridge. (+Vdc, 0, and −Vdc) by connecting the (DC) source to the (AC) output; the required output voltage is obtained by employing different configurations of the four switches (S_1-S_4). Turning S_{11} and S_{41} switches ON generates (+Vdc) output, while when S_{21} and S_{31} are in ON state, (−Vdc) output is generated. To generate a zero-level voltage, either S_{11} and S_{31} or S_{21} and S_{41} must be ON. The waveform of the output voltage created by each cell is connected in serial so that the output voltage waveform represents the sum of the outputs of two cells. In a cascaded H-bridge inverter, m = 2s + 1 is used to indicate the voltage levels per phase, where m is the number of level and s is the number of DC source. In addition, the cascaded H-bridge is free from voltage balancing issue because it does not have DC link capacitors. Different sustainable energy sources can be used to replace various individual (DC) sources including PV panel [14].

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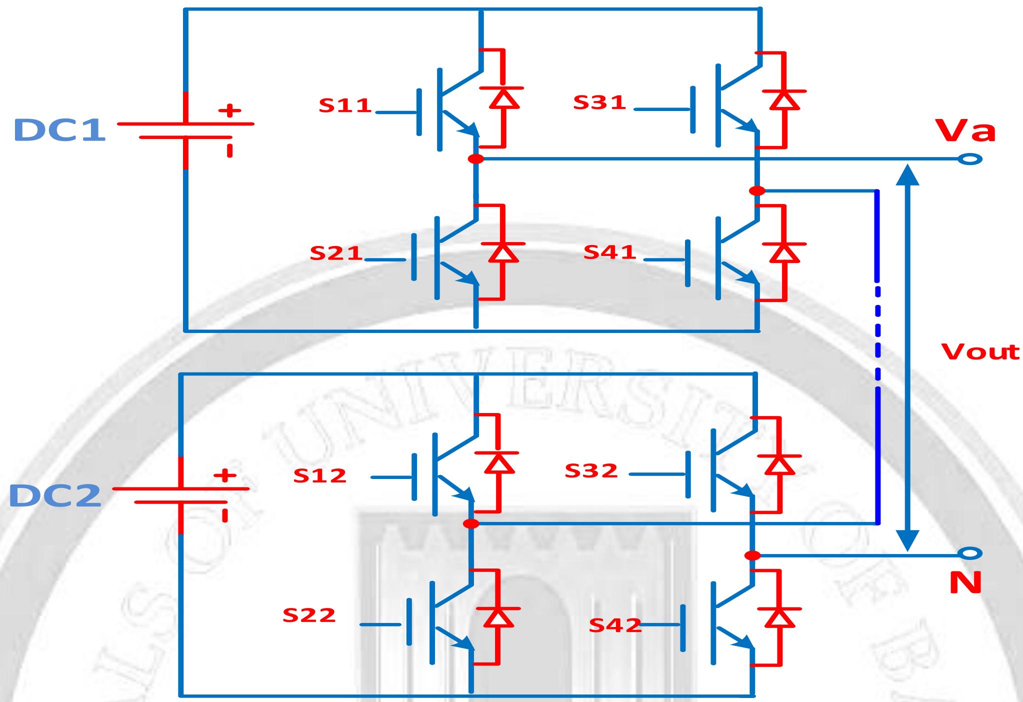


Fig. 1. Single phase 5- level CHBMLE topology.

The 5L-CHBI switching patterns are shown in Table 1 [16].

Table 1 switching pattern for 5L-CHBI

Output voltage	S11	S21	S31	S41	S12	S22	S32	S42
VDC1+VDC2	1	0	0	1	1	0	0	1
VDC1	1	0	0	1	1	0	1	0
VDC2	1	0	1	0	1	0	0	1
VDC1	1	0	0	1	0	1	0	1
VDC2	0	1	0	1	1	0	0	1
0	1	0	1	0	1	0	1	0
0	0	1	0	1	0	1	0	1
VDC1-VDC2	1	0	0	1	0	1	1	0
-VDC1+VDC2	0	1	1	0	1	0	0	1
0	0	1	0	1	1	0	1	0
0	1	0	1	0	0	1	0	1
-VDC1	0	1	1	0	0	1	0	1
-VDC2	1	0	1	0	0	1	1	0
-VDC1	0	1	1	0	1	0	1	0
-VDC2	0	1	0	1	0	1	1	0
-VDC1-VDC2	0	1	1	0	0	1	1	0

3- Common mode voltage

Figure 2 shows a schematic diagram of 5L TRL grid connected CHB PV inverter. To analyze the circuit based on leakage current, assume identical values of parasitic capacitance for each H-bridge i.e. (C_{PV1}= C_{PV2}= C_{PV}) and also identical output filter inductors (L_1=L_2) to suppress leakage current [17].

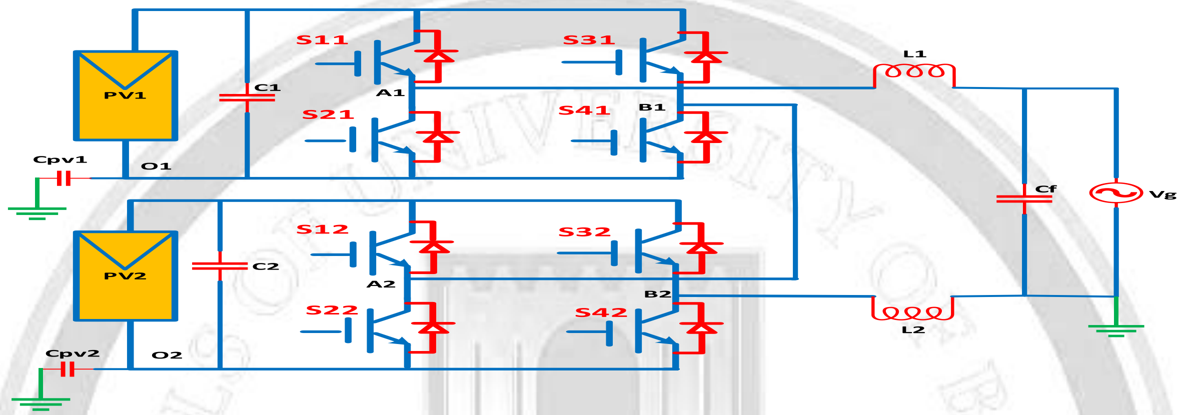


Fig. 2 Schematic diagram of 5L TRL grid- connected CHB MLI [17].

The common mode (CM) voltage (V_{CM}) and the differential mode (DM) voltage (V_{DM}) for each H-Bridge are defined as [17]:

$$V_{CM1} = \frac{1}{2}(V_{A1O1} + V_{B1O1}) \quad (1)$$

$$V_{DM1} = V_{A1O1} - V_{B1O1} \quad (2)$$

where V_{A1O1}, V_{B1O1}, V_{A2O2} and V_{B2O2} represent the potentials among the H-Bridge outputs and connection nodes (O1, O2)

$$V_{A1O1} = 2\,V_{CM1} - V_{B1O1} = 2\,V_{CM1} - V_{A1O1} + V_{DM1} \quad (3)$$

$$2V_{A1O1} = 2V_{CM1} + V_{DM1} \quad (4)$$

Then

$$V_{A1O1} = V_{CM1} + \frac{1}{2}V_{DM1} \quad (5)$$

$$V_{B1O1} = V_{CM1} - \frac{1}{2}V_{DM1} \quad (6)$$

A circuit diagram for high frequency CM model is shown in Fig. 3. In Fig. 3, V_{AO1}, V_{BO1}, V_{AO2} and V_{BO2} are replaced with CM and DM voltages.

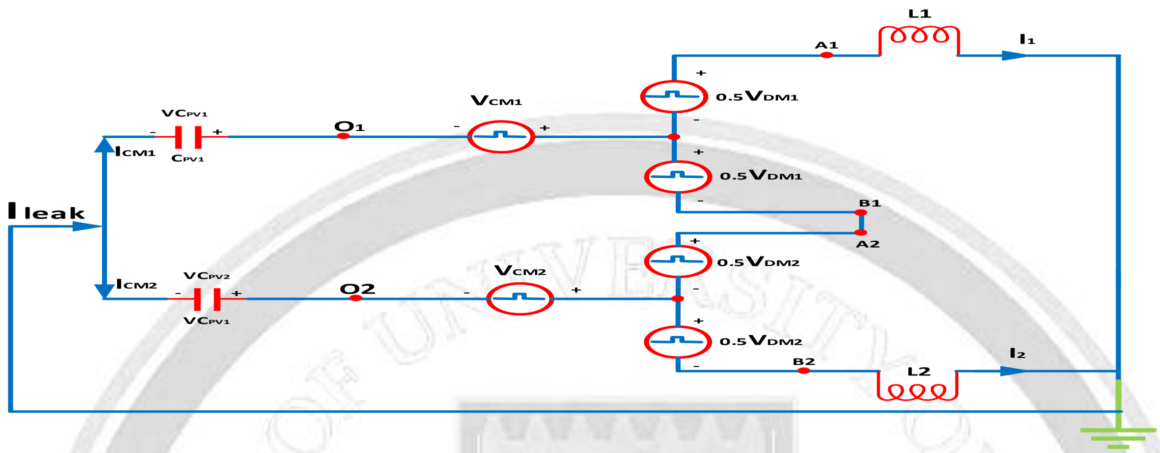


Fig. 3 Common mode model of 5 level grid-connected CHBMLI [17].

It should be noted that the CM and DM voltages are a function to the switches's modulation sequences. Since,

$$Z_{CPV1} = Z_{CPV2} = Z_C \tag{7}$$

where Z_{CPV1}, Z_{CPV2} and Z_C represent impedance of parasitic capacitance for H-bridge no.1, impedance of parasitic capacitance for H-bridge no.2 and impedance of parasitic capacitance respectively.

$$Z_{L1} = Z_{L2} = Z_L \tag{8}$$

where Z_{L1}, Z_{L2} and Z_L represent impedance of output filter inductor 1, impedance of output filter inductor 2 and impedance of output filter inductor respectively.
Therefore,

$$Z_C I_{CM1} - V_{CM1} - \frac{1}{2}V_{DM1} + Z_L I_1 = 0$$

$$Z_C I_{CM2} - V_{CM2} + \frac{1}{2}V_{DM2} + Z_L I_2 = 0$$

$$Z_C I_{CM1} - V_{CM1} + \frac{1}{2}(V_{DM1} + V_{DM2}) + V_{CM2} - Z_C I_{CM2} = 0 \tag{9}$$

$$I_{CM1} + I_{CM2} = I_1 + I_2$$

Vol. 32, No. 2. \ 2024 ISSN: 2616 - 9916

The common mode currents can be calculated as:

$$I_{CM1} = -[Z_L\left(V_{CM2} - V_{CM1} + \frac{1}{2}(V_{DM1} + V_{DM2})\right) + Z_C(V_{DM2} - 2V_{CM1})]x\frac{1}{2Z_C(Z_C+Z_L)} \tag{10}$$

$$I_{CM2} = -[Z_L\left(V_{CM1} - V_{CM2} - \frac{1}{2}(V_{DM1} + V_{DM2})\right) + Z_C(-2V_{CM2} - V_{DM1})]x\frac{1}{2Z_C(Z_C+Z_L)} \tag{11}$$

$$V_{CPV1} = -Z_C I_{CM1} \tag{12}$$

$$V_{CPV2} = -Z_C I_{CM2} \tag{13}$$

By summarizing equation (12) & (13) to obtain equation (14) as follows:

$$V_{CPV1} + V_{CPV2} = -\frac{\left(V_{CM1}+\frac{1}{2}V_{DM1}\right)+\left(V_{CM2}-\frac{1}{2}V_{DM2}\right)}{(Z_C+Z_L)} = -\frac{(V_{A1O1}+V_{B2O2})}{(Z_C+Z_L)} \tag{14}$$

Equation (14) demonstrates that maintaining the parasitic capacitance voltage constant is based on verifying equation (15), and therefore, the leakage current can be reduced.

$$V_{A1O1} + V_{B2O2} = \text{constant} \tag{15}$$

Typically, conventional modulation techniques cannot satisfy equation (15), and allowing leakage current to flow into the grid ground.

4 - Modulation Techniques of Cascaded H-Bridge Multilevel Inverter

Fig. 4 illustrates the conventional modulation strategies for multilevel inverter which can be categorized based on the switching frequencies into fundamental frequency and high-frequency switching techniques [18], [19]. In fundamental switching strategies, power switches are operated at 50/60 Hz. However, high-frequency modulation involves on/off switching at a higher frequency range (more than 1000 Hz). The high frequency operation shifts the harmonics into a range that is subsequently filtered out by a filter circuit. The most commonly used modulation strategies for CHB-MLI in PV application are sinusoidal pulse width modulation (SPWM) and selective harmonic elimination (SHE). SHE approach is one of the low-switching frequency strategies, while the SPWM (named carrier-based CB-PWM) switching technique falls into the high-switching frequency category [4]. SHE strategy is able to eliminate a specific low order harmonics in the output waveforms by solving transcendental equations to predetermined the switching angles of the power switches [4], [20]. While CB-PWM technique determines switching angles by comparing a sinusoidal reference signal with carrier waves. CB-PWM can be categorized based on the generated carrier-wave signals, with two common categories being PS-PWM and LS-PWM [21], [22].

Vol. 32, No. 2. \ 2024 ISSN: 2616 - 9916

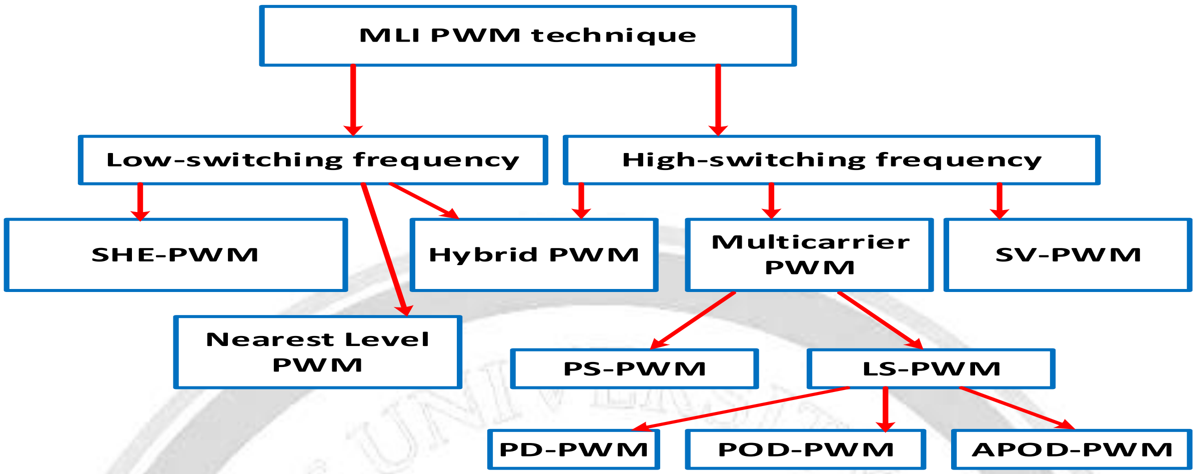


Fig. 4. The classification of MLI Modulation Techniques [12].

In PS-PWM, the carrier wave spans the entire range of modulation indices, with each carrier phase-shifted by an angle θ. On the other hand, LS-PWM offers three different configurations: PD-PWM, POD-PWM, APOD-PWM [22]. One notable drawback of the CB-PWM technique is that it tends to have a relatively high average switching frequency and THD. This results in higher switching losses compared to SHE, which can be a limitation in certain applications [23]. Due to ability of PS-PWM to maintain equal power sharing between modules, good output harmonic characteristics, and power quality, it is commonly preferred to control CHB-MLI in PV applications over LS-PWM [24], [25]. However, in TRL grid connected PV system, the leakage current circulating to the grid ground is a serious issue when using conventional CB-PWM. In addition, the high-frequency of the carrier cause some limitations for using PS-PWM, including high system losses which can result in increased heat generation, and thus reduced efficiency [25] a modification .

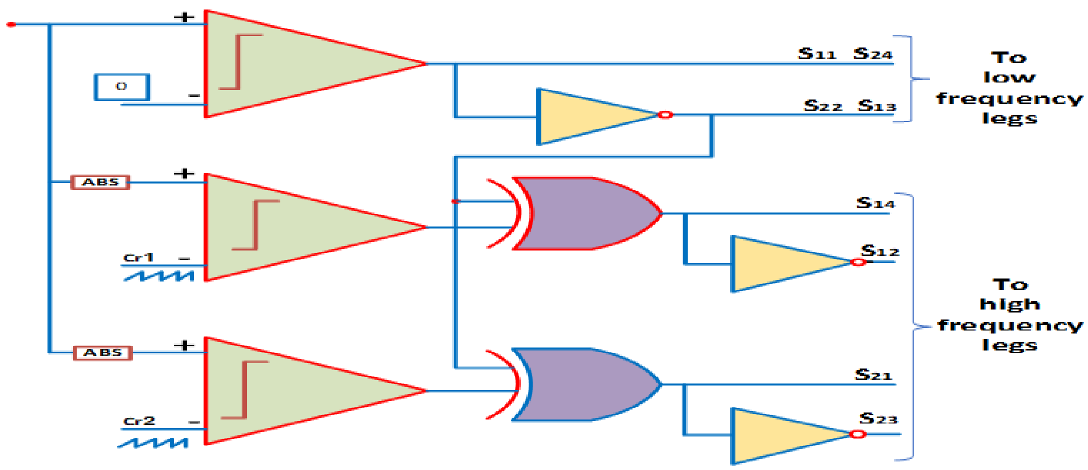
4.1 Hybrid Switching Frequency Carrier-Based Pulse Width Modulation (HSFCB-PWM) Methodes for Five-Level CHBMLI

TRL CHBMLIs are increasingly suggested for grid-tied PV systems due to their superior efficiency, cost-effectiveness, and reduced weight. Nevertheless, the absence of galvanic isolation allows for the possibility of leakage current within the system. This undesired current can result in increased losses, electromagnetic interference, current harmonic distortion, and safety-related issues [10], [17], [26] [27]. An improvement to CB-PWM is proposed to overcome the leakage current issue in such system which cannot be achieved via conventional CB-PWM.

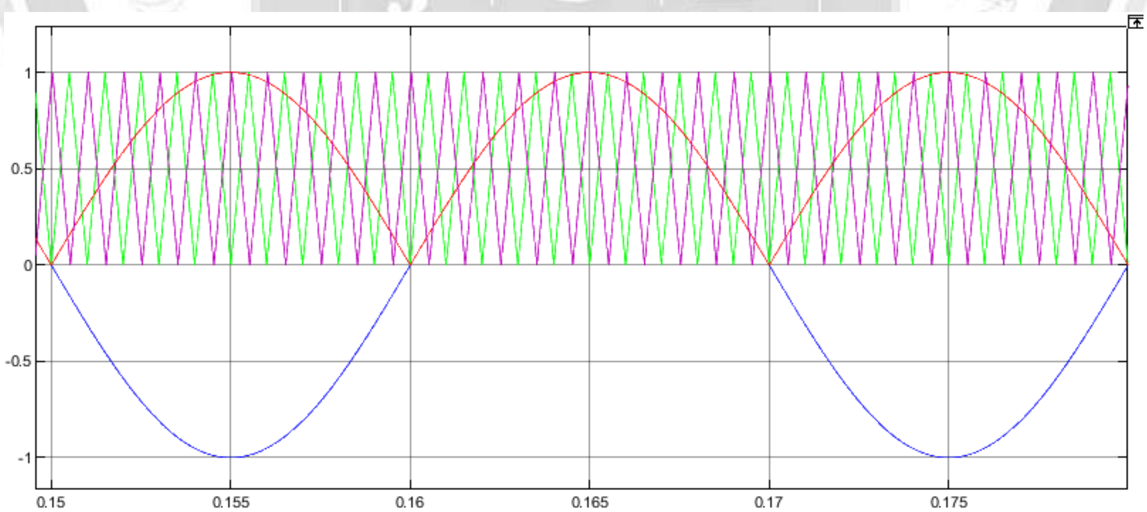
4.1.1 Hybrid Phase Shift Pulse Width Modulation (HPS-PWM)

To avoid limitation of conventional PS-PWM to suppress leakage current in such system, Shahabadini and Iman-Eini [17] proposed a hybrid phase shifted pulse width modulation (HPS-PWM) shown in Fig. 5, by switching one leg of each H-Bridge at fundamental grid frequency while the other leg is modulated at high switching frequency. This approach requires a single carrier for every H-Bridge cell and it is easy to implement. In each half cycle, S_{11} & S_{42} (shown in Fig.1) are triggered at low frequency. A reference's absolute value is compared to a unipolar triangular carrier signal to control the high frequency legs. The resulting pulses are subsequently combined using an XOR operation with a control signal. For every half-period, the control signal

is changed. It has logical values of 0 and 1, respectively to represent the positive and negative half cycles. During the positive half cycle, the pulses transmitted to the gates with no modification or alteration. However, in the negative half-cycle, XOR gates invert the PWM pulses as shown in Fig 5a. Compared to standard PS-PWM, employing lower frequencies in this (PWM) strategy reduces the switching losses. For m voltage levels in a conventional PS-PWM, (m-1) carriers with a phase shifted of [360/(m-1)] are needed. While, in HPS-PWM a reduced number of carriers are required based on [(m-1)/2] and the phase shift in this technique is equal to [2 x 360 / (m-1)].
In this PWM method, during the positive half cycle $V_{A1O1} = +V_{dc}$ & $V_{B2O2} = 0$ then ($V_{A1O1} + V_{B2O2} = +V_{dc}$), and during negative half cycle ($V_{A1O1} = 0$ & $V_{B2O2} = +V_{dc}$) then ($V_{A1O1} + V_{B2O2} = +V_{dc}$). This will verify equation (15) and thus can suppress leakage current in CHBMLI.



(a)



(b)

Fig. 5 (a) switching strategy of HPS-PWM method (b) simulation of HPS-PWM method [17].

4.1.2 Hybrid Level Shifted Pulse Width Modulation (HLS-PWM)

In this paper, a hybrid switching frequency level shifted approach is proposed for the first time to suppress leakage current in CHBMLI for photovoltaic applications. This approach is examined for all three types of LS-PWM.

A- Hybrid Phase Disposition Pulse Width Modulation (HPD-PWM)

To implement the hybrid switching frequency approach on standard PD-PWM strategy in 5L-CHBI, a reference absolute value is required and only two carriers are needed instead of four carriers required in the standard PD as shown in Fig.6. Only the carriers above the zero are used in this strategy maintaining the offset between them. In addition, a hybrid switching frequency consists of fundamental and high switching frequency are used to trigger the semiconductor switches for each H-bridge leg.

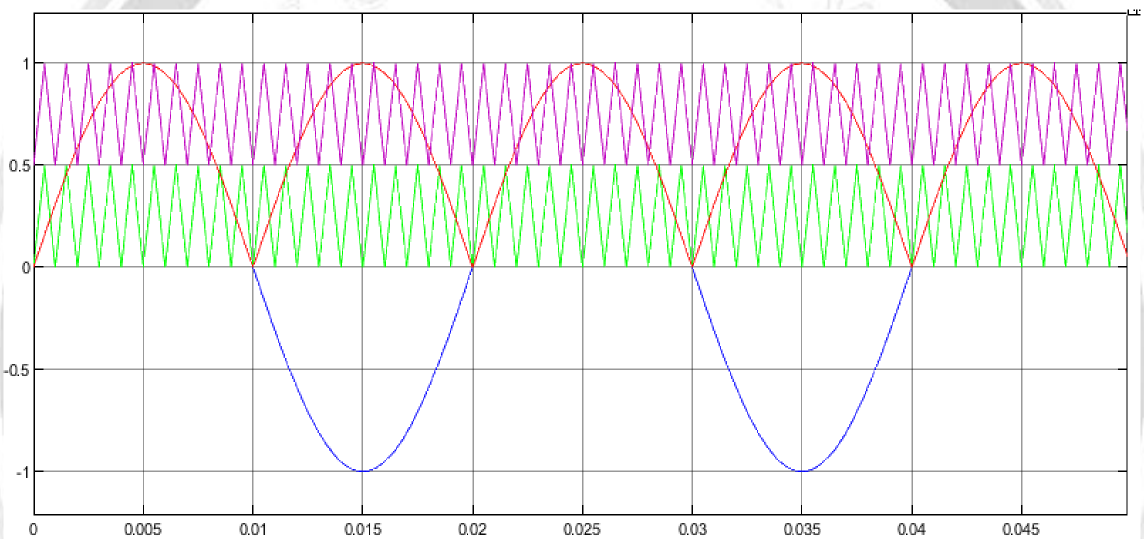


Fig.6 Hybrid phase disposition HPD-PWM for 5L-CHBI.

B- Hybrid Phase Opposition Disposition Pulse Width Modulation (HPOD-PWM)

It is impossible to test HPOD-PWM method because of the absolute in the switching strategy changes all the negative values of reference signal to positive values.

C- Hybrid Alternative Phase Opposition Disposition Pulse Width Modulation (HAPOD-PWM)

In this strategy, only two carriers are also required with 180 ° out of phase to be compared with an absolute reference of sinewave. The inverter legs are also triggered in different switching frequencies fundamental and high switching frequency as shown in Fig 7.

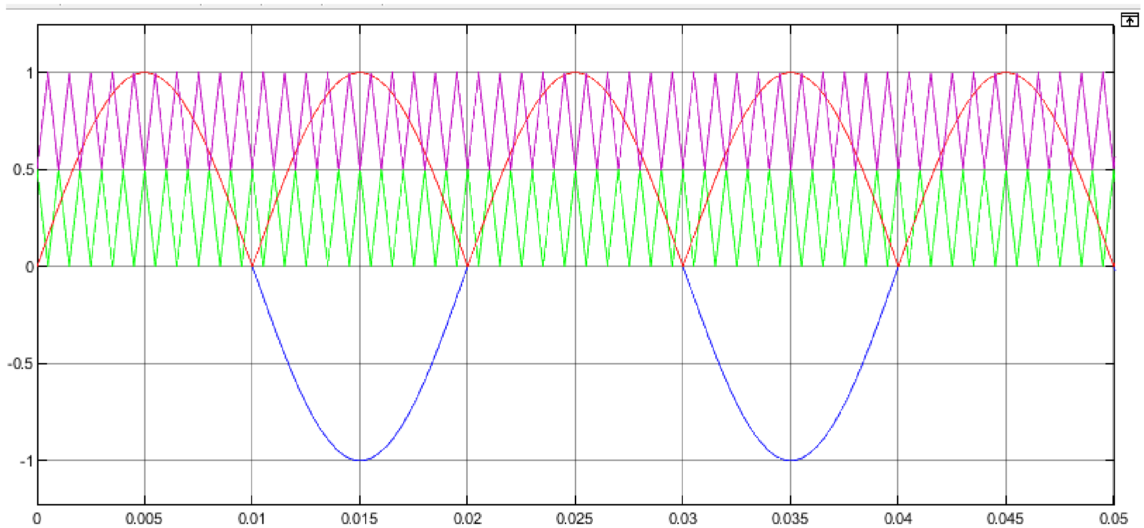


Fig. 7 Hybrid Alternative phase opposition disposition HAPOD-PWM for 5L-CHBI

D- Hybrid Phase and Level Shifted Pulse Width Modulation (HPALS-PWM)

This strategy combines the phase and level shifted under hybridization of switching frequency as shown in Fig. 8.

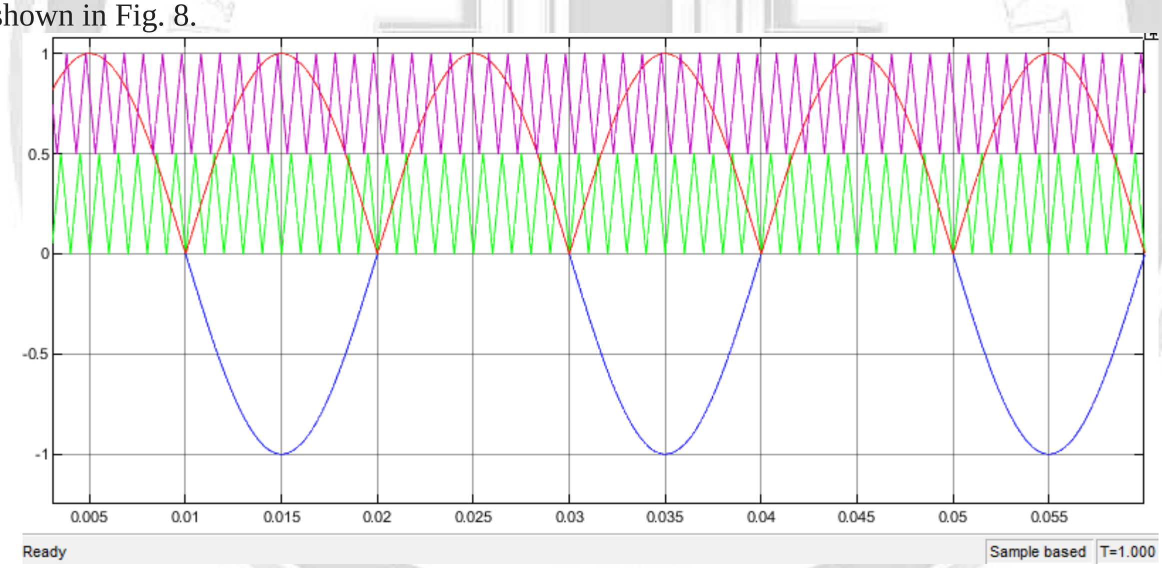


Fig. 8 Hybrid phase and level shifted HPALS-PWM for 5L-CHBI.

5 - Comparison Between Various CB-PWM Strategies

The HLS-PWM approach is verified by simulation in terms of leakage current using MATLAB/Simulink environment. To evaluate the effectiveness of various CB-PWM approaches to suppress leakage current, a comparison between standard, modified and hybrid CB-PWM is carried out. A model for grid connected 5L CHBI supplied by PV panel is created in Simulink as shown in Fig. 9. A blytek PV panel 6PN6A220-A0 from Simulink library is used to feed the

Vol. 32, No. 2. \ 2024 ISSN: 2616 - 9916

inverter with Voc=36.06V, Isc=7.95A and a maximum power of 219.876W. The simulation parameters are listed in Table 2. It is worth mentioning that similar model is used to represent the whole system (shown in Fig. 9) while pulse width modulation strategy is varied only for comparison purposes.

5.1 Leakage Current Suppression Under Various HCB-PWM

The ability of HCB-PWM to reduce the leakage current in TR-PV system is evaluated by comparison. Therefore, the standard and hybrid PWM are compared to assess the effectiveness of these strategies to overcome leakage current issue. The simulation circuit parameters are listed in Table 2.

Table 2 The simulation circuit parameters.

Parameters	Value
Switching frequency	5KHz
DC link capacitor	15mF
Filter inductance	1mH
Grid peak voltage	60V
Grid frequency	50Hz
parasitic capacitance	100nF

Figure 9. Shows the circuit model of HPS-PWM (named HPS-PWM) in [17] for 5L CHBMLI.

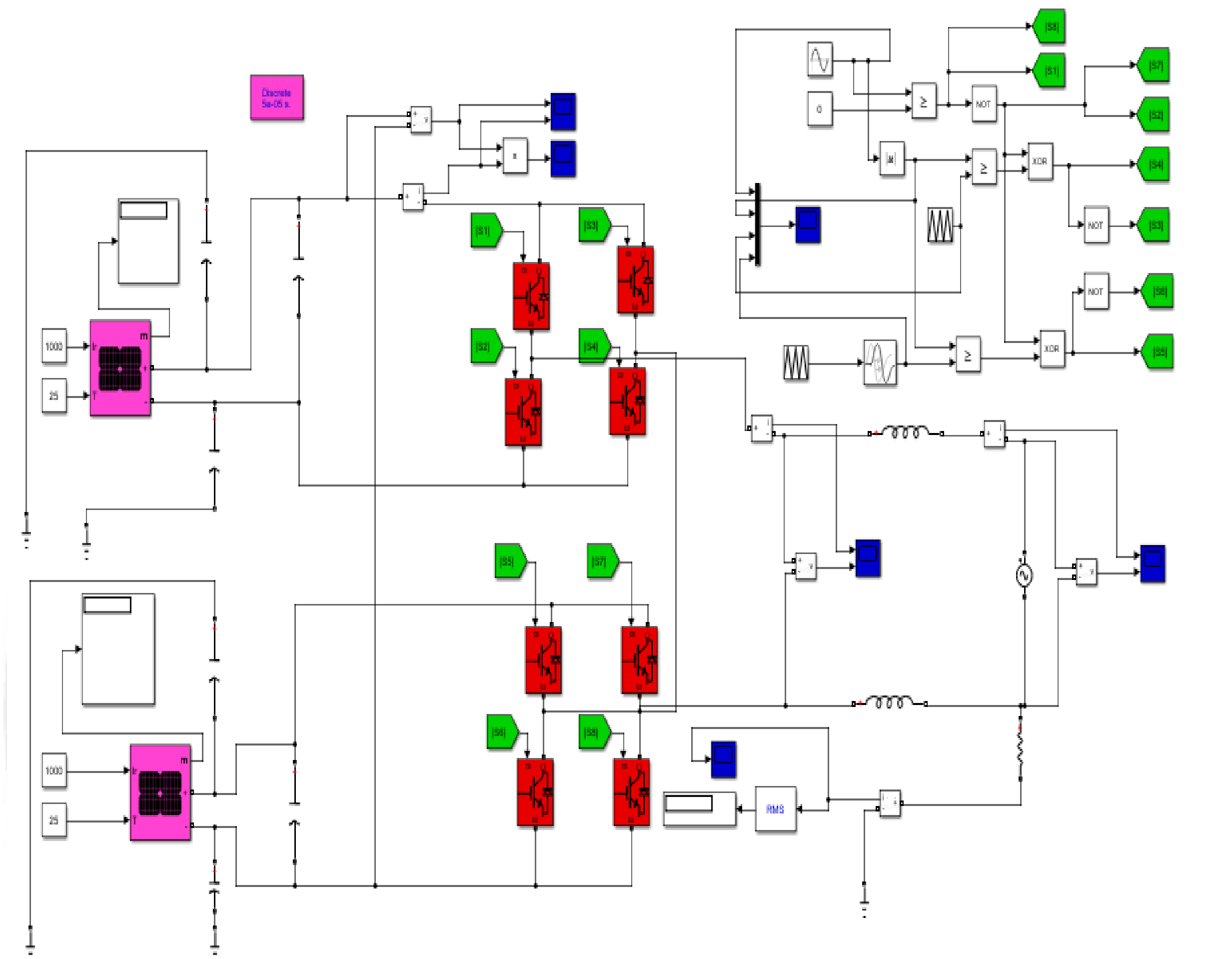


Fig. 9 leakage current model for 5 level CHBMLI with HPS-PWM.

Figure 10 demonstrates the ability of HPS-PWM to reduce the leakage current from 1116 to 4.959 mA (peak value) and the following figures depict leakage currents in standard CB-PWM techniques and HCB-PWM techniques.

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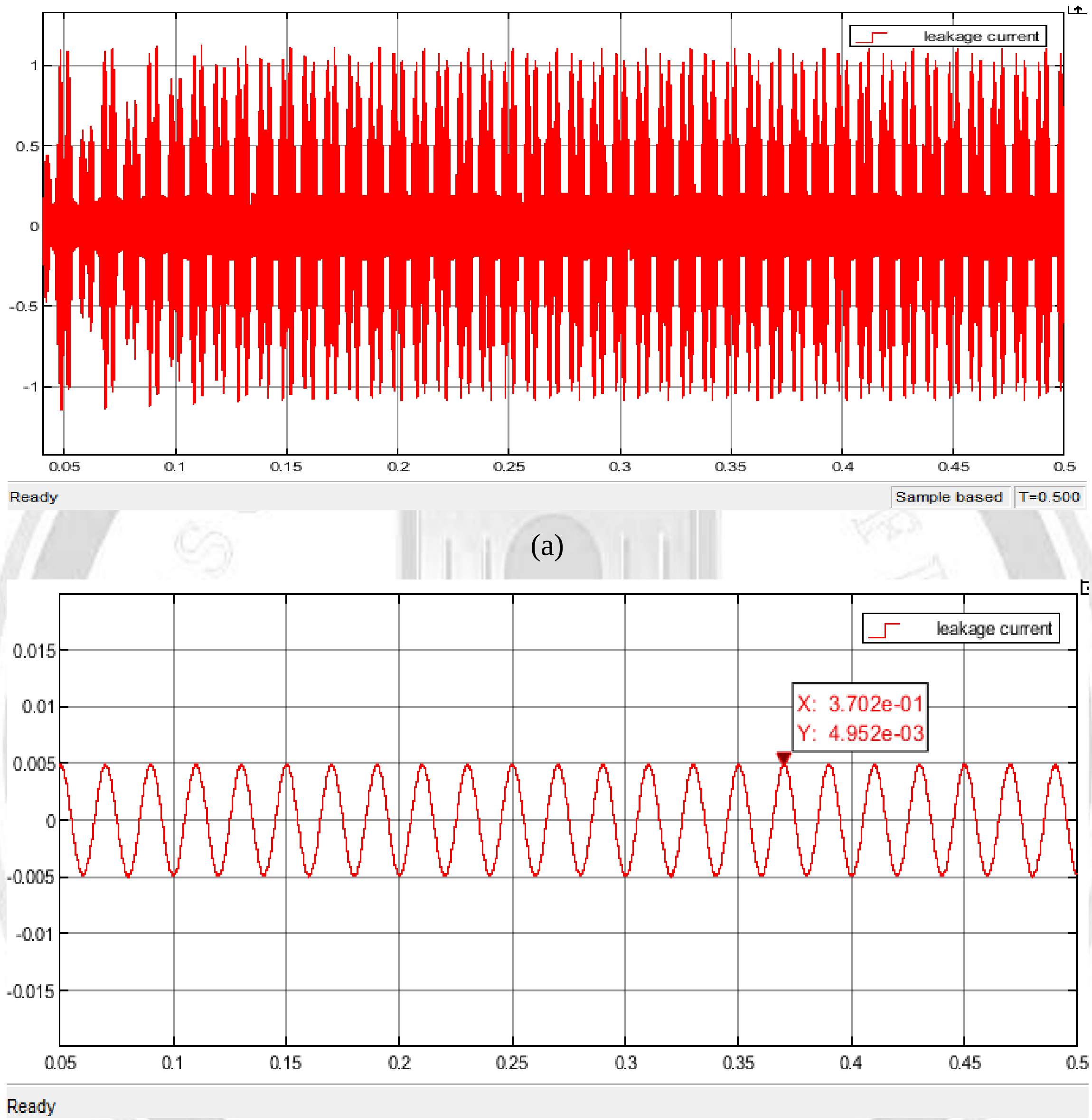

(a)

(b)

Fig. 10 Leakage current under :(a) conventional PS-PWM, (b) Hybrid PS-PWM.

By adopting the hybridization of switching frequency for LS-PWM approaches, the effect of using HPD-PWM on the leakage current in comparison with standard PD-PWM is shown in Fig. 11. The figure demonstrates that a significant reduction in leakage current is occurred. While fig. 12 demonstrates the reduction in leakage current using APOD and HAPOD techniques. Figure 13 shows the leakage current reduction under PALS-PWM compared to HPALS-PWM approach. All Figures demonstrate how using fundamental and high switching frequency to control the switching states are effective in leakage current suppression compared with standard

Vol. 32, No. 2. \ 2024 ISSN: 2616 - 9916

CB-PWM. The figures also show that the leakage current waveforms are also improved and near sinusoidal waveform can be achieved. A comparison of leakage current R.M.S values upon various CB-PWM are presented in Table 3.

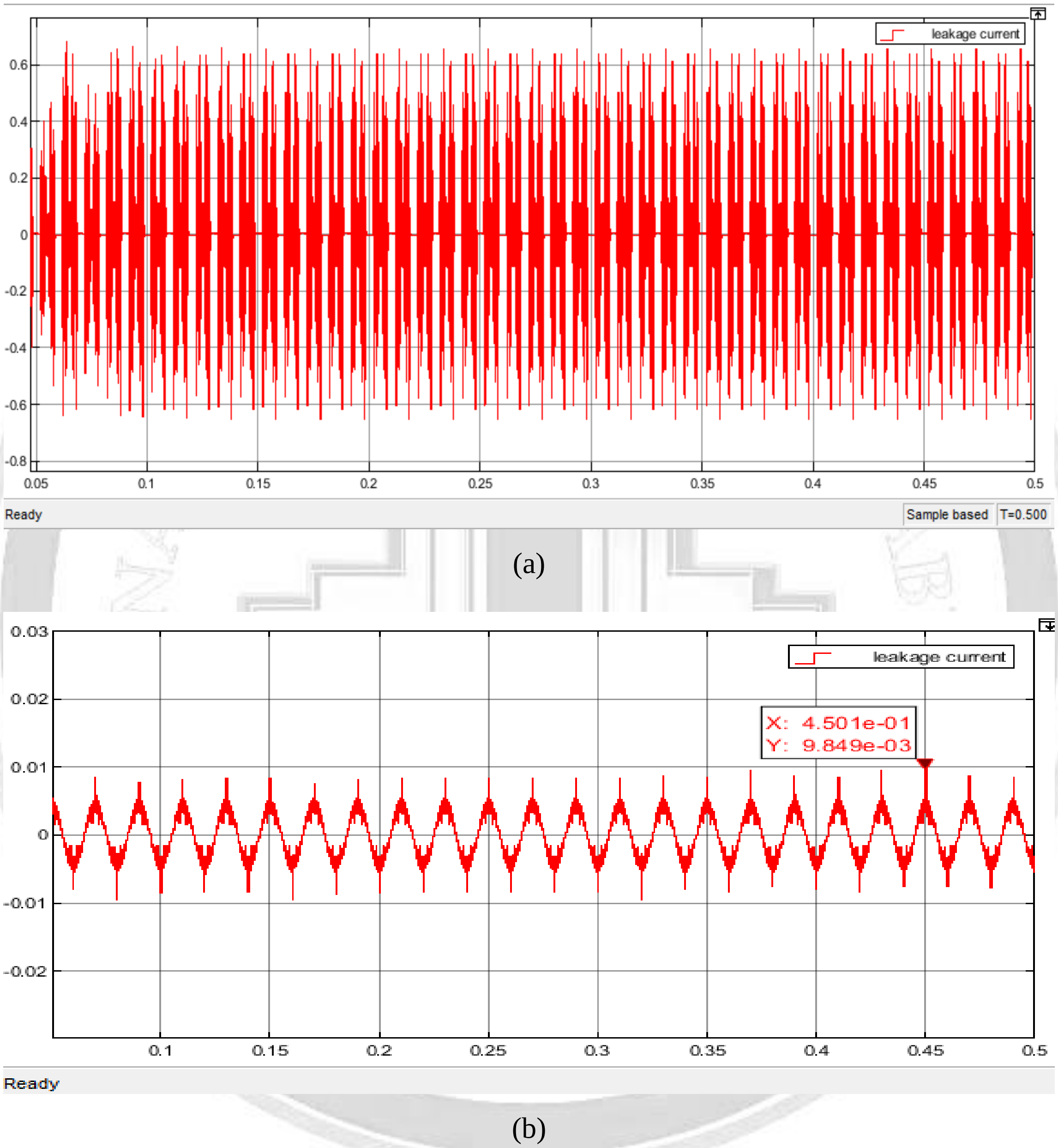

Fig.11 Leakage current under :(a) conventional PD-PWM, (b) Hybrid PD-PWM.

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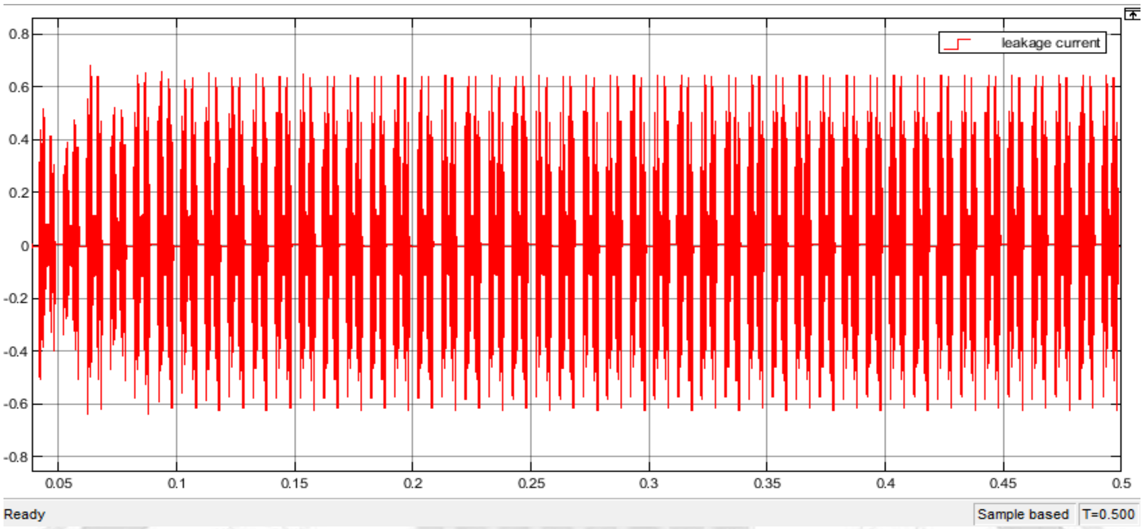
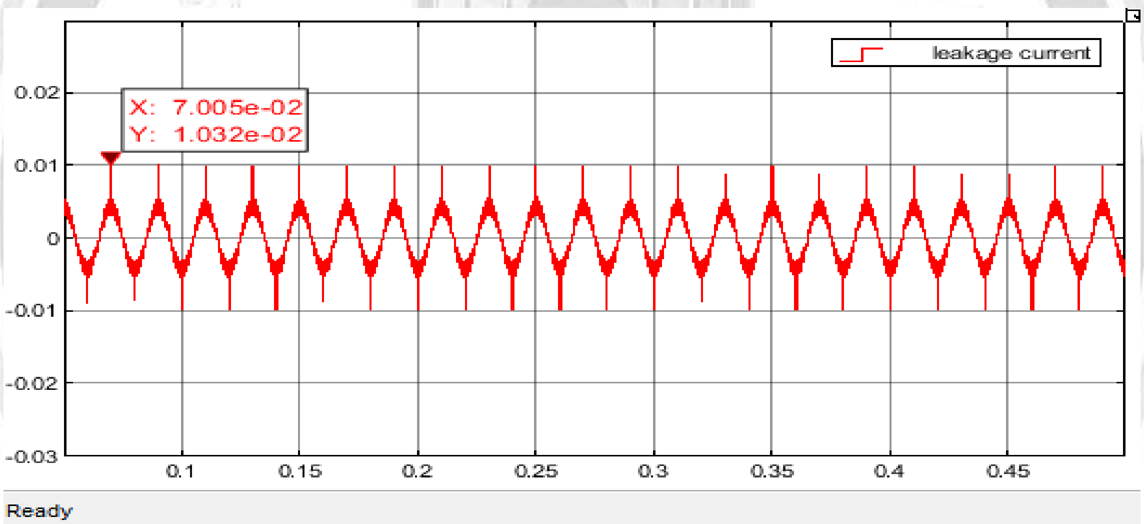


(a)



(b)

Fig.12 Leakage current under :(a) conventional APOD-PWM, (b) Hybrid APOD-PWM.

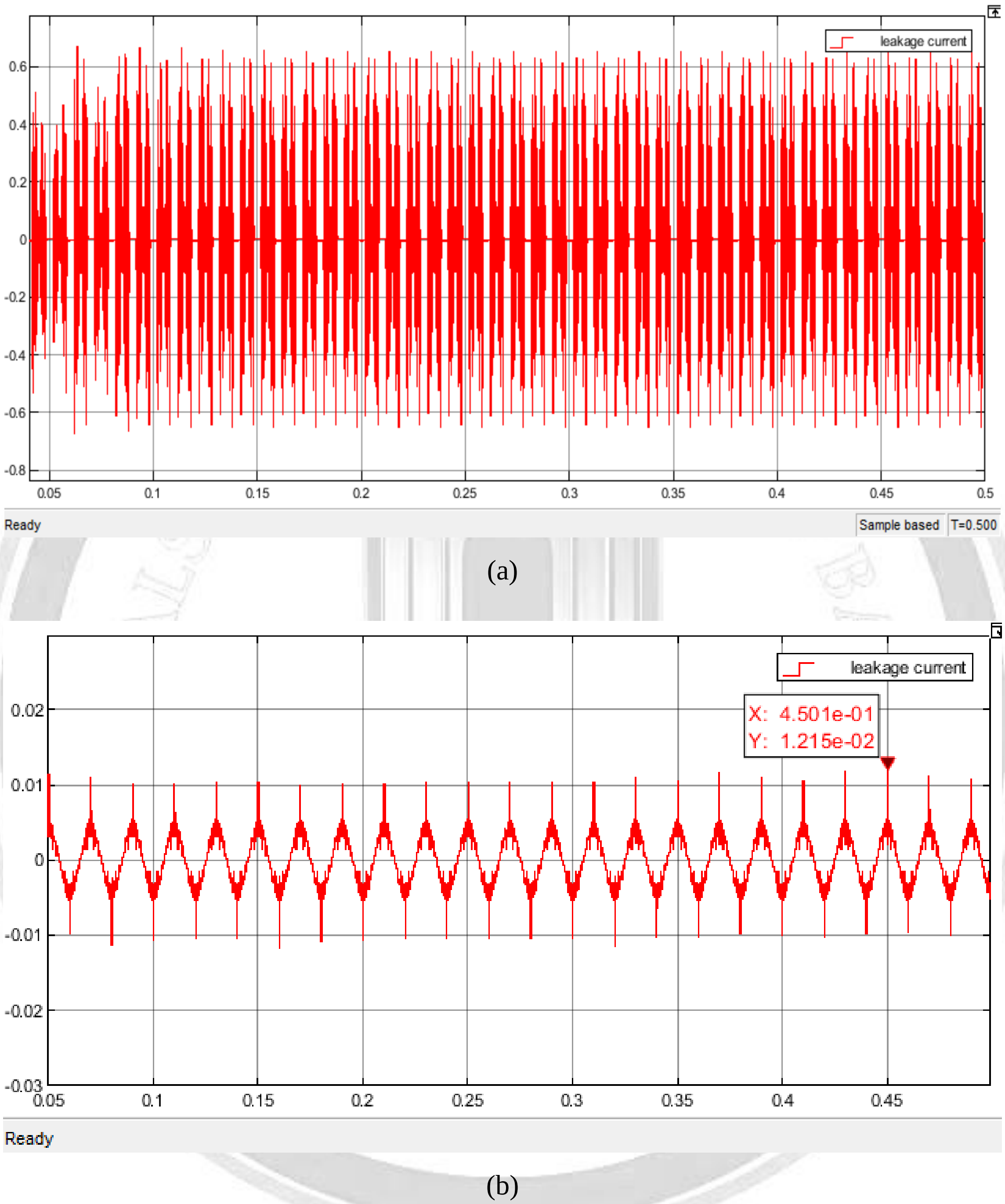


Fig.13 Leakage current under :(a) conventional PALS-PWM, (b) Hybrid PALS-PWM.

In this Table, a comparison between standard and HCB-PWM strategies in terms of RMS and peak RMS values are shown. Based on VDE-0126-1-1 standard, it is clear that all standard CB-PWM strategies are not complying with standard in term of both RMS and peak values of leakage current.

JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلـة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 32, No. 2. \ 2024 ISSN: 2616 - 9916

Table 3 Comparison between leakage current of HCB-PWM and conventional CB-PWM methods.

Name of technique	RMS of Leakage current (mA)	Peak value of Leakage current (mA)
PD-PWM	175.6	679.7
HPD-PWM	3.143	9.849
APOD-PWM	176.9	680
HAPOD-PWM	3.159	10.32
PALS-PWM	175.1	672
HPALS-PWM	3.129	12.15
PS-PWM	390.5	1116
HPS-PWM	3.441	4.952

By comparing the result in Table 3, it is also clear that adopting HCB-PWM methods produce lower leakage current that comply with VDE-0126-1-1 standards both RMS value <30mA and Peak <300 mA using half number of carriers when compared to the traditional CB-PWM methods. This indicates that the HCB-PWM methods successfully suppress leakage current and are suitable to be employed in grid connected transformer-less multilevel inverters PV systems.

6- Conclusion

To overcome the leakage current issue in transformer-less PV system, this paper investigates a hybrid switching frequency carrier based PWM approach. This approach is using fundamental and high switching frequency for 5L CHB inverter. This will reduce the system losses and therefore, improve the overall efficiency. A comparison between all standard and hybrid switching CB-PWM approaches for single phase five-level CHBMLI is carried out to evaluate the effectiveness of HCB-PWM in complying with the German standard in terms of RMS and peak values of leakage current. By modelling and comparing all the standard and hybrid CB-PWM including PS, PD, APOD, PALS with HPS, HPD, HAPOD, and HPALS in MATLAB/Simulink, it is clear that a significant reduction in leakage current values both (RMS and peak) are achieved. This means that adopting the hybrid approaches can effectively suppress leakage current in transformer-less five-level CHBMLI for grid connection photovoltaic system when compared to the traditional CB-PWM methods.

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مـــجلــة جـــامعة بـــــابـل للعلـــــوم الهندسية
Vol. 32, No. 2. \ 2024
ISSN: 2616 - 9916

تقنيات تضمين عرض النبضة الهجينة المستندة على الناقل لغرض خنق تيار التسرب في عاكس متتالي شمسي ذو خمس مستويات نوع قنطرة اتش: دراسة مقارنة

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الخلاصة

إكتسبت العواكس المتعددة المستويات شعبية متزايدة في مجال تطبيقات الجهد المتوسط والقدرة العالية. وبين الثلاث بنيات المفضلة من العواكس متعددة المستويات، يعتبر العاكس المتتالي المتعدد المستويات نوع قنطرة اتش الأنسب للإندماج في نظام الخلايا الشمسية المربوط مع الشبكة الوطنية. ومع ذلك يعاني هذا النوع من مشكلة تيار التسرب إذا كان لا يحتوي على محولة عزل. هذا البحث يحقق خنق لتيار التسرب بالإعتماد على طرق تضمين عرض النبضة المعتمدة على الناقل ذات تردد تبديل هجين. ولكي نقيم تأثير إستخدام هذه الطرق في تقليل تيار التسرب، نفذت في هذا البحث دراسة مقارنة بين كل طرق تضمين عرض النبضة المعيارية المستندة على الناقل والطرق الهجينة بإستخدام برنامج المحاكاة / ماتلاب لعاكس متتالي ذو خمس مستويات نوع قنطرة اتش احادي الطور. وتمت المقارنة بين الطرق المعيارية والهجينة لنقل المستوى والطور. وتوضح النتائج قدرة طرق تضمين عرض النبضة الهجينة المعتمدة على الناقل في تقليل تيار التسرب ليتلائم مع المعيار الألماني (في دي إي 0126-1-1) على مدى قيم الذروة و متوسط الجذر التربيعي لتيار التسرب. كما أظهرت النتائج أن أفضل قيمة جذر متوسط تربيعي لتيار التسرب البالغة (3.129 ملي أمبير) يتم تحقيقها عند تطبيق الأسلوب الهجين لتضمين عرض النبضة المتغير المستوى والطور، في حين أن أفضل قيمة لذروة تيار التسرب والبالغة (4.952 ملي أمبير) فقد تم الحصول عليها عند استخدام الأسلوب الهجين لتضمين عرض النبضة ذو الطور المتغير. لذلك تعتبر الطريقة الهجينة ستراتيجية تضمين عرض نبضة مناسبة لربط العواكس المتعددة المستويات الخالية من محولة العزل مع الشبكة.

الكلمات الدالة: عاكس متعدد المستويات نوع قنطرة اتش، تضمين عرض النبضة المعتمد على الناقل، تضمين عرض النبضة المعتمد على الناقل ذو تردد تبديل هجين، عاكس بلا محولة، خنق تيار التسرب.