



An Improved LLC Resonant DC/DC Converter for PV– Battery System

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ABSTRACT: To create reliable and effective renewable energy systems, photovoltaic (PV) systems must be integrated with energy storage devices like batteries. To maximize energy transfer between the PV array, the battery, and the load, a high-efficiency DC/DC converter is essential. The design of a high- efficiency LLC resonant DC/DC converter specifically suited for photovoltaic-battery systems is presented in this work. Because of its built-in benefits of soft switching and zero-voltage switching (ZVS), which greatly lower switching losses and electromagnetic interference (EMI) and increase system efficiency, the LLC converter was selected. A thorough examination of important factors such resonant tank design, control strategy, and efficiency optimization techniques is part of the suggested converter design. According to simulation studies, the converter is well-suited for dynamic PV situations since it can provide excellent power conversion efficiency over a broad input voltage range. Additionally, the converter achieves fast transient response and excellent load management, which provide dependable battery charging and discharging while preserving system stability. It is demonstrated that the suggested solution significantly increases system dependability, efficiency, and thermal performance, providing a viable strategy for contemporary PV-battery integrated systems.

Keywords: LLC Resonant, H-Bridge, photovoltaic system.

1. Introduction

The growing demand for renewable energy sources, particularly solar energy, has led to significant advances in energy conversion technology. One of the most important challenges in solar power generation (PV) systems is the optimization of the efficiency and performance of DC DC converters, which is essential for solar panels, battery storage and load interfaces. Highly efficient DC DC converters are important to maximize energy harvested from solar collectors and ensure reliable, energy storage in the battery. This converter works with resonance frequency, minimizing switching losses and increasing overall system efficiency, especially under different load conditions. This is a typical scenario

for solar power systems.

In this paper, we propose a highly efficient LLC resonance DC DC converter. It is specifically designed for solar battery systems (PVs) that aim to address the challenges of efficient power calculation, robustness and thermal management. The converter is designed to be seamlessly integrated into solar and BatteraNK to ensure efficient energy transfer and storage, while simultaneously minimizing energy loss during the conversion process.

A modified LLC converter with two transformers that operate over an area of four times the minimum input 23 voltage. To optimize the proposed LLC converter, numerical methods have been developed based on the fixed equation of the

LLC converter. The implemented hardware features a 250 W/210 V output with an input voltage of 25-100 V. The LLC resonance converter was developed using a fundamental harmony approximation, and experimental results show that the proposed converter reaches a maximum efficiency of up to 98% over a very wide input voltage region [1]. Isolated multi-port DC-DC converter for integrated electric vehicles in onboard chargers propose integrated onboard chargers (IOBC) based on isolated DC-DC converters. The proposed architecture integrates the onboard charger (OBC) and (OBC) into a single multiport converter, providing many low components. The proposed converter can also charge high voltage batteries (HV) and LV volt batteries (LV) over the entire battery voltage range. The current flow between the three ports is linked to provide galvanic insulation between the converter ports using a 3-turn transformer [2].

Partially isolated 3-port converter with improved current flow for PV and energy storage to integrate into the DC bus. The purpose of this paper is to provide a comprehensive, relatively useful analysis and an overview of these TPCs. Five topological structures of a 3-port DC/DC Conversion System (TPCS) with two ports to two ports, based on the power transmission and control requirements of the system, are presented [3]. The soft-switching buck/boost Voll Brücke-Drei-Port converter for DC/DC applications suggests an integrated design of a separate 3-port DC-DC converter to link PV (photo-powered) and batteries for independent systems. Three switches are required to handle the power supply between the input and output, but a minimum circulating current flow is maintained between the ports, allowing for bidirectional current flow for the battery connection. Additionally, since all switches have leaked transformers, interactive clamp circuits can be used to perform across the

operating area. As a result, there are fewer components in the converter and you can continue operating in all service modes. Most renewable energy sources have low voltage levels, so converters maintain high voltage reinforcement. Effective and inexpensive converters are the result of these characteristics [4]. Analysis and modelling of integrated magnetism of LLC resonance converters. In this topology, analysis and models of magnetization and leakage inductance are suggested by planar transformers that love shunts with and without air gaps. The desired magnetization and leakage inductance of the LLC resonance converter is simplified by creating a gap in the air along with the magnetic shunt [5].

2. Proposed System

A DC/DC converter is an essential electronic device that converts a DC input voltage to another direct current output voltage. This conversion process is extremely important for a variety of applications, including renewable energy systems, electric vehicles, and communications. With various types of DC/DC converters, LLC resonance converters stand out because they can efficiently transmit energy and minimize switching losses.

LLC resonance converters are a kind of resonance converter known for their soft switching capacitance, reducing switching losses and electromagnetic interference (EMI) and are suitable for highly efficient applications. The name "LLC" refers to a resonant tank circle. This is formed by an inductor (L), two capacitors (C), and a switching element. This resonant circuit provides zero voltage switch (ZVS) or zero current switching (ZCS) to reduce switching voltages and losses, increasing overall efficiency.

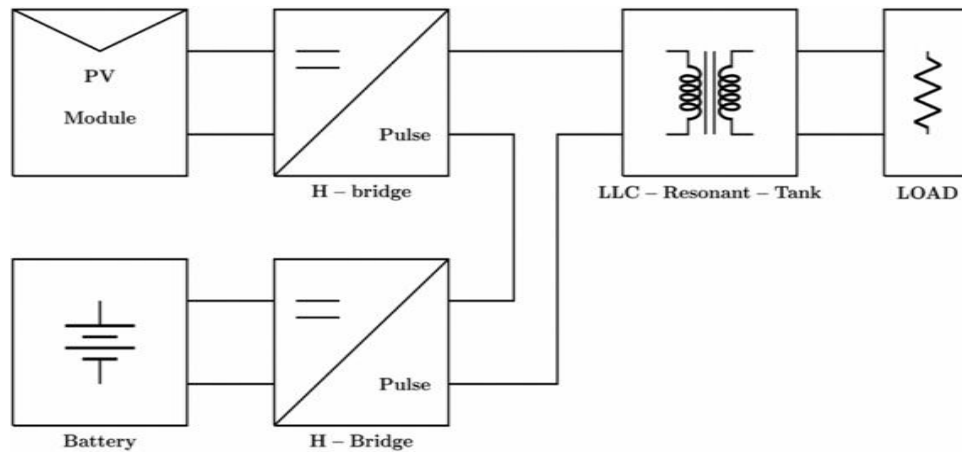


Figure 1: Proposed Block Diagram Highly Efficient LLC Resonant Dc/Dc Converter for Photovoltaic Battery System

2.1 PV Module

Solar power generation modules (PVs), commonly known as solar panels, are important components of solar energy systems, and convert sunlight into electrical energy through the solar power generation effect. Modules are usually made of silicon, which are connected in series and parallel configurations to create the desired output voltage and the desired current. When sunlight hits the surface of these cells, the energy electrons in the semiconductor material become excited and creates an electric current. The output of a single PV module is a direct current (DC), a voltage generated, and the current depends on environmental factors such as the module's sunlight intensity, temperature, and alignment.



Figure 2: PV Module

2.2 H – Bridge

An H-bridge is an electronic circuit configuration where the direction of current flow passes through the load. B. DC motor that allows for bidirectional operation. It consists of four switching devices, usually transistors or MOSFETs, arranged in a layout called "H." resemble. The cargo is placed in

the centre of H, and the four switches are placed in four corners. By selectively opening and closing the switch pair, the H-bridge enables electricity through loads in various directions. This allows you to control engine rotation both forward and backward. If the switch is closed properly, current flows the engine from one side (front) to one side, and if different switches close, current flows in the opposite direction (reverse). The H-bridge is used in conjunction with pulse width modulation (PWM) for engine speed control and plays an important role in DC - DC converters and inverters, especially systems such as photovoltaic and electric vehicles. H-bridge circuits are key to enabling accurate engine control, improving efficiency and ensuring smooth operation in a variety of electronic performance applications.

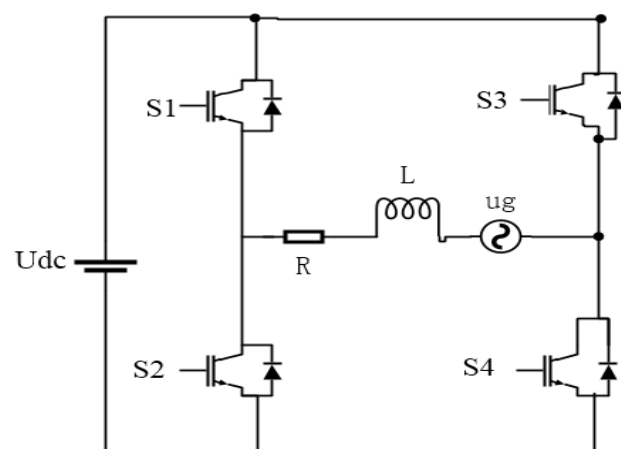


Figure 3: H – Bridge Circuit

2.3 LLC Resonant Tank

LLC resonance tanks are a critical component of resonance hiking, often used in power electronics,

especially in DC-DC converters, inverters and wireless power transmission systems. "LLC" stands for inductor inductor and refers to the combination of two inductors and a capacitor

made up of resonance groups. LLC resonance converters or tanks are particularly known for their ability to use soft switches. This reduces switching losses and increases overall efficiency.

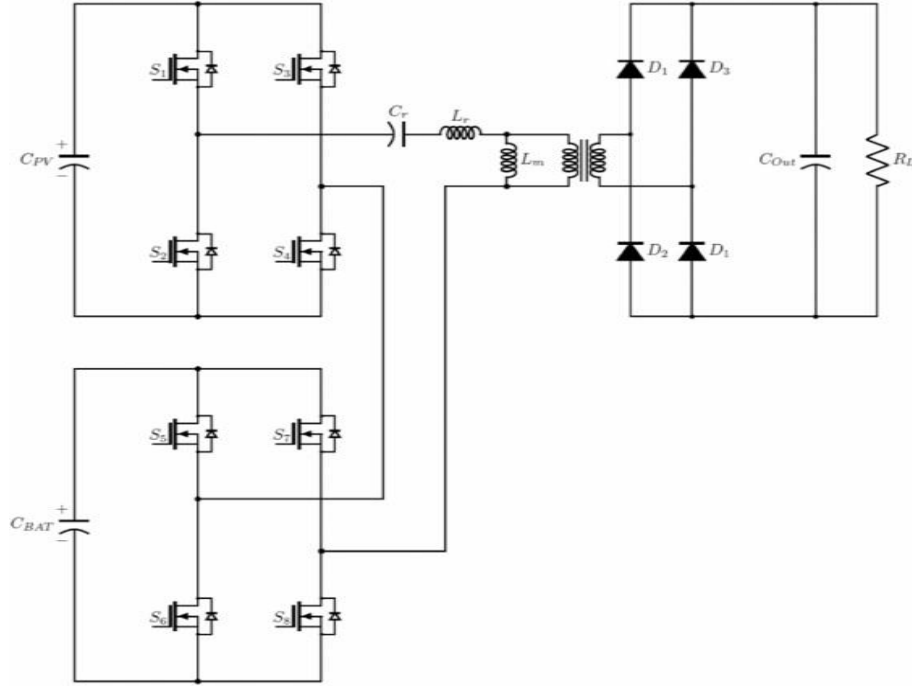


Figure 4: LLC Resonant Tank

LLC resonant tanks are particularly preferred in applications where high efficiency, reduced electromagnetic interference (EMI), and wide range of load adjustments are required.

2.4 Design Calculations

Output Voltage,

$$V_{out} = 400V, V_b=60V \quad (1)$$

V_b is the battery voltage and V_{out} is the output voltage.

Input Voltage,

$$V_{in} = V_b + V_{out} = 60 + 21.2 V_{max} = 81.2 \approx 85V \quad (2)$$

$$V_{in \max} = 21.2 \approx 20V \quad (3)$$

LLC primary and secondary turns ratio,

$$N_1 / N_2 = 24.2 / 400 = 8 / 132 \quad (4)$$

Maximum gain,

$$G_{max} = 24.2 / 20 = 1.21 \quad (5)$$

Minimum gain,

$$G_{min} = 24.2 / 85 = 0.281 \quad (6)$$

Reflected Load Resistance,

$$R_{ac} = (8 / \pi^2) (N_1 / N_2)^2 (V_{out} / P_{out})^2 \quad (7)$$

$$R_{ac} = (8 / \pi^2) (8 / 132)^2 (400 / 200)^2 = 0.2381 \quad (8)$$

Quality factor,

$$Q = \frac{\sqrt{L_r / C_r}}{R_{ac}} = \sqrt{L_r C_r} \quad (9)$$

$$Q = 0.325$$

$$L_r = 1.23e^{-7} \approx 120nH \quad (10)$$

$$C_r = 2.05e^{-5} \approx 220\mu F \quad (11)$$

Ratio of total primary inductance to resonant inductance,

$$M = (L_r + L_m) / L_r = 6.3 \quad (12)$$

$$L_m = 6.53e^{-7} = 640nH \approx 620nH \quad (13)$$

3. Result and Discussion

MATLAB stands for Matrix Laboratory. It is a

high- performance programming language and environment that is primarily used for numerical calculations, data analysis and algorithm development. MATLAB has powerful capabilities and data visualization for creating diagrams, making it easier to interpret and present results in 2D, 3D, and interactive formats. MATLAB is used to solve numerical problems such as equation solving, optimization, integration, and differentiation. MATLAB is based on the concept of matrices and arrays, making it particularly powerful to handle large data records and perform linear algebraic calculations.

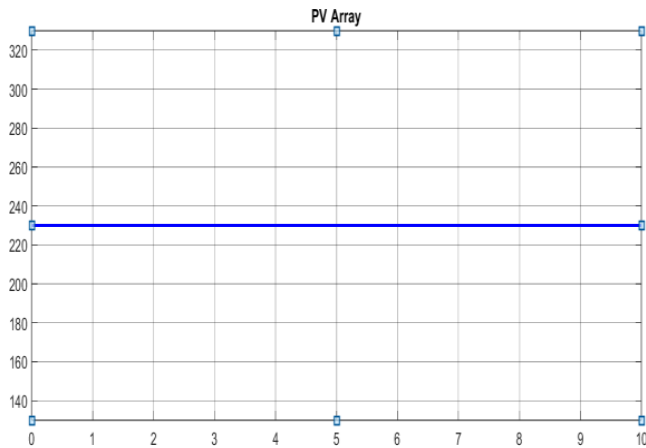


Figure 5: Voltage Measurement of PV Array

The simulation output of voltage measurements on a PV array provides the voltage values generated by the array under different conditions. It typically indicates open circuit voltage (VOC) and operating voltage (VMP) that reflect the performance of the system under different light intensities and temperatures.

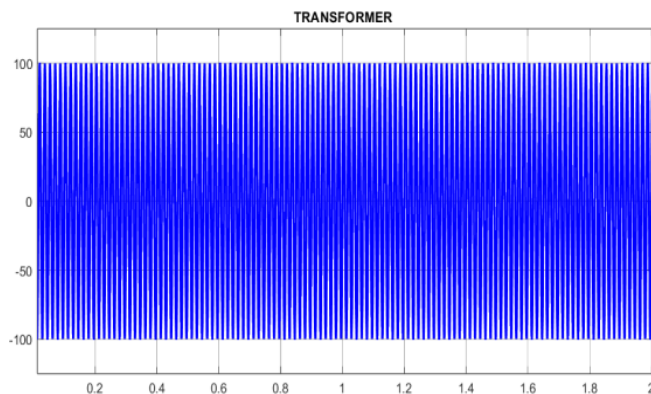


Figure 6: Voltage Measurement of Transformer

The simulation output for measuring transformer voltage shows primary and secondary tensions indicating voltage levels or strip damage based on the transformer exercise ratio. It shows how tension responds to various load conditions and highlights all voltage waste or variation. The output is used to assess the efficiency of the transformer and to ensure an appropriate voltage level.

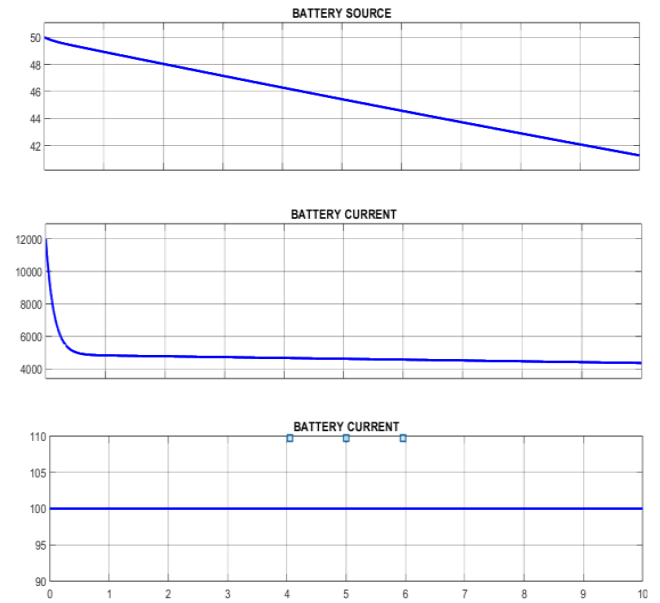


Figure 7: Waveform of Battery

The simulation output of the shape of the battery cell indicates voltage fluctuations over time during charging and unloading cycles. As the battery load state changes, the typical charging curve rises and the discharge curve drops, the voltage fluctuations are shown. The shape of the waves helps to analyze the power, efficiency, and health of the battery during operation.

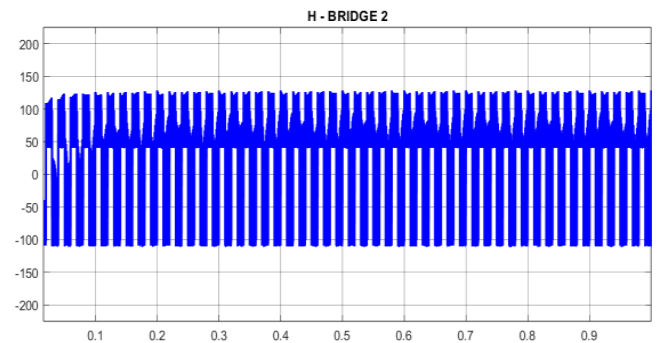


Figure 8: Voltage Measurement of H- Bridge

The simulated output of the voltage measurement of the H-bridge indicates the tension in the output connection and reflects the switching behaviour

of the transistors. When H-Bridge mode switches between forward, reverse, or brake modes, the changing voltage polarity will be displayed. This output helps to analyze the effective voltage applied to the load and efficiency of switching operations.

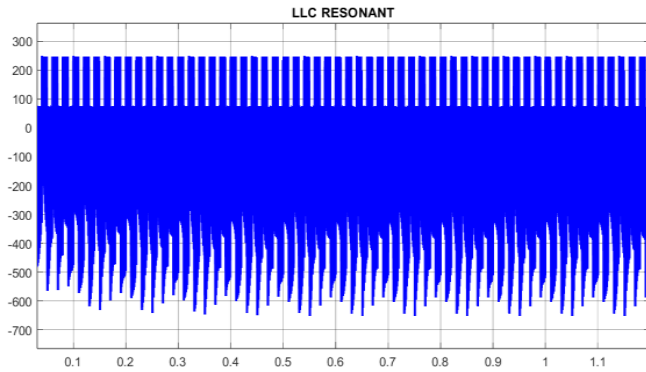


Figure 9: Voltage Measurement of LLC Resonant Converter

The simulated output of the voltage measurement of the LLC resonance converter shows the output voltage waveform and the regulated DC voltage after the resonance tank circuit. It shows steady-state stress responses under various load conditions and switching frequencies. This output helps to assess the voltage regulation, efficiency and dynamic performance of the converter.

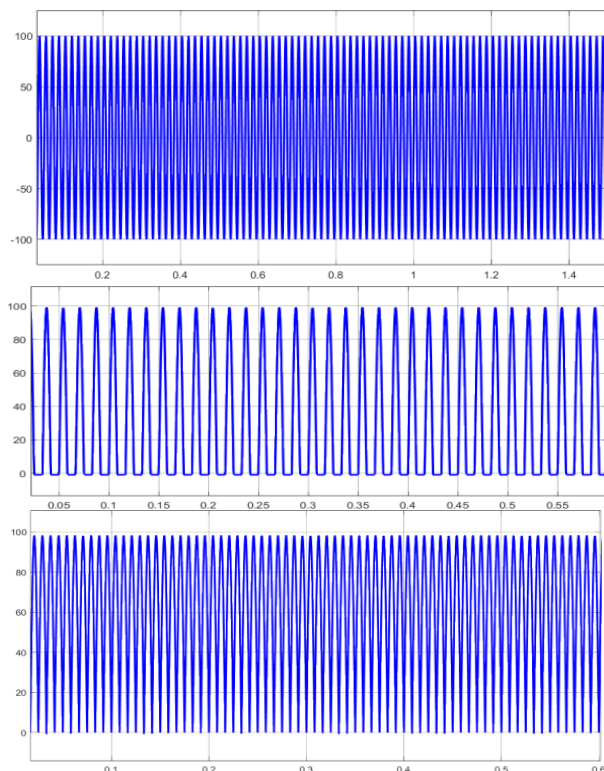


Figure 10: Waveforms of Diode Rectifier

The simulation output of the waveform of the diode judge shows a uniform output voltage, usually a pulsating DC signal. It shows how alternating current inputs are converted to unidirectional voltages and the smoothing effect is smoothed depending on the load and filter. Wave shapes help to assess the efficiency, waves and performance of the rectifier under different load conditions.

Table 1: Comparison

CONVERTER TYPE	LIGHT LOAD EFFICIENCY RANGE	FULL LOAD EFFICIENCY RANGE	TYPICAL EFFICIENCY RANGE
Boost Converter for PV Battery Systems	~90%	~85% to 90%	85% to 95%
Half-Bridge LLC Resonant DC-DC Converter for PV Battery Systems	~90% to 95%	~95% to 98%	90% to 98%
Full-Bridge (H-Bridge) LLC Resonant DC-DC Converter for PV Battery Systems	~90% to 95%	~96% to 98%	95% to 98%

4. Conclusion

The proposed high-efficiency LLC resonant DC/DC converter offers a robust solution for PV battery systems, providing several advantages in terms of energy efficiency, reliability, and scalability. The ability to efficiently convert power from photovoltaic panels and ensure proper charging of batteries will play a crucial role in maximizing the performance of solar energy systems. With ongoing developments in power electronics, the LLC resonant converter can become an integral component in the transition toward more sustainable and efficient renewable energy systems.

In summary, this proposed converter design is an excellent candidate for photovoltaic battery storage applications, offering improved efficiency, reduced losses, and optimal energy management. As renewable energy systems continue to grow, the role of such high-efficiency power converters will become even more critical in advancing the efficiency and reliability of energy storage solutions.

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