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Challenges and Opportunities in Implementing Smart Grid Technologies in Kurdistan: A Comprehensive Review

Emad Hussen Sadiq[1*], Yasir M.Y. Ameen[2], Harwan M. Taha[1], Nizar Jabar Faqishafyee[3]

[1] Department of Energy Engineering, Duhok Polytechnic University, 42001 Duhok, Iraq
[2] Department of Electrical Engineering, College of Engineering, University of Mosul, 41002 Mosul, Iraq
[3] Department of Information Technology, Technical College of Informatics-Akre, Akre University for Applied Sciences, 42004 Akre, Iraq

[*] Correspondence: Emad Hussen Sadiq (emad.sadiq@dpu.edu.krd)

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Abstract: The increasing demand for electricity, coupled with the limitations of centralised power generation, has necessitated the transition towards smart grid technologies as a critical evolution of traditional power systems. The smart grid represents a significant transformation from the conventional grid, offering a pathway towards modernising energy infrastructure. This review aims to present a comprehensive analysis of the advantages and challenges of smart grid implementation, particularly within the context of the Kurdistan Region of Iraq. Key benefits such as improved grid intelligence, enhanced reliability, and sustainability were highlighted. However, several challenges were identified, including cybersecurity risks, regulatory complexities, and issues of interoperability, which collectively pose obstacles to widespread adoption. Furthermore, the review examines the current energy network in the Kurdistan region and proposes a framework for integrating smart grid technologies. Strategies for addressing the identified challenges were discussed, emphasising the importance of overcoming these barriers to facilitate the region's transition to a more advanced and efficient energy infrastructure.

Keywords: Smart grid; Conventional grid; Challenges and opportunities; Cybersecurity risks; Power grid

1 Introduction

In recent decades, large-capacity, long-distance power grids have been widely used to meet growing electricity demand [1, 2]. Due to the nature of the distributed energy which is fluctuating and intermittent and the continuous seeking for the high conditions of living, the electrical network has encountered several difficulties. Lack of management of particular power outages could lead to accidents and other serious consequences, finally leading to a big outage in the network. A smart grid provides an ultimate solution for long-term development of the electrical network system [3]. It is expected that the smart grid will transform the generation, transmission, and distribution of electricity by adopting two-way working of electrical energy and data transformation [4].

In addition, the smart grid is capable of improving the existing power grids through the integration of renewable energy sources such as solar and wind energy sources. These types of sources are more environmentally friendly compared to traditional sources of energy such as fossil fuels which are usually utilized in a large portion of the production of electricity. Moreover, these new units of generation can be compacted and small in size and can be located close to the load centers. For these reasons, the reliability of the system can be improved and the transmission power losses can be minimized, but this adds more complexity to the structure of the power system.

The distributed generation units are small in size and located in different areas which are close to the centers of the loads, and they contribute to improving the reliability of the network. Despite increasing the flexibility and reliability of the existing network, it can lead to a more complicated system [5, 6].

In terms of functionality, the smart grid is classified into transmission and distribution systems. There is several equipment, such as generators, connecting with each other by high-voltage transmission lines. Therefore, a failure in a single component or generating unit will not have a big influence on the whole transmission system. On the other

hand, any failure in a single component of the distribution system could have a huge negative impact on the function of the whole distribution system due to the radial scheme of the scheme.

In this study, a comprehensive review of the recent published works was conducted. The main opportunities and challenges for implementing the smart grid were summarized. The background of smart grid and the motivations for the network operators for converting the conventional grid to smart grid were outlined in general and specifically for Kurdistan grid. The necessary comparison between the conventional and smart grids was studied. The required characteristics along with the architecture of the smart grid were addressed. At the end, the main benefits of the smart grid were mentioned as a part of the motivation factor for implementing the smart grid.

2 Related Works

The research was explained chronologically, including research design and procedure. After conducting a thorough investigation into the most recent research related to the smart grid implementation, Table 1 was created, including a detailed survey of the studies conducted in this field. The table highlights the main benefits associated with the integration of intelligent power grids while also underscoring the notable challenges and concerns.

Table 1. Opportunities and challenges of implementing the smart grid

Reference Number	Opportunities for Smart Grid Implementation	Challenges for Smart Grid Implementation
[7–19]	- Improving the reliability of the utility grid; - Allowing for new developments and improvements that are yet to be realized; - Providing greater choice of supply and information to consumers, reducing electricity prices paid by consumers; - Integrating renewable/nonconventional sources; - Improving security and safety; - Higher penetration of alternating power generation sources; - The integration of electrical vehicles as generating and storing devices; - Improving overall efficiency; - Reducing environmental pollution;	- Strengthening the utility grid to accommodate more energy resources; - The offshore wind farms and winds require an effective connection to be developed; - Marine technologies; - Developing decentralized architectures; - Developing a communication infrastructure; - All consumers are able to play an active role in system operation; - The best ways to be found to integrate intermittent power generation. Resolving issues related to techniques for producing enhanced intelligence;
[20–28]	- Increased grid capacity and efficiency; - Improved reliability and power quality; - Reduced carbon footprint and increased sustainability; - Integration of renewable energy sources; - Implementation of price-based incentives and two-way communication; - Use of real-time pricing to eliminate cross-subsidies between users;	- Uncertainty introduced by renewable energy generation; - Increased need for reserves due to part-loaded thermal units; - Dramatic loss of comfort for users in response to price changes; - Potential creation of even higher peaks in demand; - Requirement for very accurate representation of system model for efficient operation;
[25, 29–41]	- Environment protection; - Reliability increasing, improving service quality and better utilisation of current networks and renewable sources. Additionally, it offers better energy management and improved reliability;	- Severe security gaps; - The variety and complexity of communications in smart grids; - Different subsystems generate large data and impose a great implementation challenge;
[42–52]	- Smart grids are seen as a solution for a wide range of social challenges; - High expectations have been expressed when implementing smart grid technologies to match renewable energy; - Emerging actors, such as aggregators and ICT companies.	- Lack of a shared vision and common definition for smart grids; - The struggle is more about individual organizations' interests than a wider governmental or public debate about the purpose and organization of smart grids.

3 Background and Motivations

The technology of smart grid has transformed the power system in developed regions, particularly Europe and the United States, to ensure eco-friendly operation. The use of renewable resources for distributed generation and the implementation of energy conservation initiatives for long-term ecological sustainability are the main factors behind this shift [53, 54]. As a result, the developing and underdeveloped nations are confronting energy difficulties and are unable to efficiently exploit their internal energy resources for maintainable economic development. Therefore, it is essential for these countries to embrace modern technologies that align with the nature of their electric networks. A variety of approaches make the smart grid a comprehensive one. Therefore, it is essential to assess the feasibility for the implementation of the smart grid in the Kurdistan region electric network.

A clear path can be established once baseline studies identify the key requirements and their expected outcomes, which provides procedure guidance and organizing milestones in line with the desired future outcomes. The expected advantages of the smart grid were explained based on the international standards.

The electrical power system in the Kurdistan region has encountered several issues. The high cost of power generation, power losses and the recent controlling and monitoring system are some obstacles to the current grid. There is a significant increase in energy demand due to the rapid urbanization and fast growth of population. Moreover, in terms of reliability and power supply quality, the poor conditions of the existing network lead to the fact that the power supply is unable to reach the demand. The demand load is always higher than the supplied load. For these reasons, a more reliable and flexible power system is required in order to supply power to the industrial, residential and commercial sectors. Due to the mentioned reasons and economic reasons, there is a huge energy crisis in the region.

However, the Kurdistan region of Iraq is blessed to have a huge quantity of natural resources, such as natural gas and renewable energy sources, despite the mentioned obstacles. As a developing country, the region faces several obstacles in fully implementing smart energy policies. Some of the major constraints include a lack of start-up capital for building government-level renewable distributed power plants, a lack of financing options for consumers to build their own distributed electricity generation systems, inadequate infrastructure for transporting energy over long distances, energy theft problems, and circular debt in the electricity department, and a lack of public awareness about the economic benefits of these policies.

Implementing smart grid in the Kurdistan region will assist the ministry of electricity to overcome many issues such as power losses, grid reliability, and operation cost, thereby meeting the increasing demand. Regarding the reduction in power losses, the contribution of distributed generation will have a positive impact on loss minimization and voltage profile improvement. Although implementing this project requires a high initial cost, this cost will be paid off in the long term as the losses will decrease significantly along with the operational cost. In addition to a reduction of technical power losses, the non-technical losses will be reduced to a minimum level by using highly accurate digital energy meters and the monitoring system. As a result, the reliability of the system will be improved and the customers will be subject to less interruption of power supply.

3.1 Energy Status of Duhok in Kurdistan

The total energy demand in Duhok city areas is very high because of the significant increase in the number of consumers. The number of consumers has increased from 72,000 in 1999 to 385,000 in 2021. In addition to the rapid increase in the population, the majority of consumers use electricity for heating and other purposes, which also causes the rapid rise of electricity demand. Figure 1 shows the increase in the number of consumers.

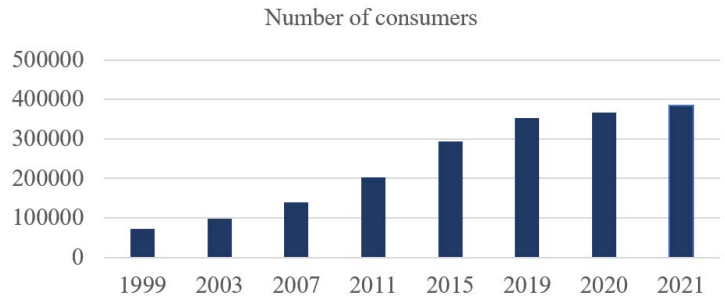

Figure 1. An increase in the number of consumers in Duhok in Kurdistan

The current grid's reliability is being challenged by numerous elements, including the congestion of the grid, larger energy transfers over longer distances, aging infrastructure, insufficient investment in maintenance, rising consumption of electrical energy, peak power demand, and the growing utilization of distributed resources. The

growth of nations is affected by power shortages. The conventional power system is less effective due to a lack of investment in technological advancements and infrastructure enhancements, as well as the continued adoption of traditional methods of operation and upkeep.

The significant environmental impacts of the conventional power system are attributed to the substantial release of greenhouse gases from fossil fuels. Greenhouse gas emissions can be significantly reduced by combining sustainable energy sources and distributed generation. To achieve this integration, it is necessary to monitor and exert greater control over the existing networks. This requires the installation of technological systems for transferring information and communication. The smart grid may take some time to integrate multiple services into the existing electrical networks [53–57]. The block diagram for the grid of the Kurdistan region is shown in Figure 2.

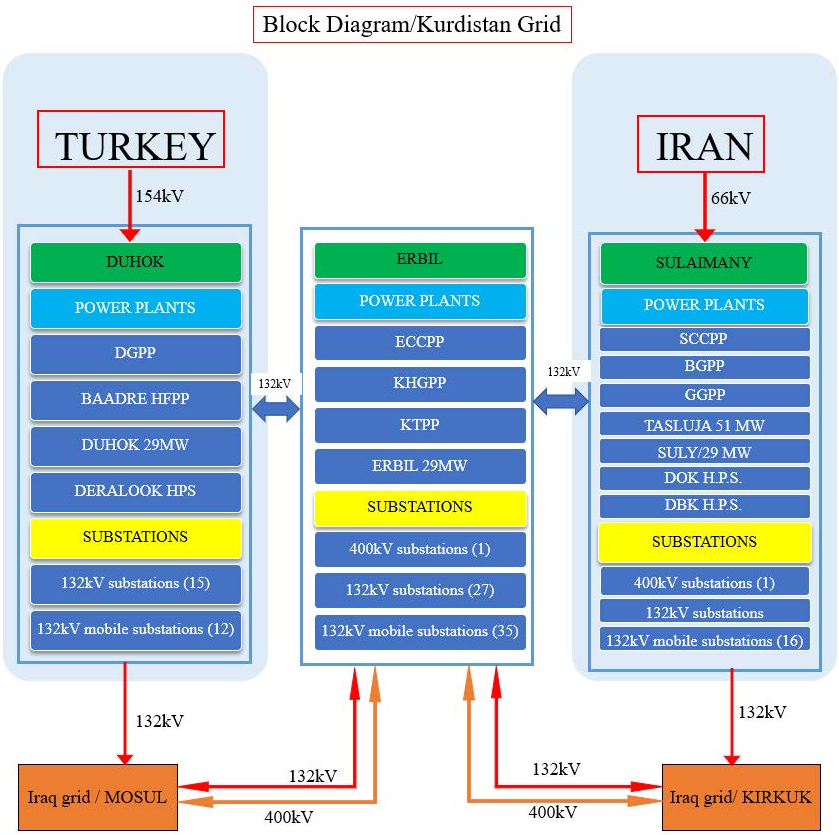

Figure 2. Block diagram for the grid in Kurdistan [58]

The services and developments of the Kurdistan electricity sector are almost entirely dependent on the government budget allocations. There is an excessive gap between costs and revenues in the electricity sector, which becomes a heavy burden for the government budget. In addition, there is a high amount of losses in the existing system, mostly non-technical losses. Low tariffs and no energy conservation measures exist. This contributes towards uncontrolled demand growth as well as a shortage of capital investments to procure additional generation capacity and to upgrade transmission and distribution networks to meet existing and future demands. On the other hand, the risks associated with the constraints on capital investments include deterioration of existing electricity infrastructure services and inability to cope with future demand growth. Under these circumstances, the electricity sector should prioritize the following actions:

- Making the Kurdistan electricity sector independent and self-reliant.
- Bridging the gap between costs and revenues.
- Reducing losses.
- Contorting the growth in electricity demand.
- Attracting the private sector to make investments in the electricity sector.
- Restructuring and reforming the electricity sector.

The above-mentioned requirements can be satisfied by converting the current grid to the smart grid.

4 Smart and Conventional Grids

A comparison between the conventional and smart grids is presented in Table 2.

Table 2. Comparison of conventional and smart grids [55, 59]

Conventional Grid	Smart Grid
One-directional communication	Two-directional communication
Electro-mechanical	Digital
Centralized generation	Distributed generation
A few sensors	A lot of sensors
Less automatic monitoring	Full automatic monitoring
Less automatic restoration	Full automatic restoration or self-healing
Difficult to adapt in case of failures and shutdowns	Easy to be adaptive, and only the faulted area is disconnected
Limited control	Universal control
Consumers have few choices	Consumers have a variety of choices
Hierarchical structure	Network structure
Network feedback is less	Network feedback is available
A big portion interrupts in case of outages	Only the faulted section is filtered and islanded
Restriction control on network	Comprehensive control on network
Limited services are available for consumers and subscriptions	Different services are available for consumers and subscriptions
Network configuration is radial	Network configuration is dispersed
The response during emergencies is slow	The response during emergencies is fast
The volume of available data is small	The volume of available data is big

5 Required Characteristics for the Smart Grid

A smart grid is a sophisticated electric system that effectively coordinates the activities of all connected users, i.e., generators, consumers, and those who do both, in order to provide eco-friendly, economical, and reliable power. The advantages of a smart grid are listed as follows [60–63]:

• Smart grid technologies are more cost-effective compared to traditional energy sources. Moreover, as technology advances, energy costs decrease over time.

• The manufacturing, installation, maintenance, and operation of smart grid components create job opportunities for both skilled and unskilled workers. Additionally, it promotes corporate growth and offers innovative technical solutions.

• Enhanced dependability and reduced expenses can increase customer satisfaction. Furthermore, smart grid empowers customers with greater control over energy distribution and consumption.

• Smart grid reduces power outages and improves power efficiency.

• As the utilization of electric vehicles (EVs) and alternative renewable energy sources is possible with the smart grid, the implementation of the smart grid can have a positive environmental impact by decreasing greenhouse gas emissions. Moreover, the oil consumption can be significantly decreased by utilizing high-efficient power generation.

• Smart grids enhance the capacity and capabilities of the existing power grid. They also incorporate self-healing and predictive maintenance features.

6 Architecture of the Smart Grid

The structure and design of a smart grid refer to the architecture of the electricity system, including the various components and technologies used in the generation, transmission, distribution and consumption of electricity. For the sake of improving the efficiency of the power system, increasing reliability and lowering costs, the structure of the smart grid needs to be well designed. The following components are the main parts of the smart grid network [64–68]:

• Generation: The smart grid consists of all types of power generation, including traditional power plants, distributed generation and renewable energy sources.

• Transmission: The transmission system includes all high-voltage lines and power substations, which are used to transfer power from the generation power plants to the consumption points.

• Distribution: This system includes all the low-voltage lines and transformers, which are used to distribute the electricity to the consumers.

• Metering and monitoring: This part of the system includes the adaption of smart meters as well as other technologies in order to monitor and control the energy consumption.

• Energy management: This portion of the smart grid consists of the systems and software, which are used to manage the energy system, such as programs of load management and dynamic pricing systems.

• Customer engagement: This includes engagement and education of the consumers in order to deal with the technologies through programs of energy saving and consumer portals.

• Data analytics: This part is achieved to study and analyze the large amount of the generated data using advanced analytical systems.

Figure 3 shows the architecture of the smart grid.

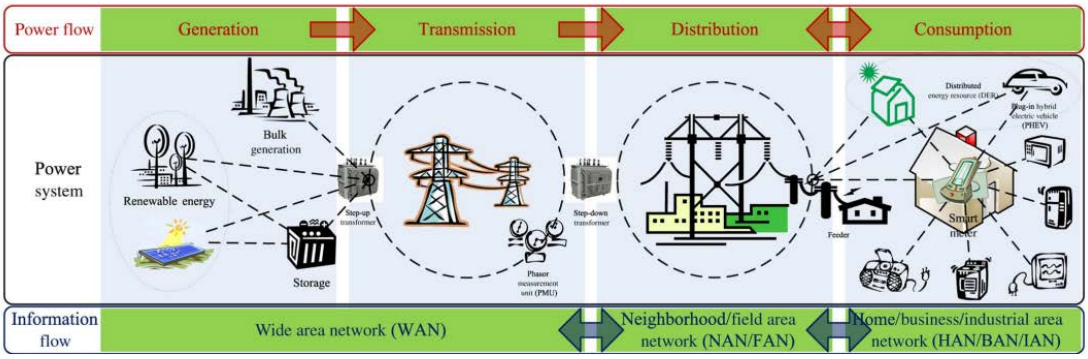

Figure 3. Architecture of the smart grid [55]

The key features of the smart grid are demonstrated in Figure 4.

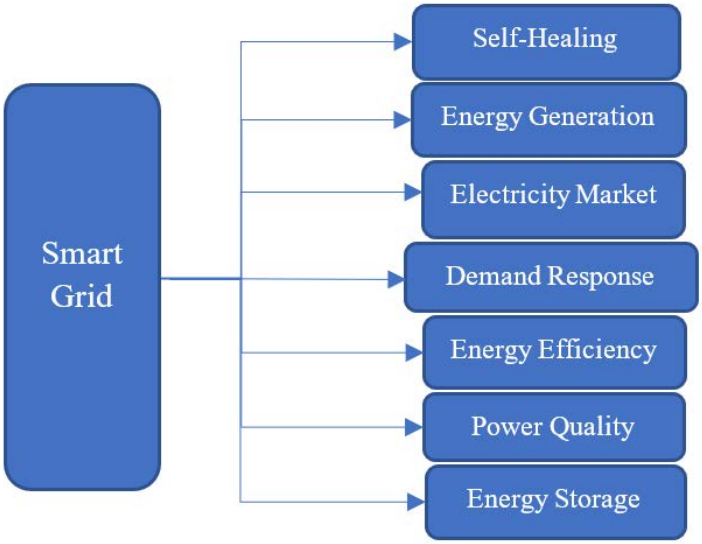

Figure 4. Features of the smart grid

7 Benefits of the Smart Grid

Smart grid implementation in Kurdistan will bring about numerous benefits, as previously mentioned. One common issue faced is the exceeding of the maximum generation limit by the total load demand, resulting in planned load shedding. However, utility engineers and experts suggest that this demand deficiency can be addressed in urban areas through peak load shaving and efficient utilization of the existing power supply. The advantages of implementing the smart grid for Kurdistan are as follows [69–74]:

• Environmental benefits: A smart grid can contribute to saving thousands of lives, particularly those who prioritize human well-being. Additionally, it can help alleviate the negative impact of polluted air on asthma and lung diseases, especially among vulnerable groups such as children and the elderly.

• Lower utility bills with user-friendly tools: Smart meters provide consumers with valuable information on their energy usage and prices through simple online displays. By utilizing set-and-forget home energy management tools, consumers have the ability to make choices to reduce their bills and minimize their environmental impact.

• Growth of economy and employment: There has been rapid expansion of the clean energy industry and the attraction of investment from different foundations. These investments are concentrated mainly on domestic

companies and projects in solar energy, wind energy, energy efficiency, smart grids and EVs, leading to the growth of the economy and employment.

• Reliability improvement and outage reduction: In the presence of a smart grid which includes sensors and communication systems, the issues can be identified and cleared prior to their occurrence. In case of the power outage, it can be restored quickly, which allows the consumers to use uninterrupted power supply so that they don't feel the outage power impact.

• A large amount of clean and renewable energy can be used with the presence of the smart grid, which reduces the dependence of dirty energy sources such as fossil fuels. This technology not only decreases the need for using fossil fuels but also reduces the negative impact of using energy on the environment. Moreover, implementing a smart grid can reduce air pollution. In addition, the smart grid simplifies the transition to clean EVs by enabling smart charging during the night, while wind energy is available and cost-effective. This method mitigates effectively another main source of harmful air pollution.

8 Challenges for Implementing the Smart Grid

The implementation of the smart grid encounters several challenges, such as the huge investment costs, the privacy and cybersecurity challenges, and the operation complexity.

8.1 Investment Costs

a) Infrastructure of communications and smart meters

It requires huge investments to build the infrastructure for the smart grid in terms of communication systems and digital smart meters. All the existing energy meters need to be replaced with smart meters and the smart meters need to be installed for all distribution transformers and feeders. The smart grid is two-way, which means that the data and the complete feedback from the consumers need to be sent to the control center, and that a communication system needs to be built, which leads to more costs to build the smart grid system.

b) Grid protection

The conventional protection system for the power network is centralized and needs to be upgraded to ensure proper operation of the protection devices. More switches and other protection devices need to be added to the system and proper settings need to be applied.

c) Storage systems

Converting the conventional grid to a smart one includes penetration of renewable energy into the network, which increases the complexity of the grid and brings new challenges. These include momentary interruptions in the energy supply caused by factors such as cloud cover reducing solar power generation or fluctuations in wind speed. Additionally, continuous fluctuations in demand occur, influenced by the time of day and seasonal variations. Therefore, the stored energy is needed in order to cover the momentary lack of power supply. The energy storage adds extra costs to the total cost of the smart grid [75, 76].

8.2 Data Management

Converting the network from the traditional grid to a smart one adds more complexity to the system as a good smart grid consists of several renewable sources. The infrastructure of the grid becomes more critical and susceptible to faults once converted to smart grid. It collects data every 2-5 seconds, whereas advanced metering infrastructure (AMI) systems collect data every 1-15 minutes [77, 78].

a) Standards and interoperability;

b) Massive data [79, 80].

8.3 Stability and Decreased Flexibility

The primary operational challenge faced by the smart grid is ensuring grid stability. The role of synchronous generators in ensuring power system stability has always been crucial. The generators contribute to the grid by supplying inertia, droop control, and reactive power compensation. The increase in the proportion of renewable energy in power generation leads to a decrease in the dependence on synchronous machines, creating new stability issues for the power grid.

The network operator should assess and predict the grid stability under different operating conditions. One of the factors in evaluating the performance and effectiveness of the smart grid is its ability to keep the system stable. Various kinds of stability aspects are as follows [81]:

• Frequency stability: It is the capability of the system to keep the frequency within the acceptable and standard limit, which is 50 Hz or 60 Hz, depending on the system frequency after subjecting to abnormal conditions.

• Voltage stability: It is the system's ability to maintain its voltage within the permissible and predefined limit after being subjected to a disturbance.

• Dynamic stability: This represents the ability of the network to keep or recover after being subjected to disturbances that lasts for long periods of time.

Table 3 illustrates the common obstacles of the smart grid and the methods for overcoming these obstacles.

Table 3. Challenges for smart grid implementation in Kurdistan and other developing countries

Challenge Categories	Other Developing Countries	Kurdistan Region	Overcoming Strategies
Infrastructure	- Replacement of existing infrastructure; - Need for high speed Internet; - Limit funding;	- Three challenges are applicable for Kurdistan;	- Smart technologies are available; - Funding requirement to guarantee;
Security and hackers	- The existing power system is outdated and vulnerable to the threats of hackers and cyberthreat terror;	- The Kurdistan grid is in the process of implementing the smart grid. Most existing energy meters have been replaced by high-quality smart meters; - The system is subjected to the threats of hackers;	- Technological companies are developing measures to overcome the threats and protect the system from hackers and cybercriminals;
Privacy concerns	- Usually there is a violation of privacy; - Large volume of evidence collected about each device;	- This case is applicable for the Kurdistan region;	- Cameras on streets and highways could help to prevent the violation; - Increasing the transparency; - Active role for local authorities is required;
Engagement and education of the community	- Education and engagement of citizens to benefit from the system.	- This case is essential for Kurdistan.	Maintaining citizens be aware and up-to-date by - Meeting with them; - Guiding them by emails; - Educational web portal.

9 Conclusions

This study outlines the major challenges and opportunities for establishing a smart grid and illustrates the main differences between the smart grid and a conventional one. According to the review conducted, a significant investment is required to build the infrastructure of the network system and complete the ongoing advanced metering system, thereby supporting the technology of the smart grid application. Converting the conventional grid to a smart one requires establishing clear and applicable regulations. In addition, the threats of cybersecurity need to be clearly addressed. The required funding needs to be guaranteed for establishing the smart grid. It has been shown that there is a serious issue for the Kurdistan grid. The entire system is under the threat of deterioration and correct measurements need to be conducted. The power loss percentage is high. In addition, there is a large gap between the costs of generation, transmission and distribution of electricity and the related incomes. This adds extra loads to the budget of the local government. Therefore, it is essential to take actions in order to stabilize the network, reduce the losses and minimize the costs of the electricity. It has been demonstrated that implementing the smart grid can mitigate several issues, such as reduction of power losses and minimization of the power outages.

Data Availability

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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