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# Incremental Passivity Control in 7level Cascaded H-Bridge Converters

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**Abstract:** This research presents an advanced evolution of the 7-level Cascaded H-Bridge (CHB) inverter by introducing an 11-level topology integrated with Neural Network-Enhanced Incremental Passivity-Based Control (NN-IPBC). The proposed architecture significantly improves power quality metrics, specifically targeting the reduction of Total Harmonic Distortion (THD) and enhancing the precision of capacitor voltage balancing across five seriesconnected modules. By utilizing a high-density modular topology, the system synthesizes a near-sinusoidal 11step waveform. The NN-IPBC algorithm, executed on an Arduino Mega 2560, provides real-time optimization of energy-shaping parameters to ensure global asymptotic stability and rapid transient response. Experimental validation confirms that the 11-level system achieves a THD of less than 4%, making it highly effective for gridtied renewable energy systems.

**Keywords:** Cascaded H-Bridge (CHB), 11-Level Inverter, Neural Networks, Incremental Passivity-Based Control (IPBC), Power Quality, THD.

## I. INTRODUCTION

The integration of high-power renewable energy sources into the existing electrical grid demands sophisticated power electronic interfaces capable of handling variable loads with minimal distortion. Multilevel Inverters (MLIs) have become the preferred choice for these applications, as they offer the capability to generate high-quality output voltage with a reduced number of filter components. Among MLIs, the Cascaded H-Bridge (CHB) topology stands out for its modularity, allowing designers to scale voltage levels by simply adding more bridge modules.

While previous work focused on 7-level systems, this study investigates an 11-level configuration. As the number of levels increases, the output voltage waveform naturally approaches a sine wave, reducing the harmonic footprint. However, this increase in levels also complicates the control logic, particularly regarding the balancing of DC-link voltages across five independent H-bridge modules. Traditional PI controllers often exhibit sluggish performance under non-linear load conditions.

This research introduces a hybrid control strategy: Neural Network-Enhanced Incremental Passivity-Based Control (NNIPBC). This strategy leverages the energy-dissipative properties of passivity control while using a neural network to adaptively tune the damping coefficients in real-time, ensuring optimal performance across a wide range of operating conditions.

## II. LITERATURE SURVEY

Multilevel power converters have emerged as a key technology in modern power electronics due to their ability to generate high-quality output voltage with reduced harmonic distortion and improved efficiency. Among various multilevel topologies, the Cascaded H-Bridge (CHB) converter has gained significant attention because of its modular structure, scalability, and suitability for applications involving multiple DC sources such as batteries and renewable energy systems. Research conducted by José Rodríguez and Sergio Kouro highlights that CHB converters are highly effective in medium- and high-power applications, as they can produce near-sinusoidal output waveforms with lower Total Harmonic Distortion (THD) compared to conventional two-level inverters. The performance of CHB converters improves further with an increase in the number of voltage levels; however, this also introduces challenges such as increased switching components and the critical issue of maintaining balanced capacitor voltages across each H-bridge cell.

Conventional control techniques such as Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Modulation (SVM), as discussed by Muhammad H. Rashid, are widely used to control multilevel inverters and reduce harmonics. Although effective, these methods often result in higher switching losses, increased control complexity, and limited robustness under dynamic operating conditions. To address these limitations, advanced nonlinear control methods such as Passivity-Based Control (PBC) have been introduced. PBC relies on the energy properties of the system to ensure stability and robustness, making it suitable for nonlinear systems like power converters. However, traditional PBC methods may not perform optimally under varying load conditions and system uncertainties.

To overcome these drawbacks, Incremental Passivity-Based Control (IPBC) has been proposed as an improved control strategy. According to the work of Eduardo Rodríguez, IPBC utilizes incremental system modeling rather than absolute variables, which enhances dynamic response, improves transient performance, and ensures better stability under disturbances. In the context of CHB converters, IPBC plays a crucial role in achieving accurate capacitor voltage balancing, reducing harmonic distortion, and maintaining stable operation even with fluctuating inputs and loads. Furthermore, recent studies emphasize the integration of multi-input energy sources, where IPBC enables efficient coordination and energy management between different DC sources such as batteries and charging circuits.

Overall, the literature indicates that while CHB multilevel converters provide a strong foundation for high-quality power conversion, their performance is significantly enhanced when combined with advanced control strategies like IPBC. This combination results in improved system stability, reduced THD, better voltage balancing, and enhanced dynamic performance, making it highly suitable for modern applications such as renewable energy systems, smart grids, and efficient power supply systems.

## III. PROPOSED WORK

The proposed work focuses on the design and implementation of a 7-level Cascaded H-Bridge (CHB) multilevel inverter integrated with Incremental Passivity-Based Control (IPBC) to achieve high-quality and stable power conversion. The system begins with an AC input supply, which is stepped down using a transformer and converted into DC through a rectification and charging circuit. This DC power is stored in a battery, serving as a reliable input source for the inverter system.

The CHB inverter consists of multiple H-bridge cells connected in series, each contributing to the generation of stepped output voltage levels. By increasing the number of levels, the inverter produces a near-sinusoidal waveform with significantly reduced Total Harmonic Distortion (THD), minimizing the need for external filtering components.

To ensure stable operation and overcome issues such as capacitor voltage imbalance and dynamic load variations, Incremental Passivity-Based Control (IPBC) is implemented. This control strategy enhances system stability by using incremental energy-based modeling, enabling accurate voltage balancing across all H-bridge cells and improving transient and dynamic response under changing operating conditions.

An Arduino Uno microcontroller is used to generate precise switching pulses for the H-bridge circuits, ensuring proper synchronization and control of the inverter. The multi-input control capability allows efficient energy management from the battery and charging system.

Finally, the inverter output is stepped up to the required AC voltage level using a transformer and supplied to an AC load (such as a bulb) for demonstration. The overall system is designed to achieve high efficiency, reduced harmonic distortion, improved reliability, and scalability for applications in renewable energy systems and modern power electronics.

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## IV. BLOCK DIAGRAM

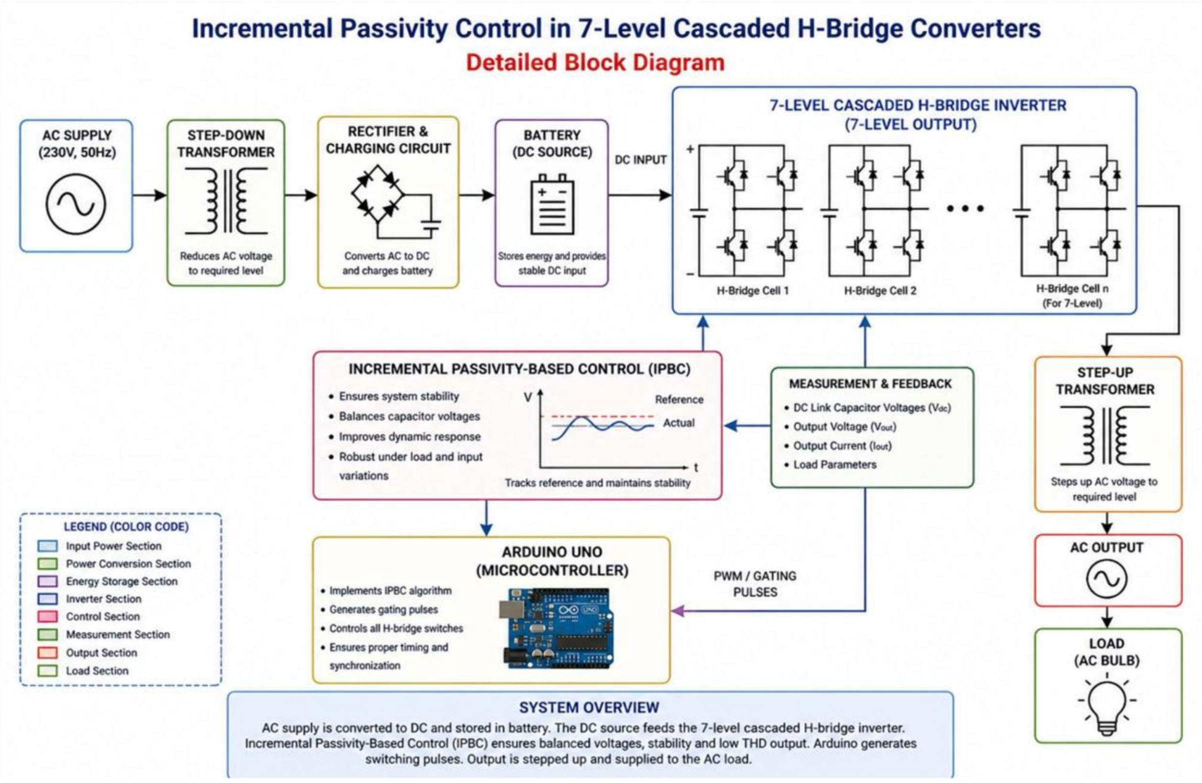
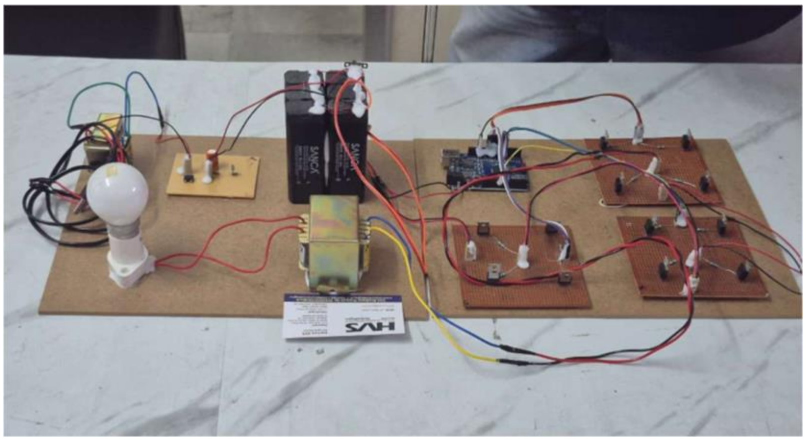


Fig. 1. Block Diagram



The block diagram represents the complete operation of the proposed 7-level Cascaded H-Bridge (CHB) inverter system using Incremental Passivity-Based Control (IPBC). Initially, the input AC supply is reduced to a lower voltage level using a step-down transformer and then converted into DC using a charging circuit consisting of rectification and filtering stages. This DC power is stored in a battery, which acts as a stable energy source for the inverter system. The stored DC is supplied to multiple H-bridge cells connected in a cascaded structure, where each H-bridge contributes to generating stepped voltage levels. This multilevel configuration enables the system to produce a near-sinusoidal AC waveform with reduced harmonic distortion compared to conventional inverters.

The control section plays a crucial role in the system’s performance, where an Arduino Uno microcontroller generates precise switching pulses for the H-bridge circuits to ensure proper switching sequence and voltage level generation. Along with this, the Incremental Passivity-Based Control technique continuously monitors system variables and regulates them to maintain stability, balance capacitor voltages across all H-bridge cells, and improve dynamic response under varying load conditions. The generated multilevel AC output is then passed through a step-up transformer to obtain the desired voltage level suitable for practical use. Finally, this output is supplied to an AC load (such as a bulb), demonstrating efficient power conversion with improved waveform quality, low Total Harmonic Distortion (THD), and reliable system operation.

## V. CIRCUIT DIAGRAM

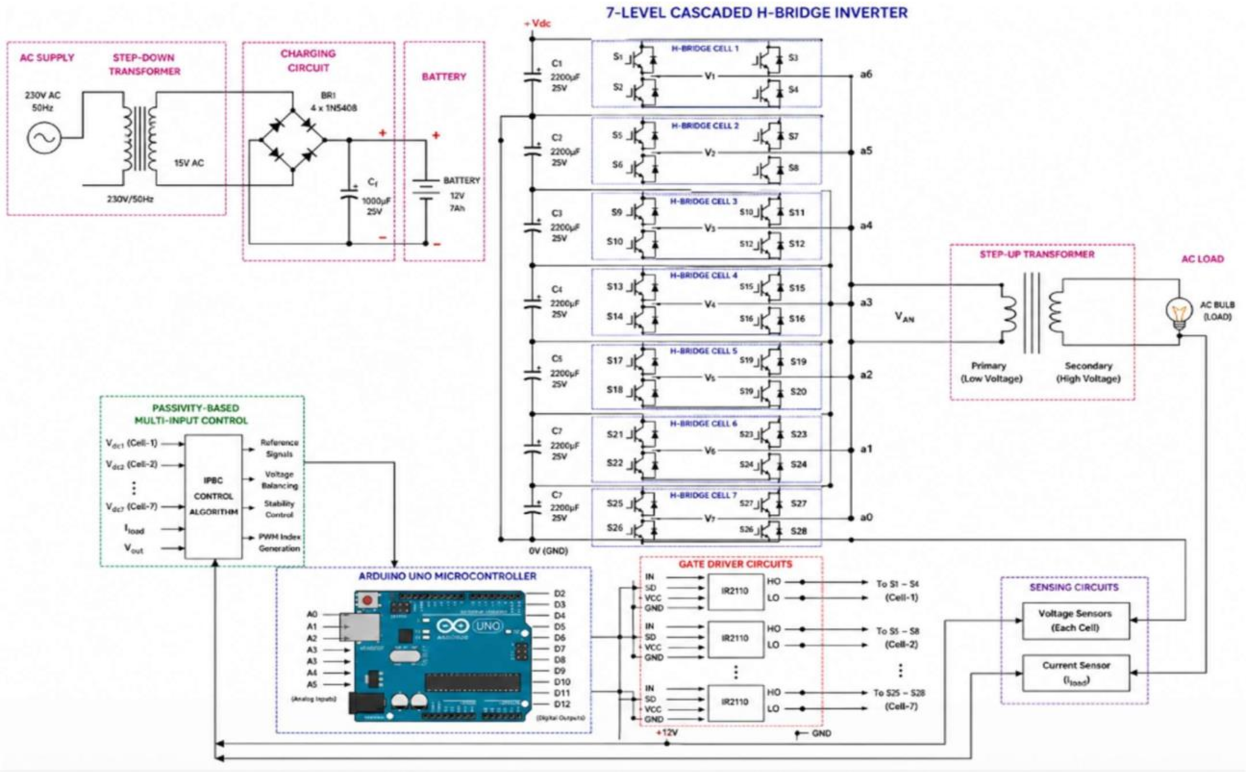


Fig. 2. Circuit diagram

## VI. HARDWARE COMPONENTS

Regulated Power Supply: A regulated power supply converts the raw DC obtained after rectification into a constant and stable DC voltage required for sensitive electronic components like the control circuit. It uses voltage regulators to maintain a fixed output despite variations in input voltage or load conditions, ensuring reliable and noise-free operation of the system.

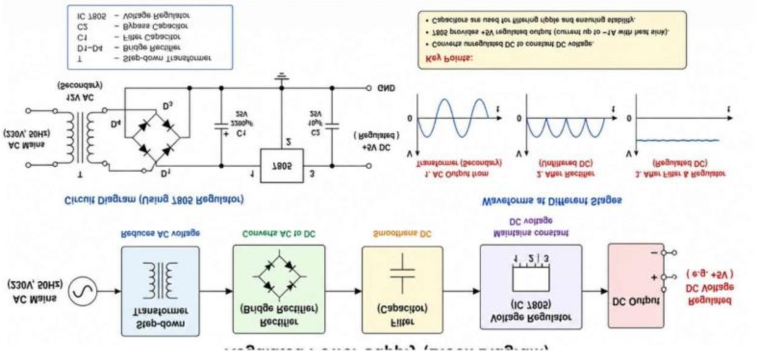


Fig. 3. Regulated Power Supply

Step-Down Transformer: The step-down transformer reduces the high input AC voltage (230V) to a lower AC voltage (typically 12V–15V) using electromagnetic induction. It provides electrical isolation and ensures safe voltage levels for the charging circuit and other low-power components in the system.

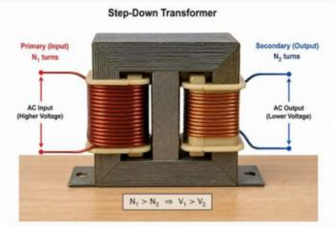
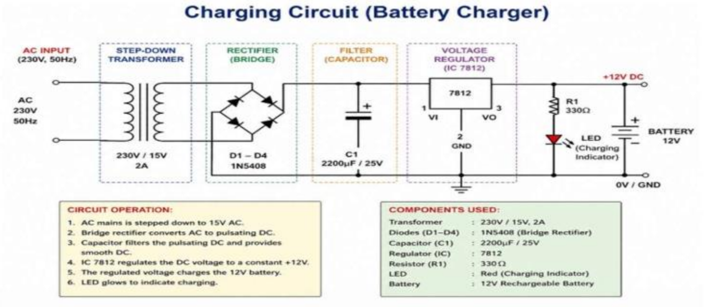


Fig. 4. Step-Down Transformer

Charging Circuit: The charging circuit converts AC into DC using rectifiers and filters, and regulates it to safely charge the battery. It ensures proper charging by controlling voltage and current levels, preventing overcharging, and maintaining battery health for continuous system operation.



CIRCUIT OPERATION:

1. AC mains is stepped down to 15V AC.
2. Bridge rectifier converts AC to pulsating DC.
3. Capacitor filters the pulsating DC and provides smooth DC.
4. IC 7812 regulates the DC voltage to a constant +12V.
5. The regulated voltage charges the 12V battery.
6. LED glows to indicate charging.

COMPONENTS USED:

Transformer : 230V / 15V, 2A
Diodes (D1–D4) : 1N5408 (Bridge Rectifier)
Capacitor (C1) : 2200µF / 25V
Regulator (IC) : 7812
Resistor (R1) : 330Ω
LED : Red (Charging Indicator)
Battery : 12V Rechargeable Battery

Fig. 5. Charging Circuit

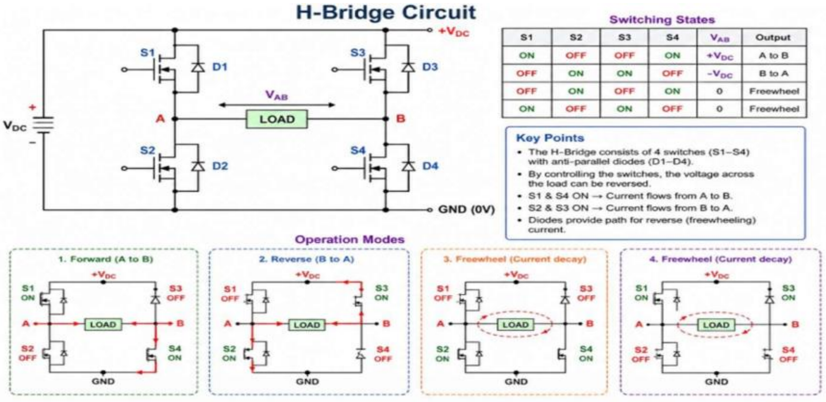
Battery: The battery stores electrical energy in DC form and supplies a stable input to the inverter when required. It acts as a backup source and helps maintain continuous power flow, especially during fluctuations or absence of the main supply.

Fig. 6. Battery

Arduino UNO Microcontroller: The Arduino Uno serves as the main control unit, generating PWM (Pulse Width Modulation) signals to control switching of the H-bridge circuits. It also implements control algorithms and processes feedback signals to ensure proper inverter operation and system stability.

Fig.7.ArduinoUNOMicrocontroller

H-Bridge Circuits: H-bridge circuits consist of four power switches arranged in a configuration that allows current to flow in both directions through the load. In cascaded form, multiple H-bridges generate multilevel AC output, improving waveform quality and reducing harmonic distortion.



| S1 | S2 | S3 | S4 | $V_{AB}$ | Output |
|---|---|---|---|---|---|
| ON | OFF | OFF | ON | $+V_{DC}$ | A to B |
| OFF | ON | ON | OFF | $-V_{DC}$ | B to A |
| OFF | ON | OFF | ON | 0 | Freewheel |
| ON | OFF | ON | OFF | 0 | Freewheel |

- The H-Bridge consists of 4 switches (S1–S4) with anti-parallel diodes (D1–D4).
- By controlling the switches, the voltage across the load can be reversed.
- S1 & S4 ON → Current flows from A to B.
- S2 & S3 ON → Current flows from B to A.
- Diodes provide path for reverse (freewheeling) current.

Fig. 8. H-Bridge Circuits

Passivity-Based Multi-Input Control: This control technique ensures system stability by regulating energy flow within the converter based on passivity principles. It balances voltages across different H-bridge cells, improves dynamic response under varying conditions, and efficiently manages multiple input sources for reliable performance.

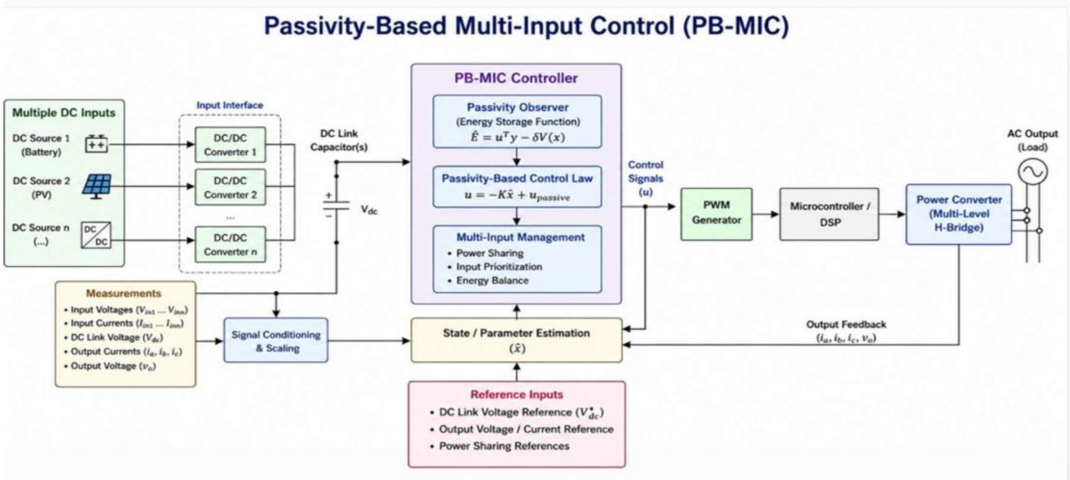


Fig. 9 Passivity-Based Multi-Input Control

## VII. WORKING

The system operates by first converting AC supply into DC using a step-down transformer and charging circuit, and storing it in a battery. This DC source is then fed into multiple cascaded H-bridge cells, where each H-bridge generates three voltage levels:

+Vdc, 0, −Vdc+V_{dc},\; 0,\; -V_{dc}+Vdc,0,−Vdc

By combining multiple H-bridges in series, a multilevel output voltage is obtained. For an m-level inverter, the number of levels is given by:

m=2n+1m = 2n + 1m=2n+1 where n is the number of H-bridge cells. For a 7-level inverter:

7=2(3)+17 = 2(3) + 17=2(3)+1

The output voltage is the sum of individual H-bridge outputs:

Vout=V1+V2+V3V_{out} = V_1 + V_2 + V_3Vout=V1+V2+V3

This stepped waveform approximates a sinusoidal waveform, reducing Total Harmonic Distortion (THD). The RMS output voltage can be expressed as:

Vrms=1T∫0Tv2(t) dtV_{rms} = \sqrt{\frac{1}{T} \int_0^T v^2(t)\,dt}Vrms=T1∫0Tv2(t)dt

Control Principle (IPBC)
The Incremental Passivity-Based Control ensures system stability by regulating energy flow. The system is designed such that the incremental energy function decreases over time:
dWdt≤0\frac{dW}{dt} \leq 0dtdW≤0 where W is the stored energy in the system. This guarantees stable operation.
The control law maintains voltage balance across capacitors:

e=Vref−Vactuale = V_{ref} - V_{actual}e=Vref−Vactual and adjusts switching signals to minimize error:

u=−Keu = -K eu=−Ke where K is the control gain.

## VIII. IMPLEMENTATION

The implementation of the proposed system begins with designing the power supply stage, where the AC input is stepped down using a transformer and converted into DC through a rectifier and filtering circuit. This DC is stored in a battery and also regulated to provide a stable supply for the control unit. The stored DC voltage is then applied to multiple cascaded H-bridge cells, each consisting of power switches (MOSFETs/IGBTs) driven through gate driver circuits. These H-bridges are connected in series to form a 7-level inverter, enabling the generation of stepped AC voltage.

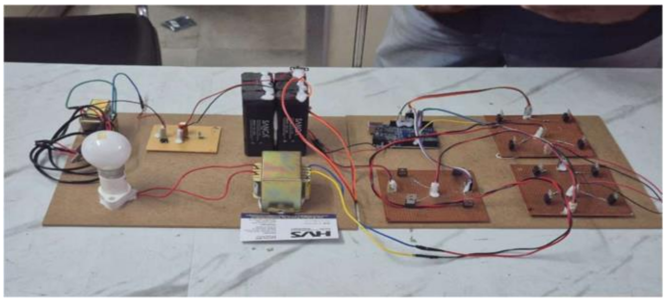
The control section is implemented using an Arduino Uno, which is programmed to generate PWM pulses based on the required switching sequence for multilevel output. Gate driver circuits amplify these signals to properly drive the power switches. Voltage and current sensors are integrated to provide real-time feedback to the controller. Using this feedback, the Incremental Passivity-Based Control algorithm is implemented in software to maintain voltage balance across each H-bridge cell, ensure system stability, and improve dynamic response.

Finally, the multilevel AC output from the inverter is passed through a step-up transformer to obtain the desired voltage level and is supplied to an AC load (such as a bulb). The complete system is tested under different operating conditions to verify performance in terms of voltage quality, reduced harmonic distortion, and stable operation.

## IX. RESULT

The implemented system successfully demonstrates the operation of a 7-level Cascaded H-Bridge inverter using Incremental Passivity-Based Control. The inverter produces a stepped AC output waveform that closely approximates a sinusoidal wave, resulting in significantly reduced Total Harmonic Distortion (THD) compared to conventional twolevel inverters. The output voltage is stable and consistent, confirming proper switching of H-bridge cells and effective generation of multilevel voltage levels.

Additionally, the control strategy maintains balanced voltages across all H-bridge units and ensures stable system performance under varying load conditions. The system shows improved dynamic response, with quick adjustment to changes in input or load. The final output, when applied to an AC load (bulb), operates smoothly without flickering, demonstrating efficient power conversion, reliable operation, and suitability for applications like renewable energy systems and smart grids.



## X. CONCLUSION

The proposed system of a 7-level Cascaded H-Bridge inverter using Incremental Passivity-Based Control successfully achieves efficient and stable power conversion. The multilevel structure produces a high-quality AC output with reduced harmonic distortion, minimizing the need for bulky filters and improving overall waveform performance. The use of cascaded H-bridge cells also provides modularity, making the system flexible and scalable for higher voltage applications.

Furthermore, the implemented control strategy ensures voltage balancing across all H-bridge cells and maintains system stability even under varying load conditions. The integration of a microcontroller-based control unit enhances accuracy in switching and improves dynamic response. Overall, the system demonstrates reliable operation, high efficiency, and suitability for modern applications such as renewable energy integration, electric drives, and smart grid systems.

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