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A review of grid connection performance of solar cells for a three-phase structure of a 7-level cascaded inverter

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Abstract: Nowadays, solar energy has become a competitive option for power generation in self-sufficient systems that may be used in both urban and rural electrification settings. High-quality alternating current output is required from the power electronic converters used in the conversion process in order to guarantee a voltage waveform that closely mimics a sinusoidal form. To get a high-quality output, the inverter's architecture and the pulse width modulation (PWM) technology it uses are essential factors. With a wide variety of industrial applications, the multilevel inverter has emerged as a major field of study in recent decades. Multilevel inverters (MLIs) are used to enhance output waveform characteristics (e.g., lower total harmonic distortion) and to offer a variety of inverter configurations and modulation methods. As a result, MLIs have attracted more attention from scholars in comparison to their two-level equivalents, attributable to their capacity to deliver reduced electromagnetic interference (EMI), enhanced efficiency, and elevated direct current connection voltages. The Cascaded H-bridge (CHB) inverter was discovered in fact more reliable, easier to build, and performing Impressively among many multilevel inverter configurations. It is the best option for energy transformation in a wide range of industrial applications because of its exceptional qualities, which include great adaptability and durability against defects. This operating efficiency for a three-phase, 7-level CHB inverter was thoroughly investigated at this work. Phase Shifted Pulse Width Modulation (PSPWM) methodology was employed at simulation to assess inverter performance. The three-phase, 7-level CHB inverter was the particular application for this PSPWM technology. MATLAB/SIMULINK software was employed at produce simulator conclusions. The thorough simulation and performance evaluation of a three-phase, seven-level CHB Multilevel Inverter using PSPWM in compliance with real-world operating conditions is what makes this work unique. As opposed to previous studies that primarily focus on generic CHB inverter designs, this paper carefully examines the complex application and performance metrics of PSPWM in a multi-phase system, clarifying issues regarding harmonic distortion properties, voltage waveform integrity, and modulation effectiveness. The suggested inverter is perfect for integration with renewable energy grids because simulations showed that it had better output waveform, reduced power losses, lower harmonic distortions, and superior voltage quality.

Keywords: Multilevel inverters (MLIs); electromagnetic interference (EMI); Cascaded H-bridge (CHB); Phase Shifted Pulse Width Modulation (PSPWM)

Abbriviations:

- MLIs Multilevel inverters
- EMI electromagnetic interference
- CHB Cascaded H-bridge
- PSPWM Phase-Shifted Pulse width modulation
- PV Photovoltaic
- THD Total harmonic distortion
- NPC Neutral Point Clamped
- FC Flying Capacitor
- MPPT Maximum power point tracking
- THD Total harmonic distortion
- SHEPWM Selective Harmonic
- Elimination PWM
- SVPWM Space Vector PWM
- P&O Perturbation and Observation
- IC Incremental Conductance
- SM submodules
- PLL Phase-Locked Loop

1.Introduction

The use of grid-supplied electricity has significantly increased recently. These phenomena can be attributed to the expansion of high-energy sectors and an expanding user demography. Traditional energy production It brought about notable rise at worldwide emissions, which has had negative environmental effects. Significant progress has been made in integrating renewable energy sources, such wind and solar, into the electrical system. Welcome to the world of photovoltaic (PV) systems, which, because of their exceptional potential, have become the best choice for

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energy capture. In actuality, grid-connected solar PV's capacity has increased to over 635 GW globally, meeting around 2% of the world's energy needs [1].

The solar photovoltaic (PV) technology has the unique benefit of directly converting solar radiation into electrical energy, which makes it especially suitable for a wide variety for geographic locations. As like, it is significantly preferred when compared to other renewable energy sources (RES). In particular, solar power is distinguished by its lack of pollution, its availability due to sun radiation, and its steadily rising prices over the previous 20 years [2]. An important factor in the planet's total energy dynamics is solar radiation. More than 100,000 terawatts for overall quantity from sun rays that solar emits make it through the Earth's atmosphere through processes of absorption and reflection. This enormous store of wasted power having capacity that establish sun power as key component of the renewable energy spectrum [3]. Out of all the photovoltaic systems, over 99 percent are either autonomous or integrated into the electricity grid. This supremacy can be ascribed to lower building costs, increased scalability, shorter downtime, and greater stability of grid-connected networks over their independent counterparts in terms of future growth. [4]. The development of photovoltaic power converters has unquestionably been accelerated by this proliferation. When attaching photovoltaic modules at alternating current (AC) loads as well as electrical network, these converters are quite important. They are therefore used ensuring dependable as well effective power transformation. This basic operations from Photovoltaic energy transformers are always the same, despite the fact that their designs can vary. MLIs had been that most common technology in the industrial sector in recent years because of their remarkable features. They're extensively utilized into network-connected PV power generation systems in medium-for high-power settings [5].

MLIs you class from energy electronic converters which can generate a given alternating waveform with several steps, depending on the number of levels and modulation method used. Due to their use in medium voltage drive applications, which typically have power and voltage ratings between 1 MW and 4 MW and between 3.3 kV and 6.6 kV, respectively, these inverters are well-known. Moreover, the ability of multilevel inverters to produce a staircase waveform that closely resembles a pure sinusoidal waveform with negligible harmonic distortion sets them apart. Depending above required number from sources, MLIs can be divided into two different types: single DC supply inverters as well multiple DC supply inverters [6]. Modular Multilevel Inverters (MLIs) are the recommended choice for integrating with medium voltage power grids because 2-Level inverters are inappropriate for medium voltage applications due to the restrictions imposed by the blocking voltage of semiconductors. In order to meet established grid codes, the MLI not only lessens the dv/dt stress that semiconductor switches face, but it also drastically lowers the voltage Total Harmonic Distortion (THD). Additionally, it has been shown that they can reduce electromagnetic interference (EMI) and power dissipation in semiconductor switches. According to their architecture, MLIs have typically separated into three main topologies: Flying Capacitor (FC), CHB, and Neutral Point Clamped (NPC) [7].

The CHB-MLI is thought to be the best topology of the ones discussed above for integrating a PV system. For every bridge, the CHBMLI includes a separate direct current (DC) supply. The DC sources can be efficiently replaced with a solar panel. Because it has fewer components and allows for the use of an asymmetrical DC source, the CHBMLI has clear advantages over the other two types of MLIs. This output voltage produced by an CHBMLI is twice that of its diode-clamped and flying capacitor equivalents while keeping the input voltage constant [8].

In this paper, design as well modeling from a Three phase 7- level CHB-MLI is discussed of PSPWM technique. This paper also presents a brief overview of modulation technique. Simulation results of output voltage waveforms obtained for Three phase 7- level CHB-MLI are presented using modification technique.

This organization of this paper is as enumerated. Following the introduction in Section 1, Section 2 presents the system General Description in this study. Section 3 presents the topology description. Section 4 presents the main controller. Section 5 provides the simulation outcomes. Section 6 provides the general conclusion as well abbreviations.

Three common types of MLIs are compared in Table 1: (FC-MLI), (NPC-MLI), and (CHB-MLI). This comparison analysis clarifies the essential technological differences that have a substantial impact on each inverter category's operational effectiveness, providing important information about their suitability for various applications. This comparison led to the selection of CHB due to its fault tolerance, modularity, high efficiency, low harmonic distortion, and applicability in solar PV applications with independent DC sources.

2. General Description

Figure 1 shows a three-phase 7-level CHB-MLI system with PV systems which is connected for electrical network and Modulation technique was used. This topology indicates to how the component arrangement and functionality by implementing the following methods: -

- The PV module converts solar energy, which is defined as solar radiation for 1000 W/m² and degree from 25°C into electrical energy in the form of current as well voltage signals.

Table 1: CHB, NPC and FC multilevel inverter comparison.

	CHB-MLI	**NPC-MLI**	**FC-MLI**	**Ref**
Response Speed	Depending on the PWM being utilized (like APOD, PSPWM, etc), the response time is medium.	Similar, but balance makes control more difficult.	Similar, but because there are more capacitors, the control is more complicated.	[9 - 10]
Losses	Reduced stress on the keys and low losses because there aren't several capacitors.	Increased losses because of capacitors used for voltage stabilization.	Losses increase as complexity and capacitor count rise.	[3,9,11]
THD	The low total harmonic distortion is a result of the independent operation of each H-bridge, allowing for modulation that produces an output waveform closely resembling a sinusoidal shape. This modular design improves harmonic performance.	Multiple voltage levels help to reduce the number of steps in the output waveform, which in turn helps to achieve a low total harmonic distortion. However, careful capacitor voltage balancing is required to achieve a moderate THD.	THD is often modest and comparable to NPC. The output waveform can be fine-tuned thanks to the voltage level flexibility, which lowers THD. However, the capacitor voltage balancing affects the THD.	[11- 12]
Efficiency	Reduced component stress and the ability to distribute power conversion over multiple modules are responsible for increased efficiency, particularly at higher power levels. (97–99%).	Due to lower switching losses, especially at lower switching frequencies, the efficiency is typically higher. Nevertheless, when the number of levels increases, the total efficiency decreases because of the additional power losses brought on by the clamping diodes. (96–98%).	usually reduced relative to the nominal power consumption due to additional energy loss associated with the charging and discharging of the capacitors. In order to maintain operational efficiency (94–97%), careful monitoring of capacitor voltages is required.	[9, 12 - 13]
Complexity Structural	Low; symmetrical cells and distinct structure H-Bridge	Medium to high (voltage stabilizer and several capacitors).	Very high (difficult to balance and too many capacitors).	[3, 11, 14, 35]
Scalability	Extremely high; increasing the number of cells to level up is simple.	Restricted; as levels rise the design gets more intricate.	Restricted; as levels rise the design gets more intricate.	[14, 35]
Cost	Reasonably low for systems with independent DC sources; particularly for modular applications.	high because of the extra ingredients.	extremely intricate and high in capacitors accumulation.	[3, 11, 35]
Fault Tolerance	Excellent; operation can continue at lesser levels and a failed cell can be circumvented.	weak	Medium (but FC allows for the usage of double cases).	[14, 35]
Applications	Widespread use is seen in medium- to high-voltage drive systems, electric vehicles, Flexible AC Transmission System (FACTS) devices, and renewable energy domains (such solar inverters and wind turbines).	frequently used in medium-voltage driving applications, Static Synchronous Compensators (STATCOMs), High Voltage Direct Current (HVDC) systems, and electrical power transmission frameworks.	Suitable for applications requiring high levels of redundancy and adaptability, such as high-voltage medical equipment and aerospace systems.	[12]

- A MPPT controller system controlled by genetic algorithms is used to monitor these signals, guaranteeing their constancy to maximize power output.
- The Boost Converter receives the constant voltage and current signals and raises the output terminal's voltage.
- A CHB seven-level inverter utilizing their Sinusoidal PWM technology is used to convert the maximum output voltage signals into alternating current voltage signals by
- comparing the reference and carrier signals.
- Additionally, sinusoidal alternating current voltage signals are produced and then filtered by alternating current filter circuits to eliminate unnecessary signals, which helps to fewer THD.

This modulation technique, an PWM circuit was utilizes generating impulses for CHB inverter. Several PWM methods, like multi-carrier PWM, Selective Harmonic Elimination PWM (SHEPWM), as well Space Vector PWM (SVPWM), are utilized to reduce harmonics in the inverter's output, which results in a more refined alternating current waveform. Harmonic distortion reduction is necessary for the reliable integration of the inverter with the main electrical grid.

2.1 Topology Description

A. Cascaded H-Bridge

Figure 2 shows a solar energy conversion system that uses the MPPT algorithm to get better the competence for energy extraction from PV panels. PV panels provide the system's initial direct current power, which is then converted by a boost converter to provide a higher DC voltage. In order to maintain optimal power output in the face of changing external conditions, the MPPT controller continuously monitors the voltage V_{PV} and current I_{PV} generated by the solar panels.

Two or more single-phase inverters have linked for series to formation CHB-MLI, which is why it is called a "H-bridge." This is the inverter's output voltage represented by line-to-line, and Everyone H-bridge is connected to two phase legs of voltage-source. As a result, an H-bridge converter could produce three various voltage levels. Moreover, the N of these H-bridges connected in series can produce a total of 2N+1 output voltage levels. This CHB-MLI was the name gave to this arrangement of series connectivity [15].

When this specific kind of inverter operates, it usually produces three different outputs: Vdc, 0Vdc, and -Vdc. Switches S1 and S4 must be engaged in order to produce a Vdc output, while switches S2 and S3 must be engaged in order to produce a -Vdc output. According to equation (1), the total of all the individual H-bridges is output voltage for CHB-MLI. This formula n = 2S + 1, wherever S is total numeral of DC sources, can be used to quantify the levels generated by this inverter setup [16]: -

$$V_a = V_1 + V_2 + V_3 + V_4 \quad (1)$$

The main benefits and drawbacks of the traditional (CHB-MLI) architecture are listed in Table 2 [3,17-20]. The chart highlights its inherent fault-tolerance, modular design, and ease of implementation as key advantages. On the other hand, it also highlights several drawbacks, such as the need for many separate DC power sources and the complex control systems required for asymmetrical arrangements.

It has been explained that the advantages of (CHB-MLI) include fewer parts, a simpler design, and an easy-to-use switching mechanism. It is easy to adjust this inverter's output voltage by increasing or decreasing that numeral of H-bridges. Since n = 2S + 1 determines that output voltage levels, this leads to values that are much higher than those obtained from a direct current source. As a result, this specific inverter creates production operation additional transparent as well economical. For conclusion, the CHB-MLI performs best Regarding dependability as well ideal error resilience capacities than Neutral Point Clamped MLI and Flying Capacitor MLI. Because of these benefits, the inverter can function more effectively when the DC input voltage is lower [16].

The uses for CHBMLI are [18, 21]: -

- This CHBMLI is suitable for large energy average voltage engines as well Facilities uses.
- crossbred electrical as well Fuel cell engines.
- Traction engines.
- Flexible alternating current transmission system.
- PV energy production.
- In constant Var generators.
- Power factor compensators.

B. Principles of Operation

The schematic design of the DC-DC boost converter used in the suggested framework is shown in Figure 3. The inductor L, input and output capacitors C_{in} and C_{out}, the switching device S, and the diodes D_1 and D_2 are among its necessary parts. In order to accommodate the load R, this type of converter is used to raise the input voltage V_I to a higher output voltage V_O, which makes it especially useful for solar energy applications that require higher power conversion competence.

The grid-tied H-bridge inverter system effectively transforms solar energy into alternating current electricity that is compatible with the electrical grid by combining a photovoltaic cell, a boost DC/DC converter, and (MPPT) technique. Direct current power generation from solar radiation is facilitated by the photovoltaic cell. To ensure that the solar cell runs at its maximum power output even when external conditions fluctuate, a MPPT approach must be used.

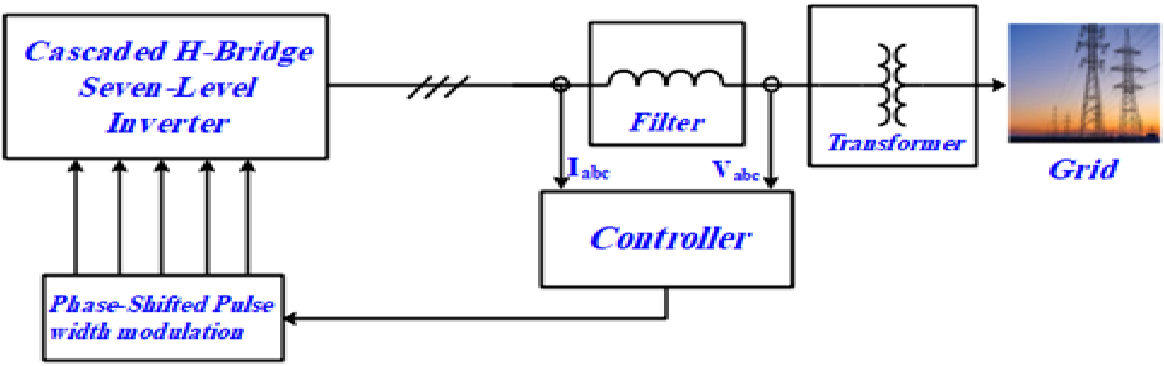

Fig. 1: Grid-Connected CHB Inverter System

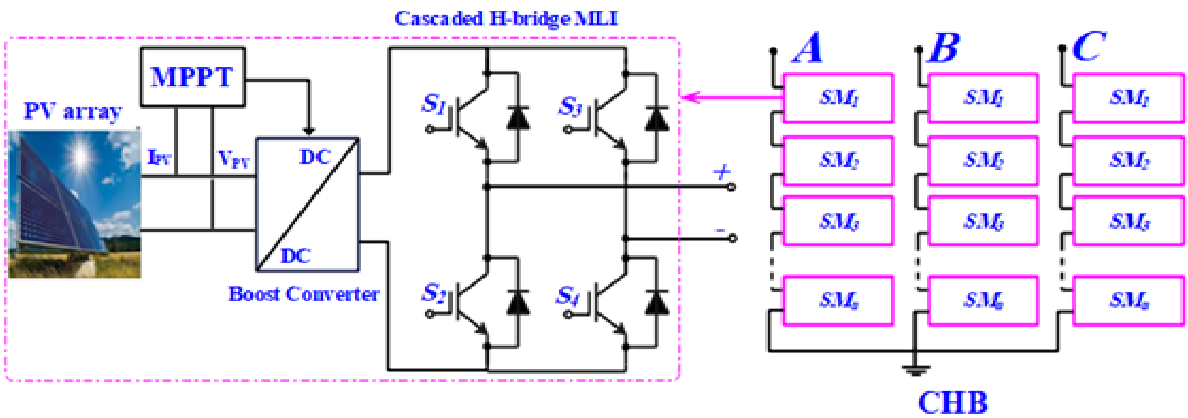

Fig. 2: Solar Power Conversion System with MPPT and CHB MLI

Table 2: Benefits and drawbacks for traditional topology CHB-MLI

Types of MLI	Benefits	drawbacks
CHB-MLI	• Simple as well modular design. • Facile into stretch for greater levels. • Demands just one-way switches. • Suitable for error-resistance application. • Possible of electric trauma is decreased due their discrete DC sources. • Asymmetrical exporter structure May be utilized. • May be executed as an one DC source structure.	• Fewer numeral of output voltage tiers. • Demands greater numeral of gateway operator circuits. • Demands sundry DC sources to increment that output voltage. • Restricted to specific applications wherever discrete DC sources were given. • Keys must carry preventing voltage equivalent to the income voltage worth. • Modularity lost (asymmetrical source structure). • Execute expense is large (asymmetrical source structure). • Keys are various voltage rankings (asymmetrical source structure).

The MPPT algorithm continuously adjusts the reference voltage or current parameters to maximize the power collected from the solar cell. The voltage thresholds required for the best possible integration into the electrical grid are usually not met by the direct current voltage generated by solar cells. To address this problem, a step-up DC/DC energy converter, as well recognized like a boost converter, is utilized to raise the DC voltage to a level that is compatible with the H-bridge inverter's operating specifications. The voltage increase ensures that the energy supplied to that H-bridge inverter meets that required input specifications, allowing for an effective conversion to alternating current power. The high voltage direct current output provided by the boost converter is changed into alternating current power by the H-bridge inverter, enabling compatibility with the power grid. The inverter is made of four electronic switching devices organized in an H-bridge arrangement. By adjusting these switches in different ways, the inverter may generate both positive and negative voltage levels, which results in an alternating current waveform. This method facilitates smooth integration with the grid system by guaranteeing that the alternating current output maintains high quality and complies with the grid's voltage, frequency, and phase specifications.

The initial stages of integrating renewable energy sources into a direct current grid are when DC–DC converters are most commonly used. It is crucial that this phase runs as efficiently as possible because RES, such wind and solar photovoltaic systems, are known to cause output voltage swings. Therefore, for the DC–DC converters in the front-end stages to operate as efficiently as possible, they must exhibit a high degree of responsiveness to such fluctuations. They inverters is frequently utilized in tiny industrial or Facilities settings due to higher voltage pressure, subpar competence, high working temperatures, and improved pressure capabilities. Because of their advantageous characteristics, many inverters are commonly utilized big, higher-energy, grid-connected replenishable power systems [1].

The output direct current voltage produced by this converter is higher than the input direct current voltage. As a result, this converter is frequently called a step-up or boost converter. That is made up of one energy storage component, an inductor, and two power electronic switches, a diode as well a metal-oxide-semiconductor field-effect transistor (MOSFET). To lessen that output voltage ripple in this situation, a capacitor is used as a filtering method. In comparison to the transformer less high-gain boost converter, the multilayer boost converter has been suggested to achieve reduced voltage stress and increased efficiency. The direct current to direct current boost converter's linked inductor has been used to generate higher voltage gain and efficiency that are suited to the particular needs of solar power applications [22].

2.2 Main Controller

A. Maximum Power Point Tracking

An integral part of solar (PV) technology's operating framework is monitoring the system's Maximum Power Point. However, the goal of precise tracking is significantly complicated by changing environmental factors, such as temperature and solar light. Numerous MPP tracking techniques been put out as well recorded at scholarly works. Despite optimal power extraction is the goal of all approaches, there are differences among them in terms of complexity, rate of convergence, regulating variables, settling time, required number of sensors, and total cost. Incremental Conductance (IC) as well Perturbation and Observation (P & O) are the most commonly used MPPT techniques in most commercially available inverters and in many academic publications [23].

Observe and Perturb (MPPT Technique) This approach is among the most widely used and conventional (MPPT) strategies used to maximize peak power extraction from solar energy systems. It is distinguished by a small temporal ratio deviation and an operating voltage change that depends on the difference between the power measured in the previous interval and the power measured in the present [22, 24]. By tailoring sample intervals to the dynamic behavior of its converters, the P & O MPPT technique can be made more effective. Using the P&O algorithm, an MPPT shipment controller over 200W standalone PV systems was created. The designed model was tested with a lead-acid battery, showing that the suggested algorithm significantly improves the solar PV model's performance in comparison to other charge controllers currently in use [25].

The flowchart for the improved (P&O) technique is shown in Figure 4. The process begins with the solar panel's voltage and current data being collected, which is followed by the calculation of power and its variations. A decision is made to increase or decrease the duty cycle to precisely follow the MPPT based on the voltage and power changes that have been noticed. This improved method reduces oscillatory around the ideal operating point and greatly improves tracking performance.

A comparison of the efficiency, complexity, cost, and THD of several MPPT control strategies is shown in Table 3. The P&O method is one of the most popular since it is easy to use, inexpensive, and sophisticated, yet it still achieves a respectable efficiency of about 97.6%. Because of this, it is a good choice for systems that need conventional and affordable solutions.

B. Control of Cascaded H-Bridge

The control mechanism used for a MLI design with a CHB for grid integration is schematically represented in Figure 5. SM-A1, SM-A2,... SM-An, SM-B1, SM-B2,... SM-Bn, and SM-C1, SM-C2,... SM-Cn are some of the submodules (SM) that make up the CHB.

Table 3: A comparison of the various MPPT control methods.

MPPT	THD	Efficiency	Complexity	Cost	Ref
P&O	Low (traditional)	~ 97.6%	Simple - medium	Low	[26]
INC	Low	~ 98.5%	average - High	average - High	[26]
FLC	Low (Better response)	very high ~ 99%	High	Very High	[27]
Hybrid	Low	very high ~ 100%	Very High	Very High	[27]

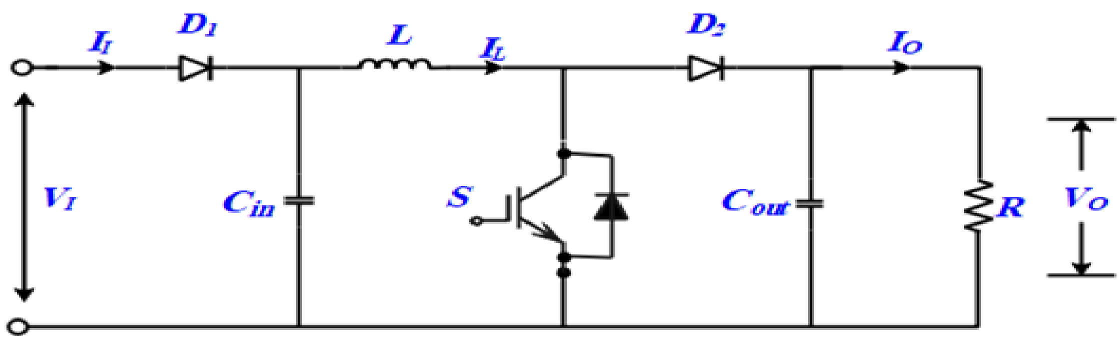

Fig. 3: DC-DC boost converter

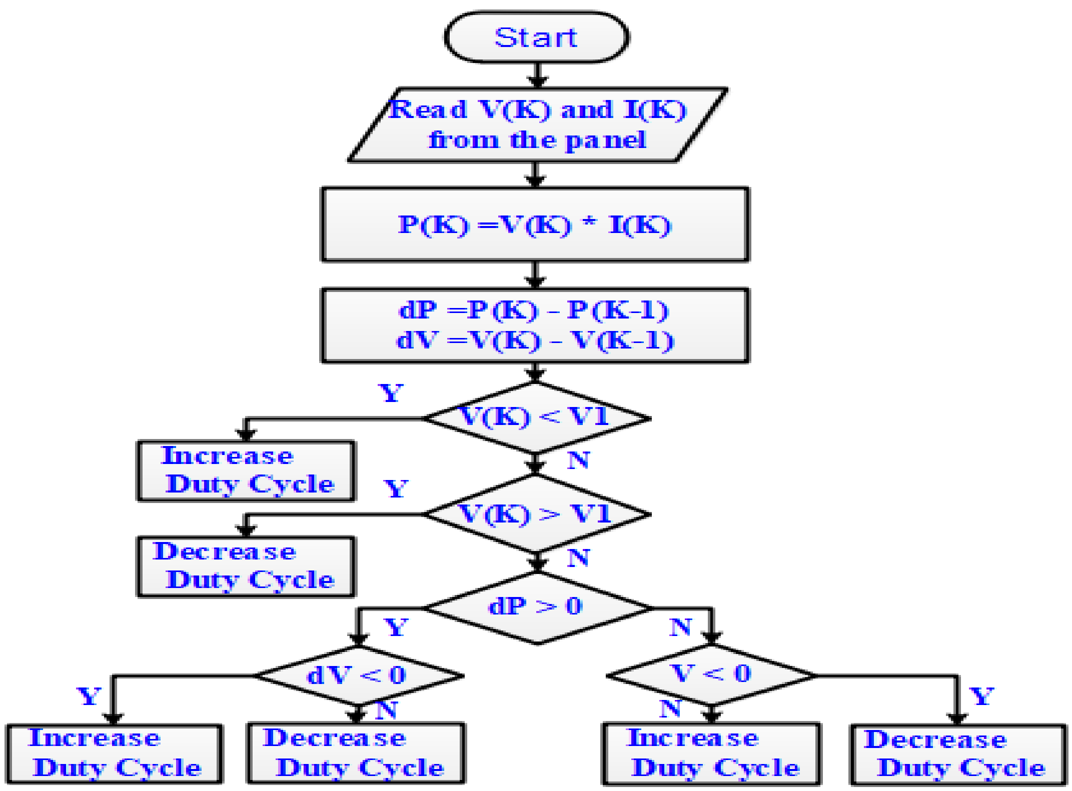

Fig. 4: Flowchart of the modified P&O technique

These submodules together generate the output voltage in a stepped waveform, which makes it easier to achieve high power quality. To synchronize the inverter with the grid's frequency, these submodules are connected to the electrical grid through a Phase-Locked Loop (PLL) as well filtering component known like L_f. order to facilitate their conversion into the dq0 reference frame for the execution of the control strategy, the PLL is in charge of continuously monitoring the grid voltage V_{abc} and the current I_{abc}.

A Proportional-Integral (PI) controller that uses the instantaneous references i_d and i_q to control the DC-link voltage V_{dcm} and manage active and reactive power is one of the several parts of the control system. The dq0 transformation block transforms the grid side currents I_{abc} and voltages V_{abc} into their respective dq components. These dq components are then adjusted by the Proportional-Integral controllers to generate necessary referring voltages, V_d and V_q. These generated reference values are then converted back into the ABC frame and integrated into the modulation phase shift block, which generates the crucial control signals for the CHB submodules, to guarantee optimal synchronization and power quality during the energy injection into the grid.

C. Modulation Technique

CHB inverters commonly use PSPWM technology because of its ease of use and ability to be implemented successfully at different inverter architectural levels. The ability of this technology to provide consistent power distribution among the individual H-Bridge cells inside the inverter system is another notable feature. The amplitude and frequency characteristics of each carrier signal must be equal for Phase Shifted Modulation to be implemented.

In an N-level inverter, however, the required number of carrier waves is N-1, which need to be phase-shifted by an angle

$\frac{\mathbf{360}^{\circ}}{\boldsymbol{N-1}}$ relative to each other [6].

When compared to other modulation techniques, the PS-PWM technique has several benefits, such as reduced THD, improved effective switching frequency, balanced power distribution, and optimized semiconductor stress profiles.

In phase-shifted modulation, a (180°⁄N) phase displacement is required when N cells are present in CHB multilevel converters. On the other hand, an (360°⁄N) phase displacement is required for the N cell design in flying capacitor multilevel converters [8].

There is intrinsic flexibility in the frequencies and amplitudes of the sinusoidal modulating signals. In this approach, the amplitude modulation index, or (m_a), makes it easier command that essential -frequency constituent of output voltage from the inverter. The formula (m_a=V_m/V_{cr}), in which V_m and V_{cr} represent the peak levels of the modulating and carrier voltage signals, respectively, is used to calculate this index. Phase-shifted carrier signals are combined with modulating signals to provide gateway signals to energy keys. Whenever modification signal was larger than transporter signal, that hybrid boost converters' upper and lower switches are activated [14].

A comparison of different PWM techniques is shown in Table 4, where the PS-PWM method stands out due to its exceptionally low THD of 1% to 4%, remarkable operational efficiency of up to 96%, ease of implementation, and significantly lower cost when compared to other approaches.

PSPWM was selected based on this comparison because it lowers THD, Programming and implementation are simple, distributes losses over all H-bridges in a good way, with many levels, it is scalable and increases efficiency, making it appropriate for applications that demand great performance at a reasonable cost.Although it is not always the best option, PSPWM in a CHB is great for its ease of use, scalability, and implementation that is not affected by distortion or efficiency[34].

Table 5. lists the factors and conditions that are relevant to the simulation, including the switching frequency, load arrangement, photovoltaic panel specs, battery charging parameters, and the time intervals for sampling. These parameters were methodically set up to enable accurate modeling and reliable system performance evaluation.

Table 4: Comparison of PWM techniques' performance

Modulation	THD (%)	Efficiency	Complexity	Cost	Ref
SVPWM	3.5% - 5%	94% - 96%	Average - High	low	[28 -29]
PS-PWM	Low (1 – 4) %	High ~ 96%	low	very low	[14, 29]
NLM	5% - 7%	90% - 93%	High	Average	[29- 31]
SVM	3.8% - 5.2%	94% - 96%	High	Average	[14, 29]
SHE-PWM	1.5% - 3%	95% - 97%	High	High	[32] - [33]

Table 5: shows simulation parameters and conditions.

Parameter Category	Parameter	Value	Unit
Switching Frequency	PWM Switching Frequency MPPT Duty Cycle Step Size	1000 1e-6	Hz -
Load Type	Load Configuration Load Type Active Power (P) Inductive Reactive Power (QL) Capacitive Reactive Power (Qc)	Y (Grounded) Three-Phase Parallel RLC 1000 400 ~ 400	- - W Var Var
PV Panel Specifications	Parallel Strings Series-Connected Modules per String Max Power per Module Open Circuit Voltage (Voc) Short-Circuit Current (Isc) Voltage at Max Power Point (Vmp) Current at Max Power Point (Imp) Series Resistance (Rs) Shunt Resistance (Rsh)	2 4 250.29 36.6 8.75 30.9 8.1 0.12527 126.1585	- - W V A V A Ω Ω
Battery Settings	Battery Charging Constant Voltage	55.4	V
Sampling Time	Power System Sample Time (Ts) Control System Sample Time (Ts_Control)	1e-5 2e-5	seconds (10 µs) seconds (20 µs)

Table 6.: Shows THD analysis before and after filter

Parameter	Before Filtering	After Filtering	Difference (Improvement)
Vabc THD (%)	1.802 V	1.042 V	0.760 V (Improved)
Iabc THD (%)	1.008 A	0.6717 A	0.3363 A (Improved)

3. Conclusions

According to the results, the suggested seven-level CHB-MLI demonstrated outstanding performance by lowering voltage stress, minimizing EMI, reducing harmonic distortion, and enabling fair power distribution among inverter cells. Additionally, the application of a customized MPPT strategy increased the PV system's efficiency. This study offers a comprehensive simulation-based analysis of a three-phase, seven-level CHB-MLI using PSPWM under realistic operating conditions, in contrast to previous studies that mostly concentrated on generic CHB architecture or isolated components like harmonic mitigation or modulation techniques. These findings demonstrate the uniqueness of this study in providing an integrated simulation and performance evaluation that has not been thoroughly covered in previous research, in addition to confirming the reliability of CHB-MLI for the integration of RES.

Contributions of the Authors

The main contributions of this study might be stated as follows considering the findings:

1.Creation of a Customized CHB-MLI for Grid-Based PV Systems:

A CHB-MLI system has been carefully planned and implemented to meet the requirements of grid-connected solar systems, with an emphasis on increasing efficiency and reducing energy losses.

2. Implementing a Customized MPPT Algorithm for Three-Phase Solar Power Systems:

To maximize the energy extraction from PV arrays in a three-phase setting and increase the system's overall effectiveness, a customized MPPT management method has been developed and put into practice.

3.Independent Voltage Regulation Across Multiple DC Sources:

To improve system reliability and voltage stability, a complex control strategy has been put in place to enable independent voltage regulation across the different direct current links of the CHB-MLI.

4.Phase-Shifted PWM Technique:

To ensure fair power distribution among the inverter cells, reduce EMI, and attenuate harmonic distortion, the PSPWM technique has been used.

5.Thorough Analysis of CHB-MLI for Renewable Energy Applications:

The study presents a thorough analysis of the potential uses and capabilities of CHB MLIs in renewable energy systems, clarifying their adaptability and effectiveness in these settings.

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