Next-Gen Energy Solutions: A Brief Study on Boosting Distribution Efficiency with IoE Technology

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***Abstract* — Integrating Internet of Energy (IoE) technology into distribution systems is a revolutionary strategy to improve energy efficiency. This study investigates the implementation of IoE technology in order to optimize energy management, lower losses, and enhance overall system performance in the distribution system. We look at many approaches to utilizing IoE, such as automated control systems, real-time monitoring, and advanced data analytics. The difficulties of putting these technologies into practice are also explored focusing on interoperability, big data, and data privacy issues. By examining current developments and case examples, we offer valuable perspectives on how to surmount these obstacles and optimize the advantages of IoE in power system. IoE has the ability to completely transform the way energy is distributed by enabling more intelligent, responsive, and effective network performance.**

***Index Terms* — Internet of energy (IoE), Energy efficiency, Distribution network, Data analytics, Real-time monitoring.**

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I. INTRODUCTION

The term “Internet of Energy” (IoE) describes how digital technologies and internet connectivity are combined to enhance energy distribution, administration, and consumption. This leads to increased efficiency and the development of smart energy systems [1]. Furthermore, the concept of the IoE is explored, highlighting how it may facilitate decentralized and intelligent power generation. The successful and effective running of the power distribution network depends on intelligent management [2].

Blockchain innovation facilitates peer-to-peer trading, energy transfers, and automated data interchange, which can help address security and privacy concerns in the decentralized IoE [3]. The primary conclusion suggests utilizing the IoE in building energy management system (BEMS) to solve problems with existing BEMS, such as excessive energy data, lost information, and energy overloading [4]. Through pilot projects, the IoE has the potential to digitize, decentralize, and reduce the carbon footprint of the electrical industry [5]. The potential complexity and expense of integrating cutting-edge digital technology into current energy systems, which could lead to implementation hurdles, are two of the IoE constraints or challenges. Furthermore, maintaining strong security and privacy in decentralized networks is still a major concern that needs to be addressed in order to safeguard private information and preserve system integrity, particularly when using blockchain for peer-to-peer energy trading. In addition to reporting the features of IoE in comparison to the old grid, this study provides insights into consumers, distributed energy resources (DERs), as well as virtual power plants (VPPs) control, management, and optimization tactics [6]. Successfully handling and maximizing the integration of various VPPs and DERs while guaranteeing smooth management and coordination throughout a range of customer demands and system specifications presents a problem in the research.

As part of the IoE, concentrated solar power (CSP) technology can offer ecologically beneficial baseload power production for regulating the power grid [7]. The study [8] demonstrates that the IoE may assist in reaching carbon-free technologies and increasing efficiency in energy use when combined with the internet of things (IoT) networks for communication and smart grids (SGs). Upcoming generation building energy utilization can be improved with IoE-BEMSs [9]. One challenge in improving building energy utilization with IoE-based systems is ensuring the integration and interoperability of diverse energy management technologies and platforms within existing building infrastructure. The study [10] aims to draw attention to the shortcomings of traditional BEMSs and near- or net-zero energy buildings (nZEBs) in order to improve future building energy consumption and sustainability. It also suggests cutting-edge IoE-based technologies and optimized controllers. The focus of [11] is on the feasibility of constructing the energy internet through the utilization of cyber-physical implementation of energy packets in conjunction with packetized management of non-industrial loads. A challenge in constructing the energy internet with cyber-physical implementation of energy packets and packetized management of non-industrial loads can be ensuring reliable and secure data transmission and management amidst potential cybersecurity threats and system integration complexities. The writers have assessed IoT's functions in SGs in [12]. Several layers of IoE in power systems are succinctly explained in this paper to illustrate the applications of the IoT in smart grids.

These include demand-side management (DSM), renewable energy sources, fault tracking, smart houses, electric cars, demand response modeling, intelligent meters, and others. The IoT-based services are also applied for administration, such as security information on electrical power flow, scheduling, management, system monitoring, load control, and distribution process data, market and pricing information, as well as profiling data. Thus, with the exciting concept of IoT, the IoE allows real-time energy resource monitoring, optimization, and automation through incorporation into distribution networks and SGs, enhancing adaptability, dependability, and efficiency while facilitating the implementation of and

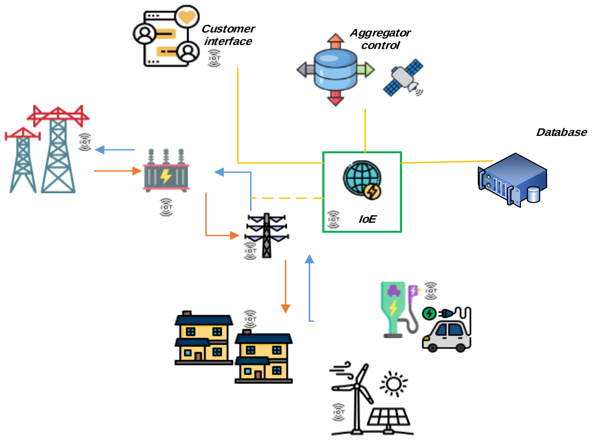

Fig. 1. The IoE framework in power system.

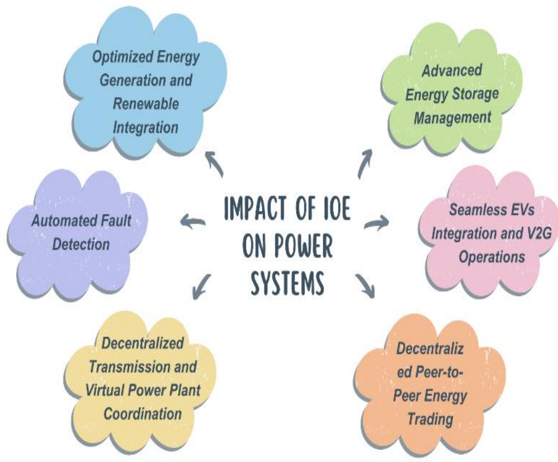

Fig. 2. The IoE impacts on power system

efficiency while facilitating the implementation of renewable energy sources (RESs).

As is evident, all of the research done thus far on the functions of the IoE in electrical grids has concentrated on a single facet within various power system scopes. It is

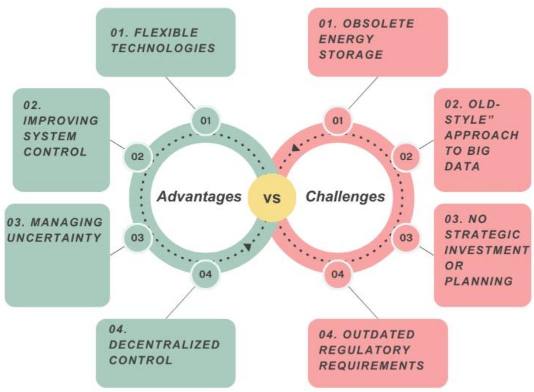

Fig. 3. Positive and negative impacts of IoE.

noted that the absence of a comprehensive classification satisfies the requirement for a thorough analysis of this subject. Figure 1 highlights the motivation for conducting research on the IoE integration in power systems.

II. THE IOE CONCEPT AND FRAMEWORK

The IoE is a new concept that has emerged as a result of recent advancements in the fields of RES, telecommunications, controlling schemes, power supply, energy storage units (ESUs), information technology, cybersecurity, computers, and especially the IoT [13]. Recently, new ideas have been developed in the field of energy investigation, such as SG-2, or the next generation of Smart Grids [14]. Many studies focus on SG-2 [14–17], while it presents challenges such as managing the additional complexity and expenses of incorporating cutting-edge digital technology into the grid's current structure and ensuring the cybersecurity of interlinked systems. Future opportunities include creating RESs, enhancing autonomous grid management, and adopting decentralized energy markets through leveraging the blockchain technology and IoE technology. The primary objective of [18] is to address information security concerns by suggesting a network security architecture and safeguards for dispersed power plants within the IoE.

Some studies focus on IoE in renewables [15, 16, 19, 20], while the integration of IoE has changed the structure of traditional power systems and imposes some challenges and advantages. Figure 2 displays the pros and cons of this integration. Table 1 presents specific areas, objectives, and challenges associated with the IoE as identified in previous research within the state of the art (SOA).

According to Fig. 3, the IoE represents a transformative framework in which advanced digital technologies, communication systems, and energy resources converge to create an intelligent and efficient energy ecosystem. As depicted in the structure, the IoE integrates various components, including power generation, SGs, energy storage, and distributed resources, all connected through a central IoE management system. This system relies on data transmission from smart devices, sensors, and satellite communication to optimize energy flow, demand response, and consumption patterns. In order to increase efficiency, strengthen grid resilience, and ease the integration of renewable energy sources, key components of the IoE include electric vehicles (EVs) and charging stations, distributed energy sources, and home and commercial energy management systems. The IoE promotes a more adaptable, decentralized, and sustainable energy infrastructure by facilitating real-time monitoring and automated decision-making, addressing issues with energy supply, as well as the rising demand for greener energy options.

III. APPLICATION OF IOE IN VARIOUS AREAS, AND ENERGY RESOURCES

The IoE allows real-time monitoring, predictive analytics, and effective load balancing for enhanced grid stability, which improve RESs and ESUs integration. Through the use of cutting-edge sensors and smart devices, it also enhances grid management and demand-side supervision, guaranteeing improved fault detection, remote control, and energy conservation.

In RES, real-time state monitoring can help with resource utilization problems. An end-to-end IoE system for wind farms and solar parks is achievable through the integration of wireless ready-to-connect systems equipped with security package solutions, like cellular modules and routers. Even with its drawbacks, the IoT can fix problems with minimal effort and investment. Operators can swiftly diagnose problems and oversee the entire grid with a straightforward, fully integrated system [21, 22]. On the other hand, Zabihi et al. [23] examines the detection of partial shading in photovoltaic (PV) generation systems, which can be helpful in detecting and monitoring faults. Two faults in a hydropower plant are simulated in [24], which can also enhance different energy resources, like the hydropower plant, through monitoring and assessing faults. Although the energy resources and plug-in hybrid electric vehicles (PHEVs) are explored in [25], wind turbine (WT) optimization can be a research gap in this study. The IoE can optimize the integration of small-scale generators, RESs, and PHEVs into the grid by enabling real-time data exchange and advanced energy management, facilitating load flow and short-circuit analyses while addressing both the challenges and benefits of these technologies in modern power systems, especially the integration of PV in power systems [26]. This incorporation can be helpful and also would improve the whole system by integrating real-time data and advanced analytics to optimize the performance of PV systems with mirrors, improving power output and irradiance. By facilitating seamless communication between tools like TRNSYS and EES, the IoE supports efficient system modeling and analysis, leading to more effective deployment and utilization of solar technologies.

The advanced methods have enabled the power sector to align generation with customer demand in real-time. However, the associated peak transmission and emission costs have led to significantly increased expenses. Nevertheless, the idea of demand response programs (DRPs) [27], which may regulate and track demand at the level of the customer, has emerged as a result of the increasing use of energy markets and the development in broadband networks.

DRPs are separated into two categories: incentive-based programs (IBP), which involve market-clearing, voluntary, and mandated programs, and time-based rate programs (TBR), which involve customer reactions to instantaneous power prices [28]. Intelligent decision-making and

TABLE 1. Application of the IoE in Previous Studies

Reference	Area	Goals	Brief Description	Challenges
[1]	Energy distribution, administration	Enhance energy distribution, administration, and consumption	Combines digital technologies and internet connectivity to improve energy efficiency and develop smart energy systems.	Handling the complexity of integrating digital technologies with current systems; high implementation costs.
[2]	Power generation	Facilitate decentralized and intelligent power generation	Focuses on intelligent management for the successful operation of power distribution networks.	Coordinating decentralized power generation and management to ensure smooth operations across networks.
[3]	Blockchain in the IoE	Enable peer-to-peer energy trading and secure data transfer	Blockchain enhances decentralized energy transfers and addresses security and privacy concerns in IoE systems.	Ensuring security and privacy in decentralized IoE networks, especially with blockchain integration.
[4]	BEMS	Solve issues with traditional BEMS	Proposes an IoE-based BEMS to tackle excessive data, data loss, and energy overloading in buildings.	Managing large amounts of energy data and ensuring smooth integration into existing BEMS systems.
[5]	Decarbonization of the energy industry	Digitize, decentralize, and reduce carbon footprint in the energy sector	IoE pilot projects aim to reduce the energy industry's carbon footprint through digital and decentralized technologies.	Dealing with high costs of digitization and decentralization; overcoming the complexity of transitioning existing infrastructure.
[6]	DERs, VPPs	Improve control and optimization of DERs and VPPs	IoE enhances DER and VPP control, management, and optimization tactics for more efficient energy distribution.	Effectively managing various VPPs and DERs while maintaining system-wide coordination and optimization.
[7]	CSP	Provide ecologically-friendly baseload power generation	IoE integrates CSP technology into the grid for more sustainable energy production and grid balancing.	Overcoming technical integration barriers with existing grid infrastructure and ensuring stable power output.
[8]	Carbon-free technologies	Achieve carbon-free energy systems and improve energy efficiency	IoE, combined with IoT and SGs, helps reach carbon-free goals and boosts energy efficiency.	Resolving interoperability issues when combining IoE, IoT, and SG technologies; overcoming high costs of implementation.
[9]	BEMS	Improve energy utilization in buildings	IoE-BEMS can optimize energy consumption in next-generation buildings for sustainability and energy savings.	Ensuring interoperability of different energy management technologies within existing building infrastructure.
[10]	nZEBs	Highlight challenges in traditional BEMS and promote IoE-based systems	Focuses on addressing limitations in current BEMS and near- or net-zero energy buildings using IoE technology.	Overcoming traditional BEMS limitations, such as data management issues and energy overloading, while transitioning to IoE-based solutions.
[11]	Energy Internet	Explore feasibility of energy packetization for non-industrial loads	Cyber-physical systems in IoE enable packetized energy management, promoting more flexible energy distribution.	Ensuring reliable and secure data transmission in cyber-physical energy systems amidst cybersecurity threats and system integration challenges.
[12]	IoT in SGs	Explore the IoT's role in demand-side management, fault tracking, and renewables	Examines layers of IoT applications in SGs, including demand response, fault detection, and electric vehicle integration.	Handling the complexity of integrating the IoT-based services, ensuring real-time data management, and addressing cybersecurity risks in smart power grids.

automated device management are made possible by the IoE technology. This enhances user convenience and energy efficiency in smart buildings [29] by providing immediate control and management of energy consumption through smart devices and cloud-based systems. The IoE makes it easier to integrate different structures, such as lighting and Heating, Ventilation, and Air Conditioning (HVAC) , enabling automated modifications based on predictive modeling and real-time data. Furthermore, it facilitates remote management using web servers and smartphones, enhancing building performance overall and optimizing the utilization of energy and expenses for operation.

A two-stage hybrid islanding recognition approach for DC microgrids is presented in [30]. It uses a superimposed voltage-based episode of care severity score and current disturbance to reduce the non-detection zone (NDZ) and prevent power quality degradation. The IoE facilitates continuous monitoring of microgrid performance, improving the accuracy of the severity index by gathering more comprehensive and real-time data on voltage, current, and other operational metrics. According to [31], which emphasizes the importance of frequency and voltage stability in island microgrids while minimizing load shedding, the IoE could enhance microgrids by facilitating real-time communication and sharing of data between distributed energy sources, loads, and control systems. The IoE can be incorporated into the suggested Q-learning-based under-frequency load shedding (QLLS) and intentional voltage manipulation (IVM) approach. This will enhance decision-making for frequency and voltage balance by means of adaptable optimization and ongoing surveillance. Features of the smart energy revolution are shown in Fig. 4.

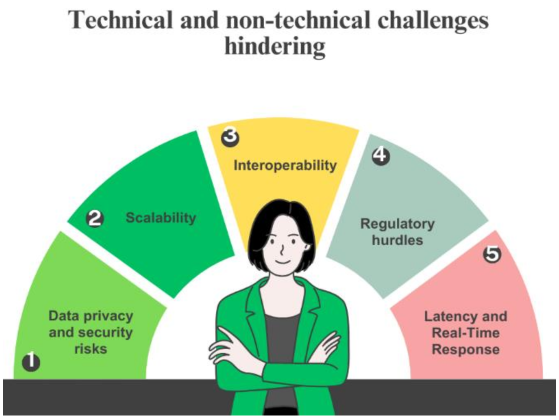

Fig. 4. Technical and non-technical challenges hindering.

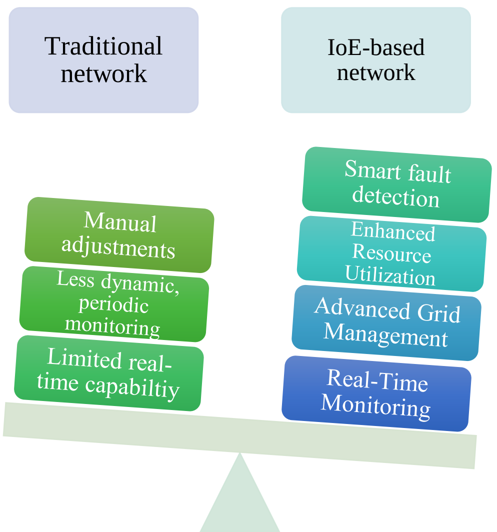

Fig. 5. Smart energy revolution.

IV. Future Direction

Major technical and non-technical challenges are pointed out in Fig. 5, for example, the vulnerability of IoE-enabled systems to cyber-attacks and data breaches, the difficulty in scaling IoE systems across large, decentralized networks. Challenges in integrating various IoE devices from different manufacturers due to the lack of common standards, policies and regulations that are not yet fully aligned with the use of the IoE in energy networks.

The following points can be highlighted for the future scope in this area:

- 5G and Edge Computing technologies will enhance real-time data processing and communication, improving the performance of IoE.
- AI (artificial intelligence) and ML (machine learning), predictive maintenance, demand forecasting, and intelligent energy management could all benefit from the integration of AI with the IoE.
- Blockchain technology, when integrated with the IoE, can facilitate secure energy trading and enable peer-to-peer energy transactions.

The integration of the IoT into SGs [32], which is directly related to the IoE, enables real-time communication and data-driven management across the energy network, optimizing energy flow, enhancing grid reliability, and facilitating predictive maintenance, collectively improving the efficiency and resilience of energy systems. Moreover, the IoE can evolve, focusing on

TABLE 2. Comparison of Previous Studies

Reference	Year	Summary	Research Area	Main Findings
[35]	2023	This systematic literature review explores the intersection of non-orthogonal multiple access (NOMA) and mobile edge computing (MEC) in the context of 6G communications, highlighting the growing interest and need for comprehensive studies in this evolving field.	Communications	It reveals a significant increase in research on NOMA-enabled MEC, emphasizing its potential to enhance data rates, reduce power consumption, and minimize offload delays, while highlighting the necessity for more extensive studies and classifications in this domain.
[36]	2019	Edge computing enables the evolution to 5G by bringing cloud capabilities to end users to overcome latency and security issues.	Edge Computing	Edge computing is a developing technology that facilitates the development of 5G by bringing cloud capabilities closer to end users, overcoming the constraints of traditional cloud-based services, such as excessive latency and the absence of security.
[37]	2020	Mobile edge computing in 5G networks can improve mobile resource utilization and enable real-time apps by putting compute-intensive jobs close to consumers.	Mobile Computing	MEC helps meet the growing demands for processing power and network traffic in 5G by deploying resource-intensive applications nearer to users, thereby enhancing efficiency and delivering cloud computing services right at the edge of the network.
[38]	2014	5G will be a major paradigm shift that integrates new air interfaces, spectrum, LTE, and WiFi to provide high-rate universal coverage.	5G Networks	5G will require the utilization of high carrier frequencies with big bandwidths, higher base station and device densities, and multiple antennas, as well as integration with existing technologies such as LTE and WiFi, to enable universal high-speed access.
[39]	2020	Multi-access edge computing works with 5G and IoT to deliver cloud computing capabilities at the network edge while lowering latency.	Edge Computing	MEC can minimize latency for end users by deploying computing and storage resources at the edge of the network.
[40]	2016	5G is a critical driver for achieving the IoT ambition by offering pervasive, dependable, scalable, and cost-effective connection.	IoT	The research study explores how 5G functions as a vital enabler for the IoT objective by enabling dependable, scalable, and cost-effective connectivity. It also examines the existing state of the IoT connectivity and the potential business implications of merging 5G and IoT technologies.
[41]	2021	The combination of 5G networks with edge computing can provide a complementary and coexisting win-win solution for meeting the demands of future IoT services.	5G Integration	The paper emphasizes the importance of combining 5G networks with edge computing to efficiently meet the performance demands of rigorous IoT scenarios, providing a detailed assessment of how these technologies can coexist and suggesting a "win-win mode" for mutual advancement.
[42]	2022	Edge computing is a collaborative computing paradigm, which processes data near its source, having implications for 5G/6G networks and smart factories.	Edge Computing	The paper examines the use of edge computing platforms by businesses to improve performance and customer needs, highlighting its advantages over cloud computing, including reduced latency and faster response times.
[43]	2022	AI/ML algorithms can improve upcoming IoT network operations and services, such as smart healthcare, agriculture, transportation, grid, and industry.	AI in IoT	The paper explores the use of AI/ML algorithms in IoT domains like smart healthcare, agriculture, transportation, and industry for energy-efficient, secure, and effective operations, and suggests future research directions for addressing challenges.
[44]	2020	AI and ML approaches can bring new possibilities for improving security across the many layers of the IoT architecture.	AI/ML in IoT	The paper investigates how AI methods, particularly ML and deep learning (DL), can improve IoT security by analyzing their technical feasibility in addressing security challenges, defining a general framework for AI-based IoT security solutions, and summarizing various AI solutions for four major IoT security threats while comparing the algorithms and technologies used.
[45]	2018	IoT devices can utilize machine learning techniques to improve security against threats such as spoofing, Denial of Service (DoS), jamming, and eavesdropping.	IoT Security	The paper explores machine learning-based IoT security solutions, specifically authentication, access control, secure offloading, and malware detection, as well as implementation issues.
[46]	2019	ML can help assess and safeguard Industrial Internet of Things (IIoT) systems by discovering vulnerabilities and breaches.	ML in IIoT	The research team used appropriate indicators to assess the effectiveness of their ML-based anomaly detection system, and discovered that it was effective.
[47]	2018	AI is required in IoT-based 5G networks in order to efficiently handle data and resources.	AI in IoT	The paper underlines the role of AI in analyzing the IoT data in 5G networks, making recommendations, and showcasing the capabilities of full duplex and cognitive radio technologies.

blockchain platforms, smart contracts, and green cryptocurrencies. It can also facilitate secure, real-time energy transactions and carbon trading, enhancing the efficiency and sustainability of energy management systems within the IoE framework [33]. The technical viability and design of the electrical infrastructure is explored in [34] for a low-energy office building, with a focus on optimizing the utilization of energy through the use of RESs, efficient technology, and adaptive energy management systems. However, the IoE would strengthen energy utilization in buildings through real-time monitoring, automation control, and intelligent optimizing of energy usage, integrating RESs, and upgrading the entire power management system.

V. Discussion

According to Table 2 presented in the previous section, the provided references collectively highlight the pivotal role of advanced technologies such as edge computing, AI, and machine learning in enhancing the efficiency, security, and functionality of IoT and 5G networks. Research focuses on integrating mobile edge computing with 5G to reduce latency and improve resource utilization, emphasizing the necessity of AI and ML for addressing security challenges and optimizing operations across various IoT domains, including smart healthcare, agriculture, and industrial applications. The studies also underline the criticality of 5G as a facilitator for the IoT, ensuring reliable and scalable connectivity while exploring the complementary relationship between these technologies.

On the other hand, the IoE with 5G and edge computing enhances communication, effectiveness, and reliability in applications such as smart cities and industrial automation. It improves data-driven decision-making, streamlines operations, and lowers costs. This collaboration supports service delivery revolution by allowing the development of new apps and business models that make use of real-time analytics of data and automated processing.

The joint use of IoE and ML is a key transitional step towards a SG [48]. In [49], authors analyze the effectiveness of recurrent neural networks (RNN) and long short-term memory in short-term electrical energy prediction, suggesting future improvements could include weather data and hybrid-ML methods.

The study [50] explored the use of AI, IoT, and ML in designing and modeling RESs.

From our perspective, the IoE is a transformative approach in the energy sector, enhancing efficiency and stability of distribution networks and power systems. It integrates various energy resources and smart home grids, facilitating seamless energy generation and consumption management. Advancements in Information and Communication Technology (ICT) enable comprehensive monitoring, fault detection, and dynamic load balancing, optimizing financial and ecological performance. As the IoE evolves, it holds the potential to drive significant innovations in the energy market, paving the way for more sustainable and efficient energy solutions.

VI. Conclusion

By integrating real-time data and advanced analytics across multiple energy resources such as PV systems, WT, and home SGs, the IoE greatly improves distribution networks and power systems. Its main goals are to enhance grid stability, maximize energy management, and boost resource use efficiency. Information and communications technology (ICT) advancements are transforming power networks to become resilient, carbon-free systems that use RESs at the grid size and support demand-side sources at

Acronym	Definition
AI	Artificial intelligence
BEMS	Building energy management system
CSP	Concentrated solar power
DC	Direct current
DERs	Distributed energy resources
DL	Deep learning
DoS	Denial of Service
DRPs	Demand response programs
DSM	Demand-side management
ESUs	Energy storage units
EVs	Electric vehicles
HVAC	Heating, Ventilation, and Air Conditioning
IBP	Incentive-based programs
ICT	Information and Communication Technology
IIoT	Industrial Internet of Things
IoE	Internet of Energy
IoT	Internet of Things
IVM	Intentional voltage manipulation
MEC	Mobile edge computing
ML	Machine learning
NDZ	Non-detection zone
NOMA	Non-orthogonal multiple access
nZEBs	net-zero energy buildings
PHEV	Plug-in hybrid electric vehicle
PV	Photovoltaic
QLLS	Q-learning-based under-frequency load shedding
RESs	Renewable energy sources
RNN	Recurrent neural networks
SG	Smart grid
SOA	State of the art
TBR	Time-based rate programs
VPPs	Virtual power plants
WT	Wind turbine

the local scale. The IoE is a notion that emerged from the integration of ICT and technical advancement in the energy sector. The IoE makes it easier to integrate different energy sources seamlessly by providing comprehensive monitoring, fault detection, and dynamic load balancing. By surpassing its capital costs, the IoE program seeks to significantly improve power system's financial and ecological performance and open up opportunities for further advancements in the energy market.

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