Electrical Smart Grid System (SG)

Received: 26 December 2025; Revised:22 June 2026; Accepted: 29 June 2026 ***Review Article***

Abakar Mahamat Hassan
Department of Electrical and Electronics Engineering
Karabuk University
Karabuk, Turkiye
abakarm786@gmail.com
0009-0000-1616-6820

***Abstract*— Smart Grids (SGs) emerge as the cutting-edge power grid system for the future, driven by their resilience, efficiency, reliability, and sustainability. This paper explores the key elements that constitute the smart grid system, management and security, and some advantages of SGs. The components discussed encompass advanced sensors like new sensor-Synchrophasors, renewable energy sources and electric storage, integrated communication systems, distributed power generation, demand response utility rates, and smart meters. Collectively, these components contribute to the evolution and establishment of the SG system. The aim of this paper is to discuss the basic components of Smart Grid (SG) with a focus on the publications between 2018 and 2023.**

Keywords*— *smart grid, microgrid, SG components, management and security

I. Introduction

Since the discovery of electricity and up to the present day, the field of energy consumption and distribution has witnessed a profound transformation at the global level, and at the forefront of this development recently comes the concept of smart grids, which will contribute significantly and effectively to the actual field instead of the traditional system. classic energy systems operate on a centralized type which is depicted by large-scale power generation from conventional sources (fossil fuel) and unidirectional distribution carried to the end users. Yet, the limitations of this traditional or existing model, coupled with increasing demands for energy efficiency, flexibility, and sustainability, have led to the discovery or development of the concept of smart grids (SGs).

Smart grids are not just an incremental improvement to existing energy infrastructure; rather, SGs represent a revolutionary reimagining of how electricity is produced, transmitted, and consumed. By using technological devices, such as communications devices and smart meter devices, these technological devices let the system create a dynamic network that can be capable of facing the challenges of the 21st century. According to several sources and perspectives within the field, the term of "smart grids" encompasses a multifaceted array of meanings and interpretations, and the most common definition of SG is tow way communication while the traditional grid is one way communication.

On the other hand, the Microgrid, which plays a crucial role in the development of the smart grid, can also be defined according to [1] as a cluster of interlinked loads and dispersed energy resources operating within well-defined electrical perimeters, microgrids function as a unified and controllable entity in relation to the larger grid.

Smart grids have been developed with the objective of providing sustainable energy by combining energy systems and new developments in communication technologies and data. The main aim of smart grids is to utilize energy efficiently by reducing the rate of loss and leakage and integrating energy produced from renewable energy sources such as solar and wind into the system [2]. The rest of the paper is organized as follows. The Smart Grid Components were presented in Section II. Management and security of SG were presented in Section III. Advantages of SG was presented in Sections IV. Respectively Conclusion was presented in V.

II. Smart Grid Components

In the complex framework of smart grids (SGs), a number of components and advanced technologies come together to form the basic elements or components of smart grids. As shown in Table 1. below, these components structure the infrastructure of smart grids.

A. New Sensors-Synchrophasors

Synchrophasors represent intricate grid measurements accessible through devices known as phasor measurement units (PMUs). These units have the capability to report up to 60 measurements per second [4]. The integration of PMUs is pervasive in the functioning of power systems, encompassing tasks such as power system control, monitoring, distribution network control, load shedding control and analysis, and state estimation. This underscores the significance of PMUs in the modern world [5]. PMU and wireless sensors networks have been observed as one of the main monitoring components of power systems in the last few years in the monitoring of the electrical grid. A synchronised phasor measurement system is a substitutional technology obtaining gauge of magnitude, the angle of voltages, and currents at spots terrestrially remote from where the electric power system is located, it also swiftly and accurately records frequencies, harmonics, active and reactive power, speedily, all while maintaining synchronization [6].

TABLE I. BASIC COMPONENTS OF SMART GRID [3]

Smart Grid components	
1	New sensors-Synchrophasors
2	Renewable energy and electric storage
3	Integrated communication systems
4	Distributed power generation
5	Demand response utility rates
6	Smart meters

Figure 1 shows the system of a phasor measurement is basically formed from:

- (PMU) Phasor Measurement Unit.
- (PDC) Phasor Data Concentrator.
- (GPS) Global Positioning System.
- Communication Channels.

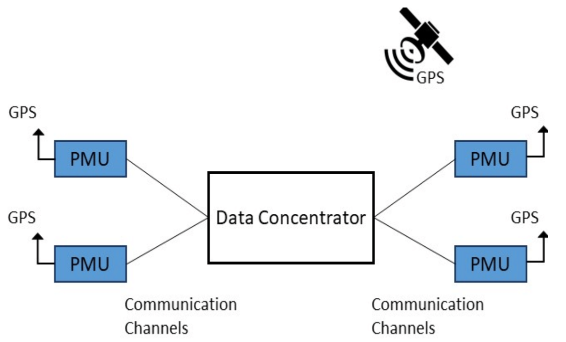

Fig. 1. Synchronized Fasorial Measurement System[6]

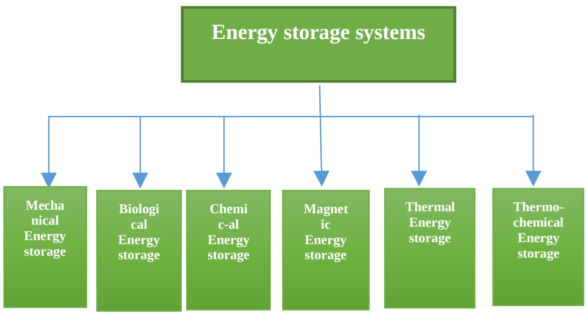

Fig. 2. Categorization of systems for storing energy.

B. Renewable Energy and Electric Storage

Renewable energies such as Photovoltaic (PV) and Wind energy are playing an important role in today's distributed energy resources (DER) and bring challenges to the grid operation, specifically concerning power quality [7] .On the other hand, PV, wind, and storage systems can be remotely controlled providing opportunities for optimizing the utilization of grid resources [7].

The novel rise in the field of renewable energy generation could be able to reduce CO2 and balance consumption. By using the Battery Energy Storage Systems (BESS) optimizing supply and demand, it is more significant than ever before to administer charge control for the interest of the all stakeholders [8]. Various energy storage system technologies can be employed for storing electrical energy. Power and energy density, both in steady-state and transient conditions, are key attributes of energy storage technology, as indicated by multiple studies. Achieving high power and energy density concurrently necessitates the collaboration of multiple energy storage technologies, known as a hybrid energy storage system (HESS) [9]. According to [10], there are different forms of energy storage that can be used, as presented in Fig. 2.

C. Integrated Communication System

For the successful operation of an active distribution network in SG, effective communication infrastructure is essential, incorporating key performance criteria techniques [11]. The communication technology process can be categorized into two primary segments: wired and wireless, in terms of generation, transmission, distribution operations of SG [12]. Wired communications technologies consist of Power Line Communications (PLC), Fiber Optic cables networks and Digital Subscriber Line whilst wireless technologies are generally EDGE/ GPRS/3G/4.5G/5G, Radio Frequency (RF-RF Mesh) Wi-Fi, Wi-Max, Bluetooth, Zigbee, LoRaW [13]. PLC is one of the most popular communication methods by comparison to EDGE/GPRS/3G because it does not need a third-party corporation consequently can eliminate addiction to other partner for communication, and this status is good in terms of cyber security [13], on the other hand using 5G provides infinite bandwidth theoretically and free from regulation also the communication security is guaranteed at physical layer [14]. The choice of communication method should be based on the specific requirements within the application area.

D. Distributed Power Generation

Distributed power generation refers to an electrical power source directly connected to either the distribution network or the customer's meter site, rather than relying solely on centralized power plants that are often far from end-users and remote areas. It includes small-scale decentralized energy sources that can be integrated into local distribution networks so that makes the distribution process easy for all users and they benefit greatly from it [15].

According to [15] distributed generation are classified on three bases: the bases of generation technology, the bases of Connection and the bases of Size.

In SGs, distributed power generation is integrated with advanced communications, control and monitoring technologies this integration let it to make a further reacting and adjustable energy infrastructure. There are some points explain how distributed power generation operates within a smart grid.

- Decentralized Generation: SGs elevate decentralized energy generation, with centering on distributed energy resources (DERs) like small wind turbines, rooftop PV panels, combined heat and power (CHP) systems, and energy storage devices.[16]
- Microgrids (MGs): Power generation is often a key entity for microgrids within smart grids. MGs are small-scale systems related to operating independently or connecting to the main network. It generates energy and supports energy generation at the community level. In a power distribution system with microgrids, habitation who use DERs and interactive devices could react with each other and the grid to exchange power [17].
- Smart Inverters: Smart inverters are devices based on power electronics and play a crucial role in converting DC power generated from renewable energy sources such as solar panels into AC power to be used in the grids. Smart inverters can perform several tasks in the context of the smart grid, such as providing network support functions, voltage regulation, interactive power control, and network synchronization[18].

E. Demand Response Utility Rate

Demand response (DR) stands for group measures to reduce energy demand dynamically at fixed times and in particular places in response to a close shortage in supply [19], in DR there are many security issues could compromise the efficiency of the DR program. Common security requirements in DR are Integrity, availability, authentication and confidentiality [19]. There are two types of programs (Price-based DR and Incentive-based DR [20]) can be used in demand response which uses monetary stimulant to encourage demand participation in balancing the discrepancy between generation and consumers[21].

Price-based DR is a strategy that involves consumers adjusting their electricity consumption patterns in response to price signals. In this approach, changes in electricity prices serve as an incentive for consumers to modify their usage, promoting more efficient and flexible energy consumption [22].

Incentive-based DR refers to a strategy where consumers actively engage with and respond to signals or requests from the grid operator or energy provider to adjust their electricity consumption. This approach involves a two-way communication process, allowing consumers to play a more participatory role in managing their energy use based on real-time information or specific instructions from the grid [23].

F. Smart Meters

In the present day, smart grids encompass various significant systems, including smart meters, distributed renewable energy, energy storage, electric vehicles, and applications for smart cities and homes. Advanced Meter Reading (AMR) stands out as a prominent element within smart grids, offering remote and real-time monitoring of all consumers through their smart meters (SM).[13] [24] also SM's application range covers various benefits, including accurate billing information, user usage information, establish two-way communication and remotely control user devices [25]. AMR can let SGs to have an extensive framework of functions parallel to conventional grid technologies.

As an example of these functions: prediction of the consumption, control of the consumption remotely and the detection of the theft and loss measurements.

In addition to these components the following features should be included in the smart grids systems;

- Intelligence;
- Personalization;
- Digitalization;
- Flexibility;
- Durability; [26]

Intelligence, a cornerstone of contemporary systems, involves the integration of smart technologies within the framework. This entails leveraging sophisticated algorithms, artificial intelligence, and data analytics to optimize operations, enhance decision-making processes, and improve overall efficiency.

Personalization is another necessary part, emphasizing the individual inclusion of customers within the system while ensuring the exclusion of third-party entities. By doing so, the sharing of information and personal data between users and the system becomes not only personalized but also highly secure.

Digitalization plays a fundamental role in transforming the smart grid into a dynamic, responsive platform. The adoption of digital technologies creates a strong foundation, enhancing reliability and facilitating swift and efficient operations. A digital platform ensures that the smart grid system can adapt to the evolving energy landscape and seamlessly integrate emerging technologies.

Flexibility is a key characteristic that underscores the adaptability, adjustability, and expandability of the smart grid (SG). This ensures that the system can accommodate diverse energy resources, respond to fluctuating demand patterns, and readily incorporate technological advancements. The flexibility of the smart grid is essential for meeting the unique needs of different regions, industries, and consumers.

Finally, durability is major in safeguarding the smart grid against potential threats and ensuring its resilience in the face of various challenges. This involves implementing robust cybersecurity measures, fortifying the system against cyber-attacks, and establishing fail-safes to protect against disruptions. A durable smart grid is one that can withstand external pressures and continue to function securely, providing uninterrupted and reliable energy services to the users.

III. Management And Security Of SG

Due to the complexity of the system Smart grid requires advanced sensing and control technologies in order to be well managed and response to the demand response (DR) of the customer. In the rapidly advancing landscape of smart environments (SE), the Internet of Things (IoT) stands out as a pivotal partner in the realm of resource and energy management. As we navigate the complexities of modern energy systems, the integration of IoT technologies has become instrumental. One specific area where this alliance is particularly impactful is in Demand Side Management (DSM) within smart grids (SG). To harness the potential of this synergy, the implementation of a Smart Energy Management System (SEMS) proves to be a strategic move. SEMS, built upon the foundation of advanced meter reading (AMR) and contemporary technologies such as the Internet of Things (IoT), plays a key role in optimizing energy consumption patterns. By leveraging real-time data provided by AMR and the connectivity capabilities of IoT, SEMS transforms into a dynamic and responsive system. The seamless integration of AMR with IoT-based technologies brings about a multifaceted enhancement in the effectiveness of SEMS within smart grids. Not only does it enable accurate and timely monitoring of energy usage, but it also facilitates intelligent decision-making processes. This amalgamation empowers DSM strategies to be more adaptive and finely tuned to the ever-changing demands and conditions of the grid. As we delve further into the era of smart environments, the collaborative interplay between IoT and energy management systems like SEMS becomes increasingly vital. This symbiotic relationship holds the promise of ushering in a new era of efficiency, sustainability, and resilience in our energy infrastructure. [27]. In smart network systems, information comes from the smart metering in the power distribution system is collected by the smart energy management system (SEMS). SEMS can measure, collect, store, analyse, manage, monitor and control the current information of the entire system in real time [25].

The Cyber-demand-side management (DSM) infrastructure combines SG communication protocols and AMR devices to allow the SG system to automatically make decisions such as balancing load requirements or/and network stability improvement requirements. In addition, the DSM platform can bring significant added value to the company by saving customers costs and reducing CO_2 emissions. However, since everything in our lives now depends on the supply of electricity, the unfavourable effects of cyberattacks are becoming increasingly severe[28].

IV. Advantages Of Smart Grids

Smart grids have many advantages compared to traditional electrical grids, and these advantages facilitate the usage of energy in a flexible and simple way in our daily lives by integrating advanced technologies and communications systems into the grid system, some of those advantages are given below.

- Improving the quality and reliability: Smart grids improve the quality and reliability of power distribution by quickly detecting errors or faults and responding directly. Automated systems can isolate and reroute power, reducing downtime and continuously improving overall grid reliability.

- Renewable energy integration: the integration of renewable energy into our energy systems is undergoing a transformative shift with the advent of Smart Grids. These sophisticated infrastructures not only simplify but fundamentally revolutionize the seamless assimilation of renewable sources like photovoltaic (PV) and wind. Smart Grids play a pivotal role in transforming the dynamics of energy production and distribution, going beyond mere simplification. The real-time monitoring and control capabilities inherent in Smart Grids act as a technological backbone, empowering Grid Operators (GO) to effectively navigate the challenges posed by the volatility and unpredictability of renewable energy production. Whether it's the variability in output from photovoltaic systems or the dependence on atmospheric conditions for wind energy, Smart Grids function as intelligent orchestrators, dynamically adjusting and optimizing energy distribution to align with the ever-changing patterns of renewable energy generation. Beyond addressing variability, the integration of renewable energy into the energy mix is a strategic move toward maximizing the utilization of clean and sustainable resources. Smart Grids facilitate the seamless blending of renewable energy, fostering a more environmentally friendly and resilient energy ecosystem. As the world moves towards a future where reliance on renewable energy is paramount, Smart Grids emerge as indispensable catalysts, ensuring that the transition is not just feasible but also efficient. The synergistic relationship between real-time monitoring, adaptive control, and renewable energy integration positions Smart Grids at the forefront of the global pursuit of sustainable and eco-conscious energy solutions. Increased Energy Efficiency: SGs can better manage and optimize energy distribution, minimizing losses during the transmissions and distributions. Increased efficiency helps save energy and lessen overall energy consumption.

- Load Management and Demand Response: SGs revolutionize energy consumption, empowering consumers with tools for active participation. Through advanced demand response programs, consumers actively contribute to grid stability, adjusting energy usage in response to real-time prices and network conditions. This dynamic approach, especially during peak demand, eases strain on the grid. Smart Grids enable informed decisions by allowing consumers to adapt energy consumption based on real-time information, optimizing load distribution for enhanced grid stability and overall energy efficiency. With the integration of renewable sources, Smart Grids seamlessly manage variable outputs, ensuring adaptive load management strategies. Smart Grids turn consumers into active contributors, shaping a sustainable and responsive energy landscape. The synergy of consumer empowerment, real-time data, and efficient load management positions Smart Grids as catalysts for a more sustainable and resilient energy future.

- Self-Healing and Resilience of the Grid: SGs are designed to be more resilient and self-healing. If an outage or failure occurs, the system can automatically detect and isolate affected areas and realign power to reduce impact and restore operations faster.[29][30].

V. Conclusion

To conclude this paper, the main components of smart grids and their important key are explained. the smart grid can be noticed as a digitally improved system of the conventional or existing energy system infrastructure. Operating the smart grids needs clever systems e.g., communication system (wired or wireless), advanced meter reading (AMR), microgrid, management, and security these play a master role in new developments and the realization of the smart grid. and the smart grid's objective is to efficiently, securely, and sustainably deliver electricity from utilities to consumers through the implementation of two-way digital technology.

Statement of Research and Publication Ethics

The author hereby declares that this study has been prepared in strict accordance with the principles of research and publication ethics. All sources of information and literature used in this study have been appropriately cited.

References

[1] "IEEE JOINT TASK FORCE ON QUADRENNIAL ENERGY REVIEW".

[2] M. Cakir, I. Cankaya, I. Garip, and I. Colak, "Advantages of Using Renewable Energy Sources in Smart Grids," 10th International Conference on Smart Grid, icSmartGrid 2022, pp. 436–439, 2022, doi: 10.1109/ICSMARTGRID55722.2022.9848612.

[3] M. Çinar and A. Kaygusuz, "Self-Healing In Smart Grid: A Review," BEU Journal of Science, vol. 7, no. 2, pp. 492–503, 2018.

[4] C. Parker and / Operations, "USING SYNCHROPHASERS AT SPP SPP PMU PROJECT TEAM AND SYNCHROPHASOR STRIKE TEAM," 2021.

[5] M. Baba et al., "A review of the importance of synchrophasor technology, smart grid, and applications," Bulletin of the Polish Academy of Sciences: Technical Sciences, vol. 70, no. 6, 2022, doi: 10.24425/BPASTS.2022.143826.

[6] A. W. Reis, F. G. K. Guarda, and C. C. Gastaldini, "Simulation of a Phasor Measurement Unit in Real Time Using Typhoon Virtual HIL," 2019 IEEE PES Conference on Innovative Smart Grid Technologies, ISGT Latin America 2019, Sep. 2019, doi: 10.1109/ISGT-LA.2019.8895261.

[7] "IEEE Xplore Full-Text PDF:" Accessed: Nov. 28, 2023. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9478925

[8] F. Oguzalp, M. Terkes, and A. Demirci, "Evaluation of technical and financial benefits of battery energy storage system control strategies INTERNATIONAL JOURNAL OF ENERGY STUDIES," Int J Energy Studies, vol. 8, no. 3, pp. 513–534, 2023, doi: 10.58559/ijes.1321550.

[9] "IEEE Xplore Full-Text PDF:" Accessed: Nov. 29, 2023. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9795622

[10] M. Mofijur et al., "Phase change materials (PCM) for solar energy usages and storage: An overview," Energies (Basel), vol. 12, no. 16, Aug. 2019, doi: 10.3390/EN12163167.

[11] A. Colak, N. Guler, and K. Ahmed, "Intelligent communication techniques for smart grid systems: A survey," 9th International Conference on Smart Grid, icSmartGrid 2021, pp. 273–277, Jun. 2021, doi: 10.1109/ICSMARTGRID52357.2021.9551027.

[12] F. Dahunsi, S. Olayanju, A. Ponnle, and O. Sarumi, "Communication Network Simulation for Smart Metering Applications: A," Review. Journal of Innovative Science and Engineering, vol. 2021, no. 2, pp. 101–128, 2021, doi: 10.38088/jise.835725.

[13] M. Şen and S. Ü. Ercan, "International Journal of Energy Applications and Technologies," International Journal of Energy Applications and Technologies, vol. 8, no. 1, doi: 10.31593/ijeat.801513.

[14] Z. Zhou, W. Wang, F. Dong, J. Jiang, and M. Kavehrad, "Application of optical wireless communications for the 5G enforced smart grids," 2020 IEEE 4th Conference on Energy Internet and Energy System Integration: Connecting the Grids Towards a Low-Carbon High-Efficiency Energy System, EI2 2020, pp. 756–760, Oct. 2020, doi: 10.1109/EI250167.2020.9347307.

[15] N. Joshi and P. Nema, "ANALYSIS OF STABILITY OF WIND BASED DISTRIBUTED ENERGY GENERATION SYSTEM," International Journal of Energy and Smart Grid, vol. 3, 2018, doi: 10.23884/IJESG.2018.3.1.01.

[16] H. J. Bhatti, M. Danilovic, H. J. Bhatti, and M. Danilovic, "Making the World More Sustainable: Enabling Localized Energy Generation and Distribution on Decentralized Smart Grid Systems," World Journal of Engineering and Technology, vol. 6, pp. 350–382, 2018, doi: 10.4236/wjet.2018.62022.

[17] I. Dimobi, M. Pipattanasomporn, and S. Rahman, "A transactive grid with microgrids using blockchain for the energy internet," 2020 IEEE Power and Energy Society Innovative Smart Grid Technologies Conference, ISGT 2020, Feb. 2020, doi: 10.1109/ISGT45199.2020.9087739.

[18] L. R. Vargas, H. S. Eichkoff, G. S. Da Silva, and A. P. C. De Mello, "Local volt/var Control Strategy for Smart Grids using Photovoltaic Smart Inverters," 2019 IEEE PES Conference on Innovative Smart Grid Technologies, ISGT Latin America 2019, Sep. 2019, doi: 10.1109/ISGT-LA.2019.8894924.

[19] M. Benmalek, Y. Challal, A. Derhab, and Z. Gheid, "An efficient key management scheme for secure demand-response communications in smart grid," 2019 International Conference on Advances in the Emerging Computing Technologies, AECT 2019, Feb. 2020, doi: 10.1109/AECT47998.2020.9194168.

[20] "Smart Grid Technology And Applications Changing The Power Industry." Accessed: Dec. 06, 2023. [Online]. Available: https://www.hivepower.tech/blog/smart-grid-technology-changing-the-power-industry

[21] B. Mohandes, M. S. El Moursi, N. D. Hatziargyriou, and S. El Khatib, "Incentive Based Demand Response Program for Power System Flexibility Enhancement," IEEE Trans Smart Grid, vol. 12, no. 3, pp. 2212–2223, May 2021, doi: 10.1109/TSG.2020.3042847.

[22] A. Etxegarai, A. Bereziartua, J. A. Danobeitia, O. Abarrategi, and G. Saldana, "Impact of price-based demand response programs for residential customers," 19th IEEE Mediterranean Eletrotechnical Conference, MELECON 2018 - Proceedings, pp. 204–208, Jun. 2018, doi: 10.1109/MELCON.2018.8379094.

[23] Y. Chai, Y. Xiang, J. Liu, C. Gu, W. Zhang, and W. Xu, "Incentive-based demand response model for maximizing benefits of electricity retailers," Journal of Modern Power Systems and Clean Energy, vol. 7, no. 6, pp. 1644–1650, Nov. 2019, doi: 10.1007/S40565-019-0504-Y/FIGURES/10.

[24] N. Sushma, H. N. Suresh, J. Mohana Lakshmi, P. N. Srinivasu, A. K. Bhoi, and P. Barsocchi, "A Unified Metering System Deployed for Water and Energy Monitoring in Smart City," IEEE Access, vol. 11, pp. 80429–80447, 2023, doi: 10.1109/ACCESS.2023.3299825.

[25] M. U. Saleem, M. R. Usman, and M. Shakir, "Design, Implementation, and Deployment of an IoT Based Smart Energy Management System," IEEE Access, vol. 9, pp. 59649–59664, 2021, doi: 10.1109/ACCESS.2021.3070960.

[26] İ. Avci, "Investigation of Cyber-Attack Methods and Measures in Smart Grids," Publisher Sakarya University | İsa AVCI, vol. 25, no. 4, pp. 1061–1074, 1997, doi: 10.16984/saufenbilder.955914.

[27] M. U. Saleem, M. R. Usman, M. A. Usman, and C. Politis, "Design, Deployment and Performance Evaluation of an IoT Based Smart Energy Management System for Demand Side Management in Smart Grid," IEEE Access, vol. 10, pp. 15261–15278, 2022, doi: 10.1109/ACCESS.2022.3147484.

[28] D. Said, "A Survey on Information Communication Technologies in Modern Demand-Side Management for Smart Grids: Challenges, Solutions, and Opportunities," IEEE Engineering Management Review, vol. 51, no. 1, pp. 76–107, 2023, doi: 10.1109/EMR.2022.3186154.

[29] "View of Smart Grid Technology." Accessed: Dec. 03, 2023. [Online]. Available: http://hmjournals.com/journal/index.php/IJITC/article/view/1136/1293

[30] M. Q. Taha, "Advantages and recent advances of smart energy grid," Bulletin of Electrical Engineering and Informatics, vol. 9, no. 5, pp. 1739–1746, Oct. 2020, doi: 10.11591/eei.v9i5.2358.