

# Internet of Energy Applications for the Brazilian Energy System

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**Abstract**—The Brazilian energy system is facing challenges such as increasing energy demand, the need for a more sustainable energy matrix, and the integration of renewable energy sources. In this context, the Internet of Energy (IoE) offers promising solutions to optimize the generation, transmission, and consumption of energy. This article explores the potential applications of the Internet of Energy in the Brazilian energy system, discussing its benefits, challenges, and future prospects.

**Index Terms**—Internet of Energy - IoE, Internet of Things - IoT, Energy System.

## I. INTRODUCTION

In recent years, the world demand for electricity has increased significantly. This growth is driven by population growth and the growing dependence on technologies that demand electricity. Consequently, this dependency results in a growing need for a greater supply of available energy to meet [1] demands. In Brazil, a country of vast dimensions and with one of the largest electrical systems in the world, the energy sector is composed of the National Interconnected System (SIN), which covers approximately 96.6% of the country's total electricity generation capacity. In addition, there are isolated systems, especially located in the Amazon Region [2]. The SIN is made up of hydroelectric, thermal, nuclear, wind and solar plants, spread over 16 river basins and connected by more than 150,000 km of transmission lines [3]. The National Electric System Operator (ONS) is responsible for coordinating the delivery of energy according to the demand of the consumer centers [4].

The Brazilian energy system, which is composed of several energy sources, which can be classified as renewable and non-renewable [4]. In the national energy balance for the year 2020 published by *Empresa de Pesquisa Energética - EPE*, renewable sources accounted for 46.1% of the Brazilian energy matrix, while non-renewable sources accounted for 53.9% [5]. Brazil is one of the countries with the highest share of renewable sources in its energy matrix, thanks to its great hydroelectric potential and its production of ethanol and biodiesel.

However, Brazil also faces challenges related to energy security, diversification of sources, efficient use of energy and reduction of greenhouse gas emissions [6]. Faced with these challenges, Internet of Energy (IoE) technology, an application of the Internet of Things (IoT), along with artificial intelligence and computing resources in distributed and decentralized energy management systems, emerges as a promising solution to optimize efficiency of the existing energy infrastructure in the country [7]. The adoption of IoE can offer significant answers to the problems faced by the Brazilian electrical system. The contribution of this article is to explore the possibilities and benefits of IoE technology in the Brazilian electrical system, highlighting the main aspects related to operational efficiency, real-time monitoring, integration of renewable energies, and the promotion of energy sustainability.

## II. IOE ARCHITECTURE

The (IoE) Architecture is a concept that aims at the intelligent integration and interconnection of devices, systems and energy sources in a unified network. IoE is an extension of the Internet of Things (IoT) applied specifically to the energy sector, enabling efficient and dynamic management of energy resources. In the literature there are several types of architectures depending on the application. In general, the IoE architecture is composed of several key elements, such as: Sensors and smart devices; Communication and connectivity; Storage and flexibility; Analytics and Artificial Intelligence and Security and Reliability.

As shown in Figure 1, IoE enables the exchange of energy between a wide variety of sources and loads, including renewable energy sources, distributed energy storage, plug-in electric vehicles, domestic and industrial “prosumers”, etc. The power grid is monitored and managed via the internet. In principle, peer-to-peer exchange of information and energy can occur in this system, although some level of central or hierarchical control may also be required. The general principle is that

power is directed from the source(s) to the load(s), similar to routing information on the [8] internet.

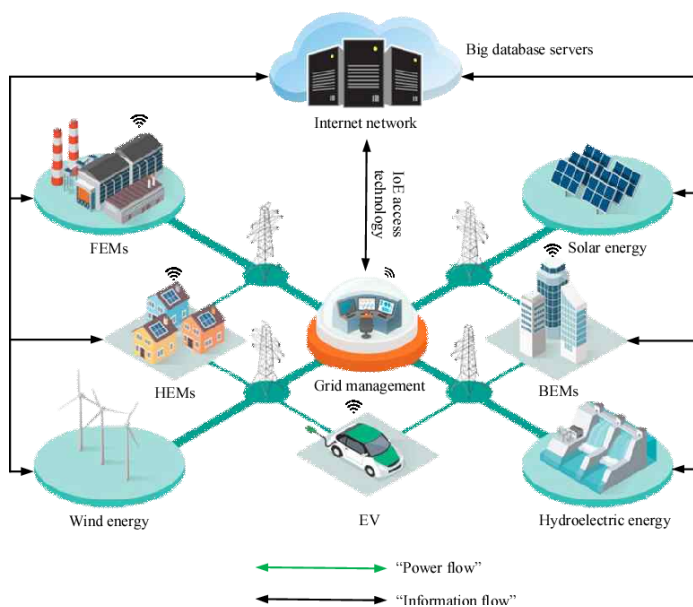


Fig. 1. IoE Architecture [8].

### III. BENEFITS OF INTERNET OF ENERGY APPLICATIONS

The benefits of (IoE) applications are numerous and have the potential to revolutionize the energy industry. Research by Aaron et al. [9], highlighted that the application of the Internet of Energy enables the creation of a more resilient and flexible energy network. By integrating intelligent devices, such as advanced meters, sensors and energy storage systems, it is possible to improve the management and monitoring of electrical consumption in real time, allowing continuous adjustments and optimizations.

The use of the Internet of Energy is also capable of promoting the adoption of renewable energy sources, such as solar and wind, as emphasized in [10]. By effectively integrating these clean sources into the system, it is possible to reduce greenhouse gas emissions and decrease dependency on fossil fuels. Additionally, according to Liu et al. [11], the Internet of Energy enables the emergence of more decentralized energy markets, where consumers can become prosumers, that is, both producers and consumers of energy. This creates a scenario of greater democratization of energy and encourages the active participation of citizens in responsible generation and consumption.

#### A. Enhanced Energy Efficiency and Demand Management

The Internet of Energy has the potential to enhance the electrical system through real-time monitoring and predictive maintenance, leading to improved efficiency, reliability, and security. Zhang et al. [12] highlight the capability of the internet of energy to gather, process, and transmit extensive data on equipment condition, performance, and operational factors.

This data is used for purposes like anomaly detection, failure prediction, resource optimization, and preventive planning. Additionally, the integration of renewable and distributed energy sources is facilitated by the Internet of Energy, enhancing sustainability and resilience [13]. Successful implementation of real-time monitoring and predictive maintenance requires a robust, secure, and scalable communication infrastructure that supports seamless data exchange among stakeholders like generators, distributors, consumers, and network operators. Moreover, developing algorithms and intelligent models is essential to extract insights from collected data and generate automated recommendations or actions. Techniques like artificial intelligence, machine learning, and cloud computing are applied to analyze data in real-time or batches, based on resource availability and operational needs [14].

#### B. Integration of Renewable Energy Sources

The integration of renewable energy sources is a topic of great relevance for sustainable development and energy security. Renewable sources have advantages such as the reduction of greenhouse gas emissions, the diversification of the energy matrix and the generation of jobs and income. However, they also present challenges such as intermittency, variability and dependence on weather conditions. Given these challenges, IoE offers a wide range of benefits for integrating these renewable energy sources. According to Wang et al. [15], the ability to collect data in real time through connected sensors allows a more accurate monitoring of the generation conditions of renewable sources, such as solar and wind. This information is essential to predict the availability and intermittency of these sources, enabling a better adaptation of generation to the demands of the electrical system. IoE can be used to empower consumers and promote energy awareness around the world. According to Jianli et al. [16], with the rapid evolution of smart grids and the increasing integration of connected devices, consumers have the opportunity to become active participants in managing their energy demand and efficiently using available resources.

In the use of IoE in an intelligent building, examples include the remote control of electricity consumption by devices such as TV, washing machine, dishwasher, refrigerator, among others. In addition, the technology allows controlling the HVAC system, managing the doors, constantly monitoring the house through security cameras and automating the lighting system. For example, a dishwasher is able to start the machine when the electricity price is cheaper or will be cheaper [17]. Figure 2 illustrates a schematic of an intelligent building.

### IV. CHALLENGES AND CONSIDERATIONS

#### A. Technical Challenges

The IoE constitutes a complex network, encompassing interconnected systems like smart grids and sensors. It involves decentralized monitoring and control, integrating with distributed renewable and handling extensive data from various communication devices. Real-time monitoring and control of

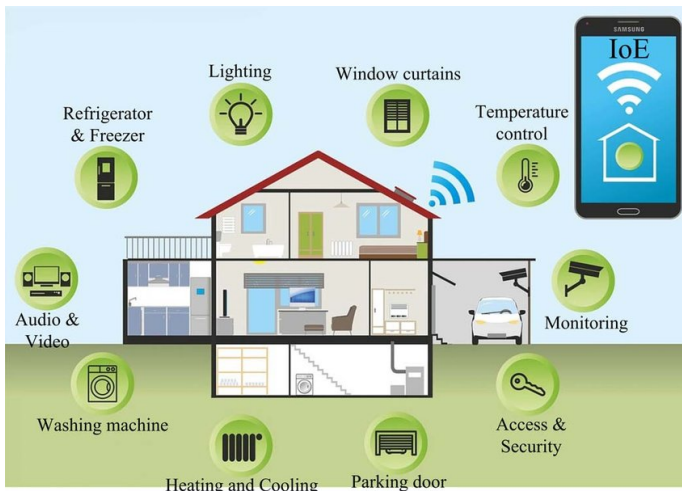


Fig. 2. Smart Building Diagram [18].

extensive resources contribute to system complexity, compounded by the intermittent nature of renewable generation and load variability. Ensuring robust smart energy management faces challenges due to these factors [17]. Although storage aids system stability, ensuring an uninterrupted supply to critical loads presents challenges, potentially addressed through demand-side management and energy pricing [18].

### B. Privacy and Security Challenges

Using the Internet for smart grid communications offers infrastructure savings but also raises significant security concerns, sparking ongoing debates about the trade-offs involved. Three main cybersecurity objectives are: i) ensuring timely and dependable access to information, ii) maintaining information integrity, and iii) safeguarding personal privacy and sensitive data [19]. Instances of cyber attacks on networks have been reported.

In an ideal IoE framework, peer-to-peer connections are supported, but this means that if a hacker breaches any node, they could potentially attack any point within the network, breaching client confidentiality and accessing electricity usage data. Essential security mechanisms for establishing a secure, reliable, and sustainable smart grid system include authentication, integrity protection, and encryption [20].

### C. Interoperability and Standardization

Interoperability refers to the seamless communication and interaction between devices and systems from diverse manufacturers. It's vital for connecting components across the energy infrastructure, encompassing smart meters, solar panels, storage batteries, and electric vehicles. Interoperability enables real-time data sharing, enhancing the integrated management of the electrical network [21]. Standardization establishes common technical standards and specifications for IoE devices and systems. This prevents fragmentation and incompatibility among products, promoting the integration and scalability

of smart energy infrastructure. Shared communication standards ensure proper device interconnection and interoperability across platforms [22]. Moreover, interoperability and standardization are pivotal in home and building automation. Compatibility among devices like smart thermostats and lighting systems allows efficient energy control, reducing waste and optimizing resource management in residences [23].

## V. INTERNET OF ENERGY APPLICATIONS IN THE BRAZILIAN CONTEXT

The Brazilian electrical transmission system is a complex and extensive infrastructure, responsible for interconnecting power generation plants to consumption centers across the country. This transmission network is one of the largest in the world, with a total length of approximately 143,000 kilometers [24].

Figure 3, shows map of the Brazilian transmission system.

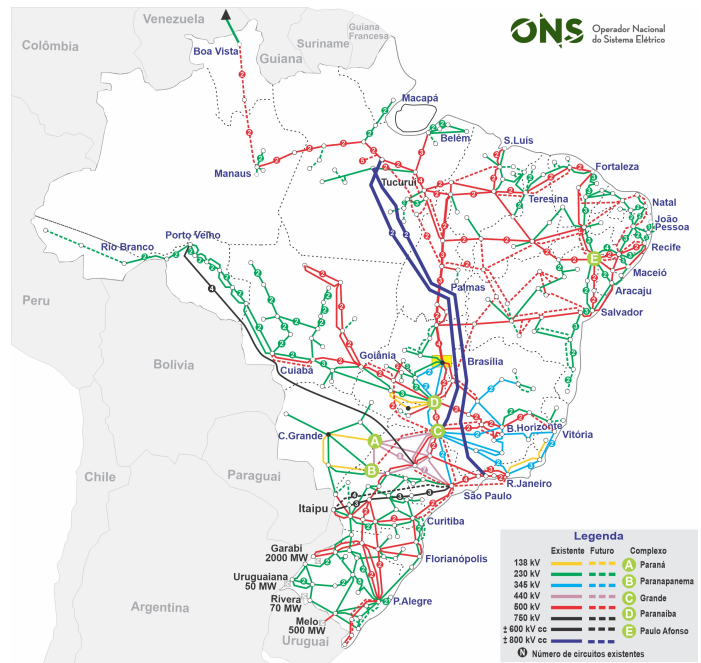


Fig. 3. Transmission System Map [24].

Despite its magnitude, the Brazilian electrical transmission system faces several challenges and problems that impact its operation and efficiency. One of the main challenges is the constant need to expand and modernize the infrastructure to keep up with the growth in demand for electricity.

Another significant challenge is the integration of renewable energy sources into the transmission system. With the growing adoption of renewable energies such as solar and wind, it is necessary to ensure that these intermittent sources can be effectively incorporated into the system, guaranteeing a stable supply of energy for [25] consumers.

In the Brazilian context, IoE has the potential to contribute to the challenges of the electricity sector, such as expanding renewable generation, improving service quality and reliabil-

ity, reducing losses and fraud, active consumer participation and efficient energy management demand.

One of the IoE applications in Brazil is the use of the 5G cellular network to provide fast and reliable communication between devices and systems that make up smart energy networks. An example is the Urban Futurability project, developed by Enel Distribuição São Paulo, which carried out a 5G concept test (PoC) in a real scenario, evaluating the main characteristics of the new technological generation: improved mobile broadband applied to remote assistance, communication massive machine-to-machine communication on the Internet of Things (IoT) and ultra-reliable low-latency communication for remote control. The results showed an improvement in speed and latency over 4G [26].

Another application of IoE in Brazil is the use of renewable energy resources, which represent 84% of the country's installed power generation capacity, above the world average of 38%. IoE can facilitate the integration of these resources into the energy matrix, through intelligent monitoring, control and storage systems, which increase the efficiency and safety of operations. An example is the growth in the share of solar energy in the Brazilian energy matrix, which reached 6.9% in 2021, thanks to massive investments in distributed and centralized generation [27].

Finally, with the application of IoE in Brazil, electricity consumers can become active agents in managing demand and offering ancillary services to the electrical system.

## VI. FUTURE OUTLOOK AND RECOMMENDATIONS

IoT applied to the electrical system (IoE), can support the development of smart grids, smart meters, smart buildings, smart cities and smart mobility, among other applications. According to a report by Accenture (2019), IoT can generate up to US\$ 14.2 billion in value for the Brazilian energy system by 2025, representing 1.8% of the country's GDP [28]. Some of the benefits of IoT include:

- Reduction of energy losses and thefts by monitoring and controlling the distribution network in real time.
- Improve demand response and load management by enabling dynamic pricing and incentives for consumers to adjust their consumption patterns.
- Increase renewable energy penetration and grid stability by facilitating the integration of distributed generation and storage resources.
- Improve customer satisfaction and loyalty by providing personalized service and feedback based on data analysis and artificial intelligence.

To realize the full potential of IoT in the energy sector, several challenges need to be addressed, such as:

- Develop a clear vision and strategy for IoT adoption that aligns with national energy policy and goals.
- Establish a supportive regulatory framework that promotes innovation and competition while ensuring cybersecurity, privacy, and interoperability standards.

- Build a robust digital infrastructure that can support the connectivity, data transmission, and processing requirements of IoT devices and applications.
- Enhance the digital skills and capabilities of the workforce and society to enable the effective use and management of IoT solutions.
- Promote a culture of collaboration and co-creation among different stakeholders, such as utilities, regulators, customers, technology providers, academia and civil society.

### A. Policy Recommendations to Promote IoE Adoption in the Brazilian Energy Sector

Based on analysis of best practices and lessons learned in other countries, some of the policy recommendations to foster IoT adoption in the Brazilian energy sector are:

- Create a national IoT plan that defines the vision, goals, priorities and roadmap for IoT development in the energy sector and beyond.
- Establish a dedicated agency or body that coordinates and oversees the implementation of the national IoT plan and facilitates cross-sectoral collaboration.
- Provide incentives and funding for IoT research, development, and innovation, as well as for pilot projects and demonstrations that showcase the benefits and impacts of IoT solutions.
- Promote awareness and education campaigns that inform and engage the public about IoT opportunities and challenges in the energy sector.
- Develop guidelines and regulations that ensure the security, privacy and interoperability of IoT devices and data, as well as the protection of consumer rights and interests.

## VII. CONCLUSION

This paper highlights the potential of IoE applications for the Brazilian energy system, emphasizing the role of technology in optimizing energy management, enhancing sustainability, and fostering a more resilient energy infrastructure. With proper planning, collaboration, and investment, IoE can revolutionize the Brazilian energy landscape and pave the way towards a more sustainable and reliable future. To advance in the energy transition and digitalization of the electricity sector, it requires a strategic vision and coordinated action by the various actors involved. In future work, a bibliometric study on IoE will be carried out and it is intended to propose a new efficient architecture compared to those present in the literature.

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