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Battery Energy Storage System (BESS), Panacea to Grid Stability in Nigeria

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ABSTRACT
Constant electric power supply is an ingredient of national and economic development of every nation. Nigeria as a nation and its populace has suffered immense economic losses along with social and technological discomfort arising from inadequate and in many instances lack of electric power supplies to consumers when needed. Largely due to inability to reliably and consistently transmit generated power to end users through the national grid system. National grid system is network of power generation and distribution facilities that connects the power sources to the end users. Battery energy storage systems (BESS) offer a solution to this distressing incessant grid stability and collapse. These BESS if incorporated into the national grid system will offer a promising solution the Nigeria's grid system collapse crisis. Although, it requires a robust connection to existing SCADA and PMS system alongside upgrade in the power assets round the country. Digital monitoring of electricity transmission and generation in real time will provide respond promptly to maintain a stable grid, eliminating the collapse both partial and complete off the grid network. Several efforts have been expended in generating more power, also investments have been made over the years to expand the grid to accommodate more power especially from different energy mix, but all this will not achieve much satisfaction, if the grid collapse continues unabated. This study therefore recommends the deployment of BESS at strategic locations around the country with an upgraded grid system as a more sustainable way to reduce or eliminate the current incessant future grid collapse.
Keywords: Grid system, Battery Energy Storage System (BESS), SCADA, PMS, Power, Transmission, Network

1.0 INTRODUCTION
The stability of Nigeria's power grid has long been a critical issue, affecting economic growth, industrial productivity, and the daily lives of millions of citizens. Frequent power outages, voltage fluctuations, and load shedding are indicative of deeper systemic inefficiencies and challenges in the country's energy infrastructure (Olatunji *et al*., 2018). As Nigeria continues to urbanize and industrialize, the demand for

reliable and stable electricity is more pressing than ever. Energy storage systems (ESS) present a transformative solution to these grid stability challenges (Ibekwe *et al*., 2024). By capturing and storing energy during periods of low demand and releasing it when demand peaks, ESS can mitigate the discrepancies between energy supply and demand (Babatunde *et al*., 2022). This technology not only enhances the reliability of the grid but also integrates seamlessly with renewable energy sources, addressing the intermittency issues associated with solar and wind power (Oladipo *et al*., 2018).

In this article, the concept of grid system, the study explored the current state of Nigeria's power grid, the underlying causes of its instability, and how energy storage systems can offer a viable and sustainable solution in stabilizing the grid, the potential of energy storage systems, particularly the deployment of BESS, battery storage energy system as a panacea for Nigeria's grid stability problems will be provided.

2.0 Nigeria National power and grid situation

As technology continues to evolve, one element that constantly remained demanding is electrical power, this power is extremely necessary to operate the many devices that is constantly been used to carry out varying kinds of activities (Akhator, Obanor, and Sadjere, 2019). These activities range from common house hold devices like cell-phones, lighting bulbs, blenders, micro-wave etc to huge industrial equipment like motors, heaters, they all consume some degree of electrical power, which as more and more of these are produced and operated, more power is required, putting immense pressure on available power (Arowolo *et al*., 2019). There are various sources of energy, according to Ogbonnaya *et al*. (2019) they are hydropower, gas power, coal power, nuclear power, wind power, solar power, oil-based fuel power, etc. Amongst these numerous powers, some has been realised to be renewable in nature like hydropower, wind, solar etc (Chanchangi *et al*., 2023). While others like gas fired are known to emit green house gases which are harmful to the environment. Renewable energy-based power has little to zero carbon footprint which makes it ideal for environmental sustainability (Liao *et al*., 2020).

The push for the reduction in global temperature to 1.5 degrees and to curb the adverse impacts of climate change, which target emissions cut by 45% by the year 2030 or reaching the target net zero dream by 2050 has led to an increase in the expansion of renewable energy power sources (Oyedepo *et al*., 2018). Despite the rising quest in renewable energy share especially in power generations Nigeria still lingers with the epileptic power outages and recurrent grid collapse in its national grid system (Rahimi *et al*., 2013). Although Babatunde *et al*. (2022), confirmed that renewable energy amongst other energy sources has the disadvantage of been unpredictable, with inherent reliability issues and worst still is heavily impacted by natural changes and disasters, making it unstable, but still there exists a proven way to manage it within a grid network, by supplementing it with a stored energy system to create the missing balance, making it stable and predictable (Mohamad *et al*., 2018).

An electric grid, which is an interconnected network that takes electric power from the points of generation to the point of consumption via various HV and LV transmission systems (Zame *et al*., 2018). It is the system that connects electricity producers and electricity consumers, ensuring multiple consumers and produces are hooked up, within a typical city or domain (Morello *et al*., 2017). Ideally there exist different electricity providers, therefore they need to be synchronised, which is the process of making all electricity producers to match their frequency, voltage and current to a uniform range, without which electricity cannot be fed into the grid by a particular producer (Worighi *et al*., 2019). A grid therefore is a complex system of networks, consisting of transformers, substations, high and low voltage lines that work together to carry electricity from the producers to the consumers (Rathor and Saxena, 2020). This process guarantees efficiency in power optimization within the system, improving quality and reliability, eliminating destructive interference that will otherwise cause the network to fail (Gur, 2018).

In Nigeria, there exists an extremely weak grid system which has consistently not lived up to expectation, its grid is connected to transmission substations across the countries powered largely by a mix of thermal and hydro plants (Alao and Awodele, 2018). Unfortunately, it has been observed that when one generator fails, it results in the collapse of the grid, the grid system should supply continuous power, irrespective of imbalances or upsets its experiencing, allowing for maximum power distribution and efficiency (Ekpe and Umoh, 2019).

Table 1 Incidences of Grid collapse between 2000-2022 (Nigerian National grid).

Year	Partial collapse	Complete collapse	Total
2001	5	14	19
2002	32	9	41
2003	39	14	53
2004	30	22	52
2005	15	21	36
2006	10	20	30
2007	8	18	26
2008	16	26	42
2009	20	19	39
2010	20	22	42
2011	6	13	19
2012	8	16	24
2013	2	22	24
2014	4	9	13
2015	4	6	10
2016	6	22	28
2017	9	15	24
2018	1	12	13
2019	4	7	11
2020	1	3	4
2021	2	2	4
2022	2	6	8

(Jimoh and Raji, 2023)

In 2023, The Nigerian grid had a partial collapsed three (3) times and one (1) total collapse that caused a nationwide blackout. While in the year 2024, the country witnessed twelve (12) national grid collapse, this therefore, underscores the complexity of the current electricity problem in Nigeria (Amadi and Ekeng, 2024). Nigeria power generators produce at 11kV and 16kV, which is then transformed to 132kv and or 330kV, with the aid of a transformers for transmission, connecting it to the grid network with varying substation, some used to step down the power for distribution to consumers (Emovon *et al*., 2018). This reduction in voltage, from 330 kV to 132 kV, then to 33 kV, regarded as the primary distribution voltage, and finally to 11 kV for primary users, while industrial users can take 33kv directly, this is utilized as the secondary distribution voltage, with a nominal frequency of 50Hz +/- 0.4%, this is also brought down to 0.415kV for a line to line and 230V for a line to neutral to make it ideal for appliances functioning properly (Zame *et al*., 2018). Nigeria is known to have only 23 operational power generators supplying to the grid, with kainji and Shiroro as the 2 main hydro power while 21 thermal power plants make up the rest, with more under construction (Owebor *et al*., 2021). The thermal power generators have a combined installed capacity of 8,457.6 MW though available capacity hover around 4,996 MW, hydropower capacity is 1,938.4 MW though hampered by water levels, with available capacity around 1,060 MW, making a total installed capacity of 10,396 MW, with only 6,056 MW maximum been able to be wheeled by the transmission grid (Heinemann *et al*., 2022).

Transmission Company of Nigeria (TCN) is responsible for the transmission of grid power with a major Control Centre at Osogbo, Osun State. Where the grid power is distributed to 11 Distribution Companies (Discos) that spans the six geopolitical zones of the country, these DisCos carryout the following function: electricity supply to desired commercial and industrial users, act as intermediaries between consumers and grid generators and they are responsible in revenue generation to fund the entire power value chain (Kemabonta and Kabalan, 2018). It is important to note that current, voltage and frequency imbalance can cause grid collapse, excess or low frequency can cause the grid to shut down, which should not be if an efficient Energy Management System (EMS) is deployed. In Western countries for instance,

grid collapse is not common, but unfortunately, that is not the case for Nigeria, were grid collapse is rampant, resulting in loss of electricity supply across the country, with consumers complaining about power unavailability, this is common phenomenon in Nigerian national grid, causing a partial or complete systemic failure (blackout), this has led to poor socioeconomic development and industrialization of Nigeria. According to Jimoh and Raji, (2023), in an 18-year review, the grid was observed to have failed at an average two and a half times per month, in reality, January 2018 saw exactly 6 grid collapses in eight days.

2.1 Causes of grid collapse in Nigeria

There are many reasons for the grid collapse in Nigeria, broadly discussed under 2 key areas, they are technical and non-technical causes. The technical causes occur due to loss of power from a generator, popularly referred to as generator outage, loos of generators supplying large loads to the grid, will typically lead grid system instability, if no measures are put in place to mitigate it (Ekeng *et al*., 2024).

Line tripping is another cause for grid collapse in Nigeria, it is the process of isolating a section of the grid or a substation supply line, physical issues line poor earthing, or an unforeseen failure in a HV accessory which has been deemed to be of high risk requiring planned isolation of that section. If not properly done, can lead to grid failure, off course the absence of a (PMS), power management system, latest technical advances to manage grid flexibility in the Nigerian grid, has made it more susceptible to collapse at any time (Jimoh and Raji, 2023). While sudden and unplanned load increase in demand or load rejections by distribution companies can also result in fast load drop on the network, causing severe instability and ending in grid collapse. Therefore, there should always be an efficient communication system round the clock between the system operators and all stakeholders in the power industry in order to mitigate such risk (Amadi and Ekeng, 2024).

The non-technical causes include; vandalism which is rampart in Nigeria has been a major non-technical cause of grid collapse. This can be vandalism of direct power equipment, like the bombings of power pylons in Maiduguri and other parts of Nigeria, or indirect like the several attacks on gas infrastructures, leading to acute gas shortages to power the thermal power plants in the Niger-delta areas of southern Nigeria (Adebayo, Oladeji and Adebayo, 2024). Planned shutdown of upstream gas suppliers, periodic maintenance both planned and unplanned are carried out on gas processing and supply facilities, this has direct impact on the likelihood of the grid collapsing, since no active mitigation system is available to manage the grid (Ekeng *et al*., 2024).

2.2 Effects of Grid Collapse

Grid collapse is no doubt associated with a number of effects among which is great deal of inconvenience, consumers observe a great deal of discomfort anytime there is no power, as most home appliances, including phones depend on electric power to function, as well as life comforting equipment like the air-conditioners and refrigerators all depend on power to run (Amadi and Ekeng, 2024). This will cause the consumers to seek alternative power sources like procuring portable generators to power their homes, exposing theirselves to hazrds of noise, hydrocarbon fume inhalation and financial losses to maintain such systems (Adamu *et al*., 2022). One major effect of grid collapse in Nigeria is loss of investments and attendant employment, businesses will not thrive, since cost of doing business will rise in such an unpredictable environment leading to higher unemployment rate, as witnessed in Nigeria in 2023 when heavy industries like Michelin and Dunlop who depend heavily on power left to neighboring countries like ghana to establish their plants (Omeiza, Ahmed and Patrick, 2023). While another important effect is overall economic stagnation, the Nigerian economic has largely remained stagnant, partly due to her inability to solve the power conundrum (Leahy, Olowosejeje and Morrison, 2019).

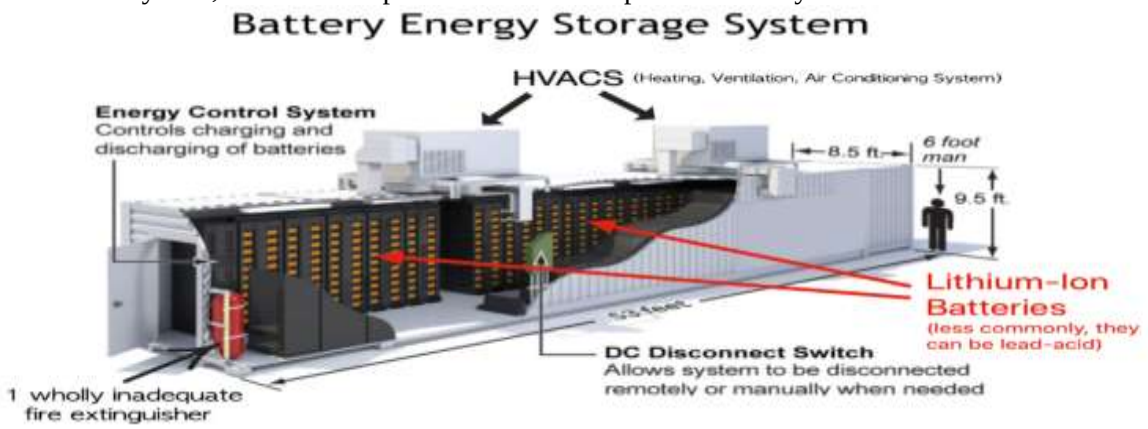
3.0 BESS Smart grid system as a panacea to stabilizing the grid

To maintain the integrity of a grid, is to create a system of sustained power supply to the grid, avoiding any imbalance in the three (3) critical elements of synchronous power, which are, voltage, current and frequency. The best-established system to guarantee that these (3) critical elements can be sustained is to deploy a reliable energy storage asset at strategic locations within the country mated with a digital smart SCADA grid controller system (Ekeng *et al*., 2014), These energy storage assets simply absorb power, storing it with the intention to release when needed to support the grid, preventing such imbalance or

disruptions within the grid from occurring (Jimoh and Raji, 2023). According to United States Department of Energy Storage Systems, there are 4 types of electric power storage systems currently in use, they are battery storage system, thermal energy storage, mechanical system storage and pumped hydro storage system.

3.1 Battery Storage System

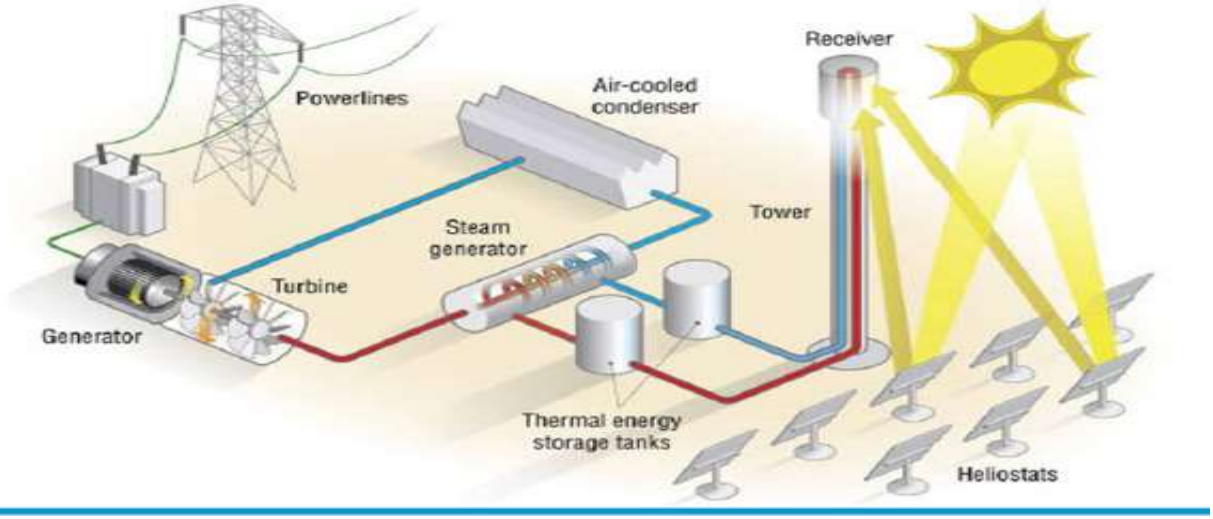
This is the most common in use, due to its variability and ease of installation and operation, Battery Energy Storage System (BESS) is simply a compartment of batteries, sized appropriately to meet design capacity, specific power and duration plan (Figgener *et al*., 2020). It could be lithium-ion, lead acid, sodium etc., it is common fitted within a container space, arranged inside a rack, it usually seems small as per the work it can do, overall cost is declining due to advancement in technology and design, especially with electric cars becoming more required to reduce carbon footprint (Figgener *et al*., 2022). Fig 3 below, shows BESS system, within it compartment with description of the key units.



(Admin, 2024)

3.2 Thermal energy storage system

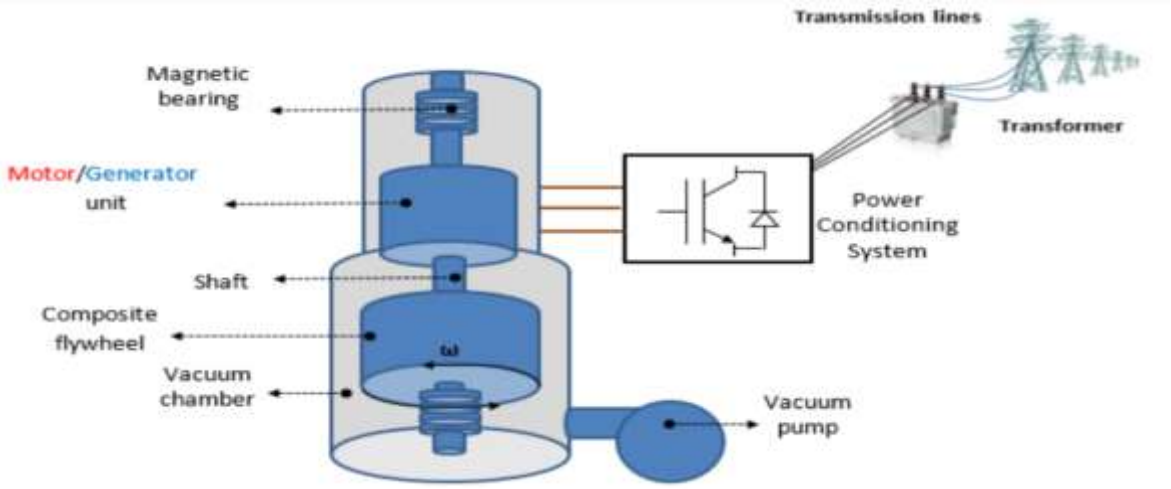
According to Sarbu and Sebarchievici (2028), thermal energy storage system is a type stores electric power by utilizing simultaneous heating and cooling method, like having a chilling ice system in buildings, eliminating the need to install air-conditioners for temperature cooling or using molten salts to store heat, in these instances excess electricity is diverted to store energies, before been reversed when the energies are required. Fig 4, showing solar energy generating heat and stored as thermal energy



(Redirect Notice, 2024)

3.3 Mechanical energy storage system

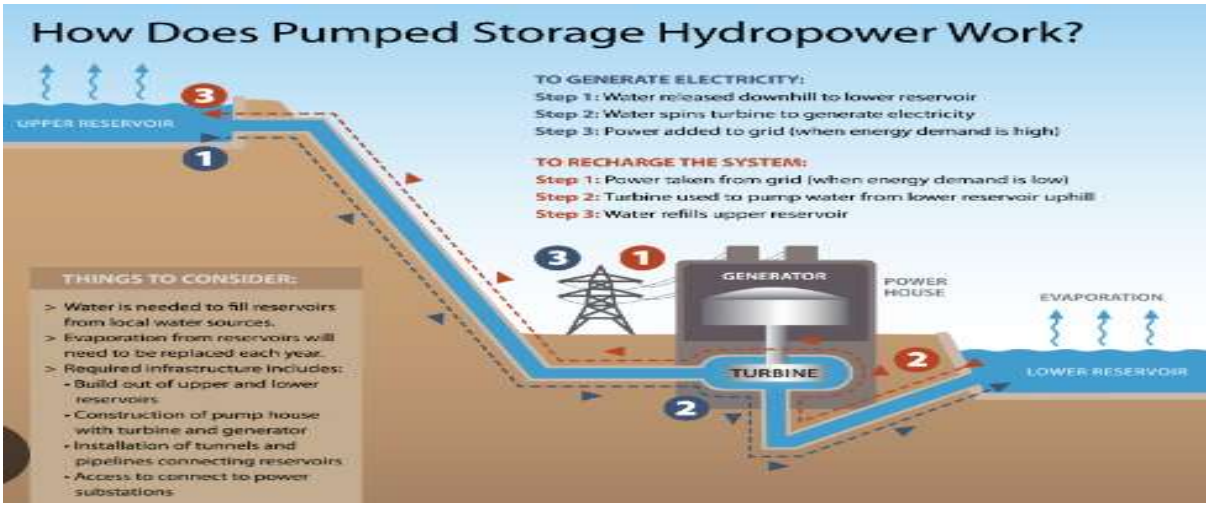
In this energy storage system, the energy can be stored within a mechanical system, like utilizing a flywheel, spinning it rapidly, it is capable of storing such energy in rotational motion and releasing it when required, it typically doesn't last long, say about 15 mins or thereabout, though development of longer duration types are ongoing, it can be used to provide short term power for critical manufacturing process, during initial trip period, until backup power comes online (Mahmoud *et al*., 2020). Fig 5 showing schematic diagram of energy storage system



(Planet Decarb. 2024)

3.4 Pumped Hydro Energy storage system

This is becoming common in developed economies, and suitable for high-capacity energy storage, it is similar to normal hydro power generation (Blakers et al., 2021). Unlike hydro power, it uses 2 reservoirs to store water, (Upper reservoir and Lower reservoir), during excess electric, non-peak period (Guezgouz *et al*., 2019). Electricity is used to pump water from lower reservoir to upper reservoir, while during peak period when electricity demand if high, water from upper reservoir is channelled downwards under gravity to drive the turbine and generate power to support peal load demanded by the grid (Javed *et al*., 2020). Fig 4 below, shows a typical pumped hydro energy storage system with description of operations



(Grand Canyon Trust, 2023)

3.4 Emerging forms of energy storage systems

According to Chang *et al*. (2021), there are also other forms of energy storage that is considered as emerging technologies, like storing energy in the form of hydrogen or ammonia, were excess electricity is used to drive an electrolysis process to split hydrogen from oxygen, this hydrogen can be converted back or utilized later to do work somewhere (Aziz *et al*., 2020). Other storage systems like the use of compressed air, underground pumped storage, superconducting magnets etc. are still emerging (Kaiser, Winde and Erasmus, 2018).

3.5 Functions of the energy storage systems

According to Nadeem *et al*. (2018), energy storage systems have enormous benefits to a national grid, since it helps with the following functions:

3.5.1 Peak demand reduction

It directly helps in reducing peak demand on a grid, since it is used to compensate for the extra demand on the grid, thereby reducing stress during such peak load demand, such as when people return home in the evening, home appliances tend to be put more in use than in the normal day time (Byrne *et al*., 2017).

3.5.2 Grid reliability

Energy storage systems, ensures grid network is more reliable, been able to support quick response to mitigate any imbalance in the transmission, even during natural disasters, if well sized should be able to weather the storm, and if a smart system is mated with it, can isolate regions of concerns while a major part of the system is left functioning, ensuring critical services remain online (Mohamad *et al*., 2018).

3.5.3 Renewable energy sources integration

Energy storage system efficiently allows multiple use of varying renewable energy sources to feed the grid; while equally compensating for their intermittencies, it stores excess energy when generation exceeds demand and releases it to support the grid when required (Kebede *et al*., 2022). It helps in maintaining consistent power supply and supporting net zero initiatives to reduce carbon footprints and the penetration and deployments of more renewable energy technologies (Olabi *et al*., 2021).

3.5.4 Allowing outage mitigation and supporting diverse applications

In areas susceptible to outages, like remote regions, a dedicated energy storage system can be designed to managed that challenge, acting as backups anytime an outage occurs in that region (Nadeem *et al*., 2018). Thereby supporting the grid there to become a micro-grid system, with the help of smart devices can be connected and disconnected from the main grid, allowing for diverse application in such modes, helping to optimize energy consumption and generation and supporting ventures like electric vehicle charging, special energy users (Faisal et al., 2018).

4.0 BESS as a solution to stabilize Nigerian grid system

This BESS system mated in a digitalized smart grid system, involved of (SCADA) Supervisory control and data acquisition, as well as advanced (PMS) power management system sized adequately, guarantees efficient and seamless stability of Nigerian grid network, eliminating grid collapse (Nasir and Marcia, 2013). Akinsooto, Ogundipe, and Ikemba (2024) confirms that smart grid is a critically part of a modern-day grid system, utilizing modern digital technology to combine different electric power sources and most importantly renewable energy sources, which in their nature are intermittent, to create a robust energy grid, capable of weathering the imbalances that grids are subjected to (Oyekale *et al*., 2020). The SCADA, PMS and Demand response functions can be better managed allowing the instant and controlled balance within the grid (Rathor and Saxena, 2020). A smart grid system will support key energy applications like load planning and forecasting, outage automation, market settlements, generation power units scheduling, power generator synchronization and many other benefits inherent in a good EMS (Meliani *et al*., 2021). Energy management system platform, allowing for mitigations to be built into all contingencies, helping system operators of the grid to battle grid instabilities with ease and return the grid back to stable state, without the consumers even feeling any loss of supply, as is obtainable in advanced nations (Ratshitanga *et al*., 2023). A control centre, built in all the 6 geopolitical areas of Nigeria should be linked to all installed BESS and SCADA and available PMS, to ensure enhanced communication and real time analyses of the grid for the system operator to develop a robust framework of procedures required to address major grid instabilities (Khan *et al*., 2022). With more advances in technology, Digital

Smart grid will continue to evolve, so it will be beneficial for Nigeria to invest more in the right technology, building intelligence into the grid network, train employee to get them qualified and competent in this new technology to be able to operate and maintain the grid better (Oyekale *et al*., 2020).

5.0 CONCLUSION

The quest for grid stability in Nigeria has faced numerous challenges, from technical inefficiencies to non-technical disruptions. With the nation's current power generation infrastructure producing electricity at varying voltage levels and encountering frequent collapses, the need for a transformative solution is urgent. Energy Storage Systems (ESS) present a viable and sustainable answer to these challenges, offering a path to a more resilient and reliable power grid. Nigeria's power grid, strained by limited generation capacity and frequent grid collapses, suffers from both technical issues, such as generator outages and line tripping, and non-technical factors like vandalism and planned gas supply shutdowns. These disruptions not only inconvenience consumers but also stifle economic growth and industrialization. As demonstrated, a grid collapse has far-reaching effects, causing significant economic and social impacts. The implementation of Energy Storage Systems (BESS) such as battery, thermal, mechanical and pumped hydro energy storage systems offer a promising solution. Among these, BESS is particularly suitable for Nigeria due to its ease of deployment, scalability, and minimal ecological footprint. BESS can be rapidly deployed and expanded, providing flexibility to meet future energy demands and supporting the integration of renewable energy sources. By deploying BESS strategically across the country and linking them to a smart grid, Nigeria can mitigate grid instability and enhance the overall reliability of its power supply. In conclusion, the adoption of energy storage systems, particularly BESS, coupled with a smart grid infrastructure, is crucial for stabilizing Nigeria's power grid. Additionally, smart grid system, integrating advanced Supervisory Control and Data Acquisition (SCADA) and Power Management Systems (PMS), is an essential system for maintaining grid stability. Such a system ensures real-time monitoring and management of the grid, enabling quick responses to imbalances and preventing collapses. This approach will not only address current technical and non-technical issues but also supports the country's long-term energy strategy, fostering economic growth and improving the quality of life for its citizens. Investing in these technologies and building a robust framework for grid management will pave the way for a more stable, efficient, and resilient power system in Nigeria.

6.0 RECOMMENDATIONS

Based on this study's finding, the following constitute some useful recommendations that will enhance Nigeria's grid system, Nigeria should therefore;

i. Make significant investment in battery energy storage system infrastructure through government and private sector partnerships.
ii. Integrate renewable energy sources such as solar, wind, and hydro energy systems which will in turn guarantee a steady power supply.
iii. Set up unambiguous policies and incentives such as tax exemptions, subsidies, and advantageous tariffs for energy storage projects so as to encourage the adoption of BESS.
iv. Maximize BESS efficiency, enhance load balancing, and lower transmission losses in the national grid systems using smart technology such as grid modernization and smart technology adoption
v. Improve energy access, emphasizing on deployment of mini-grid and off-grid BESS solutions in rural and underserved areas.
vi. Provide training programs to Nigerian based engineers and technicians for BESS administration, maintenance, and installation.
vii. Provide more funds for research and development in order to create economical and effective battery storage solutions suitable for Nigeria's energy requirements.

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