Implementation on Sustainable Solar Greenhouse Automation with PLC And SCADA

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ABSTRACT

Traditional greenhouse farming has a lot of problems like inefficient manual monitoring, water wastage, and a heavy reliance on conventional electrical grids. To fix these problems we made a smart greenhouse. This greenhouse is perfect for plants like strawberries that need care. The greenhouse has a frame that looks like a house, it's called a Gable Roof structural frame. It is covered with plastic sheets that can handle sunlight and bad weather. The greenhouse can take care of itself. Make its own power so it does not need to use the regular electricity grid. The smart greenhouse has panels that work very well because of the way it is built.

Allen-Bradley Programmable Logic Controller (PLC) is brain of the system. This Allen-Bradley Programmable Logic Controller manages a precise system that controls things automatically. The Allen-Bradley Programmable Logic Controller looks at what the sensors saying right now. If it gets too hot the Allen-Bradley Programmable Logic Controller turns on the cooling fans when the temperature goes over 28°C. The Allen-Bradley Programmable Logic Controller also controls the irrigation pumps. It does this when the soil gets too dry or too wet between 40% and 80% soil moisture so we do not waste water.

The greenhouse has panels and a battery bank so it can work on its own without needing any other power. The system uses a Wi-Fi module to connect the Allen-Bradley Programmable Logic Controller to a Supervisory Control and Data Acquisition interface. This means we can watch what is going on from away and keep track of the data all the time.

Keywords – Greenhouse Automation, Allen-Bradley PLC, SCADA, Wi-Fi module, Solar Energy, Protected Cultivation, Closed-Loop Control, Remote Monitoring, Precision Irrigation.

I. INTRODUCTION

Agriculture has never before faced such challenges as the increase in the population, the scarcity of arable land, and the unpredictable changes in the weather. While the artificial microclimate of the greenhouse allows the plants to grow, the traditional ones require the control of the process, the use of timers, and the availability of the electrical grid. The use of simple timers for the irrigation systems, despite the actual moisture, leads to the inefficient use of water, wastage of electricity, as well as the vulnerability of the systems to power outages [3], [8], [10]. There is an urgent need to adopt smart, self-regulating environments powered by renewable energy sources to develop sustainable agricultural systems.

To overcome such limitations, it is essential to have a high-grade automation system. Microcontrollers can be used to a limited extent to implement automation, but to have a more robust system, it is better to move to a Programmable Logic Controller (PLC). It can be used to implement a closed-loop system to control the environment in a greenhouse [1], [7]. Precise field devices such as a Pt100 temperature sensor and a capacitive soil moisture sensor can be used to implement a closed-loop system using a PLC to control the greenhouse based on the actual environmental conditions instead of a fixed schedule [4].

Today's agriculture also requires remote visibility. This is achieved through the integration of the Wi-Fi communication module, which sends vital information to the SCADA system [2], [6]. This way, the farmer can remotely monitor the information on the screens and receive notifications from anywhere [1], [5]. Moreover, the operation of the entire system using the solar photovoltaic system physically disconnects the greenhouse from the grid, which is particularly important in the case of power outages in the countryside [2], [8], [10].

Following this line of thought and development, this paper aims to present the comprehensive design and implementation of a fully autonomous and solar-powered greenhouse. By utilizing an Allen Bradley PLC and running it through the Wi-Fi communication layer, this industrial solution aims to provide precise and closed-loop control. The objective of this solution is to provide maximum production with minimal water, labor, and electrical requirements.

II. LITERATURE SURVEY

Significant changes in the evolutionary history of protected cultivation have involved a quick shift from manual operation via timers to highly advanced automation systems. A comprehensive literature survey reveals advancements in the fields of industrial control systems, precise sensing technologies, wireless communication systems, and renewable energy systems.

A. Industrial Control and Precision Automation

Early attempts at greenhouse management heavily relied on basic microcontrollers and rigid, clock-based scheduling, which often resulted in severe resource inefficiencies. Recognizing the limitations of open-loop systems, Dwinugroho et al. [7] demonstrated the operational superiority of Programmable Logic Controllers (PLCs) in agricultural environments. By designing a smart watering system driven by a PLC, their research validated that sensor-triggered irrigation eliminates water wastage compared to traditional timer-based methods. Further advancing the application of industrial hardware, Wu et al. [1] explored an environmental control system for greenhouses utilizing a system identification approach combined with PLC and SCADA architectures. Their results demonstrated the unmatched reliability and stability of the processing capabilities of industrial-grade controllers in the regulation of complex and multi-variable microclimates.

B. Sensor Accuracy and Data Acquisition

The efficacy of any automated control loop fundamentally depends on the accuracy of its primary inputs. Li [4] conducted an in-depth analysis of Pt100 temperature measurement sensors, focusing on transducer design and simulation. The results of this study emphasized the vital importance of using high-precision sensors that meet industry standards to guarantee the accurate provision of environmental feedback to the central processing unit before it makes the decision to operate high-load devices such as the cooling fan and the water pump.

C. Wireless Telecommunications and Remote SCADA

Beyond localized physical control, modern agricultural engineering demands continuous remote accessibility. Several recent studies have explored the integration of wireless communication protocols to seamlessly transmit greenhouse data to centralized human-machine interfaces [3], [9]. For instance, Soetedjo and Hendriarianti [5] developed an advanced SCADA monitoring system focused on plant leaf temperature and soil parameters using wireless data transmission. Similarly, Thombare et al. [6] have also focused on the use of connected wireless networks for the purpose of "real-time remote visualization of crop environment." Although these wireless systems perform well for remote telemetry of data and cloud-based logging, it is also evident from the literature that these systems are often implemented using lightweight embedded systems for both communication as well as actuation purposes, which may not be robust for long periods of operation.

D. Renewable Energy and Standalone Systems

To address the heavy energy dependency required for continuous environmental regulation, recent literature heavily emphasizes the integration of renewable energy sources to establish self-sustaining ecosystems. Hoque et al. [8] and Karthikeyan et al. [10] presented comprehensive frameworks for automated greenhouses powered entirely by solar energy. Their respective analyses successfully demonstrated that sensor networks and localized control systems can be efficiently decoupled from the conventional electrical grid. Building on the capabilities of off-grid systems, Yusoff et al. [2] have demonstrated the viability of an automated solar-powered monitoring system using an ESP32 microchip and wireless mobile application, which further validates the viability of off-grid battery-powered environmental monitoring in agricultural areas.

E. Summary and Gap Identification

Despite the significant technological advancements in the area, the literature review revealed an architectural gap in the area. Many existing systems either deploy robust industrial PLCs but remain tethered to the main commercial power grid [1], [7], or they achieve off-grid solar independence by utilizing fragile, low-level microcontrollers that are highly susceptible to failure in harsh industrial conditions [2], [8]. The research proposed in this paper aims to bridge this gap by synthesizing the industrial reliability of an Allen-Bradley PLC, the advanced telecommunications capabilities of a wireless SCADA module, and the environmental sustainability of a standalone solar PV system into a single, cohesive hybrid architecture.

III. METHODOLOGY

The proposed automated greenhouse system employs a distributed control architecture, utilizing an industrial-grade programmable logic controller for local process execution and a dedicated telemetry network for remote supervision. The system operation is categorized into five primary subsystems: structural design, power management, data acquisition, central processing, actuation, and remote monitoring

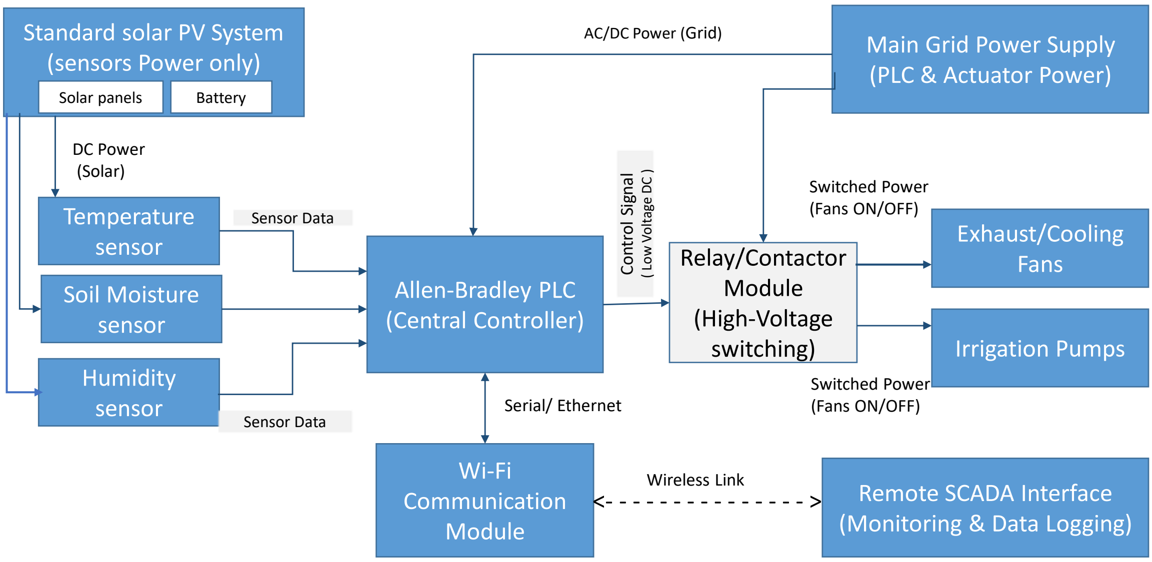

Fig. 1: 3D CAD Model of the House-Shaped Greenhouse Structure showing Sensor Mounting Points.

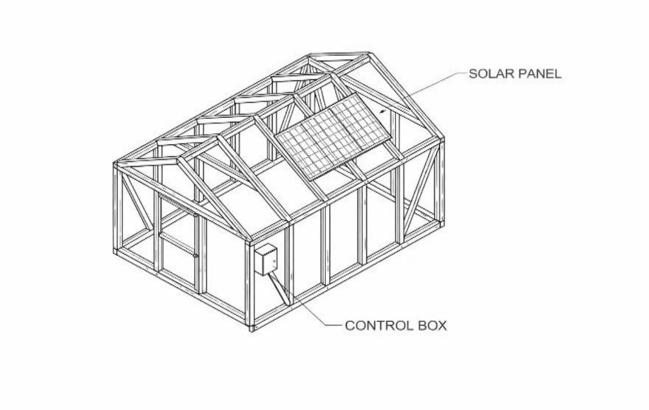

Fig. 2: Block Diagram of the Proposed Solar-Powered Green House Automation System.

Physical Framework and Structural Design: The physical structure of the automated system is based on a gable roof greenhouse structure, and the material used for the structure is high-impact polycarbonate sheets. The geometric design of the structure is such that it is maximally resilient to withstand high wind pressure, and at the same time, it is optimized for solar transmittance, as the natural light is essential for the growth of the plants, and a secure structure is needed to house the sensor nodes and wiring

Power Distribution Architecture: To optimize energy efficiency and ensure the continuous operation of critical sensing equipment, a segregated, dual-source power supply methodology is implemented. A standard solar PV system, comprising solar panels and a 12V/24V battery storage unit, generates dedicated DC power (typically 12V or 24V DC). This solar subset is strictly utilized for sensor power. Conversely, the main grid power supply provides the necessary 230V AC (converted to AC/DC power internally) to drive the higher electrical loads required for the PLC and actuator power.

Environmental Data Acquisition: Continuous monitoring of the greenhouse microclimate is achieved through an integrated array of electronic transducers operating on low-voltage DC (typically 5V or 24V DC). The system utilizes a temperature sensor, a humidity sensor, and a soil moisture sensor. These devices dynamically capture physical environmental changes and transmit the resulting analog and digital sensor data directly to the central processing unit.

Central Processing and Control Logic: The computational core of the automation system is an Allen-Bradley PLC, operating via the main grid supply, which serves as the central controller. The PLC continuously polls the incoming sensor data and evaluates it against predefined threshold parameters within its ladder logic programming. Upon calculating a required environmental adjustment, the PLC generates precise low-voltage DC control signals (typically 24V DC).

Fig3. Allen-Bradley PLC

High-Voltage Actuation and Isolation: To safely interface the sensitive microelectronics of the PLC with heavy electrical machinery, the control signals are routed to a robust relay/contactor module. This intermediate stage performs critical high-voltage switching, effectively isolating the low-voltage control circuits from the load-bearing power circuits. This module outputs switched power (typically 230V AC single-phase) to toggle the exhaust/cooling fans ON/OFF and to actuate the heavy-duty irrigation pumps.

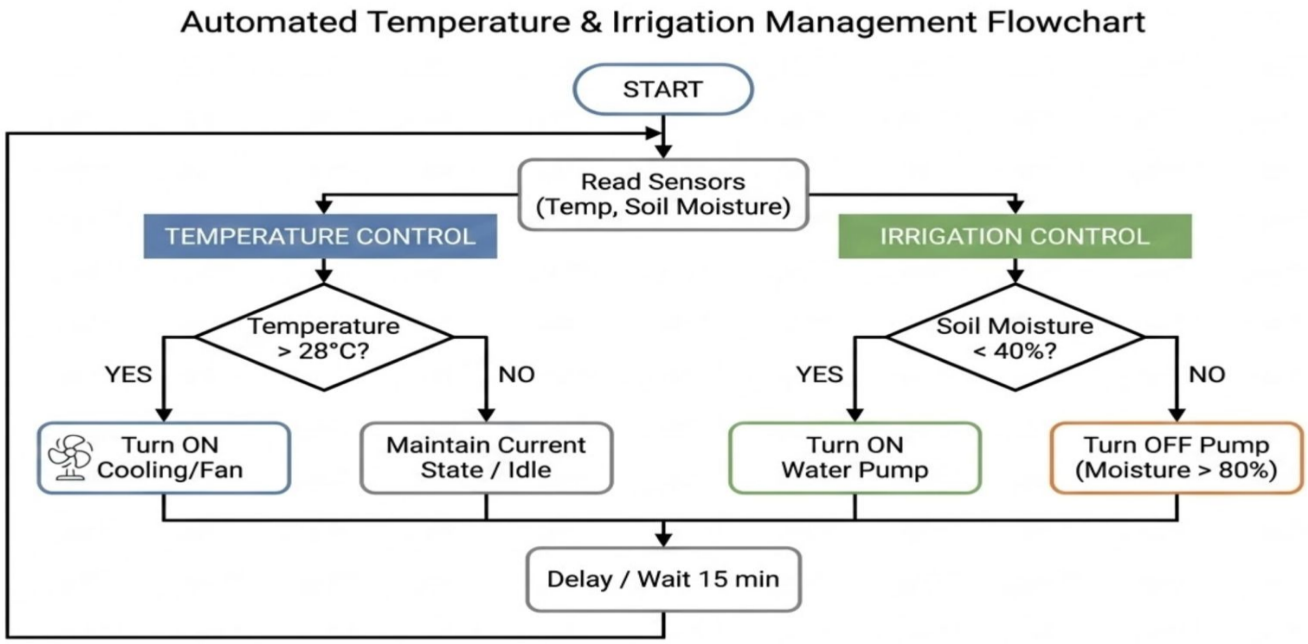

Figure 1: Simplified Schematic Flowchart of the Automated Management System.

Figure 4: Simplified Schematic Flowchart of the Automated Management System.

Telemetry and SCADA Integration: To facilitate off-site system management, a dedicated communication layer bridges the local controller with a remote SCADA interface. The central PLC interfaces with a low-power Wi-Fi communication module (typically drawing 3.3V or 5V DC) utilizing a serial/Ethernet connection. This establishes a robust wireless link, pushing real-time telemetry to the SCADA system for continuous monitoring and data logging, thereby enabling comprehensive historical analysis and remote manual overrides.

IV.HARDWARE AND SOFTWARE REQUIREMENTS

I. Hardware requirements

- PLC
- Wi-Fi Module
- Solar Panel
- Battery
- Sensor (Temperature , Soil Moisture)
- Relays
- Actuators (Fan , Exhauster , Sprinkler)

II. Software requirements

- Rockwell Automation (Allen-Bradley) Studio 5000
- SCADA

V.RESULT AND DISCUSSION

The automated greenhouse control system worked well and gave us stable results. The system combined control with remote monitoring and met all the requirements for controlling the environment.

1. Power Management Efficiency

We used a method to separate the power for the equipment. This method was very effective in keeping the low-voltage devices from big changes in power. The solar panel system, which included the panels and battery gave us a steady and reliable supply of power. This system kept the power for the sensors so the main power grid did not affect the data we collected. On the hand the main power grid gave us the power we needed for the control system and the devices that used a lot of power.

2. Data Acquisition and Processing

The sensor network gave us up-to-date information about the environment. The main controller got data from the temperature sensor, humidity sensor and soil moisture sensor without any problems. The Allen-Bradley control system, which was the controller got the data from the sensors quickly and used its programmed instructions to decide what changes to make to the environment.

3. Actuation and High-Voltage Switching

When the control system decided a change was needed it sent a low-voltage signal to make it happen. The switching system worked well. Safely switched the high-voltage power. It turned the fans on and off. Started the irrigation pumps to keep the soil moist.

4. Telemetry and SCADA Performance

The communication system worked well and connected the local equipment to a remote monitoring system. The Wi-Fi connection was stable. Gave us a continuous link, to the remote system. As a result the remote monitoring system got data and let us watch the greenhouse in real time and keep a record of what happened for later review and oversight of the automated greenhouse control system and its performance.

VI. CONCLUSION

In the end the method we use for this automated greenhouse works well. It is a good system that can control things precisely. We use an Allen-Bradley PLC as the controller. This means the greenhouse gets what it needs. We have a lot of sensors like temperature sensors, humidity sensors and soil moisture sensors. These sensors give us the information at the right time.

We also have a way to give power to the greenhouse. We use power and a battery for the sensors. The main power grid is used for the PLC and the things that make the greenhouse work. This way we do not waste energy. We have a module that helps with the electricity. It makes sure the big machines like the fans and pumps are safe to use.

We can also connect to the internet with a Wi-Fi module. This means we can watch the greenhouse from else. We can see what is happening. Keep track of the data. This is good, for the future because we can make the system bigger if we need to. So we have a system that works well and does not waste energy. It is a way to make a modern greenhouse work automatically.

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