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ENHANCED MPPT ALGORITHM WITH MODIFIED LUO CONVERTER FOR OPERATION NEAR ZERO PARTIALITY

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Abstract: The growing demand for renewable energy has led to significant research into efficient energy conversion systems, particularly in photovoltaic (PV) applications. One key technique for optimizing power output in PV systems is Maximum Power Point Tracking (MPPT), which adjusts the system to operate at its peak efficiency despite varying environmental conditions. However, traditional MPPT algorithms face challenges in low light or partial shading situations, reducing their effectiveness. This paper proposes an enhanced MPPT algorithm integrated with a modified Luo converter designed to operate efficiently even under conditions of low partial shading. The system starts with a photovoltaic (PV) panel that captures solar energy, which is processed through an optimized artificial neural network (ANN), known as the Black Widow, for MPPT. The power from the PV panel is then directed into a modified Luo converter, which efficiently converts the voltage. A high-frequency inverter produces pulse-width modulation (PWM) signals to control power flow. To ensure safe energy transfer, an isolation transformer is used, and an interleaved synchronous rectifier improves efficiency in the rectification process. Additional PWM generation regulates the output, which is then balanced by a proportional-integral (PI) controller that matches the actual output voltage to a reference voltage. This novel approach enhances energy conversion, ensuring system reliability and stability while providing power to a DC bus or battery. The entire system is simulated in MATLAB 2021a to demonstrate its effectiveness for solar energy utilization.

Index Terms **- Maximum Power Point Tracking (MPPT); Artificial Neural Network (ANN); pulse-width modulation (PWM); LUO Converter; Photo Voltaic (PV)**

I. INTRODUCTION

Photovoltaic (PV) systems, which convert sunlight into electrical energy, are among the most widely used methods for generating renewable energy. The advantages of solar PV technology include being pollution-free during operation, helping to mitigate global warming, reducing operational costs, requiring minimal maintenance, and offering the highest power density when compared to other renewable energy sources. However, despite these numerous benefits, PV systems face certain challenges that can reduce their efficiency [1,2].

Common issues include damage from hail, accumulation of dust, and high surface temperatures. Several external environmental factors, such as wind speed, ambient temperature, relative humidity, dust accumulation, and solar radiation, influence the surface temperature of a PV module. For every 1°C increase in surface temperature, the efficiency of the PV module decreases by approximately 0.5%. As a result, not all the solar energy absorbed by the photovoltaic cells is converted into electricity, as part of it is lost as heat. This excess heat not only reduces the efficiency of the system but also contributes to energy wastage, as per the law of conservation of energy. To make PV technology a more viable alternative, efficiency improvements are essential, particularly in reducing the impact of temperature on performance.

Few studies have thoroughly reviewed the various cooling technologies that can help manage the surface temperature of solar panels. These cooling methods aim to enhance both thermal and electrical efficiency, thereby slowing down the degradation of cells and extending the lifespan of PV modules. Various techniques, including schematic diagrams, mathematical models, and images, have been developed to better understand and address this issue.

B. Sri Revathi et al. (2022) explored the adoption of solar photovoltaic (PV)-fed DC microgrids as a sustainable solution for powering diverse applications, particularly in off-grid and remote areas. These microgrids use PV panels as their primary energy source, directly converting solar energy into electricity to power DC loads or charge energy storage systems. The selection of converters is critical in managing power flow between PV panels, storage systems, and loads. Isolated and non-isolated DC-DC converters are commonly used to regulate voltage levels and ensure efficient energy transfer. The design of these systems requires optimizing the converter topology to manage variable solar input while ensuring stability and high efficiency. Testing of PV-fed

DC microgrids involves evaluating system performance under various load conditions, assessing the ability to handle fluctuations in solar irradiance, and ensuring the reliable integration of energy storage systems. While solar PV-fed microgrids offer significant environmental and operational benefits, challenges include high initial costs, efficiency losses due to converter operation, and the complexity of integrating various system components. Nonetheless, the integration of solar PV into DC microgrids is a promising approach to reducing carbon emissions and improving energy access [3].

Rodrigo Aliaga et al. (2022) applied the exact linearization technique for modeling and controlling DC/DC converters in rural PV microgrid applications, providing a precise approach to power flow management and system stability. Exact linearization transforms the nonlinear dynamics of DC/DC converters into a linear model, simplifying the control process and enabling more accurate voltage and current regulation. In rural PV microgrids, where power generation fluctuates due to varying sunlight, this technique ensures more stable and efficient energy distribution. It facilitates the integration of renewable energy sources and enhances microgrid performance by reducing energy losses and maintaining a consistent power supply to remote areas. However, this method requires complex mathematical modeling and may face implementation challenges, especially in systems with multiple interacting components [4].

Jingfeng Mao et al. (2022) introduced a multivariable coordinated nonlinear gain droop control for PV-battery hybrid DC microgrid systems, utilizing a Takagi-Sugeno (T-S) fuzzy decision approach. This innovative control strategy efficiently manages energy distribution complexities by integrating photovoltaic (PV) systems with battery storage. The nonlinear gain droop control adjusts output power based on voltage and current fluctuations, ensuring optimal load sharing among distributed energy resources. Using the T-S fuzzy decision framework, the system can accommodate uncertainties and operational variations, making real-time adjustments to sustain performance. This method improves the robustness and responsiveness of microgrids, especially in situations with fluctuating renewable energy supply. However, challenges remain in fine-tuning fuzzy logic parameters and ensuring seamless coordination among various energy sources [5].

Muhannad J. Alshareef et al. (2022) developed an Effective Falcon Optimization Algorithm (FOA)-based Maximum Power Point Tracking (MPPT) for photovoltaic systems under partial shading conditions. Partial shading causes multiple local maxima in the PV power-voltage characteristic curve, making it difficult for traditional MPPT methods to identify the global maximum power point. The Falcon Optimization Algorithm, inspired by falcon hunting behavior, provides a robust solution to this issue. FOA enhances MPPT performance by efficiently navigating complex solution spaces and avoiding local maxima, ensuring better identification of the true maximum power point in partial shading conditions. The main advantages of FOA-based MPPT include its ability to achieve higher energy yields and improve system performance under partial shading. However, it also introduces challenges, such as increased computational complexity and potentially longer convergence times, which may affect real-time applications [6].

Hicham Oufettoul et al [2023] proposed comparative performance analysis of PV module positions in a solar PV array under partial shading conditions indicate a strong interest in optimizing solar energy output. The varying module arrangements significantly affect energy production, with some configurations minimizing shading losses and improving overall efficiency. The importance of understanding shading patterns to maximize energy generation, leading to enhanced system performance and better return on investment. This method also facilitates informed decision-making regarding array design and allows for tailored solutions in diverse installation environments. Additionally, implementing advanced configurations increase initial costs and complicate the installation process, necessitating skilled labor. Maintenance may also become more challenging with irregular layouts [7].

Muhammad Majid Gulzar et al [2023] developed converter less solar PV control strategy for a grid-connected hybrid system that integrates photovoltaic (PV), wind, fuel cells, and battery energy storage reveal a growing interest in enhancing the efficiency and reliability of renewable energy systems. The reduced system complexity and lower costs due to the elimination of converters, which also lead to decreased maintenance requirements and improved overall efficiency. This control strategy allows for seamless integration of multiple energy sources, enhancing energy management and grid stability and eliminating converters simplifies the system design, making it easier to manage and operate. However, challenges persist, particularly regarding power quality control and the need for precise management of energy flows between components [8].

Objectives:

- To implement a MPPT algorithm with modified Luo converter for operation near zero partiality
- To enhance the efficiency of voltage conversion using a modified Luo converter, enabling more effective energy transfer.
- To improve safety and reliability in energy transfer via the use of an isolation transformer, while increasing rectification efficiency with an interleaved synchronous rectifier.
- To ultimately provide reliable and stable energy supply to a DC bus or battery system, ensuring the effective use of solar power.

II. CONVENTIONAL POWER CONVERTER SYSTEM

The integration of renewable energy sources, such as wind, photovoltaic (PV), and others, into the utility grid is essential for meeting the growing demand for electricity. Power electronic converters are vital components of renewable energy systems to ensure high efficiency. Among these, the partial power converter (PPC) stands out due to its exceptional efficiency and power density. The core concept behind the PPC is the use of two distinct power flow paths: "Direct power flow" and "Active power flow." In this system, only a small fraction of the input power is processed to control the machine, with the direct path bypassing most of the power. As a result, PPC minimizes active power loss, leading to overall improvements in power conversion efficiency. The photovoltaic (PV) system begins by converting sunlight into direct current (DC) electricity through solar panels. This generated power is then filtered and stabilized by capacitors, ensuring a smooth voltage output before entering the energy management circuitry. An auxiliary circuit, consisting of inductors and capacitors, plays a vital role in optimizing energy flow [2].

The system uses a series of switches to control the direction of the current, enabling energy storage in capacitors or batteries, or supplying power to the load as needed. This switching mechanism allows for different operational modes, such as storing excess energy during peak sunlight hours or providing power during low-generation periods. A transformer and its associated circuitry manage the voltage levels for efficient energy transfer. A central DC bus connects the PV output, storage units, and load, facilitating seamless energy distribution. A control system continuously monitors voltage and current levels, adjusting operations to optimize performance. By maximizing energy efficiency and minimizing losses, the system ensures stable operation under fluctuating conditions. This integrated approach effectively harnesses and utilizes solar energy, ensuring reliable power delivery to connected loads. The design emphasizes the importance of energy management to enhance the overall performance and reliability of solar power systems. Figure 1 shows Block diagram of conventional system.

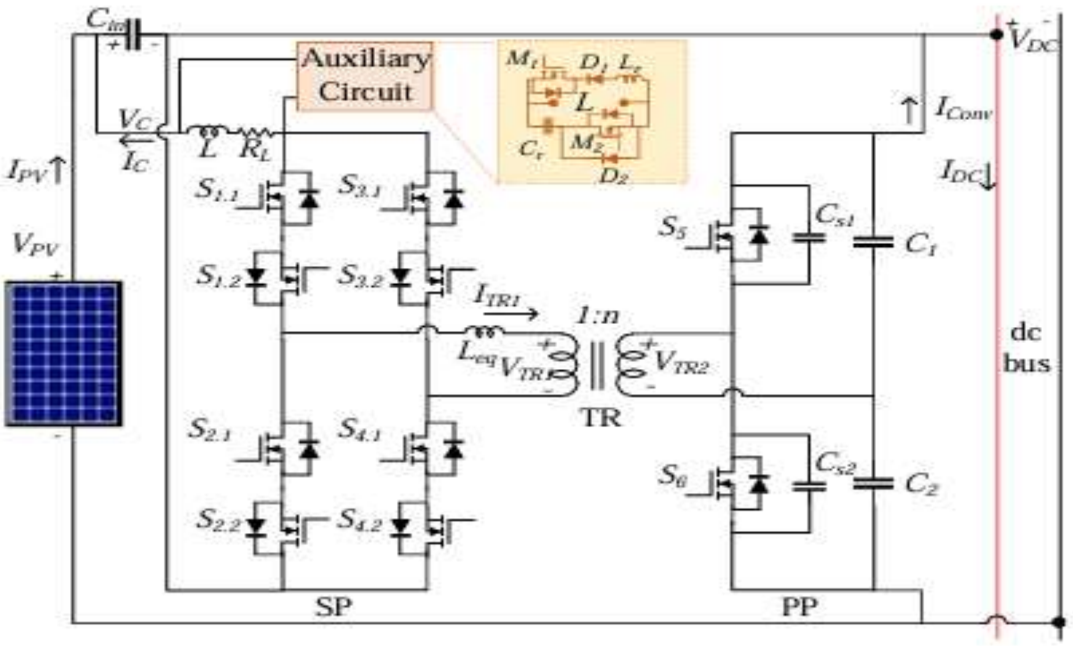

Figure 1. Block diagram of conventional system

III. PROPOSED MODIFIED LUO CONVERTER SYSTEM

In the current era, research on the utilization and exploitation of renewable energy sources has gained significant attention due to the escalating global greenhouse effect and environmental degradation. As a result, there has been a strong global push for the adoption of renewable energy, particularly in recent years. Photovoltaic (PV) power generation stands out due to its simple installation process, zero pollution, and low noise levels, all of which make it a less complex alternative compared to other Renewable Energy Sources (RES). However, PV arrays face challenges such as intermittent output and random fluctuations, with the Maximum Power Point (MPP) being influenced by variations in environmental conditions, such as ambient temperature (T) and irradiance (G) levels. This highlights the need for effective Maximum Power Point Tracking (MPPT) algorithms that can accurately determine the optimal operating conditions of PV systems while minimizing operational costs.

Traditional MPPT algorithms used in PV systems include methods such as Sliding Mode Control (SMC), Perturbation and Observation (P&O), Incremental Conductance (INC), as well as intelligent and meta-heuristic approaches. These algorithms are designed to perform well in fluctuating conditions by adjusting parameters in real-time, accurately tracking the MPP, and minimizing fluctuations. However, each technique comes with its limitations, such as complex tuning processes, slower response to rapid changes, intricate designs, and high computational demands.

In this proposed system shown in figure 2, a Modified Luo Converter is utilized in conjunction with an Enhanced Maximum Power Point Tracking (MPPT) Algorithm to operate effectively near zero partial shading conditions. The process begins with the Modified Luo Converter, which takes the input voltage (Vin) and adjusts it to an appropriate level for the subsequent stages. The output from the Luo Converter is then directed to a High-Frequency Inverter, where the DC input is converted into a high-frequency AC signal. This high-frequency AC signal is subsequently passed through a High-Frequency Isolation Transformer, which serves to electrically isolate the high-frequency AC signal from the rest of the system. This isolation ensures safe operation and helps maintain system integrity by minimizing the impact of any faults or disturbances in the AC circuit. This setup aims to improve efficiency and performance, particularly in scenarios with low or partial solar irradiation, optimizing the system's power extraction even in challenging environmental conditions.

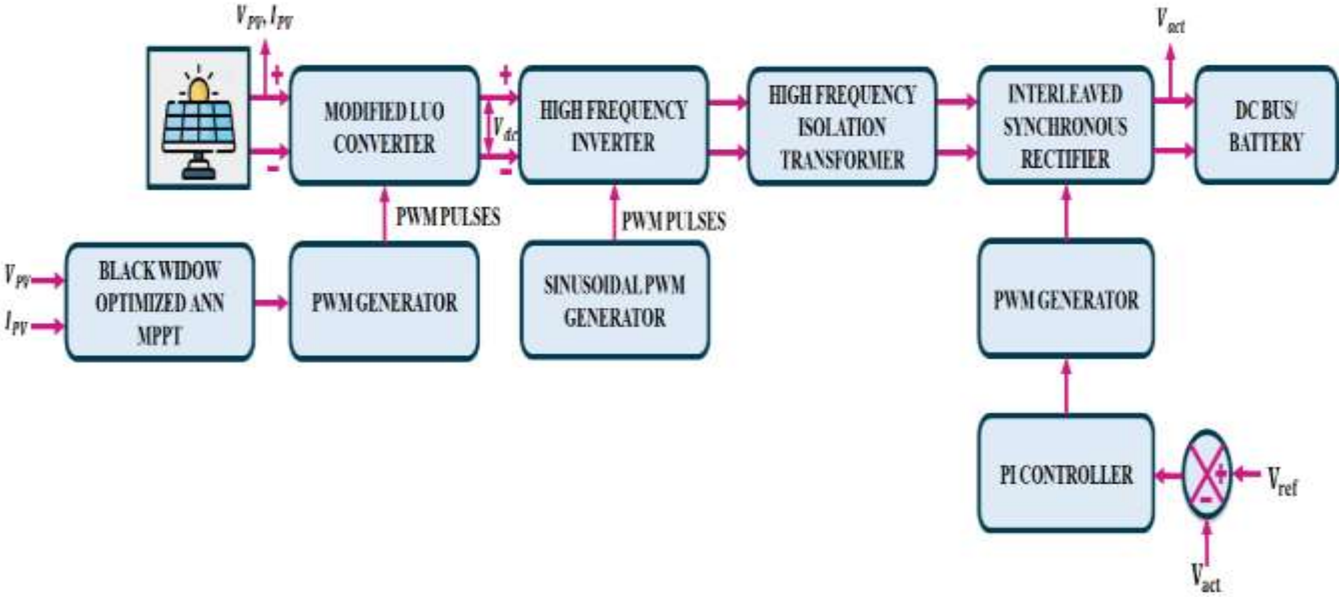

Figure 2. Block diagram of Proposed Modified Luo Converter based system

A. PV System

One dependable and eco-friendly energy source is the sun. Utilize solar energy directly and use photovoltaic power generation to create electricity. Photovoltaics (PV), which use the photovoltaic effect to turn sunlight into electricity, is one of the primary methods of exploiting solar energy. The solar cell is the fundamental component of photovoltaic modules, which use the photovoltaic effect to convert light energy into electrical power. The physical application of the solar cells and the technique used to install them in the module determine a photovoltaic module's efficiency. The efficiency of solar modules to convert sunlight into electricity is around 12-29%.

The maximum efficiency of gallium arsenide solar cells is 29%, while the efficiency of silicon solar cells is between 12-14%. The efficiency of a photovoltaic module can also decrease depending on the temperature of the photovoltaic module. Therefore, in order to improve the power production of photovoltaic modules, it is very important to operate the module at the best power point. A controller known as a maximum power point tracker is needed to accomplish this. Various materials are used to make photovoltaic cells. At the moment, monocrystalline and polycrystalline silicon are widely used silicon technologies. Many solar cells must be connected in series to provide the required output voltage because current solar cells have power levels of less than 2W, or nearly 0.5V. The panels are arranged in an array as a result. The connection between the arrays produces a high output voltage.

During this process, if the photovoltaic cell is not exposed to sunlight, it will act as a p-n junction diode. When solar radiation falls on the photovoltaic cell due to the interaction of the incoming photons with the cell atoms, an electron hole is formed. The electric current generated by the cell separates the photo generated electron-hole pair and the electrons and holes drift towards the n-region and p-region of the cell. The photocurrent is caused by this movement and is mostly determined by the wavelength and intensity of the solar radiation. As previously stated, the photovoltaic cell will function as a p-n junction diode if it is not exposed to sunlight. The solar cell in this instance doesn't generate any voltage or current. On the other hand, an I_D current known as dark current is produced when the battery is linked to an external power source that is higher than the battery voltage [9]. The equivalent circuit of PV system is shown in figure 3.

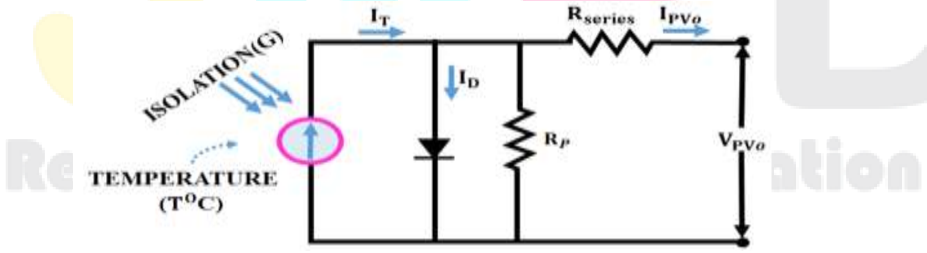

Figure 3 Equivalent diagram of PV system

The mathematical expression for output current is,

$$I_{PV0} = I_T - I_{sat} \times \left[e^{\frac{Q(V_{PV0} + I_{PV0} \times R_{series})}{\eta K_B T_P}} \right] \qquad (1)$$

Here, V_{PV0} specifies output of PV module, I_{PV0} indicates output of PV current, I_{sat} denotes reverse saturation diode, I_T is the photon current, R_{series} refers resistance in series, T_P is the operating panel temperature, Q is the charge of electron and K_B shows boltzman constant correspondingly.

B. Modified Luo Converter

The modified Luo converter plays a crucial role in the enhanced MPPT algorithm for photovoltaic (PV) systems by efficiently converting the variable DC output from the PV panels into a regulated output, suitable for load or grid applications shown in figure

4. Its unique design allows it to step-up or step-down the voltage, ensuring stable power delivery even under fluctuating sunlight conditions. In the context of the enhanced MPPT algorithm, the converter adjusts its duty cycle in response to the tracking signals, which ensures maximum power point tracking with minimal delay. The modified Luo converter's high efficiency, low switching losses, and reduced ripple further contribute to smoother power conversion. Its design also accommodates near-zero partiality, where some PV panels experience partial shading or non-uniform illumination. By maintaining stable operation and optimizing energy transfer even in suboptimal conditions, the modified Luo converter ensures that the PV system continues to extract the maximum possible power, reducing energy losses and improving overall system efficiency. This combination enhances performance in real-world scenarios with variable environmental factors [10].

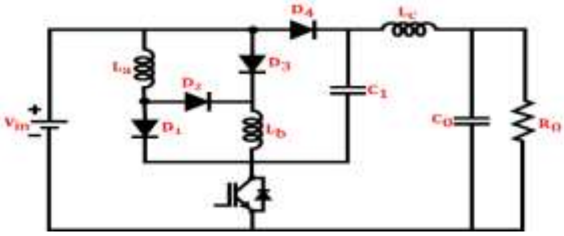

Figure 4 Circuit diagram of proposed Modified Luo converter

C. High Frequency Inverter

A high-frequency inverter is an essential device that converts direct current (DC) into alternating current (AC) at a much higher frequency than conventional inverters. This technology offers several advantages, including increased efficiency, smaller size, and lighter weight, making it ideal for various applications such as renewable energy systems, electric vehicles, and portable power supplies. The high-frequency operation reduces the size of the transformer and other components, which leads to significant space and cost savings. Additionally, these inverters often feature advanced control systems that enhance performance and reliability, enabling smooth operation even under varying loads.

IV. RESULTS AND DISCUSSIONS

The simulation results were analysed using the program called MATLAB/SIMULINK. MATLAB is a language that can be used to calculate, visualize and compute in the user environment, where the problem and its solution are expressed using the information method. MATLAB is the best tool for signal analysis. The overall simulation diagram is shown in figure 5.

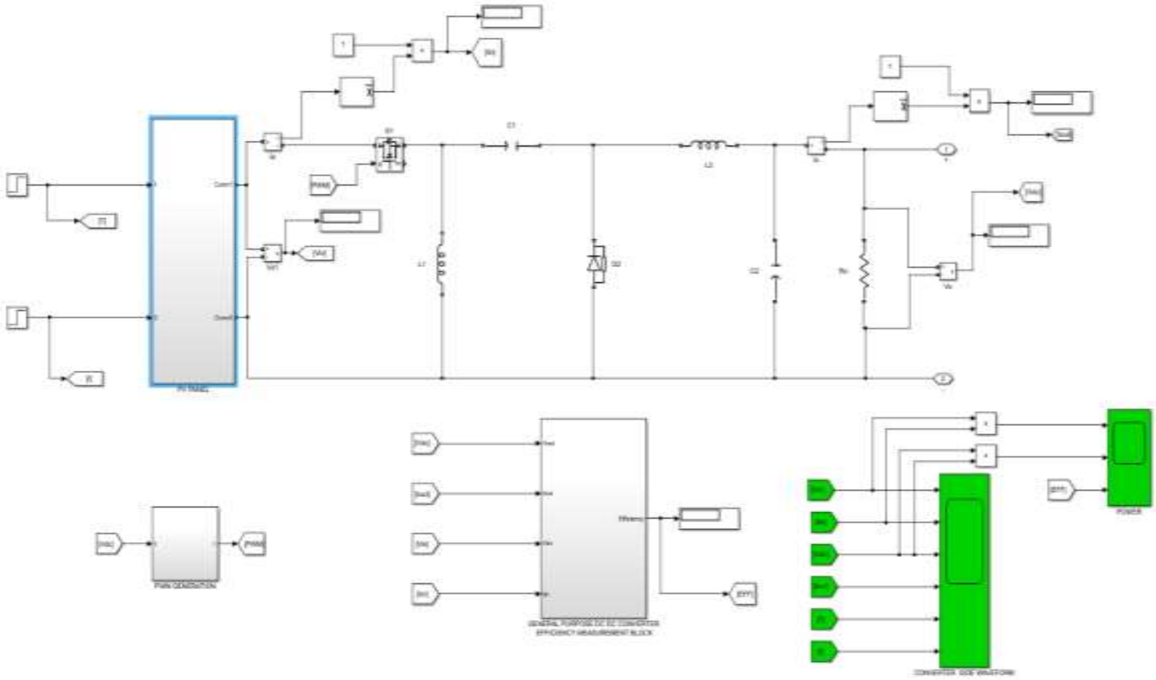

Figure 5. Overall Simulation Diagram

Figure 6 represents solar temperature and intensity waveforms showcase the dynamic nature of solar energy input, while the solar panel voltage waveform reflects the power generation capabilities of the solar panel. The modified LUO converter input current waveform demonstrates the efficient power conversion process. These waveforms collectively indicate the performance and optimization opportunities in the solar system, and analyzing them can help in designing and optimizing the solar energy system for improved efficiency and reliability.

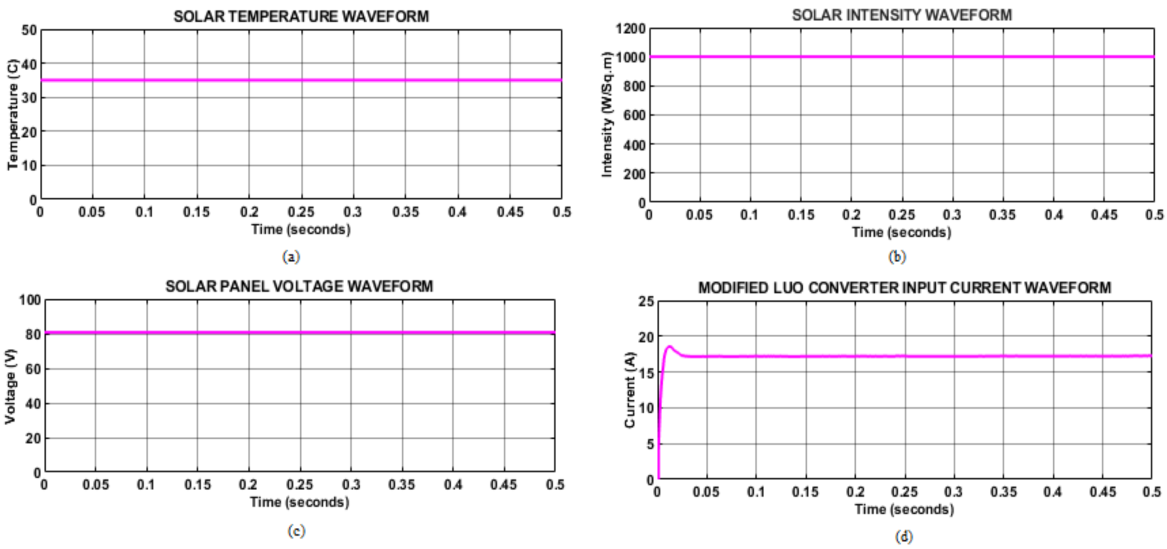

Figure 6 Solar panel Waveforms

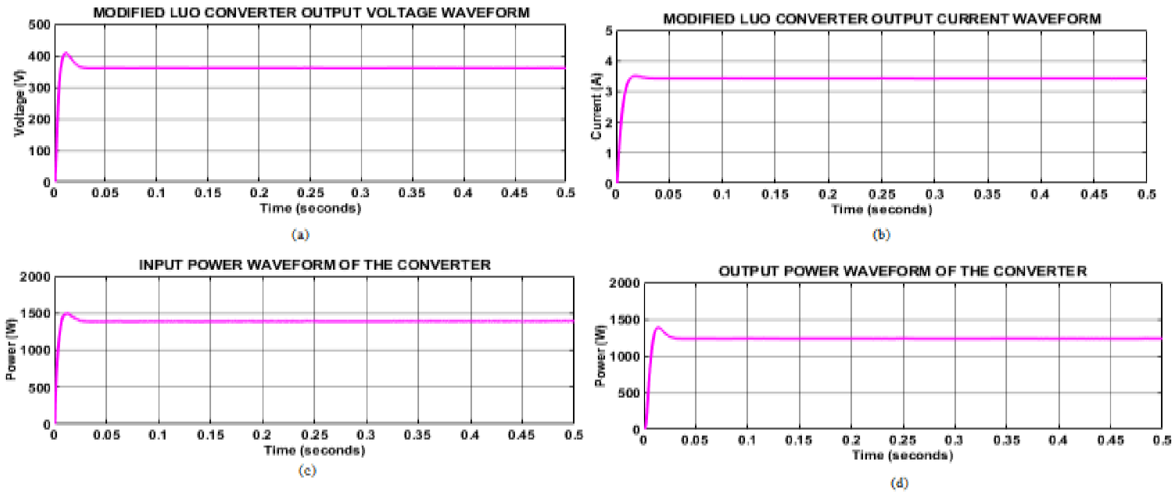

Figure 7 Proposed Modified Luo converter waveforms

Figure 7 illustrate the performance characteristics of a modified LUO converter used in a solar energy system. The output voltage and current waveforms (a and b) demonstrate the converter's ability to efficiently regulate the power generated by the solar panel, as shown in the input power and output power waveforms (c and d). These waveforms collectively indicate the effectiveness of the converter in converting and conditioning the solar energy, which is crucial for optimizing the overall system performance and ensuring reliable power delivery.

V. CONCLUSION

This paper effectively showcases the efficiency of an enhanced MPPT algorithm integrated with a modified Luo converter, specifically designed for near-zero partial shading conditions in solar energy systems. By incorporating a Black Widow-optimized artificial neural network (ANN), the system achieves precise and rapid tracking of the maximum power point, significantly enhancing energy extraction under fluctuating environmental conditions. The modified Luo converter ensures efficient voltage regulation, which is crucial for maintaining optimal performance. A high-frequency inverter generates PWM signals to facilitate effective power flow control, maximizing the utilization of energy harvested from PV panels. Additionally, the integration of an isolation transformer enhances safety during energy transfer, while the interleaved synchronous rectifier minimizes losses during the rectification process. The system also features additional PWM generation and a PI controller, which work together to maintain voltage stability, allowing for dynamic adaptation to variations in power generation and load demand. This innovative approach not only improves energy conversion efficiency but also ensures a reliable and stable power supply to a DC bus or battery system. The results obtained from the MATLAB 2021a simulation validate the proposed system's performance, demonstrating its potential for efficient solar energy utilization.

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