

Industrial Energy Monitoring and Smart Control Using IoT

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ABSTRACT

Due to the greater demand for electricity today, escalating operational costs, and increasing concern about environmental sustainability, modern industrial settings require efficient use of energy. Conventional energy monitoring systems have poor real-time visibility, lack remote access and do not provide intelligent controls leading to energy lost through waste and improper distribution of loads. This paper describes an IoT-based energy monitoring and remote load control system that was developed to improve energy efficiency in industrial settings. The system uses embedded sensors connected to a microcontroller to continuously monitor electrical parameters (i.e., voltage, current, power consumption, energy use) and transmits those parameters to an IoT cloud platform for real-time viewing, data logging, and remote access. The system also provides functionality for remote load control enabling authorized users to turn on/off industrial electrical loads using a web page or mobile device. The integration of real-time monitoring and intelligent controls will assist in responsible decision making; therefore, minimizing energy lost through waste and generally supporting environmentally friendly industrial operations. Experimental verification of the proposed solution indicates its reliability, scalability, and effectiveness in improving energy management for industrial settings.

Keyword: IoT, Energy Monitoring, Smart Industry, Remote Load Control, Power Management, Sustainable Industry

1. Introduction

There is a very basic relationship between energy consumption and growth within the industrial world, as well as between electrical energy resources and the stability of economies and the advancement of technologies. In addition, with industrialisation world wide continuing to accelerate, so too has global consumption of energy resources, which has placed additional stresses on power generation resources and has contributed to increased operational, and ultimately production costs for many industries [2], [4]. As a result, and because of the increased awareness of environmental issues, like carbon emissions and resource depletion, the need for more efficient and sustainable energy use has become one of the highest priorities for economic and environmental sustainability.

Many industrial facilities are still reliant on traditional methods of monitoring and managing energy use, such as manual meter readings, and/or by regionalised methods of monitoring systems that provide limited visibility into real-time use of electrical power and do not provide the necessary action-based data for achieving energy management on an ongoing basis. Also, when industrial facilities lack the continuous monitoring and the ability to apply intelligent analytics to their systems, there is little or no opportunity for timely abnormalities to be detected, inefficient loads to be operated and wasted energy to be consumed [1]. Additionally, a lack of remote access often prohibits timely intervention when there are problems, particularly in larger or geographically distributed industrial facilities.

The Internet of Things (IoT), energy management for the industrial sector has undergone a revolutionary change [1], [3]. The IoT creates an infrastructure where sensor-based devices, embedded controllers, communication networks, and cloud-based data storage can communicate, providing a seamless flow of data in real-time and increasing visibility into a given system's operation. IoT-enabled energy monitoring systems allow for continuous measurement and transmission of electrical parameters—including voltage, current, power, and energy consumption—to centralized data storage platforms.

2. Related Work

Recent advancements in IIoT have radically changed the way we monitor and manage energy in industrial settings. Many researchers have created a variety of IoT frameworks to enhance energy efficiency, sustainability, and operational transparency. An example of this was offered by Mirani et al. [1], who created an energy monitoring system based on IIoT that employs edge computing for preprocessing energy data on site before transmitting it to the cloud. This method reduces latency and bandwidth consumption while enabling near real-time analytics for industrial use. They showed that processing in distributed fashion enhances the scalability and responsiveness of intelligent industrial systems.

Additionally, Sulistiyanto et al. [2] created a model for real-time monitoring of renewable energy systems based on IoT. This monitoring system enables continuous tracking of voltage, current, and power parameters by using sensor networks combined with cloud-based platforms. The authors highlighted the importance of fleet management and centralized monitoring in achieving efficient energy use. Another area of exploring energy sustainability involved intelligent distributed learning systems.

Anjana et al. [3] considered how IoT-enabled distributed learning frameworks can reduce carbon footprints in the area of industrial and energy systems.

Their research provides evidence that predictive analytics and AI-optimized processes can significantly reduce unnecessary energy use while supporting environmentally-forward operations.

Usman et al. [4] developed an inexpensive IoT based smart energy monitoring and load management system that can be effectively used in small-scale industries. This system uses a wireless communication module with microcontroller based sensors to manage the loads remotely. The results showed that an inexpensive IoT solution could significantly reduce energy consumption without the need for expensive equipment and system infrastructure.

Thulasingam and Krishnamoorthy [5] developed an IoT-based intelligent monitoring system to monitor the production of energy using grid-connected hybrid energy systems and controlling the load on these energy sources using programmable logic controllers (PLCs). Their results showed that using real-time load switching would greatly increase the reliability of the energy produced by these hybrid energy systems and therefore optimize the distribution of that energy throughout the industrial environment.

Raj and Suji Prasad [6] developed an IoT based energy management framework for the purpose of sustainable manufacturing in the manufacturing sector. This system provides real-time dashboard access, automated alerts, and centralized supervisory access to provide users with greater transparency in their energy usage, thereby improving the ability for users to make informed decisions about their energy usage.

Munoz et al. [7] created a smart metering device based on IoT that can regulate load within a home energy management system by controlling how much energy is being consumed from the electrical grid to provide power to an entire home. This research, while focused primarily on residential applications, established an expandable method for implementing load control in an industrial setting.

Additionally, Abir et al. [8] addressed the larger issue of implementing IoT smart energy grids and demand-response strategies for increasing stability in the electrical grid and also for integrating renewable energy sources while using intelligent load balancing.

3. Proposed Methodology

The objective of the proposed system is to develop an IoT solution for energy management with remote load control capabilities for sustainable use in industrial settings. The system's design combines real-time acquisition of electrical parameters, cloud transfer of data, centralized reporting, and remote control of electrical loads into a single architecture.

The entire system is composed of four main components: energy sensing module; processing unit and control; communications unit; and real-time server platform. The energy sense module is responsible for continuously measuring key electrical and energy parameters (voltage, current, active power, and total electrical energy

consumed). The energy meter interface provides an extremely accurate way of acquiring electrical consumption data from industrial loads, allowing for an effective method of monitoring operational parameters accurately. These measured values are the basis for intelligent decision-making on energy optimization.

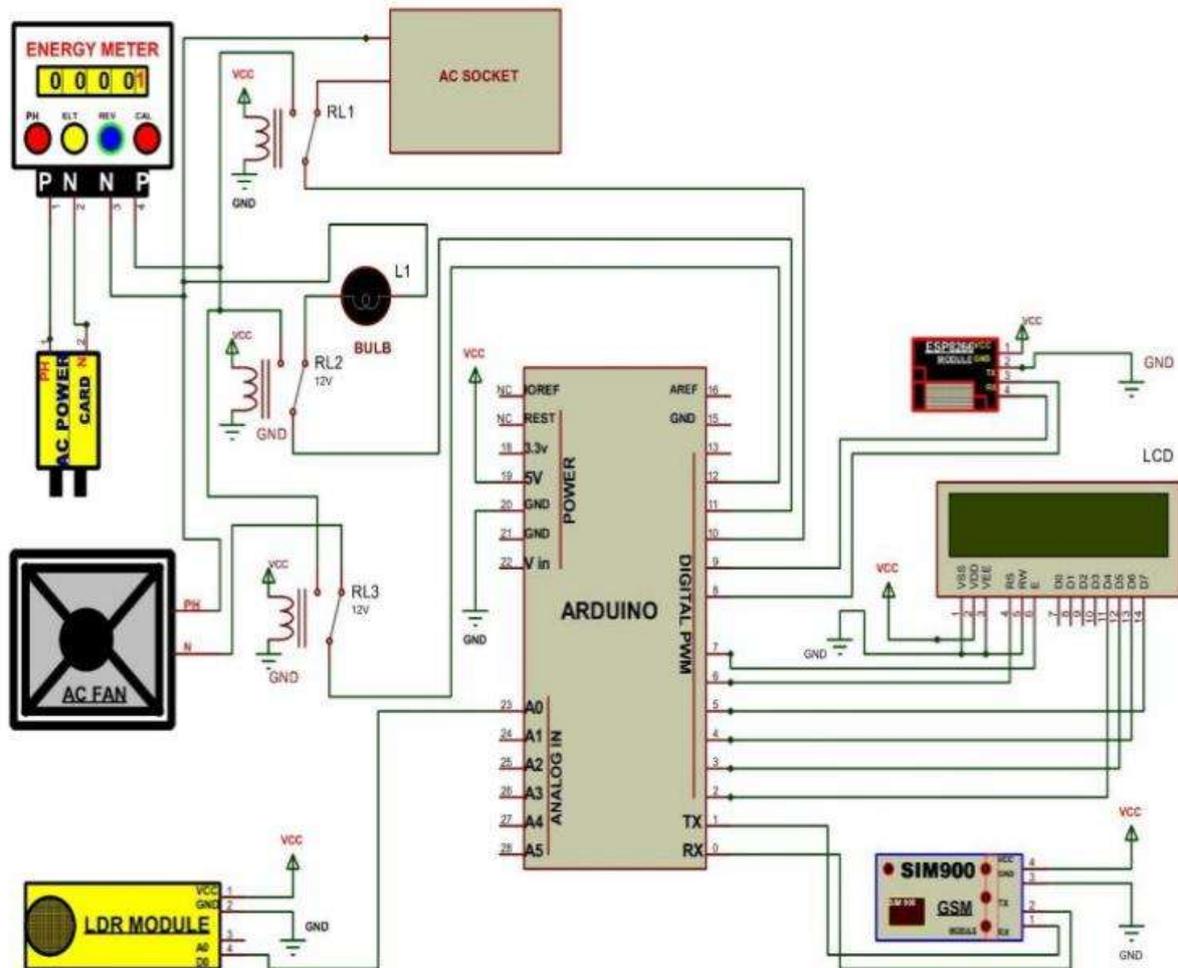


Fig1: Circuit diagram

The processing and control unit (which uses an embedded microcontroller) performs real-time acquisition of data, calculations on parameters, evaluation of thresholds, and execution of control logic. In order to accomplish this, it continuously analyses electrical data as it comes in, and compares it to predetermined safety and operational limits. If there is excessive electrical consumption or overload conditions detected, automatic load control actions will be implemented by the system in order to eliminate waste of energy and to protect equipment from damage. This intelligence integrated into the embedded software improves the speed and reliability of the systems.

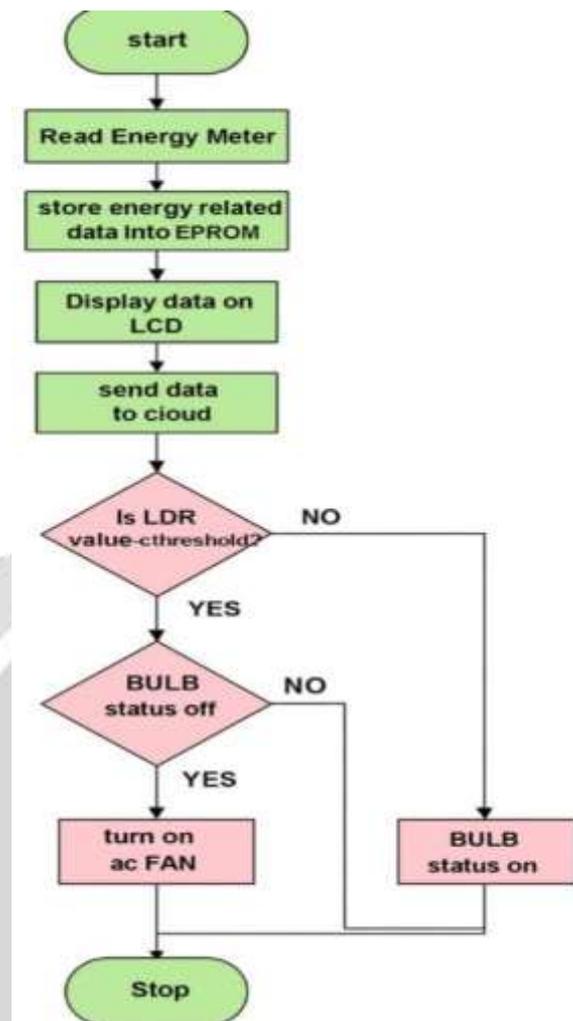


Fig2.Flow Chart

3.1 Data Acquisition and Energy Measurement:

The Data Collection and Power Measurement module is the first layer of the proposed IoT-based industrial energy monitoring system. The accurate and continuous measuring of electrical parameters is vital to enable the monitoring, intelligent control, and sustainability of energy management. The Data Acquisition Module is intended to continuously loop to allow for ongoing monitoring of industrial loads. Once measurement of the load has been taken, the Data Acquisition Module packages the measurement into a structured data packet and transmits that data packet to the Communications Module for integration with cloud services. Each data packet has a date/time stamp, which provides accurate information for historical evaluations and for viewing trends on the real-time server system.

3.2 Data Processing and Control Unit:

The Processing and Control Unit offers central intelligence to the IoT-based Energy Monitor and Load Control System. An example of this architecture would be using an Arduino as the primary embedded controller (microcontroller) that will process data in real-time, make decisions, and take control actions based on those decisions. The microcontroller continuously receives electrical parameters or values (voltage, current, calculated power) from the energy meter; it performs calculations such as calculating real-time power, accumulating energy, and comparing with thresholds. By integrating real-time calculations, intelligent threshold-based control and execution of remote commands, the Processing and Control Unit provides a responsible, responsive and sustainable means of managing industrial energy.

3.3 Remote Load Control Strategy:

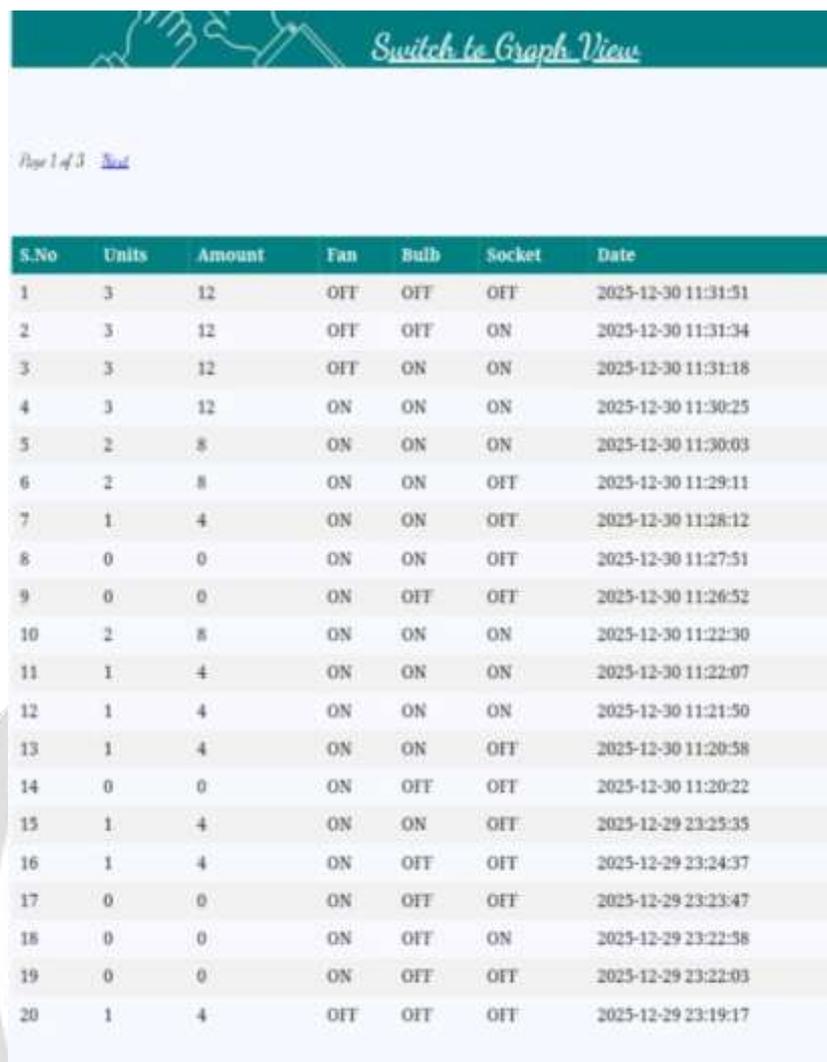
The Remote Load Control Strategy is an essential functional component of the IoT-based energy monitoring system to support operations and prevent unnecessary use of energy in an industrial facility. By providing real-time monitoring of power consumption, the proposed system measures energy efficiency, but to achieve this, the correct regulation of electrical loads must also occur in a dynamic fashion. The proposed system provides for manual/automatic remote load control through an embedded computer architecture - connected to the cloud. there are typically many electrical loads used within an industrial facility such as motors, compressors, lighting, heating, and auxiliary equipment. In many cases, these electrical loads continue to operate and consume energy during off production hours, leading to wasted energy. to address this issue, the system includes relay modules (RL1, RL2, RL3) that are interfaced with the Arduino microcontroller to allow for electrical isolation/switching of the connected electrical loads. Each of these loads is represented as binary control (ON/OFF) variable.

3.4 Communication and Real-Time Server Integration :

The communication and real-time server integration module is essential to the proposed IoT-based energy monitoring and load control system by providing the capability for remote monitoring of users, centralized supervision, and bidirectional control of systems. ESP8266 WiFi module enables real-time data transmission to a cloud-based server. The measured parameters (voltage, current, power, energy) are sent to the server using IoT communication protocols such as HTTP or MQTT. in addition, this module allows the transmission of data from embedded hardware in an industrial setting to a cloud server (accessible to users with permission) in a seamless and real-time manner. This will help prevent any unauthorized manipulation of the loads in the industrial sector as well as protect sensitive operation data.

4. REAL TIME SERVER SETUP

In the proposed system, an IoT cloud platform will manage industrial energy consumption data in real time (collecting, storing, visualizing and controlling). In this application, energy data such as Voltage, Current, Power and Total Energy consumption, will sent to the Real Time Server using ESP8266 Wi-Fi module for wifi connection between Embedded Controller and Cloud Server. after finalizing the IoT cloud server, an Initial IoT Cloud Dashboard will be created and unique authentication credentials (API key / device token) assigned to all users. This information will be embed into the microcontroller programming code for secure communication between the microcontroller and cloud server.



S.No	Units	Amount	Fan	Bulb	Socket	Date
1	3	12	OFF	OFF	OFF	2025-12-30 11:31:51
2	3	12	OFF	OFF	ON	2025-12-30 11:31:34
3	3	12	OFF	ON	ON	2025-12-30 11:31:18
4	3	12	ON	ON	ON	2025-12-30 11:30:25
5	2	8	ON	ON	ON	2025-12-30 11:30:03
6	2	8	ON	ON	OFF	2025-12-30 11:29:11
7	1	4	ON	ON	OFF	2025-12-30 11:28:12
8	0	0	ON	ON	OFF	2025-12-30 11:27:51
9	0	0	ON	OFF	OFF	2025-12-30 11:26:52
10	2	8	ON	ON	ON	2025-12-30 11:22:30
11	1	4	ON	ON	ON	2025-12-30 11:22:07
12	1	4	ON	ON	ON	2025-12-30 11:21:50
13	1	4	ON	ON	OFF	2025-12-30 11:20:58
14	0	0	ON	OFF	OFF	2025-12-30 11:20:22
15	1	4	ON	ON	OFF	2025-12-29 23:25:35
16	1	4	ON	OFF	OFF	2025-12-29 23:24:37
17	0	0	ON	OFF	OFF	2025-12-29 23:23:47
18	0	0	ON	OFF	ON	2025-12-29 23:22:58
19	0	0	ON	OFF	OFF	2025-12-29 23:22:03
20	1	4	OFF	OFF	OFF	2025-12-29 23:19:17

Fig3.Real Time Server Setup

The following will be completed by the real time server:

- 1.The Real Time Server will receive real-time energy parameters from the industrial node.
- 2.The Real Time Server stores time stamped data in a cloud database and provide graphical visualization of Voltage, Current and Power trends.
- 3.The Real Time Server will generate alerts if usage exceeds predetermined levels and will send remote ON/OFF commands to control industrial loads.

5. HARDWARE IMPLEMENTATION:

The hardware design is created from a schematic diagram that includes all elements required for sensing, processing, communicating, displaying, and controlling; therefore, each individual part serves an independent function.Hardware architecture consists of an integrated processing module, communication modules, control modules and display modules into one complete system.



Fig4. Hardware Implementation

a. Arduino Microcontroller : The Arduino microcontroller is the central controlling unit. It has the capability of reading sensor values as well as determining some electrical values (e.g., V, I, P, and E), processing control logic, and communicating via the ESP8266. It will also control relay states for load switching.

b. Relay Module : The purpose of using the relay module is to switch industrial loads either to an energized (ON) or de-energized (OFF) state. The relay acts as a simple electrically isolated switch that is controlled by the Arduino with a change in state controlled by a control signal provided by the server and/or when a set of threshold conditions are met.

c. ESP8266 Wi-Fi Module : The ESP8266 provides a means for the embedded system to connect to the internet. Therefore, it gives the ability for wireless communication to occur between the hardware elements of the embedded electronics and a cloud server; thus, allowing real-time data transmission to report streaming data to the Cloud Server and remote user command transmission back to the hardware.

d. LCD Display : The local LCD is used to display real-time values (e.g., E) for periodic monitoring/review without having to access the internet. The display is used to monitor the data on-site.

e. Energy Meter : To measure total energy consumed by the connected loads (one supplied or to be supplied) a single-phase energy meter is employed.

f. Loads : The system utilizes a variety of different electrical loads for evaluating how well the system will perform in real-world operating conditions. An AC motor-powered fan, AC bulb Additionally, a three-pin socket is provided as an external load port that allows the user to connect and test a variety of industrial under real-time operating conditions, thereby allowing for greater flexibility and applicability of the system.

g. GSM Module : The GSM module functions by sending alert notifications and status updates to the user via SMS, adding reliability to the system due to the module providing communication support regardless of internet connectivity. Therefore, the user can continue to monitor the system and receive notifications of faults.

h. LDR Module : The LDR is used to measure the ambient light intensity and is considered a light-sensitive variable resistor; as the resistance of the LDR is determined by the amount of light exposed to it, it can automatically control or measure lighting conditions to improve the efficiency of energy usage.

6. RESULTS :

The experimental evaluation of an IoT-based energy monitoring and remote load control system was performed with a hardware prototype. This prototype includes the following components: an Arduino microcontroller, an ESP8266 Wi-Fi module, a single-phase energy meter, a relay module, an LCD display, a GSM module, and three

7.CONCLUSION :

The study introduced an energy monitoring and load control system that utilizes an integrated IoT cloud server within a sustainable industrial application. This need for efficient energy consumption and centralized monitoring in industrial applications initiated the design and specification of this device. Prior to this device, operators did not have an immediate view into their processes nor the ability to remotely control them, resulting in ineffective management of their resources. The proposed design integrates all aspects of the device into a single system comprised of the following functional capabilities; sensing modules, an Arduino-based processor, ESP8266 Wi-Fi communication, relay-based load controlling units, and a real-time server platform. The experimental results confirmed the real-time capabilities of the device, whereby voltage, current, power, and cumulative consumption were able to be accurately tracked

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