

# Comparison of Traditional PWM and Phase Disposition PWM for a 5-Level Cascaded H-Bridge (CHB) Inverter in Low-Voltage Applications

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Total Harmonic Distortion (THD),  
MATLAB simulink.

## Abstract

Multilevel inverters play an important role in power systems as they provide better output waveform quality and help reduce harmonic distortion (THD). In this paper, a 5-level Cascaded H-Bridge (CHB) inverter is designed and tested using MATLAB Simulink. The inverter consists of two H-bridge cells, with each cell supplied by an equal DC voltage source. The 5-level configuration is chosen because it requires fewer switching devices compared to a 7-level inverter and is easier to implement, particularly for small low-voltage systems. Two modulation methods are used in this simulation. The first is Traditional PWM (TPWM), which employs one sine wave and one triangular carrier wave. The second is Phase Disposition PWM (PDPWM), where multiple triangular carriers are all in the same phase. Both PWM methods are tested under the same conditions, using a 50 Hz fundamental frequency to match the Malaysian power supply standard. To analyze the effect of filtering, the inverter is tested before and after applying a passive LC filter. Simulation results show that THD is reduced from 57.40% to 5.81% for TPWM, and from 27.38% to 1.83% for PDPWM after filtering. These results demonstrate that PDPWM is more effective when used with a passive filter. This work highlights the potential of PDPWM for applications in renewable energy systems, motor drives, and electric vehicles, and suggests opportunities for future exploration of advanced PWM strategies such as Modified PWM (MPWM) and AI-based modulation.

## 1. Introduction

A multilevel inverter is one of the very important solutions in power electronic systems because it improves the output waveform quality and reduces harmonic voltages. In a conventional two-level inverter, the output usually contains high switching noise and large Total Harmonic Distortion (THD), especially when supplying sensitive loads. Multilevel inverters such as the Cascaded H-Bridge (CHB) address this issue by generating stepped waveforms that more closely approximate a sinusoidal output. This makes them more suitable for applications like photovoltaic (PV) systems, small motor drives, and electric vehicles. In addition, multilevel inverters help reduce dv/dt stress and improve overall power quality in low-voltage applications [1].

Although higher-level inverters, for example 7-level or above can provide superior waveform quality, they require more components and complex switching logic. For this reason, the present study is limited to a 5-level

CHB inverter, which strikes a balance between waveform quality, circuit simplicity, and potential cost reduction for future hardware implementation.

The choice of pulse width modulation (PWM) technique is also a crucial factor affecting inverter output. Traditional PWM (TPWM) uses a single sinusoidal reference compared against a triangular carrier, while Phase Disposition PWM (PDPWM) employs multiple triangular carriers in the same phase, resulting in smoother switching and reduced distortion. Modified PWM (MPWM), another widely studied technique, is not implemented here but is noted in the keywords as a possible future extension of this work [2] [5].

Recent developments also point towards advanced strategies such as active damping control using inverter-side current feedback [3]. While this work focuses on passive LC filtering, such approaches highlight future research directions for improving harmonic suppression.

In this study, a 5-level CHB inverter is designed and simulated using MATLAB Simulink to compare two PWM techniques, that is TPWM and PDPWM. Both methods are tested under the same conditions. The inverter is evaluated before and after applying a passive LC filter to observe differences and improvements in THD. The output voltage and THD are analysed using the oscilloscope and Fast Fourier Transform (FFT) tools in MATLAB. Based on these results, a comparison is made to determine which method is more suitable for low-voltage applications.

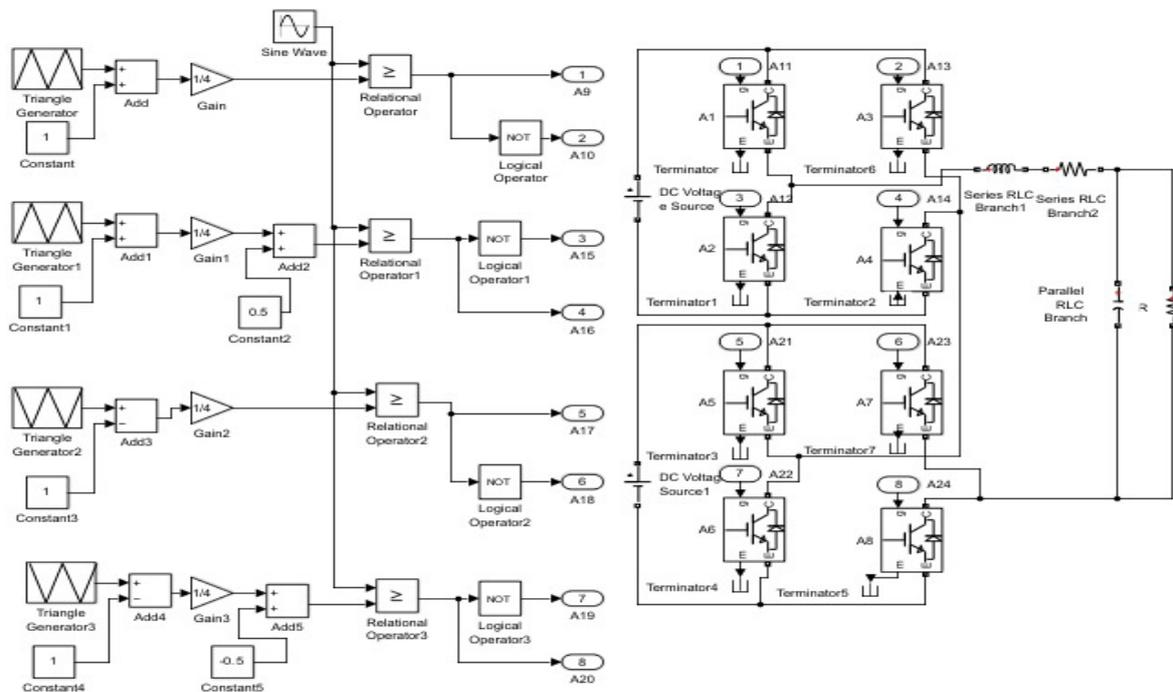
## 2. Design Development

This section presents a detailed explanation of the design considerations and analytical calculations involved in developing the inverter system, focusing on topology selection, output voltage derivation, power estimation, control strategies, and filter design.

### 2.1 Inverter Topology - 5-Level Cascaded H-Bridge (CHB)

The inverter used in this project is designed based on the 5-level Cascaded H-Bridge (CHB) configuration as shown in Fig. 1. It consists of two H-bridge cells, with each cell powered by a separate 100V DC source. When combined, this setup is capable of generating five distinct voltage levels at the output: -200V, -100V, 0V, +100V, and +200V.

This multilevel approach offers a much smoother output waveform compared to traditional two-level inverters. By producing stepped voltage levels, the waveform more closely resembles a sine wave, significantly reducing total harmonic distortion (THD). This is particularly beneficial for applications that require clean and stable voltage, such as in sensitive electronic systems.



**Fig. 1** Simulink model of the 5-level CHB inverter system: Cascaded H-Bridge (CHB) inverter with LC filter and load connection

## 2.2 Output voltage Derivation

With the two cascaded H-bridge units, the output voltage level,  $V$  can be  $-200V$ ,  $-100V$ ,  $0V$ ,  $+100V$ , and  $+200V$ . In a two-cell 5-level CHB inverter, the total output voltage is the sum of the voltages produced by each H-bridge cell. If each cell can output  $+100V$ ,  $0V$ , or  $-100V$ , then the total output voltage  $V_{total}$  is given by Equation (1):

$$V_{total} = V_{cell1} + V_{cell2} \quad (1)$$

This equation means that the total output voltage of the inverter is the result of adding the voltages produced by each of the two H-bridge cells. When connecting two such cells in series, their voltages combine. The total voltage at the inverter output is the sum of the individual outputs from both cells. Because each H-bridge can independently generate  $+100V$ ,  $0V$ , or  $-100V$ , combining their outputs leads to five possible values:

$$(+100V) + (+100V) = +200V, (+100V) + (0V) = +100V, (0V) + (0V) = 0V, (-100V) + (0V) = -100V \text{ and } (-100V) + (-100V) = -200V$$

This stepped output allows the inverter to generate a waveform that closely approximates a sine wave, helping to reduce harmonic distortion and improve power quality without requiring complex filtering. Therefore, the inverter outputs five voltage levels:  $-200V$ ,  $-100V$ ,  $0V$ ,  $+100V$ , and  $+200V$ , forming a multilevel stepped approximation of an AC waveform.

## 2.3 Current and Power Estimation

Based on the load resistor used in the simulation  $R = 10 \Omega$  and the maximum output voltage  $V = 200V$ , the current output estimated is  $20A$ . Therefore, the output power by the inverter is  $4kW$ .

This is based on estimation value based on simulation. In the actual hardware there will be losses from the switching devices, inductor resistance and capacitor would reduce the real power. However, in the MATLAB Simulink, the value provides a sufficient estimation of the system rating under ideal conditions.

## 2.4 PWM Switching and Control

Two PWM techniques were simulated:

- Traditional PWM (TPWM) uses one sine wave compared with triangular wave.
- Phase Disposition PWM (PDPWM) uses multiple triangle carriers in the same phase, giving smooth control.

Both control strategies operated at  $10kHz$  switching frequency with a  $50Hz$  output frequency, which complies with Malaysia standard.

## 2.5 Filter Design and Cut-off frequency

To improve the output quality and reduce high frequency harmonics, a passive LC filter is used after the inverter with inductor ( $L = 2.2mH$ ) and a parallel capacitor ( $C = 20\mu F$ ). A resistor  $15\Omega$  is added in series connection with the inductor to help damping the resonance and provide stability to the LC filter. This resistor also acts as practical winding resistance where it simulates the real-world energy in coil winding. The use of such damping resistance is common technique in a passive LC filter. As previous studied in [3], the damping resistor helps to reducing unwanted oscillation in LC filter and improve the system performance especially in low frequency. The cut-off frequency  $f_c$  of the LC filter is calculated using the standard formula in Equation (2):

$$f_c = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{2.2mH \times 20\mu F}} = 760 \text{ Hz} \quad (2)$$

Where  $L$  is the inductance and  $C$  is the capacitance. This filter allows the fundamental frequency to pass while attenuating the higher-order harmonics from the switching operation. The frequency allows the  $50Hz$  fundamental signal to pass while filtering most of the high frequency switching noises. The components for the simulation model are selected in Table 1. All components are selected to model practical conditions and suit low-voltage simulation testing like solar inverter.

**Table 1: Component selection**

Components	Types/Values
Switches	Ideal controlled switches (MOSFETs)
DC Source	100V for each H-Bridge
Load Resistance	10 Ω
Inductor (L)	2.2mH
Capacitor (C)	20μF
Series R (for damping)	15 Ω

### 3. Methodology

This project was designed and simulated by using MATLAB Simulink software. The design is based on the 5-level Cascaded H-Bridge (CHB) inverter topology using two H-bridge cells and each cell supplied by a 100V DC source. This setup will produce five output voltage levels, which are -200V, -100V, 0V, +100V, and +200V. The inverter circuit and switching logic is modeled using standard blocks. Two PWM control methods were tested: Traditional PWM (TPWM) and Phase Disposition PWM (PDPWM). Although Modified PWM (MPWM) was not simulated, it is included in the discussion as a relevant alternative technique for comparison in future studies. In TPWM, one sine wave is compared with one triangular carrier and in PDPWM multiple triangular carriers are in the same phase disposition. This method improves the balance of the switching between H-bridge cells and improve output waveform. The switching frequency is set at 10kHz, and the fundamental frequency to 50Hz to match Malaysia electrical standard.

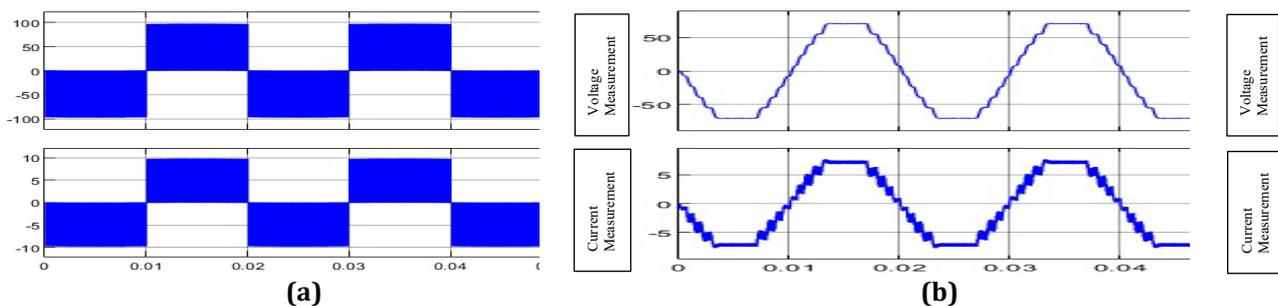
To reduce high-frequency harmonics, a passive LC filter is connected at the inverter output. The filter uses inductor (L=2.2mH) and a parallel capacitor (C= 20μF). A resistor 15Ω is added to the design where its series with the inductor to help prevent resonance and improve filter stability. This resistor also models practical winding resistance and damping effect. The actual load is using resistor (R=10Ω) as per design requirements placed after the filter. All outputs are analysed using Simulink scope and FFT analysis tools to compare waveform and THD values for both PWM techniques. Simulation is carried out before and after filter is applied to observe the effectiveness of the filter in improving signal quality. From this, the waveform quality and harmonic distortion are clearly analysed.

### 4. Results and Discussion

In this section, the simulation results from MATLAB Simulink are analysed. Both Traditional PWM (TPWM) and Phase Disposition PWM (PDPWM) methods are tested using the same 5-level CHB inverter design. Each modulation technique is evaluated under two conditions: before and after applying the passive LC filter. The analysis focuses on output waveform quality and Total Harmonic Distortion (THD) performance to assess the effectiveness of each method and the impact of filtering.

#### 4.1 Output Voltage and Current Waveform

The output waveform from the inverter shown that inverter without filter the signal contains more switching noise. After applying the passive LC filter with damping resistance, the waveform quality improves. The filter demonstrates strong harmonic attenuation and improves waveform smoothness. Figure 2 (a) and (b) are TPWM before and after filtering and Fig. 2 (a) and (b) PDPWM before and after filtering.



**Fig. 2 Results output waveform from TPWM:**  
 (a) TPWM output waveform without LC filter (b) TPWM output waveform with LC filter

#### 4.1.1. TPWM Voltage Measurement After Filtering

Even with the LC filter in place, the output voltage still shows the stepped nature of TPWM, but now with much smoother transitions between levels. The filtering has effectively suppressed the high frequency switching ripple, leaving behind a waveform that resembles a sine wave with mild “staircase” transitions.

Compared to the unfiltered TPWM output, this waveform is a major improvement. However, it still shows less waveform purity than filtered PDPWM, which tends to yield smoother modulation thanks to its multi-carrier phase control.

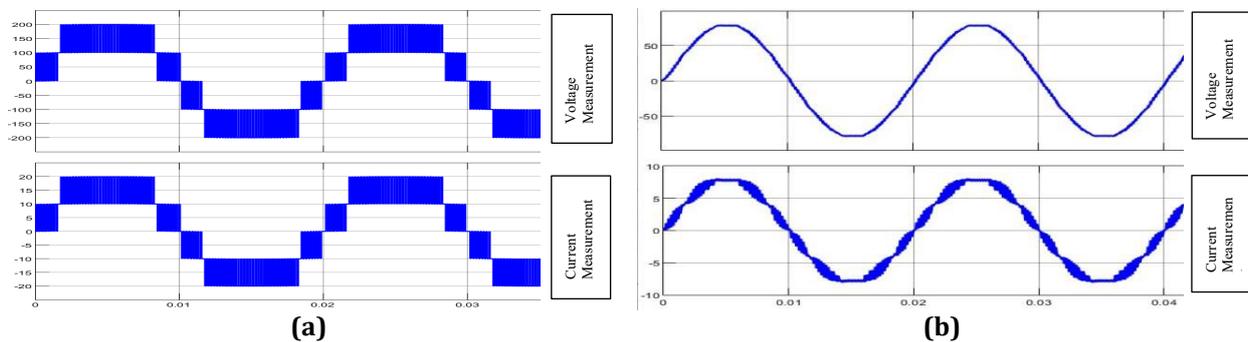
The rise and fall times ( $\sim 5.5$  ms) and the high slew rate ( $\pm 20.41$  V/ms) reflect sharper level changes, inherent to TPWM’s single-carrier approach. Despite this, the waveform remains symmetrical and centered, which confirms that the control logic and inverter are functioning correctly.

#### 4.1.2. TPWM Current Measurement After Filtering

After applying the LC filter, the current waveform from the TPWM-controlled inverter is much improved.

Although it’s not as smooth as what you’d expect from PDPWM, it is now quite usable for many real-world applications. The high frequency switching ripple has been largely suppressed, and what remains is a steady, nearly sinusoidal current.

The waveform stays symmetric, and the peaks hit consistently at  $\pm 7.68$  A as shown in Fig. 3. The RMS value is consistent at 5.44 A, which makes sense given the filtered output voltage is around  $\pm 71$  V. The filter did its job well, especially considering TPWM is a simpler control method and more prone to distortion before filtering.



**Fig. 3** Results output waveform from PDPWM:

(a) PDPWM output waveform without LC filter; (b) PDPWM output waveform with LC filter

#### 4.1.3. PDPWM Voltage Measurement After Filtering

With the LC filter in place, the inverter’s output voltage has become almost perfectly sinusoidal. It swings between  $\pm 78$  V with a consistent 50 Hz frequency, which is exactly what aimed for. The RMS voltage is around 56 V, and there are no sharp transitions or noise on the waveform, which means the filter is doing its job well.

This clean output is ideal for low-voltage applications like solar inverters or motor drives, where smooth voltage is important for performance and safety. All the readings are within expected ranges, and the inverter is behaving as designed. This test confirms that using PDPWM with a well-designed passive LC filter is a very effective setup.

#### 4.1.4. PDPWM Current Measurement After Filtering

This current waveform shows that the inverter, combined with the LC filter, is now delivering a stable and clean AC output to the load. The current closely follows the voltage, both in shape and timing, which is exactly what needed in a properly tuned inverter system. The RMS value is about 5.65 A, which is reasonable for a resistive load with a peak voltage of  $\pm 78$  V.

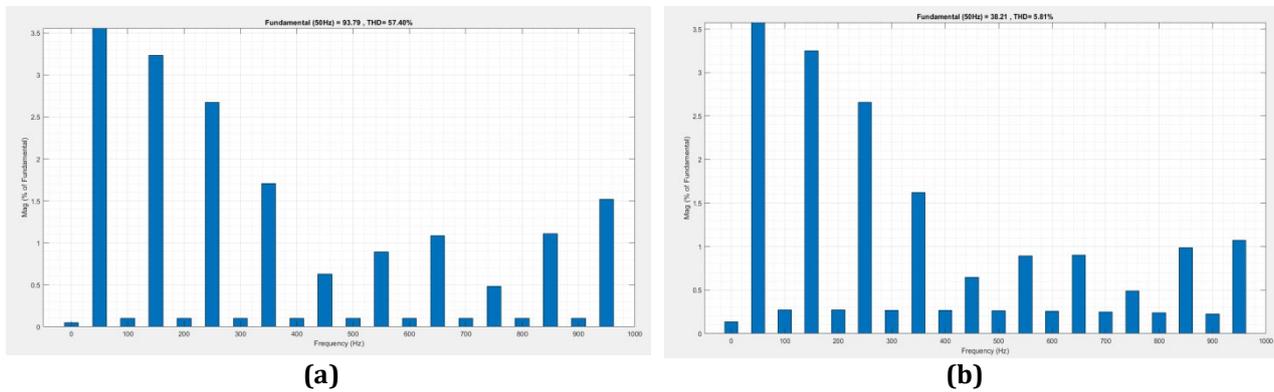
The waveform doesn’t show signs of over current, noise, or imbalance, meaning the PWM switching and filter design are working well together. Also, the symmetry in rise and fall times shows balanced power flow for both halves of the AC cycle, making the setup reliable for real applications like solar inverters or low-voltage drives.

### 4.2 FFT Analysis and THD Comparison

The FFT tool in MATLAB is used to analyse the harmonic results. Table 2 tabulates the THD values for each technique before and after filter applied. Fig. 4 (a) and (b) are THD value for TPWM before and after filtering and Fig. 5 (a) and (b) are THD value for PDPWM before and after filtering.

**Table 2** Comparison of THD values before and after filter

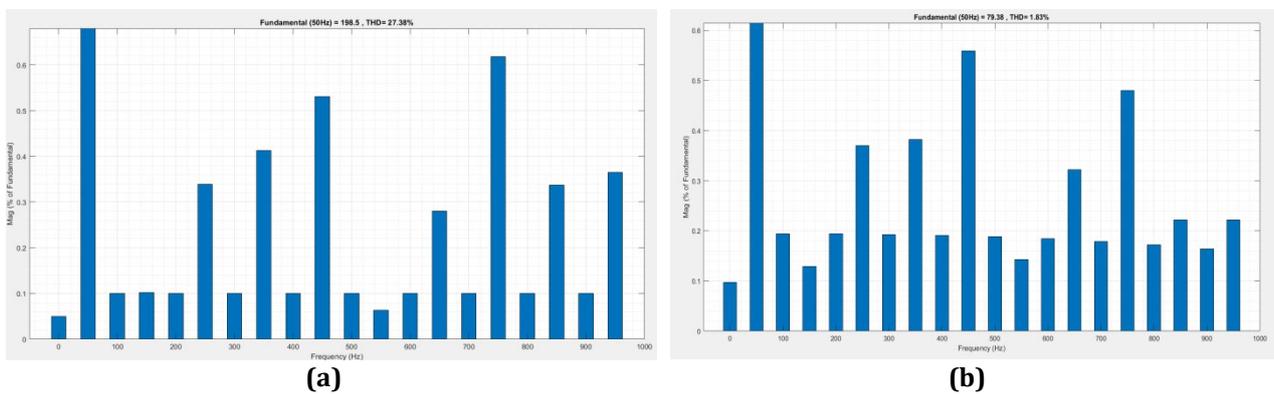
Method	THD Before Filter	THD After Filter
TPWM	57.40%	5.81%
PDPWM	27.38%	1.83%



**Fig. 4** Results THD for TPWM:  
(a) TPWM THD without LC filter; (b) TPWM THD with LC filter

The FFT analysis of the Traditional PWM (TPWM) output reveals a significant reduction in harmonic content after the application of a passive LC filter. Before filtering, the Total Harmonic Distortion (THD) is measured at 57.40%, with strong harmonic peaks visible at 150 Hz, 250 Hz, 350 Hz, and continuing at regular intervals. These high harmonic magnitudes are a result of the steep step transitions in the unfiltered output waveform, characteristic of basic SPWM modulation.

After applying the LC filter ( $L = 2.2 \text{ mH}$ ,  $C = 20 \text{ }\mu\text{F}$ ), the THD drops significantly to 5.81%, and the higher-order harmonic peaks are visibly attenuated in the frequency spectrum. While some residual harmonics remain, the filtered waveform shows a much stronger fundamental at 50 Hz and minimal distortion beyond 200 Hz. This confirms that the LC filter is effective in reducing the high frequency switching harmonics and smoothing the output waveform. The reduction from 57.40% to 5.81% demonstrates that TPWM, when paired with a properly tuned LC filter, can deliver acceptable performance for low-voltage applications where strict waveform purity is not required.



**Fig. 5** Results THD for PDPWM:  
(a) PDPWM THD without LC filter; (b) PDPWM THD with LC filter

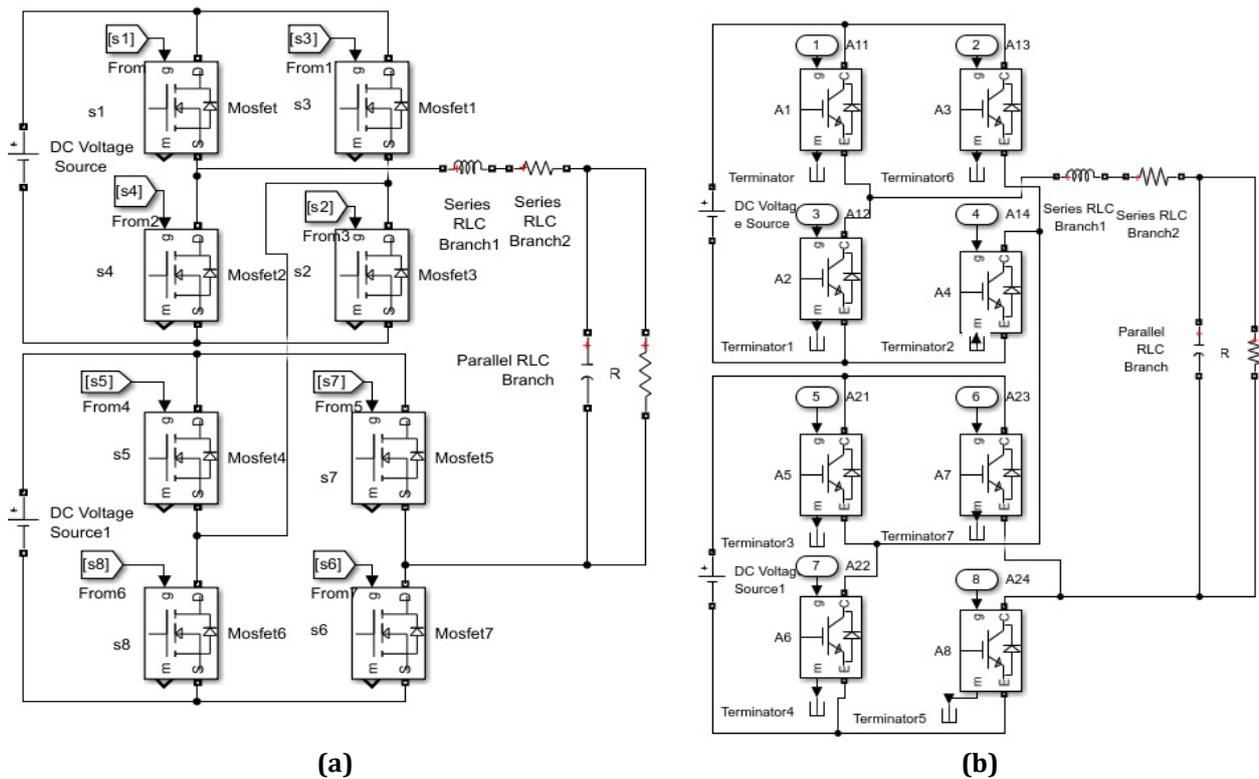
The Fast Fourier Transform (FFT) analysis of the Phase Disposition PWM (PDPWM) output demonstrates a significant improvement in waveform quality after applying an LC filter. Prior to filtering, the output contains moderate harmonic content with a Total Harmonic Distortion (THD) of 27.38%. Although the PDPWM switching technique inherently reduces harmonic levels compared to Traditional PWM, the unfiltered waveform still contains noticeable harmonic peaks across a wide frequency range, including strong components around 400 Hz, 700 Hz, and beyond. This is expected due to the high frequency switching of multilevel PWM.

After passing through the LC filter ( $L = 2.2 \text{ mH}$ ,  $C = 20 \text{ }\mu\text{F}$ ), the THD drops dramatically to 1.83%, with most high frequency components significantly attenuated. The filtered waveform has a much stronger fundamental (79.38 at 50 Hz) and very low magnitudes in the higher harmonic bands. This result confirms that PDPWM,

combined with a properly tuned LC filter, is highly effective in producing a clean sinusoidal output, making it ideal for low voltage applications such as solar inverters, battery-fed converters, and small motor drives. The improvement is more pronounced compared to TPWM, both in raw THD reduction and harmonic distribution. These results show that PDPWM gives better performance with a lower THD compared to TPWM, especially after filtering. The filter give effect and very important in smoothing the output and improving the waveform quality.

### 4.3 Effectiveness of the LC Filter

The LC Filter proves that its effectiveness in reducing the THD below the 5% threshold recommended by IEEE 519 standard and meet Malaysia grid requirements as shown in Fig 6. The LC filter is designed using  $L = 2.2\text{mH}$  and  $C = 20\mu\text{F}$  where it gives a cut-off frequency around 760Hz, which is very successful, reducing the high-frequency harmonics and passing the 50Hz fundamental component. The simulation results have confirmed this with a significant THD improvement in both TPWM and PDPWM. The filter also helps to smooth the waveform and reduce the switching spikes, making the output more stable and safer for sensitive load applications like solar inverter and motor drives systems.



**Fig. 6** LC Filter design:  
 (a) TPWM LC filter (b) PDPWM LC filter

### 4.4 PWM Technique Comparison

Comparing the PWM methods, PDPWM shows very good performance due to its balanced use of carrier signal in the same phase as tabulated in Table 3. This provides more stable switching and better waveform which will reduce the harmonics while the TPWM is simpler but less efficient in harmonic control.

**Table 3** Switching table for TPWM (Traditional PWM) and PDPWM (Phase disposition PWM)

S1	S2	S3	S4	S5	S6	S7	S8	Theoretical Vo	Vo (Value)
ON	OFF	OFF	ON	ON	OFF	OFF	ON	+Vdc	+200 V
ON	OFF	OFF	ON	OFF	ON	ON	OFF	+Vdc/2	+100 V
OFF	ON	ON	OFF	OFF	ON	ON	OFF	0	0 V
OFF	ON	ON	OFF	ON	OFF	OFF	ON	-Vdc/2	-100 V
OFF	ON	ON	OFF	OFF	ON	ON	OFF	-Vdc	-200 V

#### 4.4.1 Comparison Between the Logic Analyzer Outputs of Traditional PWM (TPWM) and Phase Disposition PWM (PDPWM)

A comparison between the logic analyzer outputs of Traditional PWM (TPWM) and Phase Disposition PWM (PDPWM) for the 5-level Cascaded H-Bridge (CHB) inverter in low-voltage applications reveals important differences in switching behavior is tabulate in Table 4. TPWM, which uses a single sine reference compared against a triangular carrier, produces gate signals with uneven spacing, narrower near zero-crossings and wider at the waveform peaks. Although the switching logic is stable and symmetrical, the lower resolution in modulation leads to broader voltage steps and increased harmonic content. This is evident in the logic analyzer waveform, where the transitions are less frequent and concentrated.

On the other hand, PDPWM employs multiple in-phase triangular carriers, enabling higher switching granularity across all H-bridge switches. The logic analyzer trace for PDPWM displays more frequent, well-distributed pulses that result in a smoother staircase voltage output and better harmonic suppression. This uniform switching also helps balance thermal stress across devices. For low-voltage applications such as solar inverters and small motor drives, where clean waveform are critical and filtering options are limited, PDPWM proves more effective in achieving low Total Harmonic Distortion (THD) with minimal post-filtering. While TPWM remains simpler and easier to implement, PDPWM provides a clear performance advantage in delivering smoother and more efficient power for sensitive low-voltage systems.

**Table 4** Comparison of TPWM and PDPWM in 5-Level CHB inverter (Low-voltage application)

Criteria	Traditional PWM (TPWM)	Phase Disposition PWM (PDPWM)
Modulation Method	Single sine reference vs. single triangular carrier	Single sine reference vs. multiple in-phase carriers
Switching Frequency Distribution	Uneven across switches; more switching at peaks	Uniform across switches; balanced switching activity
Logic Signal Pattern	Sparse, blocky transitions	Dense, fine-grained transitions
Waveform Quality (Voltage)	Coarse 5-level steps; visible harmonic edges	Smoother staircase waveform with finer steps
Current Waveform	More distortion; mild ripple after LC filtering	Cleaner sine-shaped current after filtering
THD Performance (After LC Filter)	Higher THD (~5.81%)	Lower THD (~1.83%)
Hardware Stress	Uneven thermal load on switches	Better thermal distribution due to balanced switching
Control Complexity	Simpler to implement	More complex logic due to multiple carriers
Suitability for Low-Voltage Use	Adequate with strong filtering	More efficient and cleaner output with minimal filtering

#### 4.5 Compliance with Malaysia Standard

The final output waveform after the filtering is comply with Malaysia electrical standard requirements. 50Hz frequency and THD below 5% in accordance with IEEE 519-2022 recommendation[4]. This proved that the inverter that has been designed is suitable for low-voltage real world applications.

### 5. Conclusion

In this project, a 5-levels Cascaded H-Bridge (CHB) inverter was successfully designed and tested using MATLAB Simulink. Two PWM control methods, Traditional PWM (TPWM) and Phase Disposition PWM (PDPWM), were evaluated under identical conditions before and after applying the passive LC filter.

Simulation results show that THD is reduced from 57.40% to 5.81% using TPWM and from 27.38% to 1.83% using PDPWM. These results confirm that PDPWM outperforms TPWM in terms of waveform quality and harmonic suppression.

The passive LC filter ( $L = 2.2 \text{ mH}$ ,  $C = 20 \text{ }\mu\text{F}$ ) successfully removed high-frequency harmonics and allowed the fundamental 50 Hz component to pass clearly, ensuring compliance with IEEE 519 standards and Malaysian grid requirements.

Overall, the findings confirm that PDPWM combined with passive LC filtering is highly suitable for low-voltage applications such as solar inverters and small motor drives. For future work, this design should be validated with

hardware implementation, extended to other modulation strategies such as Modified PWM (MPWM), and explored with intelligent control techniques like fuzzy logic and AI-based modulation to further enhance performance.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Ahmad Mazlan Bin Ahmad Zaidi; Brian Crisswill G Giserlerry **data collection:** Mohd Khairy Bin Hassan; Ahmad Mazlan Bin Ahmad Zaid **analysis and interpretation of results:** Mohd Khairy Bin Hassan; Paran Jonly. **draft manuscript preparation:** Brian Crisswill G Giserlerry; Paran Jonly. All authors reviewed the results and approved the final version of the manuscript.

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