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OPTIMIZING PV ENERGY EFFICIENCY WITH RE-LIFT LUO CONVERTER AND ANN-BASED CONTROL SYSTEMS

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ABSTRACT

The rising demand for renewable energy has increased interest in photovoltaic (PV) systems as a sustainable alternative to fossil fuel-based power generation. However, the inherent variability and intermittency of PV voltage output present challenges in effective energy management. To address these issues, this project proposes an optimized Proportional-Integral (PI) control strategy combined with a Re-lift Luo converter for enhanced energy efficiency.The system is designed to seamlessly integrate renewable energy sources into the grid while maintaining stable operation. The PV system generates DC voltage, which is boosted by the Re-lift Luo converter. A Firefly algorithm is employed to optimize the PI controller, ensuring precise control of the converter's output voltage. Additionally, a bidirectional DC-DC converter is incorporated to connect a battery for energy storage and load balancing. The DC voltage from both the PV system and the battery is supplied to a DC bus, which then feeds a three-phase voltage source inverter (VSI). The VSI converts the DC supply into AC, which is subsequently filtered by an LC filter before being delivered to the three-phase AC grid.This integrated system ensures efficient energy management, grid stability, and optimal utilization of renewable energy. Finally, the proposed system is validated through MATLAB simulation (version 2021a) to assess its performance.

Keywords: grid, luo converter, battery, pv

I. INTRODUCTION

With the growing emphasis on energy conservation and the rapid expansion of renewable energy sources, the energy sector is witnessing significant advancements in green technology. Among the most widely used environmental technologies today are wind turbines and photovoltaic (PV) systems. From a perspective of reliability and sustainability, photovoltaic energy generation stands out due to its low cost, minimal maintenance requirements, and high compatibility, making it an ideal choice. However, variations in operating conditions such as temperature, sunlight, partial shading, and humidity can significantly impact the stability and energy output of photovoltaic power plants, thereby affecting the security of grid connections.Energy storage systems (ESS) are implemented in microgrids to ensure continuous energy availability from intermittent sources like photovoltaics. These systems help mitigate fluctuations in energy generation and consumption, thereby improving the quality and stability of electricity supply. Among various energy storage solutions, batteries are the most popular due to their ease of use. However, they possess large capacity with relatively low power output, resulting in higher costs per unit of power. Conversely, supercapacitors offer smaller capacity but excel in high charge/discharge rates and energy density.

To leverage the advantages of both technologies, hybrid energy storage systems (HESS) integrate batteries and supercapacitors. In such systems, instantaneous battery currents are distributed to the supercapacitors, effectively extending battery life. A unidirectional DC/DC converter is employed to manage power output from the photovoltaic array, while a bidirectional converter regulates the charge and discharge cycles of the battery pack, ensuring a seamless connection to the DC bus. The DC load receives AC power via the Point of Common Coupling (PCC), which links the DC bus to the AC load. Additionally, transformers step up the AC voltage before integrating it with the utility grid. Depending on system requirements, the photovoltaic generator can operate in either grid-connected or island mode by switching the circuit breaker at the PCC. For instance, in the event of a major fault on the AC bus, the circuit breaker disconnects to prevent reverse current flow into the grid.

Shaik Rafi Kiran et al. (2022) proposed MPPT techniques for partially shaded solar PV systems, emphasizing Artificial Neural Network (ANN)-based approaches to enhance performance under variable conditions. A key advantage of ANN-based MPPT technology is its ability to continuously learn and instantly predict the optimal operating point of a PV system. This is particularly important in environments where shading creates multiple local maxima in the power-voltage curve. ANN-based methods outperform traditional MPPT techniques, such as perturb-and-observe or incremental conductance, especially under dynamic shading conditions. Additionally, ANNs can efficiently process complex input data, including temperature, irradiance, and past performance metrics, allowing for a more adaptive response to environmental changes. However, the training process requires substantial data, which can be a challenge in regions with fluctuating weather conditions. Moreover, the initial setup and computational demands for real-time processing may introduce response delays, potentially leading to energy losses during rapid shading fluctuations.Ahmet Gundogdu et al. (2022) introduced the System Identification-Based ARV-MPPT technique to optimize PV systems under variable atmospheric conditions. This method leverages system identification techniques to develop a precise dynamic model of the PV system, enabling accurate MPP prediction even under rapidly changing external conditions. A primary advantage of the ARV-MPPT technique is its adaptive and robust control strategy, which enhances energy harvesting efficiency compared to conventional methods like perturb-and-observe. Additionally, by incorporating real-time atmospheric data, the technique improves MPP prediction accuracy. However, developing a reliable system identification model requires significant computational resources and expertise, making implementation challenging, particularly for smaller systems. Furthermore, the effectiveness of the ARV-MPPT approach depends on the accuracy of atmospheric data; any measurement errors can result in suboptimal tracking performance.Noor Zanib et al. (2022) analyzed renewable energy-based distributed generation systems using an ANN-tuned Unified Power Quality Conditioner (UPQC). This approach enhances power quality by optimizing UPQC control strategies through ANN, enabling real-time voltage regulation, harmonic suppression, and power factor management. The integration of renewable sources, such as solar or wind energy, promotes sustainability and reduces reliance on fossil fuels. Additionally, the adaptive capabilities of ANN ensure efficient energy distribution under varying conditions. However, the complexity of training the ANN poses challenges, as it requires extensive computational resources and incurs high implementation costs. Furthermore, the inherent variability of renewable energy generation complicates system management, and the high initial investment in infrastructure may limit adoption, especially in resource-constrained regions.

II. EXISTING SYSTEM

The integration of renewable energy sources (RES) is a key component of the future power grid. DC microgrids are gaining popularity due to their efficiency in incorporating large amounts of renewable energy and transferring it to the AC grid. A cluster of DC microgrids enhances system quality, flexibility, efficiency, and cost-effectiveness. Unlike AC grids, DC microgrids are free from issues such as synchronization and harmonics, making them ideal for integrating renewable sources like photovoltaics (PV), wind energy, and fuel cells across various voltage levels.Among these renewable sources, photovoltaic (PV) systems offer significant advantages due to the abundance of solar energy. The declining costs of PV technology have further accelerated its adoption in power grids. However, the energy output of PV systems is highly sensitive to fluctuations in solar radiation, temperature, and other environmental factors. To address these variations and ensure a stable power supply,

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battery energy storage systems (BESS) are often used in conjunction with PV systems. As renewable energy penetration increases and consumer demand grows, efficient power management becomes crucial for the operation of DC microgrids.

III. PROPOSED CONVERTER

The growing demand for renewable energy has positioned photovoltaic (PV) systems at the forefront of sustainable power solutions. However, optimizing photovoltaic energy conversion remains a challenge due to the inherent limitations of traditional power electronics and control strategies. Recent technological advancements have introduced innovative solutions aimed at enhancing PV system performance. Among these, the Re-Lift Luo Converter stands out as a promising topology, offering high voltage gain, reduced component count, and improved operational stability—key attributes for maximizing energy extraction in PV applications.In parallel, the integration of Artificial Neural Networks (ANNs) into control systems has emerged as a transformative approach to optimizing PV energy output. ANNs can learn complex patterns and adapt to dynamic environmental conditions, enabling real-time adjustments to operating parameters. By leveraging ANN-based control strategies, PV systems can achieve more precise maximum power point tracking (MPPT), significantly improving overall energy yield.The combination of the Re-Lift Luo Converter and ANN-based control represents a major advancement in renewable energy technology. This synergy not only enhances energy conversion efficiency but also supports broader sustainability goals and energy independence. As global energy demands rise and the urgency for sustainable practices intensifies, integrating these advanced systems can accelerate the transition to renewable energy while reducing the economic costs associated with solar power generation. Ultimately, these innovations will contribute to more resilient and efficient energy infrastructures, paving the way for a cleaner and more sustainable future.

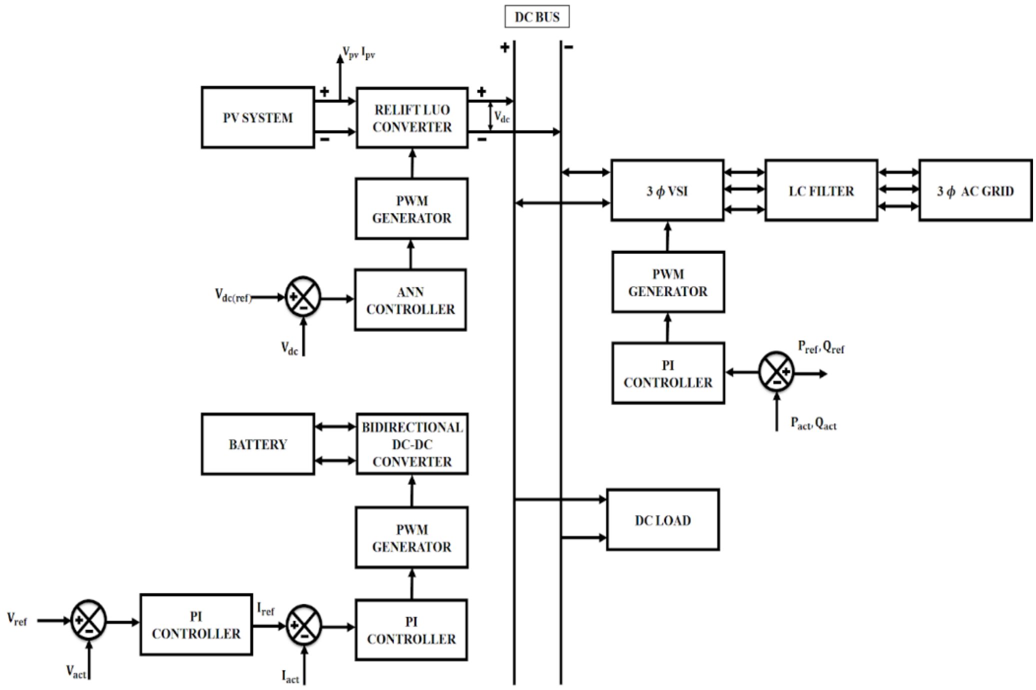

Figure 1. Block Diagram of Proposed converter

This paper aims to improve the efficiency of photovoltaic (PV) systems by integrating a Re-Lift Luo converter with an Artificial Neural Network (ANN)-based control system. The PV system efficiently captures solar energy, which is then optimized using the high-gain Re-Lift Luo converter. This converter ensures stable and efficient DC voltage boosting while

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minimizing ripple and power losses. A Pulse Width Modulation (PWM) generator regulates the converter's switching operation, further enhancing system performance.The boosted DC power is subsequently converted to AC using a three-phase Voltage Source Inverter (VSI), making the system suitable for grid-connected applications and AC loads. An LC filter is incorporated to minimize harmonic distortion, ensuring a smooth and clean power output. The ANN controller dynamically adjusts system parameters in real time, optimizing energy conversion and system performance under varying environmental and load conditions. Additionally, the system includes battery storage and a DC load, allowing excess energy to be stored and supplied as needed. To maintain voltage stability and regulation under different load conditions, a Proportional-Integral (PI) controller is implemented.By combining the high efficiency of the Re-Lift Luo converter with intelligent ANN-based control, this system aims to maximize PV energy utilization, enhance reliability, and provide a robust and sustainable solution for renewable energy applications.

RESULTS AND DISCUSSIONS:

Integrating a Re-Lift Luo converter with an ANN-based control system provides a promising approach to improving the efficiency of photovoltaic (PV) energy systems. The Re-Lift Luo converter effectively increases voltage gain and ensures efficient power conversion, even in fluctuating sunlight conditions. Meanwhile, the ANN-based control system enables dynamic and precise Maximum Power Point Tracking (MPPT). This combination enhances energy harvesting, minimizes losses, and ensures optimal performance in various operational conditions. Ultimately, this approach leads to more efficient, reliable, and sustainable PV energy systems, supporting the wider adoption of renewable energy technologies.

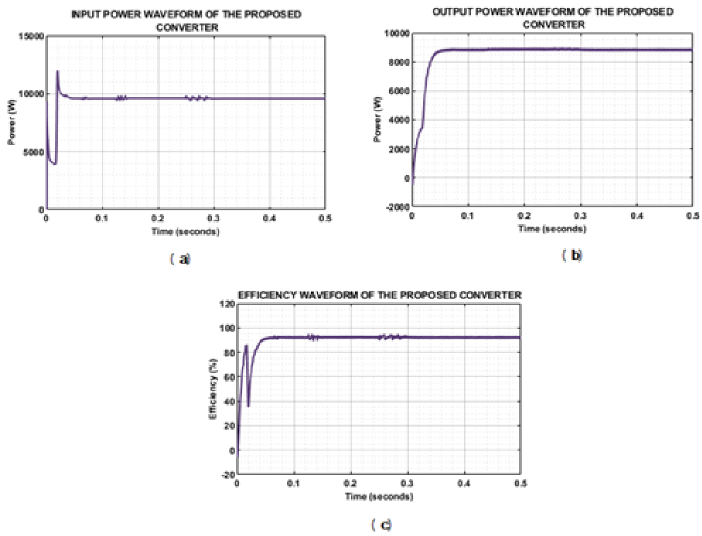

Figure 2. Input and Output power waveform and efficiency of the proposed converter

Figure 2. shows the performance of the proposed converter. Figure (a) displays the input power waveform, initially fluctuating before stabilizing. Figure (b) illustrates the output power, which quickly reaches a steady state. Figure (c) presents the efficiency waveform, demonstrating consistent efficiency after initial adjustments, highlighting the converter's effectiveness.

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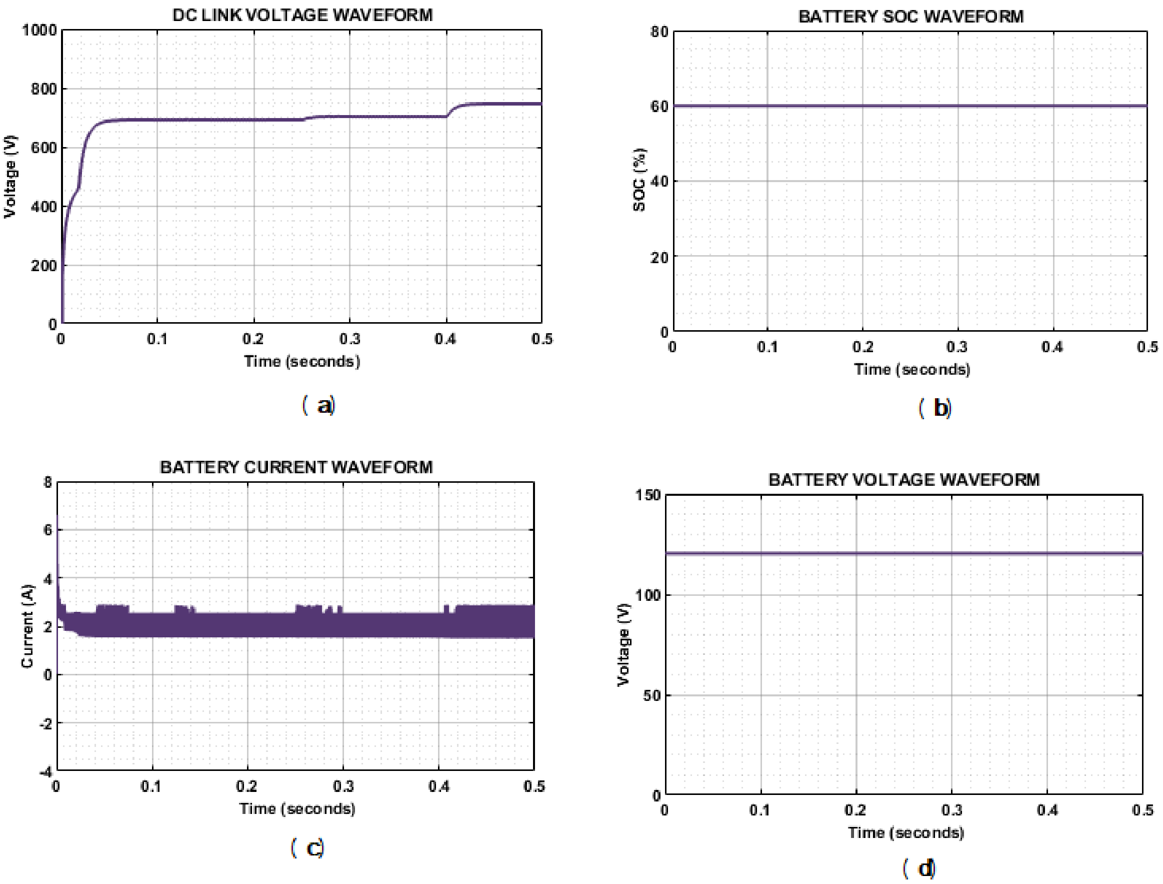

Figure 3. DC-Link voltage waveform and Battery (b) SOC (c) current and (d) voltage waveform

Figure3. illustrate the performance of a battery management system. Figure (a) displays a stable DC link voltage, essential for consistent operation. Figure (b) shows the state of charge (SOC) remaining constant. Figures (c) and (d) indicate minimal battery current fluctuations and stable battery voltage, reflecting efficient energy management.

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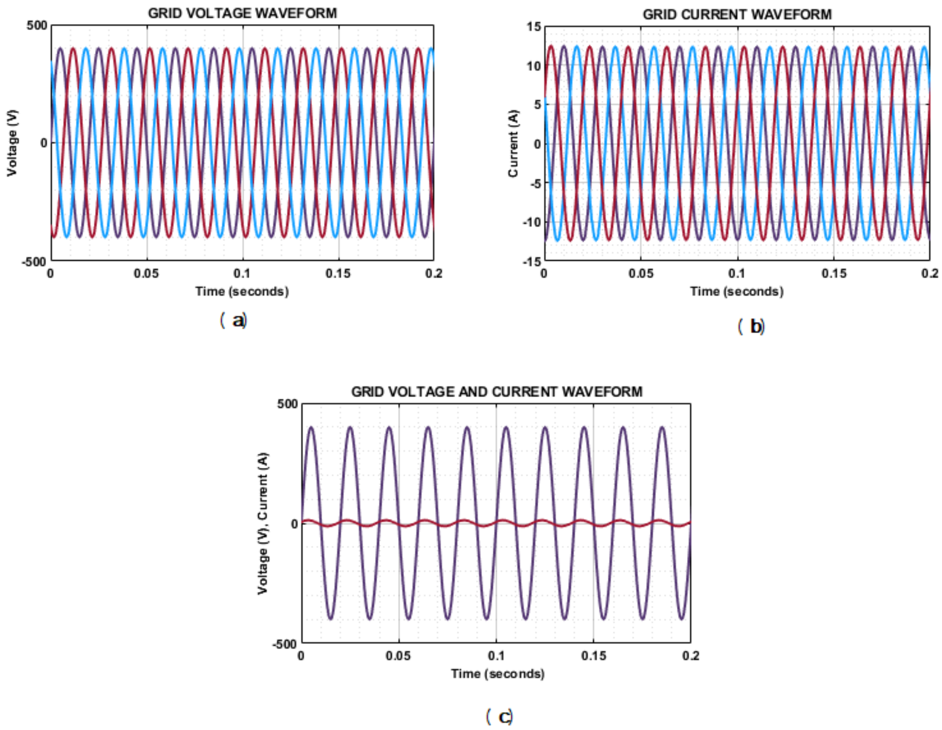

Figure 4. Grid current and voltage waveform

Figure 4. depict the behavior of grid voltage and current. Figure (a) shows the voltage waveform, characterized by its sinusoidal nature. Figure (b) presents the grid current, also sinusoidal but with phase differences. Figure (c) overlays both waveforms, illustrating their relationship, critical for understanding power quality and system performance.

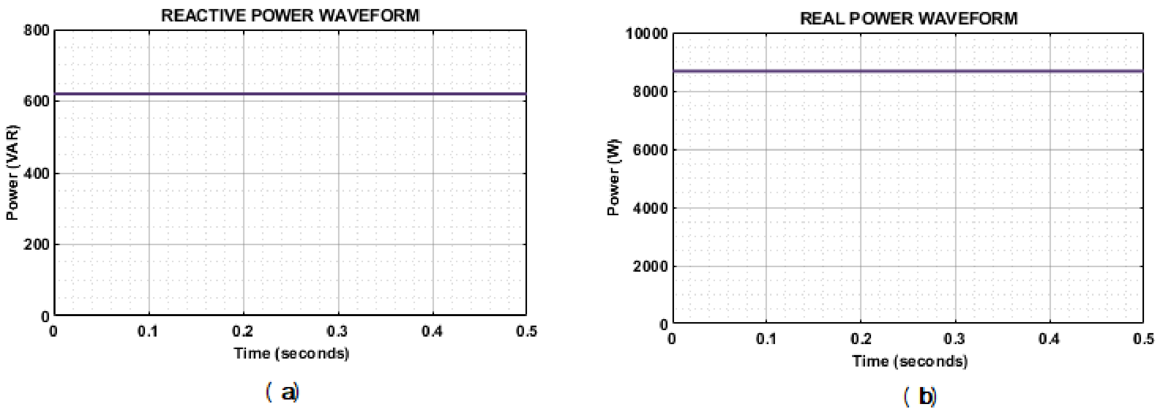

Figure 5. Reactive and Real power waveform

Figure 5. illustrate the behavior of reactive and real power. Figure (a) shows a constant reactive power waveform, indicating no energy consumption but essential for maintaining voltage levels in AC systems. Figure (b) depicts real power, which remains steady, reflecting actual energy used by the load for productive work.

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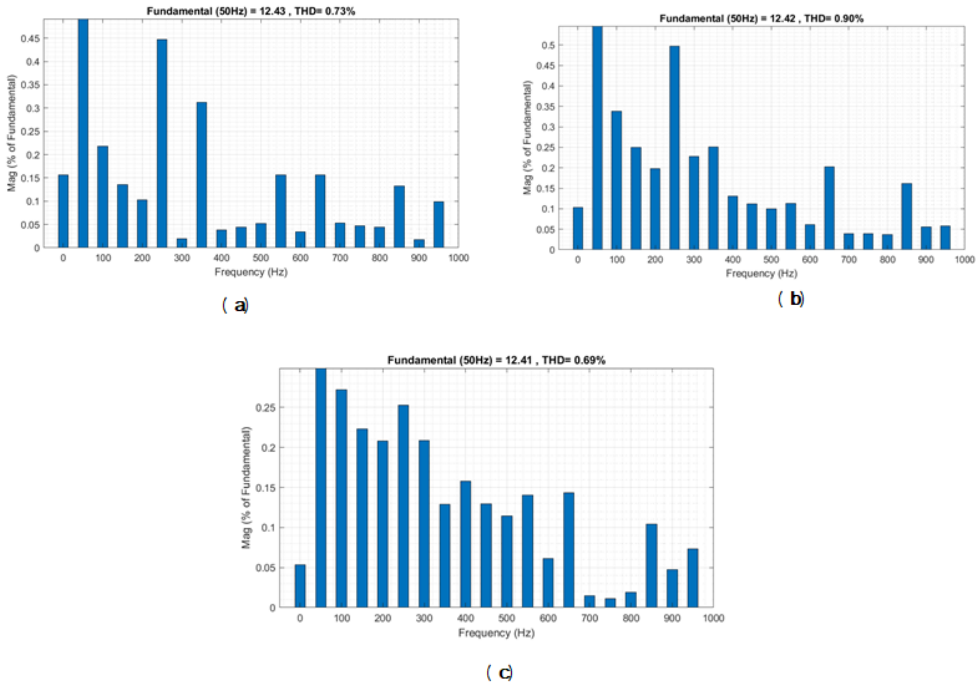

Figure 6.THD waveform

Figure 6. analyze harmonic content in a signal. Figure (a) shows the fundamental frequency at 12.4 Hz with low total harmonic distortion (THD) of 0.37%. Figure (b) highlights the increased THD of 8.95% at the 96 Hz harmonic, while Figure (c) presents a broader frequency spectrum, indicating varying harmonic contributions.

CONCLUSION

The integration of a Re-Lift Luo converter with an ANN-based control system offers a promising solution for enhancing the efficiency of photovoltaic (PV) energy systems. The Re-Lift Luo converter effectively boosts voltage gain and ensures efficient power conversion, even under fluctuating sunlight conditions, while the ANN-based control system enables dynamic and accurate Maximum Power Point Tracking (MPPT). This combination improves energy harvesting, reduces losses, and ensures optimal performance across varying operational scenarios. Overall, this approach contributes to more efficient, reliable, and sustainable PV energy systems, supporting the broader adoption of renewable energy technologies.

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