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VOLTAGE STABILITY IN NIGERIA POWER GRID: A DETAILED LITERATURE REVIEW

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Abstract

This paper presents a critical review of the current national electricity grid in Nigeria, how voltage stability is maintained in the grid, find out the limitations of the transmission network and compare the different options for overcoming them in the available literature, learn from the previous studies about the use of renewable energy sources in Nigeria, understand the prospect of developing electricity grid in Nigeria by learning about the identified challenges from literary sources.

Keywords: Voltage Stability, Power Grid, Renewable Energy

Introduction

A power grid is an interconnected network of transmission lines for supplying electricity from power supplier to consumers. Any disruptions in the network causes power outages. Electricity is usually generated at 11-16kV and thereafter stepped up to 330kV or 132kV for high voltage long distances transmission and delivered onto a common pool called the grid.

Nigeria electricity is transmitted at a frequency of 50Hz. When the frequency reaches its minimum or maximum level, there is a risk of failure of the transmission lines. The breakdown of transmission lines due to over or under frequency is called power grid failure (System failure). This could be as a result of power overdrawn by excessive loading of the transmission lines.

The Nigerian Power Grid consists of two main transmission lines of 330kV and 132kV. These are high-voltage distribution systems, whose stability plays a major factor in ensuring that the power transmission system of the country operates at its optimal capacity. The Nigerian power sector faces several hurdles. The country is vast and therefore, power distribution is often a challenge. However, with an estimated natural gas reserve of 176 trillion cubic feet, the country has all the resources required for any excess electricity generation (Sambo, et al., 2012). This review will aim to find the important elements that are already identified in the previous studies and will attempt to discuss the important themes that are present in it.

- **An Overview of the Nigerian Electricity Grid**

Sambo and others (2012) have described that the country employs various electrical grid systems. The most common systems that are employed include 330kV and 132kV distribution sub-grid systems. Maruf and Garba (2013) discussed the 330kV grid in Northern Nigeria and found that it is possible to reduce the reactive voltage losses by installing shunt capacitor compensators. They found that the generators can improve their performance and become more in line with a minimum bus voltage value that remains at least at 0.95 per unit of generation. Okpeki and Efenedo (2013) found that deregulated power systems can work well, but only if the government allows private operators to establish their own method of satisfying the varying system load requirements and ensure that that power quality can remain established. The economics remain important and therefore, it is not always possible to create the best transmission systems. The balancing of the grid is only possible in places like Nigeria, when there is effective fault management and system stability is maintained using effective causes.

Bello and others (2016) performed a detailed research using the power system analysis tool (PSAT) to determine the working parameters of the 330KV network present in Norther Nigeria. They performed the continuous monitoring of the phase angle and the magnitude of the transmission voltage to understand its economics and operational performance. They carried out the IEEE bus test, and found that three operating buses were exceeding the voltage limit set at 1.05 p.u. The reactive power at two of the buses was also high, which created a loss during the transmission. The results of this article found that the power production was inadequate to meet the demand, causing frequent problems in the transmission network. Eseosa and Ogujor (2012) determined the various parameters of the Nigerian power system. They found information using the data available from the power generation and supply company of Nigeria and employed the Transient Analyzer Environment to determine bus voltages, and reactive and real power values. They found the transmission losses as well as generator losses at the different buses available in the system. Var power levels were found that provided the information that the real powerlosses are at 2.58% in the country. There is a significant loss of reactive power both from the generating stations as well as the transmission line, meaning that there is a need to create new integrated power projects that are built with flexible alternating current transmission systems (FACTS) devices for the ideal power consumption.

Uche and Madueme (2015) have performed an analysis of the Nigerian electric power system. They found that it is important to increase the number of buses to ensure that it is possible to keep the voltage levels within the narrow range of 0.95 p.u. to 1.05 p.u. to ensure adherence to the international power supply standards. The presence of heavy load on the Nigerian 330KV system often leads to voltage drops and surges and creates the problem of reactive power loss due to a greater phase angle of the voltage. Rai and others (2014) have worked on creating an efficient electrical power transmission model for use in Nigeria. They found that the transmission is a key factor in an electricity system and needs to provide an effective solution. Their research revealed that the current system in Nigeria is limited.

Voltage Stability of the Nigerian Electricity Grid

Maruf and Garba(2013) produced a research paper in which they investigated the 330kV transmission grid in Nigeria using a software tool. They obtained data from the national control center and found that low voltage violations commonly appeared in the system in five of the total thirteen buses present in the grid system. Ibe, Omorogiuwa and Kayode (2017) performed a voltage stability analysis of the Nigerian power grid. They employed a distributed generation system, where the electricity is added from different units in the system. They found that distributed generation of the country creates unique problems in the form of voltage control, maintaining power quality, and reducing the possible faults. Their analysis revealed that the voltage profile can be improved when the current faults are analyzed and the system is set up in the form of distributed generation which follows the available buses in the system. They found that the bus, which lies closest to the power distribution center works the best, when compared to other options.

Adepoju and Tijani (2014) performed a survey in which they researched about the flexible alternating currents transmission system (FACTS) controllers that can be implemented on the 330KV transmission line in Nigeria. The survey scrutinized various publications that discussed these systems and ensured that it is possible to compare the performance of SVC, UPFC, and other FACTS Controllers for use on the power grid of Nigeria. The review performed shows that the problems of the grid system will be greatly reduced, especially with the application of different FACTS with each providing specific benefits. Onohaebi and Apeh (2007) also performed a case study of the 330KV line in Nigeria. They found with the help of the Power World Simulator that the grid is highly stable, and can quickly develop cascaded faults once it faces an isolated incident of loss of quality of power. Voltage stability becomes difficult to maintain in such circumstances. There is a need to modify the current network and add shunt compensation and network strengthening to improve the performance levels of the current 330KV Nigerian grid network. Idris and others (2015) found that voltage stability improvements are possible by installing static VAR compensators that have the ability to improve the weak bus of the network. Osahenvemwen and other engineers (2015) performed a research in which they evaluated both the 330KV and the 132KV power systems for a year for the entire 24-hour period. They found that the average loss of power in the 132KV line is around 2.76KV, while it is around 4.725KV for the 330KV line. The system provides an average of 22.5 amperes of current. The observation reveals that the losses increase as higher power is sent through the current transmission system, while the conductor size and the covered distance also plays a role in determining the electrical power loss during the transmission.

Enemouh and others (2013) argued that using the V-Q Sensitivity method, it is possible to predict the voltage instability, which is present in the interconnected electric power system in Nigeria. They described that their calculations show the Maiduguri, Gombe, Kano, and Jos as the system buses that have the successive high V-Q values. The Maiduguri Bus is at the highest risk of suffering from voltage instability. The improvement is possible by integrating the available power grids and ensuring that equipment is used to improve the voltage stability of the system. Samuel and others (2014) prepared a research in which they found that system collapses can affect the perception of electrical power and can often produce a situation, where voltage instability is commonly present in a system, like the Nigerian grid system, which often varies in terms of the voltage amplitude and phase difference. Ibe and others (2015) analyzed that it is possible to improve power transmission in Nigeria using TCSC as a solution. This model employs a power electronics device which provides better control and ensures that voltage stability can be maintained under the presence of static conditions. Their research yielded that solutions that includes FACTS equipment in the distribution, produced improved bus results in Nigeria when they were developed using MATLAB programs for load flow.

- **System Limitations in the Electricity Industry**

Abdulkareem and fellow researchers (2016) produced a research article in which they discussed the line losses that are currently present in the 330kV power lines in Nigeria. They found that it is important to reduce the system losses and always maintain the statutory voltage limits of 0.95pu-1.05pu in the bus voltages present in the system. They carried out a single line contingency analysis, which clearly showed that there are a lot of voltage bus violations when additional capacity shunt compensation is not implemented in the system. They found that the system violations reduced from 335 to 25 with the addition of shut compensation in the 330kV buses present in Nigeria. EhimenAiroboman and others (2015) have presented their research that the Nigerian power system has the problem of voltage instability. They collected the data for the period of 1995 to 2013 and performed a sequential analysis. They found out that over 50% of the collapses occurred due to a total grid failure. They identified that poor governmental policies often cause power generation problems, that in turn affect the voltage stability of the system network. Voltage instability is a technical problem, but it often arises due to the failure of power policies that are required for ensuring the ideal power generation.

Ajenikoko and Ogunmakinde (2015) researched on the power outages that occur in Nigeria. They looked at all types of faults including conductor failures, earth faults and damage to the transmission lines. They found that most problems appear to cause forced failures because the system resistance to energy disruption is high and any small issue results in a severe loss of power, which is faced by the customers. A key research in the Nigerian 330KV grid system found out the transient stability limit of the subnetwork. It found that the lack of investment in expanding the grid network has created a fragile distribution system, where a small disturbance often leads a cascaded even resulting in a complete system failure. Disturbances in a transmission system are natural to expect, but when they can cause a stability problem, there is a need to have a strong regulatory and hardware control over the quality of the transmitted power. A fragile grid is present, which can be maintained at the highest level, as long as 80% of the installed power remains available for utilization at the substations. In this case, a transient fault can be easily restored, with the power getting back to 97% of its original value, while also ensuring that the frequency is within 2.5% of the 50Hz normal value (Oluseyi, et al., 2017).

Abdulkareem and others (2016) investigated the asymmetrical faults that appear in the buses of the 330kV transmission system of Nigeria. They used the Newton-Raphson algorithm to study the voltage violations that occur in the Nigerian supply system. They found that asymmetrical faults are responsible for several stability problems. The load flow analyzed in this research shows that the Nigerian system can suffer from voltage instability as well as voltage sags. Quality can be improved by interconnecting different transmission lines and setting up multiple loops for the northern buses. There is also a need to reconfigure the existing supply lines for improvements. Aliyu and other researchers (2012) formulated a research article in which they discussed the system collapse that happens in the Nigerian power supply system. Using the ideal simulation model, they find that continuous improvement is possible by using load shedding schemes and ensuring that cascading faults do not appear. However, currently total failures are caused in the system due to the cascading effect, which affects the whole transmission system. Uche and others (2018) analyzed the Nigerian power system and found out why voltage collapse incidences occur quite frequently in the country. Using MATLAB application software, they understood that that there are total and partial power failures that have occurred in the country. Their analysis reveals that many generating companies have shut down in Nigeria because the system does not have the capability to maintain voltage stability in the case of system faults. System monitoring also needs to be improved to produce better control over the power supply in Nigeria. Ibe and Okedu (2009) performed a critical review of the grid operations in Nigeria and concluded that the current system limitations are the long transmission lines and insufficient power generation. The country has a large land mass and this makes it difficult to run a unified grid system. They argued that breaking the Nigerian grid into six separate systems will improve the transmission, allow for quick implementation of energy generation and ensure that the electricity demand is marginalized accordingly. Ahiakwo and Sigalo (2016) found that the 132KV line works better in Nigeria, but there is still a need to find out its performance parameters. They employed the Newton Raphson algorithm andused the data from the control centers of Afam and

Oshogbo. They found that the post power reform of the country is working better than the earlier very as they observed improved voltage profiles.

Renewable Energy Sources

Felix and other researchers (2017) presented a research where they assessed the voltage stability of installing a distribution system, which does not have wind turbine generators on it, as they often have varying capacity of generation. Wind turbines represent a problem when voltage stability needs to be investigated. Distribution systems like the one in Nigeria will find it difficult to be compatible when wind generation is accommodated to an existing grid. The magnitude of the voltage instability increased when connecting wind turbines and any other power generation units that often produce varying power levels, and need to have a specific system that can accept differing input power streams. Oluwatoyin and others (2015) discussed that there is a significant need to use renewable energy sources to expand the available power in Nigeria. With more power available through cost-effective means, it is possible to offer better energy transmission in the country.

Prospect of Improvements and Current Challenges

Ibe and others (2017) recommended that Nigerian grid system can improve by implementing distributed generation and setting up grid buses accordingly. They found that such a system reduces the maximum power angle deviation and ensures that the average available power remains at the lowest phase difference by having balanced inductive and capacitive load. Large disturbances are better controlled with the use of such systems. A contingency analysis of the 300KV like was carried out by researchers in Nigeria. They identified that the power sector is going through important reforms and it is important to measure the variations that appear in the power system. They used a simulator to identify the violations and discuss the contingencies that may appear. They found that bus violations appear and can only be reduced when generation contingency can be developed for the power facilities (Onojo, et al., 2015).

Oleka and other researchers (2016) argued that it is important to study the Nigerian electric power grid, especially with the rise of population which has resulted in an enhanced demand for electricity in the country. This situation produces more load on the transmission and often causes power outages and a reduction in the quality of the transmitted power, especially the 330KV main power grid of the country. Their research showed that currently the Nigerian grid is underutilized and does not perform optimally because of a lack of voltage control devices. They found that the 330KV lines are limited due to their voltage drop levels, although the lines are no way near the thermal stability limits. It is possible to use Ultra High Voltage and employ better conductors, but the main improvement required is the installation of enhanced voltage control on the 330KV grid lines. In line with this research, Ambafi and others (2012) checked the northcentral power network of the Nigerian Grid. They found that there is a need to have an improved damping controller between the power system stabilizer (PSS) and the static synchronous compensator (STATCOM). These devices provide the required damping oscillations on the 330KV power line and their performance is important to control the transmitted power and ensure that they system maintains its optimal grid efficiency. They observed using simulation tools to find that the PSS only corrects the generator swings and does not produce a positive effect on the inter-area oscillations, while an opposite case is present with the use of STATCOM, producing a gap in terms of having the ideal damping system. The research concluded that it is important to have voltage stabilization units that can improve all power profile aspects of the Nigerian grid system.

One challenge that power network designers face is to control the losses that appear in power transmission lines and reduce them with the use of the ideal grid solutions. Alumona and the fellow researchers (2014) found that industrialization requires the use of increasing electrical energy generation. However, the generation is only useful if it can be delivered to the consumers, by using a transmission system. Transmission losses can affect the overall system efficiency. The researchers presented the example of Nigeria which uses two lines of 132KV and 330KV. The researchers argued that transmission losses are best minimized when each loss element is reduced individually as much as possible, including the tackling of both the technical and the non-technical losses. Energy delivery can be improved if citizens are allowed to have an ownership stake, while the government adds its input to provide support to nationwide solutions. Obi and other researchers (2013) believed that the current electric power quality in Nigeria needs an improvement. They presented the solution of using static VAR compensator system, which has the be ability to affect the entire 28 buses that are present in the Nigerian electricity network. They found that modern methods that employ FACTS devices are required to improve the current reliability of electricity grid in Nigeria, and ensure that energy is available to the end consumers.

Ajao and other researchers (2016) presented that problems appear in the Nigerian power sector, which can be resolved by taking a smart grid creation approach. This approach is essential and is perfect for use in countries where transmission losses play an important part in determining the quality of power delivered to the consumers. Smart grid can ensure that the generated electrical power can be optimally delivered allowing Nigeria to prosper and be on a path of economic improvement by enjoying a reliable transmission grid and the ability of employing efficient energy grid. Another improvement for the Nigerian grid system is offered by a research performed by Nwohu and others. They suggested that by using thyristor-controlled series compensators (TCSC), it is possible to significantly improve the performance of the transmission grid and minimize the power losses that appear due to a variety of reasons. It is also a FACTS device, which is capable of reducing the initially measured power losses from 2.1% to 1.5% that occur due to technical problems and the slight drops of bus voltages. A genetic algorithm (GA) method is suggested in this research which greatly helps with the required improvement in providing an innovative way to improve the Nigerian 330kV Grid System (Nwohu, et al., 2016).

Idris and his fellow researchers (2015) studied how to minimize the transmission losses with the use of SVC compensators in the case of Nigeria. They found that transmission is an important part of an electricity system and it is important to improve it in order to provide better efficiency. The 33KV substation present in the system is found to have the highest losses. The installation of an SVC (Static VAR Compensator) will improve the weak bus resulting in minimizing losses and better voltage stability. Adebayo, Aborisade, and Oyesina (2013) also looked at the use of static synchronous series compensator (SSSC) to improve the 330KV grid system of Nigeria. The application of SSSC is excellent for a grid as it provides the magnitude control of the available bus voltage and improves the available power. The researchers proved using mathematical algorithms and MATLAB programs that the incorporation of the SSSC will significantly improve the reactive power supply, which is present in the 330KV grid. The system efficiency is enhanced, while the voltage collapses are better controlled by installing these static systems.

Akinloye and others (2016) evaluated the reasons behand the collapses that occur in the Nigeria power distribution system. The normal term is the voltage collapse where the instability in the voltage level reaches a position where it ultimately leads to a black out. The research aimed to look at data from 1987 to 2914 and analyze the frequency of different collapses to come up with the required improvement suggestions. They found that the system requires a complete overhaul, where the failures have produced economic problems for several companies. There is a need to improve the power generation capacity and then expand the current transmission system to ensure that the customer power demand can be met at all times. The restructuring of the distribution network is also required to ensure that the ideal economic impact is available from the system. A current challenge is that of network outages. Abanihi and others (2014) researched about the outages that occur on the high voltage transmission grid of Nigeria. They found that the 330kV line faces more problems and outages when compared to the 132kV line. They found that vandalization and weather conditions are often the cause for the failure of the high voltage line. The results also indicate that the 330KV line has a reliability issue. They recommended that more power stations must be added, while the required equipment should also be added to enhance the efficiency. Sadiq and others (2013) found the effect of contingency on the 330KV line's ability to transfer power. They found that single line outages in the 330KV network lower the transfer capability while often affecting the ability of the system to work efficiently as a power grid.

Ogbogu and Anaemeje (2011) described that optimal power flow is possible by carefully designing transmission systems. By taking the example of Nigeria, it is possible to discuss several cost minimization schemes that will also result in improved power flow and the ideal delivery of electrical power. Samuel and others (2017) discussed the use of a voltage stability index to describe the voltage collapse in power networks. They applied the test on the Nigerian power system to find out that the maximum permissible reactive load was 74.6 MVar that the system could handle, otherwise, a collapse occurs affecting the entire system. Oluwatoyin and others (2015) discussed the best ways to provide stable power in Nigeria, where instability and collapses have often produced problems. They found that the total grid capacity and the power generation capacity does not compare well in the Nigerian system. There is a need to increase the stability of the power.

Conclusions

The paper analyzed various studies that are available for finding out the performance of the national power grid of Nigeria. We have presented the review of the literature in the form of various themes that appeared in the selected papers. Here are some key conclusions that this review has found from the available literature sources that describe the Nigerian grid system and its current state:

- There are two grid voltage networks in Nigeria which work at 330KV and 132KV. The 330KV network is larger and faces the most problems that cause voltage instability and power outages.
- Voltage instability is a key problem. It can be improved by installing FACTS equipment capable of controlling the voltage drops that occur at different connected buses in the grid system.
- Total grid failure is common due to the system limitation of not employing the ideal VAR controlling equipment that can produce cascaded power outages.
- There is a capability of generating renewable energy like the wind energy. However, the current grid is incapable of incorporating a source that produces variable power supply.
- Various simulations performed on the 330KV transmission line show that improved load balancing is required, in the form of static VAR devices capable of providing better alternating current grid controls to improve voltage stability.

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