technologies

Review

An Extensive Critique on Smart Grid Technologies: Recent Advancements, Key Challenges, and Future Directions

Sonam Dorji [1], Albert Alexander Stonier [2], Geno Peter [3], Ramya Kuppusamy [4] and Yuvaraja Teekaraman [5,*]

[1] Department of Electrical Engineering, Jigme Namgyel Engineering College, Deothang 42002, Bhutan; dorjibhutan@gmail.com
[2] School of Electrical Engineering, Vellore Institute of Technology, Vellore 632014, Tamil Nadu, India
[3] Centre for Research of Innovation and Sustainable Development (CRISD), School of Engineering and Technology, University of Technology Sarawak, Sibu 96000, Malaysia
[4] Department of Electrical & Electronics Engineering, Sri Sairam College of Engineering, Bangalore 560084, India
[5] School of Engineering & Computing, American International University (AIU), Al Jahra 003200, Kuwait
* Correspondence: yuvarajastr@ieee.org

Abstract: Given the various aspects of climate change and the growing demand for energy, energy efficiency and environmental protection have become major concerns worldwide. If not taken care of, energy demand will become unmanageable due to technological growth in cities and nations. The solution to the global energy crisis could be an advanced two-way digital power flow system that is capable of self-healing, interoperability, and predicting conditions under various uncertainties and is equipped with cyber protections against malicious attacks. The smart grid enables the integration of renewable energy sources such as solar, wind, and energy storage into the grid. Therefore, the perception of the smart grid and the weight given to it by researchers and policymakers are of utmost importance. In this paper, the studies of many researchers on smart grids are examined in detail. Based on the literature review, various principles of smart grids, the development of smart grids, functionality of smart grids, technologies of smart grids with their characteristics, communication of smart grids, problems in the implementation of smart grids, and possible future studies proposed by various researchers have been presented.

Keywords: smart grid; energy storage; renewable energy; smart grid technologies; interoperability

check for updates

Citation: Dorji, S.; Stonier, A.A.; Peter, G.; Kuppusamy, R.; Teekaraman, Y. An Extensive Critique on Smart Grid Technologies: Recent Advancements, Key Challenges, and Future Directions. *Technologies* **2023**, *11*, 81. https://doi.org/10.3390/technologies11030081

Academic Editors: Valeri Mladenov and Vasiliki Vita

Received: 28 May 2023
Revised: 11 June 2023
Accepted: 17 June 2023
Published: 19 June 2023

1. Introduction

With the growing concern for the environment due to greenhouse gas emissions resulting from the use of fossil fuels to generate electricity, the concept of the smart grid has emerged. The smart grid allows renewable energy to be integrated into the power grid, reducing dependence on power plants that use fossil fuels to generate electricity. A smart grid, also referred to as an intelligent grid [1], uses network and information technology to modernize the power infrastructure and provide a better power supply to customers. The two-way communication mechanism is used by a smart grid to transmit electricity between centralized generation plants and end users and from distributed energy sources (DES) to other customers. In delivering electricity to consumers, the smart grid is much more autonomous and has higher reliability and efficiency. Utilities will use existing power grids in smart grids, which will reduce the cost of building new power plants and substations. The smart grid has evolved from a vision to a mission that is increasingly being implemented around the world. Clear energy policies and audit management are helping to support global smart grid initiatives [1–3]. The authors of [4] presented the importance and effects of big data analytics in smart grid performance to achieve sustainable development goals (SDG). Many developed countries have already implemented smart grid technology in their power grids. However, some other countries are lagging behind in implementing smart grid technology. The introduction of smart grids required the traditional utility grids to be updated [5–7]. The control system applied in smart grids and microgrids with a focus on techniques related to Petri nets is reviewed in Reference [8].

This paper discusses and explains the smart grid architecture, its operation, and implementation issues. This paper aims to show the importance of smart grid technology in designing the hybrid electricity system of the traditional grid and achieve higher efficiency in power transmission and distribution than the traditional grid. It addresses the definition of a smart grid, the growth of smart grids, technology for smart grids, innovation for smart grids, cybersecurity for smart grids, and functionality of smart grids. This paper also aims to explain the research work on smart grids, its implementation challenges and problems, and possible future research areas. More productive knowledge and experience in smart grid operation will allow researchers and policymakers to show greater interest in building the capabilities and implementation of the smart grid. A large number of research papers have been analyzed to find the most up-to-date details on the fundamentals, innovations, characteristics, threats, and future potential of smart grids. Smart grid technologies such as smart electricity meters and their applications in smart grids are also discussed. Finally, the role of smart grid metering and communication technology for real-time measurement, monitoring, and the issue of data protection are studied.

2. Definition of Smart Grid

Smart simply means intelligent, productive, clean, neat, or automatic running stuff, and grid means a network for supplying electricity to consumers. As of now, there is no single definition for a smart grid. Therefore, it can be defined in both simple and complex terms. A smart grid can be described in simple words as electricity with a brain. However, the National Institute of Standard and Technology (NIST), USA, defines a smart grid as follows [9]:

"*A modernized electric grid that enables bidirectional energy flows and uses bidirectional communication and control capabilities that will lead to a range of new functionalities and applications*". The IEEE definition of a smart grid is [10]

"*A revolutionary endeavor-with new communications and control capabilities, energy sources, generation models, and compliance with cross-jurisdictional regulatory structures*". The IEC definition of a smart grid is [11] the following:

"*It is a power grid that can intelligently integrate the actions of all connected users-generators, consumers, and those who do both-to efficiently provide a sustainable, economical, and secure power supply*".

According to the U.S. Department of Energy, a smart grid is defined as

"*A smart grid uses digital technologies to improve the reliability, security, and efficiency (both economic and energy) of the electric system-from large-scale generation to utility systems to electricity consumers and a growing number of distributed generation and storage resources*".

Based on the above definitions, the smart grid can be characterized as a bidirectional flow of energy and information that enables the utility to efficiently manage energy transmission and distribution while allowing customers to influence energy decisions. The smart grid takes advantage of real-time communications and information technology data to enable a smooth balance between energy demand and electricity supply. The main difference between the smart grid and the conventional power grid is the bidirectional energy exchange and two-way knowledge sharing between utilities and consumers. The smart grid improves reliability, infrastructure efficiency, economic development, and protection against cyber-attacks and power interruptions.

Therefore, the working definition of the smart grid can be formulated as follows: "A two-way digital communication in the electric power flow with the ability of self-healing, interoperability and prediction under various uncertainty conditions, equipped with cyber security measures against malicious attacks".

Thus, a smart power grid means smarter generation, transmission, distribution, and integration of customers, operations, markets, and service providers. The main objective of a smart grid is to enable intelligent or efficient use of available resources. In [5,6], the authors evaluated conventional power grids and smart power grids. The difference between conventional power grids and smart power grids is shown in Table 1.

Table 1. The conventional utility grid vs. smart grid.

Parameters	Conventional Grid	Smart Grid
Communications	One-way	Two-way [5]
Power generation	Centralized generation	Decentralized/distributed generation [6,7]
Control methods	Manual control	Automatic control and recovery [10–12]
Monitoring system	Manual monitoring	Automatic monitoring [13,14]
Sensors required for monitoring and control	No/fewer sensors	Large numbers of sensors for monitoring and control [15–17]
Response to emergencies	Slow response	Fast response
Choices to customer	Limited choices	Vast choices
Network type	Radial	Dispersed/distributed [18,19]
Security/privacy concerns	Less security and privacy concerns	Prone to security and privacy issues
Data involved	Less data	A huge volume of data is involved [20]
Storage system	No storage is used	A storage system is used [21]

3. Evolution of Smart Grids

With the rapid growth and urbanization in various parts of the world in the 21st century, the demand for electrical energy is also increasing, which can no longer be met by traditional power grids. Therefore, it is important to upgrade the existing power grids. The same technology is used by utilities in different parts of the world, even if they are located in different regions. The political, economic, and geographic conditions of each country affect the creation of power grids. Despite these differences, the basic characteristics of the power grid remain the same. The power industry operates with a strong distinction between generation, transmission, and distribution subsystems. At each stage, different levels of automation and transformation have emerged as the smart grid has evolved. The conventional utility grid is a hierarchical structure in which electricity is distributed to customers at the lower level, and power generation is provided by the power plant at the upper level, as shown in Figure 1. In the current power grid, the generation plants or sources do not have real-time data on the endpoints or user parameters, and the mechanism is a one-way power flow. In addition, the reliability of the system is deteriorating due to the huge increase in electricity demand and the comparatively low investment in electricity infrastructure. As the safety margin is exhausted, any disturbances or anomalies in the distribution networks and the sudden increase in electricity demand would lead to failures of system equipment, resulting in catastrophic power outages. To facilitate troubleshooting and maintenance of expensive power plants, many utilities have implemented various levels of monitoring and control functions. SCADA is a common example of where the new power system is most commonly used. Nearly 90 percent of all faults and power outages recorded by the authors in [22] originate in the distribution system, where the smart grid would come in. Additionally, the failure of utilities to produce electricity to meet energy demand and higher fossil fuel prices have increased the need to upgrade distribution grids by implementing new technologies to protect sales and demand-side management (DSM). Most utilities are investing in distribution grid metering systems.

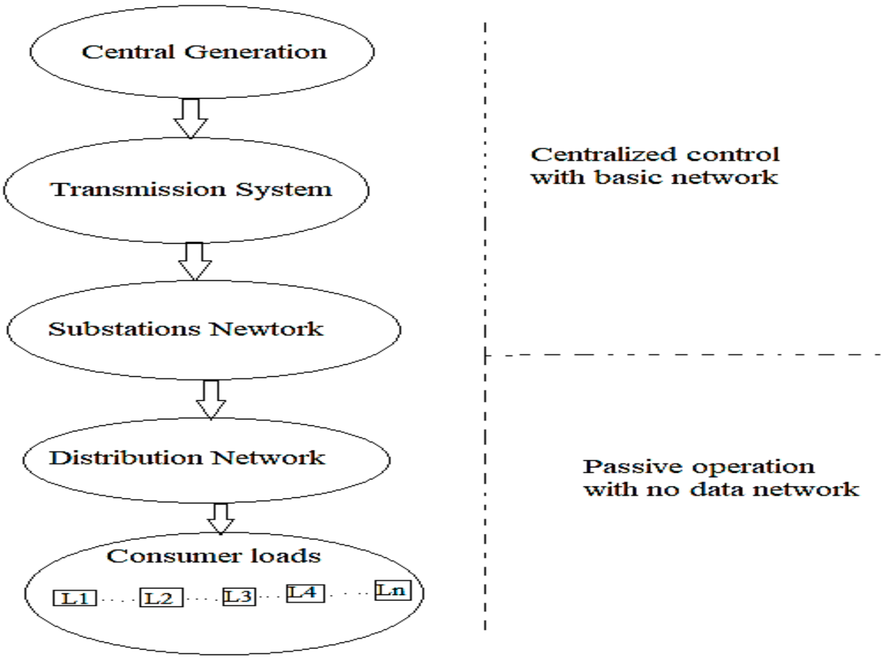

Figure 1. The current electricity utility grid.

As can be seen in Figure 2, recent investments in distribution system infrastructure have been concentrated on the metering side of the system. One example is the introduction of the automatic meter reading (AMR) system. With the introduction of AMR systems to the distribution grid, utilities can remotely read the records, alerts, and status of energy consumption. The major drawback of AMR technology is that it does not solve demand-side management (DSM) problems, as shown in Figure 3. Based on the data collected from the meter, utilities cannot take corrective action with AMR technology, which means that the transition to a smart grid is not feasible. Given all these limitations, utility spending shifted to advanced metering infrastructure (AMI).

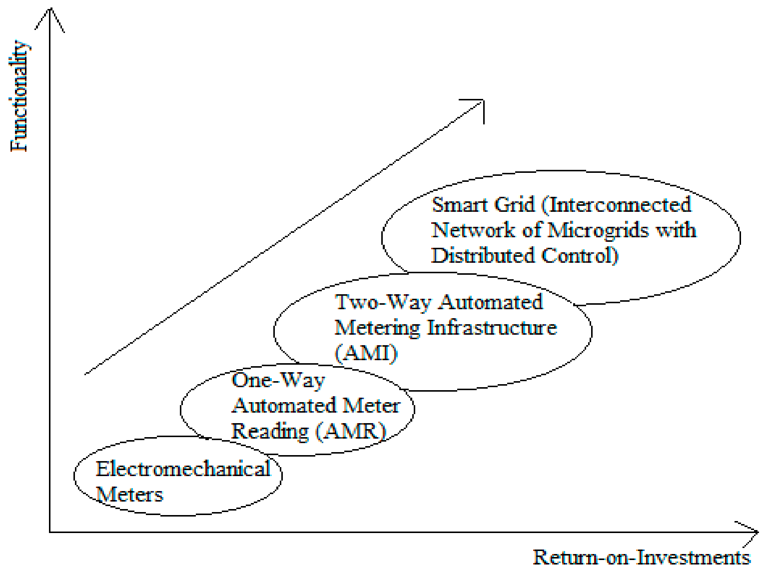

Figure 2. The evolution of the smart grid.

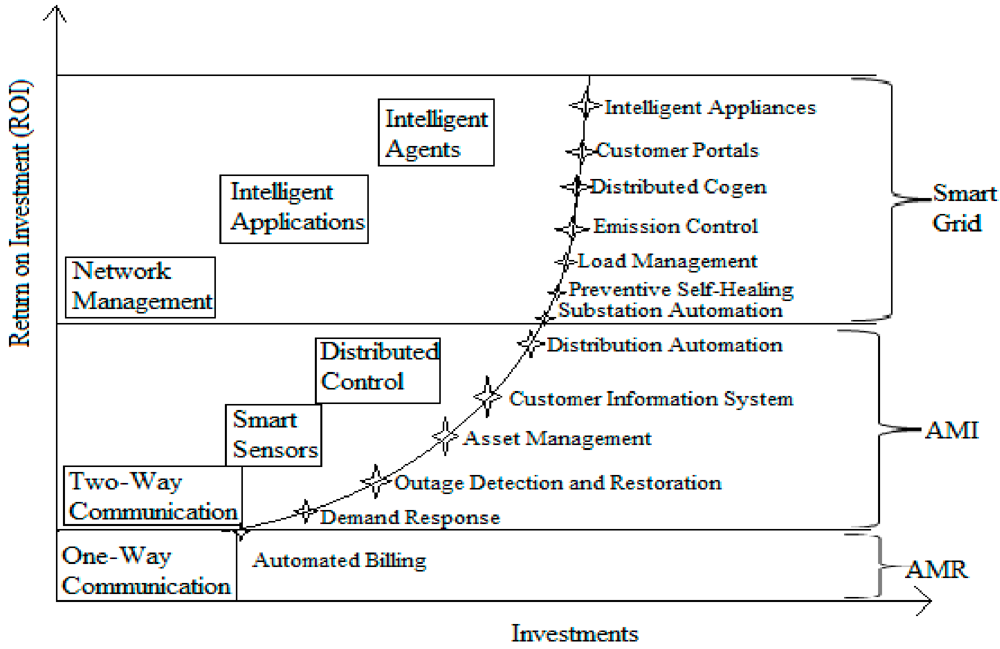

Figure 3. Smart grid return on investment (ROI).

AMI is a two-way communication system that allows utilities to both collect meter data and change parameters at the customer service level. The fundamental goal of load management and securing utility revenues can be achieved through AMI.

4. Smart Grid Architecture

Smart grid infrastructure architecture is driven by smart grid system priorities and requirements. The self-healing and interoperability capabilities of the grid, the reliability, and the robustness of the system will depend on the implementation of the smart grid [23]. The National Institute of Standards and Technology (NIST) [24] and IEEE propose and implement conceptual models to support preparation, documentation, specification setting, interconnection of networks, and smart grid equipment. As shown in Table 2, the IEEE categorizes the smart grid into eight sub-areas that pertain to smart grid actors and applications and discusses them in more detail in the following section.

Table 2. Domains on smart grid conceptual model by IEEE.

Domain	Description
Operations	The proper operation of the power system is guaranteed
Markets	Grid assets are exchanged
Transmission	Bulk transfer of electricity from generating station to distribution is carried out
Bulk generation	The bulk generation of energy is performed
Non-bulk generation	The generation from distributed energy resources such as solar, wind, etc.
Distribution	Transmission, consumer, consumption metering, and distributed energy storage are interconnected
Customer	The electricity is consumed, which includes the subdomains as homes, commercial and industrial, etc.
Service provider	The producers, consumers, and distributors' support services are performed

Figure 4 illustrates the basic support structure required in the smart grid, which communicates with actors from different sub-domains. For example, if electricity meters are located in the consumer domain, a distribution management system acts as an actor in the distribution service provider in the operational domains [24].

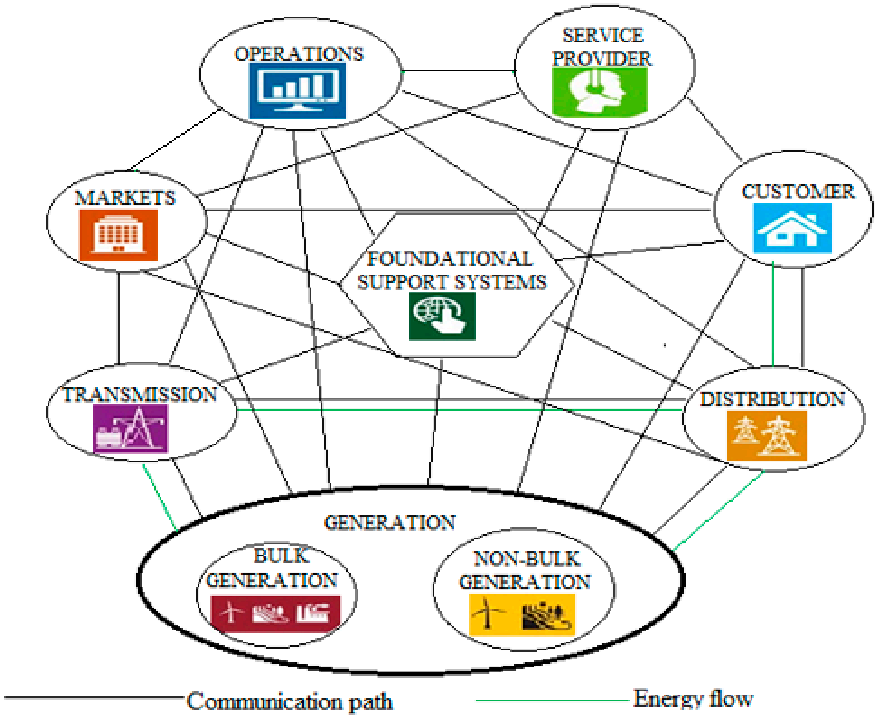

Figure 4. IEEE smart grid domains and sub-domains [24].

4.1. Operation Domain

The operational areas, as shown in Figure 5, include delivery operation, field system operation, transmission operation, and visibility and control. It regulates and monitors all other aspects of power flow in the smart grid. This area provides monitoring, regulation, reporting, status monitoring, critical processing of information, and decision making. It uses a two-way communication system to connect substations in the field substation, customer networks, and other intelligent electronic devices (IEDs). The business intelligence process collects customer and network data and generates information to support the decision-making process. The participants in the operations domain and their functions are summarized in Table 3.

Table 3. Participators of operation domains and their functions.

Participator	Functions
Monitoring	Supervise network connectivity
Control	Supervise wide area as well as localized automated or manual monitoring
Fault management	Fault identification, elimination, and service restoration
Analysis	Compare data records with the historical event data
Reporting and statistics	Achieve online data and perform feedback analysis
Calculations	Real-time network calculations actors
Training	Real-time network calculations actors
Records and assets	Provide dispatchers with facilities to practice using the systems
Operation planning	Monitor and report on the inventory of network equipment

Table 3. *Cont.*

Participator	Functions
Maintenance and construction	Maintains continuous power supply by doing different network action
Extension planning	Create long-term strategies for the stability of the power system
Customer support	Helps customers to troubleshoot power system services

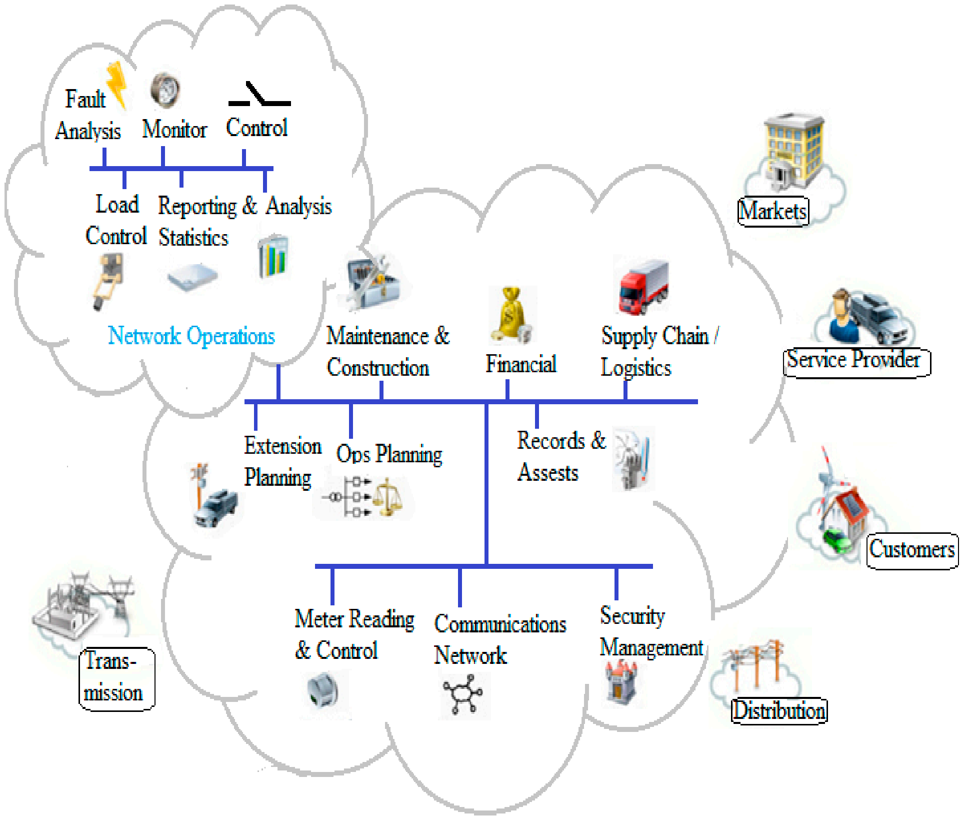

Figure 5. Operations domain [25].

4.2. Markets Domain

The markets are the places where the network assets are bought and sold. As shown in Figure 6, the market domain oversees and controls all electricity market participants within the smart grid. The boundaries of the market domains are the edge of the operating domain where control takes place, the domains that supply assets (generation domains, transmission domains, distribution domains), the domains of a service provider, and the customer domain. Market management, distribution, retail, and trading of electric energy services are covered in this domain. It acts as a clearing house for the energy information house and the exchange of information with third-party providers. One example that falls within this area is the roaming of plug-in vehicle billing information between utilities. Exchange rates and balancing supply and demand are market participants in the electricity system. High-priority challenges in the market domain include extending prices and DER signals to all customer subsets, enhancing aggregator capabilities, ensuring interoperability among all market information providers and consumers, managing the growth (and regulation) of retail and wholesale energy, and creating communication mechanisms for prices and energy characteristics. The market area participants and their functions are summarized in Table 4.

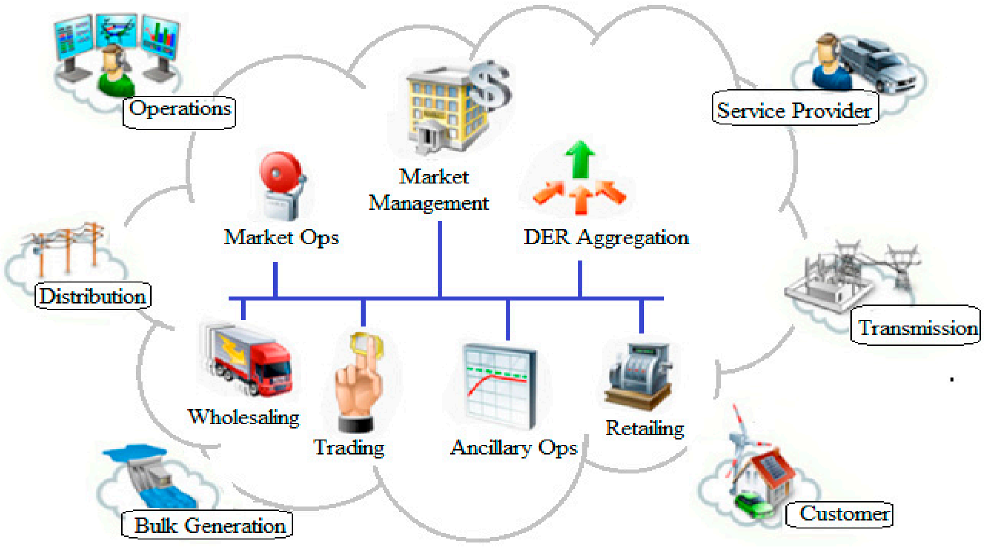

Figure 6. Markets domain.

Table 4. Participators of market domains and their functions.

Participators	**Functions**
Retailing	• Sell powers to end consumers • Connect to a trading organization
DER aggregation	Aggregators combine smaller participants
Trading	• Purchasing and selling of energy • Participants in the market
Market operations	Make the market functions smoothly Clearing of financial and products exchanged, price quote sources, audit, and balancing
Market management	Markets managers include independent system operators (ISOs) for whole markets
Ancillary operations	To provide support such as frequency, voltage, and spinning

4.3. Transmission Domain

This domain is responsible for the large-scale transmission of electricity from the power plant to the distribution grid via multiple substations. The transmission domain includes actors such as RTUs, safety relays, phasor measurement units (PMUs), power quality control, substation meters, substation user interfaces, and so on. DERs, such as electrical energy storage or peaking generation systems, are often used in the transmission domain. The majority of transmission domain activities take place in substations. Transmission systems are typically monitored and controlled by a SCADA system, which consists of communication networks, monitoring equipment, and control equipment. The primary role of a regional transmission operator (RTO) or independent system operator (ISO) operating a transmission system is to maintain system stability by balancing generation (supply) with load (demand) on the transmission system. Energy and related services are purchased through the business domain, planned and controlled by the operations domain, and then distributed through the transmission domain to the distribution system and eventually to the consumer. The market domain participants and their functions are summarized in Table 5.

Table 5. Transmission domain participators and their function.

Participator	Functions
Substation	Controlling and monitoring within a substation system
Storage	Controls how an energy storage device is charged and discharged
Measurement and control	Measure, record, and manage in order to safeguard and improve grid operation

4.4. Generation Domain

The generation sector is responsible for delivering electricity to customers. Bulk electricity is generated from renewable and non-renewable energy sources. The bulk power generation areas are electrically connected to the transmission area via a cable and share a common interface with the markets, operations, and transmission area, as shown in Figure 7. Communication with the transmission area is very important because power is delivered to customers through the transmission area. With good coordination between the generation domain and the transmission domain, the power supply deficit can be addressed directly by operations and indirectly by markets. The requirement for the generation domain is to minimize greenhouse gas emissions, provide storage to handle variable generation from renewable energy sources (RESs), and increase the inclusion of RESs. Various devices such as protective relays, remote terminal units (RTUs), programmable logic controllers (PLCs), fault recorders, and user interfaces (UIs) are used in this area. The power generation domain is further divided into two sub-domains, namely the bulk power generation domain and the non-bulk power generation domain. The participants of the generation domain and their functions are summarized in Table 6.

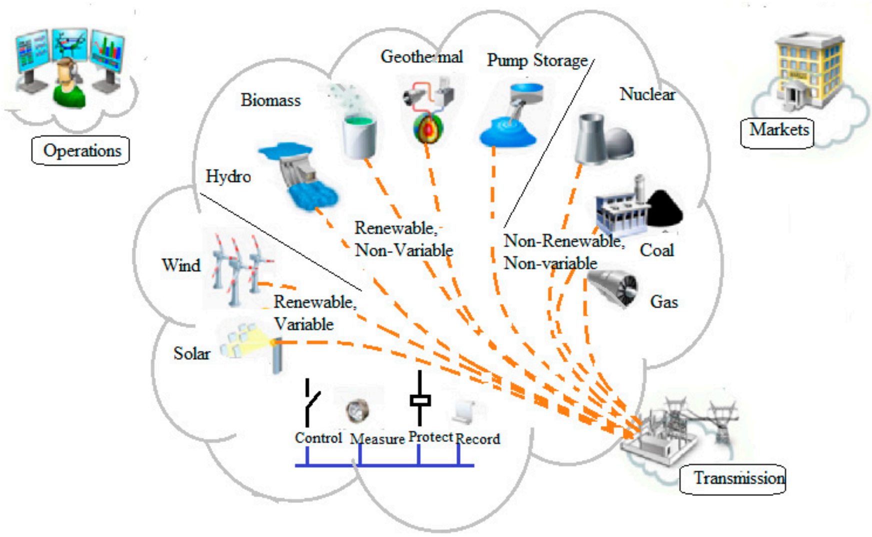

Figure 7. Generation domain.

Table 6. Generation domain participators and their function.

Participator	Functions
Control	Manage the system's power flow and reliability
Measure	Analog and digital measurements collected via the SCADA system
Protect	Protect the system from various abnormal events
Record	Keep the records of the system status for forecasting purposes
Asset management	Determining equipment maintenance schedule Finding the life expectancy of the device

4.5. Distribution Domain

The smart grid distribution areas that transport electricity to and from end consumers are depicted in Figure 8. The distribution domain is the electrical link between the transmission area, the customer area, and the meters for consumption, distributed storage, and distributed generation (DG). The electrical distribution system might be mesh, looping, or radial in design. The distribution domain can interact more directly and in real-time with the service domain to manage power flows related to a more complicated market domain and other environmental and security-based variables. It connects, manages, and monitors smart meters and other IEDs via bidirectional communication networks. The boundaries of the distribution domain include customer domains, market domains where regulation takes place, operational domains, and transmission domains. The actors of the distribution domain are protective relays, storage units, circuit breakers, capacitor banks, DG, and other regulation devices. Distribution domain participants and their functions are summarized in Table 7.

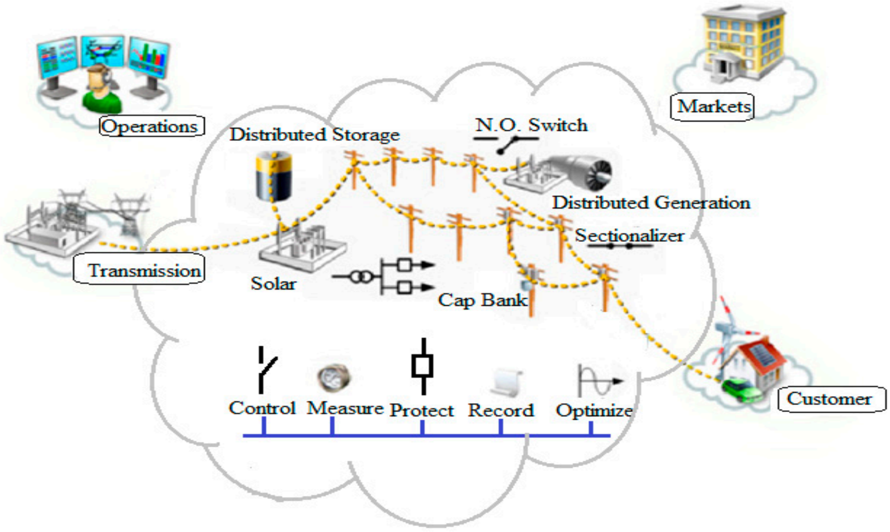

Figure 8. Distribution domain.

Table 7. Distribution domain participators and their function.

Participator	Functions
Substation	Controlling and monitoring systems within a substation
Storage	Controlling a charging and discharging of an energy storage unit
Distributed generation	Power sources located on the distributed side of the grid
Measurement and control	Measuring, recording, and controlling to protect and optimize grid operation

4.6. Customer Domain

The customer domain of the smart grid is where end users connect electricity to the distribution grid through smart meters. Smart meters track and control the flow of electricity to and from consumers and provide information about energy use and patterns. End users include commercial/building, industrial, and residential, as shown in Figure 9. The energy service interface (ESI), which provides secure communication between the utility and the consumer and the electric meter, is commonly referred to as the customer area boundary.

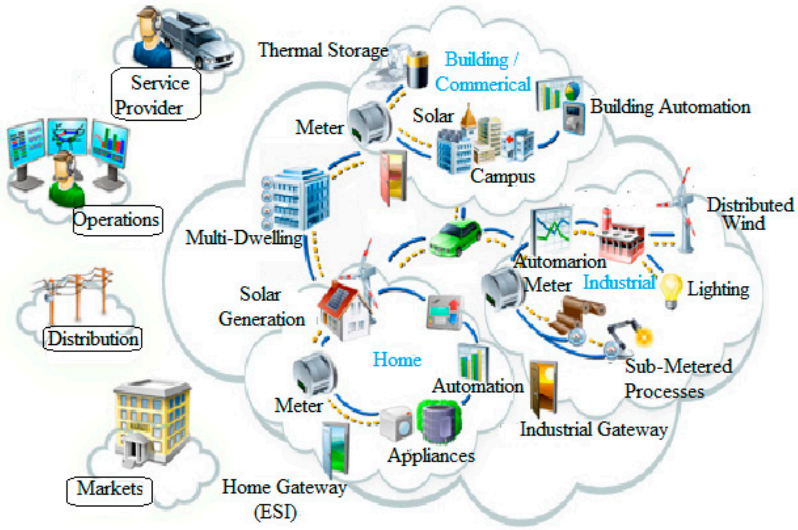

Figure 9. Customer domain.

The ESI, in turn, acts as a bridge to systems that focus on facilities such as the consumer energy management system (EMS) and building automation systems (BAS). The customer domain is further subdivided into the home (energy range $\leq$ 20 kW), building/commercial (energy range 20–200 kW), and industrial (energy range $\geq$ 200 kW) subdomains. This domain can also generate, store, and manage energy and connect plug-in vehicles. Within the consumer domain, two-way communication between the devices and the system takes place over a local area network (LAN) and a home area network (HAN). The customer domains share the interface between the service provider, operations, distribution, and business markets. The customer domain participants and their functions are summarized in Table 8.

Table 8. Consumer domain participators and their function.

Participator	Functions
Building and home automation	Control various functions within a building
Industrial automation	Controlling industrial processes such as manufacturing/warehousing
Micro-generation	Generation from distributed sources such as solar, wind, etc.

4.7. Service Provider Domain

Figure 10 shows the smart grid service provider domain, which manages all third-party operations between domains. The players in this domain provide facilities that support energy producers, distributors, and consumers in their daily tasks. Traditional utility services, such as billing and managing customer data on energy consumption, are juxtaposed with advanced market services, such as energy efficiency management, demand response systems, outage management, and home energy generation. In addition to serving customers, this division also manages the stability, reliability, cybersecurity, and safety of the electric grid. Interfaces between service provider markets, operations, and domains and consumer markets, operations, and domains are shared. In order to enable a market-driven environment and safeguard vital energy infrastructure, this domain aims to develop important interfaces and standards. Table 9 provides a summary of the players in the service provider domain and their roles.

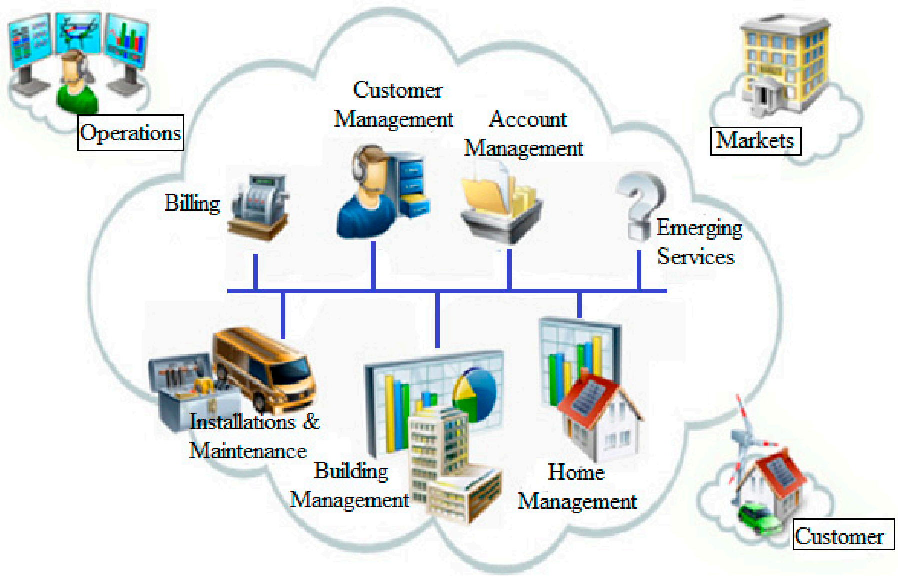

Figure 10. Service provider domain.

Table 9. Service provider domain participators and their function.

Participator	Functions
Billing	Managing customer billing information
Home management	Monitor and control home energy
Building management	Monitoring and controlling building energy
Account management	Manage supplier and customer business accounts
Customer management	Manage customer relationships
Installation and management	Install and maintain premises equipment
Emerging services	All of the services and innovations for future smart operation

5. Smart Grid Characteristics

The smart grid enables faster response and resolution in the event of disruptions in the power supply to consumers. It also stores energy and enables the integration of renewable energy sources into the grid. In the literature, the characteristics of a smart power grid are described as follows.

5.1. Efficiency, Security, and Reliability of the Grid

Increased efficiency and reliable power supply to consumers are critical to the power system evaluating the grid implementation. Therefore, a smart power grid has fast fault detection [24,25] and provides self-healing [26,27]. As the size and complexity of power grids continue to increase, it has become difficult to evaluate the reliability of power grids, but the reliability of modern power systems can be realized with the efforts of many researchers. The authors in [28] use Bayesian networks to estimate the reliability of the grid using a data mining algorithm that recognizes the structure of the grid from raw historical data. Higher efficiency is achieved by monitoring hybrid generations in a remote region and automatically managing unstable distribution [29]. The development of smart grid networks using online monitoring technologies, data collection, etc., poses a security threat to the system. However, the problems are addressed in [30] by improving the security threat model (SSTM) of integrated smart grid systems. Moreover, the problems are addressed by establishing cyber security threat requirements and policies for the smart grid [31].

The smart grid allows the integration of distributed generation (DG), which will increase the efficiency and reliability of the system. Moreover, with the introduction of information technology in smart grid systems, real-time power system data can be recorded and stored for use in determining the efficiency and reliability of the system.

5.2. Demand Response (DR) and Demand-Side Resources

The Federal Energy Regulatory Commission defines DR as "changes in electricity consumption by demand-side resources from normal consumption patterns in response to changes in the price of electricity over time or to incentive payments intended to induce lower electricity consumption during periods of high wholesale prices or when system reliability is threatened" [25]. DR would reduce overall energy consumption and required generation by allowing customers to participate in grid operations. The development of demand response strategies and the modernization of the electric grid through the deployment of grid modernization technologies is the main goal of the U.S. Department of Energy [32]. It has been noted that there is increasing investment in demand-side resources, which include energy efficiency and load management programs [33]. Economic, environmental, and reliability issues are the driving forces for demand-side services.

With the integration of distributed generation in smart grids, the customer can manage their own load depending on the consumption pattern of the customer, which will improve the efficiency and reliability of the system. The information technology in smart grids will provide real-time data on energy prices. This will allow customers to manage their load and prices.

5.3. Energy Storage

The amount of electricity generated from renewable energy sources varies by the second, depending on input parameters such as solar radiation, wind speed, etc. Energy storage is also a must in smart grids as it enables the integration of renewable energy sources. The storage system stores the excess power generated from renewable energy sources. The energy from storage systems is supplied when the demand for electricity increases. Energy storage systems include battery storage, flywheel storage, compressed air storage, ultracapacitor storage, and pumped storage. The authors of [34–37] have conducted various studies on energy storage systems for the smart grid to support the functionality of the smart grid.

5.4. Distributed Energy Resource (DER) Integration

DERs are small sources of energy that meet the constant electricity demand of a place and help us shift from the traditional grid to a smart grid. DER distributed generation, which is a renewable energy source, aims to reduce the loss of fossil fuel supplies and reduce emissions. Distributed generators include photovoltaic and wind power plants, as well as battery storage systems that combine thermal and electric vehicles [38]. The integration of distributed generation systems into the power grid requires the management and processing of a large amount of data, for which a specific architecture is needed. The authors propose this architecture in [39].

5.5. Smart Meters and Distribution Automation

A smart meter in the smart grid enables two-way communication between the meters and the utilities. The smart meters not only provide accurate bills but also let the customers monitor their energy consumption. The smart meter consists of sensors, power outage alerts, and power quality monitoring [40]. Distribution control is connected to the smart meter. Thanks to the advancement of advanced metering infrastructure (AMI), utilities can more easily collect customer information, which contributes to the improvement in grids where the integration of electric vehicles, converters, feed-in control, and fault isolation is possible. The substation automation system (SAS), which resolves power system congestion and restricts the integration of renewable energy sources less, is an example of distribution automation [41,42].

5.6. Integration of Smart Home Appliances

Smart appliances are devices that can connect to the power grid, shut off power during peak hours, and intelligently change their power consumption. Smart devices are typically installed on the user side, which includes smart buildings, and help decouple household electricity demand from peak hours. In a study from the UK, it is found that with smart device penetration of 20 percent, demand-side management can provide up to 54 percent of the operating reserve demand, depending on the time of day [43].

5.7. Device Interoperability

The components of the electric grid must work together to reliably deliver energy to customers from the power plant. Therefore, device interoperability is very important for grid architecture design and implementation. The Smart Grid Interoperability Panel (SGIP) develops the interoperability standards, which is created by NIST. The panel develops standards for smart grids that ensure seamless operation and communication between different components [44]. Some research investigated interoperability with respect to the current state of international cloud standardization activities [45].

6. Smart Grid Technologies

A wide range of technologies should be developed and implemented for the transition from the traditional power grid to the smart grid (see Figure 11). The next section discusses the smart grid technologies that facilitate the transition from the conventional power grid to the smart grid.

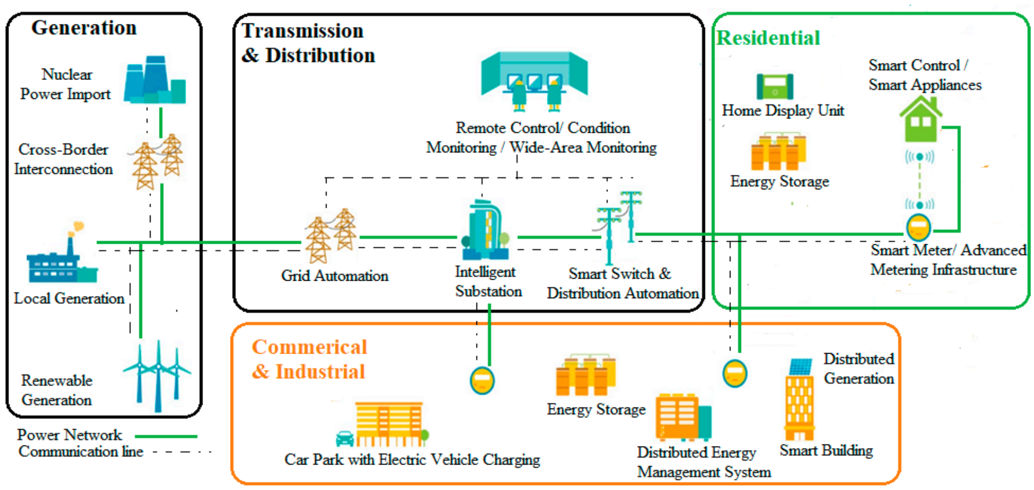

Figure 11. Overview of smart grid technologies [46].

6.1. Intelligent Appliances

Based on preset consumer preference data, smart appliances can decide on energy use. This leads to a reduction in peak load, which affects electricity generation costs. A smart building with a variety of smart home appliances can save real-time pricing costs [41], and peak demand can be reduced because the smart appliances can operate based on consumer preset data. The smart appliances help to flatten the load curve, thereby reducing the chances of grid failures.

6.2. Smart Meters

Smart meters will be the most important technology for the transition from conventional power grids to smart grids [42]. A smart meter records energy consumption hourly or more frequently and communicates with the utility, which performs billing and maintenance. It provides two-way communication between the utility and the end user for the automatic collection of billing data, detects equipment faults, and sends repair/maintenance teams to the exact location of the fault much faster. The deployment of smart meters will reduce the incidents of energy theft [43] and thus increase the revenue of service providers or utilities. Moreover, smart meters increase computational capacity for local processing to support the distributed control of future microgrid cluster operation models. Figure 12 shows the snapshot of the smart meter.

Figure 12. Smart meter [47].

6.3. Smart Substation

A substation typically controls and monitors operating data for critical and noncritical loads, such as power status, energy security, power factor performance, breaker, and transformer. An intelligent substation consists of sophisticated primary-side high-voltage devices and networked secondary devices [44]. The IEC61850 communication protocol is used in smart substations for information exchange and interoperability of smart electrical devices. Smart substations transform multiple voltages at different locations to provide a safe and reliable power supply.

6.4. Superconducting Cables

Superconducting cables can transmit electricity over long distances with minimal losses. They have mechanized monitoring and analysis tools capable of either detecting faults themselves or predicting the fault based on real-time data and failure history. Superconducting cables have high current transmission capability and low transmission loss [45]. The main drawback of superconducting cables is that they currently lack mature, practical applications under room temperature conditions, but the future of smart grids depends on superconducting cables.

6.5. Integrated Communications

Integrated communication is a basic need of the modern power grid, required by and essential to other key technologies [46]. It will create a dynamic and collaborative mega-infrastructure for the exchange of information and energy in real-time. Smart grid specifications such as programmable logic control [48], supervisory control and data acquisition [49], and wireless, cellular, and broadband power lines [50] combine communication technologies. Ease of implementation, data transmission capacity, standards, network coverage, latency, and a secure system are the factors that must be considered for integrated communications.

6.6. Phasor Measurement Units (PMUs)

PMUs are used to calculate the magnitude and phase angle of electrical waves such as voltage or current. The calculation is performed using the traditional synchronization time source. GPS provides timing control and helps synchronize multiple remote points in the power system. PMUs have real-time synchronization phase data and strong situational awareness of the power system, which can be used to take remedial actions to improve power system reliability [51]. PMUs are also used for frequency measurements in the power system. Figure 13 shows a snapshot of the typical architecture of synchro-phasor networks.

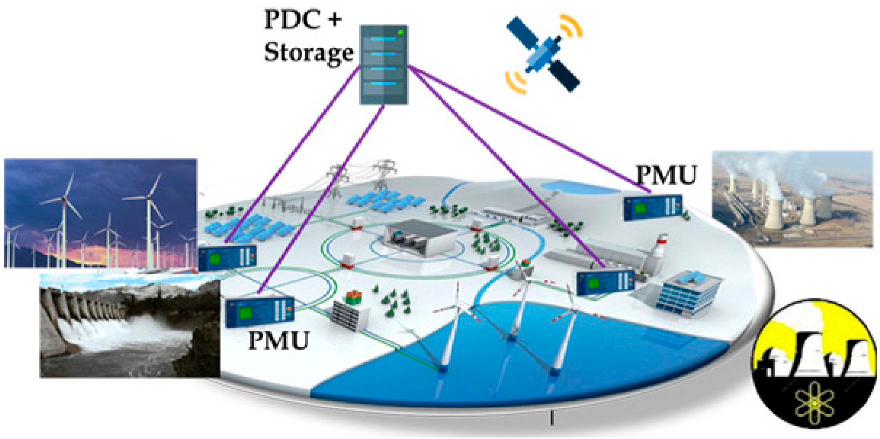

Figure 13. Architecture of synchro-phasor networks [52].

7. Smart Grid Communication and Metering

Communication plays a critical role in the real-time operation of power systems. Different types of communication technologies are being developed for applications in smart grid development, such as wired (e.g., fiber optic and telephone) and wireless (in different frequency bands, namely VHF/UHF) technologies. Wireless technologies have additional advantages over wired technologies, such as low installation cost, rapid deployment, ease of use, etc., and are ideal for isolated applications [53]. To better understand the different forms of wireless technologies, comparisons are made in Table 10.

Table 10. Comparison of wireless technologies.

Wireless Technologies	Zigbee	Wi-Fi	WiMax
Design target	Low cost Low power	Indoor WLAN and small networks	Indoor or outdoor WAN, large networks
Target application	No infrastructure, nearby devices	Indoor, high-capacity, small network	Outdoor, high capacity, large network
Range channel	10 ~×75 m	10 ~×100 m	Up to ×50 km [27]
Bandwidth	5×MHz	5 or 10 MHz	>5 MHz [27]
Maximum capacity	250 kbps	54 Mbps [54]	10–50 Mbps [27]
QoS mechanism	None	Limited to AP's local QoS, 4 types: voice, video, best effort, and background	Network-wide QoS, 5 types: UGS, ertPS, rtPS, nrtPS, and xBE
Security measures	No security measures	Security at MAC with WEP encryption, etc.	MAC layer encryption and key exchange via licensed spectrum

Initially, wired systems such as telephones are used to communicate line utilization to the control center and dispatch operators performing switching operations at substations. Due to a number of power grid constraints, such as voltage limits, thermal overloads, and other complexities of hardwired grid connections, the communication networks in individual DERs in smart grids are becoming more complicated by the day as more DGs are integrated into power grids. Therefore, the success of a smart grid implementation depends on the adoption of a reliable and cost-effective communication system for metering, control, and monitoring purposes.

8. Smart Grid Security

Security of smart grids is very important since smart grid exchange power and information online using various technologies explained in earlier sections. A smart grid's vulnerabilities are more popular in smart meters, smart electronic systems, and IP-based components that are more likely to attract the fact that many stakeholders are involved [55]. Various organizations such as NIST, IEEE Power and Energy Society, IEC Smart Grid Standardization, and National Standard of the People's Republic of China [56] created several safety standards for smart grids. The authors of [57] conducted a study on cybersecurity challenges for IoT-based smart grid networks and the financial and economic losses from cyber-attacks. The multiple types of security threats to smart grids, such as physical attacks and cyber-attacks leading to a violation of consumer privacy, energy theft, power blackouts, infrastructure failure, and operating staff protection, are discussed in [58].

The smart grid protection system literature is published in [30,31,59–64]. Work in the literature includes cyber-security assessment criteria for smart grids, security risk assessment for smart-grid-enabled software-defined networking (SDN), location-based protection for smart grid applications, ortho-code privacy mechanisms in smart grids using ring communication architecture, integrated smart grid systems security threat models, cyber-security of a power grid, analysis of smart grid communication infrastructure and smart grid cyber-security, and smart grid information security for the protection of smart grid knowledge.

9. The Future: The Challenges in Smart Grids

9.1. The key Challenges in Smart Grids

The smart grid has benefits in energy conservation, low environmental pollution, higher energy efficiency, self-healing properties, and bidirectional communication. Despite the enormous benefits stated, smart grid achievement is quite far away. Listed below are smart grid challenges, which are also potential research areas:

1. Problems in smart grid routing design [65].
2. Issues related to cybersecurity [57].
3. Interoperability and the incorporation of renewable energy [66,67].
4. Regulatory challenges [29].
5. Compatibility issues of intelligent devices, communications, and data logging standards [30].
6. Security in the handling and study of big data [68].
7. Automation of distributed system and distributed generation in distribution system [31].
8. Interoperability standard, cognitively recovering unlicensed spectrum and enhancing cybersecurity [69].
9. Physical and cyber-security, advanced metering system vulnerabilities [70].
10. Obstacles to smart grid implementation: costs and advantages, institutional inaction [71].
11. Vehicle-to-grid (V2G): low electric vehicle penetration [72].

9.2. The Future of Smart Grids

The analysis of smart grids has come a long way since the first smart meter report appeared in the late 1980s. Since then, various technologies, systems, procedures, and processes have been implemented and developed to modernize the electricity grid. Future research has tremendous potential to improve smart grids. Some of them are among several potentialities (based on literature):

1. Battery storage system, modern and improved [73].
2. Cloud-based data storage and processing studies/cloud computing [74,75].
3. Integration of electric vehicles into smart grids [76].
4. Integration of renewables into smart grids [77].

5. New communication technologies and grid self-restoration systems to increase stability and power studies [78,79].
6. Large-scale integration of renewable energy sources into the smart grid [80,81].
7. The smart grid virtual energy storage scheme [82–85].

10. Conclusions

In this paper, we provided an overview of the development, concepts, components, technologies, features, implementations, and potential scope of smart grids. The smart grid technologies mentioned include smart appliances, smart meters, superconducting cables, and the phasor measurement unit (PMU). The role of smart grid instrumentation and communication technology in real-time monitoring and measurement of power system reliability was also explored, as well as privacy challenges. The architecture of smart grids was also covered in depth. The future research opportunities on smart grids were addressed in "The Future: The Challenges in Smart Grid". If more money, time, and in-depth research are invested in smart grids, it will help achieve energy efficiency and environmental protection. It will be difficult to predict the future of smart grids precisely, but given recent advancements in smart grid technology and science, smart grids have a bright future. In the study of smart grids, there are research opportunities in the fields of power flow optimization, renewable energy integration, electric vehicle integration, cloud computing, storage systems, power quality and reliability studies, and cybersecurity.

Author Contributions: Conceptualization, investigation, writing—original draft preparation, writing—review and editing, S.D., A.A.S., G.P., Y.T. and R.K.; software, visualization, data curation, methodology, S.D., A.A.S., G.P., Y.T. and R.K.; conceptualization, Y.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by University Research Grant, Grant/Award Number: UTS/3/2022/06; Centre for Research of Innovation & Sustainable Development (CRISD) of University of Technology Sarawak, Malaysia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data will be made available upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jiang, Z. Computational intelligence techniques for a smart electric grid of the future. In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*; Springer: Berlin/Heidelberg, Germany, 2009; Volume 5551 LNCS, no. PART 1; pp. 1191–1201. [CrossRef]
2. Lopes, A.J.; Lezama, R.; Pineda, R. Model Based Systems Engineering for Smart Grids as Systems of Systems. *Procedia Comput. Sci.* **2011**, *6*, 441–450. [CrossRef]
3. Li, F.; Qiao, W.; Sun, H.; Wan, H.; Wang, J.; Xia, Y.; Xu, Z.; Zhang, P. Smart transmission grid: Vision and framework. *IEEE Trans. Smart Grid* **2010**, *1*, 168–177. [CrossRef]
4. Ponnusamy, V.K.; Kasinathan, P.; Elavarasan, R.M.; Ramanathan, V.; Anandan, R.K.; Subramaniam, U.; Ghosh, A.; Hossain, E. A Comprehensive Review on Sustainable Aspects of Big Data Analytics for the Smart Grid. *Sustainability* **2021**, *13*, 13322. [CrossRef]
5. Gao, J.; Xiao, Y.; Liu, J.; Liang, W.; Chen, C.L.P. A survey of communication/networking in Smart Grids. *Future Gener. Comput. Syst.* **2012**, *28*, 391–404. [CrossRef]
6. Dibangoye, J.; Doniec, A.; Fakham, H.; Colas, F.; Guillaud, X. Distributed economic dispatch of embedded generation in smart grids. *Eng. Appl. Artif. Intell.* **2015**, *44*, 64–78. [CrossRef]
7. Miller, S.; Ramchurn, S.D.; Rogers, A. Optimal decentralised dispatch of embedded generation in the smart grid. In Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems—Volume 1, Valencia, Spain, 4–8 June 2012; pp. 281–288.
8. Ulises, J.; Rodríguez-Urrego, L. Technological Developments in Control Models Using Petri Nets for Smart Grids: A Review. *Energies* **2023**, *16*, 3541. [CrossRef]
9. Smart Grid: A Beginner's Guide. NIST. 17 July 2012. Available online: https://www.nist.gov/el/smart-grid/about-smart-grid/smart-grid-beginners-guide (accessed on 18 January 2021).

10. About—IEEE Smart Grid. Available online: https://smartgrid.ieee.org/about-ieee-smart-grid (accessed on 18 January 2021).
11. Smart Energy | IEC. Available online: https://www.iec.ch/energies/smart-energy (accessed on 18 January 2021).
12. Zeeshan, H.M.A.; Naeem, M.; Nisar, F. Advanced techniques for control of smart grids. In Proceedings of the 2017 International Smart Cities Conference (ISC2), Wuxi, China, 14–17 September 2017; pp. 1–5. [CrossRef]
13. Law, Y.W.; Pota, H.R.; Jin, J.; Man, Z.; Palaniswami, M. Control and Communication Techniques for the Smart Grid: An Energy Efficiency Perspective. *IFAC Proc. Vol.* **2014**, *47*, 987–998. [CrossRef]
14. Dahal, N.; Abuomar, O.; King, R.; Madani, V. Event stream processing for improved situational awareness in the smart grid. *Expert Syst. Appl.* **2015**, *42*, 6853–6863. [CrossRef]
15. Ozbuber, S.; Bagriyanik, M. A smart grid integration platform developed for monitoring and management of energy systems. In Proceedings of the 2015 3rd International Istanbul Smart Grid Congress and Fair (ICSG), Istanbul, Turkey, 29–30 April 2015; pp. 1–5. [CrossRef]
16. Grzonka, D.; Kołodziej, J.; Tao, J.; Khan, S.U. Artificial Neural Network support to monitoring of the evolutionary driven security aware scheduling in computational distributed environments. *Future Gener. Comput. Syst.* **2015**, *51*, 72–86. [CrossRef]
17. Hui, W.; Zhitao, G.; Tingting, Y.; Yue, X. Top-k query framework in wireless sensor networks for smart grid. *China Commun.* **2014**, *11*, 89–98. [CrossRef]
18. Khan, A.A.; Rihan, M. Smart pH sensor for condition monitoring of insulators in the smart grid. In Proceedings of the ISGT2011-India, Kollam, Kerala, India, 1–3 December 2011; pp. 274–277. [CrossRef]
19. Kilic, N.; Gungor, V.C. Analysis of low power wireless links in smart grid environments. *Comput. Netw.* **2013**, *57*, 1192–1203. [CrossRef]
20. Bayat, A. Modified UVDA suitable for the reconfiguration of future smart grids consist of many dispersed generations. In Proceedings of the CIRED Workshop 2016, Helsinki, Finland, 14–15 June 2016; pp. 1–4. [CrossRef]
21. Bianco, G.; Noce, C.; Sapienza, G. Enel Distribuzione projects for renewable energy sources integration in distribution grid. *Electr. Power Syst. Res.* **2015**, *120*, 118–127. [CrossRef]
22. Nandury, S.V.; Begum, B.A. Big data for smart grid operation in smart cities. In Proceedings of the 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai, India, 22–24 March 2017; pp. 1507–1511. [CrossRef]
23. Saponara, S.; Mihet-Popa, L. Energy Storage Systems and Power Conversion Electronics for E-Transportation and Smart Grid. *Energies* **2019**, *12*, 663. [CrossRef]
24. Domains—IEEE Smart Grid. Available online: https://smartgrid.ieee.org/domains (accessed on 18 January 2021).
25. Smart Grid Technology. Available online: http://www.roraimaconsulting.com/it-and-telecoms/smart-grid-technology (accessed on 18 January 2021).
26. He, Q.; Blum, R.S. Smart Grid Fault Detection Using Locally Optimum Unknown or Estimated Direction Hypothesis Test. *Energy Procedia* **2011**, *12*, 170–179. [CrossRef]
27. Wang, H.; Zhao, X. Research on Smart Grid Fault Analysis Based on Simultaneous Fault Detection. In Proceedings of the 2016 International Conference on Robots Intelligent System (ICRIS), Zhangjiajie, China, 27–28 August 2016; pp. 374–380. [CrossRef]
28. Tan, Z.; Ge, L.; Kang, T.; Zhao, F.; Zhao, Y.; Huang, X.; Peng, F.; Li, X. An accurate fault location method of smart distribution network. In Proceedings of the 2014 China International Conference on Electricity Distribution (CICED), Shenzhen, China, 23–26 September 2014; pp. 916–920. [CrossRef]
29. Xia, S.; Luo, X.; Chan, K.W. A Framework for Self-healing Smart Grid with Incorporation of Multi-Agents. *Energy Procedia* **2014**, *61*, 2123–2126. [CrossRef]
30. Doguc, O.; Ramirez-Marquez, J.E. An automated method for estimating reliability of grid systems using Bayesian networks. *Reliab. Eng. Syst. Saf.* **2012**, *104*, 96–105. [CrossRef]
31. Colmenar-Santos, A.; Pérez, M.-Á.; Borge-Diez, D.; Pérez-Molina, C. Reliability and management of isolated smart-grid with dual mode in remote places: Application in the scope of great energetic needs. *Int. J. Electr. Power Energy Syst.* **2015**, *73*, 805–818. [CrossRef]
32. Suleiman, H.; Alqassem, I.; Diabat, A.; Arnautovic, E.; Svetinovic, D. Integrated smart grid systems security threat model. *Inf. Syst.* **2015**, *53*, 147–160. [CrossRef]
33. Wang, Y.; Zhang, B.; Lin, W.; Zhang, T. Smart grid information security—A research on standards. In Proceedings of the 2011 International Conference on Advanced Power System Automation and Protection, Beijing, China, 16–20 October 2011; Volume 2, pp. 1188–1194. [CrossRef]
34. Demand Response. Energy.gov. Available online: https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/demand-response (accessed on 18 January 2021).
35. Chapter_3_-_Demand-Side_Resources_12-9-08.pdf. Available online: https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Chapter_3_-_Demand-Side_Resources_12-9-08.pdf (accessed on 18 January 2021).
36. Ferrari, M.L.; Pascenti, M.; Sorce, A.; Traverso, A.; Massardo, A.F. Real-time tool for management of smart polygeneration grids including thermal energy storage. *Appl. Energy* **2014**, *130*, 670–678. [CrossRef]
37. Pascual, J.; Sanchis, P.; Marroyo, L. Implementation and Control of a Residential Electrothermal Microgrid Based on Renewable Energies, a Hybrid Storage System and Demand Side Management. *Energies* **2014**, *7*, 210. [CrossRef]

38. Eggea, R.F.; Ferreira, M.; Aoki, A.R.; Riella, R.J. Energy management including photovoltaic panel and energy storage for Smart Grids through mobile application. In Proceedings of the 2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM), Montevideo, Uruguay, 5–7 October 2015; pp. 177–181. [CrossRef]
39. Roberts, B.P.; Sandberg, C. The Role of Energy Storage in Development of Smart Grids. *Proc. IEEE* **2011**, *99*, 1139–1144. [CrossRef]
40. HHowlader, O.R.; Matayoshi, H.; Senjyu, T. Distributed generation incorporated with the thermal generation for optimum operation of a smart grid considering forecast error. *Energy Convers. Manag.* **2015**, *96*, 303–314. [CrossRef]
41. Penya, Y.K.; Nieves, J.C.; Espinoza, A.; Borges, C.E.; Peña, A.; Ortega, M. Distributed Semantic Architecture for Smart Grids. *Energies* **2012**, *5*, 4824. [CrossRef]
42. Bryson, J.; Gallagher, P.D. *NIST Special Publication 1108R2 NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0.*; U.S. Department of Commerce: Washington, DC, USA, 2021; pp. 1–227.
43. Berizzi, A.; Bovo, C.; Ilea, V.; Merlo, M.; Miotti, A.; Zanellini, F. Decentralized congestion mitigation in HV distribution grids with large penetration of renewable generation. *Int. J. Electr. Power Energy Syst.* **2015**, *71*, 51–59. [CrossRef]
44. Petrini, M.; Casale, E.; Cuccia, P.; Gnudi, R.; Bassi, F.; Giannuzzi, G.; Coluzzi, C.; Bruno, G.; Campisano, L.; Zaretti, L.; et al. A possible evolution of substation automation systems for the management of the distributed generation. In Proceedings of the AEIT Annual Conference 2013, Mondello, Palermo, Italy, 3–5 October 2013; pp. 1–6. [CrossRef]
45. Smart Grid Technology Working Operation and Applications. ElProCus—Electronic Projects for Engineering Students. 20 February 2017. Available online: https://www.elprocus.com/overview-smart-grid-technology-operation-application-existing-power-system/ (accessed on 18 January 2021).
46. Nistor, S.; Wu, J.; Sooriyabandara, M.; Ekanayake, J. Capability of smart appliances to provide reserve services. *Appl. Energy* **2015**, *138*, 590–597. [CrossRef]
47. kristy.thompson@nist.gov. Smart Grid Interoperability Panel. NIST. 18 June 2012. Available online: https://www.nist.gov/programs-projects/smart-grid-national-coordination/smart-grid-interoperability-panel-sgip (accessed on 18 January 2021).
48. Mezgár, I.; Rauschecker, U. The challenge of networked enterprises for cloud computing interoperability. *Comput. Ind.* **2014**, *65*, 657–674. [CrossRef]
49. Dileep, G. A survey on smart grid technologies and applications. *Renew. Energy* **2020**, *146*, 2589–2625. [CrossRef]
50. Salles-Loustau, G.; Garcia, L.; Sun, P.; Dehnavi, M.; Zonouz, S. Power grid safety control via fine-grained multi-persona programmable logic controllers. In Proceedings of the 2017 IEEE International Conference on Smart Grid Communications (SmartGridComm), Dresden, Germany, 23–27 October 2017; pp. 283–288. [CrossRef]
51. Mak, S.T.; So, E. Integration of PMU, SCADA, AMI to accomplish expanded functional capabilities of Smart Grid. In Proceedings of the 29th Conference on Precision Electromagnetic Measurements (CPEM 2014), Rio de Janeiro, Brazil, 24–29 August 2014; pp. 68–69. [CrossRef]
52. Thomas, M.S.; Chandna, V.K.; Arora, S. Parametric representation and modeling of indoor broadband power line channel for data transmission. In Proceedings of the 2015 International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART), Kuwait City, Kuwait, 23–25 November 2015; pp. 1–6. [CrossRef]
53. Song, E.Y.; FitzPatrick, G.J. Interoperability test for IEEE C37. 118 standard-based phasor measurement units (PMUs). In Proceedings of the 2016 IEEE Power Energy Society Innovative Smart Grid Technologies Conference (ISGT), Minneapolis, MN, USA, 6–9 September 2016; pp. 1–5. [CrossRef]
54. CRE. Phasor Measurement Unit for Monitoring Power Systems. PHOENIX—H2020. 27 January 2020. Available online: https://phoenix-h2020.eu/phasor-measurement-unit-for-monitoring-power-systems/ (accessed on 5 February 2021).
55. Parikh, P.P.; Kanabar, M.G.; Sidhu, T.S. Opportunities and challenges of wireless communication technologies for smart grid applications. In Proceedings of the IEEE PES General Meeting, Minneapolis, MN, USA, 25–29 July 2010; pp. 1–7. [CrossRef]
56. Wi-Fi IEEE Standards. Available online: https://www.tutorialspoint.com/wi-fi/wifi_ieee_standards.htm (accessed on 19 January 2021).
57. Otuoze, A.O.; Mustafa, M.W.; Larik, R.M. Smart grids security challenges: Classification by sources of threats. *J. Electr. Syst. Inf. Technol.* **2018**, *5*, 468–483. [CrossRef]
58. Wang, Y.; Ruan, D.; Gu, D.; Gao, J.; Liu, D.; Xu, J.; Chen, F.; Dai, F.; Yang, J. Analysis of Smart Grid security standards. In Proceedings of the 2011 IEEE International Conference on Computer Science and Automation Engineering, Shanghai, China, 10–12 June 2011; Volume 4, pp. 697–701. [CrossRef]
59. Kimani, K.; Oduol, V.; Langat, K. Cyber security challenges for IoT-based smart grid networks. *Int. J. Crit. Infrastruct. Prot.* **2019**, *25*, 36–49. [CrossRef]
60. Wazid, M.; Das, A.K.; Chaola, V. Uniting Cyber Security and Machine Learning: Advantages, Chellenges and Future Research. *ICT Express* **2022**, *8*, 313–321. [CrossRef]
61. Leszczyna, R. Standards on cyber security assessment of smart grid. *Int. J. Crit. Infrastruct. Prot.* **2018**, *22*, 70–89. [CrossRef]
62. Maziku, H.; Shetty, S.; Nicol, D.M. Security risk assessment for SDN-enabled smart grids. *Comput. Commun.* **2019**, *133*, 1–11. [CrossRef]
63. Location Based Security for Smart Grid Applications—ScienceDirect. Available online: https://www.sciencedirect.com/science/article/pii/S1876610213017323 (accessed on 19 January 2021).
64. Li, S.; Choi, K.; Chae, K. OCPM: Ortho code privacy mechanism in smart grid using ring communication architecture. *Ad Hoc Netw.* **2014**, *22*, 93–108. [CrossRef]

65. Sun, C.-C.; Hahn, A.; Liu, C.-C. Cyber security of a power grid: State-of-the-art. *Int. J. Electr. Power Energy Syst.* **2018**, *99*, 45–56. [CrossRef]
66. Jahan, S.; Habiba, R. An analysis of smart grid communication infrastructure cyber security in smart grid. In Proceedings of the 2015 International Conference on Advances in Electrical Engineering (ICAEE), Dhaka, Bangladesh, 17–19 December 2015; p. 190193. [CrossRef]
67. Saputro, N.; Akkaya, K.; Uludag, S. A survey of routing protocols for smart grid communications. *Comput. Netw.* **2012**, *56*, 2742–2771. [CrossRef]
68. Vineetha, C.P.; Babu, C.A. Smart grid challenges, issues and solutions. In Proceedings of the 2014 International Conference on Intelligent Green Building and Smart Grid (IGBSG), Taipei, Taiwan, 23–25 April 2014; pp. 1–4. [CrossRef]
69. Ourahou, M.; Ayrir, W.; Hassouni, B.E.; Haddi, A. Review on smart grid control and reliability in presence of renewable energies: Challenges and prospects. *Math. Comput. Simul.* **2020**, *167*, 19–31. [CrossRef]
70. Faheem, M.; Shah, S.B.H.; Butt, R.A.; Raza, B.; Anwar, M.; Ashraf, M.W.; Ngadi, M.A.; Gungor, V.C. Smart grid communication and information technologies in the perspective of Industry 4.0: Opportunities and challenges. *Comput. Sci. Rev.* **2018**, *30*, 1–30. [CrossRef]
71. Ma, R.; Chen, H.; Huang, Y.; Meng, W. Smart Grid Communication: Its Challenges and Opportunities. *IEEE Trans. Smart Grid* **2013**, *4*, 36–46. [CrossRef]
72. Massoud Amin, S. Smart Grid: Overview, Issues and Opportunities. Advances and Challenges in Sensing, Modeling, Simulation, Optimization and Control. *Eur. J. Control.* **2011**, *17*, 547–567. [CrossRef]
73. Muench, S.; Thuss, S.; Guenther, E. What hampers energy system transformations? *The case of smart grids. Energy Policy* **2014**, *73*, 80–92. [CrossRef]
74. Reports on Demand Response and Advanced Metering Federal Energy Regulatory Commission. Available online: https://www.ferc.gov/industries-data/electric/power-sales-and-markets/demand-response/reports-demand-response-and (accessed on 19 January 2021).
75. Battery Storage Systems in Smart Grid Optimised Buildings—ScienceDirect. Available online: https://www.sciencedirect.com/science/article/pii/S1876610218305630 (accessed on 19 January 2021).
76. Mital, M.; Pani, A.K.; Damodaran, S.; Ramesh, R. Cloud based management and control system for smart communities: A practical case study. *Comput. Ind.* **2015**, *74*, 162–172. [CrossRef]
77. Bereş, A.; Genge, B.; Kiss, I. A Brief Survey on Smart Grid Data Analysis in the Cloud. *Procedia Technol.* **2015**, *19*, 858–865. [CrossRef]
78. Misilu, F.; Justo, J.J.; Kim, E.-K.; Do, T.D.; Jung, J.-W. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. *Renew. Sustain. Energy Rev.* **2014**, *34*, 501–516. [CrossRef]
79. Liu, L.; Kong, F.; Liu, X.; Peng, Y.; Wang, Q. A review on electric vehicles interacting with renewable energy in smart grid. *Renew. Sustain. Energy Rev.* **2015**, *51*, 648–661. [CrossRef]
80. Dorsch, N.; Kurtz, F.; Georg, H.; Hägerling, C.; Wietfeld, C. Software-defined networking for Smart Grid communications: Applications, challenges and advantages. In Proceedings of the 2014 IEEE International Conference on Smart Grid Communications (SmartGridComm), Venice, Italy, 3–6 November 2014; pp. 422–427. [CrossRef]
81. Haidar, A.M.A.; Muttaqi, K.; Sutanto, D. Smart Grid and its future perspectives in Australia. *Renew. Sustain. Energy Rev.* **2015**, *51*, 1375–1389. [CrossRef]
82. Atasoy, T.; Akınç, H.E.; Erçin, Ö. An analysis on smart grid applications and grid integration of renewable energy systems in smart cities. In Proceedings of the 2015 International Conference on Renewable Energy Research and Applications (ICRERA), Palermo, Italy, 22–25 November 2015; pp. 547–550. [CrossRef]
83. Worighi, I.; Maach, A.; Hafid, A.; Hegazy, O.; Van Mierlo, J. Integrating renewable energy in smart grid system: Architecture, virtualization and analysis. *Sustain. Energy Grids Netw.* **2019**, *18*, 100226. [CrossRef]
84. Cheng, M.; Sami, S.S.; Wu, J. Virtual Energy Storage System for Smart Grids. *Energy Procedia* **2016**, *88*, 436–442. [CrossRef]
85. Peter, G.; Iderus, S.B. Design of enhanced energy meter using GSM prepaid system and protective relays. *Mater. Today Proc.* **2021**, *39*, 582–589. [CrossRef]