# Data Analysis for Smart Grid and Communication Technologies

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*Abstract –* Smart grids and communication technologies are among the significant advancements in the energy sector. These technologies improve energy efficiency by increasing the use of renewable energy sources. However, the integration of these technologies also creates a vast amount of data that requires analysis to optimize energy management and improve system performance. In this context, data analysis plays a crucial role in identifying patterns, predicting energy demand, and managing energy supply. This paper provides an overview of the importance of data analysis in smart grids and communication technologies and discusses various data analysis techniques used in energy management systems. Additionally, it highlights the challenges and opportunities associated with data analysis in the context of smart grids and communication technologies.

*Keywords – Communication Technologies, Data Analysis, Energy Management, Energy Efficiency, Smart Grids*

## 1. Introduction

Smart grid and communication technologies represent critical areas in today's energy sector, which is undergoing significant change and transformation. These technologies aim to increase the efficiency, safety, and sustainability of energy production, transmission, and distribution processes [1]. By utilizing these technologies, better management of energy consumption and more effective use of energy resources become possible. Furthermore, the deployment of these technologies can reduce environmental impacts by promoting the use of sustainable energy sources. Thus, smart grid and communication technologies play a crucial role in the energy sector's ongoing transformation.

The rapid advancement of digital technology and cloud computing has resulted in an increased production of data through various tools such as smart devices, computers, and human interactions. Effective analysis of these data can provide significant value and benefits to our daily lives and businesses [2]. However, the volume and complexity of data are rapidly increasing, and processing and analyzing these data have become a new challenge and opportunity of this century due to the concept of "big data" [3].

Data analysis assists grid operators in identifying energy consumption trends, optimizing energy flow in the event of excessive demand, and planning the integration of renewable energy sources [4]. Furthermore, data analysis is used to monitor the performance of communication technologies such as IoT devices (Internet of Things) and sensors utilized in smart grids. This facilitates important processes such as fault detection and prevention, as well as reducing energy losses [5].

In conclusion, this paper underscores the significance of data analysis for smart grids and communication technologies, which are managed based on more data collection and analysis than traditional energy grids.

## 2. Smart Grid and Communication Technologies
### 2.1. Definition and Components of Smart Grid

While there is no universally accepted simple definition of what a smart grid constitutes, the European Smart Grids Technology Platform has provided a working definition as "an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers, and those that do both – in order to efficiently deliver sustainable, economic, and secure electricity supplies" [6]. The concept of a smart grid has emerged in response to the needs of evolving technologies to make electricity production, distribution, and consumption more efficient, safe, high-quality, environmentally friendly, and manageable [7]. In essence, smart grids represent an intelligent energy network that can adapt to changes in energy supply and demand by automatically tracking energy flows.

One of the core features of smart grids is the use of smart metering systems, which continuously monitor the parameters of the grid in real-time, enabling the exchange of information between consumers and suppliers to balance energy supply and demand. For instance, consumers can adjust their energy usage throughout the day based on fluctuating energy prices, with smart meters allowing them to take advantage of lower-priced periods and thus achieve cost savings on their energy bills [8]. In this manner, smart grids are capable of promoting a more sustainable and efficient use of energy resources, while at the same time contributing to a more stable and secure energy supply.

The structure of a typical smart grid is illustrated in Figure 1. In essence, smart grids are a complex network of components, including distributed energy resources, advanced communication networks, intelligent sensors, and control systems. These components work together in a coordinated manner to optimize energy supply and demand, manage power quality, and ensure grid stability and reliability. By leveraging these advanced technologies, smart grids are able to transform the way we generate, distribute, and consume energy,

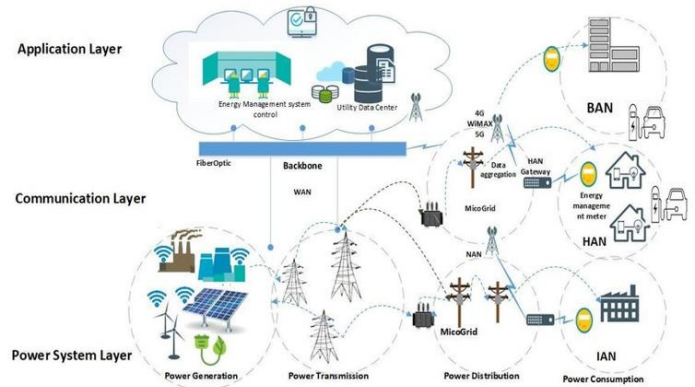paving the way for a more sustainable, secure, and efficient energy future.



Figure 1. Smart grid structure [9]

Smart grids represent a more advanced and sophisticated alternative to traditional energy systems, characterized by higher levels of intelligence and controllability. Leveraging a diverse range of sensors and data collection devices, these systems are able to constantly monitor electricity consumption and analyze the data gathered to predict electricity demand and enable more effective resource utilization. Moreover, smart grids offer a wealth of options to consumers seeking to monitor and manage their energy consumption, resulting in greater flexibility and control over their energy usage [8]. A comparison between the characteristics of smart grids and traditional energy systems is presented in Figure 2.

Compared to conventional energy systems, smart grids offer a host of benefits, such as increased reliability, improved efficiency, and reduced environmental impact. By leveraging advanced technologies and sophisticated control mechanisms, smart grids are able to optimize energy flow, improve power quality, and reduce energy losses. Furthermore, they enable the integration of renewable energy sources and other distributed energy resources, paving the way for a more sustainable and resilient energy future [10].

In essence, smart grids are characterized by their ability to adapt to changing energy demands and supply conditions, and to intelligently manage energy consumption and distribution through the use of cutting-edge technologies. By embracing the principles of innovation, intelligence, and automation, smart grids represent a significant advancement over traditional energy systems, with

the potential to transform the way we produce, distribute, and consume energy.
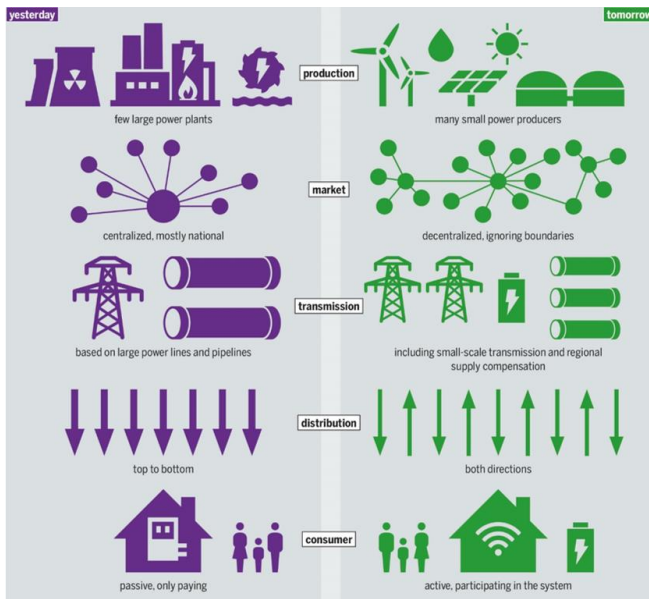


Figure 2. Characteristics of a traditional system (left) and a smart grid (right) [11]

In addition to the definition and characteristics of smart grids, it is important to highlight the significance of smart grid components. These components work in concert to promote more efficient, sustainable, and flexible network management. The ultimate goal of these components is to optimize electricity grids, ensure safe and uninterrupted energy flow, integrate renewable energy sources, improve energy efficiency, and provide consumers with greater control and options.

Smart grid components include a diverse array of technologies and systems, such as advanced metering infrastructure, energy storage systems, renewable energy systems, distribution automation systems, and demand response systems. Advanced metering infrastructure, for example, enables the real-time monitoring of energy consumption and facilitates communication between energy consumers and utilities. Energy storage systems, on the other hand, allow for the storage of energy during periods of low demand and the release of stored energy during periods of high demand.

Renewable energy systems, such as solar panels and wind turbines, are essential for integrating renewable energy sources into the electricity grid. Distribution automation systems are responsible for the automatic monitoring and control of the electricity grid, while demand response systems enable the participation of energy consumers in grid management by reducing energy consumption during periods of high demand.

The fundamental components and technologies of a smart grid are as follows:

1. Smart Production
2. Smart Stations
3. Smart Distribution
4. Smart Meters
5. Communication
6. Advanced Control Methods

Smart production is an approach that involves integrating data and information from networks to facilitate real-time information flow, establish logical cause-and-effect relationships, and provide a planning and management tool for the production and supply chain. By analyzing, modeling, and simulating sensor-based data in real-time, smart production helps to make production processes more efficient and flexible. It simplifies the processes of data collection, analysis, and utilization, providing real-time information flow in the production and supply chain, making planning and management more effective. Smart production also optimizes production processes, personalizes products, reduces costs, and achieves more sustainable production by analyzing, modeling, and simulating sensor-based data in real-time [12].

Smart stations are components that control protection equipment, such as circuit breakers, between high voltage and medium/low voltage sides. They also provide power factor and process control.

Smart distribution is a system that is made more reliable with the inclusion of devices that have reading and monitoring features, providing the highest level of protection against unexpected power outages.

Smart meters are devices that replace traditional meters and constantly communicate with other devices and the central system to accurately measure and transmit consumers' energy consumption. By monitoring the parameters of the network and providing real-time information, smart

meters can measure power quality, power outages, meter tampering information, production and consumption information, enabling technicians to be quickly directed to the correct location. Additionally, smart meters have the ability to be read remotely, allowing for the automation of meter reading processes and reducing human error.

Integrated communication involves SCADA, which is a data collection, protection, and control system that enables users to interact with smart electronic devices in an integrated system [12].

Advanced control methods refer to control methods developed to make processes more efficient and stable, typically used in industrial processes. These methods provide feedback control by using sensors and other measurement devices to measure and analyze process variables. Advanced control methods utilize various technologies such as machine learning, artificial neural networks, fuzzy logic, genetic algorithms, etc., to make processes more intelligent and predictive. The benefits of advanced control methods include reduced energy consumption, fewer errors, and less waste, resulting in environmental and economic benefits.

## 2.2. Definition and Features of Communication Technologies

Communication technologies refer to the various tools and systems that facilitate the exchange of information, ideas, and messages between individuals through different media, such as text, voice, and video. These technologies have a wide range of applications, including phones, email, instant messaging, social media, and video conferencing.

In the realm of smart grids, communication technologies play a crucial role in gathering information about the condition of components for the purposes of control, monitoring, and maintenance [13]. Smart meters used in smart grids are a prime example of communication applications. Today, different communication methods are used for remotely reading meter indexes. These methods can be one-way or two-way. The index information can be tracked one-way, or the information can be transmitted to the user, or remote control can be provided by intervening in the energy, such as energy cutoff. By monitoring annual subscriber

consumption and transformer consumption, these systems allow for the detection of irregular energy usage [14]. As a result, problems such as energy theft can be prevented, and energy resources can be used more effectively [15]. Two-way communication methods enable consumers to more effectively track and manage their energy consumption. As a result, consumers can make more conscious use of energy and reduce their energy bills.

There are two primary communication technologies for transmitting data between smart meters and electrical facilities: wireless and wired. Wireless communication technologies enable communication between smart meters, sensors, and other smart devices and make it easier for these devices to interact with each other and the central control system. While wireless communication has advantages such as low-cost infrastructure and ease of connection to inaccessible or difficult-to-reach areas, it also has a disadvantage of causing signal attenuation due to the nature of the transmission path. Wired communication technologies, on the other hand, provide reliable and fast data transfer and are not affected by the effects of electromagnetic interference. In addition, wired communication technologies provide an advantage in terms of security, and their functions are not dependent on batteries, as is often the case with wireless solutions [16], [17].
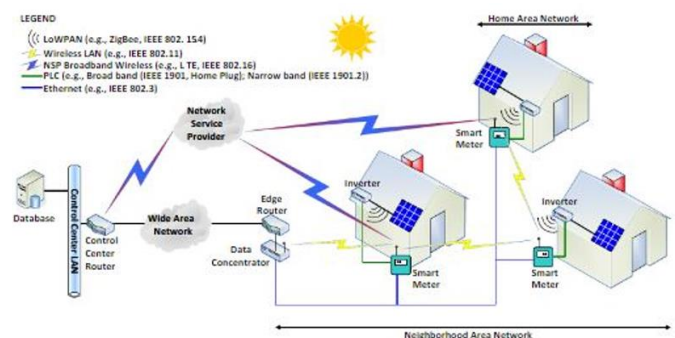


Figure 3. Projected smart grid communication networks [18]

Information flow in smart grids requires two types of communication infrastructure. The first type is the flow of information from sensors and electrical devices to smart meters. This can be achieved through power line communication or wireless technologies such as ZigBee, 6LowPAN, and Z-wave. The second type of communication is between smart meters and data centers. For this type

of data flow, cellular technologies or the internet can be used. However, factors such as distribution time, operating costs, technology availability, and environmental characteristics are crucial in determining the most suitable communication technology to be used [17]. An overview of communication technologies used in smart grids is presented in Table 1.

Table 1. Smart Grid Communication Technologies [19]

| Compunction Technology | Frequency Range | Date Rate | Range |
|---|---|---|---|
| GSM | 900-1800 MHz | Up to 14.4 Kbps | 1-10 km |
| GPRS | 900-1800 MHz | Up to 170 Kbps | 1-10 km |
| WiMAX | 2.5 GHz, 3.5 GHz, 5.8 GHz | Up to 75 Mbps | 10-50 km |
| PLC | 1-30 MHz | 2-3 Mbps | 1-3 km |
| ZigBee | 2.4 GHz, 868-915 MHz | 250 Kbps | 30-50 m |
| 3G | 1.92-1.98 GHz, 2.11-2.1 GHz | 384 Kbps-2 Mbps | 10k m |
| DASH7 | 433 MHz | 28-200 Kbps | 250 m-5 km |
| Bluetooth | | 721 Kbps | 1-100 m |
| Z-Wave | | 40 Kbps | 30 m |

## 3. Data Analysis
### 3.1. Definition and Importance of Data Analysis

Data analysis refers to the process of utilizing statistical and mathematical techniques to comprehend and interpret information within a given dataset. Within this process, data scientists collect, organize, clean, and analyze data. Data analysis is an indispensable tool used in a wide range of industries, including finance, business, healthcare, marketing, and scientific research. It plays a significant role in the decision-making process and facilitates the ability of businesses, organizations, and governments to make more informed decisions. When combined with advanced technologies like big data analytics, machine learning, and artificial intelligence, data analysis can lead to even more comprehensive results.

In the context of smart grids, large quantities of data are collected to forecast fluctuations in energy consumption and manage future demand. This data comes from various sources, such as consumption trends, weather patterns, user behavior, and other factors. Through data analysis, this information can be processed to help energy producers and distribution companies make informed decisions based on real-time and historical data. These decisions encompass various critical aspects, including determining the quantity and method of energy production, optimizing transmission and distribution networks, improving energy efficiency, and transitioning to renewable energy sources [4] [20].

In summary, data analysis is a vital tool used across a multitude of industries, and it helps to make sense of the growing quantities of data generated through the use of big data sets, the internet, and mobile devices. Ultimately, it empowers accurate decision-making processes.

### 3.2. Methods and Techniques of Data Analysis

Data analysis methods and techniques encompass a range of tools used to summarize, analyze, predict, discover, and apply data in the decision-making process. These methodologies and techniques can be instrumental in enabling businesses or organizations to extract valuable insights from their existing data, enhance business efficiency, curtail costs, and improve business processes. Utilizing data analysis methods and techniques in conjunction with advanced technologies such as data mining, natural language processing, machine learning, artificial intelligence, and other such technologies can provide more comprehensive results [21]. In this context, Figure 4 presents an overview of the most commonly utilized data analysis methods.
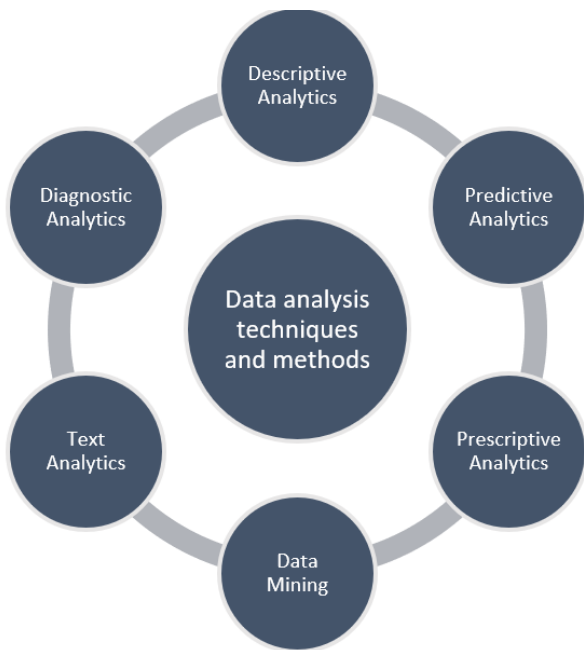
Figure 4. The most used data analysis methods

Data analysis involves a variety of methods and techniques that are used to summarize, explain, diagnose, predict, and prescribe solutions for various problems in a business or organization. Descriptive analysis is used to gain insights into the current state and trends of data by using statistical methods, visualization tools, and data tables. Diagnostic analysis is employed to analyze the causes and effects of data, with the aim of developing solutions for specific events or problems. Predictive analysis uses technologies like machine learning and artificial intelligence to predict future events or trends, and helps businesses plan their future activities. Normative analysis helps businesses or organizations choose the best solution for a specific goal and utilizes optimization and simulation techniques in addition to using data in the decision-making process. Data mining is used to discover patterns and relationships in large data sets and can be used in combination with techniques such as artificial intelligence and machine learning to gain a better understanding of customers. Text analysis is used to analyze text data and employs natural language processing techniques to extract valuable information from sources such as social media comments, customer complaints, or survey responses.

### 3.3. Data mining and machine learning

The subject of data mining and machine learning has become increasingly popular in modern times and is a widely applied field. These fields have a critical role in enabling businesses to transform vast datasets into meaningful and useful information. Data mining is a complicated process involving several iterative steps to extract significant information from extensive datasets [22]. Figure 5 presents a comprehensive visualization of this process. Data mining necessitates accessing and employing valuable data from databases that store vast amounts of information, with the goal of attaining our objectives [23].
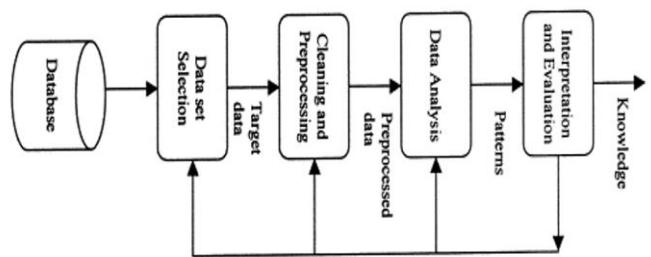


Figure 5. An overview of the data mining process [24]

Machine learning is an artificial intelligence branch that empowers computers to analyze data, learn from it, and make decisions. This technology is deployed to identify intricate patterns and relationships within vast datasets, and to make predictions and decisions. The primary machine learning approaches can be classified into two categories: supervised and unsupervised learning. Supervised learning utilizes pre-labeled data to achieve specific outcomes, whereas unsupervised learning employs unlabeled data to discover patterns within the data. Reinforcement learning is a method that employs feedback, such as rewards or penalties, to achieve particular outcomes [25], [26]. Machine learning has a wide range of applications in various fields, such as automated vehicle control, speech recognition, image recognition, natural language processing, and others. This technology has immense potential in data analysis, prediction, and decision-making processes, and is extensively utilized in many industries today. Data mining and machine learning are interconnected disciplines. While data mining encompasses a set of techniques used to discover meaningful information from massive datasets, machine learning is concerned

with developing algorithms that can analyze and learn from data to make decisions.

## 4. Big Data and Data Mining Methods
### 4.1. Definition and Characteristics of Big Data

Big Data is a term used to describe data sets that are typically too large, complex, and diverse to be effectively managed by traditional data processing methods. The definition of Big Data goes beyond just the size of the data and includes the meaningful and actionable processing of data collected from various sources and in different formats, such as social media posts, network logs, blogs, photos, videos, and log files. These data sets are often generated at high volumes, in diverse formats, and at an ever-increasing velocity. Consequently, managing and analyzing Big Data necessitates specialized tools and techniques that go beyond the traditional methods of data management. Big Data is characterized by three primary attributes, namely volume, variety, and velocity [27], [28]. Figure 6 provides a visual representation of the three main characteristics of Big Data, also known as the 3V rule.
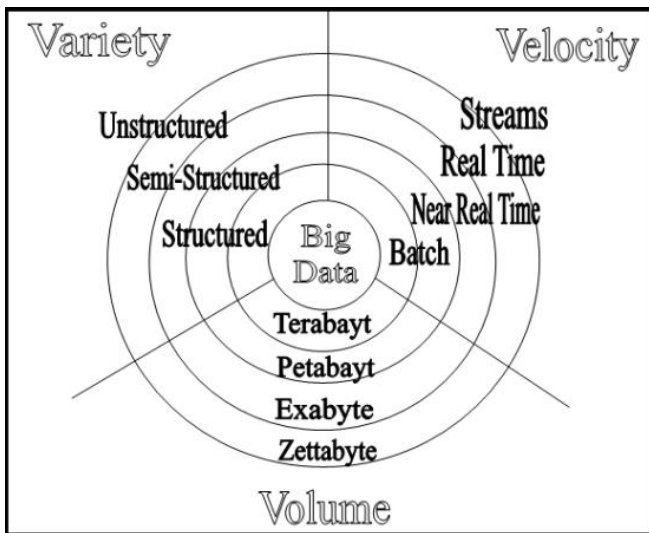


Figure 6. The Three V's of Big Data [29]

The term "volume" denotes datasets that are characterized by their immense size, often exceeding the capacity of traditional data processing methods. For instance, data originating from social media platforms or IoT devices may display such a volume that conventional databases are unable to accommodate it. The concept of "variety" refers to the presence of diverse types of data. Big Data may

encompass unstructured, semi-structured, and structured data that are derived from a variety of sources and formats. The third "V," velocity, reflects the need for prompt data production and processing. To exemplify, a bank requires the real-time tracking of customer transactions, or a weather application necessitates the instantaneous collection of weather data, both requiring a swift data processing capacity.

Big Data plays a crucial role in enabling businesses to comprehend customer behavior, evaluate business performance, create novel products and services, make informed decisions, and much more. However, the transformation of this vast volume of data into meaningful and actionable insights necessitates specialized expertise in terms of its management and analysis [30].

### 4.2. Data Mining Methods and Techniques

Data Mining is a set of techniques and methods developed to discover, analyze, and understand data within large datasets stored in data warehouses. The aim of data mining methods is to transform these datasets into a comprehensible and usable form by uncovering hidden patterns and relationships within the vast amounts of data stored in data warehouses. These methods assist in processing large quantities of data stored in data warehouses, identifying trends, patterns, and relationships, and enhancing the potential for data utilization [31] [32].
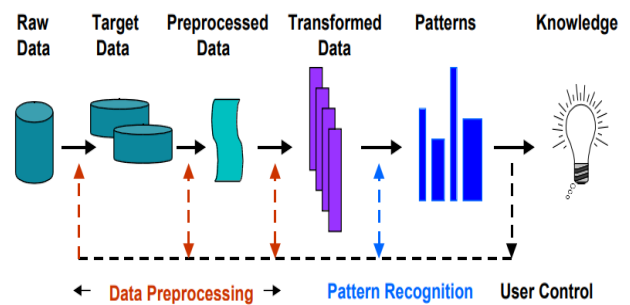


Figure 7. The Data Mining Knowledge Discovery Process [33]

Data mining methods and techniques include:

1. Classification: A technique used to determine if data belongs to a certain class. For example, a bank can use customer data

to determine if they should approve a credit card application.

2. Clustering: A technique used to group data with similar characteristics. For example, a store can use customer data to identify customers with similar shopping habits and use this information in their marketing strategy.

3. Association Rules: A technique used to determine relationships between data. For example, a grocery store can use customer data to determine which products are often purchased together and create promotions accordingly.

4. Prediction: A technique used to predict future events or outcomes. For example, an insurance company can use customer data to predict which customers are more likely to file a claim in the future.

5. Data Visualization: A technique used to make data more understandable by presenting it through graphs, tables, and visual elements. Data mining is a widely used technique in many fields and helps businesses extract valuable insights from their data. However, selecting the right data, performing data preprocessing, and using appropriate data mining techniques are important in obtaining accurate results.

### 4.3. Data Mining Applications for Big Data

Big data, which refers to massive volumes of data coming from different sources, is one of the most important technological trends of our time. Data mining is a method for extracting meaningful information from these data sets. Data mining applications for big data are used to reveal patterns, relationships, and trends in these data sets by employing techniques for extracting meaningful information [34]. Examples of data mining applications for big data include:

- Data analytics: Techniques and methods used to analyze big data sets.

- Machine learning: Techniques and methods that enable computers to learn automatically from big data sets.

- Data visualization: Techniques and methods used to represent big data sets visually for better understanding.

- Data mining tools: Software and tools used to perform data mining operations on big data sets.

- Natural language processing: Techniques and methods used to analyze and process text-based big data sets.

- Internet of Things (IoT): Techniques and methods used to analyze big data sets collected from IoT devices Data mining applications for big data can help businesses better understand their data, discover new opportunities, and increase efficiency. However, caution must be taken in areas such as data security, privacy protection, and data management [35].

### 5. Data Analysis Applications for Smart Grid and Communication Technologies
### 5.1. Applications of Data Analysis in Smart Grid and Communication Technologies

Data analysis applications in smart grid and communication technologies involve the collection, analysis, and management of data in power grids. These data can provide useful information on topics such as grid security, energy efficiency, consumption management, and making the grid more sustainable [36]. These applications are typically used to analyze and manage large amounts of data obtained through various sensors and devices. Some examples of data analysis applications are:

6. Energy consumption monitoring: Devices such as smart meters are used to collect consumer energy consumption data. This data can be analyzed by energy management firms and electric distribution companies to gain insight into consumer energy use habits. This can help determine appropriate strategies for more efficient energy use.

7. Grid monitoring: Smart grid systems continuously collect and analyze data in energy grids. This data can be used by grid managers to gain information on the overall

performance of the grid. This is an important tool for improving grid security and performance.

8. Data analysis: The analysis of data in the grid can provide useful information on grid security, energy efficiency, and making the grid more sustainable. These analyses can be conducted using technologies such as artificial intelligence and machine learning.

9. Load forecasting: Load forecasting is a method used to predict future energy consumption by consumers. These predictions can be used by energy suppliers to make appropriate plans to meet future demand.

10. Fault detection: Smart grid systems can detect grid faults more quickly. This results in faster repairs and makes the grid more secure.

In conclusion, data analysis applications in smart grid and communication technologies are important tools for improving grid performance, promoting energy efficiency, and making the grid more sustainable.

## 5.2. Big Data and Data Mining Methods for Analyzing Data from Smart Grid and Communication Technologies.

Big data and data mining methods are advanced techniques that are utilized to analyze large quantities of structured or unstructured data. These techniques are used for various applications, such as data discovery, modeling, classification, clustering, prediction, and many others [37].

Smart grid and communication technologies are characterized by the collection of significant amounts of data from multiple devices, resulting in big data sets. Consequently, big data and data mining methods are frequently employed in this area. The widespread adoption of smart meters has led to the generation of more detailed electricity consumption data [38], [39]. Devices such as smart meters with real-time data collection and transmission capabilities enable the analysis of big data using big data technologies, facilitating the acquisition of useful insights into consumer energy consumption patterns, energy usage behavior, and grid performance.

The following are some of the commonly used big data and data mining methods for smart grid and communication technology data analysis:

Big Data Processing: This technique involves processing and managing large datasets using specialized software, algorithms, and hardware. It is used for processing, analyzing, and managing the large amounts of data collected from smart grid and communication technologies.

Machine Learning: Machine learning is an artificial intelligence method that enables a computer system to learn from and make decisions based on data analysis. Machine learning algorithms process data to create models and use those models to predict or classify future data. The creation of these models is managed by a system that understands the data's features and correct outcomes, thereby improving the system's performance over time. Machine learning techniques can be used to analyze the data collected from various sensors used in smart grids, enabling meaningful results to be obtained from large amounts of data.

Data Mining: Data mining is a discipline that uses statistical, artificial intelligence, and machine learning techniques to find information in large datasets. Data mining uses data analysis and statistical methods to discover patterns, relationships, and trends in large datasets. Data mining methods can be used to extract meaningful information from the data collected from smart grid and communication technologies.

Artificial Intelligence: Artificial intelligence refers to computer systems that work similarly to human intelligence. These systems can think, learn, make decisions, and even surpass humans in many areas. Artificial intelligence is another method used for analyzing the data collected from smart grid and communication technologies. With artificial intelligence algorithms, the analysis and processing of data from smart grid and communication technologies can be carried out faster and more accurately.

Data Visualization: Data visualization is a technique used to make large datasets more understandable. During the analysis of smart grid and

communication technology data, data visualization techniques can be used to make the data more meaningful and understandable.

In conclusion, big data and data mining methods are essential tools for improving grid performance, achieving energy efficiency, and making the grid more sustainable.

## 6. Result

The efficient management of smart grids and meeting future energy demands are crucial for a more sustainable world. In this context, data analysis plays a key role in providing useful insights for better management and optimization of energy and communication grids. Smart grid and communication technologies have resulted in an increase in the amount of data collected by devices and systems, which can be analyzed in various ways to provide better performance, management, and service provision.

The applications of data analysis for smart grid and communication technologies are diverse, including energy management, network performance, customer behavior, security, prediction and optimization, and resource management. These applications provide a better understanding of the performance of energy and communication grids, enabling more effective decision-making.

In the future, data analysis for smart grid and communication technologies will be combined with artificial intelligence, machine learning, and other advanced technologies to make them even smarter and more predictive. This will result in faster and more accurate data analysis, better monitoring of device and system performance, quicker detection of errors, and more effective management of energy and communication grids. As such, data analysis is expected to become even more important in the future, with a continued trend towards its widespread use and application.

Overall, data analysis is of great significance in the efficient management of smart grids and meeting future energy demands. It provides numerous benefits, including increased efficiency, reduced costs, improved customer experience, and safer and more sustainable energy systems. As a result, it is expected to play an increasingly important role in the infrastructure sector.

## 7. Conclusion

In conclusion, the implementation of smart grids and communication technologies has revolutionized the energy and communication sectors, bringing about a new era of enhanced efficiency, sustainability, and service delivery. However, the growing volume of data produced by these systems requires effective analysis to unleash their full potential. Data analysis plays a crucial role in enabling better management, optimization, and performance of grids and systems. The integration of advanced technologies such as artificial intelligence and machine learning will further augment the data analysis capabilities for smart grids and communication technologies. Therefore, data analysis is anticipated to confer a range of benefits, including cost reduction, improved customer experience, and heightened energy security and sustainability.

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