Smart Grid Key Products Core Services, Main Functionalities and Key Capabilities

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Abstract

Electrical power grids have encountered many challenges in recent years, including global warming, the quest for energy security, increasing cultural conservation, and the stringent power reliability and quality requirements of the digital age. Many studies have been conducted on the development and implementation of the smart grid (SG) to address these issues. The essential technical characteristics of the SG are: the two-way flow of electricity and information in order to establish a highly automatic and widely distributed energy exchange network; and the utilization of distributed computation, communication, and Internet within power grids in order to realize the real-time exchange of information and a near-instantaneous balance between power demand and supply at the device level. The following four features are important in this regard. A smart grid is a digital, modernized electrical grid employing a two-way communication, sensors, and automation to monitor and manage electricity which replaces the e traditional, one-way power flow to increase energy efficiency, integrate renewable energy sources, improve system reliability, and lower cost. The key products and technologies of the smart grid are advanced Metering Infrastructure (AMI) i.e. digital "smart meters" that track electricity use in real-time and send it to utilities, Sensors and IEDs i.e. Intelligent Electronic Devices and sensors monitoring grid health., Energy Storage Systems (ESS) like utility or residential batteries that store excess power, distribution namely Distribution Management Systems (DMS) i.e., Software used by power companies to monitor and control the grid and distributed Energy Resources (DERs) which are Small-scale solar panels and home wind turbines. The core services offered by the smart grids are demand Response which are Programs that reward users for reducing energy use during peak demand periods, dynamic Pricing i.e. Variable electricity pricing where power is cheaper during low-demand hours, grid Analytics like data analysis services including predicting power failures and optimizing energy distribution and Microgrid Management which includes Services like design of localized grids that can run independently during main grid outages. The main functionalities of the smart grids identified in the study include Two-way Communication with continuous, instant exchange of data between the grid operator and the customer, automated Fault Detection with ability to automatically identify grid problems and reroute power. Renewable Integration for balancing intermittent wind and solar power with battery storage and Real-Time Monitoring involving constant tracking of voltage, current, and energy consumption. The key Capabilities of smart grids include Self-Healing with ability to automatically isolates damaged sections of the grid to prevent widespread blackouts, Peak Shaving which employs stored battery power to reduce high-demand spikes and lower energy costs, electric vehicle Grid Integration to supports electric vehicle charging without overloading the local power network and consumer empowerment which gives electricity users to make own informed decisions by providing detailed information to optimize their own energy consumption and costs

Key words: Smart grids; smart grid capabilities; smart grid core functionalities; smart grid services; power distribution; power supply; energy integration

1. Introduction

Power systems originated in the 1880s as localized, vertically integrated systems with generation, delivery infrastructure, and load designed and built by single companies. Isolated systems in major cities became interconnected to improve their load factor and

to share generation reserves between areas, made possible by increasingly higher-voltage transmission and buoyed by economies of scale of increasingly efficient steam turbine. As power systems become smarter, digitalization of the electric grid is inevitable[1]. Digital transformation supports operational and business-model changes for smart grid operators, energy value-chain integrators, and energy ecosystem service providers, and it accelerates development of a modern energy system that emphasizes cleanliness, low carbon, safety, and efficiency. These trends help advance the smart grid sector. The concept of "smart grid" has been widely advocated to describe a set of transformative solutions for modern power systems. However, despite the ubiquity of the term in operation, policy, and industry discourse, the precise definition of a "smart grid" remains ambiguous, with interpretations varying across technical, regulatory, and market-driven perspectives[1, 2].

A smart grid can be defined as electricity network consisting of transmission lines, substations, transformers, and other devices that use digital and advanced technology to monitor, manage and evacuate electricity from all power stations in a manner that copes with load variation. They use information technology to deliver electricity in a planned, efficient, reliable, and secure manner by enabling two-way communication and two-way energy and information flow. Unlike the traditional grid, they have ability to self-monitor, self-heal or regain and can facilitate pervasive control and enhanced interoperability [3-5]. The smart grid system can be integrated from different sources of renewable energy, such as photovoltaic panels, wind farms [6] and also integrates distributed energy resources to optimize electricity production and delivery [5, 7].

For smart grids to realize their objectives, they are equipped with computer technology and programs that facilitate communication, automation and connectivity of the various components and functionalities of the electricity generation and supply system by facilitating communication between electricity consumers, power generating plants and electricity transformers [8]. Components of a smart grid include smart meters, computers, controls, smart appliances, energy efficiency management systems, and renewable energy sources [2, 3]. By use of phasor measuring unit (ppm), current and voltage is measured severally per second and can give the location as well as a smart shot of the power system which enables a dynamic visibility into the system. Smart grid involves simultaneous modernization of the transmission and distribution grids[9].

To function properly, smart grids need electronic power control and distribution. Figure 1 illustrates a smart grid with its basic components.

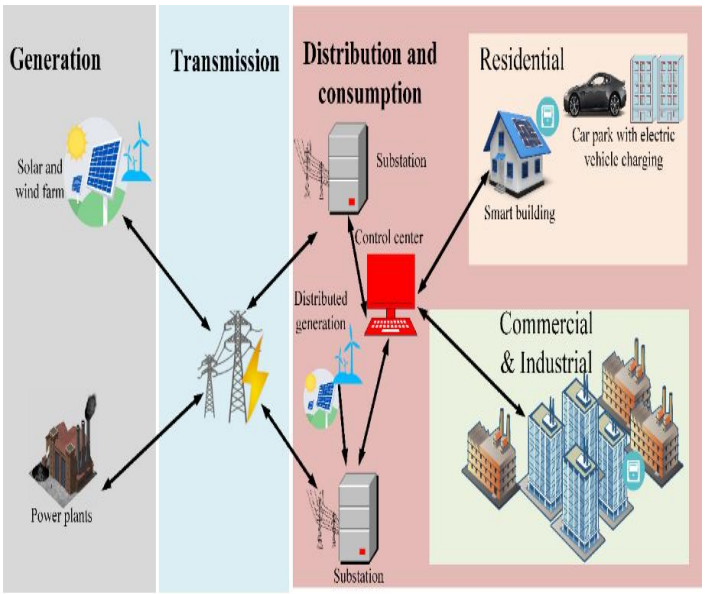

Figure 1: Illustration of a smart grid [10].

Figure 1 is an illustration of a typical smart grid showing various elements namely transmission lines, power plants, renewable energy sources i.e., wind, solar, consumers like factories, transmission grid, distribution grid with city and rural networks, substations, nonrenewable sources like coal, nuclear with all elements interconnected.

Smart grids improve both efficiency and of the traditional grid and create opportunities for enhanced uptake of variable renewable energy sources by use of computers and communication technology for advanced data processing, analysis, and control. Besides increase accommodation of variable renewable sources, the technology also supports variable loads like charging electric vehicles and support for the V2G technology [10]. Therefore smart grids will coordinate the needs of power plants, consumers, and other stakeholders to ensure efficiency, minimum cost, and environmental impact while ensuring maximum system reliability, stability and

resilience [4, 8]. These are the key requirements for sustainability.

2. SMART GRID DESIGN AND OPERATION

. The traditional grids simply transmit power generated at central power stations with voltage. transformers that increase and reduce voltage to supply electric power to consumers. Unlike the traditional grid, smart grids, perform the functions of the traditional grid and added ability to remotely monitor all activities or faster and better responses and performance of the power grid [11, 12].

A smart grid is an upgraded electrical network that uses digital technology, sensors, and software to monitor and manage electricity. Unlike traditional grids that rely on one-way communication and central power plants, smart grids enable two-way communication between the utility and consumers, allowing for automated control, renewable energy integration, and greater overall reliability. Figure 2 shows the smart grid design and environment

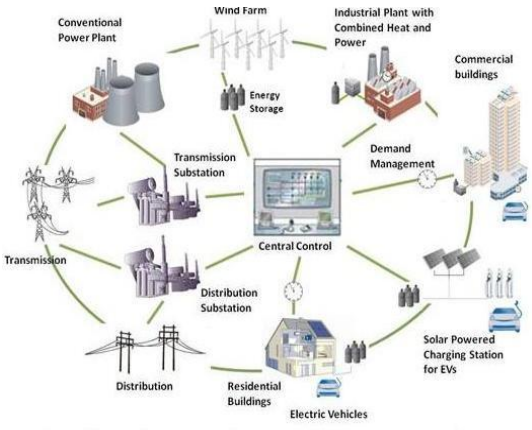

Figure 2: The smart grid design and construction

From figure 2, the main elements of a smart grids are conventional power plants, distributed/decentralized energy resources and generation systems, transmission and distribution substations, users like electric vehicles, residential buildings, demand side management, energy storage, industrial plants, commercial facilities, and central controls.

2.1. Key Design Principles

The design of a smart grid is done on the basis of modernization of the physical hardware and integrating digital intelligence in the conventional grid[7]. The main elements are;

i.) Advanced Metering Infrastructure (AMI) which is a digital electric meter with ability to record consumption and communicate consumption data back and forth.
ii.) Sensors & Automation which are devices placed throughout the grid that for tracking parameters like voltage, temperature, and current to pinpoint outages and prevent overloads.
iii.) Communication Networks which employ high-speed digital networks that that allow devices, substations, and control centers to share data in real time basis necessary for control
iv.) Energy Storage Systems which include large-scale batteries like lithium-ion systems for energy storage during low-demand for peak time release and usage.
v.) Distributed Energy Resources (DERs) which are small-scale power generation systems located on as solar panels and wind turbines which are grid connected.

2.2. Core Operational Concepts

The core operational concepts for smart grids define how they operate on daily basis. The operations in smart grids focus on efficiency, resilience, and adaptability as modernized electricity networks employing a two-way digital communication, smart sensors, and automation to monitor, manage, and optimize the production, delivery, and consumption of energy. As upgrade traditional grids, the smart grids increase energy efficiency, enhance grid resilience, and smoothly integrate renewable energy sources[7]. Two-Way Power Flow and information flow that allows electricity and information to flow from power plants to consumers, and from consumers the grid and converting consumers to prosumers. The core operations concepts are based on;

i.) Demand Response programs which encourage electricity consumers to reduce and shift their electricity usage during peak hours for a stable grid and cost reduction.
ii.) Self-Healing capability through of automated software with ability to re-route power around points or areas with fault which effectively reduces outage times and limit the number of affected customers

iii.) Grid Energy Management Systems which are Software platforms providing provide real-time monitoring and control over energy supply and demand for maximum efficiency.
iv.) Microgrid Integration which are small, localized grids with ability to operate in island mode upon disconnection from the main grid for independent operation when emergencies occur.

3. SMART GRID PRODUCTS AND SERVICES

Smart grid products and services constitute the modern, digital upgrade to conventional grids and utilize sensors, smart meters, software, and communication networks to support two-way flow of electricity, data and information between consumers of power and utilities. These functions and solutions serve to optimize power supply, seamlessly seamless energy integration, and enhanced overall system resilience[13, 14]. Globally, the smart grid technology has ability to address the energy sustainability and transformation challenges like over reliance on fossil fuels, large gap between demand and supply and limited access to renewable energy resources. If well addressed, they will enable a smooth transition to the smart energy systems[11, 15, 16]. The specific products and services or of smart grids are as follows;

3.1. NET metering

Integration of renewable energy sources with smart grids means that power can flow in either direction. Smart meters have capacity to meter both flows compute the net energy at the consumer premises. Smart meters can measure three important components of energy i.e., kWh, kVArh and kVAh. The smart meters are also equipped with communication facilities for two-way exchange with the control center, to transfer data and receive control commands[17]. Net kWh curve represents the difference between import kWh curve and export kWh curve, where the positive indicates that the consumer imported more than he supplied to the grid, while the negative portion shows that the consumer injected more power into the grid than he imported. [30].

3.2. Time of Use (TOU) Metering

This metering or billing system is based on the time that power is consumed with higher charges during the peak and lower charges during off-peak to facilitate better load management[17]. The TOU tariff helps shift load from the peak load time to off peak period which has potential to increase the performance of the system by reducing maximum flow through the system. as maximum power flow in the network would be reduced and reduce pressure on power generation. which often use fossil fuels sources for peak supply.

3.3. Peak load shaving

Peak load is an important factor for power grids because it only for a small percentage time duration in a day and requires extra generation capacity which is economically feasible and is inefficient use of generation capacity required for just limited time[18]. Peak load shaving refers to the shifting loads from peak periods to off peak periods. By use of smart grids, it is possible to shift various demand to operate within minimum ranges. Smart grid facilities create flexibility and demand shifting leading to load management, peak shaving and energy saving through moving loads from peak period to off peak periods. The Peak load benefits both consumers and the utility operators[17].

The growth in peak load increases chances of power failure and also increases the marginal cost of electricity supply hence the increasing need to reduce peal demand. Peak demand is often met by gas turbine and diesel engine power plants which is expensive power and polluting from greenhouse gas emissions. Therefore, peak load shaving has economic and environmental benefits. And is achieved mainly by three different strategies namely.

i.) Integration of Energy Storage System (ESS)
ii.) Integration of Electric Vehicle (EV) to grid
iii.) Demand Side Management (DSM)

3.4. Billing efficiency with Smart Meters

A smart meter is an electronic a device used for measuring natural gas, water or heating. The smart meter is equipped with real-time or near real-time sensors, outage notification, and ability to monitor power quality. Smart meters are similar in many respects to Advanced Metering Infrastructure (AMI) meters. As

opposed to interval and time-of-use meters smart meters have automatic reading ability [19, 20].

A smart meter records energy information like electricity consumption, voltage levels, electric current, and power factor and communicate to the consumer thus ensuring clarity on consumption behavior. They also communicate with the utility company for system monitoring and billing. The smart meters facilitate a two enable two-way communication between the central system and the meter[20].

The smart meter differs from automatic meter reading (AMR) due to its ability to effect two-way communication between the meter and the supplier. The communication facility in smart meters is achieved through wireless, or fixed wired connections. Common wireless options for smart meters are cellular communications, Wi-Fi (readily available), wireless ad hoc networks over Wi-Fi, Wi-SUN (Smart Utility Networks, wireless mesh networks, low power long-range wireless (LoRa), Wize (high radio penetration rate, open, using the frequency 169 MHz), and ZigBee (low power, low data rate wireless) [19]. Smart grids make use of smart meters as the backbone in the development of smart grids. have made billing, free from manual operation as opposed to the traditional billing cycle usually done once in a month by many utilities. With smart grids billing can be done over shorter cycles like 30 minutes and in some cases, prepaid services are available. Accuracy in metering is also significantly improved by smart metering and in some up to 655 improvement has been achieved by conversion from manual to smart meters which reduces commercial losses[17].

3.5. Power quality control

The integration of renewable resources via power electronic devices into the grid is one achievement of smart grids. Variable renewables introduce harmonics into the power system which can deteriorate the quality of power. Smart grids use automatic power factor correction (APFC) devices and active filters to improve the power factor and power quality. The Installed Automatic power factor correction devices are equipped with modern communication functions for regular reporting to the utility control center[17].

3.6. Outage Management

The smart grid has the Outage management system (OMS) which can enhance the reliability of the power systems by application of the grid smartness for operational benefits like power restoration, reliable and cost-effective services. This is technically achieved by incorporating AMI, DA, ICT and other smart devices in the smart grid power system [17]. Outage management can be realized by distribution transformer monitoring system (DTMS) and in addition fault passage indicators (FPI. In some typical installations, DTMS systems is equipped with oil sensors, palm sensors, CT and PT. The Distributed Transformer Monitoring System can measure all phase current loadings, transformer oil levels and temperatures of DT. [17].

3.7. Loss detection

The use of smart meters to collect, compute, store, and transfer energy data to control center occurs at constant intervals of say 30 minutes. Power losses can be determined by comparing the energy data at different nodes and DT terminals, power. This enables quick measures to restore power to consumers [17]

3.8. Tamper analysis

Tampering of meters includes deviation from defined limits some fault or malpractice or damage on the metering system. Smart meters are designed in a way that that they send a signal the server and information to all parties concerned in the event of tampering in the form of SMS and e-mail and SMS alerts. Examples of t tampering cases, include over-current, terminal cover open and flow of current through the earth. Tamper alerts facilitate quick and specific response by authorities from the utility company. Through tampering cases, consumers may be drawing current than the limit, the meter may change locations without prior information or authority, the meter itself may be faulty hence malfunction. Other tempering cases include bypassing the meter and connecting undesirable loads[17].

3.9. Better Reliability

Reliability of a power system depends on customer needs and is measured as ability to meet customer needs. Therefore, a reliable power system implies having a flaw less and error less system continuously

supplying power to consumers. This is achieved in Smart Grid by ability to detect faults and self-healing potential of the system. The limitation of the conventional grids is with regards to interaction of renewable resources, support of micro grid and demand response. Smart Grids can monitor and all information and data and can establish system reliability. It is possible to monitor hybrid generation and management of the grid remotely which improves reliability. Smart grids make use of technologies like Dynamic Stochastic Optimal Power Flow (DSOPF) which make it possible to estimate and optimize power flow in the system. Therefore Smart Grids can improve system reliability through enhanced metering and communication[21].

3.10. Demand Side Management

Demand side management refers to programs and measures that can be used to influence consumers to balance their consumption and generation capacity of the utility [18]. Demand-side management is a direct effect and benefit of smart grid systems whose key objective is to allow the utilities to manage consumer loads. An important feature of demand side management is development of incentives for smart customers to modify their temporal use of power for reducing peak loads. Demand side management is strongly connected to demand response models, as programs that seek to shape the demand and supply to achieve an efficient power system. Interconnection of consumers, micro grids, electric cars, as well as utility companies can only be made possible by means of efficient and effective demand-side management [22] Demand side management is categorized into two main parts: namely energy efficiency and demand response.

3.10.1. Energy efficiency

Energy efficiency refers to the use of less energy economically to provide same or better services to customers[18]. Energy efficiency is important as it ensures sustainable use of energy resources by reducing a country's dependence on imported and expensive energy resources and serves to increase the awareness on environmental challenges which is a key requirement for sustainable development l[23]. Use of smart grid technologies helps in dealing with intermittent power and the low power system utilization efficiency. Smart grid techniques increase the amount of intermittent renewable generation in power system, by increasing the capacity of grid-connected clean energy like solar energy, wind energy and photovoltaic system while at the same time promotes energy saving in power system. Therefore smart grids improve the power system efficiency by improving the utilization efficiency and the power consuming efficiency of the power systems[24].

3.10.2. Demand response (DR)

Demand response refers to the change in electricity consumption using the demand-side resources away from the normal consumption patterns as a result of response to applied changes in electricity price over time, or as a result of application of incentive payments that are meant to motivate electricity price reduction meant to avoid the system reliability from being jeopardized[18]. Demand response is the ability of residential, commercial, and industrial sectors to modify energy consuming models in response to variations [25]. Demand response plays a very important role in peak shaving to balance generation and consumption. There are various demand response techniques that can be adopted to shave peak load e.g., incentive based direct load control programs through lower pricing or coupons [18].

The two-way communication provided by smart grids enable consumers to interact with the grid and other stakeholder which provides an opportunity a more economical use of grid power and hence higher efficiency and reduced peak time stress by shifting load and self-generation. Many demands side management options focus or rely on adequate communication between utility company and end users, a facility that is provided by smart grids. With further evolution, scheduling of consumption by end users will enable the distribution system to schedule resources based on requirement. The system also provides financial incentives by scheduling consumer needs[21].

Demand side management (DSM) is an important feature of smart power grids that can be defined as a set of techniques applied to modify the electricity consumption pattern by end users. Demand side management methods motivate consumers to optimize energy consumption and reduce energy costs and improve efficiency. The benefit to consumers is to reduce electricity energy bills but energy systems or utilities benefit through demand shifting from peak to non-peak hours. The DSM actions are applied in smart meter management to control the load profile of the of consumers to realize efficient utilization of power plants. The Smart grids overcome support help address challenges of conventional electricity gird through support

for new concepts and technologies like, renewable energy resources, distributed power generation (DG), smart meters, and energy storage [26]

Smart grid facilities have also led to the development of smart devices which have ability to communicate with the grid and make the consumer or facility more autonomous through effective and efficient use of power or energy resources. Smart appliances can shift demand of household electricity to off-peak or low-price period. Which saves on cost of power for the consumer. Household appliances can also be remotely operated by means networking protocols like 'ZigBee' which provide a solution to have a wireless control. These protocols facilitate communication and coordinate with all the stakeholders in the energy management system thus they provide optimal solution to the use[21]

The smart grids are of significant benefits to the Retail Electricity providers (REPS) who can make us of demand response programs. REPS fill the space between wholesale electricity markets and final consumers. REPS use forward contracts and can purchase part of the consumer demand through the pool market. The retail electricity providers face financial risks from factors like volatile loads, price variations, and actions of generating companies with market implications. However, REPS can manage these risks by employing demand response programs. For example, reps can propose selling price based on fixed tariffs, time-of-use price, or actual time price during the contract period. Power end users can shield themselves against financial risks by long-term contracts with REPs. Therefore, REPs can apply a blend of methods to control the financial risks from wholesale markets by means of well-designed demand response program (DRP) [25].

To implement demand response, it is necessary for consumers to have smart meters. Demand response plans can be exploited by retail electricity providers as an alternative allowed through smart technology to enhance the anticipated benefits of varying demand. Smart grids provide intelligent technologies in grids and home energy management systems, for moderation of financial risks. REPs can also use distributed generation and ESS (energy storage system) they possess to manage costs and financial risks and these resources can effectively be managed smart grid systems[25].

3.11. Decentralised Generation

Decentralization of generation has generated global interest in the development of reliable and sustainable electric power systems as a strategy to use more local renewable and alternative sources of energy. In addition to reducing stress and loss in transmission , it reduces transmission and distribution losses [22, 27]. Decentralized generation uses different local energy sources to meet the demand of local electricity demand [22]. The integration and interconnection of distributed energy sources to the grid is challenging because traditional power systems are not usually designed to incorporate energy storage at distribution level[22, 27]. Another challenge with decentralized generation is that different sources have different characteristics hence a challenge on stability of a power system upon integration for example fuel cells and micro turbines large scale wind turbines and solar panels present different characteristics and hence impacts on the grid. Therefore there is need for clear definition of standards and procedures for integration of different distributed energy sources in distributed systems[22]. . Distributed generation helps to address twin challenges of generation fluctuations and huge land requirements associated with wind and solar energy resources [27-30].

Several recent advances in energy technologies and grid infrastructures have increased the interest in the use of distributed generation (DG) resources for grid electricity generation. The exploitation of distributed generation (DG) for grid electricity subject to technical constraints to extend distribution and transmission networks to some areas as well as the deregulation of the electric power sector. There are many benefits of distributed generation depending on the characteristics of the sources like photovoltaic (PV), diesel engines, wind power systems, type, and characteristics of the loads, availably and access of local renewable resources and power grid network configuration. The benefits can be technical, environmental, social, political, and economic benefits like line-loss reduction, system reliability improvement, local revenue, employment and economic benefits and reduction in environmental pollution. The various benefits can be optimized by optimal sizing, optimal location, as well as optimal configurations [31]

3.12. Smart Micro-grids

Micro grids are defined as electrical networks with ability to operate in isolated mode or grid-connected mode and have their storage units, whose size and capacity depend upon the extent of integrated distributed generation[32]. A micro grid is a group of localized generators, loads and storage devices, and loads which can play an important role in the context of the smart grid because they can be integrated into the main grid and can also supply loads connected during islanding situation[33]. Micro grids are linked to distributed generation (DG) which has become important because of growing interest in reliable and sustainable energy supply based on more renewable and alternative sources of energy with the objective of reducing stress and losses in power systems. The objective of decentralized generation is to meet local electricity demand by different energy sources in the power system. This is achieved by development of micro grids which constituted a controlled system of loads and distributed energy sources meant to supply power to the local neighborhood[22]. A micro grid can be said to be a smart power network designed to operate independently from the main or central grid but can as well be synchronized to the main power grid besides having ability to operate autonomously. Micro grids supply energy obtained by means of distributed energy resources (DERs) to nearby consumers. It is therefore a local form of energy. Micro grids have emerged as the power system of the future with significant ongoing improvement. Several demand side management programs can as well be implemented in micro grids for energy management [26].The U.S. Department of Energy defines a micro grid as "a group of interconnected loads and distributed energy resources (DERs) that have well defined electrical boundaries that can operate as a single controllable system within the grid and used to connect and disconnect from the bigger or main grid hence can operate in both grid-connected and island modes"[22]. A distributed energy system qualifies as a micro grid if it obeys the three criteria that includes having own electrical boundary, have a main controller for the subsystem and have power generation capacity that is higher than peak load and additionally can operate in island mode. Therefore a micro grid has capacity to supply enough power in island mode but is still connected to the main or wider grid[34].

The concept of a micro grid is a result of the proliferation of distributed resource (DR) in the form of distributed generation (DG), or distributed storage (DS), or a combination/hybrid of distributed generation and storage which can be operated in three modes namely grid connected mode, islanded or autonomous mode or between the two modes of grid and island modes. Micro grids are expected to have multiple generators and loads operating reliably and economically viable as operational power systems [35]. The sustainability of micro grids is significantly enhanced by the development of smart grids.

Micro grids are designed as small and autonomous subsets of the main electricity grid, which help reinforce the self-healing characteristics of smart grids[36]. Smartening of electricity grids by installation of intelligent systems and applications into the grid infrastructure improves their reliable, efficiency and capacity to integrate variable renewable sources of energy[28, 37]. The smart grid achieves operational efficiency by means of distributed monitoring and control, and energy management. Use of micro grids with smart facilities bring renewable sources of energy into the mainstream, besides increasing efficiency and optimal use of grid facilities through demand response and peak shaving. Micro grids introduce resiliency and autonomous re-configurability in the electric power grid to guard against man-made and natural disasters [36] which is an ultimate benefit of smart grids.

Operationally, micro grids can be defined as low voltage intelligent distribution networks made up of distributed generators, energy storage devices and controllable loads which can be operated as interconnected power systems with the main power distribution grid. They can also be operated as islanded systems if the operate independently or are disconnected from the main power distributed grid. From the point of view of the main grid, micro grids are said to be controlled entities within a power system with ability to be operated as a single aggregated load and as small sources of electricity or ancillary services that support the main grid. To an electricity customer, a micro grid is viewed as a traditional low voltage (LV) local distribution network supplying electricity. Properly deployed micro grids improve local power system reliability, reduce emissions, support local voltage hence power quality, and reduce costs of power supply. Different micro grids may be unique in terms of source of power, type of load. Different micro grids could have different types of load and energy sources. Therefore micro grids can enable energy resource sharing [36]. Energy or power

sources for micro grids includes dies engines, micro or mini-turbines, fuel cells, wind turbines and photovoltaic sources.

A micro grid (MG) refers to a distributed energy resources having energy storage facilities and controllable loads and have ability to operate as a self-sufficient energy network. They help to improve reliability , resilience, flexibility, and accessibility renewable energy resources with ability to optimize and implement demand response programs [38]. Use of many micro grids in a power system with many energy sources leads to large amount of data to process and handle. The solution to these challenges is the use of an architecture with significant degree of intelligence across the grid for effective and efficient electricity distribution. With smart grids, the micro grids are not used as centralized units but instead they operate as individual systems connected to the main grid by means of individual intelligent nodes[21].

The main challenges facing micro grid design and operation is the use of many small generators with different capacities and characteristics, lack of a dominant and more reliable source of energy during island mode of operation and high demand or need for very quick response for electronically interfaced generator units which has adverse effect on voltage/angle stability if not properly managed. These critical challenges require a power management strategy (PMS) to facilitate a reliable or sound operation of a micro grid with multiple generators especially during the island operation. Compared to the large interconnected grid, a micro grid needs faster response of the power management strategy(PMS)[35]. Distributed energy sources interfacing with a micro grid can be achieved by use of rotating machines or electrical coupling using power electronic converters that provide coupling media with the main or host system[22]. The converters are connected parallel via a micro grid. Circulating currents are prevented using droop control methods to prevent circulating currents among the converters without critical communication between them. However, the main challenge of droop control method load-dependent frequency and amplitude deviations which can be solved by installation of a secondary controller, in the central control of the micro grid[22].

The role of the PMS in a micro grid is to assign real and reactive power references for generator units, quick response to disturbances and transients and establish the required power generation set points for all the generator sets and provide a means of resynchronization of the main grid and the micro grid [35]. Since PMS is a function of a smart grid, it is demonstrated that the development and harmonious operation of micro grids is dependent on the level of smartness of the power systems involved. The various technical and management experienced by micro grids can be solved by application of smart grid components like introducing smart technologies like energy storage devices, use of advanced metering infrastructure (AMI), application of smart appliances, integration of computational intelligence, application of demand response management, and the Internet of Things (IoT) in operation of micro grids[32].

3.13. Integration of Renewable Resources

Renewable energy sources particularly wind is solar are huge but variable and intermittent making exploitation to meet the demand difficult. Electricity from renewable sources can from solar, wind, battery storage devices can meet the growing electricity demand and reduce emissions with the right technology in place. The ideal location of these renewable resources may be far from a functional grid for transmission and distribution making exploitation impossible for conventional grid delivery. Under such circumstances, micro grids become the best option to distribute renewable electricity from these widely distributed sites that can be joined together to form a bigger electricity distribution network [21]. Whereas the wind does not blow every time and the sun does not shine always, providing information on electricity demand and weather forecasts made possible by use of smart grids, helps the grid operators to plan for the integration weather dependent renewable energy to the grid and hence stabilize or balance the electricity networks. [39].

The grid needs conventional back up power and huge energy storage so as it can accommodate more renewable energy would need large quantities of conventional back up power and huge energy storage. These is necessary to accommodate the natural variations and intermittence of energy supply in terms of time of day, and season.[40]

To realize commercialization and commercialization and large-scale use, of renewable energy systems like solar and wind,

needs to address issues related to design and sizing of the system, effective and suitable technical and financial models, balance electricity price for integrating the renewable sources. Balance electricity price for integrating PV in a smart grid system dealing with challenges of using variable renewable systems are limited for several countries[40]. The development of power electronics to handle variable electric power by fast semiconductor switching using IGBTs has a significant role to play in the integration of renewable energy sources. The challenge of power electronic circuits is that they may cause harmonics in the power system. As a solution, FACTs devices which include static synchronous compensator (STATCOM), static series synchronous compensator (SSSC) and unified power flow controller (UPFC) can help to improve the stability and reliability of the grid having renewable energy sources. These systems provide filter circuits which mitigate the harmonics injected in the grid caused by power electronics circuits. Additionally, use of real-time computer controllers equipped with advanced and complex algorithms facilitate maximum extraction of renewable energy power and reduce fluctuation in the renewable energy generation. besides protecting storage devices like battery from over charging which enhances the storage battery life. Renewable energy generation fluctuations can also be adopting distributed energy generation from a larger geographical area in small power plant instead of large power plant in few places. The challenge of huge land needs can also be taken care of by adopting distributed generation from renewable energy resources[27].

3.14. Reduce Transmission and Distribution Losses

The purpose of electricity grids is to transport electricity to consumer's point by performing four critical activities. These activities are support generation, transmission, distribution and retailing of electricity. The traditional power system involves use of large power plants to generate electricity located several kilometres away from consumers and hence has to be delivered to distribution networks vial long transmission networks where transmission losses are experienced. In modern grids electricity is produced in small power plants connected to the distribution grid, in an arrangement referred to as distributed generation (DG). In distribution networks, power is delivered to consumers via low voltage) LV) distribution lines up to the electricity or energy meters [41, 42].. Retailing of power is in charge of or responsible for electricity billing. Energy is always lost through the components of the power systems like cables, electric transformers, etc.[41]. The shorter the length of travel and resistance, the less the power losses.

Power transmission and distribution losses refers to deviations between electricity generated and electricity delivered to consumers, for reasons that are technical and nontechnical in nature. For many reasons, different countries have different levels of transmission and distribution losses[43]. The global average for transmission and distribution losses is about 10%, Sub-Saharan Africa (SS) has average of 18% while some countries have extremely high losses e.g., Togo has about 29% and Congo has average of 33%. The electricity transmission and distribution losses have increase the demand on demand on power plants to meet the losses in power which has a significant impact on the environment due to increased emissions associated with the increased demand on generation[43]. Consumption out of the meter is another common loss classified as non-technical energy losses (NTLs), which affects for total electricity demand, electricity quality and overall income of the power system[41].

The main reasons for losses in power distribution are theft and a weak electricity grid. Theft can be reduced by positive interaction between all stakeholders which can facilitate awareness about the benefits and motivating the consumers to be active participants where they see benefits from connecting to the grid as well as use of modern technology and infrastructure. Smart grid Infrastructure and devices like energy meters in every bus for power system, monitoring can help the authorities to detect and control electricity theft.[27]. Therefore, smartening of the electricity grid will reduce transmission and distribution losses leading to efficiency and reduced avoidable generation as well as related emissions and environmental pollution.

Since electricity consumption by end users varies over the day, consumption has direct implications on electricity losses. Since demand-side management seeks to reduce peak hour power consumption, the effect is to reduce network congestion and system losses. From the perspective of generation, the distributed generation modifies the traditional, unidirectional, downward flows in electricity system and so it directly affects power transmission and distribution losses as energy

is produced at voltage network which is close to the consumers[41].

3.15. Smart Homes and Internet of Things (IoT)

Advances in technology have changed the way energy is produced, stored, saved and consumed laying the ground for the deployment of smart energy systems. Incorporating the Internet of Things sensors, digitization, distributed generation, micro grids, and automation is creating a new smart energy ecosystem like smart grids. .Just like the internet facilitates information flow and data interchange between computers connected to the same network, the smart grid is also powered by a web of interconnected electric grid devices[12].

In general, the IoT refers to a collection of internet-enabled devices that facilitate the collection of data and information, data pipelines, and the real-time information transmission between devices and other people. [44, 45]. Therefore, the Internet of Things (IoT) is a connection of people and things at any place and time, by use of any network and any service. It is further said to be a global network infrastructure of Internet-enabled entities with web services. The smart grid is a data communications network which is integrated with the power grid to collect and analyze data that are acquired from transmission lines, distribution substations, and consumers [46]. Smart grids are a typical application of Internet of things (IoT) technology in electricity sector and if well implemented can resolve several challenges facing the traditional grids like security of supply, outages, high greenhouse gas emissions, and other issues. [44, 45].

The facilities that enable the operation of Internet of Things (IoT) include sensors, actuators, RFID tags or any device that requires communicating interface and a computing ability, into the Internet. It is now possible to access, manage and communicate through the internet -based protocol like IPv6, UDP/TCP, HTTP, and others for objects like fridges, heaters, windows, switches, washing-machine, etc. For devices compliant with the IEEE 802.15.4 standard, the IETF (Internet Engineering Task Forces), several protocols are proposed for their efficient integration and at different layer to the Internet. These protocols include Constrained Application Protocol (CoAP) which is a specialized web transfer protocol used with constrained nodes and constrained networks; Routing Protocol for Low-Power and Lossy Network (RPL), and IPv6 over Low Power Wireless Personal Area Networks (6LowPAN) which is an adaption layer used to support the IPv6 protocol on IEEE 802.15.4 networks. For functions that cannot support internet protocol (IP) or functions that cannot be updated to support the internet protocol, gateways where proprietary non-IP stack protocols like Zigbee v1, HART, Z-Wave, etc., are translated to/from IP stack protocols can be used but are expensive [47].

Smart grids can use wireless sensor networks (WSNs) unlike the traditional communication technologies since it is cheaper, fast to deploy, has high flexibility, and has aggregated intelligence via parallel processing capabilities[12, 48]. The internet of Things in smart grids refers to the application of WSNs, smart meters, actuators and components with information and communication technology (ICT). The main limitation or challenge with integration of the IoT technology within the smart power grid introduces the cost of large data processing. The data includes end users load demand, power lines faults, network's components status, scheduling energy consumption, forecast conditions, advanced metering records, outage management records, and enterprise assets. Smart grid utility companies should be equipped with software and hardware capabilities to efficiently handle data collected[48].

The internet of things applies bidirectional flow of energy and information within the smart grid to get deeper insights on current and future/predicted actions whose aim is to improve energy efficiency and reduce overall cost. Big data technologies must be adopted by the smart grids for accurate monitoring and scheduling, information from the grid within short intervals[47, 48]. The ICT infrastructure should have high degree of reliability to avail available data for information extraction needed to perform critical functions like fault detection and fault resolution. Security is an important requirement for the ICT to avoid or limit failures from cyberattacks or by combined attacks to the grid and ICT infrastructures. It is necessary to guarantee high reliability for the health and industrial systems.[48, 49]

The internet of things (IoT) is used to describe common items like medical wearables, housewares, and equipment the

monitor users' physical condition, automobiles and tracking devices among others that are connected to the internet and identifiable by other devices in the system. Through internet of things, it is possible to collect data from connected devices and products and determine the usage by and use the same in energy planning and market campaigns. At industrial scale, farmers can apply IoT sensors into fields to monitor and hence control soil parameters like nutrients or fertilizer use and needs[50]. The Internet of Things (loT), Internet of Everything (loE) and Internet of Nano Things are new approaches that incorporate the internet into personal, professional, and societal life. 'Internet of Things' or 'Internet of Objects' represent electronic or electrical devices that vary in size and ability and are connected to the internet in a way that goes beyond mere machine-to-machine communication. Through internet of things, one can access information any time wherever you are connecting devices via real-time information generated by the interconnected devices[51]. Smart homes are an important segment that has significantly been affected by the Internet of Things. Smart home-Internet of Things is a new domain created when smart homes are connected to the IoT [52]. The main benefits of smart homes energy efficiency and comfortable living. Smart homes are created by integrating ICTs and energy technologies for home or end user applications.

A smart home refers to a residential environment where information and communication technologies, are applied by the resident for convenience, security, entertainment, and comfort needs. This enables home owners to employ well-designed management functions for optimal control and maintenance of their homes[52].Through integration of recent and modern Information and Communication technologies (ICT) and energy technologies in the housing environment gives rise to new applications and services. Examples of technologies in smart homes include ubiquitous computing technologies, that make it possible to connect objects anywhere and at any time, and apply small sensors to provide information to entire network systems making users part of the network [53]. Therefore, users become part of a system of interconnected computing machines sharing information via the network without traditional forms of communication which is the main concept behind the IoT. Therefore, based on the IoT environment, equipment or home users can interact with objects or devices and services in smart homes[52, 54].

Internets of Things (IoT) uses computation and communication technology to make life easier, automatic and handy by exploiting the internet revolution. The development of the smart grid and its components created need for a technology to interact these components efficiently, reliably and in a smarter way. These new technologies have however come with serious security concerns like data tampering, impersonation, overdoing, privacy, authorization, and cyber-attack [32]. These implies that the IoT base smart grid needs services like authentication, confidentiality, user's privacy, and data integrity to avoid any security risk [32]. The connectivity brought about by the IoT enhances customer experience and efficiency. This facilitates flexibility and easy interaction with the grid leading to cost reduction incurred by diagnostics and meter reading. Therefore the internet of things makes the smart grid smarter[21].

With the Internet of Things (IoT), the Internet has evolved from connecting machines and peoples to connect (smart) objects/things. Therefore, the IoT communications is an evolution of M2M communications. The objects in the IoT can be anything/device/entity equipped/embedded with computation, storage, and communication capabilities with different capacities in terms of sensors, mobile phones, actuators, laptops, printers, computers, car, fridge, ovens among others. Smart objects are connected through proprietary non-IP solutions in different applications like Zigbee, HART/ Wireless HART, Z-Wave. Additionally , IoT aims at connecting objects or devices on a larger scale using IP-based solutions like IP, TCP/UDP, either directly or through gateways if at all if IP support is not possible as long as they allow them to communicate or interact with any other communicating party over or through the Internet[47]

The IoT facilitates smart energy solutions needed to strengthen smart grids through functions like;

i.) Provision of real-time alerts with respect to meter, grid damage or system outages.
ii.) Modification of supply and price based on data insights Power quality monitoring and control.

iii.) Gathering information necessary for system optimization e.g. factors like tilt angle and direction of rotation for wind power system.
iv.) Greater energy savings in the system.
v.) Software installation and continuous updates to keep the system safe and functional[45].
vi.) Enhancing the predictive analysis by collection and analysis of data while at the same time varying variables like the weather, and individual panel performance in solar systems.
vii.) Attaching monitors to individual solar panels, wind turbines and other equipment providing feedback on performance to streamline maintenance
viii.) Theft detection and prevention into the 21st century

The Internet of Things (IoT) solutions many and may be unique to specific power system. It functions through ability to monitor, important and relevant indicators to the power system like availability of energy and consumption, in real time basis. Other than monitoring, control is another key feature of the Internet of Things (IoT) especially ability to remotely download and as well as install critical software updates through the cloud and management of vital asset data from any location. The IoT allows businesses access real-time alerts on deterioration for timely repairs to crucial important infrastructure which improves the overall system efficiency[12]. The main risk of the IoT in smart grids is that it can lead to disasters as it becomes exposed to cyber-attacks, because its monitoring and control can be done over standard internet-based protocols and solutions and also can rely on public communication facilities which can cause financial loses to the utility and damage connected assets [68].

3.16. Electrification of Transport and Smart Charging

Electric vehicles introduce both opportunities and challenges for the power systems. Peak energy demand can be significantly increased id many electric vehicles are charged at the same time or uncontrollable causing overloading and power loss. The solution is to employ electric vehicles as dynamic loads used to offer balancing services to the power system. For full realization of the capability of electric vehicles as a flexible or dynamic load, there is need to introduce smart charging procedures which can be executed of the smart grid power system[55]. The transport industry particularly cars is one of the biggest contributors of greenhouse gas emission, hence the need to shift to the use of electric vehicles. Electric vehicles use the chemical energy stored batteries that can be recharged for use in vehicle propulsion and powering other automotive systems[16, 56, 57]. Although various fuels and technologies are under development for the transport sector, electric vehicles represent one of the most feasible options other than using grid electricity for charging, electric vehicles have potential to act as independent distributed energy sources for the grid[49]. Electric vehicles offer an efficient opportunity to reduce carbon emissions in the transport sector and hence mitigate climate change. The share of electric vehicles in transport is increasing globally with Europe having over 15% sales share by mid-2021[58-60].

Vehicle batteries can be charged by means of the grid by plugging the vehicles to the grid and by means of regenerative braking. Electric vehicles can be classified based on charging typologies. They are battery electric vehicles (BEV), plugin vehicles (PHEV), Hybrid Electric Vehicles (HEV) and Fuel cell Electric Vehicles (FCEV)[49]. The main motivation for electrification of transport sector is that it accounts for about 30% of world energy consumption and 72% of global oil demand making electric vehicles a key avenue for greenhouse gas emissions control and the attainment of the global climate targets [49]. The main challenges facing electric vehicles include grid infrastructure, the communication, and control[21, 61]. Electric vehicles promise to play a key role globally in the energy transition because of growing concern on fossil fuel depletion and related emissions. Since vehicle battery energy is not fully used each day, they have a potential to provide peak shaving service [18]. Smart charging can be centrally done through aggregators or can be decentralized using decentralized control structures. Aggregators are used to achieve optimal scheduling of each electric vehicle (EV). In decentralized charging system, electric vehicles choose own charging methods without contacting the central controller or other linked electric vehicles. Smart charging using both centralized and decentralized systems can effectively reduce energy costs and prevent the overloading of grid components by shifting peak demand[32]

The main challenges facing electrification of transport and application in peak shaving are.

i.) The electric vehicles can only deliver power to the grid when the vehicle is packed, and they are currently not widely deployed.
ii.) It is not practical for a single vehicle to meet peak load demand alone hence many vehicles and infrastructure has to be deployed and controlled together by a third party.
iii.) It is a technical challenge to synchronise the charging and discharging of a multitude of electric vehicles simultaneously
iv.) Lack of critical infrastructure for grid integration of electric vehicles especially in highly urbanised regions[18].
v.) Charging can cause direct stress to the grid as it is often done at home, commercial and public ideally designed for other applications[21, 61].

However, when parked and plugged into power grid, electric vehicles absorb energy and store it in batteries. By provision of two-way power flow capability, these vehicles can also supply power back to the electricity grid in a concept popularly known as V2G (Vehicle to Grid) concept[61].

Since smart grids are equipped with advanced technologies for communication, metering and control, they offer electric vehicles the ability to charge and act as a flexible energy source for the grid[62]. Therefore if well planned and with adherence to standards set, electric vehicles charging can improve power quality and the performance [61, 62]. An important feature or capability of smart grids is accommodation of support of electric vehicle services making them an important tool in the energy transition[56]. Electrification of transportation is becoming a reality with advances in battery storage technology and the development of the smart grids. The main motivation is that the transport sector accounts for about 30% of world energy consumption and 72% of global oil demand making electric vehicles a key avenue for greenhouse gas emissions control and the attainment of the global climate targets [49, 63-65].

Electric vehicles have continued to increase globally with 10 million electric cars by the end of the year 2020. Registration of electric cars increased by 41% in 2020, even in the face of the global pandemic-related global economic downturn and reduction in car sales by 16%[66]. About 3 million electric accounting for a 4.6% share of global sales were realized with Europe overtaking China as the world's largest market for electric vehicle (EV). Electric bus and truck increased in numbers globally to reach 600 000 and 31 000 respectively[66, 67]. The global share of electric vehicles is increasing with sales rising to 15% of sales in Europe mid 2021 mainly consisting of plug-in hybrid electric vehicles (PHEV) and the battery electric vehicles (BEV) [58].

Electrification of transportation is becoming a reality with advances in battery storage technology and the development of the smart grids. Therefore, a key requirement for successful energy transition via the electrification of transportation sector is the development of the smart grid. The exact amount of actual number of emissions reductions due to electrification of transport vehicles dependent on when and where drivers charge the vehicles and composition of electricity mix[12, 16, 49].

3.17. Smart Cities and streetlight automation

Smart devices are key to efficient energy management and optimization while the intelligent application of smart grid is a key requirement for the establishment of smart cities.

Smart cities have been identified as the ultimate solution to complex challenges facing urban centers. Cities are important entities because it is estimated that by the year 2050, about 70% of the world population will be living in urban centers or cities[34]. There is growing interest in linking in linking interfacing items via networks. The objective of smartening of devices is to enable sharing of information or access with other devices to facilitate smart decisions with available internet and communication infrastructures. Smartness of a city refers to the desire of improve the quality of life in a city and living standards of the city residents in terms of information use and communications technology (ICT) capabilities and applications, although use of ICT per se does not constitute a smart city [34]. The main challenges facing urbanization which should be resolved are shortage of resources, energy management, waste management, obsolete or aging of existing infrastructures, environmental and human health problems among others [34] .

Smart grid technologies are playing an important role in the urban low-carbon

transitions. As they are seen as clean innovations and indispensable strategy to realize the mass integration of renewable energies in cities[68]. Smart grid solutions have become useful in the development of smart cities. As the Growing populations has created jam-packed cities. As technology continues to advance, the concept of a smart city is quite appealing. To realize the dream of a smart city, require advanced power networks that can handle the plethora of information transmission requirements[69]. A smart city can be defined as a city that takes advantage of computers, information, and communication technology to generate interactive and responsive infrastructural systems and public services. The goal of a smart city is to use critical data and information to ensure efficient delivery of utilities, like water, public road transport, power supply, and other consumer services. .Therefore smart electricity solutions form the basis of smart city development and transformation [68, 69]. According to [34]. The smart city concept elevates the intelligence of the city by connecting the physical environment, social, business, and ICT infrastructure for of the city and balances the demand and supply of different functionalities[34, 70].

Smart cities like Berlin are increasingly relying on high-tech innovation to deal with urban problems like transport congestion, people's participation in governance, and environmental management. City administrations are putting in place measures and strategies like opening urban laboratories, creating innovation spaces and other sites for technological experimentation to attract ICT companies and compete in the race for digital modernization and progress. Smart urbanization is rapidly being developed in many countries and major cities globally in both developed and developing countries[68, 69].

Cities around the world spent significant energy resources on street lighting and traffic control. Use of smart grids can enhance efficiency, reliability and hence reduce the energy consumption on street lighting. This can be achieved by seamless connection to different supplier's sources, use of on/off timing control facilities equipped with ability to synchronize with an astronomical clock. Others are use of voltage dimming facility that responds to time-setting and traffic condition. Additionally, each lamp can be facilitated with elements for power factor improvement as well as individual lamp control. These combination leads to significant saving in energy costs. Installation of street light automation (SLA) systems can lead to energy savings by as much as 50% based on experience from similar programs[17].

Smart power grids are adding value to the concept of smart cities by enabling the following services and products to urban dwellers.

i.) Efficient power transmission and distribution within cities
ii.) Better security measures and infrastructure like affordable street lighting
iii.) Faster restoration of electricity whenever disruptions are experienced
iv.) Efficient and cost-effective service delivery through cost reduction and wastage minimisation
v.) Reduced electricity tariffs and lower energy costs
vi.) High integration of urban renewable energy sources like solar power from rooftops

The concept of smart cities is realised by use digital technologies like the Internet of Things (IoT), artificial intelligence (AI), automation, and 5G, that facilitate a two-way communication between various utilities in a smart city and the dwellers. These technologies are already in use by industries, like health care. The development of smart cities relies on key power key electricity grid technologies like electric cars, distributed energy or electricity storage, smart meters, smart appliances, smart buildings, and decentralised generation. With global smart grid technology market expected to reach $55.9 billion by 2026, it is evident that smart grid technology has an important socioeconomic and technical role to place in the smart cities development [34, 69].

3.18. Grid Integrated Energy Storage

Energy storage is a very important component of smart grids because if renewable energy is not extensively stored, its usage becomes less feasible. The main benefit of smart grids is ability to balance the variable and intermittent renewable sources of energy whose performance in balancing is enhanced by storage of some quantities of energy by the grid. Storage is an important component of a modern grid with Japan having 15% of stored energy for the grid, Germany 10%, and the US

about 2% of grid capacity. Energy storage is an important function of demand side management, with power storage being engaged in the speed of feedback, spinning reserve and frequency adjustment. Energy storage in various forms like compressed air, pumped hydro, battery, super capacitors, and flywheels have wide engineering applications and can seamlessly be integrated in smart power grids. Electric springs are examples of innovative equipment that have been developed and proved effective in supporting smart grids by considerable absorption of renewables by facilitating the harmonizing of demand-supply [46]. According to [71] adding compressed air energy storage (CAES) to multi-generation systems can improve the sustainability and use of renewables when used with smart grids.

Energy storage technologies have significant potential role to play in achieving load leveling, like matching intermittent source of renewable energy with customer demand as well as storage of excess power for peak time use or when the variable resource is not available. Pumped hydro storage and compressed air energy storage are notable examples of mechanical methods of energy storage-based that can be used to supply peak time power. CAES is an efficient storage system that can regenerate up to 80% of the electricity production need to support variable renewable (RES) based power plants. The energy storage systems are used to store excess energy during off-peak when power is cheap and from clean sources to compress the air and pump in umped storage for use in peak time when demand and price of power is high. For pumped storage, the water that was pumped upstream is allowed to run through turbines to generate clean power while for CAES, high-pressure air stored in underground reservoir or tank is released to drive the turbine, and supply power for peak time use or when the renewable sources decline. This is the same for pumped storage power plants [70, 71].

Besides the mechanical storage methods, other storage methods are battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) which can be configured as dispersed energy storage for use in vehicle-to-building (V2B) and vehicle to grid (V2G) operating mode where stored energy in batteries is used to supply power during the peak or when renewables decline in supply. With smart grids and dynamic energy storage/management by means of V2B, V2G, and applying BEVs and PHEVs via peak load shifting, energy expenses can be controlled why demand side management can be enhanced by optimum use of the storage facilities whose functionalities can be significantly enhanced by use of smart grid technologies and products. the purchase price of the electricity for the client and vehicle owner would decrease. Technological advances in battery story and development of smart grids will ultimately make storage as a reliable source of grid electricity and hence a key strategy in the energy transition[34, 56].

3.19. Smart Grids and Industry 4.0 and Industry 5.0 Applications

The first industrial evolution was ushered in by the invention of the steam engine in the 18th century which significantly transformed the industry and transport sector while the introduction of electricity led to the second industrial revolution. These two revolutions paved way for mass production and mechanization of functions for the first time, and these drove social change because of urbanization[50, 72].

The third industrial revolution was ushered in by electronics, information technology systems and industrial automation [73]. The third industrial revolution was a result of wider use of information technology and electronics products in industry. This revolution began in the 1950s and it saw the emergence of computers and digital technology. This further accelerated automation of manufacturing and the disruption of service industries like banking, communication and energy[50, 72].

The Fourth Industrial Revolution (4IR) or Industry 4.0 is identified with 21st century rapid transformation of technology, industries, and societal patterns as well as processes and systems because of growing interconnectivity and smart automation. The term was popularized by Klaus Schwab in 2015, who was the founder and executive Chairman of the World Economic Forum . He asserted that changes realized are more than just improvements to efficiency and express a shift in industrial capitalism. The fourth industrial revolution is a result of advances in internet of Things (IoT) and cyber-physical systems (CPS). It is characterized by application of emerging technologies that revolutionize the production and operation systems from machine dominant manufacturing to digital dominated manufacturing and operations. It

can be said to be an integration of technologies such as CPS, IoT, Big Data and Cloud manufacturing. In addition, industry 4.0 is also concerned with the whole concept of data and resource acquisition, sharing, use, and organization that leads to faster, cheaper, more effective, and more sustainable product and service deliver [50, 72].

The overall result of 4IR is growth in automation, better communication, self-monitoring, and application of smart machines which have ability to analyze and diagnose issues without with little or no human intervention. The revolution also represents a social, political, and economic shift from the digital age of the late 1990s and early 2000s to a connectivity embedded era distinguished by the omni-use and commonness of technological use throughout society. The fourth industrial revolution technologies have potential to connect billions of people globally to the web and significantly improve the efficiency of doing business [73].

Through automation, systems are augmented with wireless connectivity and sensors to use for monitoring and visualisation of the entire system and process functions as well as make autonomous decisions. With the use of wireless connectivity and the augmentation of machines will be greatly enhanced by the full roll out of the 5G which promise to provide faster response and near real time communication across systems[73].

Beyond industry 4.0. is the industry 5.0 which involves the wider use of robots and smart machines which allows humans to work better, efficiently, and smarter. The industry 5.0 will make the factories working laces for creative people to work and create a more personalised and human experience for the workers and customers through connecting man and machines. It is projected that Industry 5.0 will make it necessary for about 60% of logistics, manufacturing, and supply chains, mining, agriculture as well as oil and gas sectors employ chief robotics officers by 2025 [73]. The operation of smart grid technology places them between industry 4.0 and Industry 5.0. but with potential to transform to industry 5.0 technology as an intelligent man machine system with automated operation.

Industrial revolution in the 4th / Industry 4.0 is a new turning point in appropriate technologies applied in all fields and industries including power generation. In the energy sector, industry 4.0. requires that energy and power generation, transmission and distribution should be more efficient and of high reliability with application of next generation software and hardware resulting from the concept of the 4th industrial revolution[74]. The use of smart grids enable flexibility, reliability, clean energy systems that are sustainable and highly efficient. The main components of the intelligent energy network system that reciprocate with industry 4 are the Cyber-Physical System, M2M (machine to machine), the Internet of Things (IoT) which result in intensive application of technology at all levels in the power system. Industry 4.0/4 Industrial Revolution and smart grids commonalities include elements of optimization, systems automation, efficient use and management of energy, application of intelligent production, and use of the internet [74]. Therefore, the overall effect of application industry 4.0 principles in smart grids includes better system operation, higher energy efficiency, reduced costs, reduced greenhouse effect, reduced downtime with reduced human intervention, reduced loss/leakage rates, improved energy quality, effective management of generation and storage systems, intelligent meter reading and load management and real-time supply-demand management.

Smart Grids provide an intelligent infrastructure that has potential to transform power systems into more secure, efficient, reliable, flexible, and sustainable energy systems. The smart grids are equipped with smart devices and smart metering like sensors and sensor networks. They are installed at multiple places along the grid like transformer customer premises, substations. The sensors monitor the state and operational health of the grid infrastructure by monitoring various parameters like temperature, quality disturbances, and outage detection. This sensing functions enable control centers to receive accurate information about the actual condition of the grid[48].

3.20. V2X Technologies

V2X technologies refers to various technologies associated with grid connected vehicles like the Vehicle to Grid (V2G), vehicle to house (V2H), and vehicle to vehicle (V2V) technologies. V2G refers to an arrangement where electric vehicles are in are linked to the electricity grid to facilitate grid charging and discharge of batteries. In this case, the electric vehicles are referred to as grid-connected EVs (GEVs) [32, 75].. These

vehicles have a plug-in feature equipped with a bidirectional charger enabling the battery to draw energy from the grid to the battery and back. Other potential products and services related to V2G concept depending upon the discharging and charging ability of the GEVs and grid efficient and energy needs are vehicle-to-home (V2H), vehicle-to vehicle (V2V). These technologies will enable the vehicle to act as a variable load and source of distributed electricity for the grid. Extensive research is done and is still ongoing to optimize the performance and cost of the V2X technology to make it technically and economically viable[12, 32].

Peak demand occurs between 5 p.m. and 11 p.m. for most grids which is often a time when most private and public vehicles are parked at homes or stations. During this period, the vehicle to house (V2H) technology facilitates connection of parked l vehicles to an electricity distribution board of home to meet demand peak demand. During off peak hours, the same vehicle can be changed later from vehicle to grid or vehicle to house to grid to vehicle connection to have the batteries charged preferable by power from intermittent sources like rooftop solar PV. The V2G technology be used to have EVs may clustered via aggregator to offer grid power services like load leveling, voltage regulation, and peak shaving, at a lower cost and with less environmental impact. Therefore, smart grid technology deployment will enhance the operation and control of electric vehicles making them important energy transition facility[16, 32, 76].
[77].

4. SUMMARY, DISCUSSION AND RECOMMENDATIONS

4.1. Summary and discussion

Advances in smart grid technology present opportunities to efficiently meet the future energy needs by reducing carbon emission and increasing the integration of renewable energy resources in the electricity mix. The technology can improve power system reliability, quality, and efficiency of power delivery by introducing and facilitating positive consumer behavior in energy use. Significant potential exists for improvement and implementation of smart grid concept which is still under development and adoption and hence the need for government policies and measures to facilitate the implementation of smart grids globally. The capacity of the grid to absorb variable renewable sources of energy is achieved by grid smartening using intelligent systems. These intelligent systems improve reliability, efficiency, and capacity of the grid to deal with variability and intermittence. The use of micro grids as building blocks for smart grids increase access of renewable sources of energy into the mainstream power systems besides increasing efficiency and optimal use of grid facilities through demand response and peak shaving.

New approaches in grid operation, control, and maintenance ae needed to successfully accommodate high penetration of highly variable renewable and distributed energy resources. Other than variable sources, new types of loads like plug-in electric vehicles and vehicle-to-grid potential have huge potential for increased use with development of smart grid infrastructure. Therefore, smart grids enable the implementation of strategies to achieve energy and environment sustainability, and climate change control which makes smart grids very useful infrastructure to use in realisation of sustainable energy development. The use of Information Communication and Technology (ICT) in the form of digital and internet technology in electricity networks is a working strategy to realise low-carbon power systems by integration of the fluctuating renewable energy sources, improve conversion or generation efficiency by application of real-time coordination of energy flows, and improved power supply security by means of automatic grid reconfiguration and more active consumer participation in energy markets. The digital technology in power generation and supply within a smart grid system provides an opportunity better economic competitiveness through price competitiveness and high-tech infrastructural modernisation and the attraction and development of high-skilled, well-paying jobs while guaranteeing sustainable energy.

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 smart grid technology incorporates components of the intelligent energy network system which reciprocate with industry 4.0 namely, Cyber-Physical System, M2M (machine to machine), the Internet of Things (IoT) whose outcome is the application of technology at all levels in the in the electricity network. Industry 4.0/4 Industrial Revolution and smart grids commonalities include elements of optimization, systems automation, efficient use and management of energy, intelligent decisions, and use of the internet. The overall effect of application industry 4.0 principles in smart grids is better system operation, higher energy efficiency, reduced costs, reduced greenhouse effect, reduced downtime, reduced power losses, improved power quality, effective management of generation and storage systems which are key requirements for the energy transition.

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.

4.2. Applications of Smart grids

Energy sustainability and transformation is a global challenge which faces issues like wide demand supply gap, overreliance on fossil fuels, and low penetration of variable renewables. The smart grid has been identified as a potential solution in the smooth transition from traditional to modern smart energy systems [32]. They facilitate integration of all forms of electricity generation across the in the grid coverage. Smart grids can be used to optimize energy consumption because of their ability to integrate sources, direct and coordinate operations. throughout the entire energy supply chain. Smart grids can enable electricity consumers to realize financial savings and income through measures like flattening peaks and conversion of consumers to prosumers who not only consume power but also supply power in a two-way power flow process in a smart grid[12, 16, 56]. As a result, smart grids offer opportunities for new, energy-related services while making energy system more dynamic and improve security of electricity supply. Therefore smart grids have an important role to play in the global energy transition to renewable and low carbon energy sources [12, 75, 78].

There are various applications and features of smart grids which significantly make them superior compared to the traditional grid. These are summarized in table 7 below.

Table 7: Applications of smart grids

	Function	Application	Impact
1	NET metering	Electricity imports and export	Turns consumers of electricity to prosumers who are keen to be net exporters not importers
2	Time of Use (TOU) Metering	Enables variable pricing of power	Facilitates demand side management by demand shifting
3	Peak load shaving	Demand shifting which reduces maximum demand and cost.	Smart grids create flexibility and demand shifting leading to load management, peak shaving and energy saving by moving to off

			peak hours. The Peak load benefits all consumers and the utility operators by avoiding overloading of the system
4	Power quality improvement	Reliability and quality improvement. SGs are equipped with automatic power factor correction devices and modern communication functions for regular reporting to the utility control center	The grid intelligence, resilience, flexibility, and adaptability are enhanced by use of smart grids. Smart grids use automatic power factor correction (APFC) devices and active filters to improve the power factor and power quality.
5	Outage Management through self-healing and early detection	SG are equipped with Outage management system (OMS). The DTMS systems is equipped with oil sensors, palm sensors, CT and PT. which enable Distributed Transformer Monitoring System to detect and correct faults	The outage management system enhances the reliability of the power systems by application of the grid smartness for operational benefits like power restoration, reliable and cost-effective services with less manpower and hence costs
6	Loss detection which ensures timely action and low outage	This is made possible by use of smart meters to collect, compute, store, and transfer energy data to control center occurs at constant intervals. Power losses can be determined by comparing the energy data at different nodes and DT terminals, power	This enables quick measures to restore power to consumers immediately power loss is identified.
7	Improves power system reliability	This is achieved in Smart Grid by ability to detect faults and self-healing potential of the system. SG can monitor all information and data and can establish system reliability. Smart grids make use of technologies like Dynamic Stochastic Optimal Power Flow (DSOPF) which make it possible to estimate and optimize	Facilitates efficient monitoring of hybrid generation and management of the grid remotely which improves power reliability. power flow in the system. Therefore, Smart Grids can improve system reliability through enhanced metering and communication
8	Demand Side Management through participation of consumers	Demand response is the ability by consumers to modify energy consuming models in response to variations made possible by the two-way communication ability of smart grids.	Enable a more economical use of grid power and hence higher efficiency and reduced peak time stress by shifting load and self-generation. Demand response enables the distribution system to schedule resources based on requirement. The system also provides financial incentives by scheduling consumer needs.
9	Decentralised power generation.	Decentralized generation uses different local energy sources to meet the demand of local electricity demand by integrating various forms of locally available supplies including energy storage.	Leads to more use of renewable sources and hence emissions. Distributed generation also helps to address twin challenges of generation fluctuations and huge land requirements associated with wind and solar energy resources
10	Micro grids which are more resilient	Micro grids are small and autonomous subsets of the main electricity grid, which help reinforce the self-healing characteristics of smart grids and support decentralized generation	Micro grids supply energy obtained by means of distributed energy resources (DERs) to nearby consumers. Smart grid components can be used to fix issues facing traditional micro grids thus transforming them into smart micro grids by introducing smart technologies
11	Integration of Renewable Resources	Substitution of fossil fuel sources	More reliance on local resources hence lore energy security
12	Internet of things (IoT)	The internet of things enables access to information any time wherever you are connecting devices through real-time information	Helps to achieve optimal control and maintenance of home appliances by integrating recent and modern Information and Communication technologies (ICT) and energy technologies in the housing environment. These reduces energy cost and wasteful use of energy.
14	Smart charging Electrification of transport hence	Electric vehicles use the chemical energy stored batteries that can be recharged and used in vehicle	Smart charging can be centrally done through aggregators or can be decentralized using decentralized control structures. Smart

	reduced emissions	propulsion and supply of power to the grid when prices are favorable. Reduces emissions from transport sector which is about 14% of global GHG emissions from anthropogenic sources.	charging using both centralized and decentralized systems can effectively reduce energy costs and prevent the overloading of grid components by shifting peak demand
15	Reduce Transmission & Distribution Losses hence high efficiency	Decentralization of generation at sites close to consumers hence less transmission and distribution costs and losses.	Increased use of decentralised resources increases energy security and more use of renewable sources in power generation, increases access and reduces cost of power.
17	Development of smart cities and streetlight automation	Smartness of a city refers to the desire of improve the quality of life in a city and living standards of the city residents in terms (ICT). Intelligent application of smart grid is a key requirement for the establishment of smart cities.	Smart cities have been identified as the ultimate solution to complex challenges facing urban centers like energy supply, emissions, water supply, traffic congestion. Cities will account for about 70% of global population by 2050.
18	Grid Integrated Energy Storage	Seamless integration of energy storage to the grid	Optimum use of energy storage leading to increased uptake of variable renewable sources of energy.
19	V2X technologies	Smart grids will enhance electrification of transport creating opportunities for related sustainable technologies like V2V, V2H, V2G	Therefore smart grid technology deployment will enhance the operation and control of electric vehicles making them important energy transition facility
20	Rural electrification	The smart grid also provides significant opportunities for alleviation of rural electrification through development of smart micro grids based on renewable energy sources	Through smart grids, significant opportunities for alleviation of rural electrification challenges are addressed by providing infrastructure for wider exploitation of renewable energy sources like biomass, solar PV, and wind, through active engagement of individuals, private business and connecting them to the national grid

Table 7 summarizes the various applications of smart grids which improve the sustainability of grid electricity. This is realized by increasing system efficiency, increased uptake of renewable sources of energy, increased energy security by enhanced decentralized generation utilizing local energy resources. By two-way communication and flow of power, consumers are converted to prosumers. Improved stakeholder interaction due to active participation using two-way communication increases social sustainability of energy systems.

Smart grids use semiconductor-based FACTS and RACDS devices, replace mechanically-driven devices making the grid responsive in case of faults and reduces electricity losses. The smart grid also provides significant opportunities for alleviation of rural electrification through development of micro grids based on renewable energy sources like biomass, solar PV, and wind, through active engagement of individuals, private business and connecting them to the national grid[32]. Additionally, through scheduled charging of electric vehicles, the smart grid will encourage people to embrace EV technology leading to emissions from the transport sector and significant reduction in dependence on fossil fuel and transforming the transport sector into a partaker in demand response management [12, 32].

4.3. Smart grid Functionalities

The Smart Grid functionality has a very critical role in the delivery of electricity to consumers in a participatory manner by many players[44, 79]. These ids achieved through the following function;

4.3.1. Monitoring of distribution grids

The primary objective of smart grids is to increase the transparency in the operation of the distribution grid through improvement in the monitoring capabilities. According to [79] the traditional grid needs extra technologies in the distribution domain that are required for deployment of smart grids. They include Automated re-closers, switches, remote controlled distributed generation and energy storage, sensors for cables and cables and transformer. The sensors needed can be dedicated grid sensors especially for transformer substations and at critical locations within the network. The smart energy meters can also be used to reveal essential data for grid operation, control and planning. The smart

grid ICT has the main duty of transporting grid monitoring data across the power grid [44].

4.2.2. Provision of ancillary services for users

Ancillary service are services provided by power network participants particularly the large power plants required for safe and reliable operation of the power system. These services include frequency control, reactive power control, and voltage regulation . With smart grids, significant generation is shifting to the distribution grids hence connected generators will increasingly be involved in provision of the ancillary services. Additionally, the power customers will also provide ancillary services in form of active management of load flexibility. Virtual Power Plants or aggregators can combine small units of generators, loads, storages and generate ancillary services from their resources which increases power system reliability and efficiency. The communication and management between individual units and the aggregators and ancillary service providers to consumers is another important application for smart grid information and communication technology (ICT)[44, 79]..

4.2.3. Advanced control of distribution grids

Technical barriers to grid integration of variable renewable energy sources has been a major driver for smart grid deployment. The main technical barrier is increase in line voltage levels from distributed generators[44]. The approaches used to solve the problem are;

i.) Grid reinforcement which involves building of new lines or transformer stations, option which is considered expensive and economically to sole voltage problems although it may be ideal for line overloads.

ii.) Transformer or line-based techniques where components like on-load tap changers or alternative continuous techniques are applied to change the voltage on a particular line. This consists of the hardware component like a transformer with switchable windings and an associated control algorithm. The hardware components are currently available as products today e.g. in medium voltage level, and at low voltage level. However, the control algorithms are still under research and development. Today, the products like “intelligent secondary transformers are equipped with simple controllers based on local measurements [44, 79].

iii.) Generator-based techniques: In this techniques, the unit causing rise in voltage is also used to keep this rise within limits through reactive power (Q) management or by shedding of active power (P) as last resort. Modern photovoltaic inverters are equipped with selectable P(U), Q(U), Q(P) and cosφ(U) characteristics which are controlled based on local parameters in the inverter. The parameters can also be remote controlled for some products although we are yet to have a widely accepted standardized way to realize this end [44, 80].

4.3. 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].

5. CONCLUSIONS

Electrical power grids have encountered many challenges in recent years, including global warming, the quest for energy security, increasing cultural conservation, and the stringent power reliability and quality requirements of the digital age. Many studies have been conducted on the development and implementation of the smart grid (SG) to address these issues. In terms of power grids, the development of the SG is aimed at achieving at least four major objectives: ① the secure operation of large power grids under disturbances, the minimization of the risk of blackouts, and enhanced resilience; ② the seamless accommodation and efficient utilization of vast amounts of distributed energy resources (DERs); ③ the facilitation of an advanced electric power market and demand response; and ④ the provision of electric power with high reliability, high quality, and high efficiency for a digital society. From a broader perspective, considering that the implementation of the SG draws on many technical and business fields, the key goal is to encourage the innovation of relevant technologies and business models in order to create an industrial revolution.

The Smart grids constitute a future technology that will reduce costs and costly peak demands, increase integration of variable renewables and reduce energy related greenhouse gas emissions, increase energy efficiency and enable dynamic pricing and enhance consumer awareness and participation in grid affairs in a bidirectional relationship Smart grids will add value to electrification of transport by enabling millions of not just to act as variable loads, but also serve as renewable energy storage devices and sources of decentralized electricity for the power grids. The smart grids use digital communication, sensors, and automation to

modernize electricity supply and they use like smart meters**,** grid management software**,** and battery storage to provide modern and improved services like real-time usage tracking**,** outage detection**,** renewable energy integration, and demand response programs that enable optimal energy supply, use and cost reduction.

Smart grids can use wireless sensor networks (WSNs) unlike the traditional communication technologies since it is cheaper, fast to deployment, flexibility, and aggregated intelligence via parallel processing capabilities[12, 48]. The internet of Things refers to the application of WSNs, smart meters, actuators and components with information and communication technology (ICT). The main limitation or challenge with integration of the IoT technology within the smart power grid introduces the cost of large data processing. This data includes end users load demand, power lines faults, network's components status, scheduling energy consumption, forecast conditions, advanced metering records, outage management records, and enterprise assets.

The smart grid is a product of the fourth industrial revolution whose overall result is growth in automation, better communication, self-monitoring, and application of smart machines which have ability to analyze and diagnose issues without with little or no human intervention. The revolution also represents a social, political, and economic shift from the digital age of the late 1990s and early 2000s to a connectivity embedded era distinguished by the omni-use and commonness of technological use throughout society. The fourth industrial revolution technologies have potential to connect billions of people globally to the web and significantly improve the efficiency of doing business.

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The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

10.5. Ethical Approval and Consent to participate

Not applicable

10.6. Consent for publication

The authors have freedom and authority to publish the manuscript for public use

10.7. Authors contribution

The first author (Moses Kabeyi) drafted the manuscript which was reviewed and improved by the second author (Alodulapo Olenwaraju).

[1] M. Wolsink, "Conceptualizations of smart grids –anomalous and contradictory expert paradigms in transitions of the electricity system," *Energy Research & Social Science,* vol. 109, p. 103392, 2024/03/01/ 2024, doi: https://doi.org/10.1016/j.erss.2023.103392.

[2] O. Malik *et al.*, "Smart Grid Origins, Definitions, Technologies, and Emerging Trends: A Power Community Perspective," *Journal of Modern Power Systems and Clean Energy,* vol. 13, no. 6, pp. 1845–1853, 2025, doi: https://doi.org/10.35833/MPCE.2025.000807.

[3] US Department of Energy, "Department of Energy FY 2018 Congressional Budget," US Department of Energy, 2018. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/05/f34/FY2018BudgetVolume3_0.pdf

[4] International Energy Agency. "Electricity security in tomorrow's power systems." https://www.iea.org/articles/electricity-security-in-tomorrow-s-power-systems (accessed.

[5] S. G. Kumaran, S. Singaravelu, and K. Vivekananda, "Advance Technics, Challenges and developments in smart grid system," *International Journal of Engineering and Advanced Technology (IJEAT),* vol. 3, no. 1, pp. 107–114., 2013. [Online]. Available: https://www.ijeat.org/wp-content/uploads/papers/v3i1/A2179103113.pdf.

[6] A. Belkaid, I. Colak, K. Kayisli, M. Sara, and R. Bayindir, "Modeling and Simulation of Polycrystalline Silicon Photovoltaic Cells," presented at the 7th International Conference on SmartGrid (icSmartGrid), Newcastle, Australia, 2019.

[7] Y. Yu, Y. Liu, and C. Qin, "Basic Ideas of the Smart Grid," *Engineering,* vol. 1, no. 4, pp. 405–408, 2015/12/01/ 2015, doi: https://doi.org/10.15302/J-ENG-2015120.

[8] D. Defranza. "Understanding smart grid technology " https://science.howstuffworks.com/environmental/energy/smart-grid-technology2.htm (accessed 2020).

[9] T. Vijayapriya and D. P. Kothari, "Smart grid: An Overview. Smart Grid and Renewable Energy," *Renewable Energy,* vol. 2011, no. 2, pp. 305–311 2011, doi: 10.4236/sgre.2011.24035.

[10] M. I. Prasad, "Smart Grid Technology: Application and Control," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,* vol. 5, no. 5, pp. 9533–9544, 2014.

[11] Elservier, "Chapter 1 - Introduction," in *Smart Grid Security*, F. Skopik and P. Smith Eds. Boston: Syngress, 2015, pp. 1–10.

[12] M. J. B. Kabeyi and O. A. Olanrewaju, "The Use of Smart Grids in the Energy Transition," in *2022 30th Southern African Universities Power Engineering Conference (SAUPEC)*, 25–27 Jan. 2022 2022: IEEE, pp. 1–8, doi: https://doi.org/10.1109/SAUPEC55179.2022.9730635. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9730635

[13] M. J. B. Kabeyi and O. A. Olanrewaju, "Smart grid technologies and application in the sustainable energy transition: a review," *International Journal of Sustainable Energy,* vol. 42, no. 1, pp. 685–758, 2023/12/14 2023, doi: https://doi.org/10.1080/14786451.2023.2222298.

[14] M. Khalid, "Smart grids and renewable energy systems: Perspectives and grid integration challenges," *Energy Strategy Reviews,* vol. 51, p. 101299, 2024/01/01/ 2024, doi: https://doi.org/10.1016/j.esr.2024.101299.

[15] M. J. B. Kabeyi, "Sustainable energy transition and optimization of grid electricity generation and supply," Doctor of Engineering, Industrial Engineering, Durban University of Technology, Durban, South Africa, 2024. [Online]. Available: https://doi.org/10.51415/10321/5485

[16] M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable Energy Transition for Renewable and Low Carbon Grid Electricity Generation and Supply," (in English), *Frontiers in Energy Research,* Review vol. 9, no. 743114, pp. 1–45, 2022–March–24 2022, doi: 10.3389/fenrg.2021.743114.

[17] R. Kappagantu, S. A. Daniel, and N. S. Suresh, "Techno-economic analysis of Smart Grid pilot project-Puducherry," *Resource-Efficient Technologies,* vol. 2, no. 4, pp. 185–198, 2016/12/01/ 2016, doi: https://doi.org/10.1016/j.reffit.2016.10.001.

[18] M. Uddin, M. F. Romlie, M. F. Abdullah, S. Abd Halim, A. H. Abu Bakar, and T. Chia Kwang, "A review on peak load shaving strategies," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 3323–3332, 2018/02/01/ 2018, doi: https://doi.org/10.1016/j.rser.2017.10.056.

[19] Federal Regulation Commision, "Assment of demand respnse and advanced metering," Federal

Regulation Commision, Wasington DC, USA, December 2008 2008. [Online]. Available: https://www.ferc.gov/sites/default/files/2020-05/12-08-demand-response.pdf

[20] National Institutte of Standards and Technology (NIST), "Guidelines for Smart Grid Cybersecurity," National Institutte of Standards and Technology (NIST), Gaithersburg, MD, USA, September 2014 2014. [Online]. Available: https://nvlpubs.nist.gov/nistpubs/ir/2014/NIST.IR.7628r1.pdf

[21] O. Majeed Butt, M. Zulqarnain, and T. Majeed Butt, "Recent advancement in smart grid technology: Future prospects in the electrical power network," *Ain Shams Engineering Journal,* vol. 12, no. 1, pp. 687–695, 2021/03/01/ 2021, doi: https://doi.org/10.1016/j.asej.2020.05.004.

[22] A. Bari, J. Jiang, W. Saad, and A. Jaekel, "Challenges in the Smart Grid Applications: An Overview," *International Journal of Distributed Sensor Networks,* vol. 10, no. 2, p. 974682, 2014/02/01 2014, doi: 10.1155/2014/974682.

[23] B. Duzgun and G. Komurgoz, "Turkey's energy efficiency assessment: White Certificates Systems and their applicability in Turkey," *Energy Policy,* vol. 65, pp. 465–474, 2014/02/01/ 2014, doi: https://doi.org/10.1016/j.enpol.2013.10.036.

[24] Z. Hu, C. Li, Y. Cao, B. Fang, L. He, and M. Zhang, "How Smart Grid Contributes to Energy Sustainability," *Energy Procedia,* vol. 61, pp. 858–861, 2014/01/01/ 2014, doi: https://doi.org/10.1016/j.egypro.2014.11.982.

[25] F. Separi, A. Sheikholeslami, and T. Barforoshi, "Scheduling of demand response program in the presence of retail electricity providers using multi-objective uncertainty-constrained optimization," *Journal of Energy Management and Technology,* vol. 5, no. 4, pp. 57–67, 2021, doi: 10.22109/jemt.2021.239162.1249.

[26] T. Nasir *et al.*, "Recent Challenges and Methodologies in Smart Grid Demand Side Management: State-of-the-Art Literature Review," *Mathematical Problems in Engineering,* vol. 2021, p. 5821301, 2021/08/09 2021, doi: https://doi.org/10.1155/2021/5821301.

[27] C. P. Vineetha and C. A. Babu, "Smart grid challenges, issues and solutions," in *2014 International Conference on Intelligent Green Building and Smart Grid (IGBSG)*, 23–25 April 2014 2014, pp. 1–4, doi: 10.1109/IGBSG.2014.6835208.

[28] M. J. B. Kabeyi, "Feasibility of Wellhead Technology Power Plants for Electricity Generation," *International Journal of Computer Engineering in Research Trends,* vol. 7, no. 2, pp. 1–16, 2020, doi: https://doi.org/10.22362/ijcert/2020/v7/i02/v7i0201.

[29] M. J. B. Kabeyi, "Investigating the challenges of bagasse cogeneration in the kenyan Sugar Industry," *International Journal of Engineering Sciences & Research Technology,* vol. 9, no. 5, pp. 7–64, May 2020 2020, doi: 10.5281/zenodo.3828855.

[30] M. J. B. Kabeyi and O. A. Olanrewaju, "Central versus wellhead power plants in geothermal grid electricity generation," *Energy, Sustainability and Society,* vol. 11, no. 1, p. 7, 2021/03/20 2021, doi: https://doi.org/10.1186/s13705-021-00283-8.

[31] T. Adefarati and R. C. Bansal, "Integration of renewable distributed generators into the distribution system: a review," *ET Renewable Power Generation,* vol. 10, no. 7, pp. 873–884, 01 August 2016 2016, doi: https://doi.org/10.1049/iet-rpg.2015.0378.

[32] T. N. Bhattarai, S. Ghimire, B. Mainali, S. Gorjian, H. Treichel, and S. R. Paudel, "Applications of smart grid technology in Nepal: status, challenges, and opportunities," *Environmental Science and Pollution Research,* 2022/02/09 2022, doi: 10.1007/s11356-022-19084-3.

[33] M. A. Elgenedy, A. M. Massoud, and S. Ahmed, "Smart grid self-healing:

Functions, applications, and developments," in *2015 First Workshop on Smart Grid and Renewable Energy (SGRE)*, 22–23 March 2015 2015, pp. 1–6, doi: 10.1109/SGRE.2015.7208737.

[34] M. Farmanbar, K. Parham, Ø. Arild, and C. Rong, "A Widespread Review of Smart Grids Towards Smart Cities," *Energies,* vol. 12, no. 23, 2019, doi: https://doi.org/10.3390/en12234484.

[35] F. Katiraei and M. R. Iravani, "Power Management Strategies for a Microgrid With Multiple Distributed Generation Units," *IEEE Transactions on Power Systems,* vol. 21, no. 4, pp. 1821–1831, 2006, doi: 10.1109/TPWRS.2006.879260.

[36] T. Logenthiran, D. Srinivasan, and A. M. Khambadkone, "Multi-agent system for energy resource scheduling of integrated microgrids in a distributed system," *Electric Power Systems Research,* vol. 81, no. 1, pp. 138–148, 2011/01/01/ 2011, doi: https://doi.org/10.1016/j.epsr.2010.07.019.

[37] M. J. B. Kabeyi, "Geothermal electricity generation, challenges, opportunities and recommendations," *International Journal of Advances in Scientific Research and Engineering (ijasre),* vol. 5, no. 8, pp. 53–95, 2019, doi: https://doi.org/10.31695/IJASRE.2019.33408

[38] K. Masoudi and H. Abdi, "Optimal stochastic scheduling in microgrids under managed risk," (in en), *Journal of Energy Management and Technology,* vol. 6, no. 1, pp. 33–43, 2022, doi: 10.22109/jemt.2021.279635.1292.

[39] UNECE, "Electricity system development: Focus on smart grids," UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, 2022 2016. [Online]. Available: https://unece.org/fileadmin/DAM/energy/se/pdfs/eneff/eneff_h.news/Smart.Grids.Overview.pdf

[40] N. Phuangpornpitak and S. Tia, "Opportunities and Challenges of Integrating Renewable Energy in Smart Grid System," *Energy Procedia,* vol. 34, pp. 282–290, 2013/01/01/ 2013, doi: https://doi.org/10.1016/j.egypro.2013.06.756.

[41] M. T. Costa-Campi, D. Daví-Arderius, and E. Trujillo-Baute, "The economic impact of electricity losses," *Energy Economics,* vol. 75, pp. 309–322, 2018/09/01/ 2018, doi: https://doi.org/10.1016/j.eneco.2018.08.006.

[42] T. Ackermann, G. Andersson, and L. Söder, "Distributed generation: A definition," *Electric Power Systems Research,* Article vol. 57, no. 3, pp. 195–204, 2001, doi: 10.1016/S0378-7796(01)00101-8.

[43] S. Adams, F. Atsu, E. M. Klobodu, and L. Richmond, "Electricity transmission, distribution losses and economic growth in South Africa," *Heliyon,* vol. 6, no. 11, p. e05564, 2020/11/01/ 2020, doi: https://doi.org/10.1016/j.heliyon.2020.e05564.

[44] F. Skopik and P. Smith, "Chapter 1 - Introduction," in *Smart Grid Security*, F. Skopik and P. Smith Eds. Boston: Syngress, 2015, pp. 1–10.

[45] Particle Industries. "How IoT Enables the Smart Grid - Applications, Benefits, and Use Cases." https://www.particle.io/iot-guides-and-resources/iot-smart-grid-applications-benefits-and-use-cases/ (accessed 15 October 2022, 2022).

[46] A. Ghasempour, "Internet of Things in Smart Grid: Architecture, Applications, Services, Key Technologies, and Challenges," *Inventions*, vol. 4, no. 1, doi: 10.3390/inventions4010022.

[47] A. Kumar. "Challenges for IoT-based Smart Grid." Electrical India. https://www.electricalindia.in/challenges-for-iot-based-smart-grid/ (accessed 2022).

[48] S. Venticinque and A. Amato, "Chapter 6 - Smart Sensor and Big Data Security and Resilience," in *Security and Resilience in Intelligent Data-Centric Systems and Communication Networks*, M. Ficco and F. Palmieri Eds.: Academic Press, 2018, pp. 123–141.

[49] P. A. S. Kiran and B. L. Rao, "Smart grid functionalities at distribution

level," *International Journal of Pure and Applied Mathematics,* no. Special Issue, p. 17, April 17, 2018 2018. [Online]. Available: https://acadpubl.eu/hub/2018-118-24/1/177.pdf.

[50] D. McGinnis, "What Is the Fourth Industrial Revolution?," in *The 36 Blog* vol. 2022, ed. San Francisco, CA, 2020.

[51] E. Lo Cascio, L. Girardin, Z. Ma, and F. Maréchal, "How Smart is the Grid?," (in English), *Frontiers in Energy Research,* Review vol. 9, 2021–June–24 2021, doi: 10.3389/fenrg.2021.637447.

[52] W. Choi, J. Kim, S. Lee, and E. Park, "Smart home and internet of things: A bibliometric study," *Journal of Cleaner Production,* vol. 301, p. 126908, 2021/06/10/ 2021, doi: https://doi.org/10.1016/j.jclepro.2021.126908.

[53] S. Shapsough and I. A. Zualkernan, "IoT for Ubiquitous Learning Applications: Current Trends and Future Prospects," *Ubiquitous Computing and Computing Security of IoT. Studies in Big Data,* vol. 47, pp. 53–68, 2019.

[54] G. Neagu, S. Preda, A. Stanciu, and V. Florian, "A Cloud-IoT based sensing service for health monitoring," in *2017 E-Health and Bioengineering Conference, EHB 2017*, 2017, pp. 53–56, doi: 10.1109/EHB.2017.7995359. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028527121&doi=10.1109%2

[55] International Renewable Energy Agency, "Global energy transformation: A roadmap to 2050 (2019 edition)," International Renewable Energy Agency, Abu Dhabi., 2019 2019. [Online]. Available: https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

[56] M. J. B. Kabeyi and A. O. Oludolapo, "Managing Sustainability in Electricity Generation," presented at the 2020 IEEE International Conference on Industrial Engineering and Engineering Management, Singapore, Singapore, 14–17 December 2020, 2020, IEEM20-P-0406 [Online]. Available: https://ieeexplore.ieee.org/document/9309994.

[57] M. J. B. Kabeyi and A. O. Oludolapo, "Preliminary Design of a Bagasse Based Firm Power Plant for a Sugar Factory," presented at the South African Universities Power Engineering Conference (SAUPEC), Nortn West University, South Africa, 27–28 January 2021, 2021, 104. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9377242.

[58] P. Sabine, K. Robert, Z. Jakob, M. Jonas, P. Patrick, and W. Martin, "The share of renewable electricity in electric vehicle charging in Europe is higher than grid mix," Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany, 2021. [Online]. Available: https://www.econstor.eu/bitstream/10419/248253/1/1780486596.pdf

[59] M. J. B. Kabeyi and O. A. Olanrewaju, "Fuel from plastic wastes for sustainable energy transition," presented at the 11th Annual International Conference on Industrial Engineering and Operations Management, Singapore, March 7–11, 2021, 2021. [Online]. Available: http://www.ieomsociety.org/singapore2021/papers/199.pdf.

[60] M. J. B. Kabeyi and O. A. Olanrewaju, "Development of a cereal grain drying system using internal combustion engine waste heat," presented at the 11th Annual International Conference on Industrial Engineering and Operations Management Singapore, March 7–11, 2021, 2021. [Online]. Available: http://www.ieomsociety.org/singapore2021/papers/188.pdf.

[61] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Integration of Electric Vehicles in the Electric Power System," *Proceedings of the IEEE,* vol. 99, no. 1, pp. 168–183, 2011, doi: 10.1109/JPROC.2010.2066250.

[62] J. R. Young, "Smart grid technology in the developing world," Seattle Pacific

University Seattle, USA, 2017. [Online]. Available: https://digitalcommons.spu.edu/cgi/viewcontent.cgi?

[63] M. Kabeyi and O. Olanrewaju, "Slaughterhouse waste to energy in the energy transition with performance analysis and design of slaughterhouse biodigestor," *Journal of Energy Management and Technology,* vol. 6, no. 3, pp. 188–208, 2022, doi: http://dx.doi.org/10.22109/jemt.2021.292954.1309.

[64] M. J. B. Kabeyi and O. A. Olanrewaju, "Geothermal wellhead technology power plants in grid electricity generation: A review," *Energy Strategy Reviews,* vol. 39, p. 100735, 2022/01/01/ 2022, doi: https://doi.org/10.1016/j.esr.2021.100735.

[65] M. J. B. Kabeyi and A. O. Oludolapo, "Viability of Wellhead Power Plants as substitutes of Permanent Power plants," presented at the 2nd African International Conference on Industrial Engineering and Operations Management, Harare, Zimbabwe, December 7–10, 2020, 2020, 77. [Online]. Available: http://www.ieomsociety.org/harare2020/papers/77.pdf.

[66] International Energy Agency, "Global EV Outlook 2021:Accelerating ambitions despite the pandemic," in "Electric Vehicles Initiative," International Energy Agency, Paris, France, 2021. [Online]. Available: https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf

[67] C. Taliotis *et al.*, "The Effect of Electric Vehicle Deployment on Renewable Electricity Generation in an Isolated Grid System: The Case Study of Cyprus," (in English), *Frontiers in Energy Research,* Original Research vol. 8, no. 205, 2020–August–27 2020, doi: https://doi.org/10.3389/fenrg.2020.00205.

[68] L. Quitzow and F. Rohde, "Imagining the smart city through smart grids? Urban energy futures between technological experimentation and the imagined low-carbon city," *Urban Studies,* vol. 59, no. 2, pp. 341–359, 2022/02/01 2021, doi: 10.1177/00420980211005946.

[69] D. Partida. "Smart Power Grid Technologies for Smart Cities." Planetize. https://www.planetizen.com/blogs/115628-smart-power-grid-technologies-smart-cities (accessed 2022).

[70] Y. Ma, X. Chen, L. Wang, and J. Yang, "Investigation of Smart Home Energy Management System for Demand Response Application," (in English), *Frontiers in Energy Research,* Original Research vol. 9, 2021–November–16 2021, doi: 10.3389/fenrg.2021.772027.

[71] G. Venkataramani, P. Parankusam, V. Ramalingam, and J. Wang, "A review on compressed air energy storage – A pathway for smart grid and polygeneration," *Renewable and Sustainable Energy Reviews,* vol. 62, pp. 895–907, 2016/09/01/ 2016, doi: https://doi.org/10.1016/j.rser.2016.05.002.

[72] M. Gebhardt, M. Kopyto, H. Birkel, and E. Hartmann, "Industry 4.0 technologies as enablers of collaboration in circular supply chains: a systematic literature review," *International Journal of Production Research,* pp. 1–29, 2021, doi: 10.1080/00207543.2021.1999521.

[73] TWI. "Industry 4.0." TWI. https://www.twi-global.com/what-we-do/research-and-technology/technologies/industry-4-0 (accessed 9 April 2022, 2022).

[74] T. Ö and K. A, "Smart Grids and Industry 4.0," in *2018 International Conference on Artificial Intelligence and Data Processing (IDAP)*, 28–30 Sept. 2018 2018, pp. 1–6, doi: 10.1109/IDAP.2018.8620887.

[75] M. J. B. Kabeyi and O. A. Olanrewaju, "Relationship Between Electricity Consumption and Economic Development," presented at the International Conference on Electrical, Computer and Energy Technologies (ICECET), Cape Town-South Africa, 9–10 December 2021, 2022. [Online]. Available:

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9698413.

[76] M. J. B. Kabeyi and O. A. Olanrewaju, "A Techno-economic Assessment of Diesel to Gas Power Plant Conversion " presented at the 12th Annual Istanbul International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, March 7–10, 2022, 2022, 406. [Online]. Available: https://ieomsociety.org/proceedings/2022istanbul/406.pdf.

[77] K. A. Adeyeye and C. Mbohwa, "Decentralized energy transition in urban Nigeria: institutional barriers and policy pathways for hybrid renewable energy systems," *Oxford Open Energy,* vol. 4, p. oiaf010, 2025, doi: https://doi.org/10.1093/ooenergy/oiaf010.

[78] R. Smale, B. van Vliet, and G. Spaargaren, "When social practices meet smart grids: Flexibility, grid management, and domestic consumption in The Netherlands," *Energy Research & Social Science,* vol. 34, pp. 132–140, 2017/12/01/ 2017, doi: https://doi.org/10.1016/j.erss.2017.06.037.

[79] International Energy Agency, "Technology Roadmap Smart Grids," International Energy Agency, Paris, France, 2011. [Online]. Available: https://iea.blob.core.windows.net/assets/fe14d871-ebcb-47d3-8582-b3a6be3662ba/smartgrids_roadmap.pdf

[80] international Energy Agency, "Smart Grids in Distribution Networks," in "How2Impliment " International Energy Agency, Paris, France, 2015. [Online]. Available: https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/technologyroadmaphow2guideforsmartgridsindistributionnetworks.pdf