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Voltage Collapse In Nigeria Power System- Causes And Remedies

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Abstract:
The Nigerian grid is presently dealing with several power issues that cause constant voltage falls and an inconsistent and unstable supply of electricity throughout the nation. This has adversely affected a country that was once tipped as the giant of Africa. These effects range from low productivity, a spike in the unemployment rates, high inflation rates, and the winding up of industries, etc in the country. This voltage collapse can be total or partial and this is a major concern for everyday power system operations and the economy of the nation. Over the previous 14 years, the Nigerian National Grid had an average of 16 system failures annually. This paper examined the reasons behind Nigeria's power system's voltage fall and proposed some potential fixes. The methodology employed in this study comprised gathering voltage collapse data and performing analysis for the years 2010 through 2023. Outcomes from the study showed that in the period under study, there were a total of 223 voltage collapses, out of which 158 were total system collapses while 65 were partial system collapses also in relative terms, 71 percent and 29 percent were total and partial system collapses respectively. Also in 2010, the highest number of collapses in the grid was recorded with a value of 42, and June 2016 had the highest number of collapses in a single month with a value of 8.

Keywords: *Voltage collapse, Nigeria National Grid, Power System*

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I. Introduction

An electrical power system's primary purpose is to supply enough power to all points of utilisation at a rate that is both economically feasible and reasonably reliable, hence preventing system collapse while it is in use. Therefore, every power system is expected to run optimally without experiencing any system collapse during its operations [1]. The nation has been experiencing frequent blackouts, which have disrupted several activities and wrecked numerous industrial processes. Numerous power outages around the country are causing constant voltage collapses. Furthermore, it has led to an inconsistent and unstable electrical supply across the nation. It has raised the nation's unemployment rate and decreased production.

Accordingly, voltage collapse is the instability of a highly loaded power system network resulting in a voltage drop and occasionally a blackout [3]. When every power generating station linked to the grid shuts down completely or partially, either simultaneously or right after one another, leaving the whole area supplied by the grid in a blackout, the situation is referred to as a "system collapse." This undermines the vital service of providing consumers with consistent, dependable power and has serious repercussions for the security of the system. In power system networks, voltage collapse is an undesirable occurrence that can arise for several causes, some of which will be covered later in this paper. This system collapse phenomenon, which commonly occurs in

Nigeria's national grid and has frequently resulted in either a partial or whole system collapse (blackout), has a significant impact on the country's industry and socioeconomic development.

The nation's energy demand has increased at a rate never seen before due to the quick rise in both the population and small- and medium-sized businesses. However, the Nigeria power system components have not witnessed adequate expansion facilities, the non -integration of newer and smart technology, and the non-implementation of robust predictive and condition-based maintenance models thus leading to unprecedented voltage collapse. In addition, the has been the challenge of power system control and management which is becoming a challenge as a result of expansion restriction, demand increase, and the competitive and now deregulated power industry due to current evolution [4].

This paper presents the VOLTAGE COLLAPSE IN NIGERIA POWER SYSTEM- Causes and Remedies. The paper intends to provide recent performance data that will enable the policy makers to make decisions and proffer solutions to the reoccurring problem of grid collapse facing the nation - Nigeria.

What is Voltage or Grid Collapse?

The national grid is an interconnecting system that comprises all generation stations, transmission substations, and distribution substations. If there is a technical issue with an interconnecting unit, it could harm the system partially or totally. One of these adverse effects is the inability of electric power to be generated, transmitted, or distributed. In some cases, there is a partial or total blackout on the system. This is known as a grid collapse: which could be partial or total [10].

There is a tendency for a system to collapse once it operates close to its security limits, therefore, there is a need that the system to maintain stability at all points becomes necessary in prevent its collapse. Hence, it becomes necessary to maintain a considerable security limit in both normal operating conditions and under contingency cases to ensure the reliable operation of a power system.

Partial Grid Collapse

A partial grid collapse occurs when there is a blackout in a section or sections of the grid. This could be a result of a generation station or generation stations being unable to continue supplying power to the grid or a transmission substation being unable to transmit electrical power to the grid. Certain areas getting supply from the national grid will be cut off instantly once there is a partial grid collapse.

Total Grid Collapse

A total grid collapse occurs when there is a total blackout on the grid. This still could be a result of a generation station or generation stations being unable to continue supplying power to the grid or a transmission substation being unable to transmit electrical power to the grid. When a total grid collapse occurs, there is a total blackout to feeders from the national grid.

Causes Of Voltage Collapse

There are several causes of grid collapses, the reasons behind a system's collapse could be either non-technical or technical fault(s). Some of the causes of voltage collapse include but are not limited to the following;

- **Grid Frequency:** When a generation station ties to the grid, it does so at a synchronized frequency. The turbines at the generation stations no longer operate on their design frequency because they have been synchronized to the national grid; hence they operate at grid frequency. The nominal frequency in Nigeria is fifty hertz (50Hz), but system disturbances and harmonics don't allow for this nominal frequency. With this in mind, manufacturers of turbine generators allow for a frequency tolerance band which usually falls between 48.5Hz and 51.5Hz on average. When the grid frequency exceeds this bandwidth, the turbine generators at the generation stations can no longer hold, and they pull out automatically from the grid. The imbalance of such an action can lead to a grid collapse. For reference purposes, the grid collapse could be a result of over-frequency (when grid frequency exceeds 51.5Hz) or under-frequency (when grid frequency recedes 48.5Hz). Also when there is an additional demand on reactive power, a security violation is created which results in a voltage reduction hence, a collapse of voltage in the system [5].

- **Grid Voltage**: In every generation plant, there is a switchyard that serves as a switch between the transmission substation and the generation plant. This switchyard consists mainly of isolators, instrument transformers, and breakers. The switchyard is interconnected between the generation station's power transformers and the transmission station's transformers. The operating voltage of the grid is 330,000 volts (330kV). With this in mind, transformers are designed to operate at 330kV output, with a tolerance of +15kV. Once the voltage on the grid exceeds 345kV, system protection is automatically initiated. The action of the protection system takes out the transformer from the grid, which in turn means the generation station is taken out from the grid also. This imbalance can lead to a grid collapse.
- **Loadability**: When there is an increase in the load into the system, this results in a decrease in the distribution voltage, and some cases, the voltage drops rapidly to a point beyond which the voltage becomes untrollable, voltage instability. Hence, this results in a voltage collapse which leads to a blackout.
- **Issues With Generation Plants:** Mostly with generation plants that rely on fossil fuels as the source of fuel (in this case gas turbine generation plants). If during operation, the source of gas is taken out (maybe due to sabotage on the line, or a fault from the gas pumping station, or a fault at the gas receiving station at the generation company end), the turbines will instantaneously shut down. This unperceived shutdown can cause an imbalance in the system (in most cases grid frequency becomes unstable), leading to a grid collapse. Also, the issues of low water levels at the various hydro power stations.
- **System Operator Faults or Accidents:** The grid system operator (in this case the Transmission Company of Nigeria) can witness certain faults at their facilities. Such faults could include fire outbreaks, sabotage, equipment malfunction or failure, and in some cases: system operator error. All these are liable to cause system instability leading to grid collapse.
- **Inadequate Power Generation:** is caused by a load demand placed on the grid that exceeds the capacity of all connected generating stations put together. We will constantly be operating close to low system frequency because of our low generating capacity of roughly 4000MW compared to the real demand in our nation. When one of the several transmission lines that comprise the grid experiences a defect (i.e., a short circuit), the system becomes overloaded and the frequency of the system drops. Our transmission lines travel through thick forests for many thousands of kilometres, so there is always a chance that vegetation would clog the lines and create problems.
- **Load Rejection:** There has been an issue with load rejection by Nigerian distribution providers. When the distribution companies reject the electricity that the transmission companies have transferred, this is known as load rejection. Faulty electrical lines and the disrepair of the transmission and distribution network are contributing factors to the rejection. In these situations, supply is being generated and transmitted but not distributed. Also, this is because most distribution companies intentionally refuse to pick load to manage load and make more revenue from estimated bills.
- **Network Design/Age:** After closely examining the power system network of Nigeria, as depicted in Fig 2.1 below, it can be seen that there is just one ring network in Nigeria (Benin – Ikeja – West Aiyade – Oshogbo – Benin). Because power flows in one direction only through a significant component of the grid, there is a

lack of redundancy in the transmission lines, which exposes the grid to extreme instability during fault conditions. Some Circuits were constructed in the '60s and are aging and inadequate to sustain the load demand requirements. Most of the lines and generators have been due for replacement due to age and are dilapidated. Our grid is not evenly distributed and is not synergized with other sources of renewable energies to still provide power during faults situations.

- **Technological Backwardness -** unwillingness to upgrade their facilities to meet up with the current technology trends such as the integration of SCADA, GPRS, PLCs, IT applications, etc; to make the system SMART ("Self-Monitoring, Analysis, And Reporting Technology"). So, this lack of upgrade leads to grid collapses because the system is unable to adequately monitor and sense the system against the possibility of faults for prompt predictive and preventive maintenance. In October this year, we had two systems collapse and one was due to the explosion of an explosion of a capacitive voltage transformer, CVT at Kanji power station. This could be prevented if our systems are SMART enough to detect and predict fault situations.

Other causes of voltage collapse apart from the few highlighted above have been attributed to poor maintenance culture, inadequate compensation equipment in the system, neglect by the government over a long period, and political interference.

Consequences/ Economic Implication Of System Collapse

In the previous nine years, Nigeria's national energy infrastructure has failed more than 200 times, frequently leading to extensive blackouts. There are significant financial and social costs associated with power outages because they make it difficult for people to meet basic household and business demands. Nigeria, with a GDP of USD 375.8 billion as of 2017, has the biggest economy in Africa. In contrast to its contemporaries, the Nigerian grid has performed below expectations. Every 1% increase in power outages (measured in hours) in sub-Saharan Africa has been linked to a 2.5% decline in GDP [8]. This corresponds to a GDP decline of almost USD 28 billion. It was assessed that the emissions of hydrocarbons from generators, which are extensively used throughout Nigeria and harm the ozone layer, also pose health hazards. Fuel consumption for electricity generator sets is predicted to be $22 billion annually according to [7]. Also, in [11] electricity is the primary factor driving socioeconomic development in any country and accounts for roughly 35% of industry production costs.

The whole Power system network is becoming more unstable and unreliable due to the growing issue of system collapse. According to Table 1 above, Nigeria had roughly ten separate grid collapses in 2019 alone. The economic damage and annoyance these incidents cause to both residential and commercial consumers are severe and intolerable. Many industries that heavily rely on an adequate power supply have closed as a result of inadequate electric power. The poor operation of the country's power infrastructure has a significant impact on small enterprises and heavy machine manufacturers. The residents' social, psychological, and physical well-being are generally negatively impacted by an inadequate and inconsistent power supply. The unreliability of the country's power supply has played a significant role in the stagnation of the nation's economy. Poor services have forced most industrial customers and individuals to install their power generators, at high costs to themselves and the Nigerian economy.

II. Materials and methods

This paper utilizes materials from the historical data of the national grid operations under review. These data, which cover from 2010 to 2023, were derived from the daily dispatch and operational logbooks TCN National Control Centre O.F. 56, Dispatch and Operational Logbooks., 2010-2023 under review which are owned by the Transmission Company of Nigeria. Likewise, supplementary data was gathered from other institutions and pertinent literature. After the data were gathered, the relevant calculations were performed to ensure that the results were appropriate for this paper.

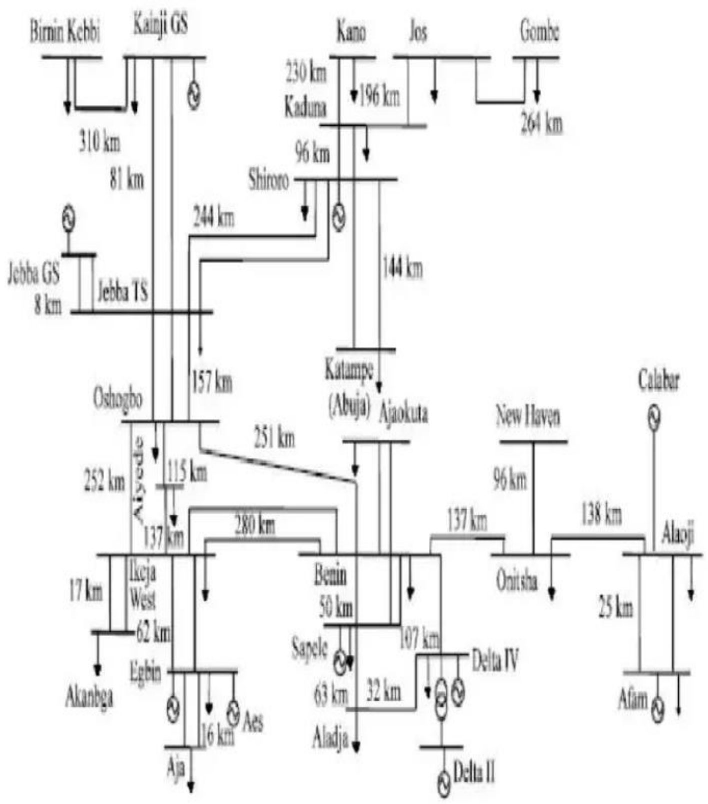

Fig. 2.1: One-line diagram of Nigeria's 330-kV transmission network [9].

Methodology

The data was analyzed using descriptive statistics (tables, frequency counts, charts, and graphical depictions) to extract the prominent elements required for the study's conclusion.

Table 2.1: Statistical performance data of the Nigerian National grid showing both Total and Partial Collapses from 2010 to 2023 [6].

Date of last total collapse: 19/Sep/2023							**No. of days since the last tot collapse**				**43**			
Date of last partial collapse 26/Sep/2022							**No. of days since the last partial collapse**				**401**			
Highest No of days ever attained in betwee total collapses:						**421**	**Highest No of days ever attained in betwee partial collapses:**						**445**	
		J	**Fb**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**
	Total	**0**	**3**	**1**	**0**	**3**	**3**	**3**	**0**	**2**	**2**	**1**	**4**	**22**

2010	**Partial**	**1**	**0**	**0**	**1**	**1**	**3**	**4**	**4**	**3**	**2**	**0**	**1**	**20**
2011	**Total**	**0**	**0**	**0**	**0**	**4**	**3**	**1**	**1**	**1**	**2**	**1**	**0**	**13**
	Partial	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**2**	**0**	**6**
2012	**Total**	**0**	**0**	**2**	**1**	**5**	**2**	**1**	**0**	**0**	**2**	**2**	**1**	**16**
	Partial	**0**	**0**	**2**	**3**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**8**
2013	**Total**	**0**	**1**	**2**	**2**	**3**	**4**	**1**	**1**	**1**	**1**	**4**	**2**	**22**
	Partial	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**2**
2014	**Total**	**2**	**0**	**0**	**2**	**0**	**3**	**1**	**0**	**0**	**1**	**0**	**0**	**9**
	Partial	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**4**
2015	**Total**	**1**	**0**	**1**	**0**	**2**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**6**
	Partial	**0**	**0**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**4**
2016	**Total**	**0**	**0**	**2**	**3**	**6**	**5**	**0**	**0**	**1**	**1**	**2**	**2**	**22**
	Partial	**0**	**0**	**1**	**0**	**1**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**6**
2017	**Total**	**5**	**3**	**0**	**3**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**15**
	Partial	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**3**	**3**	**0**	**0**	**9**
2018	**Total**	**5**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**2**	**0**	**0**	**2**	**12**
	Partial	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
2019	**Total**	**4**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**9**
	Partial	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**
2020	**Total**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**4**
	Partial	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2021	**Total**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**
	Partial	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**
2022	**Total**	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**4**
	Partial	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**
2023	**Total**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**2**
	Partial	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

III. Results and Discussion

The results obtained are presented and discussed in this section. In the period under study, there were a total of 223 voltage collapses, out of which 158 were total system collapses while 65 were partial system collapses as shown in Table 3.1. In relative terms, 71 percent and 29 percent were total and partial system collapses respectively. From Fig 3.1 we can see that 2010 recorded the highest number of collapses of 42 and coincidentally 2023 has the lowest so far with 2 recorded. Fig 3.2 and Fig 3.3 show the number of both total and partial system collapses and their trend over the period under study. Also as seen in Fig 3.4, June 2016 has the highest number of collapses in a single month with a value of 8.

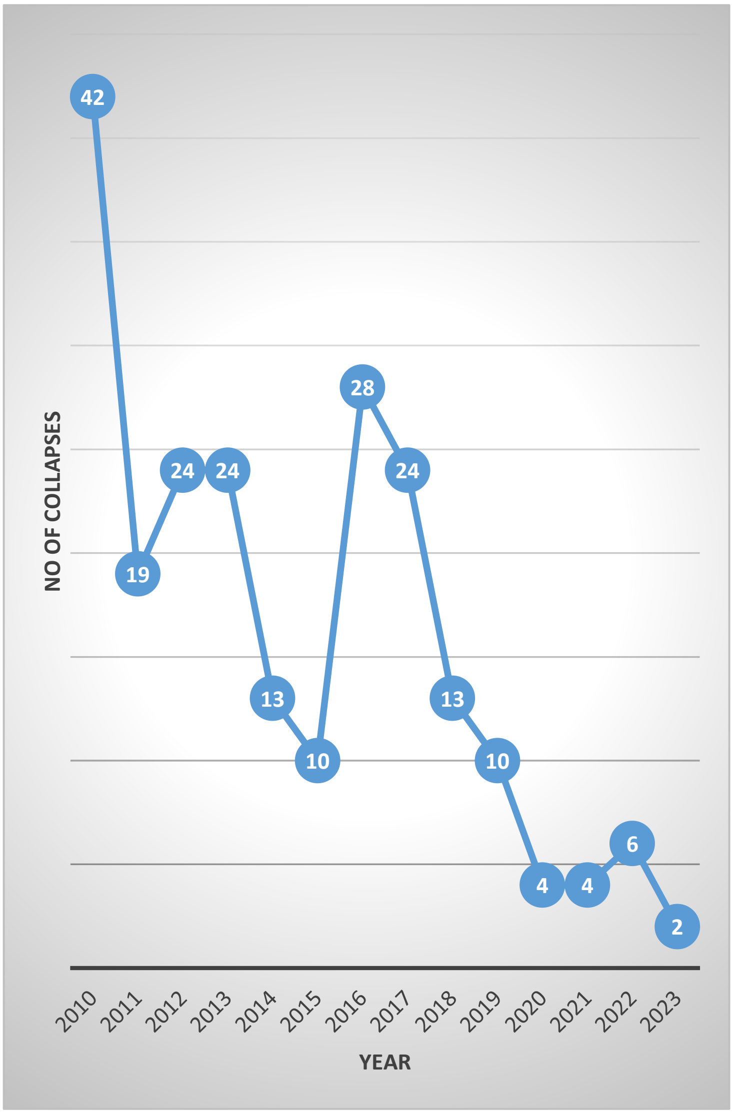

Fig. 3.1: Yearly Grid Voltage Collapses Chart (2010 – 2023)

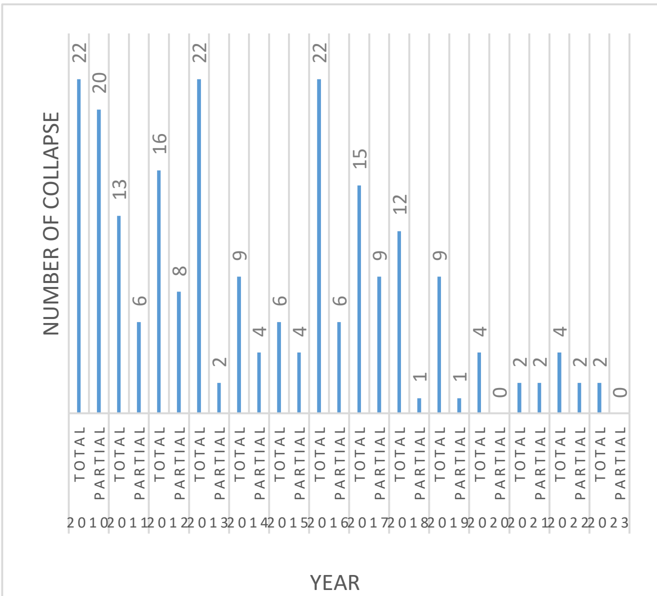

Fig. 3.2: Total and Partial Voltage Collapses Chart (2010 – 2023)

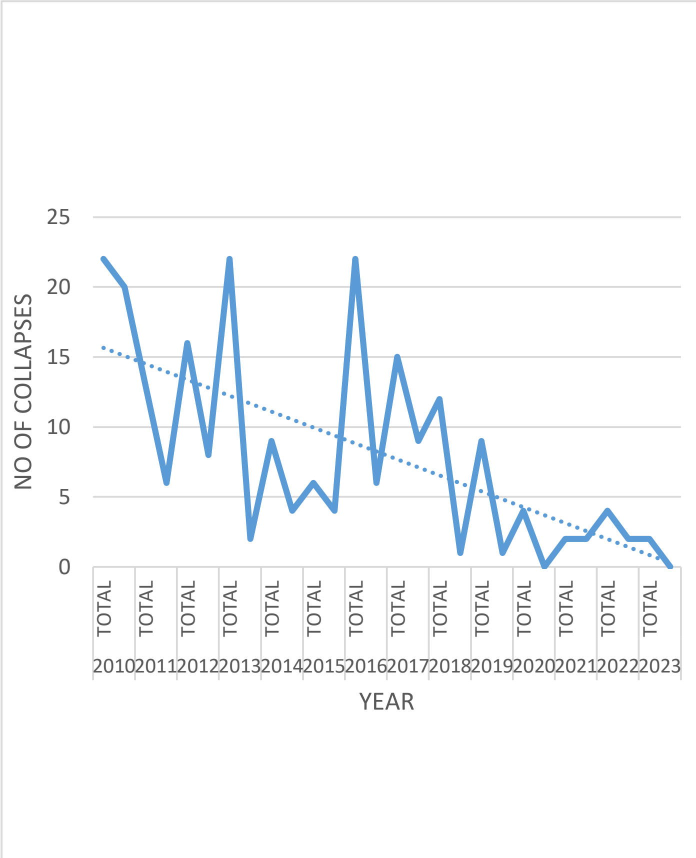

Fig. 3.3: Total and Partial Voltage Collapses Trend (2010 – 2023)

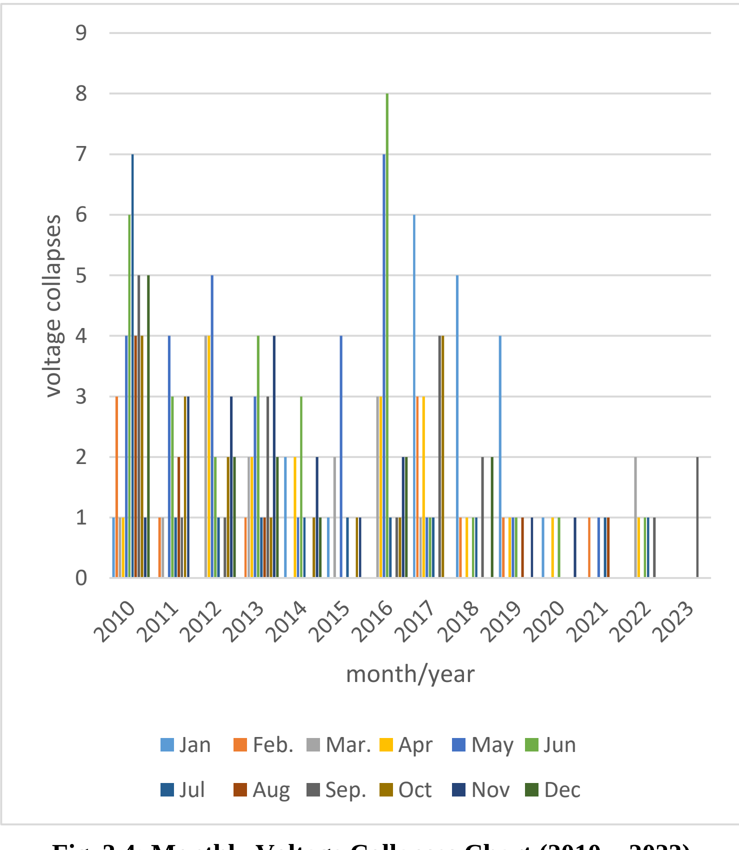

Fig. 3.4: Monthly Voltage Collapses Chart (2010 – 2023)

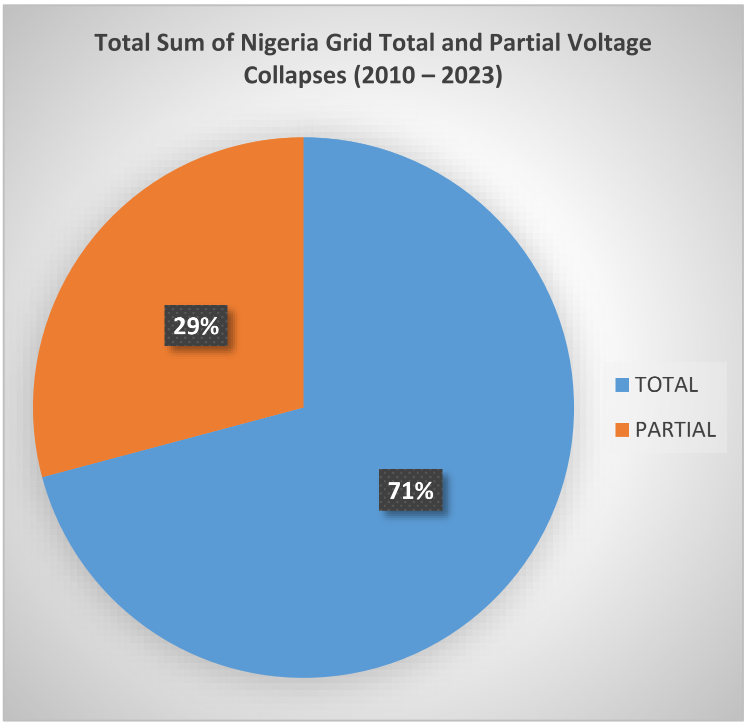

Fig. 3.5: Total Sum of Nigeria Grid Total and Partial Voltage Collapses (2010 – 2023)

Table 3.1: Sum Total of Total and Partial System collapses in the Nigerian National grid from 2010 to 2023

YEAR	TOTAL SYSTEM	PARTIAL SYSTEM
2010	22	20
2011	13	6
2012	16	8
2013	22	2
2014	9	4
2015	4	4
2016	22	6
2017	15	9
2018	12	1
2019	9	1
2020	4	0
2021	2	2
2022	4	2
2023	2	0
Total	158	65

IV. Conclusions

The country's electrical system will undoubtedly continue to suffer from frequent grid failures, especially given how dated, fragile, and old it is. Given the extent of the decrepit state of Nigeria's grid infrastructures, the country must maintain a safe baseline daily load to help safeguard the national grid from frequent collapses.

Enhancing the current spinning reserves and expanding the capacity by adding new spinning reserves are necessary. Effective communication between the GENCOs, DISCOs, and TCNs is vital, as is transparency in the field of information management. Massive investments must be made by the government in Nigeria's grid infrastructure and the prioritization of manpower training is necessary to ensure progressive stability of the nation’s power system.

Finally, Nigeria needs to move from the dependent on just the national grid to the integration of mini and micro grids across the nation by harnessing our natural resources (renewal energy resources) that are currently wasted. Hence, there is a need to look towards moving from a classical grid to a smart grid. Other ways of minimalizing or eradicating voltage collapses in the system include, Voltage collapses can be prevented or eliminated through the use of newer technology and approaches in fault prevention, finding, and clearing**,** constant expansion, and adequate investment into transmission and distribution capacity. Also is in provides adequate security to protect power infrastructure from theft and sabotage and decentralizes the grid to smaller integrated grids. All these if done will go a long way to prevent nationwide blackout and an eventual total voltage collapse which is what this paper is about.

Conflicts of Interest
“The authors declare no conflicts of interest.”

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