Utilization of IoT and Smart Meters for Energy Management

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Abstract An exponential rise in energy consumption has resulted from the population's unrelenting expansion and the constant introduction of new technology, creating significant obstacles to effective energy management at the consumer level. Smart meters (SMs) have taken advantage of technology advancements to become more than just instruments for monitoring energy use; they are now essential parts of energy management systems. The SEMS that is being shown integrates with any software-based smart solution with ease by using a variety of communication interfaces and protocols. Entrack software is used in this research to collect and analyze data. The examination of the case study shows how effective the IoT-based SEMS that is being presented is at improving energy management.

Keywords: Energy Management System (EMS), Internet of Things (IoT), Smart Meter (SM), Smart Grid (SG), Smart Energy Monitoring System (SEMS)

I. INTRODUCTION

The increasing rate of urbanization has resulted in a significant challenge for energy management, especially in areas with high temperatures where demand-side energy management is made more difficult by power-hungry devices like air conditioners. [1] With an emphasis on monitoring and computing smart grid characteristics using IoT-enabled smart meters (SMs), this work presents and evaluates an IoT-based SEMS.

Smart Grid (SG): The SG is a collection of technology that goes beyond smart energy meters to provide control, integration, and communication between utilities and consumers, resulting in smooth power transfer. [2] It permits bidirectional electrical flow, instantaneous demand-supply balancing, and real-time monitoring.

What the Smart Meter (SM) Means: SMs are essential components of SGs because they provide two-way communication by storing and sending data for analysis, control, and monitoring. [3] SMs, as opposed to typical meters, monitor a variety of electrical characteristics that help with fault investigation, load profiling, and load control.

Internet of Things (IoT): With the ability to monitor, connect, and respond to different applications, IoT becomes a vital ally for power and resource management. [4] It makes two-way communication between networks, devices, and sensors possible, which is essential for efficient use of available resources.

Inputs:In order to facilitate effective data analysis, this paper describes the design and deployment of a SEMS based on an IoT solution that combines SMs and IoT middleware. The system has been implemented at four Stylo Pvt. Ltd. sites in Pakistan. [5] It highlights important environmental indicators, talks about the development of meters, suggests ways to raise user knowledge, and describes system architecture, design, and integration. A case study that highlights the possible benefits of the system that is being described closes the article.

Urban Energy Management Challenges: The growing urban environment poses a variety of difficulties for efficient energy management. With more people living in cities and power-hungry technologies becoming more common, there is a greater need for advanced energy solutions. considerable-temperature regions, where cooling needs are considerable, have a very difficult time balancing energy use. [6] It becomes essential to use creative methods to lessen the burden on energy resources. Energy Management Systems (EMS) have become a key technical option in response. These systems aim to bring in a new era of effective energy management in urban contexts by combining various tactics including smart grids, microgrids based on Renewable Energy Sources (RES), and IoT-enabled control of consumer products.

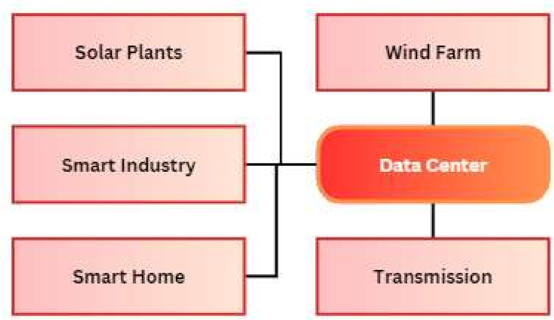

Fig. 1. Visualizing the Comprehensive System Approach

Smart Grid Technologies' Evolution: The notion of the Smart Grid (SG) goes beyond the traditional comprehension of energy meters, developing into an all-encompassing set of technologies that enable uninterrupted power transmission from utility companies to end users (figure 1). [7] In addition to its primary role of real-time monitoring, the SG facilitates bidirectional power flow and instantaneous demand-supply balancing. It integrates with the end user as well as the utility industry, creating a networked ecosystem that makes energy use a responsive and dynamic process. [8] A more sustainable and intelligent energy future may be possible as a result of this

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progression, which has the potential to improve the resilience and flexibility of energy infrastructures.

II. Literature Review

A. History And Development Of Smart Meter And Smart Energy Systems

1) History

Although the idea of electrical grids dates back to the 1800s, it wasn't until the 1960s that they were widely adopted, mostly in wealthy nations. Power grids showed notable penetration, capability, efficiency, and dependability throughout this time. Because of their efficiency and economic feasibility, hydroelectric, nuclear, and fossil fuel plants supplanted other power sources as the main suppliers. [9] Power consumption significantly rose over the 20th century due to the expansion of the industrial and residential sectors. More electric power grids were needed to fulfill the growing demand for energy in order to deliver electricity during peak hours and maintain system resilience against problems with voltage oscillations and power supply quality.

Electricity suppliers used Demand-Side Management (DSM) methods in response to the spike in energy demand. [10] These strategies try to optimize energy consumption at the customer level using various energy consumption modes, including peak clipping, load shifting, and valley filling, as well as laws. Peak clipping reduces capital costs, maintenance expenses, and fuel costs by actively monitoring the systems that cause peaks and assisting in balancing existing capacity with demand without the need for additional production. By allowing customers to move their load to off-peak hours, load shifting provides flexibility in how much energy is used.

Energy usage in modern buildings is tracked and measured by gadgets that communicate with a data center, giving suppliers and customers access to data. [11] This enables providers to effectively manage the load on the grid and lets consumers monitor and automate their appliances' energy use. The basis for the creation of Smart Energy Management Systems (SEMS) was established by these smart systems.

B. Smart Meter Evolution

This section outlines how meters evolved to become Smart Meters (SMs).

1) Meters for electro-mechanical

The first and most common kind of electrical meter was the electromechanical watt-hour meter, which used a revolving metal disk and two inductive coils. The disk rotated because electricity passed via inductive coils created magnetic flux. [12] The speed at which the disc rotated, in relation to electricity, was measured in order to charge customers for the amount of energy they used. Despite being favored for their straightforward construction, electromechanical meters were devoid of further functions. Electronic meters were developed as a result of the need for better monitoring and management of energy meters due to technological improvements.

2) Digital electronic meter

With the elimination of the bulky moving parts of electromechanical meters, electronic meters—which are based on digital microtechnology (DMT)—offer greater precision. [13] Additional capabilities were added as technology developed, making them more intelligent and beneficial to providers as well as customers. Effective power supply was made possible by electronic digital meters' load leveling and Real-Time Pricing (RTP) via remote access features.

3) Smart meters

An important development was the emergence of smart meters (SMs), which track energy use and regularly send data for monitoring, control, and analysis to a central server. [14] In contrast to conventional meters, SMs assessed a broad variety of electrical characteristics, including power, frequency, current, voltage, and power factor, in addition to energy consumption.

III. Proposed Methodlogy

The System Model

A. Overview of The Presented System

In this attempt, the suggested fix aesthetically unifies all specified features into a comprehensive and scalable application. This system guarantees easy installation and scalability by using the indicated promising methodologies. The solution's core components are a thorough load control and monitoring system and real-time monitoring hardware that optimizes grid efficiency parameters. In addition to providing external control of loads for appliances like air conditioners and lighting systems, this framework has a software architecture that makes it easier to analyze grid characteristics for installed facilities and provide management reports that are enlightening.

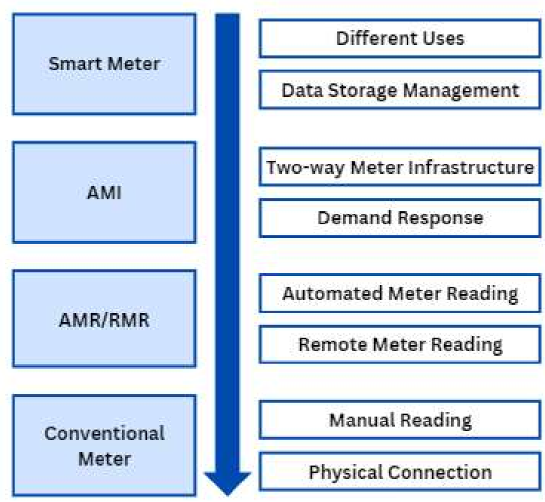

Fig. 2. Analyzing the System Workflow Through a Comprehensive Flowchart

In terms of hardware architecture, an advanced Smart Measurement (SM) is constructed, which includes the MSP430F67641 Arduino unit (MCU) for monitoring energy in three phases and the NodeMCU for creating a wireless bidirectional user interface for an Entrack-based oversight platform, as shown in Figure 2. [16] The next part explores the SM's intricate architecture.

1) architecture of the smart meter

Three advanced System-on-Chips (SoCs) are included into the SM architecture to transport data to the IoT bridging module. The first device-on-a-Chip (SoC) is the MSP430F67641 MCU from Texas Instruments, a reliable device designed for tracking grid parameters [17]. Voltage, current, authority (active, reactive in nature and apparent), efficiency, and frequency are all properly computed by this potent MCU. The next chapter goes into the mathematical model used to calculate these parameters.

2) mathematical model for grid parameters

The computational framework for sensing and gathering grid parameters—voltage, current, apparent, reactive, and power—as well as power factor and frequency—is presented in this chapter using the Texas Instruments MSP430F67641 MCU platform [18]. While the input circuit detects the voltage across the 12.40 ohm resistor load, the analog output design measures the phase current utilizing Current Transformers (CTs) that handle internal currents up to 50 mA.

3) the smart energy management system (sems) working

This section uses the components stated before to explain the SEMS's operating flow. Periodic stages are involved in SEMS operation:

- The MSP430F67641 MCU detects grid parameters, gathers data (voltage and current), and sends data to the TM4C129x MCU via UART.
- Every thirty seconds or so, the TM4C129x gathers and saves data, updating it in EEPROM memory via an interrupt.

Concurrently, a function from TM4C129x creates a connection between every grid parameter that is gathered from MSP430F67641 and a legitimate JSON format. This makes it possible to send data via UART via the third MCU, NodeMCU. The IoT router module may utilize the MQTT protocol thanks to NodeMCU, and data transfer happens around every 30 seconds.

- The acquired data is sent to the Internet of Things middleware, which connects intermediary apps and base systems [19]. Acting as a translation layer, the middleware guarantees users always have access to data and real-time processing.
- SEMS connects the IoT middleware to users by using an API to provide remote and real-time connectivity and bidirectional communication.
- The analytical part of the server tool offers a multitude of results that enable SEMS to assess the power efficiency of buildings, as well as use patterns and cycle analysis at various intervals (daily, monthly, and immediate).

B. Potential of the Implemented Sems

Future academics and developers working on developing or improving IoT-based energy management systems will find great value in the insights our study provides. In addition to addressing resource exploitation that occurs unintentionally, the energy management system that is being given highlights the necessity for customers to be environmentally aware in order to deter energy usage. Offering clients a service that provides real-time data on power use and access to installed loads (such lights and air conditioning) is the main benefit [20]. Furthermore, the SEMS that is being offered may be easily included into either new or old systems without the need for patented solutions, which makes it adaptable to a range of scenarios including energy consumption and quality control.

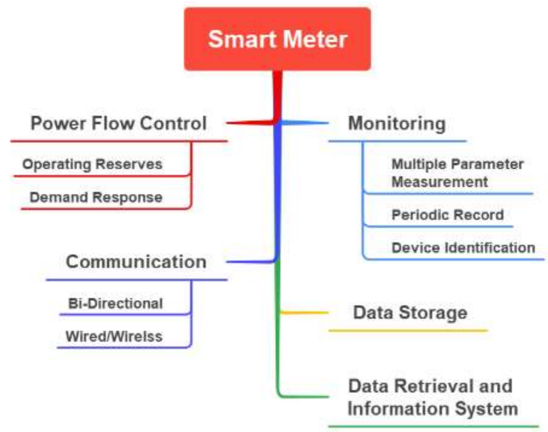

Fig. 3. Exploring System Applications and Their Implications

Applications like real-time energy and power quality monitoring and control are possible with SEMS (Figure 3). Customers may avoid the depletion of energy resources by enabling or disabling HVAC or lamp circuits via the use of a middleware module, which facilitates efficient power use. This clever method, if extensively implemented by enterprises, has the ability to detect energy-intensive machinery and processes, allowing for the creation of energy-saving plans and providing a comprehensive picture of power usage for bigger areas (cities or nations). Variations in the current and voltage have the ability to harm industrial equipment, posing a substantial expense for repair or replacement. By placing SMs on electrical lines within industrial buildings, industrial facilities may follow the power that the utility provides.

IV. Result And Discussion

The suggested Smart Meter design, which makes use of Texas Electronics' MSP430F67641 MCU, demonstrates the accuracy and flexibility required for effective grid parameter monitoring. The theoretical foundation for grid parameter monitoring clarifies the technical complexities needed to record important data points such current, voltage, energy, energy-related components, and frequency. This degree of detail is necessary to spot patterns, carry out fault investigations, and put load management plans into action—all of which improve overall energy efficiency.

A physical proof of concept is provided by testing and deploying the suggested SEMS in four Stylo Pvt. Ltd. buildings in Pakistan. The case study carried out on these locations demonstrates how the IoT-based SEMS may really improve the handling of energy. Making educated decisions about energy use is made possible by the system's immediate data gathering, transmission, and analysis capabilities. By facilitating continuous electricity transfer and immediate demand-supply balancing, the implementation of SEMS provides a responsive and fluid strategy for consumption of electricity in line with the concepts of a Smart Grid (SG) that went beyond mere monitoring.

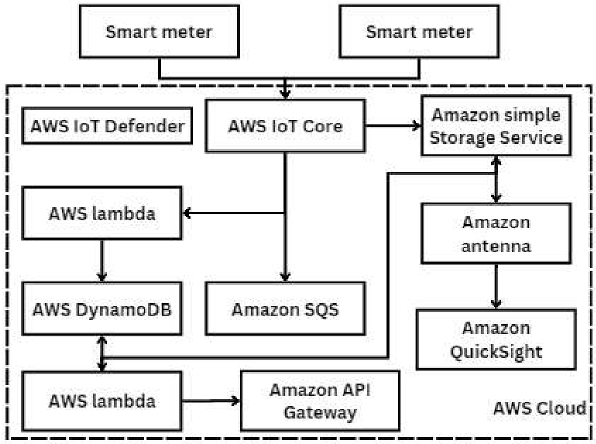

Fig. 4. Demonstrating Practical Aspects of System Implementation

Moreover, the implemented SEMS has potential that goes beyond short-term advantages. It establishes the framework for future innovations and improvements in the field of Internet of Things-based systems for energy administration (figure 4). The system's flexibility is increased by its capacity to adapt new or current settings without relying on legal solutions. By delivering immediate fashion power use statistics and enabling connection with installed loads, the SEMS may play a crucial role in promoting environmental awareness among customers. Through its integration with industrial settings, energy-intensive equipment may be identified, opening the door to energy-saving methods and advancing knowledge of regional power usage.

Fig. 5. Cost Saving Over Time with Smart Energy Management of The Applied System

In summary, the SEMS that has been shown offers a strong response to the urgent problems associated with urban energy management thanks to its integration of smart metres and Internet of Things deployment (figure 5).

V. Conclusion

In conclusion, this study effectively creates a Smart Energy Monitoring System (SEMS) using an Internet of Things (IoT) architecture with the goal of tracking smart homes' daily power use.

Future plans call for the inclusion of IoT-based smart energy meters in order to improve overall system performance and billing procedures via improved connectivity with power grids. Prospective advancements, such as the amalgamation of machine learning and deep learning methodologies, provide prospects for forecasting ideal power grid arrangements. However, issues like revamping safety regulations, standardizing communication protocols, and enhancing infrastructure in poorer nations need to be addressed. Because they may be used for tracking, surveillance, and remote control, smart devices are essential to SEMS. SEMS is expected to grow by combining consumer-side data measures with cutting-edge technology for predictive effectiveness. Finally, utility billing techniques, including the investigation of cryptocurrency possibilities, highlight the potential for creative solutions in the ever-changing field of energy management and conservation.

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