

SMART GRID: THE VIABLE ROUTE TO TROUNCING NIGERIA'S RECURRING SYSTEM COLLAPSES

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ABSTRACT

As of 2018, the National Grid of Nigeria (NGN) experienced an average of twenty-eight (28) system collapses in each year of the preceding twelve years. The NGN suffered three collapses in 18 hours of May, 2019 after collapsing six (6) times in Q1 of the same year. The recent suspension of Distribution Companies (DisCos) like Kano Electricity Distribution Company (KEDCO) due to ancillary payments failure has brought to light the dishonest and arbitrary estimated metering scheme adopted by the DisCos which lead customers owing them billions of Naira. A Smart Grid (SG) is a self-healing, consumer and market friendly grid using digital electric meters that records consumption in real-time, help in responding to demand and on or off power remotely. This paper presents an overview of the epileptic Nigerian power industry and the introduction of the SG as a solution to the lingering NGN system failures. It establishes how using swift Phasor Measurement Units (PMUs), Advanced Metering Infrastructure (AMI) coupled with the self-healing attribute of the SG can facilitate fault detection, isolation and services restoration which would in turn help eliminate the recurring blackouts experienced in Nigeria.

Index terms: smart grid, system collapse, blackouts.

1 INTRODUCTION

Electricity provides the basic infrastructure needed as an input to the economic furtherance of any country. The per capita consumption of electricity is regarded as an index of a nation's advancement in technology and economic development. Nigeria's present per capita consumption around 145kWh (per person per year) is far less than the world average of 3,013kWh [27]. The exponentially growing population, the pace of urbanization and the rise in the use of electric power dependent devices has skyrocketed the demand, while the installed generating capacity remains unchanged, if not plummeting *i.e.* in comparison to the ever-growing population.

Nigeria is blessed with monumental treasure troves of resources which gives it myriad opportunities of changing the course of its economy and the wellbeing of its citizens. It has huge reserves of energy resources amounting to over 5.6 trillion litres of oil, 4 trillion kilograms of coal and lignite and 5.2 trillion cubic meters of gas, as well as huge reserves of hydropower and solar radiation, among others [2]. These would have helped the country in generating sufficient electricity for her citizens, but that is not the story today.

The electricity subsector development has been clogged by monopoly of the electricity market structure, macroeconomic forces, lame regulatory framework, insufficient investment into the subsector, deficient and ageing infrastructure, poor return of government investment, mismanagement of resources including revenue leakages [5, 30]. Before the establishment of the Electricity Power Sector Reform Act (EPSRA) in 2003, \$3.6 billion were infused in the Independent Power Projects (IPP) between the years of 1999 to 2007. On September 25, 2019 the Federal Government (FG) claimed to have injected 1.5tr Naira in the power industry within a period of two years, but all these, without any significant improvement of the power subsector [5].

According USAID Power Africa Fact Sheet, Nigeria (as of November 2018) has an installed generating capacity of 12,522MW with thermal fired stations accounting for 10,142MW whilst hydroelectric accounts for the remaining 2,380 [30].

The Nigerian transmission network run by the Transmission Company of Nigeria (TCN) has theoretical wheeling capacity of 7,500MW consisting of High Voltage Alternating Current (HVAC) 330-kV and 132-kV substations [21]. The current practical wheeling capacity of 5,300MW of the TCN is far below the installed generating capacity, but well above the average practical generation capacity of 3,879MW.

It is hardly surprising that emergency outages (system load shedding) are experienced in a country whose generation capacity is far less than its demand. It is estimated by the International Energy Agency (IEA) that almost 60% of the population are off-grid with many having no alternative of small capacity generating sets that have become commonplace in Nigerian households.

Smart Grid (SG) is an an integration of intelligent technologies that monitors the situations and conditions of the electric power system and decides intelligently in terms of swiftly clearing faults, restoring power and maintaining the stability of the electric power network. Self-healing is one amongst the many vital peculiarities of the SG from the Conventional Grid (CG) [6, 8 and 11].

The paramount aim of this study is to center on the use of the SG to combat incidences of system collapses on the NGN by taking into account the emerging intelligrid technologies, deployment possibilities and challenges. Thus, the study is organized as follows: Section 1 introduces the paper and defines the study problem. Section 2 reviewed study literature. Section 3 states the research methodology of the study. Section 4 discusses the study. Section 5 draws conclusions and inferences from the study.



Figure 1. Map of Nigerian Electricity Grid

Source: Global Energy Network Institute

2 LITERATURE REVIEW

2.1 Instabilities and Blackouts on the NGN

Electricity is the basic sine qua non for the progression of a country's economy in the present world. Shall the supply of electricity pause, many necessary day-to-day activities would also stop. The relationship between energy need and human life in twenty-first century is a direct proportional relationship (the other automatically affecting the other). Access to electricity has reshaped human life in every aspect, from decreasing the working hours in a day and ensuring more agricultural produce to improved transportation facilities and communication interactivity. Literally speaking, the relationship between the per capita energy consumption of a country and the wellbeing of its inhabitants is linear, the increment of the former directly increasing the latter.

The causes of power system blackouts experienced by the NGN are usually due to generation-load mismatch where the connected load is often greater than the generation thereby overburdening the system generation resulting in an eventual failure.

Power system failures inflict consumers in a negative way. The vitiation of the economy caused by the NGN collapses for both domestic and industrial consumers are hair-raising leading to the strategic crackdown of many industries, these in turn affecting the country's Gross Domestic Product (GDP) by about 2.5% [12].

The frequent collapses of the NGN are not pocket and eco-friendly. They have led to increment in carbon emission into the atmosphere due to increase in using heavy machineries by elephantine industries and small generating sets used by domestic consumers. This, as a result, has contributed greatly towards the deterioration of the ozone layer [4, 26].

System collapse might occur due to myriad reasons which include (but not limited to) deployment of radial scheme in the grid network, low inertia of the system and loopholes in protection mechanisms. A faulty governor might also be the reason of a collapse as it is needed to maintain the fuel flow into the engine in order to arrest any frequency deviation. Other reasons that can facilitate the occurrence of collapse include human errors, vandalization, incidents facilitated by nature and poor maintenance of the grid components. [13].

Voltage instability in a power system network occurs when a gradual decline in voltage happens due to a disturbance. The NGN has witnessed a lot of instabilities and system collapses, the highest being 2003 in which the country recorded fifty-three (53) system collapse incidences.

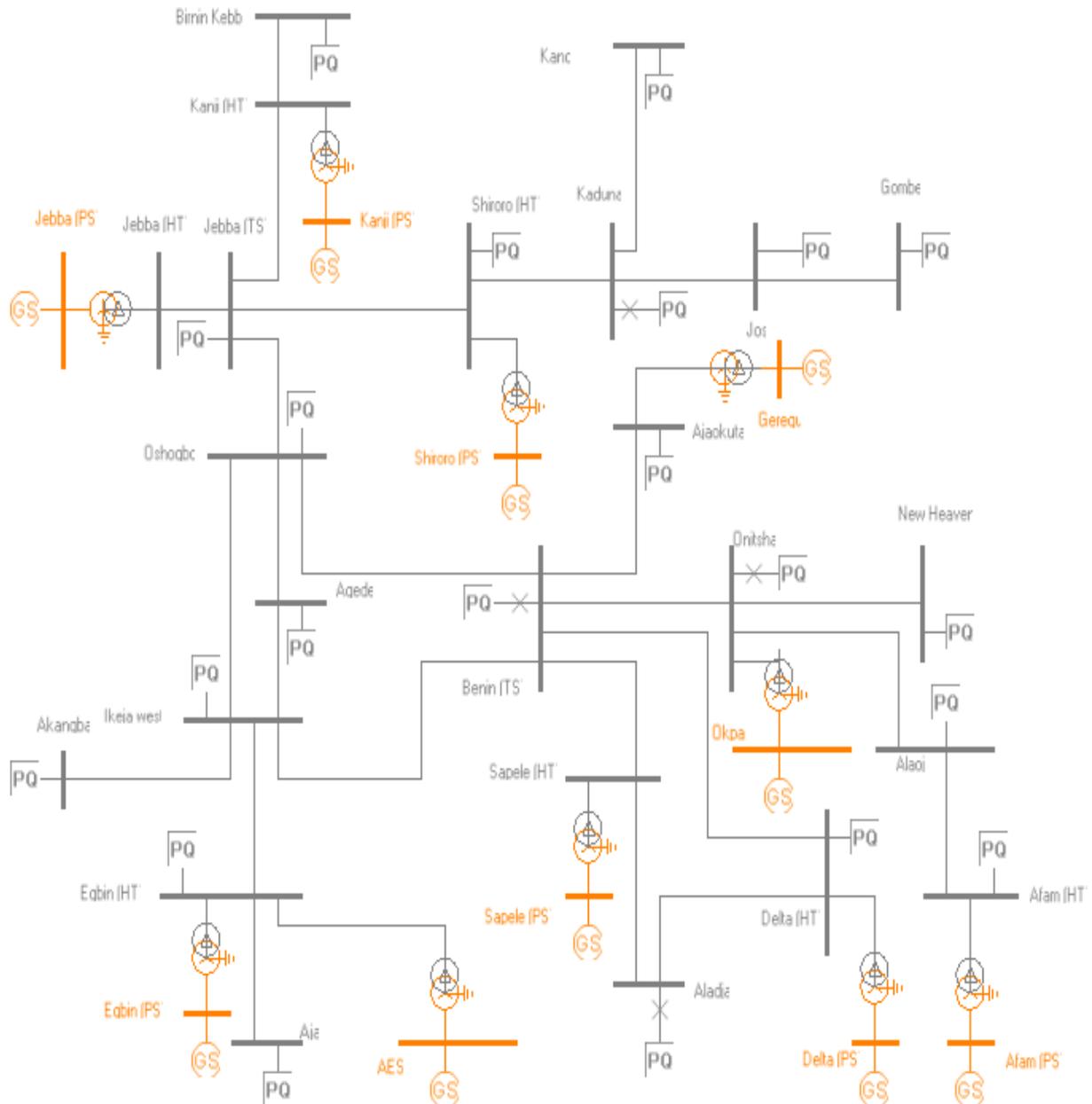


Figure 2. A single-line Diagram of Nigerian transmission network
 Source: Research Gate

In Table 1 below, the partial and total collapses experienced by the NGN from 2000 to 2017 were given. Also, the total of the partial and the total were calculated giving the aggregation of system collapse incidences in Nigeria.

Year	Partial Collapse	Total Collapse	Aggregated System Collapse
2000	6	5	11
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	9	18	27
2008	15	25	40
2009	20	19	39
2010	20	22	42
2011	6	13	19
2012	8	16	24
2013	2	22	24
2014	7	2	9
2015	2	10	12
2016	6	4	10
2017	2	12	14

Table 1. Incidences of system collapse from 2000 to 2017 [13].

2.2 Overview of the Smart Grid (SG)

The continuity of economic advancement and wellbeing of human life cannot be separated with access to affordable, reliable and sustainable power supply. However, power grids are prone to instabilities due to the infrastructural depreciation of the grid leading to incapability of the network to cope with demand increment and the continuous complexity accompanied with the increased demand [9].

SG is an electricity network that allows seamless communication between utilities and consumers from generation spot to the load centers with intelligent components that ensures reliability of the whole power system. It is a self-healing network that ensures better participation of consumers and resiliently counter attacks and natural disasters [17, 20]. It facilitates the inclusion of services and allows distributed generation with an improved efficiency [25, 28, 8].

The smart grid ensures more efficiency of the power system network by using advanced technologies that can sense and monitor the whole system over wide area and ensure the distribution of power supply with minimal interruptions [6].

The SG improves asset utilization and efficiency of operation by accommodating distributed generation and different storage alternatives. It can predict and swiftly respond to system disturbances using its self-healing feature. It gives consumers more autonomy in participation by the deployment of smart meters and other remote metering products which gives the customer a direct say in his power consumption pattern [7, 8 and 9].

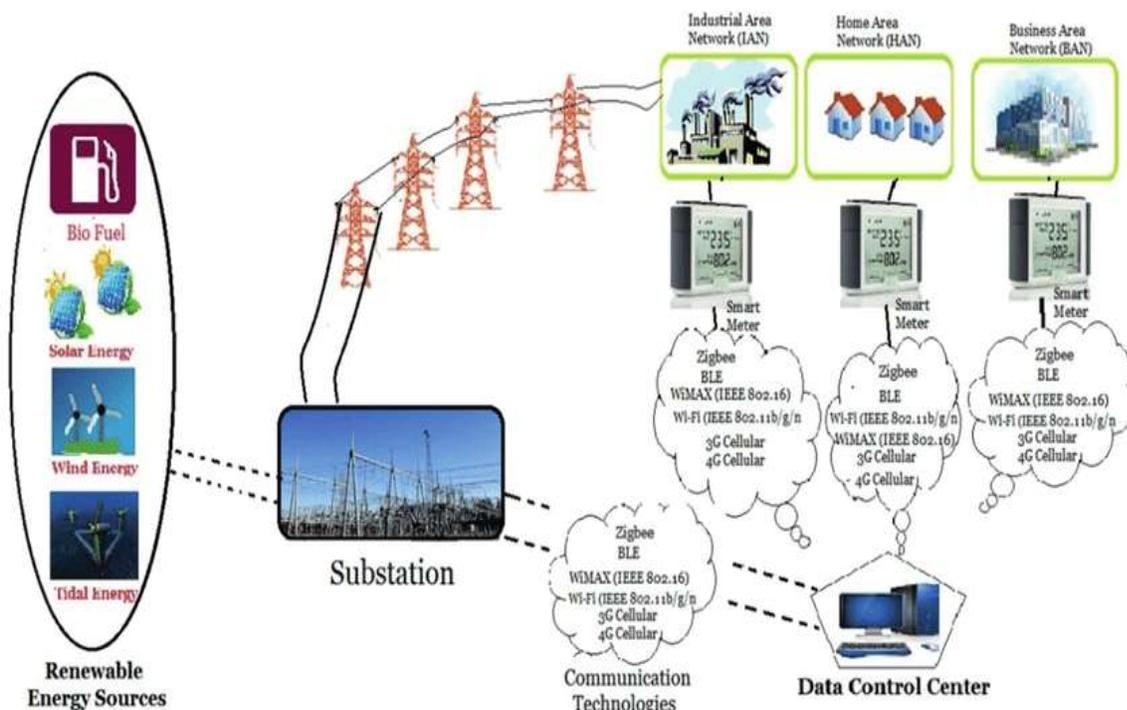


Figure 3. SG infrastructure with communication networks [14].

Table 2 gives an analogy between the Conventional Grid (CG) and the SG. The table has clearly described all the major features of each grid in relation to the other as can be seen.

Diagnostic	Conventional Grid (CG)	Smart Grid (SG)
Restoration capability after Disturbance	Manual	Self-healing
Control of load flow	Restricted	Wide ranging
Customer participation	Little to none	Full participation
Reliability	Prone to instabilities	Intelligent, can predict and curb outages before they commence.
Information flow	No feedback	Feedback path employed
Overall losses	About 2%	About 10%
Generation of electricity	Central	Distributed
Environmental pollution	Unbearable	Bearable
Efficiency of overall grid	Poor	Excessive
Ability to monitor	Poor	Supports remote monitoring
Topology of the grid	Spiral	Networked
Metering	Electromechanical	Automated

Table 2. Analogy between Conventional Grid (CG) and the Smart Grid (SG) [24, 32].

In brief, SG constitutes communication devices that facilitates monitoring, self-healing and control innovations. The following are features of SG [10]:

- Facilitates the participation of consumers on consumption decision making. The consumer is provided with more information and supply choices.
- Reacting to demand variations via smart meters integration and deployment of smart appliances providing the customer with information on pricing and electricity marketing.
- Customers can adjust their connected loads especially during demand spikes so as to reduce the possibilities of outages.
- It gives room to distributed generation.
- Ability to re-route power and ability to predict on what should be done and when it should be done.
- Improved resistance and resilience against faults natural triggers.
- Improved reliability and security of supply by anticipating and responding in a self-healing manner
- Improved supply quality.

2.2.1 An Overview of Phase Measurement Units (PMU) and Automated Metering Infrastructure (AMI)

Reliability and sustainability of power supply within the SG is of utmost importance. Information in real-time is disbursed from generation plants to the end user. Therefore, technologies that would enable control and remote monitoring are of paramount importance to ensure flawless operation and system management [10].

Phasor Measurement Units: PMUs application started in 1980s [3]. They monitor and measure the synchronization of the phases and detect faulty lines whilst ensuring voltage stability [14]. They use GPS signals of one pulse per second. The measured value by the PMU is simply known as synchrophasor. PMUs give system operators improved system state estimation and better energy management procedures [1, 15].

Operation: The PMU extracts and measures the phasor of the currents and voltages in an electric power network so that all phases components are time-stamped. A phasor data concentrator serves as a memory for the dispatched load data [15].

The proposed NGN PMU scheme would collect data from the data concentrator and dispatch it to the Independent System Operator (ISO) of the TCN for monitoring. This, if implemented, would render effective power flow with minimum number of collapses. Increased power flow over the overburdened transmission network of Nigeria can also be realized by utilizing the synchrophasor's ability to allow power flow via dynamic line limit whilst ditching the old worst-case limit. By implementing PMUs, the efficiency of the overall power system will increase improving its equipment protection and failure prediction [15, 23].

Using the existing Supervisory Control and Data Acquisition (SCADA), PMUs can improve the overall stability of the system whilst fixing monitoring loopholes to improve the state estimation of the NGN [14].

PMUs are not myth as they have already been implemented by power system utilities such as Bonneville Power Administration, the New York Independent System Operator and the North American Synchrophasor Initiative (NASPI) [22, 29 and 31].

They can carry out myriad of operations including automatic load shedding and improved power quality, demand response, early faults detection and isolation and subsequent prevention of outages. PMUs can also be used for detecting and classifying power system events [18, 19].

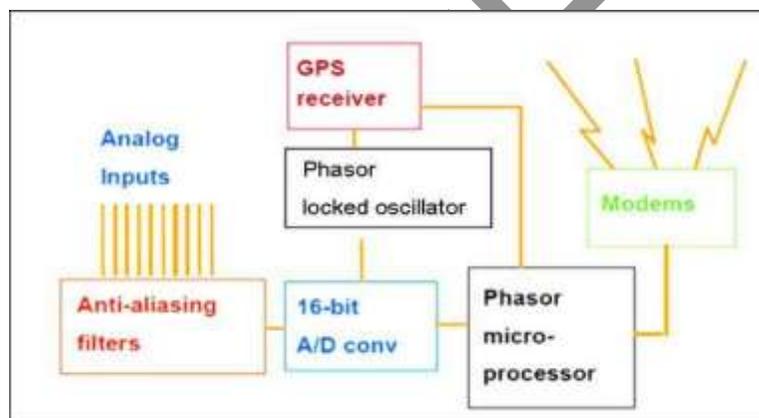


Figure 4. Block diagram of PMU
Source: Research Gate

Advanced Metering Infrastructure: According to Electric Research Power Institute (EPRI) AMI systems measure clocked information and transmit the obtained information to various parties using electronic components. The most important building block of AMI is a smart meter which can measure consumer consumption on a preset time interval. Smart meters automatically send their obtained results to utilities for better system management. AMI is an important and vital element in modern SG deployment. It is an admixed system of Smart Meters, communication

system and data logistics that ensure a back and forth communication between utilities and power consumers [15].

When a measurement system is planned and deployed in a robust way, it can reduce or, at its peak, eliminate faults and improve the sustainability of the electric power grid. The measurement side of the SG constitute systems that would best manage energy (known as energy management system—EMS). The EMS may be centralized which harbor smart algorithms or decentralized which employs operations (typically logical) that are dispersed on the entire system. Metering in SG is also called Smart Metering (SM). SM devices are capable of detecting the consumption rates of energy in the actual time during which the energy is consumed [15].

At the distribution end, automation always goes hand in hand with smart meters. These so-called smart meters enables feedback communication between consumers and the utilities. The meters provides more accurate billing system in contrary to the conventional energy metering system. Their incorporation ensures that consumers are in control of their energy consumption. Smart meters employ sensing devices, power blackout notification and seamlessly monitors power quality of supply.

AMI facilitates collection of consumption information of the consumer by the utilities in a fast and more reliable way.



Figure 5. A typical smart meter. Source: mdsafetech.com

3 METHODOLOGY

The method used in this research involves data collection and analysis. A general search was done in Google Scholar using keywords like smart grid, blackouts, system collapse and voltage instability. The search led to redirection to different journals. From Research Gate to

ScienceDirect, from IJAET to Elsevier and many other journals . A total of sixty-seven (67) papers were downloaded. After going through each abstract, twenty-eight (28) papers were studied and thirty-two (32) sources were cited (including internet sources) in the work. Conclusions were drawn from experience garnered during an internship at Transmission Company of Nigeria (TCN), 132/33-kV Wudil Transmission Station.

Issue	Number	Percentage
Research Papers	23	59%
Websites	4	10%
Books and Book Chapters	7	18%
Conference Papers	5	13%

Kano state was used as a case study where system failures observed during an experience garnered at 132/33-kV Wudil Transmission Station as an intern were used as research input. Difficulties and outcries observed within the populace were also used as providential evidences of the system collapses domino effect.

4 DISCUSSION

Looking at the current Nigerian scenario, the DisCos are passing the buck of poor electric power supply to the TCN, claiming that the TCN has low wheeling capacity whilst the TCN suspends the DisCos for non-remittance of transmission charges, due to this back and forth the Nigerian power sector and economic future are at stake. The claims from both sides indicate lack of Energy Management Systems on the NGN. Kano Electricity Distribution Company (KEDCO) has claimed that customers are owing it billions of Nigerian Naira, maybe due to insufficient intelligent metering systems and other forms of revenue leakage. This has resulted in shutting down some of KEDCO 33-kV feeders as a partial suspension by the TCN sequel to the KEDCO's ancillary payments failure. The same trend happened to Enugu Electricity Distribution Company (EEDC) but in more severe form putting many households in unnecessary blackouts.

Incorporation of SG will be the solution to a good number of the aforementioned problems as electricity distribution will be automated *i.e.* by use of intelligent prepaid energy meters and customers will account for every kWh consumed. The blame game between the DisCos and the TCN would be unnecessary as system failures will be sensed and combatted by the use of phasor measurements and other accompanying technologies. This would certainly improve the energy management system of the grid and save the country from the blackouts so common these days.

With the FG unfolding plans of achieving 30% of renewables into its energy mix by 2030, it can only be utilized by incorporating SG into the power system. The present system of electric power transmission by the TCN has loopholes e.g. transmission losses that would be better managed if smart systems were incorporated. At the distribution end smart grid technology comes most handy in billing and faults clearance.

4.1 Challenges

There are challenges to be addressed for the practical deployment of SG in Nigeria as discussed below:

- Bad government policies in coordinating network expansion and upgrade mainly due to corrupt practices. The TCN is still unable to wheel the totality of Nigeria's theoretical generating capacity. This could be achieved by first building a more robust ring transmission network and then incorporating intelligent systems for more efficient execution of system plans.
- Wide investment gap in the power subsector. It is obvious from the government's claim of injecting 1.5tr Naira into the subsector even though the Generation Companies (GenCos) and the Discos are no longer owned by the government that private investment is quite low in the subsector.
- Corruption and insufficient willpower of stakeholders to resort to providing clean reliable, sustainable and affordable energy to the populace.

- Power consumers who despite the paralytic supply system of the country feel the grid should suffer more by vandalization.
- Failure of customers to pay for the power consumed. It was estimated that 30-40% of Nigeria's consumed electricity is unbilled.

4.2 Significance of Study

- Eradication of environmental pollution: Incorporating the SG in Nigeria will help curb the excess carbon emitted by small capacity generating sets almost in every household. SG employs the use of eco-friendly sources which stand as better alternatives to be adopted to limit the level of climate change threatening our environment.
- Spike in economic development of the populace and the country at large: Many industries have gone into coma, if not dead, due to the paralytic power industry of the country. With an improved power industry, the industrial and individual businesses would bounce back to life and more money would be saved by the industries and small scale businessmen used in buying alternators and fuel.
- Automatic load shedding: Automatic load shedding can be initiated by the SG-incorporated grid when frequency ebbs below the custom 50Hz of the network. A frequency usually falls below the custom value when demand swings up and there is no spinning reserve to fill up the demand. This would save the country from some of the overall system collapses.
- System Protection: The high-speed PMUs have an attribute of automatic system protection. They have the capability to isolate faulty components and ensure frequency and voltage stability based on the calculated voltages and phase angles.
- Communication levels will be paced up: The backbone of proper operation and safety in bulk electric stations is speedy and accurate information. Incorporating PMUs and AMI into the Nigerian grid will speed up information extraction and disbursement between utilities and power distribution equipment.
- Shorter Period for Electric Power Restoration: With the self-healing attribute of the SG, faults can be easily detected and cleared so as to allow quick recovery and restoration of operation on the power grid.
- Curtailment of meter tempering and electricity theft: AMI can detect attempts to temper with the installed smart meters. Consumers in Nigeria are known to go extra miles to steal electricity, many a times breaking into and bypassing electric meters. This will help in better revenue collection as unaccounted energy bypassed by the consumers would then be accounted for.

4.3 Recommendations

- The FG should define a long-term strategy for the electricity subsector and mandate the National Electricity Regulatory Commission (NERC) to find effective long lasting solutions by challenging the market players through regulation policies and deadlines to comply.
- NERC should provide better regulations that would accommodate more investors in the electric energy market.
- NERC should sponsor a bill to the National Assembly that enables legislation to be passed on stricter punishments for electricity infrastructure vandals.
- The NERC should mandate the Meter Asset Providers (MAPs) with a deadline of providing Nigerian consumers with world-class smart meters with payments being in instalments.
- The government should intervene and subsidize the metering process as many consumers might not be able to possess the smart meters.

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5 CONCLUSIONS

The NGN has been in paralysis since its inception to this day. System failures have become one of its most identifiable features leading the populace into believing in a wrong and bogus notion that Nigerians will never enjoy 24/7 electricity supply. This paper is among the first to give a review of SG as a solution to the recurring system failures of Nigeria. It has presented the related background and the better perspective of combating Nigeria's system collapses. It has introduced some key technologies like PMU and AMI with a captivating feature of self-healer reinforcement, technologies which can support and analyze the potential challenges involved, revolutionize the NGN and Nigeria's economy as a whole. The paper has outlined the challenges facing the deployment of SG in Nigeria and recommended possible ways out of the conundrum.

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