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Overview of Smart Grid: A Review

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ABSTRACT

The smart grid complements the deficit in traditional electrical energy such as the pollution issues that come with certain energy resources such as fossil fuels and nuclear energy. Many literature discusses various technologies but very few talk about the implementation of the smart grid and its considerations to be implemented, the assessment of the power system with the communication network put into play, how to optimize technological schemes with economic and political constraints put into consideration and many other considerations. Governments across the globe and related organizations such as utility companies are eager to assess the cost and advantages of new technological mechanisms scientifically as opposed to decision making with no scientific base. Decision Support System is a system of information that is interfaced with computers to support the making of decisions in operations, management, and planning for assessing the technologies. A lot of advanced technologies, creative architectures, and paperback algorithms have been deployed into the existing electrical power systems for improved energy efficiency and accomplish resource allocation optimization and ultimately make the grid “smart”. Two-way communication systems’ deployment is one of the distinctive mark of the smart grid. The smart can gather and transfer monitored data from the power system elements to operators of the system using the smart grid monitoring system and form a two-way communication system via the grid power plant and the end user of electricity. The smart grid implementation is a gradual process to substitute the conventional power systems’ elements built on the basis of existing systems and building brand new systems which would be very costly. Smart grid planning involves not only the consideration of these creative technologies but also respecting the interest of all the stakeholders involved. Decision making requires to be executed to analyze each smart grid component and its cost before investment and consequently deploying into the real grid.

Keywords: Smart Grid, Support System, technologies and conventional power.

INTRODUCTION

Both developed and developing countries are advocating a Smart grid that has the requirement to feed the congested large energy consumption in industry and commerce which is ever-growing. The smart grid is a new concept which involves a vast number of advanced technologies, excellent methodologies, paperback algorithms and creative construction which are meant to solve problems such as the deduction of carbon emission, optimize the resource allocation, the security for the grid and improve the reliability and efficiency and delivery of power system with optimization.

The Smart Grid Definitions

Organizations, research institutions, and governments across the world have conceptualized, expanded, and developed the smart grid. There is no standard definition of the smart grid, so far, as things stand, each country seems to have a different concept and definition of the smart grid. For example, the Chinese are aiming at establishing a robust smart system from generation to utilization, this includes transmission and distribution. In the UK, the definition of the smart grid is within the distribution network. So far, a lot of publishers focus on defining the features of the smart grid or the kind of technology that is involved in the smart grid. For planning and operations, some new issues that have never occurred on the conventional power system also need to be considered as a way of understanding the smart grid. For example, one would ask a question like, what is the most efficient way of operating the system with the increasing number of consumers getting involved in the power system?. Another question would be, in the event of a cyber-attack in the communication channel, how will the smart grid detect this kind of attack and how will it defend the network from damage?

According to the Department of Energy, National Energy Technology Laboratory of the United States (DOE NETL), the smart grid utilizes digital technology for reliability, efficiency and security improvement of the power system from the point of generation through the distribution systems to the smallest consumers including the increasing number of distributed energy (distributed generation) generation and storage facilities. The coming in of the Smart grid deals with a broad arrangement of electrical systems and its capabilities and services allowed by a prevalent information and communications technology with the main aim of reliability, efficiency and operability improvement, resilience to threats, and the impact on the environment. The International Energy Agency (IEA) of the United States defines the smart grid as “an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users” [1]. A Smart grid is an intelligent electrical network that incorporates the activities of all its involved parties (everything connected to it) and these are generators and consumers and those that do both for the sole purpose of the efficient delivery of sustainable, economical and secure electrical supply (*Anne Harris, “Smart Grid Thinking”, Engineering*, n.d.), which is illustrated by the European Technology Platform. The IEEE describes the "smart grid" as the next-generation electrical power system which is epitomized by the rise in the utility of communications and information systems, delivery, and usage of electrical energy. A typical visionary future smart grid network is shown in Fig. 1. It does not matter which definition best suits you but the concept of the smart grid must include at least the following;

1. Aggregation of digital technologies in the entire power systems from generation to the consumers.
2. The smart grid must have improved reliability, efficiency and security of the power delivery systems.
3. Must integrate bulk generations and distributed energy (distributed generation) generations, conversion of non-renewable energy and also the conversion renewable energy.

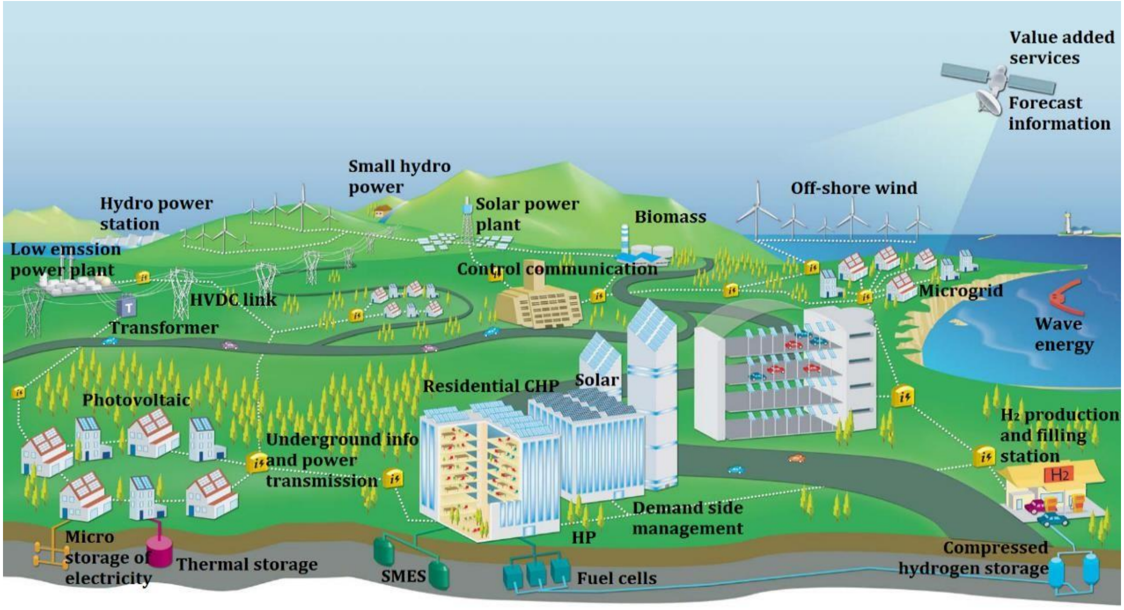

Fig. 1: Future network vision (*European Commission, Report 'European Smart Grids*, n.d.)

Differences between Traditional Grid and Smart Grid

Table. 1 demonstrates the differences between the smart grid and the traditional grid. The Smart grid uses the two-way communication system that enables the customer to also take part in the grid activities. For example, the extra energy that is generated by the photovoltaic solar panels during the day at the roof of the customer can be sold to the grid: solar panels do not generate energy in the night due to lack of sunlight. In as much as new technologies are evolving such as distributed energy generation, charging and discharging of electric vehicles, Flexible Alternating Current Transmission (FACT) in regards to the enhancement of the overall energy efficiency and reduction of the emissions of carbon, there are new challenges that come along with these new applications. Table. 2 provides information on various technical solutions associated with power systems. For better solutions, a careful cost-benefit analysis required.

Table 1: A comparison between the traditional grid and the smart grid ("*Understanding the Smart Grid: Features, Benefits*, n.d.)

Aspects	Traditional Grid	Smart Grid
Link between Grid and Customers	Customers just accept service from grid	Customers participation in the activities of the on the grid
The incorporation of Renewable Energy	Having trouble with renewable Penetration	Integration with renewable resources Enhancement
Alternatives for Customers	It's more of a monopoly market since the customer has no choice	With digital market trading, PHEV, introduce bids and competition, more choice for customer
Power Quality (PQ) options	There is no choice of power quality and no price plan alternatives for consumers	There are various levels of power quality for various consumers
Operation of the System	Compromised operation efficiency due to the aging assets	Optimal utilization of the operating assets hence less power losses
Protection	Fault detection is done manually and the system relies on protection devices which are not 100% reliable	The extent of the damage is less and the system has self-healing capabilities
Reliability and Security	**Vulnerable to physical and cyber Attack**	**It is reliable for national security and human Safety**

Technology Solutions	Reliability	Economics	Efficiency	Environmental	Safety	Security
AMI	Yes	Yes	Yes	Yes	Yes	Yes
CSS		Yes	Yes	Yes	Yes	Yes
DER	Yes	Yes	Yes	Yes	Yes	Yes
DMS	Yes		Yes	Yes	Yes	Yes
Network Optimization	Yes	Yes	Yes	Yes	Yes	Yes
Transmission enhancement application	Yes	Yes	Yes	Yes	Yes	Yes
ICT	Yes	Yes	Yes	Yes	Yes	Yes
EV Charging and Discharging	Yes	Yes	Yes	Yes	Yes	Yes

Table 2: Smart grid technology solutions .vs. benefits

Smart Grid Features and Technologies

The smart grid is the next generation as compared to the conventional power system in terms of delivery of the system which incorporates a lot of features and new technology. National Institute of Standards and Technology (NIST) United States Department of Commerce split the smart grid into seven categories as shown in Fig. 2. The smart grid is a composition expanding collection of interrelated networks and equipment (*International Energy Agency, Report 'Technology*, n.d.).

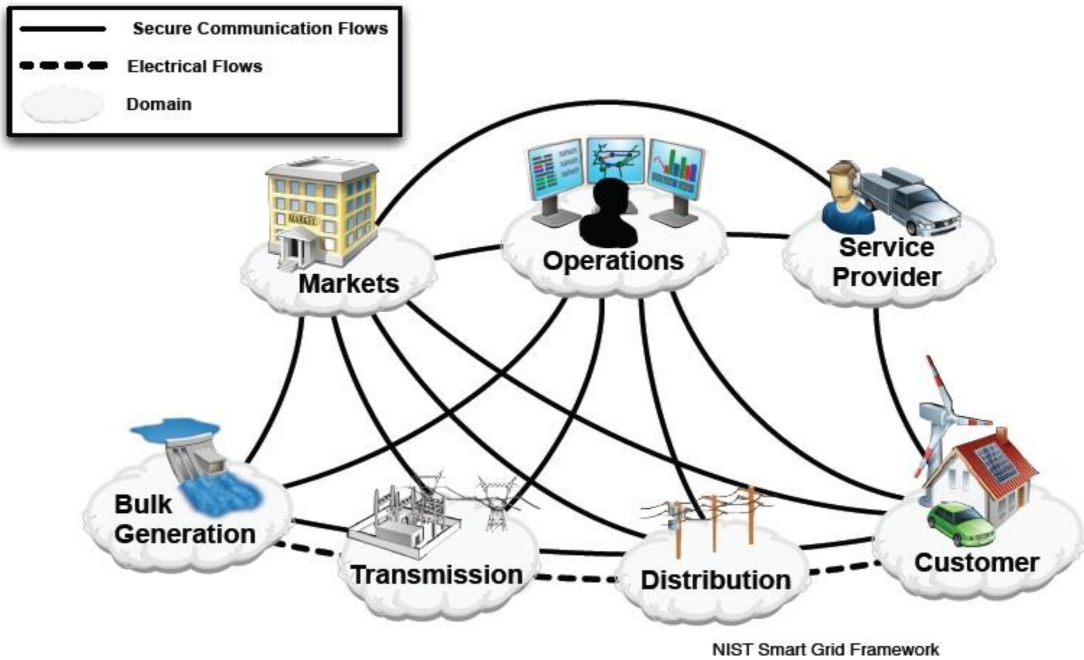

Fig. 2: communication network in smart grid (*"NIST Framework and Roadmap for Smart Grid Interoperabi*, n.d.)

Illustrated above is the NIST smart grid framework of how communication and electrical flows within smart grid seven domains (*International Energy Agency, Report 'Technology*, n.d.). NETL provides 8 solutions to technology that are needed to accomplish improved reliability, efficiency, economics, environmental, safety and security, as shown below:

1. Advanced metering infrastructure (AMI)
2. Customer Side Systems (CSS)
3. Charging systems for Electric Vehicles (EV)
4. Transmission enhancement application
5. Distribution grid management system (DMS)
6. Incorporation with renewable energy and distributed energy resources (DER)
7. Information and communication technology incorporation (ICT)
8. Wide-area monitoring, measurement and control (*U.S. Department of Energy, National Energy Technology*, n.d.).

Different technologies have been deployed all over the power system grid, from generation to the consumer side (see Fig. 3). To meet the consumer's demand, a virtual electrical market is built in order to examine more alternatives for the consumers.

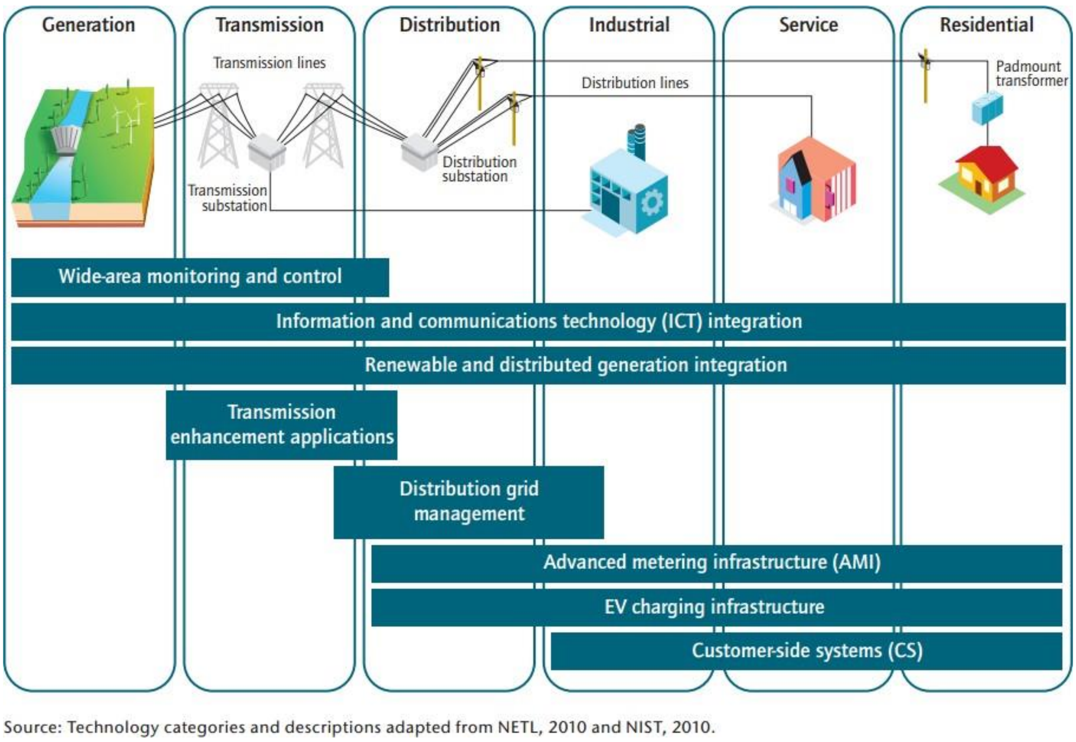

Fig. 3 Smart grid technologies deployment in power systems (*International Energy Agency, Report 'Technology*, n.d.)

Advanced Metering Infrastructure (AMI)

AMI provides a two-way communication system that gives a platform for customers and service providers to interact and acquire real time pricing of electricity consumption. The AMI caters for power losses and provides for theft detection schemes. The AMI works to the benefit of the customers such as providing the consumers with the required information for intelligent decisions, the ability to implement those decisions, plus a number of other alternatives that are beneficial to the customers. On the other hand, using the AMI data, the system can improve its operability as well as asset management process in order to improve customer services. Furthermore, the AMI provides an important link between the grid, customers and the loads plus the generation and storage resources including the incorporation of several technologies such as smart metering, Home Area Network (HAN) aggregated communication systems and standardized software interaction (*U.S. Department of Energy, National Energy Technology*, n.d.). An illustration of the AMI technology and how it interacts with domestic, commercial and industrial are shown in Fig. 4.

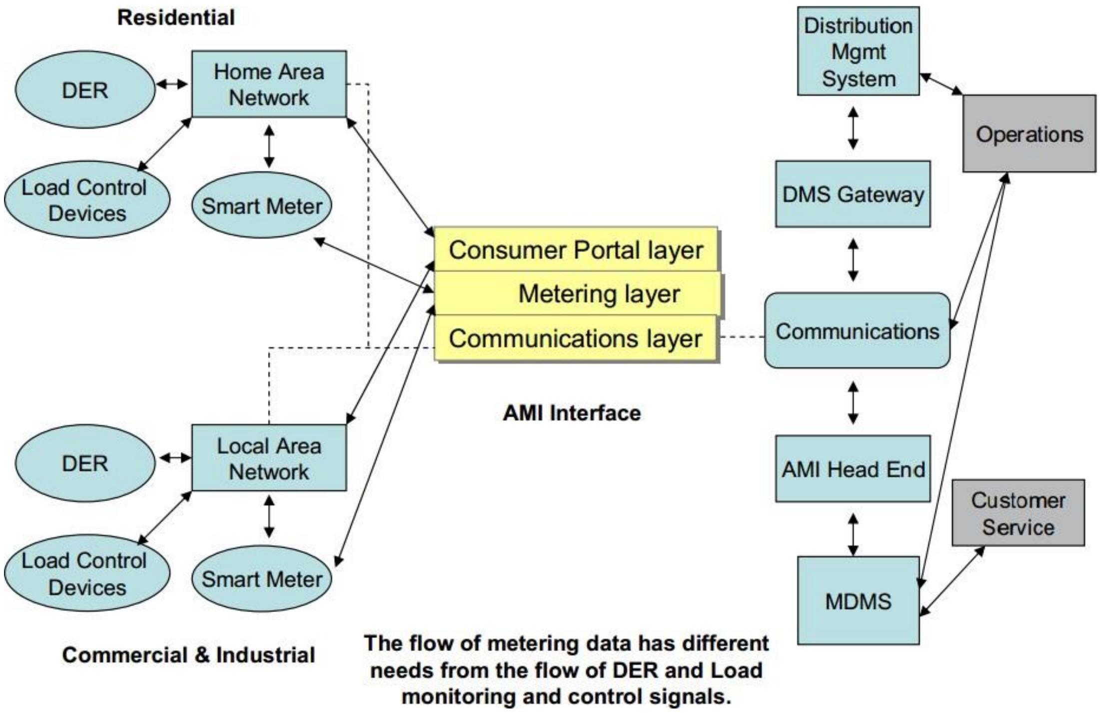

Fig. 4 AMI Technology and Interface (*U.S. Department of Energy, National Energy Technology*, n.d.)

With the AMI deployed and the risk of communication which apparently is the immanent factor, is added to the smart grid, it does more harm than good to the economy, the health of the public, to the safety of the public and the integrity of the environment. The economic risk and the government trust could increase from low to somewhat moderate in the event where there is a misunderstanding between the regulators and utilities and also when there is a rise in the rates of the residential customers (*SANDIA REPORT, "Advanced Metering Infrastructure*, n.d.). Therefore, the system security requirements have to be suggested and clearly identify the smart grid security aims are meant to protect (*"AMI System Security Requirements", Available... - Google Scholar*, n.d.).

Customer Side Systems (CSS)

Customer side systems are employed to help regulate energy consumption at different usage levels such as commercial level, industrial level, service level, and residential level. There are four aspects that are involved in the customer side systems (*International Energy Agency, Report 'Technology*, n.d.) and these are:

- energy management systems
- energy storage devices
- intelligent electronic devices
- distributed generations

On displays in homes such as smart appliances, energy dashboards, and load storage employment can cause a high rise in the profit of energy efficiency and have a reduced peak demand. The demand response is a situation where the end-use customers reduce their electricity consumption as a response to the power grids' requirements, indices of economics from a wholesale market with the competition or retail rates [2]. Both responses from the customer, either manual or automated, price-responsive appliances, and thermostats are connected to the Energy Management System or controlled by a signal from the company or the operating system (*International Energy Agency, Report 'Technology*, n.d.).

Electric Vehicle Charging and Discharging

The demand for electricity vehicles' charging infrastructure can be regulated through charging and discharging. Electric vehicles charging and discharging has four operational modes and these are Grid to vehicles (G2V), vehicles to grid (V2G), storage to vehicles (S2V), and vehicles to storage (V2S). Vehicles operate as moving storage constituents of the grid because of the rise in penetration of the demand response and constant change in the pricing. In the event where the EV is fully charged and the grid is subjected to peak demand, the EV will discharge to the grid or maybe a home storage device as a backup for residential consumption. The storage devices will charge the EV when the grid is subjected to peak demand for everyday utilization. This implies that the EV will charge from the power grid when the grid is subjected to low energy demand and the price of electricity is low.

Transmission Enhancement Applications

There is a lot of technologies that are applied in transmission systems in order to improve the control, transferring abilities and to reduce power losses. The four main applications are listed below:

1. Flexible AC Transmission Systems (FACTS)
2. High Voltage DC Systems (HVDC)
3. Dynamic Line Rating (DLR)
4. High-Temperature Superconductors (HTS)

Distribution Grid Management System (DMS)

The DMS operates through real-time processing of information, deployment of meters and sensors and it performs the following functions;

- Power outages are reduced as well as time is taken to repair faults.
- The voltage levels are maintained
- The faults can be detected
- Asset management is improved
- Feeders are reconfigured automatically
- There is the optimization of the reactive power and voltage
- Distributed generation is controlled

Incorporation with Renewable Energy and Distributed Energy Resources (DER)

There are various scales of renewable energy resources that are deployed in various levels of the power grid: i.e., the transmission level belongs to the large scale renewable energy resources, the distribution level is for the medium scale and the small is for consumer side premises. The ability to control and dispatch electricity remains as a challenge for the incorporation of DERs and renewable energy operations of the power system. The storage devices for thermal and electrical can relieve the repercussions from the state of having a stop and resume situation of renewable energy such as solar and wind to be precise. Distributed generation (DG) incorporation improves the reliability of the power grid and can help to reduce the heavy loads.

Information and Communication Technology Integration (ICT)

Information and communication technology integration (ICT) supports the transmission of data for postponed and real time operation and also in the event of an outage. This is regardless of which network is being used, for example private (which includes radio network and meter mesh networks) or public (i.e., cable, telephone, internet and cellular). The interested parties are therefore in a position to utilize and manage the grid efficiently by applying communication devices, computing, control of system software and planning of enterprise resources into a two-way communication system.

Wide-area Monitoring, Measurement and Control

Wide-area monitoring, measuring and control supervises all the power system elements and their performance in real time by way of interfacing within a large geographical area and making optimum use of the components of the power system. Operation of advanced system tools incorporating wide- area situational awareness (WASA), wide- area adaptive protection, control and automation (WAAPCA) and wide area monitoring systems (WAMS), prevent the system from blackouts and creates a platform for the incorporation of various renewable energy resources. Furthermore, the data that is generated by Wide-area Monitoring, Measurement and Control systems can also help along with the system's operation by;

- informing decision makers
- alleviating wide-area disturbance and
- improvement of the transmission capacity and reliability

Table 3 represents the software and hardware that is associated with each of the technologies and the smart grid issues. It is seen from this table that the communication network components are key elements for the smart grid formation which have been deployed in many aspects of the smart grid. Communication network is deployed to deliver the data of the consumption of energy and the storage levels to the control centers. The Ethernet and the Industry standard PC, is used to communicate between control centers and substations in the smart grid. General control and monitoring of devices which are positioned in the control center are used for the generation of energy, storage of energy and its consumption. The generation of non-conventional energy, storage and the usage of energy is regulated in accordance with the oscillating generation forecasting (most especially the non-conventional energy) and the constantly changing load curve. New algorithms are being built for the control and monitoring of devices. For example, the management system for the micro-grid energy is supposed to be more intelligent to handle any skepticism and changes in the generation and demand. One of the intelligent algorithms that can update the information while the system is in operation is the Computational Algorithm (CA).

Table. 3 Hardware and software employed into smart grid (*International Energy Agency, Report 'Technology*, n.d.)

Smart Grid Technologies and Issues	Hardware	Systems and Software
Cyber Security	Communication equipment (Power line carrier, WIMAX, LTE, TF mesh network, cellular), routes, relays, switches, gateway, computers (servers)	Supervisory control and data acquisition (SCADA), distribution management system (DMS), Firewall rules, Vulnerability management
Protection	Fiber communication network, routes, relays, switches, computers (servers)	wide-area adaptive protection, control and automation (WAAPCA), wide-area situational awareness (WASA), distribution management system (DMS), Agent-based Supervision
Wide-Area Monitoring and Control	Phasor measurement units (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), wide-area adaptive protection, control and automation (WAAPCA), wide-area situational awareness (WASA)
Information and Communication Technology integration	Communication equipment (Power line carrier, WIMAX, LTE, TF mesh network, cellular), routes, relays, switches, gateway, computers (servers)	Enterprise resource planning software (ERP), customer information system (CIS)
Renewable and Distributed Generation Integration	Power conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology	Energy management system (EMS), distribution management system (DMS), SCADA, geographic information system (GIS)
Transmission Enhancement	Superconductors, FACTS, HVDC	Network stability analysis, automatic recovery systems
Distribution Grid Management	Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable Sensors	Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS)
Advanced Metering Infrastructure	Smart meter, in-home displays, servers, relays	Meter data management system (MDMS)
Electric Vehicle Charging Infrastructure	Charging infrastructure, batteries, inverters	Energy billing, smart grid-to-vehicle charging (G2V) and discharging vehicle-to-grid (V2G) methodologies

Customer Response Side	Smart appliances, routes, in-home display, building automation systems, thermal accumulators, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tablets

Smart Grid Benefits

According to the NETL, the smart grid can improve the operability energy consumption in the following areas:

1. Reliability — the reliability is improved by reducing interruptions and the power quality disturbances and also the extent of widespread outages.
2. Economics — there is a downward price of electricity charges, the consumers pay less in comparison to "Business As Usual" (BAU), creation of jobs as well as improving the gross domestic product (GDP).
3. Efficiency — high efficiency is achieved by a reduced cost of production, delivery and consumption of electricity.
4. Security — security in the smart grid is treated as top priority thus a reduction in probability and repercussions of cyberattacks.
5. Safety — by reducing injuries and loss of life from grid-related events
6. Environment– the smart grid has reduced emissions.

General benefits of the smart grid are:

The system performance of the meters are improved asset management is improved Data is available for strategic planning and support digital summary .The information flows and the communication is secure thus it is more reliable and an economical way delivering power. The smart grid design has an improved life cycle management, end to end delivery of power and containment of the cost. The information supplied is accurate.

EXISTING SYSTEMS

[3] Provided an overview of the smart grid and the role it plays in the development of electrical systems. This was accomplished by defining the smart grid and hinting the main driving factors for deployment. [4] This paper was intended as a pragmatic on the users' on how to make maximum use of the smart grid technologies for the incorporation of renewable energy into the grid. The systematic approach to both technical and non-technical issues that are associated with the implementation of the smart grid for the renewable energies were addressed. [5] Addressed the issue of security and described it as very important due to the fact that the improvement on the power system has brought new challenges such as the cyber-crime. For this reason, there is need to detect cyber criminals early enough to reduce the damages and money losses that arise from cyber-attacks. [6] This paper is an analysis that provides information for the support of decision making when developing new policies for the smart grid. [7] Proposed a smart grid control three phase power selector and an overload system based on a GSM technology. This proposal ensures that is uninterrupted power supply, the voltage is stable and there is a scheme for overload protection. (Blech et al., n.d.) This is a report that presents the Smart Space event handling framework for managing the smart grid and renewable energy installations. [8] Did a research on the improvement of the rate of detection of the aggregation of cyber-attacks by attaching feature selection and assessing which combination of features that would provide the best accuracy in checking the validity of the K-fold cross technique and the random forest algorithm.

CONCLUSION

A lot of advanced technologies, creative architectures, and paperback algorithms have been deployed into the existing electrical power systems for improved energy efficiency and accomplish resource allocation optimization and ultimately make the grid "smart". Two-way communication systems' deployment is one of the distinctive mark of the smart grid. The smart can gather and transfer monitored data from the power system elements to operators of the system using the smart grid monitoring system and form a two-way communication system via the grid power plant and the end user of electricity. The smart grid implementation is a gradual process to substitute the conventional power systems' elements built on the basis of existing systems and building brand new systems which would be very costly. Smart grid planning involves not only the consideration of these creative technologies but also respecting the interest of all the stakeholders involved. Decision making requires to be executed to analyze each smart grid component and its cost before investment and consequently deploying into the real grid.

REFERENCES

1. IEEE. (n.d.). IEEE - The world's largest technical professional organization dedicated to advancing technology for the benefit of humanity.
2. Patel, M. (2005). Wind and solar power systems: design, analysis, and operation. https://books.google.com/books?hl=en&lr=&id=CfbLBQAAQBAJ&oi=fnd&pg=PP1&dq=%5B101%5D%09Mukund+R.+Patel,+Wind+and+Solar+Power+Systems:+design,Analysis+and+Operation,+Taylor+and+Francis,+2006.&ots=V1CSrl94Zp&sig=KT9x7ns_wQXXVjhoZZd9Ox84WKA
3. Nations, U., Commission, E. and Europe, F. O. R. (n.d.). UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE ELECTRICITY SYSTEM DEVELOPMENT : A FOCUS ON SMART GRIDS OVERVIEW OF ACTIVITIES AND PLAYERS IN SMART GRIDS.
4. Renewable Energy Consumption and Electricity Preliminary 2006 Statistics." IEA, Paris. http://www.eia.gov/cneaf/solar.renewables/page/prelim_trends/rea_prereport.html.
5. Delgado, P. A. (2019). DEVELOPMENT OF A DEEP LEARNING BASED ATTACK DETECTION SYSTEM FOR SMART GRIDS.
6. Evora, J., Hernandez, J. J. and Hernandez, M. (n.d.). Decision support for Complex Systems : a Smart Grid case.
7. Emalu, M., Ibrahim, A., Kalulu, M., Mufana, M., William, G., Otiang, O. and Faseun, Y. (2020). Electrical Smart Grid Resilience Based on GSM Technology ISSN: 2643-9085 .Vol. 4, Issue 4, Pages: 36-49
8. Atawodi, S. (2005).Comparative in vitro trypanocidal activities of petroleum ether, chloroform, methanol and aqueous extracts of some Nigerian savannah plants. African journal of Biotechnology, 2(3): 177-182.