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USER-CONFIGURABLE VOLTAGE AND CONTROL OF IOT-BASED ELECTRICAL LOAD MONITORING SYSTEM (ELMS) FOR RESIDENTIAL APPLICATIONS

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Abstract:

The increasing adoption of Internet of Things (IoT) technologies in smart residential environments has intensified the need for scalable and cost-effective electrical load monitoring systems. Most existing IoT-based Electrical Load Monitoring Systems (ELMS) rely on dedicated voltage and current sensing circuits, increasing hardware complexity, calibration requirements, and deployment cost. However, for residential environments with relatively stable supply voltages, continuous voltage sensing provides limited additional benefit while significantly increasing system complexity. This study proposes an IoT-enabled ELMS that replaces dedicated voltage sensing with a cloud-configurable voltage estimation mechanism, enabling real-time power monitoring using only non-invasive current measurements. The

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proposed system integrates a non-invasive current transformer, an ESP32 microcontroller, and a cloud-based IoT platform to estimate real-time power consumption through user-configurable voltage parameters while supporting wireless data synchronization and remote monitoring. Experimental evaluation under varying load conditions demonstrated accurate real-time power computation, reliable wireless communication, and correct transitions between standby, normal, and overload operating states. Compared with conventional ELMS, the proposed architecture reduces hardware complexity by eliminating dedicated voltage-sensing circuitry while maintaining sufficient accuracy for residential energy monitoring. These findings demonstrate that configurable voltage estimation provides a practical, low-cost, and scalable solution for IoT-based residential energy awareness applications by significantly reducing hardware complexity without compromising real-time monitoring capability.

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Keyword:

Electrical Load Monitoring; Embedded Systems; Internet of Things (IoT); Residential Energy Management; User-Configurable Voltage

Introduction

The fast evolution of the Internet of Things (IoT) technologies has greatly enhanced residential energy monitoring systems as it allows acquiring data in real-time, visualising it remotely, and storing it in a cloud (Yaïci et al., 2021). Growing residential electricity demand and more awareness of energy efficiency have motivated the requirement to measure and monitor residential electricity consumption in a more cost-effective and scalable manner (Bakare et al., 2023). IoT-based systems contribute to better user interaction, increased transparency, and smart load management in smart homes.

Traditional electrical load monitoring systems calculate the instantaneous power by measuring current and voltage. Although true, this dual-sensing design adds more hardware, including voltage divides, isolation and signal conditioning units, which complicate the circuit and make it more expensive (Nur-A-Alam et al., 2021). To deploy on low-cost residential, reducing the complexity of hardware with little loss of monitoring capability is a key engineering requirement.

The most recent smart metering systems emphasise the centralised monitoring and integration with clouds (Ahmad et al., 2024; Joseph, et al., 2025). Smart meters based on machine learning will enhance the classification of appliances but add complexity and computational load to the system (da Costa Filho et al., 2025). NB-IoT systems are better in the scalability of communication but add infrastructure-dependence and increase operational (Pasaribu & Muhamad Asvial, 2024).

In spite of these developments, little focus has been put on simplifying sensing architecture using other strategies to do computations. Normal operating conditions in most residential settings have a narrow tolerance range of supply voltage. High-precision voltage tracking may not be necessary in energy awareness applications and overload supervision applications. This finding inspires research into simplified architectures, which minimally decrease the number of hardware elements, but still allow reasonable monitoring accuracy.

The proposed research hypothesises an Electrical Load Monitoring System based on IoT that allows users to customise through a dynamically adjustable voltage parameter and replaces the hardware-based voltage sensing method with an IoT dashboard system. This goal is to simplify architecture, not to increase metrological accuracy. The system is a compact ESP32-based system that combines real-time current sensing, embedded power computation, overload detection, and dual local-remote control.

Literature Review

Residential energy monitoring has increasingly leveraged IoT to enable remote visualisation, automated logging, and user-centric feedback. Reviews on IoT infrastructures for building energy systems emphasise that low-cost connectivity and cloud integration are key enablers of scalable monitoring deployments (Yaïci et al., 2021). In parallel, demand-side energy management surveys highlight that actionable monitoring is a prerequisite for effective demand response and consumer participation (Bakare et al., 2023). Smart home energy management reviews further indicate that the integration of sensing, communication, and control is typically achieved through layered architectures that increase system complexity as functionality expands (Badar & Anvari-Moghaddam, 2022b).

In real-life applications, numerous IoT energy monitoring systems are based on full voltageand-current sensing chains in order to obtain a greater measurement fidelity. For example, IoT smart metering and monitoring systems commonly integrate sensing, embedded computation, and networking features to support real-time reporting and analytics (Ahmad et al., 2024; Avancini et al., 2021). IoT-based appliance monitoring frameworks also commonly retain conventional voltage measurement paths and communications modules to ensure accurate computation and remote operation (Nur-A-Alam et al., 2021). NB-IoT-based household monitoring is communication-oriented, showing scalability of connection to residential monitoring, yet it still presupposes a traditional sensing structure and stable functioning of the backhaul (Pasaribu & Muhamad Asvial, 2024).

Recent research has also expanded toward higher-level functionalities such as smart energy management middleware and cloud integration for demand-side management (Saleem et al., 2021, 2023), and smart-meter architectures that incorporate flexible communication interfaces to improve interoperability and deployment practicality (Avancini et al., 2021). Besides direct metering, non-intrusive load monitoring (NILM) and energy disaggregation surveys show that, at the cost of signal processing and model robustness, appliance-level inference can be made as minimally invasive of sensing as possible (Huber et al., 2021; Kaselimi et al., 2022; Schirmer & Mporas, 2023). Subsequent NILM scaling reviews continue to focus on the practical

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implementation issues, such as home-to-home generalisation and noise sensitivity in measurements (Luo et al., 2025; Papageorgiou et al., 2025).

Although these studies demonstrate substantial progress in sensing accuracy, scalability, and analytics, fewer works focus on reducing the sensing hardware footprint when the target use case is residential energy awareness rather than billing-grade metrology. This gap motivates the proposed system, which removes dedicated voltage-sensing hardware and instead adopts a user-configurable voltage parameter to reduce component count and simplify deployment, while clearly bounding the application scope to environments with relatively stable supply voltage.

Methodology

The proposed IoT-based Electrical Load Monitoring System (ELMS) was developed to enable real-time monitoring of residential electrical loads with user-configurable voltage input and overload indication. Monitoring architectures with IoT have been popular in the construction and residential energy systems because of their ability to obtain remote data and visualise it (Yaïci et al., 2021). The methodology will include system architecture design, hardware implementation, embedded firmware development, IoT communication, and experimental setup to validate this.

The overall system architecture is illustrated in **Figure 1**. The system integrates sensing modules, a central processing unit, local display components, indicator outputs, and IoT communication interfaces. The ESP32 microcontroller serves as the primary processing and communication unit. It performs sensor data acquisition, power computation, threshold comparison, output control, and wireless transmission to the IoT platform via integrated Wi-Fi.

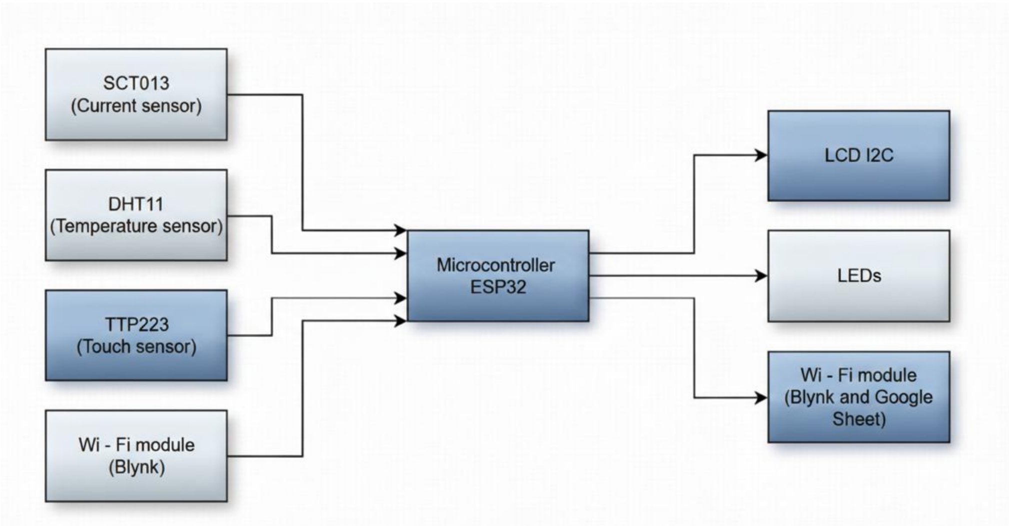

Figure 1: Block diagram of the IoT-based ELMS

AC current measurement is implemented using the SCT-013 non-invasive current transformer sensor. Measurement Current transformer (CT)-based measurement is popular in residential energy monitoring systems because it has electrical isolation and safety in operation (Ruano et al., 2019). Alternating current is measured on the sensor by clamping around the live conductor of the load without electrical contact. The analogue signal is connected to the ESP32 analogue-

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to-digital converter and processed with the EmonLib library. The firmware included calibration parameters to scale the sensor with reference measurements.

The system does not use a specific voltage-sensing circuit, but rather, a user-configurable voltage parameter, which would be defined in the Blynk IoT application. The mobile slider interface is used to set the voltage value and send it to the ESP32 in real time. This will minimise the complexity of hardware but still allow flexibility in residential use. The immediate power consumption is calculated by taking the basic electrical power equation (Badar & Anvari-Moghaddam, 2022a):

$$P = V \times I$$

where V is the user-defined voltage, and I is the measured current. The computed power value is constantly checked against a predefined power threshold in order to identify overload conditions.

The temperature sensor is added by the DHT11 digital sensor that would give additional environmental data. Monitoring of environmental parameters is usually incorporated in IoT-based energy systems to improve operational awareness (Yaïci et al., 2021). The sensor connects with the ESP32 and reports ambient temperature, which is used with electrical parameters. A local visualisation is carried out with a 16×2 I2C LCD module to show the voltage, current, power and temperature in real time. Two LEDs are used for system indication: a green LED represents system activation status, while a red LED is triggered when the calculated power exceeds the predefined limit.

The system operation sequence is shown in Figure 2. After initialisation and Wi-Fi connection establishment, the system can be activated via a capacitive touch sensor or remotely through the Blynk interface. During operation, the ESP32 performs current acquisition, retrieves the configured voltage value, calculates power consumption, evaluates the overload condition, updates display outputs, and transmits data to the IoT platform and Google Sheets for logging in a continuous monitoring loop. The IoT-based monitoring and remote visualisation solutions align with the modern smart home energy management deployments (Badar & Anvari-Moghaddam, 2022a).

To achieve hardware implementation, a printed circuit board (PCB) was developed and manufactured as a way of assembling all the components. The experimental design was to test the prototype in various residential load conditions. Measured current values were taken and equated with reference measurement instruments. The quantitative evaluation of system performance is presented in Result & Discussion Section.

Results & Discussion

The experimental evaluation of the proposed IoT-based Electrical Load Monitoring System (ELMS) was conducted to validate hardware integration, functional logic, user-configurable voltage operation, IoT synchronisation, and dynamic parameter response. The findings verify a stable behaviour of systems in a variety of operating conditions.

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Hardware Implementation and Functional Verification

The fabricated PCB and final enclosure are shown in **Figure 3**. The ESP32 microcontroller was integrated with the SCT-013 current sensor, DHT11 temperature sensor, LCD module, capacitive touch sensor and LED indicators, which have been staged tested. Functional verification under standby, normal operation, and overload conditions was done to systematically validate system logic. The observed behaviour is summarised in **Table 1**.

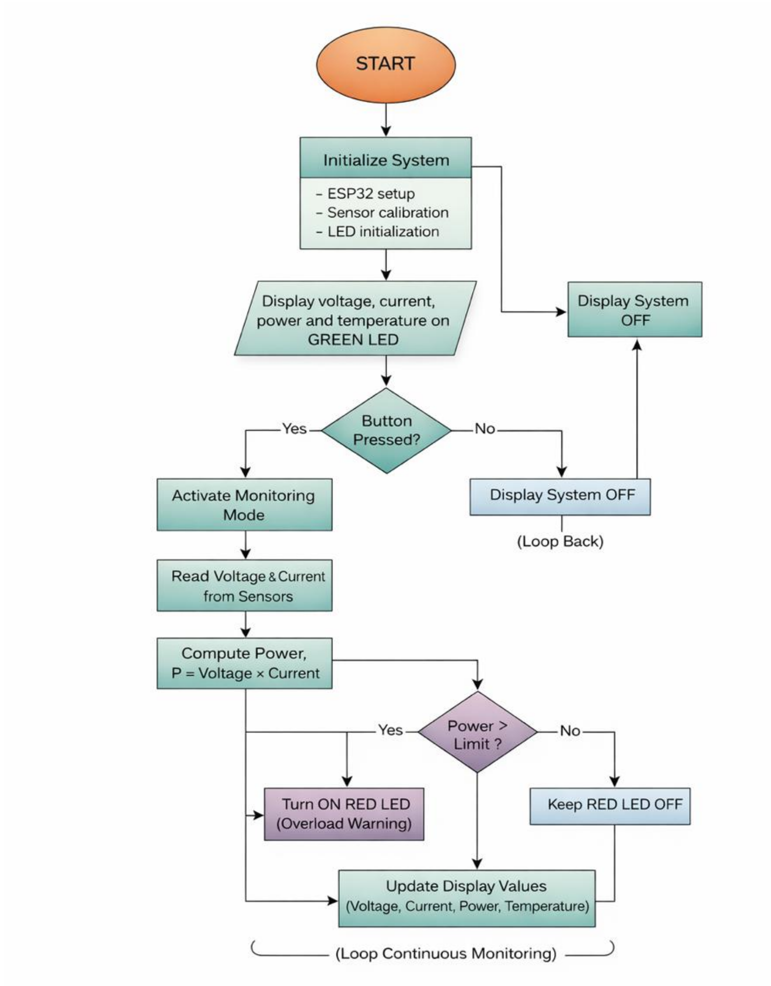

Figure 2: Operational Flowchart Of IoT-Based ELMS

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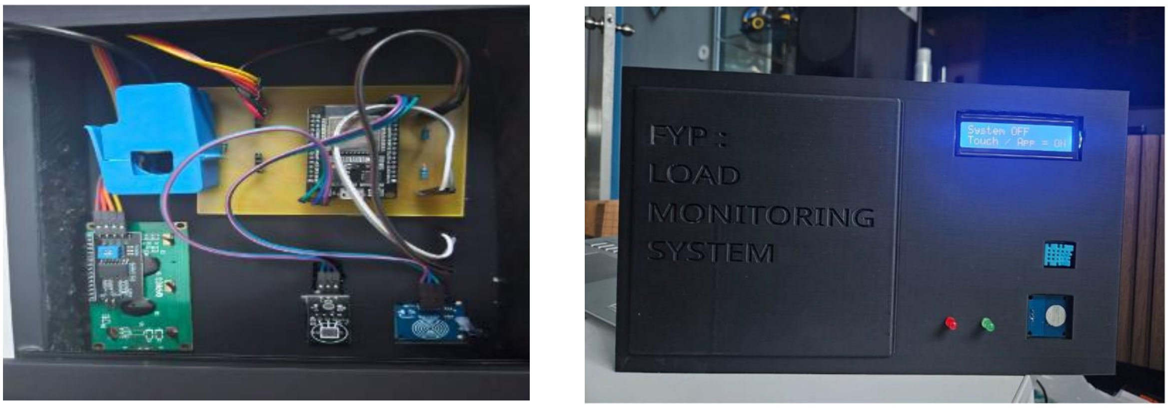

(a) (b)

Figure 3: Hardware Prototype of IoT-based ELMS (a) Internal (b) External

Table 1: Functional Verification of System Operating States

Operating State	User Action	LCD Display	Green LED	Red LED	Interpretation
Standby	No Activation	"System OFF"	OFF	OFF	System inactive
Normal Operation	Touch/App ON	Voltage, Current, Power Temperature displayed	ON	ON	Power below threshold
Overload	Load Exceeds 5000W	Power Exceeds limit	ON	ON	Threshold condition triggered

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Figure 4: Blynk Dashboard of ELMS

Evaluation of User-Configurable Voltage Mechanism

A key feature of the proposed system is the elimination of a dedicated voltage-sensing circuit and the adoption of a user-configurable voltage parameter through the IoT interface. The Blynk dashboard shown in
Figure **4** enables dynamic voltage adjustment via a slider control. When testing was done, variations in the set voltage were accompanied by proportional variations in the calculated power as the measured current was held constant with a particular load. This validates that the embedded firmware is properly updating the computation of power in real time because of user defined voltage input. The bidirectional communication between the mobile interface and the ESP32 controller operated without observable delay. This approach reduces hardware complexity and cost while maintaining computational flexibility. However, the accuracy of power estimation depends on the correct voltage input by the user.

Dynamic Parameter Variation Analysis

To evaluate system responsiveness under varying conditions, voltage, current, power, and temperature variations during the monitoring period are illustrated in Figure 5 using a compact 2×2 bar chart representation.

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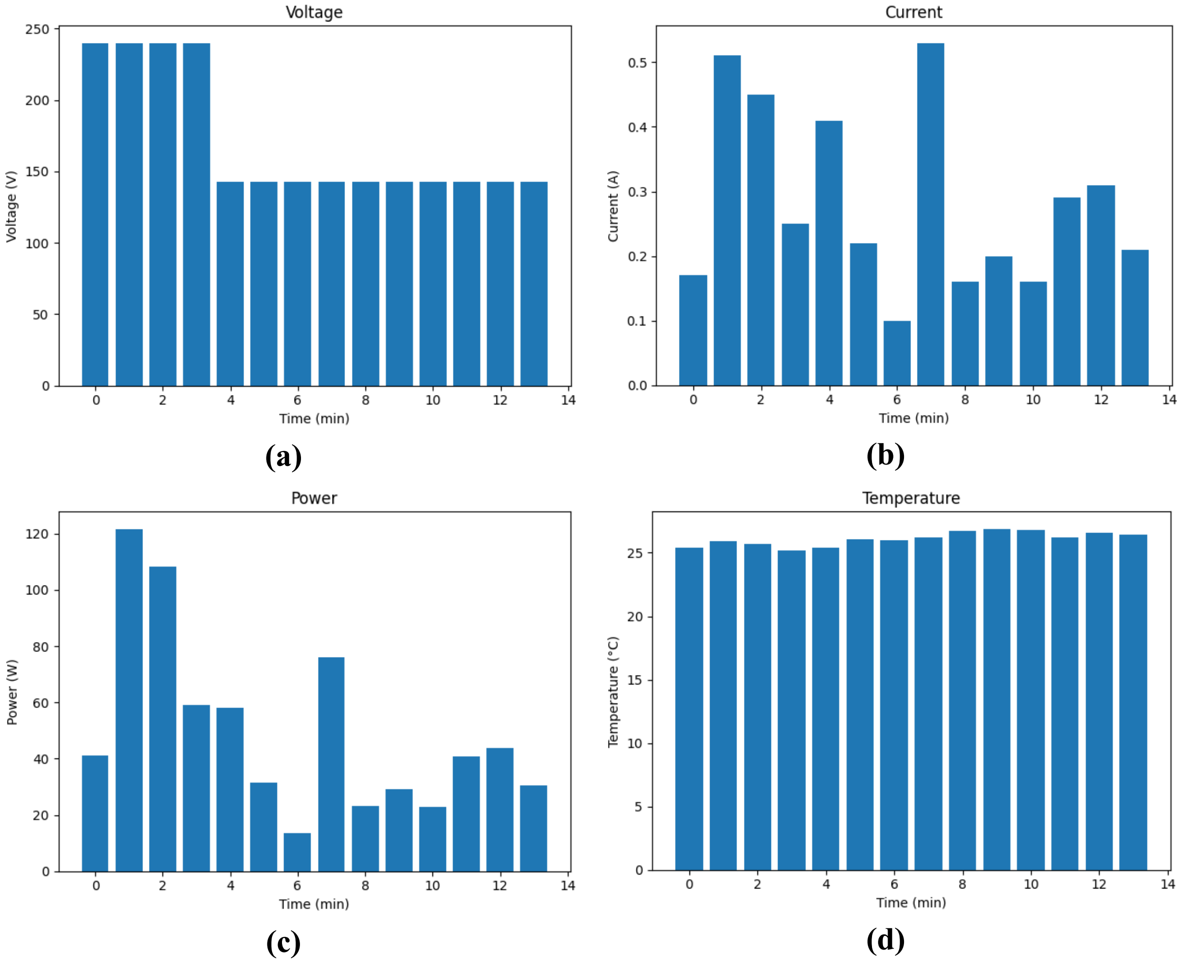

Figure 5: Electrical And Environmental Parameter Variations During Monitoring Period: (A) Voltage, (B) Current, (C) Power, And (D) Temperature.

Figure 5(a) of the voltage profile indicates that there are two different levels of voltage, 240 V and 143 V, that represent different configured voltage settings and conditions observed. This confirms that the system is able to adjust to the voltage input specified by the user. The current variation, as in Figure 5(b), is between about 0.10 A and 0.53 A. In Figure 5(c), the power change is proportional to the values of the power changing between about 13.66 W and 121.7 W. The embedded computational model is confirmed by the direct correlation between current and power. The temperature range in Figure 5 (d) is very narrow (25.2°C to 26.9°C), which means that there were no significant changes in temperature, and the sensor functions correctly. The timing alignment of current, voltage and power is a validation of the proper real-time interrelation of sensing and computational modules.

The integrated experimental results demonstrate consistent system operation across standby, normal load, and overload conditions. . The programmable computation chip precisely adds measured current to a user-adjustable voltage to calculate real-time power consumption. The mechanism that detects overload reacts suitably in case defined limits are crossed, and the warning indicator is activated. The suggested ELMS has a functional monitoring performance and minimises the complexity of the hardware by dropping the direct voltage sensing circuitry. The system is flexible and low-cost, although it requires user-dependent variability due to the dependence on manual voltage input.

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Conclusion

This paper introduced the design and experimental validation of an IoT-based Electrical Load Monitoring System (ELMS), which is user-configurable and can be used in residential environments. The suggested system incorporates non-invasive current sensing, embedded real-time power calculation, overload sensing, local display, and cloud-based monitoring into a small ESP32-based system. The working of the system under normal load, standby and overload was tested experimentally. The linear correlation between measured current and calculated power confirmed the operation of the implemented power model, whereas the alignment of the local LCD interface with the IoT dashboard confirmed the feasibility of the wireless communication and data recording.

One of the contributions of this work is that the IoT platform has been used to implement a user-configurable voltage mechanism, which does not require specific voltage sensing hardware. This strategy minimises the circuit complexity and cost and still maintains its flexibility to various residential voltage settings. In spite of the fact that power estimation relies on the proper input of the users, the system offers a feasible and scalable solution to low-cost residential energy monitoring. Enhancements in the future could involve automatic voltage sensing and long-term field validation to further increase autonomy and robustness in measurements.

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References

Ahmad, S. S., Almasalha, F., Qutqut, M. H., & Hijjawi, M. (2024). Centralized smart energy monitoring system for legacy home appliances. *Energy Informatics*, *7*(1). https://doi.org/10.1186/s42162-024-00334-2

Avancini, D. B., Rodrigues, J. J. P. C., Rabêlo, R. A. L., Das, A. K., Kozlov, S., & Solic, P. (2021). A new IoT-based smart energy meter for smart grids. *International Journal of Energy Research*, *45*(1). https://doi.org/10.1002/er.5177

Badar, A. Q. H., & Anvari-Moghaddam, A. (2022a). Smart home energy management system – a review. *Advances in Building Energy Research*, *16*(1), 118–143. https://doi.org/10.1080/17512549.2020.1806925

Badar, A. Q. H., & Anvari-Moghaddam, A. (2022b). Smart home energy management system– a review. In *Advances in Building Energy Research*. https://doi.org/10.1080/17512549.2020.1806925

Bakare, M. S., Abdulkarim, A., Zeeshan, M., & Shuaibu, A. N. (2023). A comprehensive overview on demand side energy management towards smart grids: challenges, solutions, and future direction. In *Energy Informatics* (Vol. 6, Number 1). https://doi.org/10.1186/s42162-023-00262-7

da Costa Filho, P. E., Marques, L. A. de A., Lima, I. da S. F. de, Sousa, E. L. de, Kreutz, M. E., Neto, A. V., Cunha, E. N., & Vieira, D. (2025). Machine-Learning-Based Classification of Electronic Devices Using an IoT Smart Meter. *Informatics*, *12*(2). https://doi.org/10.3390/informatics12020048

Huber, P., Calatroni, A., Rumsch, A., & Paice, A. (2021). Review on deep neural networks applied to low-frequency nilm. In *Energies* (Vol. 14, Number 9). https://doi.org/10.3390/en14092390

Joseph, B., Gayathri, P., .Vamshi, A., .Prabhas, B., & .Sridhar, G. (2025). IOT Based Smart Energy Meter. *INTERANTIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT*, *09*(04). https://doi.org/10.55041/ijsrem43659

Kaselimi, M., Protopapadakis, E., Voulodimos, A., Doulamis, N., & Doulamis, A. (2022). Towards Trustworthy Energy Disaggregation: A Review of Challenges, Methods, and Perspectives for Non-Intrusive Load Monitoring. In *Sensors* (Vol. 22, Number 15). https://doi.org/10.3390/s22155872

Luo, Q., Yu, T., Liang, M., Pan, Z., Guo, W., & Hu, X. (2025). Review of advances in scaling non-intrusive load monitoring for real-world applications. *Applied Energy*, *398*. https://doi.org/10.1016/j.apenergy.2025.126462

Nur-A-Alam, Ahsan, M., Based, M. A., Haider, J., & Rodrigues, E. M. G. (2021). Smart monitoring and controlling of appliances using lora based iot system. *Designs*. https://doi.org/10.3390/designs5010017

Papageorgiou, P. G., Christoforidis, G. C., & Bouhouras, A. S. (2025). NILM in high frequency domain: A critical review on recent trends and practical challenges. In *Renewable and Sustainable Energy Reviews* (Vol. 213). https://doi.org/10.1016/j.rser.2025.115497

Pasaribu, S. T., & Muhamad asvial, M. asvial. (2024). Design of NB-IoT Based Household Light Electric Energy Monitoring System. *International Journal of Electrical, Computer, and Biomedical Engineering*, *2*(1). https://doi.org/10.62146/ijecbe.v2i1.34

Ruano, A., Hernandez, A., Ureña, J., Ruano, M., & Garcia, J. (2019). NILM techniques for intelligent home energy management and ambient assisted living: A review. In *Energies* (Vol. 12, Number 11). https://doi.org/10.3390/en12112203

Saleem, M. U., Shakir, M., Usman, M. R., Bajwa, M. H. T., Shabbir, N., Shams Ghafaroki, P., & Daniel, K. (2023). Integrating Smart Energy Management System with Internet of

Things and Cloud Computing for Efficient Demand Side Management in Smart Grids. *Energies*, *16*(12). https://doi.org/10.3390/en16124835

Saleem, M. U., Usman, M. R., & Shakir, M. (2021). Design, Implementation, and Deployment of an IoT Based Smart Energy Management System. *IEEE Access*, *9*. https://doi.org/10.1109/ACCESS.2021.3070960

Schirmer, P. A., & Mporas, I. (2023). Non-Intrusive Load Monitoring: A Review. *IEEE Transactions on Smart Grid*, *14*(1), 769–784. https://doi.org/10.1109/TSG.2022.3189598

Yaïci, W., Krishnamurthy, K., Entchev, E., & Longo, M. (2021). Recent advances in internet of things (IoT) infrastructures for building energy systems: A review. In *Sensors*. https://doi.org/10.3390/s21062152