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From Smart Meters to Smart Sentinels: Advancements in Energy Management

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ABSTRACT : This paper presents a comprehensive review of the literature surveyed as part of the development of the Smart Sentinel project. The reviewed works focus on advancements in energy management technologies, particularly in areas such as real-time device-level monitoring, voltage protection, and IoT-enabled solutions. Each study offers insights into addressing challenges like energy inefficiency, appliance safety, and sustainability. Through this review, the comparative strengths and limitations of existing systems are highlighted, laying the groundwork for the design and implementation of the Smart Sentinel, which aims to integrate these features into a unified and user-friendly energy management solution.

Keywords: *Energy Management, IoT, Smart Sentinel, Voltage Protection, Energy Optimization, Smart Meters*

I. INTRODUCTION

Effective energy management is essential for saving money and protecting the environment. Traditional EMS often lack detailed insights, meaning users can't see which devices are driving up their energy bills. They also often skip the important job of regulating voltage, which can harm appliances and create safety risks. Not to mention, their complex interfaces deter users from adopting energy-saving habits.

Smart technology has revolutionized energy management. The Smart Sentinel is an advanced solution offering real-time monitoring at the device level, recommendations for improving energy efficiency, and alerts for voltage issues— all wrapped up in an easy-to-use interface. This makes it easier for users to save energy, extend the life of their appliances, and cut costs.

II. LITERATURE SURVEY

Irfan Mujawar, Anwar Mulla, Taha Karbhari [1], The focus of this paper is on merging advanced smart technologies with traditional energy grids to address their historical limitations. Traditional grids offer a broad overview of energy consumption but often fall short in providing detailed, appliance-level insights. The proposed system integrates sophisticated algorithms to track real-time energy consumption for each appliance. This granular data allows users to identify energy-wasting appliances and adjust their usage patterns, resulting in substantial energy and cost savings. Additionally, this system fosters user empowerment by providing the tools necessary for active energy management and sustainability. By highlighting which appliances consume excessive energy, users can make informed decisions to replace or better manage these devices. The system promotes sustainability by enabling targeted energy-saving modifications, such as turning off high-energy devices when not in use or optimizing their operation during off-peak hours. These measures ensure financial benefits and positive contributions to environmental conservation. Unlike traditional EMS, which provide generalized consumption figures, this system focuses on individual appliance usage. This detailed approach helps users make more precise and impactful adjustments to their energy habits, ultimately supporting a more sustainable future. Furthermore, the system promotes sustainability by enabling more targeted energy-saving modifications. By focusing on specific appliances, users can implement changes that have a greater impact on their overall energy consumption. This could include turning off devices when not in use, optimizing usage during off-peak hours, or replacing high-energy-consuming appliances with more efficient models. Such measures contribute positively to environmental conservation efforts by reducing energy waste and lowering carbon footprints.

Sudhakar K N, P.T. Devadarshini, Ramu K N, Deshveer, N.V.S. Suryanarayana, V Raviteja Kanakala [2], This study emphasizes the crucial yet often-overlooked role of voltage stability in effective energy management. The authors propose integrating IoT-enabled devices to enhance voltage stability and comprehensive energy management. IoT sensors continuously monitor voltage levels, identifying fluctuations in real-time and alerting users to potential issues. This enables users to take swift corrective actions, preventing appliance damage and avoiding costly repairs. The collected real-time data also offers deep insights into energy usage patterns, helping users develop more efficient habits. By integrating IoT technology, the system ensures voltage levels remain within a safe range, safeguarding household appliances and promoting proactive energy management. This approach reduces overall energy consumption and encourages users to adopt more sustainable practices, ultimately contributing to a lower carbon footprint. Unlike traditional EMS, which often lack real-time feedback and detailed voltage stability information, this IoT-enabled system offers a seamless, user-friendly experience that optimizes energy use and promotes user convenience. On a larger scale, such systems can enhance the efficiency and reliability of energy grids, supporting broader sustainability goals. Moreover, the system's ability to monitor and manage energy consumption in real-time promotes proactive energy management. Users are not just passive recipients of energy bills but active participants in controlling and optimizing their energy use. This approach aligns with modern energy management trends, which emphasize user engagement and sustainability.

Aaesha Alshehhi, Fatma Alawadhi, Meera Baqer, Rached Dhaouadi [3], The integration of Internet of Things (IoT)-based devices into household energy management systems offers significant enhancements in energy efficiency. This paper proposes a centralized platform that connects all energy-consuming appliances within a household, leveraging IoT technology to monitor and optimize energy usage effectively. Central to this approach are smart plugs, which track the specific energy consumption of each connected appliance. The paper provides compelling evidence that adopting IoT-based systems can lead to substantial energy savings. These savings translate into lower utility bills, offering financial benefits to households. Additionally, the detailed insights gained from monitoring individual appliance consumption empower users to adopt sustainable practices, reducing their overall carbon footprint. By identifying high- energy-consuming devices, users can make informed decisions to ensure more efficient energy use. A significant advantage of this system is its ability to foster proactive energy management. Users are not just passive recipients of energy bills but active participants in controlling and optimizing their energy use. The centralized platform enables users to set schedules for appliances, receive notifications about unusual energy consumption, and remotely control devices to avoid unnecessary energy waste. This approach simplifies the process of maintaining energy-saving habits over time, making it easier for users to achieve and sustain energy efficiency. Furthermore, the potential for IoT technology to significantly enhance the efficiency and sustainability of energy consumption is emphasized. By providing real-time data and control, the system simplifies the process of making informed decisions about energy use. This shift towards smarter, more connected households represents a significant step forward in contemporary energy management.

Anandhu Anilkumar, Anie George, Aswin M R, Devika G, Anu Jyothy [4], This paper discusses the innovative use of IoT-based smart plugs designed for real-time energy monitoring at the appliance level. These smart plugs gather precise energy usage data and relay it to users through an interconnected cloud- based platform. The system provides users with detailed insights into their energy consumption patterns, enabling them to identify which appliances are consuming unnecessary power and to make informed decisions to optimize their energy use.The smart plugs are equipped with advanced sensors that track the energy consumption of each

connected appliance in real-time. This granular data visibility allows users to turn off devices that are consuming unnecessary power, set schedules for high-energy-consuming appliances, and receive notifications about irregular usage patterns. For example, if a smart plug detects that an appliance is using more energy than usual, it can alert the user, who can then investigate and address the issue.The cloud-based platform integrates the data collected by the smart plugs, offering users remote access and control over their appliances. This capability enhances convenience by allowing users to manage their energy consumption even when they are not at home. Users can remotely turn off appliances that were accidentally left on, ensuring energy is not wasted. Additionally, the platform's scheduling feature enables users to automate the operation of high-energy devices, optimizing their usage during off-peak hours when energy is cheaper and consumption is lower.

Zhixi Deng, Yuanfeng Zhou, Ahmad Kamal, Risha Na, Ian P. Brown, Z. John Shen[5] ,Electrical faults pose significant fire or shock hazards in homes and offices, and flexible power cords are especially vulnerable due to metal or insulation degradation. This vulnerability can lead to various types of electrical faults, making it crucial to have effective protective measures. This article introduces an innovative device called Smart Plug 2.0, which offers comprehensive protection against multiple electrical faults, including short circuits, overloads, arc faults, and ground faults. Unlike conventional smart plugs that primarily focus on wireless power control and monitoring, Smart Plug 2.0 goes a step further by integrating advanced protection features into the same hardware structure, ensuring all-in-one safety. In addition to its protective features, Smart Plug 2.0 retains the wireless power control and monitoring functions of conventional smart plugs. Users can remotely control their appliances, monitor energy consumption, and receive alerts about potential issues. This combination of advanced protection and user-friendly features makes Smart Plug 2.0 a versatile and valuable addition to any smart home or office setup. Smart Plug 2.0 represents a significant advancement in electrical safety technology. Its ability to detect and respond to electrical faults with microsecond precision, coupled with its comprehensive protection features, sets a new standard for smart plug devices. By reducing electrothermal stress and preventing potential hazards, it ensures a safer environment for users. Its cost-effective design and integration of multiple protective functions make it an innovative and essential tool for modern homes and offices.

M Karthik, R S Reshmin Shafi, M Ramasubramanian, M Pranavsai[6], Overloading electrical circuits poses significant risks, including severe damage or appliance failure. This paper introduces a smart load safety system that continuously monitors power consumption levels to detect potential overloads in real time. When consumption surpasses safe thresholds, the system alerts users and can automatically shut down specific appliances to prevent damage. This proactive approach enhances safety and efficiency, safeguarding appliances and optimizing energy management practices. The system's real-time monitoring and data collection emphasize modern technology's role in energy management. By merging safety with efficiency, the smart load safety system helps users reduce utility costs, prolong device lifespan, and maintain optimal energy use. Beyond protecting appliances, this system empowers users to take a more active role in managing energy consumption. Immediate feedback and automated protective measures offer a comprehensive solution to energy management challenges, highlighting the necessity of integrating advanced technologies into residential and commercial environments. This fusion of safety and efficiency underscores the importance of modern technology in ensuring sustainable and secure energy use.

Muhammad Haseeb Raza, Yousaf Murtaza Rind, Isma Javed, Muhammad Zubair, Muhammad Qasim Mehmood, Yehia Massoud [7], Smart Energy (SE) technology, crucial in tackling climate change and rising energy demands, integrates information and communication technologies into energy systems for optimized operation. At the heart of SE operations, smart meters collect detailed energy consumption data, forming the basis for Business Intelligence (BI) across various levels, from sensing infrastructure to cloud computing, leveraging Internet of Things (IoT) frameworks. The evolution and increasing complexity of smart meters have enhanced their role in real-time energy monitoring, management, and distribution, providing valuable insights that help optimize energy use, reduce waste, and promote sustainability. The paper thoroughly examines different layers of SE systems, current technological advancements, and the diverse applications of smart meters, ranging from consumer-level use to fog computing environments. Through the stratification of computational loads across IoT layers, SE systems efficiently handle the growing complexity of energy management. The integration of BI and smart meter data facilitates proactive energy management, ensuring accurate and timely data processing. Despite significant advancements, the paper identifies existing research gaps and future directions, particularly in developing next-generation smart metering infrastructure and adapting these systems to evolving energy needs. This ongoing research is pivotal in enhancing SE systems' efficiency and effectiveness, ultimately contributing to more sustainable and optimized energy management solutions, thereby driving towards a greener and sustainable future.

III. COMPARATIVE ANALYSIS OF LITERATURE REVIEWS

Table 1: Comparison study of papers

Paper Title	Authors	Comparative Study
IoT-Based Smart Energy Meter for Recording Device-Level Electrical Parameters	Irfan Mujawar, Anwar Mulla, Taha Karbhari	This paper discusses the development of a real-time, appliance-level energy optimization system, which is quite similar to the approach taken by Smart Sentinel. However, Smart Sentinel stands out by offering a more advanced set of features that elevate its overall functionality and user experience. In addition to providing detailed, real-time monitoring of energy consumption at the appliance level, Smart Sentinel includes essential voltage protection mechanisms that safeguard appliances from potential damage due to voltage fluctuations. This ensures a longer lifespan for household and office devices. Furthermore, Smart Sentinel's user-friendly interface simplifies the process of monitoring and managing energy usage, making it accessible and practical for a wide range of users. By integrating these advanced features, Smart Sentinel not only enhances energy optimization but also promotes electrical safety and sustainability, offering a more comprehensive and appealing solution compared to traditional IoT-based energy-efficient devices. This holistic approach ensures that users can enjoy a smarter, safer, and more efficient energy management experience in both residential and office environments.
IoT based Smart Automation System For Energy Management	Sudhakar, Devadarshini, Suryanarayana, V Raviteja Kanakala	This paper delves into the capabilities of IoT-based energy-efficient devices, with a focus on device- level monitoring, which is also a key feature of Smart Sentinel. However, Smart Sentinel sets itself apart by offering a more comprehensive suite of functionalities. It not only provides real-time monitoring of voltage fluctuations, which helps in safeguarding appliances from potential damage and prolongs their lifespan, but also delivers tailored energy-saving recommendations. This allows users to proactively optimize their energy consumption based on detailed and personalized insights. Such a holistic approach ensures that Smart Sentinel not only enhances energy efficiency and sustainability but also improves overall electrical safety. By integrating advanced monitoring, predictive maintenance, and an intuitive user interface, Smart Sentinel effectively addresses the inherent limitations of traditional energy management systems. This makes it a more robust and eco- friendly solution for energy management in both residential and office environments, creating a smarter, safer, and more efficient experience.
Scheduling Optimization of Household Equipment Using a Wireless Home Automation System	Aesha Alshehhi,Fatma Alwadhi,Meers Baqer, Rached Dhaouadi	This paper delves into the realm of IoT (Internet of Things)-based energy-efficient devices, highlighting their capabilities in device-level monitoring, muchlike Smart Sentinel does. However, Smart Sentinel sets itself apart by offering a broader range of functionalities. It provides real-time monitoring of voltage

		fluctuations, which safeguards appliances from potential damage and extends their lifespan. In addition to this, Smart Sentinel delivers tailored energy-saving recommendations, enabling users to optimize their energy consumption proactively. Its comprehensive approach ensures not only energy efficiency and sustainability but also enhances overall electrical safety, making it a more holistic solution compared to standard IoT-based energy- efficient devices. By integrating advanced monitoring, predictive maintenance, and a user- friendly interface, Smart Sentinel addresses the inherent limitations of traditional systems and fosters a more efficient, reliable, and eco-friendly energy management experience in both residential and office settings.
Iot Based Smart Plug	Anandhu Anilkumar, Anie George, Aswin M R, Devika G	The smart plug system presented in this study shares similarities with Smart Sentinel's emphasis on energy monitoring. However, Smart Sentinel goes further by incorporating advanced features like voltage fluctuation detection, which helps protect appliances from potential damage and ensures their longevity. Additionally, it includes predictive maintenance capabilities that allow users to anticipate and address issues before they become significant problems, thereby reducing downtime and maintenance costs. Moreover, Smart Sentinel boasts a more robust user interface, designed to be user-friendly and intuitive, encouraging users to adopt energy-efficient practices. This combination of advanced monitoring, predictive maintenance, and a user-centric design makes Smart Sentinel a comprehensive solution for not only optimizing energy consumption but also enhancing overall electrical safety and promoting sustainability in residential and office environments. By addressing the limitations of traditional systems, Smart Sentinel provides a more efficient, reliable, and holistic energy management experience.
Smart Plug 2.0: A Solid-State Smart Plug Device Preventing Fire and Shock Hazards	ZhixiDeng, Yuanfeng Zhou, Ahmad Kamal, Risha Na	Smart Sentinel and Smart Plug 2.0 both address critical aspects of modern energy management and electrical safety. Smart Sentinel transforms traditional energy management systems by offering real-time device-level monitoring, custom energy- saving recommendations, and protection against voltage fluctuations. Its intuitive interface improves energy efficiency and sustainability while reducing utility costs. On the other hand, Smart Plug 2.0 advances electrical safety by integrating comprehensive protection against short circuits, overloads, arc faults, and ground faults. Along with microsecond-scale fault detection and machine learning-based arc detection, it ensures rapid response to electrical faults, reducing electrothermal stress and preventing hazards. Both projects highlight the importance

		of modernizing traditional systems to enhance safety, efficiency, and sustainability. Smart Sentinel promotes a sustainable lifestyle through energy optimization, while Smart Plug 2.0 ensures a safer electrical environment, protecting appliances and infrastructure. Together, these innovations pave the way for smarter, safer, and more efficient energy use in residential and office settings.
Smart Load Safety System	MKarthik, R Reshmin, Ramasubramaniam , M Pranavsai	This paper introduces a load safety system that includes certain protection features similar to those found in Smart Sentinel, such as safeguarding against potential electrical faults. However, Smart Sentinel goes beyond mere safety by offering a more comprehensive suite of functionalities. It provides detailed insights into energy consumption patterns at the device level, allowing users to monitor and manage their energy usage more effectively. In addition to real-time optimization and personalized energy-savingrecommendations,Smart Sentinel includes voltage fluctuation alerts to protect appliances and ensure their longevity. This holistic approach makes Smart Sentinel not only a tool for enhancing electrical safety but also a powerful solution for promoting energy efficiency, sustainability, and cost savings in residential and office environments. By integrating advanced monitoring and optimization features within a user-friendly interface, Smart Sentinel addresses the inherent limitations of traditional systems to create a more efficient and eco-friendly energy management experience.
Smart Meters For Smart Energy : A Review Of Business Intelligence Applications	Muhammed Haseeb , Yousaf Murtaza Rind, Isma Javed, Muhammed Zubair	Both Smart Sentinel And Smart Energy (SE) system highlights advancements in energy management technology, with distinct focuses.SE emphasizes the integration of information and communication technologies with smart meters within Iot frameworks to drive Business Intelligence for optimizing energy systems. It delves into the evolution of smart meters ,computational load distribution across Iot Layers and future research directions. While Se offers a comprehensive analysis of infrastructural integration and application , Smart Sentinel ensures immediate, actionable insights and enhanced appliance safety for users, making energy management more efficient and practical in residential and office settings

IV. CONCLUSION

The comparative review of the seven papers presents a variety of solutions aimed at improving energy management through real-time monitoring, voltage protection, and optimization across different dimensions. Many of these studies have dedicated their focus to specific aspects. Some zero in on voltage regulation, ensuring that electrical systems maintain a stable voltage to protect devices from potential damage. Others emphasize device-level monitoring, providing detailed analytics on energy consumption patterns and helping users identify areas of inefficiency. These solutions often present fragmented approaches that

tackle one or two aspects of energy management, leaving gaps that can result in inefficiencies and higher energy costs.

On the other hand, Smart Sentinel stands out by offering a well-rounded, comprehensive solution that integrates these features into a unified, user-friendly platform. It not only provides detailed insights into the energy consumption of individual devices but also offers robust protection against voltage fluctuations, ensuring the longevity and safety of household and office appliances. Smart Sentinel's intuitive interface further encourages energy-saving behaviors by making complex data accessible and actionable for every user.

V. STATEMENTS AND DECLARATIONS

Author contributions: Every author contributed to the research topics by conducting a thorough analysis of all relevant research papers through a comprehensive literature review. The tasks of data collection and analysis were executed by AG, AK, BS, and MK, under the supervision and guidance of AAG. The first draft of the manuscript was written by AG and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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VI. REFERENCE

[1] I. Mujawar, A. Mulla and T. Karbhari, "**IoT-Based Smart Energy Meter for Recording Device-Level Electric Parameters**," 2023 Innovations in Power and Advanced Computing Technologies (i-PACT), Kuala Lumpur, Malaysia, 2023, pp. 1-5, doi: 10.1109/i-PACT58649.2023.10434810.

[2] S. K N, P. T. Devadarshini, R. K N, Deshveer, N. V. S. Suryanarayana and V. R. Kanakala, "**IoT-based Smart Home Automation Systems for Energy Conservation,**" 2023 7th International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), Kirtipur, Nepal, 2023, pp. 12-16, doi:10.1109/I-SMAC58438.2023.10290633

[3] A. Alshehhi, F. Alawadhi, M. Baqer and R. Dhaouadi, "**Scheduling Optimization of Household Equipment using a Wireless Home Automation System,**" 2022 5th International Conference on Communications, Signal Processing, and their Applications (ICCSPA), Cairo, Egypt, 2022, pp. 1-7, doi: 10.1109/ ICCSPA55860.2022.10019216

[4] Z. Deng, Y. Zhou, A. Kamal, R. Na, I. P. Brown and Z. J. Shen, "**Smart Plug 2.0: A Solid-State Smart Plug Device Preventing Fire and Shock Hazards**," in IEEE Transactions on Power Electronics, vol. 38, no. 3, pp. 3140-3151, March 2023, doi: 10.1109/TPEL.2022.3224483.

[5] M. Karthik, R. S. R. Shafi, M. Ramasubramanian and M. Pranavsai, "**Smart Load Safety System,**" 2023 International Conference on Circuit Power and Computing Technologies (ICCPCT), Kollam, India, 2023, pp. 247-252, doi: 10.1109/ICCPCT58313.2023.10244986

[6] M. H. Raza, Y. M. Rind, I. Javed, M. Zubair, M. Q. Mehmood and Y. Massoud, "**Smart Meters for Smart Energy: A Review of Business Intelligence Applications**," in IEEE Access, vol. 11, pp. 120001-120022, 2023, doi: 10.1109/ ACCESS.2023.3326724

[7] A. Anilkumar, A. George, A. M R, D. G and A. Jyothy, "**IoT Based Smart Plug**," 2023 International Conference on Innovations in Engineering and Technology (ICIET), Muvattupuzha, India, 2023, pp. 1-4, doi: 10.1109/ ICIET57285.2023.10220898.

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