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Design and Implementation of Resonant Converter for Green Hydrogen Storage in PV System

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Abstract: *With the growing global emphasis on decarbonization and sustainable energy alternatives, solar-driven hydrogen production has emerged as a promising solution for clean fuel generation. This study proposes a simulation-based design of a green hydrogen production system powered by photovoltaic energy. The architecture integrates SunPower SPR-215-WHT-U solar modules, a DC-DC boost converter, a full-bridge LLC resonant converter, and a Proton Exchange Membrane (PEM) electrolyzer. The boost converter enhances the PV voltage with reduced ripple, while the LLC resonant converter—operating at 65 kHz—enables soft-switching for improved efficiency. A two-stage LC filter is implemented for grid-friendly power delivery. The PEM electrolyzer is modeled based on thermodynamic and electrochemical parameters to evaluate hydrogen output. The entire system is simulated in MATLAB/Simulink to assess performance under dynamic conditions. Results confirm efficient power conversion and consistent hydrogen generation, demonstrating the viability of resonant converter-based PV systems for renewable hydrogen production.*
Keywords: *Boost Converter, Full-Bridge LLC Resonant Converter, Green Hydrogen, MATLAB/Simulink, Maximum Power Point Tracking (MPPT), PEM Electrolyzer, Photovoltaic (PV).*

I. Introduction

The increasing global emphasis on combating climate change has intensified the pursuit of clean energy solutions, with green hydrogen emerging as a pivotal enabler in the transition toward a low-carbon future. Produced via water electrolysis driven by renewable energy sources, hydrogen holds considerable promise across diverse sectors such as industrial manufacturing, transportation, and grid-scale energy storage applications [1], [2].

Among renewable options, solar photovoltaic (PV) energy stands out due to its widespread availability, declining cost trends, and ease of integration into modular systems for on-site hydrogen production [3]. However, directly connecting PV arrays to electrolyzers presents significant technical challenges. These stem from the inherently intermittent nature of solar irradiance and the nonlinear current-voltage characteristics of PV systems, which can lead to unstable operation and reduced efficiency [4].

To mitigate these issues, intermediate power electronic converters are introduced to regulate voltage levels and ensure stable power delivery to the electrolyzer unit. Moreover, Maximum Power Point Tracking (MPPT) algorithms such as Perturb and Observe (P&O) are widely employed to extract maximum energy from the PV system by continuously adjusting its operating point under varying environmental conditions[5].

Recent research has explored various DC-DC converter topologies and high-frequency isolated stages to optimize the performance of renewable-to-hydrogen systems. These topologies are tailored to meet the voltage and current demands of different electrolyzer technologies while enhancing overall energy transfer efficiency. Additionally, advanced control models for hybrid microgrids integrated with hydrogen storage have been investigated to improve dynamic response and system flexibility [6], [7].

In this context, the present work proposes a simulation-based design for a green hydrogen production system powered by solar PV energy. The proposed system includes a SunPower SPR-215-WHT-U PV module, a DC-DC boost converter integrated with a P&O-based MPPT controller, a full-bridge LLC resonant converter, and a Proton Exchange Membrane (PEM) electrolyzer. Developed and simulated in MATLAB/Simulink, the design is analyzed under dynamic operating conditions to evaluate energy conversion efficiency and hydrogen yield. The integration of efficient converter stages and closed-loop control mechanisms ensures a regulated DC supply to the electrolyzer and supports the system's scalability for larger applications [8], [9], [10].

The paper focuses on the design and control of a photovoltaic-powered system incorporating a full-bridge LLC resonant converter and a Proton Exchange Membrane (PEM) electrolyzer for efficient hydrogen storage. It includes modeling, simulation-based analysis, and highlights the system’s performance and potential for sustainable energy applications.

II. SYSTEM STRUCTURE AND CONTROL SYSTEM

The proposed system enables solar-powered green hydrogen production by integrating key power conversion and storage elements in a single framework. The overall architecture includes a solar photovoltaic (PV) array, a DC-DC boost converter with MPPT control, a full-bridge LLC resonant converter, a PEM electrolyzer, and grid interfacing through a three-phase inverter. A hydrogen storage mechanism is included to ensure energy flexibility. The complete system architecture is shown in Fig. 1.

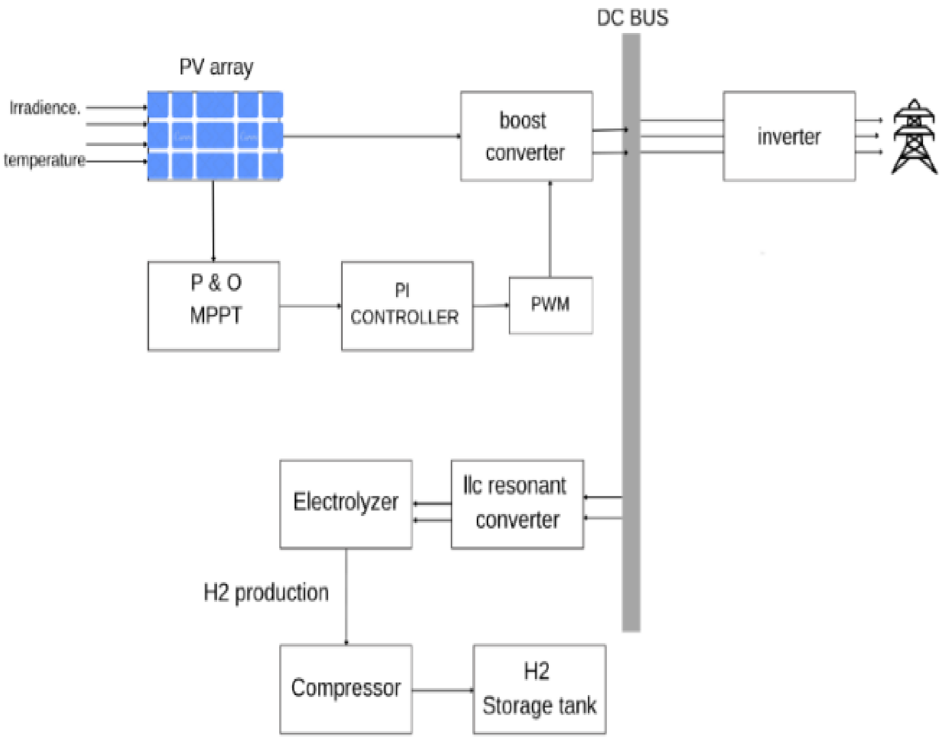

Fig. 1.Block Diagram of the Proposed Green Hydrogen Generation System

2.1 SOLAR PV ARRAY SYSTEM

The solar generation subsystem utilizes SunPower SPR-215-WHT-U PV modules configured in a 47-parallel and 10-series layout Each solar module comprises 72 cells and is capable of generating a maximum power output of 214.92 W.The output is optimized using a Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) algorithm, which adjusts the duty cycle of the boost converter based on power variation to ensure operation near the maximum power point. The PV output is conditioned to a regulated DC level (~600 V) using a PI-controlled boost converter.

Table I. PV Array Module Parameters

Parameters	**Values**
Maximum power (W)	214.92
Parallel Strings	47
Series-connected modules per string	10
Cells per module	72
Open circuit voltage (Voc)	48.3
Short circuit current (Isc)	5.8
Voltage at maximum power point	39.8
Current at maximum power point	5.4

2.2 RESONANT CONVERTER

The designed converter topology consists of a full-bridge MOSFET inverter stage followed by an LLC resonant tank composed of a series inductor and capacitor. This tank is magnetically coupled to a high-frequency transformer that provides galvanic isolation and facilitates voltage conversion. The output of the transformer is rectified by a full-bridge diode rectifier and filtered to obtain a regulated DC output. A PI-based voltage feedback control loop modulates the gate signals to maintain output stability under varying load conditions. The converter is optimized for high-efficiency operation in renewable-to-hydrogen energy transfer applications.

Table II. LLC Converter Parameters

Parameters	**Values**
Input DC Voltage	600V
Switching Frequency	65kHz
Resonant Inductor	63.8µH
Resonant Capacitor	44µF
Magnetizing Inductance	1.635 mH

The Full-Bridge LLC Resonant Converter facilitates efficient DC-DC power conversion by tuning the resonant tank to operate at a specific frequency and impedance, based on the load and system requirements.The resonant frequency defines the point at which the inductor and capacitor achieve resonance for optimal energy transfer:

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}$$

The characteristic impedance of the resonant tank determines the voltage gain profile and influences the converter's dynamic response:

$$Z_r = \sqrt{\frac{L_r}{C_r}}$$

The quality factor relates the effective load resistance reflected to the primary side with the tank impedance and impacts the bandwidth and power transfer capability:

$$Q = \frac{R_{ac}}{Z_r}$$

2.3. PEM ELECTROLYZER

The Proton Exchange Membrane (PEM) electrolyzer in the proposed system enables clean hydrogen production by converting DC electrical energy into chemical energy through water electrolysis. This method is favoured for its high efficiency, compactness, and ability to operate at high pressures—making it ideal for integration with solar-powered systems.

Water enters the anode chamber, where it is split into oxygen, protons, and electrons:

Anode Reaction: $H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$

Hydrogen ions pass through the membrane and react with electrons at the cathode, resulting in hydrogen gas formation.

Cathode Reaction: $2H^+ + 2e \rightarrow H_2$

Overall Reaction: : $H_2O \rightarrow H_2 + \frac{1}{2}O_2$

Hydrogen production is modeled using Faraday's law, where the molar flow rate is directly proportional to the current and system efficiency:

$$n_{H2} = \frac{n_F \cdot i_e \cdot n_c}{2F}$$

The volumetric hydrogen output is:

$$V_{H2} = n_{H2} \cdot 0.022414\ [m^3/s]$$

This model ensures accurate tracking of hydrogen generation under varying power inputs from the solar-driven converter system.

2.4 THREE-PHASE TWO-STAGE GRID INTEGRATION

The grid integration stage converts the regulated 600 V DC from the boost converter into a synchronized 415 V, 50 Hz three-phase AC using a voltage source inverter (VSI). A two-stage LC filter is placed between the inverter and the grid to suppress switching harmonics and improve power quality. A Phase-Locked Loop (PLL) ensures synchronization with grid frequency and phase, while a dq-axis current controller regulates active and reactive power, enabling stable and efficient grid interaction.

III. SIMULATION ANALYSIS AND RESULTS

The proposed solar-powered hydrogen generation system integrates key subsystems including the PV array, MPPT-controlled boost converter, full-bridge LLC resonant converter, PEM electrolyzer, and a grid-tied inverter. The overall Simulink model reflects the coordinated operation of these components to enable efficient hydrogen production and grid interaction under dynamic solar conditions.

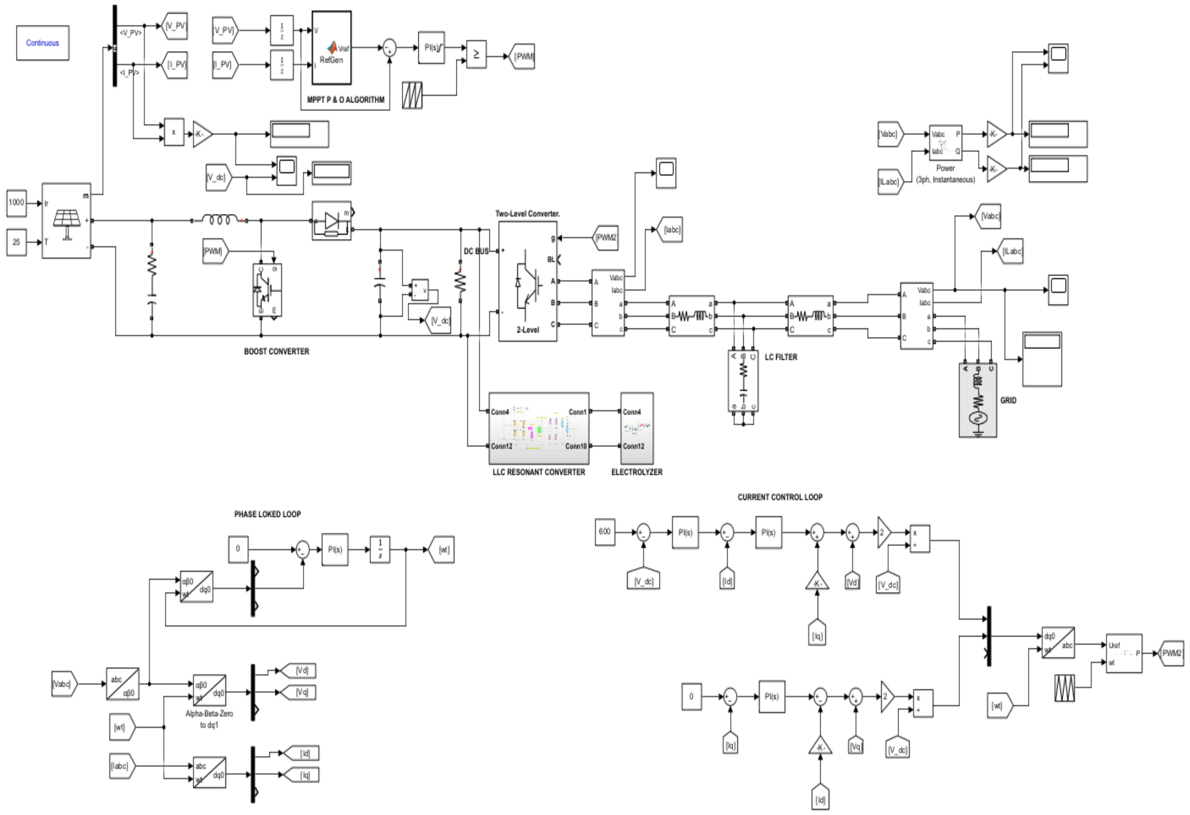

Fig. 2. Simulink model of the complete PV-based hydrogen generation system

3.1 HYDROGEN STORAGE

The hydrogen storage system stores the hydrogen generated by the PEM electrolyzer using a Simulink-based model. The model calculates the hydrogen output in real time based on electrolyzer current and converts it into volumetric flow. A compressor increases the pressure of the hydrogen before storing it in the tank, while flow control ensures safe and continuous operation.

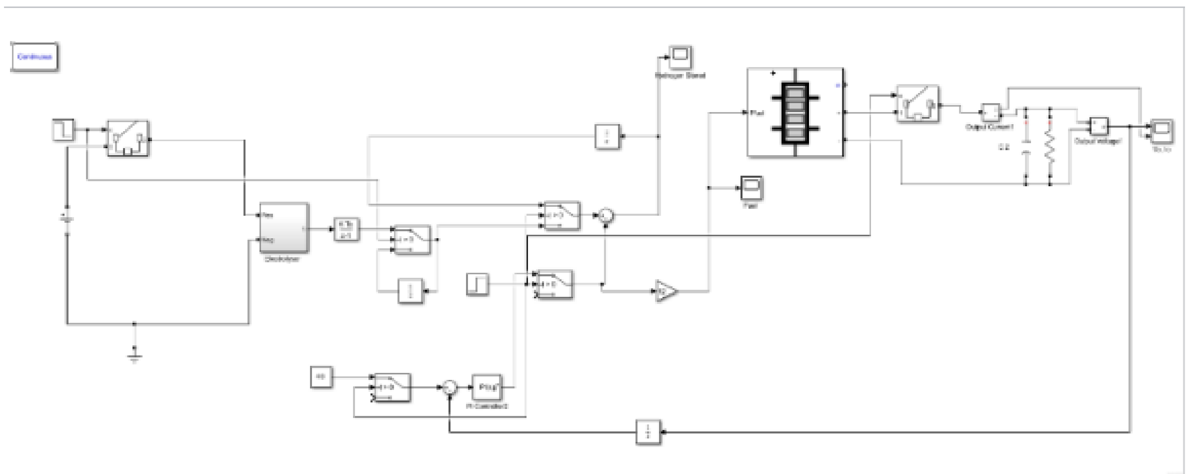

Fig. 3. Simulink model of hydrogen storage system with flow control and compression

Fig. 4 illustrates the output voltage and current of the boost converter, showing a regulated DC level around 595–600 V and an output current of approximately 166 A. The waveform confirms stable performance and effective MPPT-based control despite variations in solar input.

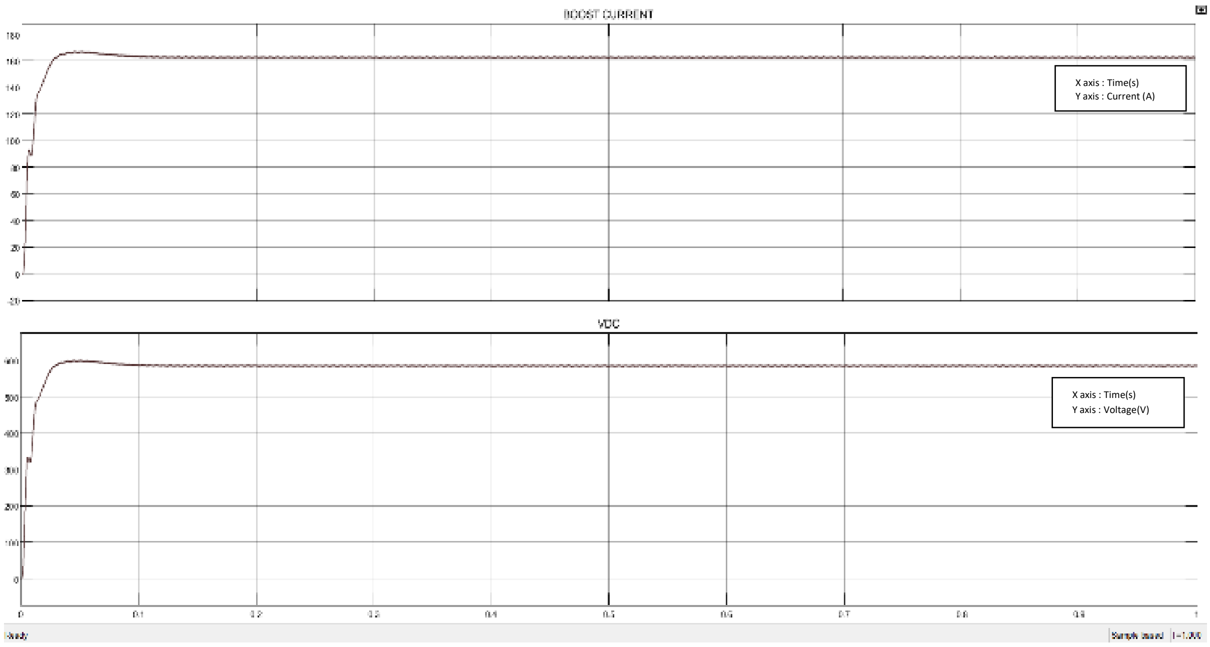

Fig. 4. Boost converter output voltage and current waveform

Fig. 5 illustrates the three-phase output voltage and current waveforms of the grid-tied inverter, showing a balanced AC voltage with an RMS value of around 367 V. The current waveform closely follows the voltage, indicating proper inverter operation and phase alignment.

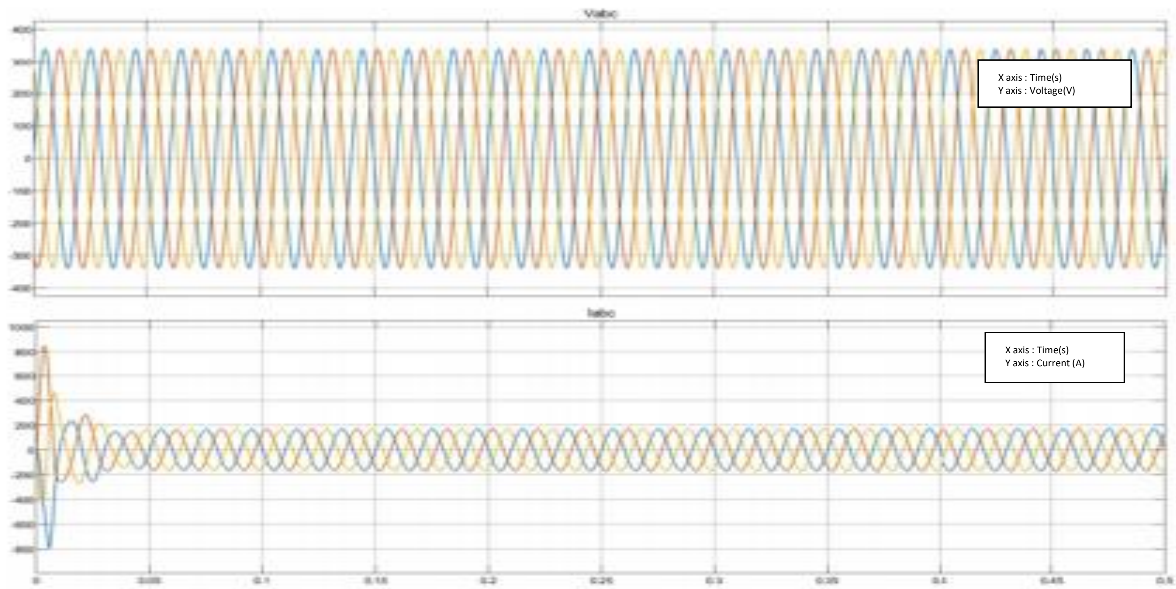

Fig. 5. Grid-side voltage (Vabc) and current (Iabc) waveforms

Fig. 6 illustrates the output voltage waveform of the Full-Bridge LLC Resonant Converter, showing a stable response that settles around the desired 400 V. This confirms effective voltage regulation suitable for powering the PEM electrolyzer in the solar-based hydrogen generation system.

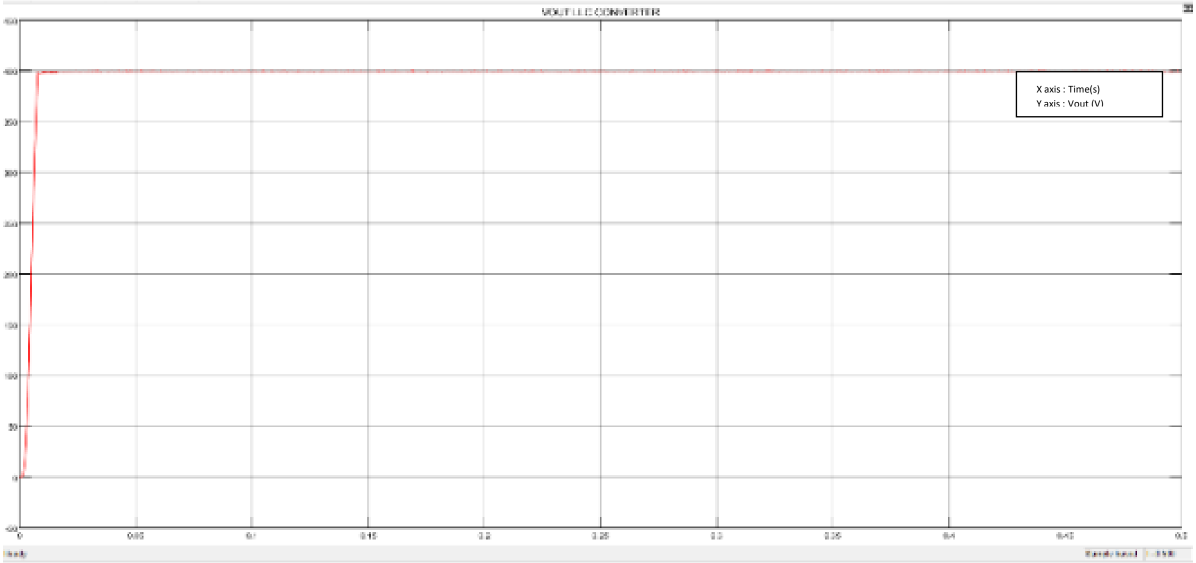

Fig. 6. Output voltage waveform of LLC resonant converter

Fig. 7 depicts the 24-hour hydrogen production and usage cycle. From 0 to 12 hours, hydrogen is actively produced; between 12 to 16 hours, production continues and storage reaches capacity; and from 16 to 24 hours, stored hydrogen is gradually utilized.

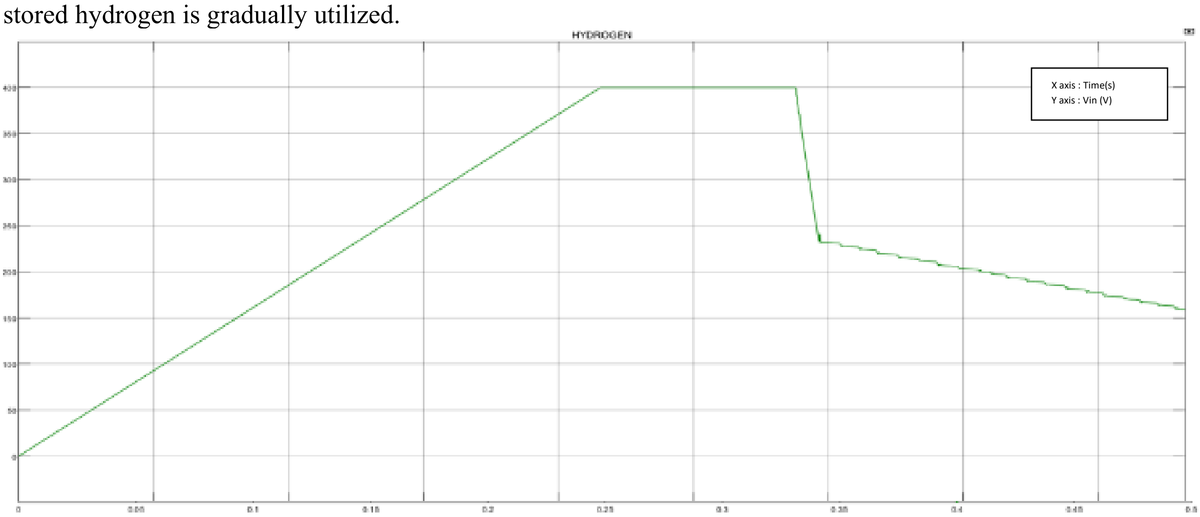

Fig. 7. Simulated hydrogen production and utilization cycle over 24 hours

IV. CONCLUSIONS

A photovoltaic-based green hydrogen generation system is successfully developed and simulated with an integrated Full-Bridge LLC Resonant Converter and PEM electrolyzer. The coordinated design ensures efficient DC-DC power conversion, stable voltage regulation, and reliable hydrogen production. Simulation results highlight effective maximum power extraction, regulated power delivery, and real-time adaptability to solar variations. The system efficiently handles production, storage, and utilization phases, establishing its potential for clean and continuous energy generation through renewable-driven electrolysis.

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