**“IoT-Based Solar Power Monitoring and Optimization System for Industrial Applications”**

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**ABSTRACT**

This study introduces an IoT-enabled solar monitoring and optimization system tailored for industrial applications, aimed at improving the efficiency and reliability of solar photovoltaic (PV) systems in response to fluctuating environmental conditions. Utilizing an ATmega328 microcontroller, ESP32 Wi-Fi module, and super-capacitors, the system performs real-time monitoring of voltage, current, and light intensity, with data displayed locally and transmitted to the cloud via Thing Speak. Super-capacitors provide short-term energy storage to stabilize output during power drops, while a relay-based mechanism ensures seamless power switching. The system offers a cost-effective, scalable solution for improving solar energy self-consumption and reducing grid dependence.

**Keywords:** IoT-based Solar PV Systems with Super-Capacitors enable Real-Time Monitoring, Light Intensity Tracking, and Relay-Controlled Load Management using Thing Speak API, MPPT (P&O) Algorithm, and Smart Energy Storage, Data Logging, Renewable Energy, Hybrid Energy Storage, Industrial Solar Monitoring.

**1. INTRODUCTION**

As industries shift toward sustainable energy solutions, solar photovoltaic (PV) systems have become essential for clean power generation. To maximize their efficiency and reliability, especially in variable environmental conditions, intelligent monitoring systems are crucial. This project introduces an IoT-based solar monitoring and optimization system designed for industrial applications. By integrating super-capacitors for energy buffering and leveraging real-time data acquisition via ATmega328 and ESP32 modules, the system ensures stable power output, remote monitoring, and improved solar energy utilization.

**2. HYBRID STORAGE SYSTEM**

Glavin et al. (2008) proposed a stand-alone hybrid energy storage system combining photovoltaic modules with super-capacitors and batteries​. This system demonstrated how integrating super-capacitors can enhance energy availability and smooth out fluctuations in solar energy output. In a follow-up study, Glavin and Hurley (2007) focused on ultracapacitor-battery hybrids, highlighting their capability to manage energy bursts and reduce strain on batteries.

 **3. SUPER-CAPACITORS APPLICATIONS IN PV SYSTEMS**

 Fahmi et al. (2014) investigated Performance of solar PV systems enhanced using super-capacitors under fluctuating load conditions. Their results indicated an improvement in system responsiveness and stability, proving that super-capacitors are effective in dealing with rapid changes in power demand and sunlight availability​ .Additionally, Smith et al. (2002) emphasized the role of Solar PV performance optimized with super-capacitors under variable loads.

**4. MAXIMUM POWER POINT TRACKING (MMPT) TECHNIQUES**

 To maximize energy conversion, the use of MPPT algorithms is widely implemented. Rajeev Valunjkar (2017) designed and implemented an MPPT-based solar charge controller, demonstrating improved performance in variable weather conditions​.Villalva et al. (2009) analyzed the widely used Perturb and Observe (P&O) algorithm with a linearized PV array model, showing how proper MPPT implementation can significantly increase the efficiency of solar systems​.

**5. ALGORITHMS AND SOFTWARE IMPROVEMENTS**

Several studies have contributed to the advancement of software-driven MPPT techniques. A thesis from Delft University (2012) developed MPPT software optimized for dynamic sunlight conditions, further validating the importance of algorithmic precision in improving solar energy capture​. Sharma and Purohit (2012) proposed an enhanced P&O MPPT algorithm to address rapid fluctuations, ensuring better adaptation to changes in irradiance levels​.

  **6**.  **ENERGY FLOW AND LOAD MANAGEMENT**

Temporal resolution in energy load analysis has a direct impact on accuracy and efficiency. The project discussed in the document shows that low-resolution analysis can lead to significant errors—up to 37%—which can be mitigated through the use of real-time monitoring and high-resolution data logging. The combination of super-capacitors and intelligent microcontroller-based monitoring (such as with the ATMEGA328 and ESP32 modules) allows for better load management and energy self-consumption.

**7. CONCLUSION**

The study conducted on a photovoltaic (PV) system that includes a monitoring mechanism to enhance the efficiency of renewable energy utilization. The primary objective of the investigation is to increase self-consumption—that is, to ensure that the energy produced by the solar panels is primarily used within the household or facility rather than being sent back to the power grid. Another critical focus is to reduce power fluctuations, which can occur due to variations in load demand or solar generation caused by environmental conditions like cloud cover or shading. To achieve this, the study evaluates the impact of electrical load temporal resolution on the energy flow of the PV system. Temporal resolution refers to how frequently the system records data about energy consumption—for example, whether it tracks usage every second, minute, or hour. The research aims to determine the optimal temporal resolution that provides accurate energy flow data with minimal error. Too low a resolution may fail to capture rapid changes in energy usage, while too high a resolution might result in excessive data and processing requirements.

The key finding of the paper is that even for a single household, the choice of temporal resolution has a significant impact on both the accuracy of energy flow measurements and the effectiveness of energy self-consumption. In other words, accurately and efficiently managing how and when energy is used depends heavily on how finely the system monitors and records energy usage over time.

This highlights the importance of precision in data collection and analysis for optimizing the performance of residential solar power systems, which can be crucial for energy savings, cost reduction, and system stability.

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