Opportunities, Characteristics and Challenges of Smart Grids

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Abstract

Future electricity should be flexible, accessible, reliable and economically viable for them to achieve the smart grid initiative which include the reduction in greenhouse gas emissions (GHG) through increased penetration of Renewable Energy Sources (RES) such as solar, wind and other micro-sources. The grid is undergoing significant changes because of increasing demand of electricity, growing political pressure and public awareness on the need to reduce carbon emission and integrate large scale renewable power by blending information and communication technologies with power system operation which led to the microgrid concept which has evolved into smart grid technologies. Smart grids constitute an evolution of traditional grids by integrating digital communication, automation, and data analytics in the conventional grids. The smart grids offer improved efficiency and more efficient renewable integration enhanced by the two-way communication and self-healing ability. However, they face significant technical, non-technical and economic hurdles like high cots, cybersecurity risks, interoperability, privacy and confidentiality issues. Smart grids are networks employing digital communications, automated controls, and advanced sensors for optimal power generation, distribution, and use by offering efficiency, sustainability, and reliability. The conventional power grids are experiencing significant expansion which calls for reliability and efficiency in operation and maintenance to guarantee efficient and sustainable power generation, delivery and end use capable of supporting a diverse, heterogeneous operating measures and devices like smart appliances, smart meters, and renewable plug-in vehicles, energy resources generation systems supported by the grid. The growing electricity demand, expansion of the grid and high number of generating plants and customers have continuously increased the complexity and challenges of the electricity grid in delivering quality and reliable electricity to end users. These challenges require greater system reliability, improved efficiency, more security, cleaner environment and higher system sustainability can be realized by use of smarter electricity grids. The smart grid is a rapidly growing concept in the electricity industry that has potential to transform the use of variable renewables variable loads and improve energy efficiency in grid power systems. The smart grid technologies have demonstrated potential to revolutionize the electricity grid by means of two-way communications to improve power system reliability, economy, efficiency, and sustainability in power generation, transmission, and distribution. The objective of this paper is to present a technical overview of smart grid fist by discussing its features and capabilities followed by a discussion of the challenges, communication features, policies and regulation, and recommendations for sustainable implementation.

Key Words: Application of smart grids; Optimization of grid electricity, smart grid technology; Internet of Things; smart grid architecture; industry 4.0; sustainable energy; renewable energy; non-renewable energy; energy transition.

I. Introductions

The modern society faces unsustainable energy because of ever-growing energy demand, reducing availability of primary energy sources, aging traditional power transmission and distribution networks, growing populations as well as economies[1]. The modernization of traditional grid architectures, adoption of innovative solutions and technologies have become inevitable because of concerns over global warming, limited investment in power systems, curtailed power generation resources and increasing energy dependency globally [2]. As Distributed Generation (DG) takes attention because of their higher efficiency and environmental protection, reduction transmission and distribution losses, stabilizing local power grid and better system stability, there is growing integration of renewable energy technologies which can create many problems to the power systems[3, 4]. This emerging potential of distributed generation can be achieved by adopting a system approach which treats generation and associated loads as a "microgrid"[5-7]. In this approach, microgrids can be defined as small, local distribution systems which include a set of micro sources and, storage systems,

and controllable and uncontrollable loads which may or may not be connected to the utility grid which increase the quality of supply, increase power system efficiency, lower costs and increase access to cleaner energy. which is one of the key features of smart grids. Microgrids can also enhance local reliability, reduce investment cost, minimize emissions, improve power quality and reduce the power losses in the distribution system[3, 8, 9].

Although smart grids have many advantages, they encounter many major challenges which can be classified as technical challenges which are mainly associated with the control and protection system, regulation challenges and customer engagement challenges. The regulation challenges are related to regulation policies, smart grid legality and engagement between smart grid firms and customers. The technical challenges involve integration of renewable sources and protection issues as well as operation constraints[10-12].

Smart grids connect the traditional grids with modern control technology and a smart metering system that reduces the pressure on the power grid by offering a two-way infrastructure for exchanges between energy and information. The smart grids facilitate efficient integration, delivery and management of clean, renewable energy technologies in the energy market. In order to develop a sustainable energy infrastructure, there is need to address some technical challenges like long-distance transmission, carbon emissions, environmental pollution, and the energy crisis[13]. There is a global transformation of the traditional power system that is unidirectional in structure and operation to a configurable and participatory two-way structure where actors or participants can interact with one another [14-16]. The main motivation for this transformation is advances in communication, power electronics, and computer technology and increasing need to accommodate the variable renewables and electric cars on the power grid while maintaining. maximum reliability, quality of service, with minimum economic and ecological costs, while maintaining maximum safety for equipment and users and always keeping the voltage and frequency values within the permitted range [17-19].

The traditional electric power grid technology is over 100 years old, and its design is meant to feed electricity from large central power plants using high voltage network, covering considerable distances to deliver power to end users via lower voltage distribution network with little flexibility[16, 18]. Over years now, electricity demand has grown rapidly mainly due to social-economic development and industrial growth but the supply mainly comes from cheap traditional sources of energy like coal, gas and petrol that are associated with release of greenhouse gas emissions (GHG) to the atmosphere that are responsible for climate change[20, 21]. The electricity grid is being modernized towards advanced consistency, less costs, and greater efficiency through more uptake of renewable energy, advanced control technology and two-way communication. There has been growing need for substation modernization to cope with fast growth of the grid, growing consumer needs, and technological innovations leading to grid transformation. The Smart grid can help accomplish these technological reformations across the grid in power n generation, transmission and distribution, through more use of sensors, communication and computers[22].

The rest of this paper is organized as follows: Section II presents the smart grid design with detailed specification and its essentials. Section III I. covers the characteristics and functions of Smart Grids, Section 4 presents an overview of challenges of Smart Grids while Section V presents sustainability issues of smart grids. The paper summary, results, discussions and recommendations ae presented in section VI. Finally, the paper ends with conclusions in Section VI.

II. Smart Grid Design

The smart grid is an electricity network which can cost efficiently integrate the behavior and actions multiple users, generators, and loads to ensure economical, efficient, sustainable power system with limited losses and high quality and security of power supply and safety[2]. Figure 1 demonstrates the concept of the smart grid

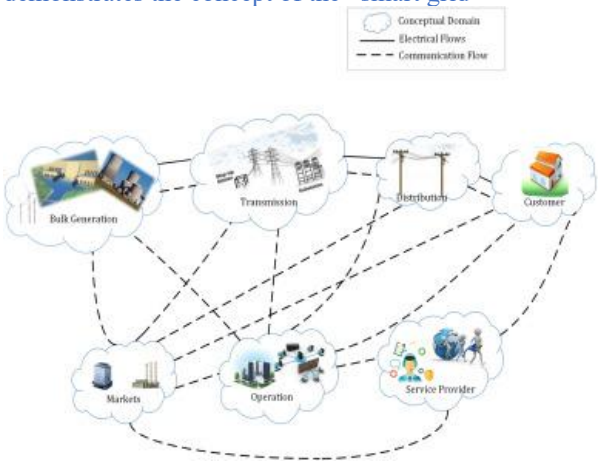

Figure 1. Smart grid conceptual model.

The smart grid is generally characterized by the following:

i.) Self-healing ability upon and failure incident
ii.) Consumer friendly
iii.) Resistant to physical and cyber attacks
iv.) Optimizes asset utilization hence better efficiency is achieved
v.) Eco-friendly as it increases the uptake of variable renewables
vi.) The use of robust two-way communications, advanced sensors and distributed computing technology.
vii.) Improve the efficiency, reliability and safety of power delivery and use[23, 24].

Although smart grids have many advantages, they are faced with numerous barriers like as bidirectional communication systems, integration to grid with renewable energy resources, ineffective utilization of the distributed generators (DG), inadequate grid infrastructure and storage etc. Effective utilization of the distrusted energy resources is handle electricity generations, energy storages, and loads at localized level[25]. Microgrids which involves nearly all of components of utility grid, although smaller and can operate independently from the larger utility grid and still function as the grids itself although at a smaller level which effectively increases the use of decentralized resources[2].

III. Characteristics and Functions of Smart Grids

The electrical grid spans kilometers of terrain supplying power to industries, businesses, homes by connecting electricity customers to power generating stations. The grid in arguably the biggest stationary machine ever assembled by mankind [22]. One of the greatest challenges facing the traditional grid is the risk of impaired consistency and security of power supply load when renewable electricity is disrupted. It is important improve the capacity of the transmission and distribution structure to accommodate growing distributed energy resources [15, 22]. Modernization of the grid is a development guided by finances, universal rules and technological advances in ICT. Currently, desirable grid improvements should ensure supply of green and sustainable energy and electricity. The smart grid which is an improved grid works with a two-way power flow [16, 22, 26]

Smart grids can be used to address the growing social, economic and environmental challenges encountered in the delivery of energy resources and generated electricity. This is achieved through increased awareness of the operation of the system and informed participation by in smart grids which improves end-use efficiency while optimizing utility of network assets, and increased resilience of the grid [16, 27]. The use of smart grids will also enable efficient integration of variable renewables and electric vehicles and provision of new grid services new products. Smart grids co-ordinate the abilities and needs of all generators, grid operators, consumers, and stakeholders of the electric power market. This coordination function increases system efficiency, reduces costs, wastage and environmental impacts and maximize system reliability, stability and resilience. These optimizations by the smart grids is achieved by applying digital and other advanced technologies in monitoring and management of electricity transmission and distribution to meet the variable power demands of consumers. Therefore successful deployment and use of smart grids will enable the global community realize shared goals securing energy security, economic growth and development and mitigation of climate change [18, 27].

The Smart grid technologies and their applications prescribe power system that is significantly different from common or traditional power system[28]. The basic characteristics of smart grids that define the new model of the grid are;

i.) They are equipped with extensive metering, control and communications throughout the distribution system with ability to meter individual customers and grid equipment like switches, transformers, capacity banks, voltage regulators, and others across the distribution system and have ability to relay the information back to utility through the communication system [28, 29].

ii.) Two-way communication

Smart grids are equipped with Two-Way Customer Communication and Power Flows

as opposed to the one direction flow to the customer alone in the traditional system and but the feedback of information is in the opposite direction to the utility often on monthly basis. The smart grid supports frequent and on-demand two-way flow of both power supply and information [21, 28, 30-32].

iii.) Stakeholder Participation and engagement

Stakeholders in a grid environment like the customers can participate actively in the grid operations. Customers can supply own produced power from local resources like cogeneration, wind, solar and biogas and they can respond to signals from the utility to reduce peak power consumption when the system is under stressed[28]. Therefore, Smart grids can accommodate new energy or electricity products, services, and new energy markets and segments[18], since they can

accommodate different conversion or generation technologies, sizes, characteristics, and storage options.

iv.) Better system control

Smart grids facilitate increased distribution system infrastructure control by the utility operator through the services and products like demand response and self-healing abilities [28]. This enhances system resilience and stability to deliver smooth power and services to stakeholder.

v.) Integration of coordination

The Smart grids create synergy and harmony in the system by coordinating and integrating advanced metering, control, communications, customer service and strategies, leverage technologies and programs to realize across the utility system objectives like reliability, efficiency, safety and economy[28].

vi.) High system reliability and resilience

The Smart grids facilitate optimal asset assets and enhanced operational efficiency. This is further enhanced through operational resilience against physical and cyber-attacks to the power system. Therefore, Smart grids Smart grids facilitate power quality requirements for 21st century energy requirements.

Therefore, smartening of the grid equips it with the digital technology and capacity to improve its resiliency, reliability, economic efficiency, energy efficiency, and flexibility of the power system.

IV. Challenges of Smart Grids

Smart grids apply modern cutting-edge technology to address multiple challenges of the traditional grid while at the same time providing opportunities to improve their efficiency and reliability. However, several technical and socioeconomic challenges limit the development and application of the smart grid[18, 33]. Smart grids employ power electronics technologies like FACTS and RACDS, efficient energy storage systems, etc. which have high initial cost requirements.

Technical challenges in operation of smart grids include database management and cyber security. Lack of consumer understanding on operation and opportunities of smart grid technology is lack of consumer understanding about the smart grid, hence the need to educate the public on the concept of a smart grid, applications, opportunities and its role in the energy transition. For consumers to effectively participate in demand response and other services requires training [16, 32, 33]. The challenges facing development and application of smart grids are summarized in figure 2.



Figure 2: Challenges of smart grid development and use

Figure 2: shows the various challenges facing smart grid development. The challenges are inadequate grid infrastructure, lack of knowledge and skills by industry workforce, limited capacity of energy storage systems, database management to secure user confidentiality and privacy, cyber security challenges like viruses and cyber-attacks, high initial capital; investments, lack of supporting policy and legal framework, and lack of consumer awareness hence ignorance of immense opportunities offered by smart grids.

Smart grid development is both a social and technological endeavor. The introduction of smart grids has profound effect on rules, regulations, norms, socially and culturally guided patterns of thinking and operation of power systems since they are highly institutionalized. Smart grids development require the development of new standards and regulations, new policies, and new market mechanisms while at the same time new technologies must be natured and allowed to mature with minor disruptions[34]. Stakeholders like technology manufacturers and information and communication technology developers, have to develop use friendly and effective novel technologies and business models in power system operations and maintenance[18, 26, 35].

There are several challenges affecting smart grid development and deployment. There is need for greater awareness among policy makers and stakeholders on the various capabilities and benefits of smart grids to facilitate energy-efficiency and renewable resource in power systems. Rapid changes in information and communications technologies and how they are being deployed in other areas of an economy like manufacturing, finance, healthcare offers new solutions for faster

deployment of smart grid technology. Developing countries are most affected by the challenges of smart grid development as they are still grappling with other important developmental and technical issues like extreme poverty, limited access to capital, political instability, government bureaucracies, high level of power theft and other system losses which may have precedence and hindrance to investment in grid smartening [20, 36].The main technical and socio challenges or limitations of smart grids include interoperability issues, cyber and physical security, high costs, confidentiality, and privacy challenges among others.

A.) Cost challenges

The biggest impediment to the development and implementation of smart grids is cost. The main cost elements in smart grid development are associated with the power transmission and distribution system, electricity metering, and critical technologies. In economic analysis and financial feasibility, a country's capacity to pay for the development cost for smart grid infrastructure is paramount which ultimately disadvantages the developing countries in implementing smart grid infrastructure[37, 38]. Smartening of the traditional grid requires the integration of additional sensors to the infrastructure which is an expensive investment undertaken by distribution grid operators[27, 39].

B. Cyber Security

There are increased possibilities of remote operation of smart grid power systems because the grids are large-scale system with participants widely spread between power plants and electricity consumers and devices which also creates demand for protection of resources against theft, abuse, and malicious activities [40].The Electric Power Research Institute has identified power system cyber security as one of the greatest issues facing smart grid. It is necessary to identify weaknesses of the smart grids exploited by attackers by use of Smart Grid Systems Treats Analysis and by integration of Systems Security Threat Models. There are various approaches used to address cyber-physical security issue for Wide-Area Monitoring and protection and control which are vulnerable to a coordinated cyber-attack. Overall, it is necessary to assess the Smart Grid security by review of its methodology to identify weaknesses[38]. Since smart grids are deployed across the value chain, there is increase in points of interconnection with other information networks which exposes the system to potential threat of cyber-attack to important power management systems and infrastructure[41].

The smart grid is heavily dependent on ICT which ultimately increases the complexity and the number channels for possible cyber-attacks. The cyber-attacks may target the distribution infrastructure not necessarily to cause power blackouts but other destructive disruptive activities like energy meter manipulation, blackmail, power supply disruptions, damage of equipment, damage of distribution or customer equipment [27, 39]

Therefore, it is necessary to ensure that cyber security is an essential aspect of any smart grid design and operations[42]. The interoperability and cyber security can be achieved only through rigorous implementation of various standards.

C. Interoperability

The communication infrastructure for smart grid should meet specifications in terms of time synchronization, data delivery efficiency, latency reliability, and multicast support. Additionally, the main challenge in networking communications in smart grid is interoperability[40]. Rigorous implementation of applicable standards is an effective measure to achieve interoperability. The National Institute of Standards and Technology (NIST) has put in place interoperability standards in areas like advanced metering infrastructure (AMI), end to end security, metering, communication between control centers, substation automation and protection, energy management system interfaces, power system control operations information security, phasor measurement unit (PMU) communications, electrical and physical interconnections between utility and distributed generation (DG), security for intelligent electronic devices (IEDs), cyber security standards and guidelines for federal information systems and bulk power systems, home area network (HAN) device communication, measurement, and information model and smart grid Interoperability Panel (SGIP) catalogue of standards.

It is advisable for each country to develop their own standards for smooth implementation of smart grid considering their existing standards and for easy implementation. However, internationally accepted standards and security should also be put in by all countries involved in the smart grid implementation to make the power grid a homogeneous global grid[43].

D. Confidentiality challenges

Access Control and Identity Management is needed for confidentiality of data transmitted via smart grids. There is need for authentication to verify identity of the receivers of and avoid any disruption or exploitation. Only authenticated users should be allowed access to the control center for transmission, and distribution grids[44].

E. Privacy and Security Policies

With wide scale interconnectivity and system access including the growth of Internet of Things associated with smart grid development, privacy,

and development of far policies for all stakeholders is a real challenge as objectives and needs may differ and even conflict among stakeholders[44]. Therefore, there is a huge necessity for suitable security policies to establish relationships between the consumers, utilities, generating companies, transmission firms, and third parties, although applying security and privacy policies in a manner that does not lead to dissatisfaction which is a complex affair[44].

F. Defence Against Threats

The smart grids have inherent vulnerabilities against which it must be protected. This can be achieved by building an effective, layered defence system for protection of the smart grid infrastructure[44]. This defence or protection against the threats or vulnerabilities give the network segmentation and access control to defend against denial-of-service (DoS). Technologies used include firewall, virtual private network (VPN), intrusion prevention system (IPS) [66]. This leads to extra investment in technology and resources adding to system costs[45].

G. Physical Security

Smart grid systems have thousands or millions of widely spread remote points and networks. This the challenge of policing or physical protection from theft, sabotage and illegal or unauthorised access[44]. Therefore, physical protection is a real challenge for smart grids. Additionally, the wider geographical dispersion of the many assets and systems makes it difficult to access all of the terminals for both maintenance and protection[45, 46]

H. Connectivity challenges

This refers to the communications connectivity and interchange within the smart grid infrastructure and between users or stakeholders[44]. The current trend in communication technology also implies a transition from analogue to digital communication and towards an Internet like distributed environment where large number of devices are interconnected. Not all regions, devices or users have access to modern and effective internet and communication infrastructure especially where the services a publicly accesses and not limited to the grid system[44, 45]

V. Sustainability And Sustainable Development

Sustainability concept is a new idea in energy sector, but the movement has roots in social justice, conservationism, internationalism, and other past movements with rich histories which cumulatively led to the call ‘sustainable development in the 20th century [47]. Sustainability embodies the promise of social evolution towards an equitable and wealthy world where the environment in its natural form and cultural achievements are preserved for future generations [48]. To realize sustainability, the organizations must also be sustainable in their undertakings. This is referred to as organizational sustainability. The minimum criteria for sustainability is acceptability, and so for sustainability to be realized, policies, measures or strategies must be accepted by stakeholders [49].To this effect, energy or electricity producers should grow their social, economic and environmental capital base while adding value on sustainability in the political arena or domain. Therefore, long term sustainability requires satisfaction of social, economic, and environmental dimensions in power or electricity generation, supply, and consumption.

a.) Sustainability in Electricity Generation and role of smart Grids

The increasing global concern over greenhouse gas emissions and the threat of global climate change and its consequences has generated s growing need for alternative energy solutions to the conventional energy sources mainly natural gas, coal, oil, uranium [50-52]. Energy projects have a number of long-term non-financial benefits like increased productivity, attraction of expertise and its retention, better health and higher quality of products and which are key sustainability concerns [53-55]. Therefore, sustainability is an important dimension in the energy transition.

Sustainability is concerned with desirable or acceptable long-term conditions, is applied in many fields including project management [29, 56]. Energy projects should manage and control time, scope and budget which are the main dimensions of project management but should additionally address socially and environmentally concerns which are important dimensions of sustainability and sustainable development. Sustainability requires that electricity or energy planners be aware of the impact of their activities on the environment. There is need to evaluate the risks related to labor practices, human rights, fair business dealings, and consumer issues. Electricity projects should integrate sustainability practices and guide organizations towards sustainability. When an organization incorporates sustainability practices into its processes, it takes responsibility for the impact of its activities on customers, employees, shareholders, communities, and the environment through all aspects of operations [26, 57]. The use of Key Performance Indicators (KPIs) is necessary in project decision-making process when selecting viable and sustainable energy projects is recommended for sustainable electricity generation [58]. A sustainable focus recognizes the interdependence between companies and the broader society and encompasses aspects like human rights, labor issues, environment and ethical aspects

which can be integrated in smart grid development strategy.

b.) Energy for Sustainable Development and Role of Smart Grids

Mankind needs energy as heat and electricity to meet his everyday needs of life to improve through economic and productivity development. Renewable energy sources are from natural sources and replenish themselves through natural forces. They include hydropower, bioenergy, direct solar, hydropower, geothermal and wind [51]. The use of renewable energy sources will help mitigate climate change. Renewable technologies are considered as clean with less wastes and less environmental impact compared to conventional and non-renewable energy sources. Therefore, renewable energy sources play a leading role in the low carbon energy transition [54, 59, 60]. However the consumption of renewable energy also needs to be sustainable for them to remain renewable [61]. Factors considered in energy evaluation include economic, institutional, technological development, energy security, environmental protection, and prevailing state of the energy market [53]. According to [62] a sustainable energy system has to take into consideration the limits of resource supply and environmental impact more so accumulation of greenhouse gases and hence the need to shift from fossil fuels to non-fossil fuels before 2050. Maximum advance should be taken of immense resource supply for renewables like geothermal, solar and wind [62]. Development and climate change mitigation have become integral aspects of energy planning, analysis and policy making globally. This is because energy production is responsible for over two-thirds of combined greenhouse gas emissions and over 80% of CO_2, any effort to reduce emissions and mitigate climate. Management of energy mix and energy efficiency play key roles is managing greenhouse gas emissions from power generation and energy use[63-65]. Meeting the long-term climate objectives of the Paris agreement requires urgent tackling energy-related greenhouse gas emissions through scale up of renewable energy contribution to grid electricity system [66].

The benefits of onsite power include direct access to renewable energy, hedging against financial risks, and reduced emissions and environmental impact from power generation. Countries can also share energy resources since they are endowed differently. For example, France is rich with low carbon nuclear electricity while and Sweden and Ethiopia have huge hydro potential which can be shared with neighbors as a strategy for de-carbonization. A sustainable strategy may involve integration of the onsite power plants, regional grids, and diversified conventional grid components. This is made possible by use of smart grids to provide the necessary infrastructure and capability [49, 67].

c.) Smart Grids in Sustainable Energy Transition

De-carbonization of grid electricity is a leading option in the effort to minimize greenhouse gas emission and related consequence of climate change [58].Several technical and non-technical measures can be adopted to ensure that energy systems promote sustainable development [26].The main challenges are expanding access to affordable, reliable, and adequate energy supplies while addressing environmental impacts at all levels [49, 58]. Policies can support sustainable development by:

i.) Supply affordable and adequate energy and electricity to unserved or underserved areas and populations.
ii.) Increase the contribution of renewable energy sources in power generation.
iii.) Adopt new and modern technology in power generation, transmission, and distribution.
iv.) Optimization of operations in grid power systems

With the right policies, prices, and regulations, energy markets can achieve many of these objectives. But where markets do not operate or where they fail to protect important public benefits, targeted government policies, programs, and regulations are justified when they can achieve policy goals. Whereas strategies to encourage sustainable energy systems are straightforward there is need for wider acknowledgement of the challenges and stronger commitment to specific policies, strategies, and technology [45, 62, 68]. The realization of these multiple strategies to realize sustainable energy and electricity requires smart grids for efficiency and effectiveness of execution.

Challenges facing the development of renewable energy and low carbon sources of energy require that governments should put in place measures that promote investment and use of these renewable energy sources which ultimately requires the use of the appropriate technology and infrastructure. There is need for several incentives that promote renewable energy, including information on financial incentives and net metering policies, as well as related awareness and investment programs. Due to several challenges facing renewable energy development, authorities and governments should guide and motivate investors [69].

Smart grids can help in the reduction of carbon emissions in the in-power generation and supply by connecting more renewable energy sources especially the variable renewables like wind and solar, and reduction in greenhouse gas emissions through efficient resource use. Network operators have an obligation to minimize their carbon footprint in their operations and measures used to achieve these include reducing call-outs with and associated vehicle fuel usage, reduce and leakage of SF_6 in gas-insulated switchgear besides reducing operation and maintenance costs. This is achieved by provision of faster automated services for operations like real time automated meter reading, automated outage management done remotely with limited site visits by technicians and engineers[70, 71].

VI. Summary, Results, Discussions and Recommendations

Progress in technology has made it possible to have enabled society to achieve its vision to utilize sustainable energy by use of technologies like the internet of things Internet of Things (IoT), data analytics, blockchain-enabled smart contracts, and artificial intelligence that off significant opportunities for energy management like efficient management of electricity consumption during peak hours. Smart grids have enables smart electrical devices which reduce pressure on power grids and reduces the consumer's electricity bills. However, smart grids have numerous limitations shortcoming's fault monitoring for generation panels, dust accumulation on electricity-generating panels, icing and conductors galloping. Currently, most of the smart grids use renewable energy sources to generate electricity. Realtime monitoring system needed to obtain power generation data from the power plants in smart grids[13].

i.) Challenges Facing Smart Grid Power Systems and Technologies

Smart grids have ability to deal with many current issues with the traditional grid by application of the cutting-edge technology with a plethora of chances to improve efficiency and reliability of power systems. However, several socioeconomic and technical can hinder there deployment and applications[72]. Since the grid is a complex architecture, decentralization by use of smart grids brings tremendous benefits at a cost. However, digitalization and integration of a large number of growing users makes smart grids soft targets for cyber-attacks and breach of confidentiality among other limitations[39]. Smart grid technologies although promising to have several challenges as summarized in table 1 below.

Table 1: Challenges facing smart grids

	Challenge	Causes and Impact	Solution/Recommendations
1	Cost challenges	The main cost elements in smart grid development are associated with the power transmission and distribution system, electricity metering, and critical technologies. In economic analysis and financial feasibility	A country's capacity to pay for the development cost for smart grid infrastructure is paramount which disadvantages developing countries. `Funding by international institutions can facilitate access to requisite funding for smart grids.
2	Cyber Security	As smart grids are deployed across the value chain, there is increase in points of interconnection with different information networks which exposes the system to potential threat of cyber-attack to important power management systems and infrastructure.	cyber security can be achieved through rigorous implementation of various standards. Therefore, it is necessary to ensure that cyber security is an essential aspect of any smart grid design and operations. It is necessary to identify weaknesses of the smart grids exploited by attackers by use of Smart Grid Systems Treats Analysis and by integration of Systems Security Threat Models

3	Interoperability	Interoperability facilitates connection of different parties to the devices and systems for proper interaction	The interoperability can be achieved through strict implementation relevant standards
4	Physical Security	There is risk to valuable assets and systems that are widely spread across the country of power system boundaries	Investment in facility security and proper siting away from danger and keeping of intruders and risks through access control.
5	Privacy and Security Policies	Wide scale interconnectivity and system access including the growth of Internet of Things associated with smart grid development, privacy, and development rises privacy and confidentiality concerns.	Put in place security policies to establish relationships between the consumers, utilities, generating companies, transmission firms, and third parties, although applying security and privacy policies
6	Connectivity	Refers to communications connectivity and interchange within the smart grid infrastructure and between users or stakeholders.	It is necessary to develop internet and communications infrastructure across the whole power system coverage area.
7	Confidentiality challenges	Access Control and Identity Management is needed for confidentiality of data transmitted via smart grids.	Only authenticated users should be allowed access to the control center for transmission, and distribution grids
8	Defence	The smart grids have inherent vulnerabilities against which it must be protected. This can be achieved by building an effective, layered defence system for protection of the smart grid infrastructure.	This defence or protection against the threats or vulnerabilities give the network segmentation and access control to defend against denial-of-service (DoS). Technologies used include firewall, virtual private network (VPN), intrusion prevention system (IPS) [66]. This leads to extra investment in technology and resources adding to system costs

From table 1, challenges facing smart grids include high cost of investment and limited access especially

for developing countries having multiple socioeconomic challenges, interoperability of standardization related issues, cyber and physical security, communication and internet connectivity challenges and high system security requirements.

ii.) Role of smart grids in the sustainable energy transition

Smart grids have an important role to play in the sustainable energy and electricity transition within the framework of the 5 dimensions of energy sustainability. They are summarized in table below

Table 2: Role of smart grids in the energy transition and related challenges

	Dimension of sustainability	**Sustainability impact**	**Challenges**
1	Economic sustainability	Coverts consumers to prosumers who make	− Understanding and communicating the value proposition of a smart grid deployment for each

		revenue and save on cost through variable pricing	stakeholder in the electricity supply chain is daunting. − The financial environment for risk and reward can challenge business plans for smart grid investments. − Regulatory understanding and sensitivity to providing an appropriate environment for smart grid investment takes time. Regulatory decisions (or lack of decision) can create new challenges. − Developing an appropriate incentive structure that aligns economic and regulatory policies with energy-efficiency and environmental goals.
2	Environmental sustainability	Reduces greenhouse gas emission through higher absorption of variable renewables. As well as high efficiency hence less consumption	The level of emissions reduction is highly dependent on the energy mix. Not all areas are endowed with abundant supply of solar and wind resources to exploit decentralized power generation.
3	Social sustainability	Maximum use of local energy resources, employment and cleaner environment and participatory operations	-It is difficult to assign values to externalities like environmental impact which is necessary for balanced decision making. − Smart grids need highly skilled manpower hence need to train staff and users which is a cost in terms of time and services. − It is not easy to account for beneficial aspects of smart grid investments as a mechanism for job creation and advancing a technically skilled.
4	Technical sustainability	Facilitate micro grids and decentralized generation. Increases reliability, efficiency and optimum use of energy resources and infrastructure	-Constantly changing technologies means that a heterogeneous mix of technology must be accommodated - Flexibility to changing technologies requires identifying the important interfaces between technology components. .

5	Institutional sustainability	Facilitates active participation of all stakeholders where all stakeholders benefit.	Consideration should be given to develop smart grid policies supporting renewable energy and energy efficiency. Such a framework could be used as a starting place for each member economy and serve to help engage. all electricity stakeholders (including consumers, service providers, suppliers, and regulators) in shaping these goals. Regulatory regimes should provide appropriate environment for smart grid investment − Developing an appropriate incentive structure that aligns sustainable energy smart grids.

From table 2, the role of the smart grids in the sustainable energy transition is presented with current challenges. Overall, it is noted that whereas smart grids have huge capability or potential to transform the power systems, they have several challenges that need to be overcome in all dimensions of sustainability. They include high cost, risks to the infrastructure, volatility of related technology, and huge policy and institutional requirements for sustainable adoption and transformation.

iii.) Recommendations

The successful adoption of smart grids to make them sustainable option in the energy transition require measures that include.

i.) Put in place policy measures to development a common framework for development of smart grid that may be unique to each country for successful deployment of smart grids globally.

ii.) All stakeholders like consumers, service providers, suppliers, and regulators should play leading roles in shaping the goals and required standards and level of performance

iii.) There is need for education and sensitization is on use and benefits of deployment of smart grids to governments and stakeholders

iv.) Understanding and communicating the value proposition of a smart grid deployment for each stakeholder in the electricity supply chain is daunting.

v.) The financial environment for risk and reward can challenge business plans for smart grid investments.

vi.) Need for development of internationally acceptable quality and operational standards to manage the challenge of interoperability.

vii.) Governments should put in place necessary regulatory measures to govern the development and operation of smart grids and facilitate harmonious integration and cooperation between all stakeholders. This is because regulatory decisions (or lack of decision) can create new challenges to deployment and operation of smart grids.

viii.) There is need for the developing an appropriate incentive like attractive fed in tariffs for prosumers and flexibility in pricing that is aligned with requisite economic and regulatory policies where energy-efficiency and environmental protection needs to be the ultimate objective or target

ix.) The volatile nature of smart grid related technologies implies that there should be provision for a heterogeneous mix of technology so that existing generation and delivery infrastructure (i.e., legacy) systems can be seamlessly adapted to work with new technologies. To be flexible to technology changes need the identification of important interfaces between various technology components.

x.) To realize or achieve alignment across stakeholders like service providers, end-users, and technology suppliers is a challenge which should be addressed by enforcing interoperability can allow multiple parties and devices to interact smoothly and seamlessly. The requires standards and an effective legal and regulatory framework to facilitate a smooth transition and operations.

Wider adoption or development of smart grids requires amendment or development of facilitating legislative and regulatory frameworks for countries still using the traditional grid [1]. There is need to develop incentives for increased adoption of renewable energy technology, measures that promote electrification of transport which is an important user of smart grids like tax measures, workforce capacity building and wider public awareness campaigns to enlighten the general public and grid stakeholders to create a mass movement for development and adoption of smart grid technologies and related products and services for sustainable transition [1, 40, 41].

iv.) Conclusion

Smart grids constitute an evolution of traditional grids by integrating digital communication, automation, and data analytics in the conventional grids. The smart grids offer improved efficiency and more efficient renewable integration enhanced by the two-way communication and self-healing ability. However, the face challenges like high cots, cybersecurity risks, interoperability, privacy and confidentiality issues. The significance and provenance of power system reliability and intelligence has positioned the smart grids at the backbone future power and supply systems with throwing demand of energy and hence more grid related challenges. On the other hand, highly distributed and decentralized energy resources cause problems that require smart grids to provide necessary services to both the consumers and prosumers. Technologies and capabilities like the Internet of Things (IoT) which are integrated with smart grids enable distributed monitoring for smooth running of power grids. The deployment of smart grids is also associated with multiple challenges like lack of security, decentralization, transparency, and trust-less approaches.

As the world transitions from centralized electricity systems to decentralized systems whose control is influenced by dynamic market forces for investment, operational stability and reliability, smart grids will play a key role in the transition by facilitating greater absorption of variable electricity supply like wind and solar and variable load like electric vehicle battery recharging system. A sustainable electricity mix and power system will require seamless coordination of both centralized and decentralized power generation and distribution. Therefore, to achieve sustainable development requires electricity systems to adequately respond dynamically, and intelligently to change in demand and supply. This will facilitate energy security, and power quality which are requirements for realization of technical, economic, and environmental performance sustainability. Therefore, smart grids will transform the power sector into a desirable system with reliability, availability, and efficiency, which are requirements for improving the world economy and guarantee environmental protection. However, the transition period requires tests, technological innovations and improvements, consumer education, development of appropriate or requisite standards and regulations, and information sharing or networking between all players in the energy sector to ensure that the benefits of smart grids will be realized globally for all humanity.

The deployment and optimum use of smart grid infrastructure may require advancement in energy storage technology and facilitating policy, legal and socio-economic environment. The study showed that many components of smart grid systems can be progressively deployed based new initiatives, policy initiates, and specific frameworks adopted for implementation by the government or responsible authorities. There exists significant potential of smart grids technology in the entire energy sector that can deliver effective and efficient utilization renewable energy resources, protection of the environment, better energy management, and overall socioeconomic development of all countries. The success of smart grids technology requires that governments and energy sector authorities should put in place policies and frameworks that support and prioritize the investment that promote the use of renewable energy technologies and integration in the

entire national electricity grid and all electricity applications.

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