Chapter 11
Smart Grid Fault Detection and Classification Framework Utilizing AIoT in India

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ABSTRACT

The energy sector is facing obstacles such as increased consumption, efficiency, and losses affecting mainly developing countries. One of the major challenges is unauthorized power connections due to which a significant portion of consumed energy is not billed, causing business loss. The misuse of energy indirectly increases the amount of CO2 emissions because unauthorized users utilize energy irresponsibly. As the third-largest producer and consumer of electricity in the world, India is facing a variety of power-related issues such as distribution losses, electricity fraud, and environmental issues. The artificial internet of things (AIoT) is proving beneficial in energy use optimization, fault detection, and identification. The technological issues and solutions are discussed for fault detection and classification in a smart grid. A case study is provided as a first step towards automated fault detection in smart grids. This chapter aims to identify factors that could assist India in developing its smart infrastructure and evaluate the numerous components of the smart grid.

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1. INTRODUCTION

AI is capable of reducing energy waste, minimizing energy prices, and facilitating and accelerating the global implementation of renewable energy sources. AI can also improve the design, operation, and control of power systems. Thus, AI technologies are inextricably related to the capacity to provide development-critical, affordable, and clean energy. The power sector has a promising future due to the creation of AI-powered smart grids and electrical networks enabling communication between consumers and utility companies. The information layer of Smart Grids establishes communication, observes rapid changes in energy usage, and handles emergencies efficiently by utilizing modern technology such as AIoT. The use of Smart meters along with sensors makes it possible to collect and store data and supports the different functions of the information layer. In the rapidly evolving world of the Internet of Things, which connects and exchanges data across a vast network of devices or "things," organizations flourish via the use of analytics. AI is a critical sort of analytics for any organization that wants to maximize the value of IoT since it can make snap decisions, find significant insights, and "learn" from massive amounts of IoT data at the same time. In this article, we'll look at how IoT analytics, also known as the "Artificial Intelligence of Things" or AIoT, helps businesses in a variety of industries, such as manufacturing, retail, energy, smart cities, healthcare, and more, provide new value to their customers. These industries include and are not limited to manufacturing, retail, energy, smart cities, and healthcare.

Smart devices connected to the Internet contribute to collective intelligence with the help of Artificial Intelligence when applied to data from a network. Utility companies and the manufacturing sector can benefit by detecting underperforming assets and can use AI to predict maintenance requirements (Abdalla et al. 2021, Franki & Majnarić 2023, Lyu & Liu, 2021). In addition, AI AI-powered system will guide when to shut the system so that hazardous failure situations can be avoided. A variety of sensors and equipment cannot rely on cloud-based information or instructions. Sometimes it is just not necessary. It makes sense to analyze as close to the unit as feasible for monitoring, diagnosing, and taking action on certain pieces of equipment, such as home automation systems. Transferring locally gathered and used data to a distant data center causes unnecessary network traffic, slowed decision-making, and battery drain in mobile devices. Analytics has moved from traditional data centers to devices on the edge — the "things" — or additional processing resources close to the edge and cloud — the fog — due to the exponential growth of IoT devices and related data volumes as well as the necessity for low latency. Fog computing, a notion that is still in its infancy, shifts networking, security, and networking tasks from a centralized cloud to distributed clouds that are closer to IoT devices and services. Fog computing, also referred to as "fogging," enables local data processing. A centralized data center only receives notifications, exceptions, and outcomes. performance improvement while bandwidth reduction.

Energy sustainability and environmental protection are currently major global issues as a result of the multiple effects of climate change and the increasing energy demand. Cities and countries use more electricity as a result of their increased technological sophistication, and it may become hard to maintain without outside help. The transition to environmentally friendly technology, including distributed generation and microgrids, has prompted the development of the smart grid (Şerban & Lytras, 2020, Khosrojerdi et al., 2021). This document offers an overview of the Smart Grid, including its main functions and traits. The basics of the Smart Grid and related technologies are covered. Additionally, it covers the research processes, challenges, and issues (Dhanabalan & Sathish, 2018). It demonstrates how the current power grid has changed as a result of these technologies and how it has continued to develop while improving its ability to balance supply and demand. Furthermore, highlighted are the deployment and use of the Smart Grid in various areas. Initiatives for the Smart Grid are made easier in all countries by concrete energy rules (Yousuf et al.,2020, Kannan & Madhumita 2020). The practices of Smart Grid in numerous fields are noteworthy because they don't necessarily show competitiveness. Instead, they show a global society with common goals and lessons.

There are a growing number of high-performance IoT devices and environments with tens of thousands of connection points on the network. The perfect storm has arrived. Due to declining hardware costs, it is now possible to put sensors and connections in nearly anything. Analytics, light-speed communications, and computer advancements have enabled the development of AI-driven intelligence wherever it is necessary, including at the network's edge. Together, these technologies are ushering in a new era in which the Internet of Things is only the state of things and the phrase is rendered redundant, similar to the World Wide Web or "internet-connected," which are no longer required.

1.1 Power Crisis in India

For the continuous progress of people and to improve their development, development seeks to eradicate poverty and increase access to basic requirements, one of the key factors is energy. Communities are surrounded by the institutions, laws, and policies of the state; they do not exist in a vacuum. Thus, it is our job to provide an energy strategy that will assist us in achieving our objectives. Industrialization and population growth have increased India's energy needs. By 2040, India's primary energy consumption will climb from 6% to 11% (BP Publishers, 2019). In November 2021, India had 150.54 GW of renewable energy capacity, with solar at 48.55 GW, wind at 40.03 GW, small hydro at 4.83 GW, biomass at 10.62 GW, and large hydro at 46.51 GW (MNRE, 2021). The NITI Aayog (2015) expects India to generate 175 GW of renewable energy by 2022 and 500 GW by 2030. This goal intends to reconstruct the energy system to integrate renewable energy sources and accelerate the green energy transition due to global warming and fossil fuel depletion. India's power system has high transmission and distribution losses due to operational inefficiencies (Jadhav & Dharme, 2012, Sharma et al., 2017, Avasthi et al, 2023).

Predictive maintenance can reduce capital expenditures associated with equipment maintenance in the renewable energy sector. By anticipating asset breakdowns, energy companies can reduce unplanned downtime and associated costs. They can help reduce asset repair costs by responding to data-driven maintenance schedules.

1.2 Toward a Smart Power Sector

The integration of renewable energy sources and the optimization of energy usage considerably aids climate change mitigation and sustainable energy transitions. The Internet of Things (IoT) and other modern technologies can considerably assist the energy business in a variety of ways, including energy production, transmission, distribution, and consumption. Energy consumption can be made less detrimental to the environment by utilizing the Internet of Things, more renewable energy can be produced, and energy efficiency can be raised (Rahman, et al., 2013). The present literature on the use of IoT in energy systems in general, and smart grids in particular, is reviewed in this paper. In addition, we explore the enabling technologies of the Internet of Things, such as cloud computing and other data analysis platforms. Furthermore, we look at the problems of integrating IoT in the energy sector, such as privacy and security, as well as potential solutions like blockchain technology (Chakraborty et al., 2017, Zanella et al., 2014). This survey provides an overview of the importance of IoT in energy system optimization to energy policymakers, energy economists, and managers (Avasthi et al., 2023, Yan et al., 2014).

The rising need for energy can be traced back to urbanization, better living standards, and technological advancements. Thus, if nothing was done, the amount of energy required to power homes and businesses would grow to unsustainable proportions. The natural ecology and the worldwide supply of renewable energy are in a dangerous spot right now. Urban areas are responsible for between 75% and 80% of global energy use and emissions. During the day, power is often distributed via a centralized grid. often just called "the grid" when discussing electricity. Despite technological developments, the fundamental structure, dynamics, and underpinnings of the world's electric grids have remained unchanged since the invention of electricity. Traditional power networks focus on the production, delivery, and control of electrical energy.

1.3 Data Analytics for Fault Detection in Smart Grid

Generally, any Smart Grid can face challenges such as fault, which is a condition where a certain component in the electric grid is not working properly. The fault is usually associated with abnormal electric current such as a short circuit, a fault occurs due to excessive operating power. Smart Grids are an interconnected electric network of end-users that integrates actions and behaviors. Business scenarios previously discussed involve both discrete data (like customer profiles and past purchase history) and continuously changing and moving data (like a driver's geolocation or the temperature inside a data center) (Jadhav & Dharme, 2012). Analytics must be used in a variety of ways and for a variety of reasons in light of this fact. To draw value from the linked environment, the AIoT system must first have access to a range of data to recognize what is significant as it occurs (Chakraborty et al., 2017). It must then derive insights from the data in a rich context. Finally, it must produce results quickly, whether to notify a device operator, extend an offer, or modify how a device performs. Figure 1 depicts various dimensions of analytics and their interactions.

The smart grid is a multi-stakeholder, intricate system. It is vital to comprehend the needs and viewpoints of various stakeholders while implementing novel technologies and formulating fresh rules. The smart grid is also a consumer-driven technology, meaning that advancements in technology are determined by human demands and habits. The power grid these days has installed IoT sensors for real-time monitoring of the power grid. In addition, the organization wants to utilize the sensors' data by integrating AI with smart grids. The purpose is to reduce the operating cost of maintaining units and losses in the distribution of energy. AIoT architecture powered through edge computing supports connections, management of terminals, data privacy, data analysis, fault prediction, and classification of faults.

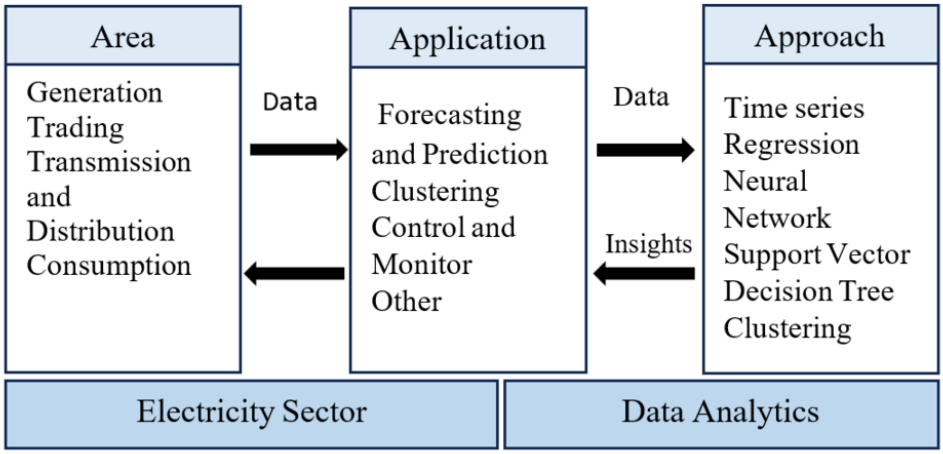
The main contribution of this chapter is listed as follows.

i. The chapter provides concepts of Smart Grid and its architecture
ii. The chapter provides an analysis of the various components of smart grid technology and its development prospects.
iii. The chapter describes the smart grid fault detection and classification framework.
iv. Issues and challenges in the development and maintenance of smart grid in India are discussed.

2. AIOT APPLICATIONS IN THE ENERGY SECTOR

Past researches show various application domains that utilize AIoT technologies (Avasthi et al., 2022, Shi et al., 2020, Samantaray, 2014). Some of the applications

Figure 1. Three dimensions of analysis and their interaction



include smart cities, smart healthcare (Avasthi et al., 2022), smart homes (Chauhan et al., 2021), smart agriculture, and smart industry. Additionally, there has been a rapid development of Internet of Things applications that are centered on particular things, such as the Internet of Vehicles (IoV) and the Internet of Video Things (IoVT). The key technology used in AIoT is artificial intelligence, hardware accelerators, and 5G networks. 5G (fifth generation networks) delivers fast speed which is faster than 4G/LTE for advanced data analytics needed for fast transmission over the cloud.

The use of Artificial Intelligence in smart grids for security purposes is beneficial too. A Deep learning solution based on a Deep Belief network can detect false data injection attacks quickly and with good accuracy. Another useful solution is a cloud-centric system for theft detection that detects abnormal behavior in smart grids.

3. SMART POWER SECTOR SOLUTIONS

Smart grids and smart meters are two examples of the technology employed by smart energy solutions for the collection of relevant data. This information pertains to the flow of electricity and may range from equipment performance to end-user energy consumption. By analyzing this data, an energy provider may make prudent judgments to govern power flow in all three verticals of generation of power, transmission, and distribution. The Internet of Things is crucial for ensuring that electricity flows through each of these three processes. It helps power companies to regulate the flow of electricity even during peak demand and reduce waste.

3.1 Smart Grid and Role of AIoT

Smart grids can track and schedule loads, detect grid failures, and identify cyberattacks by applying the latest AIoT tools and methodologies. The power distribution poles classification and estimate of any damage are done through Unmanned aerial vehicles (UAVs) which are part of a cellular network and directly connected to a control center (Beg, 2016). This concept began to take shape with the introduction of electrical network distribution systems. Different requirements, such as those for control, monitoring, tariffs, and services, were required over time for the transmission and distribution of electrical power. Typically, smart meter installation and smart grid implementation occur together. They were used in the 1970s and 1980s to transmit consumer data back to the grid. Despite the most recent technological advancements, the dependability and efficiency of energy transmission and distribution via the electric power grid remain the most fundamental requirements that are currently being met.

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both to efficiently deliver sustainable, economical and secure electricity supplies. (Shahzad, 2020)

To distribute electricity to users, a grid or network of electrical cables is required. The term "Smart Grid" may apply to this network if its control and monitoring mechanisms are automated and it is intelligent. A "smart grid" is a technical term for conventional networks that combines current, automated technologies to boost their sustainability and dependability. In the past, grids were just used to transfer and distribute electricity, but today's smart grid can interact, store data, and even make decisions based on the circumstances. Therefore, a smart grid is an intelligent network of electricity that integrates the actions of all stakeholders—generators, consumers, and one who does both—to supply electricity with efficiency, sustainability, economy, and security, according to the Strategic Deployment Document for Europe's Electricity Networks of the Future. Thus, Smart Grid technology will not be the only one used.

Knowledge illustration and causal relationship development are also studied for power grid breakdown diagnosis and effect cause analysis (Aboumalik et al., 2019). Transfer learning and deep reinforcement learning methods for load monitoring and electric car charging scheduling are given (Wang, 2015, Avasthi et al., 2022). A distributed deep reinforcement learning method is useful in safeguarding and maintaining the privacy of households while managing load schedules. This method is based on the idea of federated learning implemented using action networks at distributed households and the critic network belongs to an aggregator from a third party(Jenkins, 2015). The security issue of cyberattacks on smart grids has received substantial attention. Recently, a semi-supervised deep learning system based on generative adversarial networks and autoencoders was suggested, and it is capable of identifying attacks in smart grids that use bogus data injection.

3.2 Smart Meter

Utility companies all around the world are currently in the process of putting in place expansive networks of advanced metering infrastructure (AMI), sometimes known as smart meters (Hosseini et al., 2020, Chen et al., 2016). But are utilities truly optimizing their use of both their investment and all of this data to its full potential? The continuous and real-time analysis of meter data to continue providing utilities with important answers to their operational and business-related questions is the key to realizing the full potential of smart meters and the smart grid. This analysis is the key to realizing the full potential of smart meters and the smart grid. Take, for example:

- Which customers have the most potential to help manage peak demand using our time-of-use pricing or demand response programs?
- To effectively plan for power generation and negotiate the most affordable contracts for wholesale market electricity, how can we make sure that our estimations of load and peak demand are as accurate as possible?
- To construct larger transformers or switch meters to transformers that are not running at capacity, how can we shift the load off of these transformers temporarily?
- Is the rollout of our smart meters proceeding on time and with minimal equipment or installation issues? How well does our network of smart meters perform over time?
- Is it possible to use new ways to save energy or lower reactive power on a large scale? For example, could conservation voltage reduction programs be used to save energy or lower reactive power?
- What proactive maintenance strategies can we implement to replace our current reactive maintenance approach and focus our meager field personnel on the equipment that is most likely to malfunction?

***Understanding and engaging customers through AMI analytics*-** With the use of AMI analytics, utilities can enhance several client programs, including demand response, energy efficiency, and time-of-use pricing, which have advantages for both the business and its clients (Liu et al., 2016). Some common activities are program design, identifying participants, helping customers to make choices, evaluation, and reporting incidents. In the program planning step, the right mix of customer-facing measures and rewards is chosen. Based on their real energy data, online calculators can tell each customer if they could save money or get other benefits from joining a program or switching to a time-of-use rate. The different programs that people are using are looked at every so often to see if they're meeting their goals.

Optimizing and improving the energy market- The energy industry and its structure have a significant impact on the financial landscape. Utilities that possess the capability to accurately predict their power requirements generally enjoy the advantage of negotiating more cost-effective long-term contracts when procuring wholesale power (Liu et al., 2016). Additionally, they avoid significantly more expensive last-minute power purchases on the secondary market. This results in cost savings for regulated distribution utilities, which may be transferred to consumers, or potentially even profits for shareholders. The utilization of AMI analytics facilitates more precise prediction of system capacity and peak demand, leading to more informed procurement decisions. Through the use of analytics, utilities can determine when and how system peaks occur, as well as divide system loads into significant customer and regional peaks. By utilizing such real-time and detailed data, utility companies can observe the evolution of consumer behavior regarding device and energy consumption (Chen et al., 2016).

3.3 Fault Detection and Classification

Smart Grid (SG) defect detection is a crucial research topic that is gaining attention from both the academic world and business. Identifying problems or potential failures on the smart grid involves sensing and assessing variations in electrical power (such as current and voltage), environmental, and equipment characteristics. System status awareness, system maintenance, and system functioning depend on autonomous smart grid fault detection. Continuous monitoring and fault detection are imperative steps for maintaining quality of service (QoS) in different SG applications. Power transmission, distribution, and consumption all necessitate the implementation of autonomous smart grid fault detection (Raza et al., 2022). The faults that can be found at different layers of SG systems can be faults due to Physical devices/component *failures*, *communication faults,* and *software/hardware* level faults (Vyas et al., 2019). There are two primary categories for faults: balanced faults and unbalanced faults. In general, unbalanced faults occur frequently which are divided into series and shunt faults. Shunt faults can easily be detected by observing an increase or decrease in voltage and frequency. The common problems related to energy distribution and management are discussed as follows.

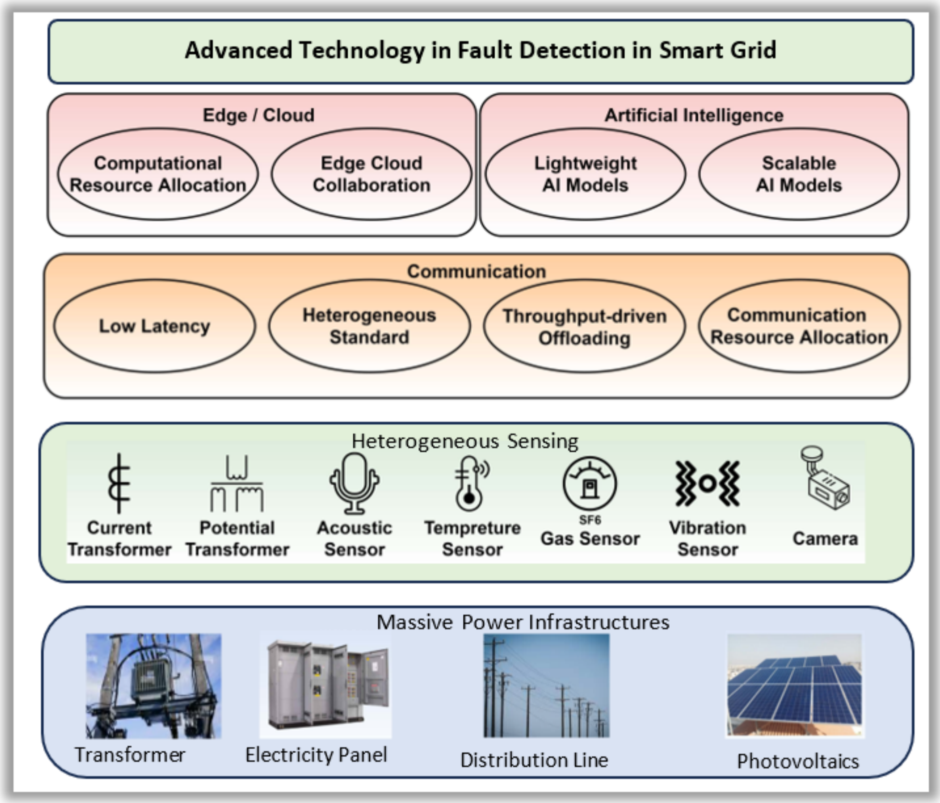
- **Power Transmission**: As the size, complexity, and intelligence of UHV AC and DC transfer systems have grown, the way the power grid works has changed in big ways. On the one hand, things like changing regional climate and a complicated operating environment can affect UHV power transmission. At the same time, it is important to keep an eye on how the power grid is running. On the other hand, AC and DC are closely connected to UHV power grid transfer and reception, which can easily make global security risks worse. So, finding bugs and early warnings of cross-regional risks in real-time at the network level is very important for helping to plan operations (Li et al., 2023).
- **Power Distribution:** More and more distributed generators, devices that charge electric cars, devices that store energy, and microgrids are connected to the distribution network as the penetration rate rises. Large power changes and voltage over-limits are likely to happen because of the random nature of green energy sources and loads, as well as the spread multi-agent control. This makes it hard to run the distribution network. On the other hand, the tie switch-based method of network reconfiguration has limits on its response time, working life, and inrush current. This means that it won't be able to meet the needs of future users who need high reliability (Sidhu and Xu, 2010).
- **Power Consumption:** Low-voltage power grids are very complicated in how they are put together. During operation, electrical faults like leaky faults, short circuit faults, overload faults, and high contact resistance often happen, making it hard for users to do the things they need to do every day. The only way to make sure that the collection system works well and that different rating signs get better is to get better at running and maintaining it.

The data-driven method uses different machine learning algorithms to classify faults and perform better than conventional methods. Some Data-driven methods for fault detection are Artificial Neural networks, Fuzzy logic, Support Vector Machines and Genetic Algorithms.

4. AIOT TECHNIQUES FOR SMART GRID FAULT DETECTION

The electricity demand is growing due to the smart city and Industry 4.0 application development. For getting insights on usage and optimizing performance Fault analysis and detection have become an essential task. This is the basic measure that can be taken to detect, locate, classify, and clear faults in the power system for proper functioning without interruptions. The recent technology being used in Smart Grid fault detection is shown in Figure 2.

Figure 2. Technology used in fault detection in smart grid



(a) **Advanced Sensing and Communication**: The smart grid is continually developing, and fault detection technology is changing with it. Together with the standard current and voltage transformers, the grid system also includes a range of sensing devices, such as phasor measuring units, smart meters, vibration, acoustic, and environmental sensors, in addition to visible and infrared cameras. One of the imperative steps in SG system is the transfer of sensor data generated in real-time to cloud storage/server or edge devices for processing further and to perform analysis. The connections to edge devices and cloud servers are generally low latency connections so improvement is essential. The different communication standards such as Ethernet, optical fiber, LTE, WiFi, Zigbee are utilized in the smart (Xiong et al., 2020). 5G technology helps in real-time identification of faults in the distribution network (Chang et al., 2019). 5G features like Ultra Reliable Low-Latency Communications provide high data rates and support multiplexing. Massive Machine Type

Communications (mMTC) enables connectivity for IoT devices and supports low latency and highly reliable communication between connecting nodes.

(b) **Machine Learning Methods**: With continued advancement, advanced artificial intelligence (AI) technology will no longer require manual control throughout the process as it enters the stage of autonomous learning based on huge data. This is especially clear in the process of detecting faults in power systems. Conventional power systems have a complicated internal network with incredibly laborious linkages. Using conventional manual troubleshooting techniques will be exceedingly challenging and error-prone if the power system breaks while the system is in use. As artificial intelligence (AI) becomes more widely used, machine learning algorithms can be used to deeply integrate, analyze, and extract mapping relationships from the massive amounts of online and offline multi-source heterogeneous power system data. This allows for the quick, accurate, and efficient detection of most power system faults as well as their intelligent handling. Different models work well with different kinds of data, and deep learning can combine heterogeneous data from several sources, which increases efficiency and guarantees the power grid's safe and dependable functioning.

(c) **Edge Computing and Cloud-Edge Collaboration**: Even though AI and computing technologies are getting better, there is still a need for quick access to the computing power that is needed. This is because the number of smart devices is growing and machine learning algorithms are becoming more complicated. Communication and cloud computing make it possible for cloud servers to store and handle huge amounts of data. Cloud computing systems, on the other hand, have problems with network lag and high dynamic jitter, which makes it harder to meet the strict delay requirements for fault detection in smart grid [43-44].

5. POWER MANAGEMENT THROUGH AIOT: CASE STUDY INDIA

Indian government's efforts to increase metering because of the growing popularity of smart meters on a worldwide scale is worth appreciable. The budget for the Financial Year 2022 included £29 billion ($39 billion) for smart metering as part of the Smart Metering National Initiative; over the following five years, 250 million conventional electricity meters will be replaced with smart meters. Governments are in charge of providing water, and each state uses its system to obtain and distribute it (Shankar & Singh, 2022). For instance, Maharashtra is at the forefront with more than 500,000 smart water meters installed in the state's two largest cities, Pune and Nagpur. The city of Jaipur will continue to use the current meters even though Rajasthan has allocated over $53 million to replace all current meters in the city of Jaipur over the next three years.

In terms of gas distribution, pipeline natural gas (PNG) and compressed natural gas (CNG) are new to the country, with only 4 - 5% of the population receiving supply. The Ministry of Petroleum and Natural Gas in India is working hard to accelerate the adoption of gas as the primary fuel for consumers in the home, cars, and businesses. Key figures include 50-55 million new PNG connections over the next six years, as well as 6.6 million PNG connections today (Sinha et al., 2011). Even though smart metering initiatives to reduce customer attrition and increase efficiency are already underway, water utility metering is a zero-tech industry, with manual meters and readings and pipeline gas being a recent phenomenon (Vyas et al., 2019, Kumar et al., 2023). These utilities, however, are set to grow exponentially as a result of government mandates. For example, domestic gas supply will shift away from LPG, and cities must provide at least 200 liters of water per person per day. The Indian government's aim of lowering transmission and distribution losses depends on the Internet of Things (IoT). This relates to the statewide deployment of smart meters under state supervision. One important requirement is that all meters bought under the initiative have to be produced locally, with at least 50% of the value added happening in India. As of March 2022, 15 million meters had been bought; to meet government commitments, an additional 235 million must be purchased by 2025.3.

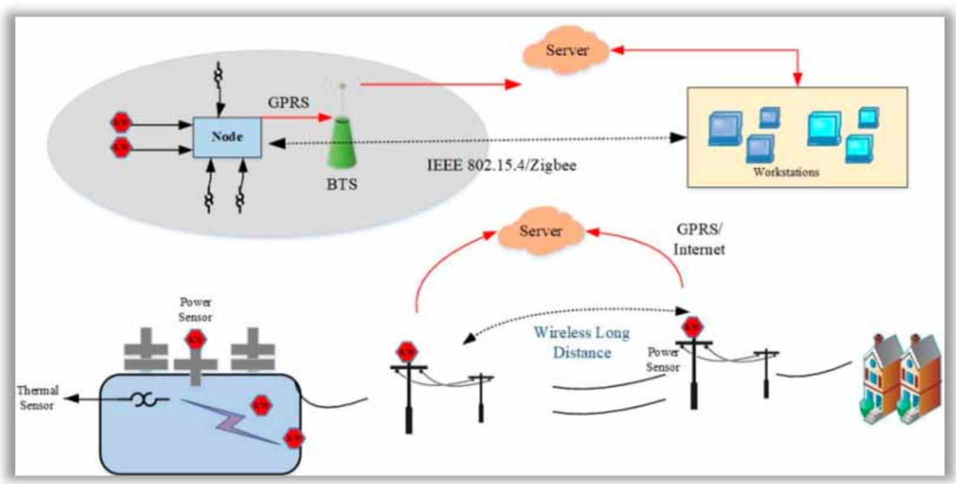
5.1 IoT as Part of the Ecosystem

When it comes to smart metering in India and other developing nations, the business model and the entire customer solution are the most innovative aspects. The managed services or hybrid CAPEX/OPEX models that utilities pursue depend on the country in which they operate. The ecosystem contains essential elements such as IoT networks and device-manufacturing companies. This implies that IoT companies should exert significant pressure to overhaul the entire utility, as opposed to simply connecting the meter to the cloud. Collaboration is required to develop an end-to-end solution involving the utility, device makers, software suppliers, billing platforms, ERP systems, and customer support. For example, we partner with Raychem, a large industrial group that makes gas meters and has the greatest number of gas meters in use in India (Salkuti, 2020).

5.2 AIoT Architecture

AIoT architecture shows the design that identifies each layer as having a distinct task to accomplish is commonly done layer by layer (Li et al., 2018). More pertinent to IoT applications and energy system regulations compliance is the four-layered approach. The 4 layers are the physical layer, communication network layer, cyber layer, and application layer. The cyber layer uses cloud-based processing applications and distributed systems to optimize computing. The layer of application known as the management layer is used in analyzing concerns from economic, social, and environmental viewpoints from collected data about market regulation, incentive measures, and pricing. Figure 3 describes different components in layers and protocols that can be used in energy distribution networks.

Figure 3. The architecture of energy distribution networks



6. CHALLENGES IN SENSOR DATA PROCESSING

The primary challenges in smart grid fault detection and classification are discussed here.

- **Lack of theoretical background-** The decision maker's lack of knowledge of the technology is one factor contributing to the sluggish adoption of AI in the sector of energy. Many organizations just lack the technical knowledge to understand how incorporating AI might improve their operations. Conservative stakeholders would rather take the risk of trying something new than deviate from tried-and-true tactics and resources. As more sectors, including education, healthcare, finance, and transportation, embrace AI's promise, decision-makers in the energy industry are focused on it (Rahman et al., 2013).

- **Lack of practical expertise**- AI is still a young technology, with few professionals who have mastered it. There are many experts with wide theoretical knowledge of the issue. However, finding experts who can create robust AI-powered software with practical applications is very challenging. Furthermore, the sector of energy is notoriously conservative. Energy companies gather and handle data, but it can be challenging to digitize that data using state-of-the-art technology. There are risks associated with data loss, improper modification, system failure, and unauthorized access. Due to the high cost of error in the energy sector, many businesses are reluctant to explore new approaches that they are inexperienced with (Lyu et al., 2021, Butt et al., 2021).
- **Heterogenous Sensing**- Utilizing sensor data is essential for assessing the hardware infrastructures of the power grid. The data can be divided into three different categories based on sampling frequency: static data, dynamic data, and quasi-dynamic data. Information like an equipment account, nameplate specifications, pre-commissioning test results, a location, and other pertinent specifics are examples of static data. Periodic changes to dynamic data are often made every few seconds, minutes, or hours. This category includes a variety of data types, including operational data, records from inspections, real-time detection data, and environmental meteorological data. Regular or sporadic updates to quasi-dynamic data often occur on a monthly or annual basis. The majority of this information consists of records of equipment concealed risks, fault defects, and maintenance.
- **Financial pressure-** Putting cutting-edge smart technology to use in the energy field might be the best thing to do, but it's not cheap. It takes a lot of time and money to find an expert software services provider, make software that fits your needs, and keep an eye on it while you make changes and manage it. Before energy companies can get the most out of AI, machine learning, and deep learning, they need to be ready to spend a lot of money and risk a lot to replace their old systems.
- **Abnormality in power equipment-** The reason for power equipment failure is mainly abnormalities that generally pre-occur, also known as incipient faults that last for a short period and then recur. The characteristics of such faults are uncertainty and random arcs, which last between quarter to four cycles making it difficult for analysts to work on it for any analysis purpose. The majority of conventional techniques for detecting early-stage faults first analyze the waveform's properties before classifying the fault. AI techniques enable speedy defect detection and simple response to waveform characteristic changes. On the other hand, incipient defects are extremely brief and rarely arise. When they do, the fault recorder won't be able to capture the signals

and the protection mechanisms installed in the power system might not function. As a result, insufficient training data are available to build a reliable AI model.

- **Edge computing with resource limitations-** The advantage of edge computing is due to the processing that takes place on communicating nodes which saves time. Edge computing powered with artificial algorithms also known as edge intelligence is capable of analysing data on a device locally. Most edge devices have limited resources that limit the accuracy of detecting data locally. Therefore large models that depend on billions of parameters implementation and deployment becomes difficult and sometimes impossible.

7. CONCLUSION

The fundamental technologies employed in the smart grid encompass sensing, communication, optimization, and data analysis, serving diverse objectives. The power sector can enhance its value by integrating smart devices, advanced user interfaces, cloud computing, big data, and services. The smart devices or objects of AIoT are wi-fi chipsets, and sensors such as accelerometers. The power network in question facilitates bidirectional transmission of electricity and data utilizing digital communication technologies, hence enabling the detection, response, and proactive management of fluctuations in consumption and various concerns. The primary emphasis of this chapter is to provide the use of Artificial Intelligence, and sensor data processing for fault detection and a brief discussion of challenges that exist in this research area.

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