# MATLAB-Based Boost PWM Control Scheme for a Half-Bridge LLC Resonant Converter Integrated with Solar PV and P&O MPPT for High-Power Hold-Up State Operation

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## Abstract

In this paper, a Boost PWM-Controlled Half-Bridge LLC Resonant Converter Integrated with Solar PV and P&O MPPT for High-Power Hold-Up State Operation is proposed. The converter is based on a half-bridge LLC resonant structure, enhanced by integrating a single auxiliary switch at the primary side for improved hold-up operation. Under normal conditions, the converter operates like a conventional LLC resonant converter, ensuring efficient power conversion from the solar PV source managed by a Perturb and Observe (P&O) MPPT algorithm. However, during an AC line loss or hold-up time—where wide voltage gain variation is required—the control strategy transitions to a PWM-controlled mode through the auxiliary switch.

This approach significantly reduces the frequency variation range typically required by conventional LLC converters, allowing optimal design of the transformer and minimizing conduction losses of the magnetizing inductor current. Additionally, the voltage gain can be easily increased by adjusting the duty cycle of the auxiliary switch, enabling reduced link capacitance requirements. To validate the effectiveness of the proposed system, the operational principles are detailed, and experimental results will be presented based on the following specifications: 50 kHz switching frequency, 250–400 V input voltage range, 250 V output voltage, and 1 kW output power.

Index Terms—Boost PWM control and zero voltage switching (ZVS), hold-up time, LLC resonant converter.

## 1. Introduction

Photovoltaic (PV) systems to enhance power density and improve overall system efficiency. Most studies have focused on two-stage converter topologies, comprising a Power Factor Correction (PFC) stage followed by a DC/DC conversion stage. The PFC stage optimizes the input characteristics, while the DC/DC stage ensures galvanic isolation and regulates the output voltage. Among these stages, the DC/DC converter plays a crucial role in improving system efficiency, as it converts the high-voltage solar PV output into variable load voltage and current—often contributing significantly to power losses shown in Fig.1. Furthermore, solar PV-based applications demand reliable operation under fluctuating irradiance and temperature conditions, making efficient power conversion essential for optimal system performance.

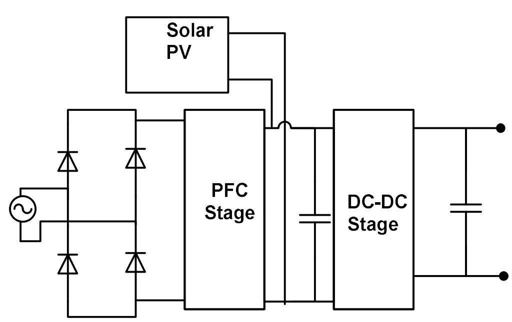


Fig. 1Shows the structure of two-stage ac/dc converter with Solar PV.

The PFC stage is utilized to achieve unity power factor of the system and galvanic isolation and output voltage regulation characteristics are gratified by the dc/dc stage. In these two components, the dc/dc stage is regarded as the more critical part to ameliorate the efficiency of the system, because it converts high voltage input into variable load voltage/current output, which results in a consequential power loss. Furthermore, some designations require that the system.

During this time, a dc/dc converter is powered by the stored energy in link capacitors, so that the dc/dc converter should be designed to be able to compensate the wide input voltage range. Many approaches have been suggested for a high efficient dc/dc converter [1]– [3]. Among these approaches, LLC resonant converter [3] is culled as the most promising candidate in low power application, due to the zero-voltage switching (ZVS)characteristic for the primary switches and no inversion-instauration quandary for the rectifier diodes

.An LLC resonant converter shows the maximum efficiency in the nominal condition, when the converter is operated at the resonant frequency. However, the switching frequency becomes reduced and growing apart from the resonant switching point as the input voltage decreases. This frequency change becomes a considerable issue under a wide input variation condition. It makes LLC resonant converters have arduousness in magnetic design, and it withal decreases nominal efficiency of the converters. The dc conversion ratio of a conventional LLC resonant converter is represented as follows [3]–[5]. A number of different methods have been proposed to surmount this drawback of the LLC resonant converter [5]–[6].

Converter have low power density and incremented circuit intricacy. Boosting-up primary current is another method proposed in Fig.3 The converter applies zero voltage to the transformer utilizing the secondary auxiliary circuit and the primary current is build up during this period. Albeit higher voltage gain characteristic can be achieved with this method, the proposed converter requires many bulk components. Asymmetric PWM control scheme is proposed in Fig.4 [14]. This method increases voltage gain without utilizing any supplemental components, but with transmuting control scheme from frequency modulation (FM) to PWM control for the hold-up time operation. High voltage gain is achieved utilizing this method while maintaining high power density characteristic. However, the gain variation range is constrained in the converter (optically discern Fig3) and the maximum gain is tenacious by the resonant tank design.

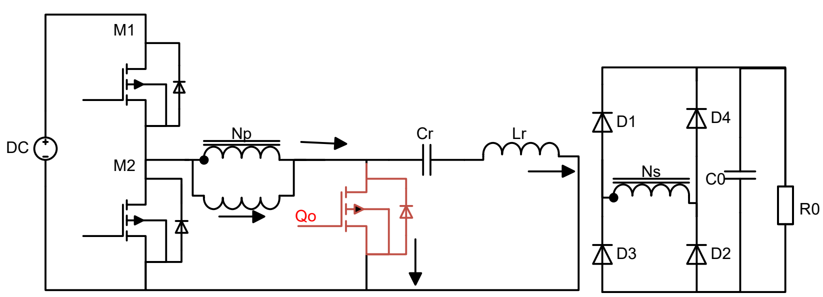


Fig. 2. Schematic diagram of the proposed converter.

## 2. Proposed Converter

The presented circuit shown in Fig.2 is a Half-Bridge LLC Resonant Converter with an Auxiliary Boost Switch (Qa) designed for high-efficiency DC-DC power conversion. The main objective of this design is to ensure efficient operation during both nominal and hold-up states, providing a wide voltage gain range while minimizing switching losses. The converter is designed as a Half-Bridge LLC resonant converter integrated with an auxiliary boost switch to enhance performance under varying operating conditions. Showen in Fig.2.The circuit consists of two main switches, M1 and M2, connected in a half-bridge configuration on the primary side. These switches work together to excite the resonant tank, which is composed of a resonant inductor (Lr), a resonant capacitor (Cr), and the magnetizing inductance of the transformer (Lm). This resonant tank enables soft-switching operation, allowing Zero Voltage Switching (ZVS) of the main switches during the normal or nominal operation, which significantly reduces switching losses and improves efficiency.

$$\frac{V_{Cr}}{L_r} D_{Qa} T = \frac{(nV_0 - V_{Cr})}{L_r} D_P T \text{ ..................................(1)}$$

$$= \frac{V_{Cr}}{(nV_0 - V_{Cr})} D_{Qa} T$$

Using the voltage-second balance rule of the magnetizing inductance Lm the voltage of the resonant capacitor is expressed as (2) and the final equation of (3) means the average magnetizing inductor voltage during the time "$D_{Qa}$T + $D_P$ T,"

$$0.5\mathrm{T}(V_S - V_{Cr}) = nV_0 D_P \mathrm{T} + V_{Cr}(0.5 - D_{Qa} - D_P)T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$V_{Cr} = \frac{0.5V_0 - nV_0 D_P}{1 - D_{Qa} - D_P}$$

$$\frac{nV_0 D_P}{D_{Qa} - D_P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In this mode, the converter operates similarly to a conventional LLC resonant converter. Power is smoothly transferred from the input source through the resonant tank and transformer to the secondary side, where it is rectified and filtered to supply a stable DC output to the load. The transformer isolates the primary and secondary sides while also stepping the voltage up or down as required by the load conditions.

An auxiliary switch, labeled Qa, is introduced on the primary side of the circuit to handle situations when the converter experiences low input voltage or enters into the hold-up state. During such conditions, the control strategy shifts from conventional resonant operation to boost mode operation. When the auxiliary switch turns on, it allows additional energy to be stored in the resonant inductor Lr. Once the auxiliary switch is turned off, the stored energy in Lr is released and transferred to the load, effectively boosting the output voltage. By controlling the duty cycle of the auxiliary switch, the converter achieves a wide voltage gain range without forcing the system to operate at high switching frequencies. This operation minimizes core losses and prevents saturation of the transformer, which in turn enhances the reliability of the system.

On the secondary side, a center-tapped transformer winding is used, connected to four diodes that perform full-wave rectification. The rectified output is then filtered through the output capacitor Co, ensuring smooth DC voltage is supplied to the load. The load receives continuous power regardless of changes in the input conditions, thanks to the intelligent operation of the auxiliary switch.

The proposed converter design offers significant advantages, including high efficiency during normal operation due to ZVS and reduced conduction losses. The ability to seamlessly switch to a boost mode operation ensures that the converter maintains output voltage regulation even under low input voltage conditions. This design is particularly suitable for applications requiring high power density and stable operation, such as solar photovoltaic integrated systems, electric vehicle charging, or hydrogen generation systems where maintaining output voltage during fluctuating input conditions is critical.

## 3. Simulation implementation

Experimental The proposed system consists of a solar photovoltaic (PV) integrated boost converter with a Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) algorithm, followed by a half-bridge LLC resonant converter to achieve efficient power conversion for high-power applications. The PV array generates power based on varying irradiance and temperature conditions, which are simulated using a ramp-up and down irradiance profile shown in Fig.3. The PV output voltage and current are continuously monitored and fed into the P&O MPPT algorithm to track the maximum power point dynamically. This MPPT controller generates a pulse width modulation (PWM) signal that controls the operation of the boost converter switch. The boost converter elevates the PV voltage to the required level, ensuring the system operates at its maximum efficiency point under varying environmental conditions.

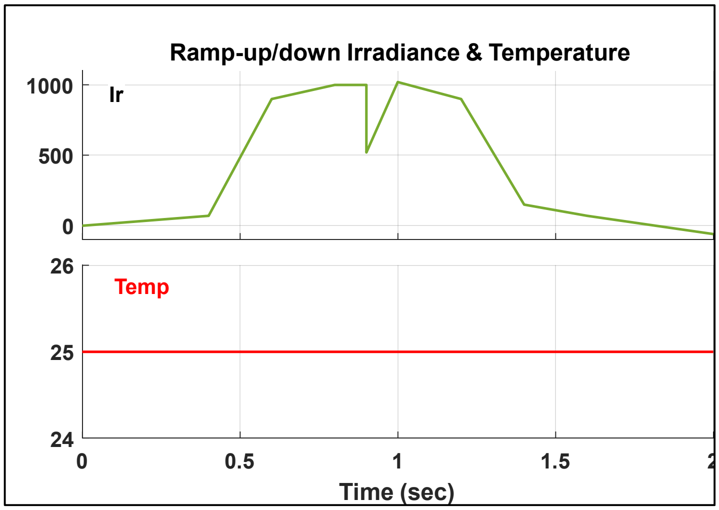


Fig.3 Solar profile waveforms

The boosted DC voltage is then supplied to the half-bridge LLC resonant converter, which is designed to operate under soft-switching conditions to minimize switching losses. The LLC stage includes resonant components such as a resonant capacitor and inductor along with a high-frequency transformer that provides galvanic isolation and voltage transformation. The converter operates near its resonant frequency during nominal conditions, achieving Zero Voltage Switching (ZVS) for the power switches, thereby improving the overall efficiency of the system. On the secondary side, the AC output from the transformer is rectified through a full-bridge diode rectifier and filtered using an output capacitor to provide a smooth DC output voltage across the load. Various measurement blocks are integrated into the model to monitor PV parameters, output voltage, and current waveforms. This design effectively demonstrates the combination of MPPT control with resonant conversion technology, making it suitable for high-efficiency solar energy conversion systems in renewable energy applications.

## 4. Results & Discussions

The simulation of the proposed PV-integrated boost converter with P&O MPPT and half-bridge LLC resonant converter was carried out in MATLAB/Simulink to evaluate the system's performance under varying irradiation conditions. The PV array model was subjected to a ramp-up and ramp-down irradiance profile to analyze the dynamic response of the MPPT algorithm and the overall power conversion efficiency. The P&O MPPT algorithm effectively tracked the maximum power point of the PV array during changing irradiation levels, ensuring maximum power extraction from the solar source. The generated PWM signal successfully controlled the boost converter switch, increasing the PV output voltage to the desired level required by the LLC stage.

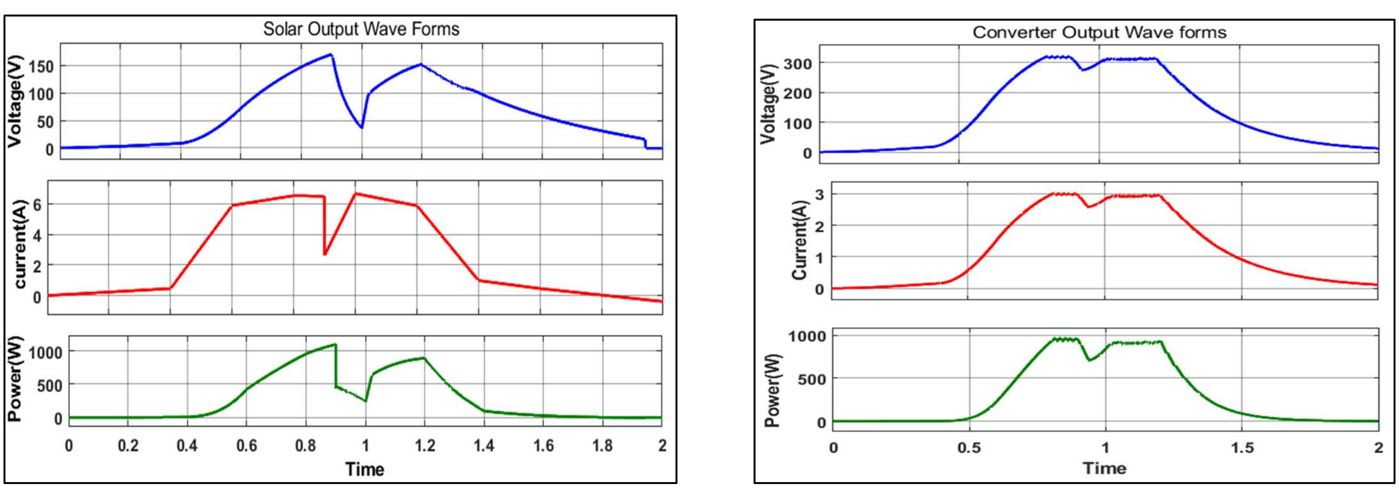


Fig.4. Solar and Converter Output waveforms

The boost converter demonstrated stable operation with minimal ripple in the output voltage due to the effective action of the MPPT algorithm, as shown in Fig. 4. The voltage gain of the boost converter dynamically responded to the varying solar input, reflecting the efficiency of the MPPT technique in maintaining continuous power flow to the LLC resonant stage. During the operation of the LLC converter, soft-switching conditions were successfully achieved as the primary switches operated near the resonant frequency, significantly reducing the switching losses. Fig. 5 illustrates the switching waveforms and shows that an appropriate delay is provided to ensure soft-switching action. The resonant tank elements (Cr and Lr) along with the transformer efficiently transferred the energy to the load while maintaining galvanic isolation.

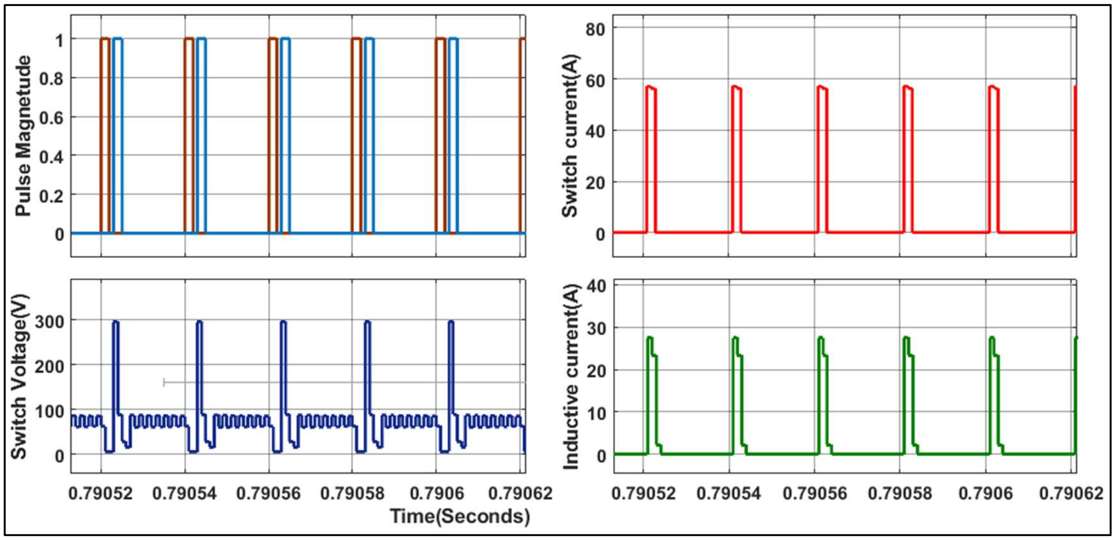


Fig.5. Switching Waveforms

The output voltage across the load remained stable throughout the simulation, demonstrating the robust control capability of the proposed design. The voltage waveform showed minimal overshoot and steady-state oscillations, ensuring a smooth DC output. The current waveform confirmed reduced ripple and proper power delivery, validating the LLC's capability in handling high-frequency operations while maintaining system efficiency. The simulation results also indicate that during variations in solar irradiance, the MPPT adjusted the duty cycle to maintain optimal power transfer, thereby improving system performance and reliability.

Overall, the proposed PV-fed boost converter with MPPT and LLC resonant stage demonstrated superior performance in terms of maximum power extraction, reduced switching losses, and stable output voltage. The integration of MPPT ensures efficient utilization of the available solar energy, while the LLC resonant operation provides high efficiency and reliability, making the system suitable for high-power renewable energy applications.

## 6. Conclusion

In this paper, a solar PV integrated boost converter with Perturb and Observe (P&O) MPPT algorithm combined with a half-bridge LLC resonant converter has been proposed and analyzed. The system is designed to achieve efficient maximum power extraction from the solar PV under varying irradiation conditions and to deliver a stable output voltage suitable for high-power applications. The boost converter, controlled by the MPPT algorithm, effectively stepped up the PV voltage, ensuring that the solar array operates at its maximum power point. The half-bridge LLC resonant converter, operating under soft-switching conditions, minimized switching losses and improved the overall system efficiency. The resonant operation also provided galvanic isolation and reduced current ripple, making the converter reliable for continuous operation. Simulation results validated the effectiveness of the proposed system, demonstrating stable output voltage, reduced ripple, and efficient power transfer even under fluctuating solar conditions. The proposed system architecture thus proves to be a suitable solution for renewable energy-based high-power applications, where efficient power conversion, maximum power extraction, and stable output are crucial. The combination of MPPT control and resonant converter operation significantly enhances the performance and reliability of the system, making it an ideal choice for integration into advanced solar power systems.

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