AN OVERVIEW OF THE CHALLENGES TO THE ADOPTION OF SMART GRID TECHNOLOGY IN THE NIGERIA POWER SYSTEM

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ABSTRACT

The growing complexities of modern power systems have driven the need for efficient and effective energy distribution mechanisms. Smart grid system has several advantages on power generation, transmission and distribution in power system. However, in Nigeria power system, this smart grid technology has not been utilized optimally due to certain challenges. These challenges are discussed. This work is divided into five parts which are: first is introduction which contains explanation of what smart grid is and components of smart grid system. Second part contains the smart technologies and third part contained factors challenging smart grid adoption in Nigeria power system. The fourth section focused on the attacks that smart grid system while in operation while the last is conclusion.

Key words. Smart grid, Power system, technology, electricity etc AMI, DER etc.

1. INTRODUCTION

Many nations have moved from traditional grid system to smart grid system to enhance quality, efficiency and sustainability of power supply. The current Nigeria grid has capacity to meet the energy demand in Nigeria according to (Olusola et al., 2018) but most of the equipment in the present grid structure are outdated and need constant maintenance.

Nigeria struggles to generate enough electricity to over 220 million of her citizens with 60% of these populations living in rural communities with no or unsatisfactory access to electricity not withstanding that Nigeria is abundantly blessed with oil and gas. Smart grid network enables the generation and supply of power into the system through many renewable energy sources which is ecosystem friendly (Folasade et al., 2022).A smart grid is 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. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability (Ejededawe, 2018). According to the Canadian Electricity association, a smart grid is a collection of information–based applications that are made possible by the electricity grid's increased automation and the underlying automation itself. These technologies combine various supply and load behaviors and actions through distributed communication capabilities to provide secure affordable and sustainable power sources (Elejeet al., 2024). Smart grid is an advancement of the conventional power grid or the traditional power grid which its core is the interconnection of all the essential power system elements like power generators and transformers, synchronous machines, transmission substations, transmission lines, distribution lines and substations, and other types of loads that on the average could be distant from the power consumption areas (Azodo, 2018). The concept of Smart grid is the result of a confluence of economic, social, political, technological, and environmental factors and distribution system is having the highest impact on power supply infrastructure. The system is known for having smart appliances, smart meters, renewable energy sources and energy efficient resources which constitute the operational and Energy- saving features (Jema, 2020).

According to European technology, Smart grid is an efficient network that integrates user actions in delivery efficient, economical and sustainable electricity to the consumers connected to its power generators (Edeh, 2024). A power system network, where the bidirectional flow of electricity and data is obtained using digital technologies for communication is known as smart school and the purpose of smart school is to transform traditional electricity networks into the modern grid with the help of information and communication technologies (ICTs) (Usman et al, 2022, Kabalci, and Kabalci, 2019).

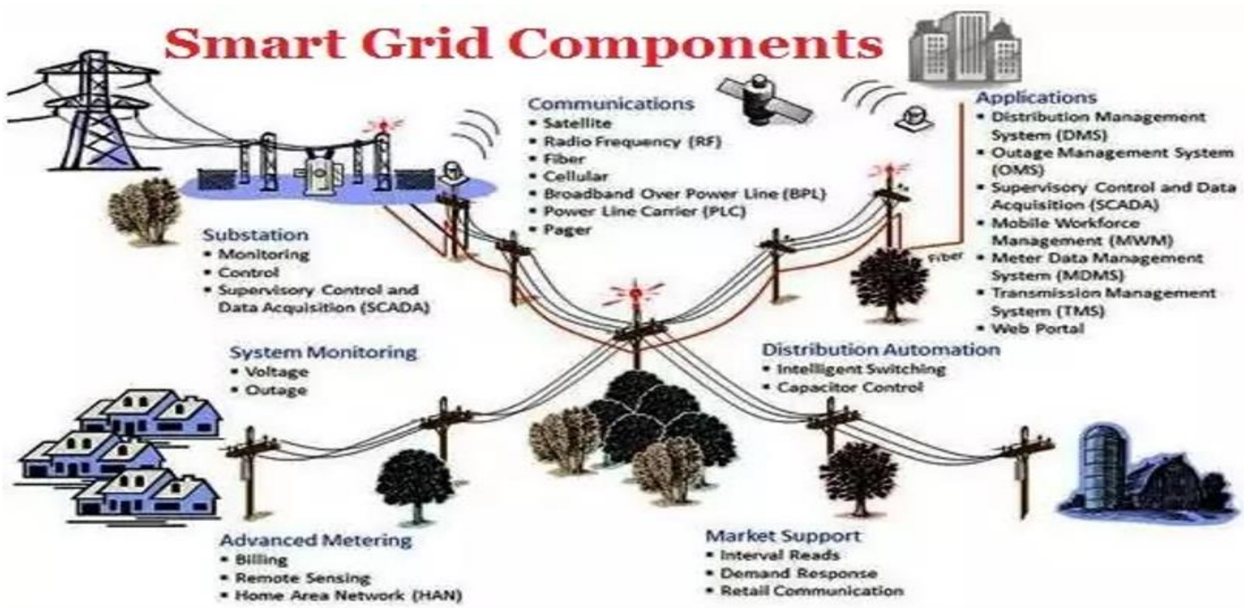

Fig 1. Smart Grid Network Architecture

Furthermore, using smart technologies effectively in Nigerian power system needs the application and integrating infrastructure of communication that enhances data transmission. Significant issues with the current Nigerian traditional grid would be eliminated with the effective usage and control of the emerging smart grid technologies, which would be made possible by a two-way interchange of network information and data, enterprise resource planning software, and collaboration tools (Folasade et al., 2022; Patrick et al., 2013; Ajayi et al., 2014; Fadel et al.., 2015).

Phasor measuring units (PMU), accelerators, infrared sensors, strain gauges and magnetic sensors are sensory devices that are connected to the grid network are used by smart grid systems to automatically correct, report or react to internal alteration conditions. Moreover, smart technologies enables communication networks delivery systems to function as remote intelligent agents, producing information (data) that is sent to the monitoring center. While sophisticated analytics tools facilitate the gathering of data for decision-making, modern network management technologies help prevent blackouts and take advantage of variable renewable energy supplies. These data's deep availability makes it possible to take practical steps to reduce disruptions in wide area and increase reliability and efficiency of transmission system (Folasade et al, 2022; Emmanuel and Rayudu, 2016).

Table. 1 Comparison of the general features of the Smart Grid System and the current Traditional Grid

S/N	Features	Traditional Grid	Smart Grid
1	Communication	One-way	Two-way
2	Power Flow	Unidirectional	Bidirectional
3	Generation	Centralized	Centralized and Distributed
4	Monitoring	Manual, periodic	Real-time, automated
5	Outage Response	Slow, manual restoration	Fast, automated "self-healing"
6	Consumer Role	Passive consumer	Active participant ("prosumer")
7	Renewable Integration	Limited	Seamless
8	Technology	Electromechanical	Digital, IoT-enabled
9	Attacks	Not Vulnerable to cyber attacks	Vulnerable to cyber attacks
10	Metering system	Not net metering system	Enhances net metering
11	Control and monitoring	Manual	Automated and use of AI
12	Reliability	Prone to blackouts and faults as well slow fault detection	Automatic fault detection, isolation, and restoration
13	Energy sources	Mainly fossil fuels and centralized power plant	Integrate renewable energy sources.
14	Efficiency	Low efficiency due to poor load management	High efficiency due to peak load

		and transmission losses	management and optimization.
15	Role of Consumers	Consumers are passive	Consumers are active, can monitor usage and adjust demand.
16	Maintenance	Reactive maintenance	Predictive and preventive maintenance.

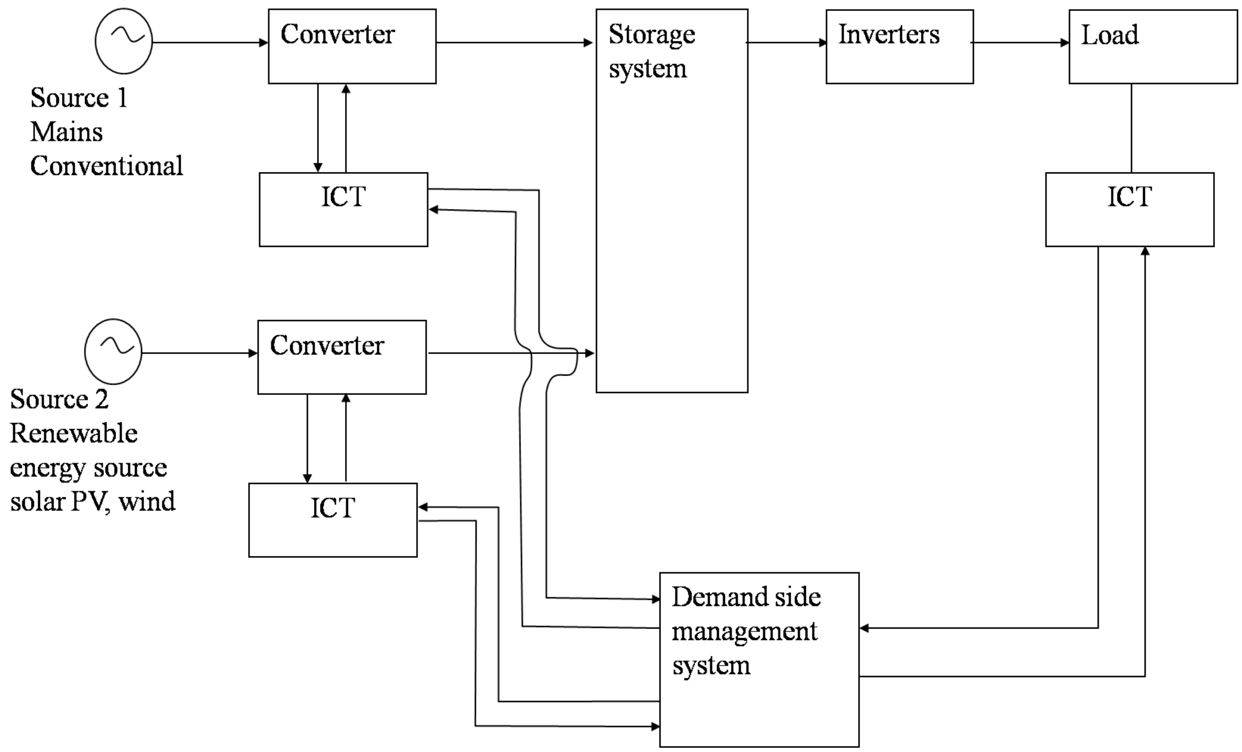

Fig.2 Block diagram Representation of Smart Grid (Eleje.N.E et al, 2024)

2. SMART GRID TECHNOLOGIES IN NIGERIA POWER SYSTEM.

The smart grid technologies used in Nigeria are; Information and Communication Integration (ICI), Wide Area Monitoring and Control (WAMC), Advanced distribution Automation (ADA), Customer Side System (CSS), Demand Response (DR), Advanced Metering Infrastructure (AMI), Transmission Enhancement Applications (TEA) and Microgrids and Distributed Energy Resources (DERs) (Folasade, et al, 2022). Other technologies are, Supervisory Control and Data Acquisition (SCADA), Artificial Intelligence (AI) and Machine Learning (ML), Cybersecurity for Smart Grids and Energy Storage System (ESS) and Integration of Renewable Energy Sources (IRES). However, few of these technologies will be discussed in details below.

a).Information and Communication Integration (ICI). The introduction and integration of communication infrastructure that is supporting data transmission is important for applying Smart grid to Nigeria's power system (Ajayi et al, 2014 and Folasade, et al 2022). A foundational element that links smart grid devices and wired (fiber optic) or wireless (RF, Cellular, Wi-Fi, LPWAN) technologies.

b). Wide Area Monitoring and Control (WAMC): The wide area monitoring and control (WAMC) is a crucial smart grid feature that allow energy consumers to participate directly in Energy use tracking and regulation (Folasade, et al, 2022, Reddy et al, 2014; Saleem et al. 2019; Wang et al, 2019). It is designed to enhance the reliability, stability and efficiency of modern power systems by using real – time monitoring and control over large geographic areas. It integrates advanced sensing, communications, and control technologies to provide operators with a comprehensive real – time view of the entire power grid.

c).Advanced Distribution Automation (ADA): The Advanced distribution automation system is power system is a smart grid technology that uses advanced communication and control system to optimize the distribution of electricity and the purpose of automated distribution system in power system engineering is to efficiently manage the flow of electricity from power generation to consumers (Kendule et al, 2024).

d). Customer Side System (CSS). This is all technologies, devices and systems located on the consumer's premises that interact with the smart grid network. It is a key part of Advanced metering Infrastructure (AMI) and Demand Side Management (DSM). It is a collection of customer owned equipment with the ability to manage electricity usage, improve energy efficiency, and enable two way energy and information flow. CSS components are; smart meters, Home Energy Management Systems (HEMS), Smart Appliances, Distributed Energy Resources (DER) etc.

e). Demand Response (DR). This is a deliberate modification of electricity consumption by end –users during peak periods or emergencies, triggered by price signals, incentives or direct control actions from the utility.DR is a program designed to influence consumers to change their immediate electricity consumption in response to changes in price (indicative of scarcity) or some form of incentive payment (Adeyemo and Amusan, 2021). According to US department of energy, it is incentive payment programme to reduce electricity usage when grid safety and reliability is imperiled (U.S DOE, 2006). DR programmes can be grouped into tariff based programmes and incentive based programmes (Adeyemo and Amusan, 2021).

f). Advanced Metering Infrastructure (AMI).AMI is a system consisting of modern electronic-digital hardware and software, which enables data measurement intermittently and remote communication continuously. These systems have an infrastructure that can make detailed measurements, collect time-based information constantly and share this information with the parties as needed (Akpolat and Dursun, 2017). This is metering system that measures hourly consumption of customer or more regular than hourly. AMI is about smart meters and smart meters functions include measurement and communication. Implementation of AMI softwares into these meters support variety of controls, facilities and features (Nimbargi et al, 2016). AMI enables utilities and customers to exchange information automatically and supports many smart grid functions such as demand response, outage management, and dynamic pricing.

g). Transmission Enhancement Applications (TEA). These are intelligent applications that enhance transmission system operation by providing real – time monitoring, analytics, automation and control to improve power flow, stability, security, and asset utilization within the smart grid. This smart transmission grid will employ a unique, digital platform for fast and reliable sensing, measurement, communication, computation, control, protection, visualization, and maintenance of the entire transmission system (Li et al, 2014).

h) Distributed Energy Resources (DERs). This is a small scale decentralized energy sources or devices located close to consumers that can produce, store or manage electricity like microgrids. It can adjust consumption to support grid operations. Examples of DERs are solar panels on roof tops, Home battery, EV charging at home or office, industrial plant reducing load during peak, community wind farms and residential smart thermostats responding to price changes.

2.1 Challenges of smart grid technology adoption in Nigeria power system.

Smart grid technology is important for the growth of power sector in Nigeria but there are many factors hindering its adoption. These factors are:

a).Cyber-attacks, Infrastructure Theft, and Terrorism

Cyber-attacks affect countries, businesses, organizations, security agencies, and infrastructures. They are a worldwide phenomenon. The software and hardware infrastructure that governs the smart grid may sustain damage from them. Additionally, SG is susceptible to cyber threats due to its reliance on information technology.(Reddyetal.,2014).The projected annual cost of fighting cybercrimes worldwide is $445 billion. (Jiang et al, 2014) and third world countries, such as Nigeria, allocates small or no funds in combating cybercrime which attacks smart grid network. For a safe and reliable system, SG deployment in Nigeria must be combined with organized cyber security (Otuoze et al., 2017).

b). Lack of routine maintenance.

Over time, the power industry has shown a weak maintenance culture; the major repair or maintenance done by electricity personals is clearing of faults and this reactive process is good for the system. For the best performance and life cycle extension of electricity infrastructure, however, planned maintenance does not exist. Therefore, capacity may still be constrained even if producing capacity increases as a result of the adoption of an intelligent grid, (Akpojedje et al., 2016).

c). Low financial allocations and inadequate enforcement of regulatory rules.

Since consistency and good articulated plan are necessary for the sustained projects implementation, most developing countries' poor regulatory regulations and implementation act as a barrier to the deployment of SG. Since the pertinent electricity stakeholders disregard the regulations, regulatory agencies like the Nigerian Electricity Regulatory Commission (NERC) are content to carry out their main duty of regulating the power sector,(Akpojedjeetal.,2016).The limited budget allocations in many underdeveloped countries are another obstacle to increased funding, given the cost of SG deployments. When SGs are implemented, excellent and consistent regulatory policies will be beneficial (Otuoze *et al,* 2017).

d).The volatility of the production of renewable energy sources

Natural occurrences that change according to the weather, the time of day, the season, and other variables are the foundation of renewable energy sources. It would be difficult to provide consistent electricity supply for a day, month, and year due to these fluctuations. If the frequency is maintained within a suitable range with the Ancillary Frequency Support Service (FSAS), the generated electricity would be safely absorbed into the grid. This would supplement the frequent shifts in energy generation, (Aliyu *et al.,* 2018). To accommodate variations in the production of renewable energy, a dispatch plan for FSAS can be developed based on the regular environmental prediction. Hence, a system which minimizes negative impacts on issues of quality power on current power systems while improving sustainability, supply synchronization, and power generation distribution in emergent power systems can be established using micro grids and distributed energy resources.(Emodietal.,2014)

e). Vandalism of equipment for transmission and distribution systems.

Vandalism of Nigeria's distribution equipment and transmission infrastructure was common prior to the most recent power sector reforms. Business men that import stand-alone power generation are mainly held accountable for these types of saboteurs. One major concern that could hinder Nigeria's implementation and integration of the smart grid is vandalism of the country's electric infrastructure.(Emodi andYusuf,2015).

f). Inadequate smart grid technology research, knowledge, and marketing

Information regarding Nigeria's potential for green energy is currently unavailable. The discovery and utilization of renewable energy sources will therefore be difficult for potential investors to evaluate from a business standpoint. Thus, the creation and administration of such trustworthy data is essential to the appropriate design and implementation of the system. But considerable work has still to be done to support research and collect information on strategies, practices, and tactics that might be applied to the implementation of smart grid technologies in Nigeria.(Samboetal.,2012). Smart sensor, secure relay, and control device research and merchandising would need to be innovative in order to integrate DER into the network. The installation of DER will be reduced by less expensive sensors and controllers, which will also ensure the dependability of interconnected DER systems and safeguard line operators and the general public during maintenance and rebuilding. As autonomous operation grows, however, so will the technical expertise of smart grid technology (Amuta etal.,2018; Rehmani etal.,2018).

g). Lack of Institutional arrangement.

The spread of renewable energies is hampered by discrepancies caused by the failure of government agencies to coordinate and execute clean energy programs. Nigeria's renewable energy sector seems dwarfed when compared to smaller nations like Kenya due to lack visible government oversight and guidance, lax regulatory frameworks, shortage of human capital and limited government support. There is now little chance for a quick transition to a green energy economy since no efforts are being made to educate and raise awareness of basic renewables among rural residents. (Ikem et al, 2016)

h). Corruption

Among its peers, the country has regressed due to the corruption issue. Every sector of Nigeria's economy has been severely damaged by the widespread epidemic of corruption, including the electrical sector. Several cases of corruption have sparked controversy in the power industry (Ndinechi *et al.,* 2011). For some high-ranking private citizens and government officials, corruption has become the norm in the majority of developed countries. A strong government penalty against corruption would aid in the deployment of SGs, as corruption also leads to increased theft, (Otuoze *et al.,* 2017).

3. Attacks on Smart grid system.

Apart from the factors listed above, attacks on smart network is one the major setbacks confronting smart grid system in Nigeria and also across the globe. Attacks on smart grids pose significant risks to infrastructure, security, and public safety. A smart grid integrates digital communication and automation technologies into the electrical grid, making it more efficient but also more vulnerable to cyber threats. Notable among the attacks on smart grid system includes;

a). Denial of Service (DoS) Attacks: These attacks scenario try to overwhelm grid components with traffic or commands, causing system slowdowns or outages. For example, an attacker might flood the network with fake requests, preventing legitimate commands from being processed.

b). Data Manipulation and Spoofing: Attackers might alter data being transmitted within the grid to mislead operators or disrupt operations. Spoofing involves sending fake data that masquerades as legitimate information to deceive grid systems.

c). Control System Attacks: These attacks target the control systems used to manage and operate the grid. By gaining access to these systems, attackers can potentially take control of critical functions, causing operational failures or equipment damage.

d). Phishing and Social Engineering: Attackers might use phishing emails or social engineering tactics to trick individuals into revealing login credentials or installing malware, giving them unauthorized access to grid systems.

e). Malware and Ransomware: Malware can be used to compromise grid systems by corrupting or stealing data, while ransomware encrypts data and demands a ransom for its release. Both types of attacks can disrupt grid operations and pose significant risks.

f). Man-in-the-Middle (MitM) Attacks: In MitM attacks, attackers intercept and potentially change flow of information between grid components. This can lead to incorrect data being used for decision-making, affecting grid stability and reliability. Such data interception can also happen during recharging processes where the attackers send recharge tokens to customers but the money doesn't get to the electricity provider.

g). Physical Attacks: While less common, physical attacks on the infrastructure that supports smart grids (like substations or data centers) can also disrupt operations. These can range from vandalism to more sophisticated sabotage. This also include meter bypassing, meter tampering, illegal tapping etc

h). Insider Threats: Employees and contractors that good knowledge the system can pose a threat compromising grid security intentionally and unintentionally. They might misuse their access to disrupt operations or steal sensitive information.

4. CONCLUSION

The adoption of Smart grid technology in Nigeria's power system offers a significant opportunity to improve reliability, efficiency, and sustainability, but numerous challenges continue to militate against good progress in this technology. Technical constraints like aging transmission and distribution network, inadequate infrastructure, criminal activities like vandalism, lack of trained, experienced personnel and limited ICT constitute serious challenges towards actualizing smart grid technology in Nigeria's power system. These are compounded by economic barrier, corruption and government unwillingness to invest in power sector.

Despite these problems, the long term benefits of smart grid deployment remain compelling. Achieving this requires coordinated action, stronger policy framework, capacity building, public education and a strategic modernization of grid infrastructure. Nigeria can overcome these challenges and limitation toward smart grid technology adoption in her power system through deliberate planning, stakeholder's commitment and investment.

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