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Design and Implementation of a Smart Control Panel Using Cloud Computing for Real-Time Electrical and Environmental Monitoring

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Abstract: *In the pursuit of efficient and reliable operation of electrical systems, this paper presents the design and implementation of a cloud-connected smart control panel for real-time monitoring and remote control of electrical devices in a poultry-farm application. The proposed system enables continuous monitoring of electrical and environmental parameters, including voltage, current, power, temperature, humidity, and vibration, with the acquired data transmitted to a cloud server for remote observation. In addition, the system facilitates remote control of connected electrical devices through relay- and contactor-based switching. The proposed control panel integrates real-time monitoring and remote load control within a unified platform, providing centralized access to the operating conditions and connected devices of the electrical system.*

Keywords: Smart control panel, Internet of Things, cloud computing, real-time monitoring, remote control, electrical loads.

I. INTRODUCTION

Electrical power systems have become increasingly interconnected, requiring effective methods for monitoring, control, and operation of electrical equipment. Conventional electrical installations have traditionally relied on electromechanical and manually operated devices to perform these functions. With the growing complexity of electrical loads and the increasing requirement for operational information, there is a need for improved monitoring and control capabilities within electrical systems [1], [2].

Control panels constitute an important interface between electrical power sources and connected loads, incorporating switching, protection, measurement, and control functions within a centralized arrangement. Their design must also consider appropriate component placement, wiring, safety, and accessibility to support reliable operation and maintenance [3]. However, conventional panels are generally centered on local operation, and the information available at the panel may not be readily accessible from a remote location with conventional panel [2], [4].

The advancements of Internet of Things (IoT) technology has created new possibilities for extending the capabilities of conventional electrical systems. IoT enables physical devices to exchange data through communication networks and allows electrical equipment to be monitored and controlled remotely through connected interfaces [2], [5]. The integration of sensing, communication, and embedded control has consequently led to the development of smart electrical panels capable of providing real-time information and remote access to connected loads [1], [2].

Several smart-panel implementations have demonstrated the feasibility of combining electrical measurement with remote load control. IoT-based panels have been developed to acquire electrical parameters and transmit the collected information to online platforms, while relay- and contactor-based arrangements have been used to control connected equipment remotely [1], [5]. Centralized intelligent panel designs have further demonstrated the integration of

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monitoring and control functions within the panel architecture, reducing the dependence on extensive external interfacing [4].

The application of such technology is particularly relevant to poultry-farm electrical systems, where multiple loads such as lighting, ventilation, cooling equipment, and motors are required for routine operation. Continuous access to electrical and environmental parameters can provide useful information regarding the operating state of the system, while remote control can allow connected equipment to be operated without direct access to the panel.

In this work, a cloud-connected smart control panel is proposed for real-time monitoring and remote control of electrical loads in a poultry-farm application. The system enables the acquisition of selected electrical and environmental parameters and their transmission to a cloud server for remote observation. In addition, connected devices can be controlled remotely through relay- and contactor-based switching. The proposed system therefore integrates electrical monitoring and remote load control within a unified control-panel architecture.

II. LITERATURE REVIEW

The integration of communication and automation technologies into electrical panels has been explored through various approaches, with particular emphasis on remote monitoring, load control, and intelligent power management. Existing studies provide a foundation for developing electrical panels that extend beyond conventional local operation by incorporating sensing, wireless communication, and remote-control capabilities.

A smart three-phase electrical panel was developed using IoT connectivity to provide both monitoring and control of electrical loads [1]. The system incorporated a microcontroller, relay, contactor, and sensing arrangement, with an IoT platform providing remote interaction with the panel. The implementation also considered both online and offline operations, demonstrating the feasibility of combining remote control with conventional local operation.

An IoT-enabled low-voltage distribution panelboard was proposed with real-time measurement of electrical quantities and cloud-based data visualization [2]. The system employed voltage and current sensing together with an ESP32-based processing unit and wireless communication. In addition to monitoring and remote control, the study incorporated load forecasting through machine-learning techniques, extending the functionality of a conventional distribution panelboard toward intelligent energy management.

A smart distribution board for energy management was investigated with emphasis on multiple control options and the operation of both low- and high-energy loads [3]. The proposed arrangement incorporated relays, contactors, a control unit, and online connectivity, allowing electrical devices to be accessed and controlled from remote locations. The study also emphasized the importance of maintaining alternative means of control and considered scalability for larger applications.

The development of smart power and motor control center panels has also been investigated for centralized monitoring and control applications [4]. The design incorporated intelligent interfacing of switchgear and metering components while reducing the dependence on extensive external hardwiring. The study highlighted the importance of remote ON/OFF functionality, communicable metering, and integration of control and monitoring functions within the panel architecture.

An Internet-based smart panel system was further developed for monitoring electrical consumption and remotely controlling connected equipment [5]. The system used wireless communication, electrical measurement, a web server, and a remote application to transmit operating information and execute control commands. Experimental testing included sensor-data monitoring and remote switching of connected loads, demonstrating the practical implementation of internet-based panel control.

The reviewed studies establish the feasibility of integrating electrical panels with IoT communication, real-time monitoring, and remote load control. However, the existing approaches differ in application, system architecture, control methods, and the range of monitored parameters. The present work builds upon these developments by integrating real-time electrical and environmental monitoring with cloud-based remote supervision and relay- and contactor-based control for a poultry-farm electrical system.

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III. METHODOLOGY

The proposed system is developed as a cloud-connected smart control panel for real-time monitoring and remote control of electrical loads in a poultry-farm application. The methodology integrates electrical and environmental parameter sensing, embedded data acquisition, wireless communication, cloud-based visualization, local display, and relay- and contactor-based load control within a single control-panel architecture. The overall arrangement of the proposed system is illustrated in Fig. 1.

A. System Architecture

The proposed control panel receives a 230 V AC supply, which is utilized for operating the connected poultry-farm loads and for supplying the low-voltage control circuitry through a step-down transformer. The sensing section consists of voltage, current, power, temperature, humidity, and vibration sensors. The measured parameters are acquired by the ESP32 microcontroller, which processes the sensor data and provides the required information for local and remote monitoring. The measured values are displayed locally using a 16×2 LCD and are transmitted through Wi-Fi to the cloud server for remote access. The ESP32 also provides control signals to the relay module, which operates the corresponding contactors connected to the poultry-farm loads. The connected loads include lighting, exhaust fans, coolers, and motor-operated equipment. Thus, the proposed architecture combines electrical parameter monitoring with remote operation of connected loads within a common control panel

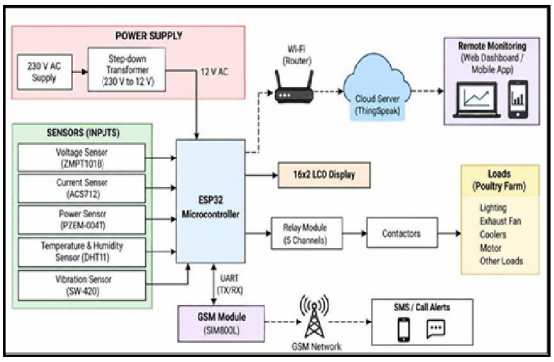


Fig. 1. System block diagram of the proposed cloud-connected smart control panel.

B. Parameter Sensing and Data Acquisition

The monitoring section continuously acquires the major electrical and environmental parameters of the system. The voltage sensor measures the AC supply voltage, while the current sensor measures the current drawn by the connected loads. The power measurement section provides corresponding power information. Temperature and humidity are measured to monitor the environmental conditions of the poultry-farm application, while the vibration sensor provides vibration-related information from the monitored system. The outputs of the sensors are interfaced with the ESP32 microcontroller. The controller processes the acquired measurements and makes the information available through the local LCD and cloud connected monitoring interface. The use of an ESP32-based architecture for receiving, processing, and transmitting measured electrical data to an IoT platform is consistent with the methodology reported in previous smart-panel research [2].

C. Cloud-Based Monitoring and Remote Control

After processing the acquired data, the ESP32 transmits the monitored parameters through a Wi-Fi network to the cloud server. The cloud platform stores and graphically represents the measured parameters, allowing voltage, current, power, temperature, humidity, energy-related information, and contactor status to be accessed remotely. The cloud-

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based arrangement provides access to the operating information of the control panel without requiring continuous physical observation.

The relay output operates on the associated contactor, thereby controlling the respective poultry-farm load. This arrangement enables individual remote operation of the connected loads while maintaining the conventional electrical switching arrangement. D. Local Display and System Operation In addition to cloud-based monitoring, the measured parameters are displayed locally using the 16×2 LCD installed within the control panel. This provides direct access to the operating parameters when the panel is physically accessible. The overall system therefore provides two levels of access: local observation through the LCD and remote monitoring and control through the cloud-connected interface. The remote monitoring and relay-control interface provides access to the measured parameters and individual relay channels, allowing the connected loads to be operated remotely.



Fig. 2. Remote monitoring and relay-control interface.

The cloud platform provides graphical visualization of the monitored parameters over time. The voltage, current, power, temperature, humidity, average power, and contactor-status data are represented through the corresponding monitoring graphs.

The proposed smart control panel was successfully developed and implemented as a functional prototype for monitoring and controlling electrical loads in a poultry-farm application. The prototype demonstrates the practical integration of the proposed system architecture and provides the required interface between the monitoring circuitry and the connected electrical loads.

The developed system enables real-time acquisition of electrical and environmental parameters and makes the acquired information available through both the local display and the cloud-based monitoring platform. The remote-control interface shown in Fig. 2 provides individual control of the connected relay channels. Commands issued through the interface are transmitted to the ESP32 and subsequently applied to the corresponding relay circuits and contactors.

The developed prototype therefore demonstrates the practical feasibility of combining electrical parameter monitoring, environmental monitoring, cloud connectivity, and remote load control within a single control-panel architecture. The implemented system provides the intended monitoring and control functions and establishes a suitable platform for application in poultry-farm electrical systems.

V. CONCLUSION

This paper presented the design and implementation of a cloud-connected smart control panel for real time monitoring and remote control of electrical loads in a poultry-farm application. The developed system integrates electrical and environmental sensing, ESP32-based data acquisition, local display, Wi-Fi communication, cloud-based monitoring, and relay- and contactor-based load control within a unified architecture.

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