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DESIGN AND PERFORMANCE ANALYSIS OF SOLAR PV SYSTEM USING CASCADED H-BRIDGE MULTILEVEL INVERTER WITH MPPT CONTROL

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ABSTRACT

This paper presents the design, modelling, and performance analysis of a solar photovoltaic (PV) system integrated with a Cascaded H-Bridge (CHB) multilevel inverter and Maximum Power Point Tracking (MPPT) control using MATLAB/Simulink. A Perturb and Observe (P&O) MPPT algorithm is implemented to continuously extract maximum power from the PV array under varying irradiance and temperature conditions. A DC-DC boost converter regulated by the MPPT-generated duty cycle stabilizes the DC-link voltage. The conditioned DC power is then converted to high-quality AC power by a five-level CHB multilevel inverter controlled via a pulse-based switching strategy. Results demonstrate that the proposed system reduces Total Harmonic Distortion (THD) from 21.58% (full-bridge) to approximately 11% (five-level CHB), confirming the effectiveness of multilevel inverter technology in renewable energy applications.

KEYWORDS: Solar PV, Cascaded H-Bridge, Multilevel Inverter, MPPT, Perturb and Observe, THD, Boost Converter, MATLAB/Simulink.

INTRODUCTION

The rapid depletion of fossil fuels and growing environmental concerns have accelerated the global shift toward renewable energy. Solar photovoltaic (PV) systems have emerged as one of the most promising technologies due to their abundance, sustainability, and zero-emission characteristics. However, PV systems inherently produce direct current (DC) that must be converted to alternating current (AC) for practical applications such as motor drives, industrial loads, and grid integration.

Conventional two-level inverters are commonly used for this purpose, but they suffer from high Total Harmonic Distortion (THD), elevated switching losses, and the need for large output filters. Multilevel inverter (MLI) technology overcomes these drawbacks by synthesizing an output voltage from multiple DC levels, producing a staircase waveform that closely approximates a sinusoid. Among available topologies, the Cascaded H-Bridge (CHB) inverter is particularly attractive for PV applications owing to its modular structure, scalability, and the natural match between its multiple isolated DC inputs and separate PV sources.

A further challenge unique to PV systems is the nonlinear, irradiance- and temperature-dependent output characteristic of PV modules. Maximum Power Point Tracking (MPPT) techniques are therefore essential to extract maximum available power under all operating conditions. The Perturb and Observe (P&O) algorithm is widely adopted in practice due to its simplicity and satisfactory steady-state performance.

This paper proposes an integrated system comprising: (i) a PV array modeled with a single-diode equivalent circuit, (ii) a P&O MPPT controller, (iii) a DC-DC boost converter, and (iv) a five-level CHB multilevel inverter. The complete system is simulated in MATLAB/Simulink and its performance is evaluated against a conventional full-bridge inverter using THD as the primary metric.

4. MATERIALS AND METHODS

A. SOLAR PV ARRAY MODEL

The PV array is modelled using the standard single-diode equivalent circuit, comprising a photo-current source, a diode, a series resistance R_s, and a shunt resistance R_{sh}. Multiple cells are connected in series and parallel to form the required module and array. The output characteristics are highly nonlinear and shift with irradiance and temperature, necessitating continuous MPPT operation.

B. DC-DC BOOST CONVERTER

A boost converter is interposed between the PV array and the inverter DC link to step up the PV voltage and maintain a regulated DC link. It consists of an inductor, a controlled switch (IGBT/MOSFET), a freewheeling diode, and an output capacitor. The steady-state voltage gain is: $V_{dc} = V_{pv} / (1 - D)$, where D is the duty cycle set by the MPPT controller.

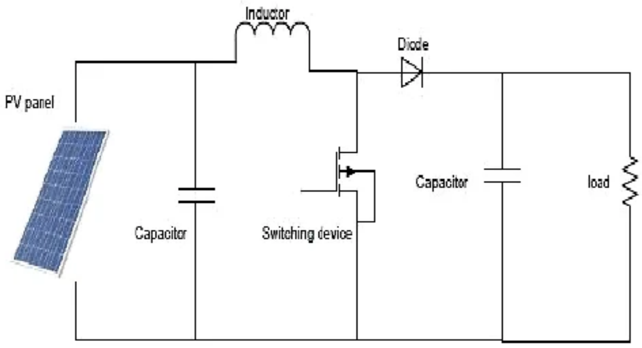

Figure 1: DC-DC Boost Converter Topology Interfacing the PV Array to the Inverter.

C. FIVE-LEVEL CASCADED H-BRIDGE INVERTER

Two H-bridge cells are connected in series, each supplied by a separate DC source. Each cell can contribute +Vdc, 0, or -Vdc, giving a total output level count of m = 2s + 1 = 5 (with s = 2 DC sources). The load phase voltage is the algebraic sum of the two cell voltages, yielding five distinct levels: -2Vdc, -Vdc, 0, +Vdc, +2Vdc.

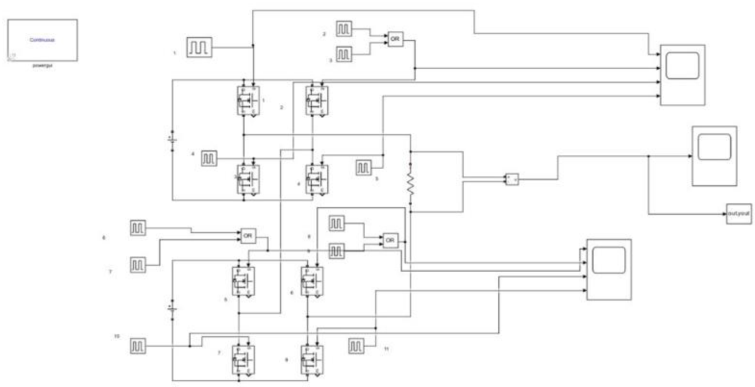

Figure 2: Circuit Topology of the Five-Level Cascaded H-Bridge Inverter.

D. MPPT CONTROL - PERTURB AND OBSERVE ALGORITHM

The P&O algorithm periodically perturbs the PV operating point by incrementing or decrementing the duty cycle and observes the resulting change in output power. If power increases, perturbation continues in the same direction; if power decreases, direction reverses.

This process repeats until the maximum power point (MPP) is reached. Key simulation parameters include:

- **PV Array:** V_{mpp} = 54 V, I_{mpp} = 5.45 A, P_{mpp} = 294.3 W
- **Boost Converter:** L = 2 mH, C = 470 uF, switching frequency = 10 kHz
- **LC Output Filter:** L = 56 mH, C = 150 uF, R_{load} = 100 Ohm
- **Inverter Load:** L = 470 mH
- **Simulation Tool:** MATLAB/Simulink R2023b, Powergui discrete mode

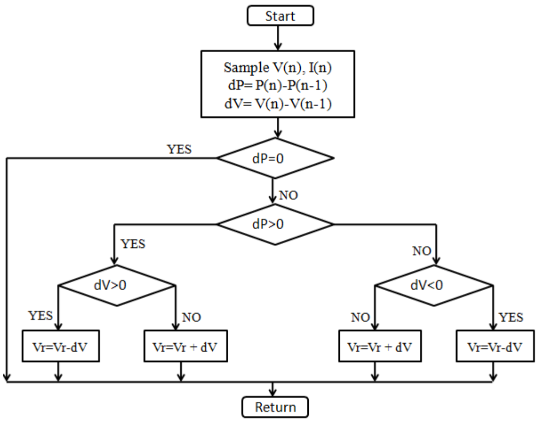

Figure 3: Flowchart of the Perturb and Observe (P&O) MPPT Algorithm.

E. SWITCHING STRATEGY

The five-level CHB inverter is controlled via a fundamental-frequency switching strategy where only one H-bridge changes state per transition, minimizing switching stress and producing smooth staircase voltage steps. While simpler than carrier-based sinusoidal PWM, this scheme effectively suppresses low-order harmonics relative to a two-level full-bridge.

Switching States for Single Phase 5-Level Inverter

Output Voltage	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
$+2V_{dc}$	1	0	0	1	1	0	0	1
$+V_{dc}$	1	0	0	1	1	1	0	0
	OR							
	1	1	0	0	1	0	0	1
0	1	1	0	0	1	1	0	0
	OR							
	1	1	0	0	0	0	1	1
$-V_{dc}$	0	1	1	0	1	1	0	0
	OR							
	1	1	0	0	0	1	1	0
$-2V_{dc}$	0	1	1	0	0	1	1	0

1 = ON | 0 = OFF

Figure 4: Switching States for Single-Phase Five-Level CHB Inverter.

5. RESULTS AND DISCUSSION

A. CONVENTIONAL FULL-BRIDGE INVERTER

The conventional PV-fed full-bridge inverter produces a quasi-square output waveform containing strong odd-harmonic components (3rd, 5th, 7th, ...). FFT analysis of the steady-state output voltage yields a Total Harmonic Distortion (THD) of approximately 21.58%. This level of distortion makes the output unsuitable for sensitive loads without substantial additional filtering, motivating the adoption of a multilevel topology.

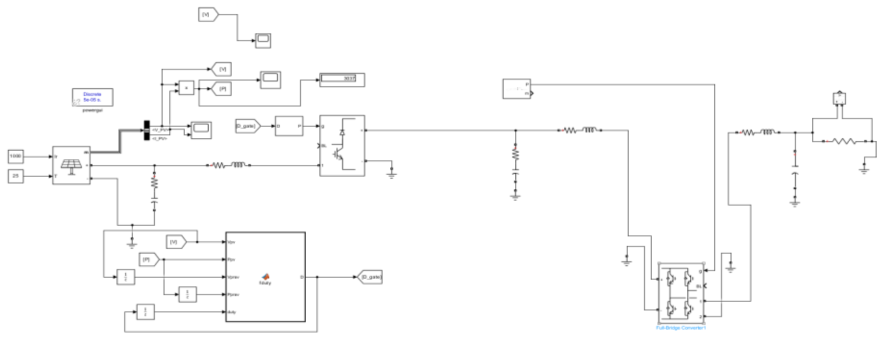

Figure 5: MATLAB/Simulink Model of the PV-Fed Conventional Full-Bridge (Two-Level) Inverter.

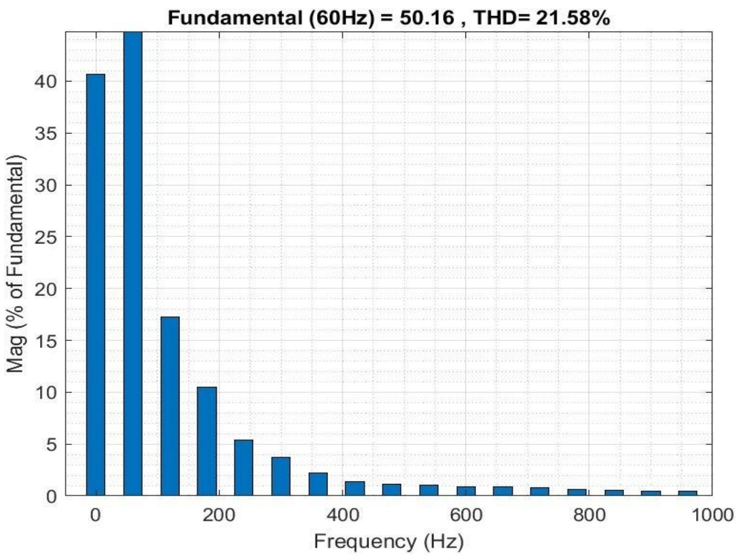

Figure 6: FFT Analysis of the Full-Bridge Inverter Output Voltage (THD = 21.58%).

B. PROPOSED FIVE-LEVEL CHB INVERTER

The proposed PV-fed five-level CHB system synthesizes five distinct voltage levels per fundamental cycle. The resulting staircase waveform closely approximates a sinusoid. FFT analysis confirms a THD of approximately 11%, representing a reduction of nearly 49%

compared to the conventional full-bridge inverter. With the LC output filter, waveform quality is further improved, approaching a pure sinusoid suitable for industrial and grid-connected loads.

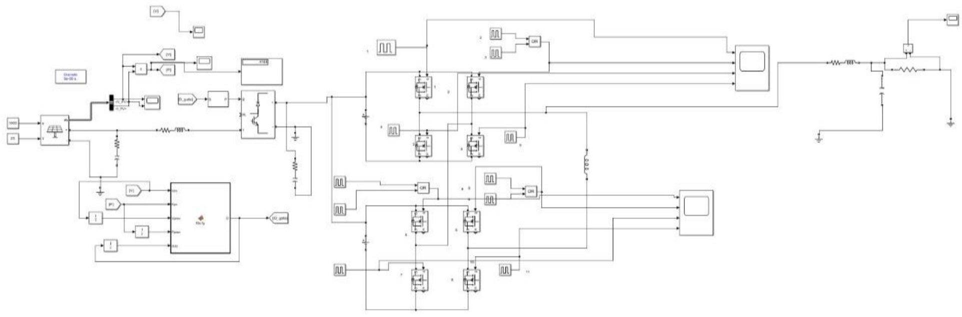

Figure 7: MATLAB/Simulink Model of the Proposed PV-Fed Five-Level CHB Multilevel Inverter System.

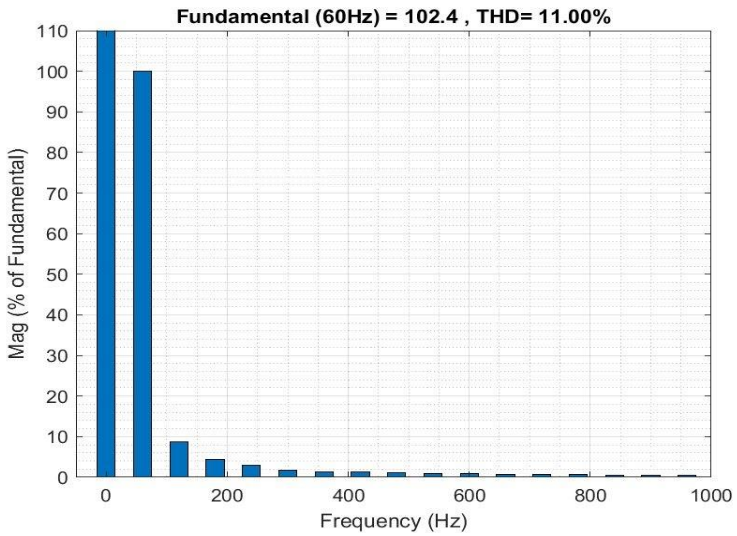

Figure 8: FFT Analysis of the Five-Level CHB Inverter Output Voltage (THD = 11%)

C. PERFORMANCE COMPARISON

The table below summarizes the key performance metrics for both configurations:

Table 1: Performance Comparison: Full-Bridge vs. Five-Level CHB Inverter

Parameter	**Full-Bridge**	**CHB-MLI (5-Level)**
Output Levels	2	5
THD (%)	21.58	11.00
Filter Requirement	Large	Smaller
Switching Losses	Higher	Lower

CONCLUSION

This paper has presented the design and simulation of a solar PV system integrated with a five-level Cascaded H-Bridge multilevel inverter and P&O MPPT control. The key outcomes are summarized below:

- **THD Reduction:** The five-level CHB inverter achieves a THD of approximately 11%, versus 21.58% for a conventional full-bridge, representing a reduction of nearly 49%.
- **MPPT Performance:** The P&O MPPT controller coupled with the boost converter ensures stable DC-link regulation and maximum power extraction under varying irradiance conditions.
- **Output Quality:** The LC output filter further improves waveform quality, making the output suitable for industrial and grid-connected applications.

The results validate that combining multilevel inverter technology with MPPT control and boost-converter interfacing is an effective approach to improving the efficiency and power quality of solar energy conversion systems. Future work will explore seven-level or higher CHB configurations, phase-shifted SPWM modulation, and hardware-in-the-loop validation.

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