

ELECTRICITY TRANSMISSION LOSSES IN NIGERIA POWER SECTOR: A SMART GRID APPROACH

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Corresponding Email: kajao@unam.na**ABSTRACT**

This paper analyzes factors responsible for losses in electricity transmission in Nigeria and proposed innovative ways for grid modernization. At 126 kWh per capita, Nigeria is lagging behind many developing countries in terms of grid-based electricity available for consumption. An estimated 40% of industries and businesses generate their own power supply to augment the national grid supply. In February 2016, Nigeria reached electricity transmission capacity of 5074 MW which was still less than the generation capacity at that time. With a target of 20,000 MW transmission capacity by 2021, Nigeria urgently need to evolve new ways to minimize transmission losses and deliver quality electricity to commercial and domestic consumers for rapid economic development of the country. Optimizing the functioning and reliability of the transmission grid can be achieved by improved technology in sensing, communications, metering and control using the smart grid approach. These dynamics can boost transmission grid efficiency, reliability, capacity utilization and ensure more rapid response to remediate emergencies.

Keywords: power supply, transmission capacity, generation capacity, losses, reliability, efficiency

INTRODUCTION

Nigeria is the seventh largest country in the world with approximately 186 million people, the largest of any country in Africa (more than 15% of the entire African population) and the Africa's largest economy. But, only about 40% the country's population have access to electricity supply due to inadequate investment and re-investment in the power sector, high operating costs, high energy losses (technical and non-technical losses) and lack of expertise in the power sector (Nnaji, 2011).

In 1929, the Nigeria Electricity Supply Company began operation as a hydroelectric station in Jos, Plateau state. The Electricity Corporation of Nigeria

(ECN) was subsequently established in 1951, while the first 132KV line was constructed in 1962, linking Ijora Power Station to Ibadan Power Station. However the Niger Dams Authority was merged with ECN in 1972 to form the National Electric Power Authority (NEPA). The law establishing the National Electric Power Authority (NEPA) in 1972 specified that it should develop and maintain an efficient, coordinated and economical system of electricity supply for all parts of Nigeria. At the inception of NEPA in 1973, only five of the then nineteen Nigerian state capitals were connected to the national transmission grid system. But today, nearly all state capitals are being served from the national grid,

although this may sometimes be epileptic in nature (Onochie et al., 2015).

In 1988, the National Electric Power Authority (NEPA) was partially commercialized, supported by an upward review in tariffs. As part of the restructuring effort of the power sector, the Electric Power Sector Reform Act 2005 was enacted. Consequently, this led to the defunct National Electric Power Authority (NEPA) and later known as Power Holding Company of Nigeria (PHCN). The law paved the way for the unbundling of PHCN into the 18 companies; 6 generating companies, 1 transmission Company and 11 distributing companies (Ogagawwodia et al., 2014).

The Nigerian power sector is marked by low generating capacity relative to installed capacity and much of the country's citizens do not have access to uninterrupted supplies of electricity. At present, electricity generation ranges from between 2,500 MW to about 4500 MW, even with the inclusion of three gas-powered independent power projects in the Niger Delta region. The estimated national consumption is in excess of 10,000 MW. While the potential demand in the next few years is estimated at about 15,000 megawatts (Adetunji & Isa, 2008).

The nation is deep-rooted in a serious energy crisis. The energy delivery infrastructure is absolutely inadequate to handle the energy demand of the country. Moreover, efforts towards considerable expansion in the quantity of electric power generated are not simultaneously accompanied by tactical expansion of the transmission and distribution systems. There has been a consistent drop in power production from the nation's power sector due to inadequate funding, persistent economic regression, poor system maintenance strategies and constraints of technical reliability (REEEP, 2014).

Electricity Generation and Transmission in Nigeria

There are currently 26 grid-connected generating plants in operation in the Nigerian Electricity Supply Industry (NESI), with a total installed capacity of 13,597MW and available capacity of 6,056 MW. Most generation is thermal based, with an installed capacity of 8,457.6 MW (81% of the total) and an available capacity of 4,996 MW (83% of the total) (Transaction, 2016). Hydropower from three major plants accounts for 1,938.4 MW of total installed capacity (and an available capacity of 1,060 MW) (Transaction, 2016). A study by a major engineering firm has estimated that demand for electricity in Nigeria will rise from around 33 terawatt hours in 2011 to between 56 and 95 terawatt hours by 2020. This will result in an increase in peak load demand from around 5,000 MW in 2011 to between 9,000 MW and 16,000 MW by 2020 (Transaction, 2016).

Installed capacity for electricity generation increased six-fold between 1968 and 1991. Between 1991 and 1999, no new power plants were built and the government substantially under-funded both capital projects and routine maintenance operations. Hence, increased pressure on existing generation and inadequate overhauling of the generating stations proved to be an albatross as most units began to fail (GENI, 2014). Nigeria has been marked by an unstable and epileptic power supply for the past two decades. Power supply to homes average about 6 hours per day. Electricity is largely supplemented by private producers such as the use of individual generators powered by fossil fuel for the privileged classes. Over 90% of businesses and companies have private generators, leading to high production costs. For Nigeria to meet its energy needs, it requires per capita power capacity of 1000 Watts or a power generating/handling capacity of 140,000 MW compared with the current deliverable capacity of just over 5,000 MW. Nigeria's development is severely hampered by this deficiency.

Table 2.1: Planned power plants (Source: Wikipedia)

S/N	Power plant	Type	Capacity (MW)	Year
1	Kano Power Station	Hydro	100	2016
2	Kiri Power Station	Hydro	35	2016
3	Mambilla Power Station	Hydro	3050	2018
4	Itobe Power Station	Coal	1200	2018
5	Azura Thermal Power Station	Natural gas	450	2017
6	Proposed nuclear power station	Nuclear	6000	2035

In order to boost electricity generation in Nigeria, Kano and Kiri hydro-electric power stations are set to be completed in the year 2016, Mambilla hydro-electric power project is expected to be completed in 2018 and these three hydropower plants can add about 3185 MW to the national grid in the next two years. Azura power plant (gas) and Itobe (coal) are planned to generate 450 MW and 1200 MW respectively by 2018 as shown in Table 2.1 above. Although still at the planning stage, Nigeria plans to build four nuclear power plants with a total generation capacity of 6000 MW by 2035. All these are geared towards the energy security of the country for massive industrial development.

The transmission system is potentially the weakest link in the entire chain of the Nigeria electricity network. Inadequate transmission infrastructure has been consistently reported as being responsible for stranded capacity that is characteristic of the electricity grid. Consequently, significant investment is required to

improve the transmission system if it is to keep pace with the expected growth in the generation capacity and consumers' expectations of improved power supply (KPMG, 2013).

The appointment of a management and technical contractor for the Transmission Company of Nigeria (TCN) seems a step in the right direction. The Transmission Company of Nigeria (TCN) is a successor company of PHCN, following the unbundling of the sector, and is until recently being managed by a Management Contractor, Manitoba Hydro International (Canada). Manitoba was responsible for revamping TCN to achieve technical and financial adequacy in addition to providing stable transmission of power without system failure. Currently, the transmission capacity of the Nigerian Electricity Transmission system is made up of about 5,523.8 km of 330 KV lines and 6,801.49 km of 132 KV lines (KPMG, 2013) as shown in Figure 2.1.



Figure 2.1: Nigeria's Transmission Line System (Source: (Nnaji, 2011))

National Integrated Power Projects

Nigeria plans to increase electricity generation from fossil fuel sources to more than 20,000 MW by 2020. The Nigerian government has set several targets to increase power generation over the past decade, but none of these targets have been met. The NIPP was initially established in 2004 by the Nigerian government as a plan to construct multiple natural gas-fired power plants using natural gas that was flared. Although progress has been slower than initially expected, some of the power plants are expected to come online in the short term. According to the August 2013 Roadmap, NIPP projects currently contribute more than 1,000 MW to the national grid capacity, and it was expected to reach 4,771 MW in 2015 when all planned units are expected to be completed and commissioned. A major source of capacity expansions is expected to come from Independent Power Projects (IPPs). IPPs currently contribute around 1,674 MW to the national grid capacity, and capacity from IPPs is expected to grow to between 14,000 MW and 20,000 MW by 2020, according to the August 2013 Roadmap (NIPP, 2014).

Nigeria also plans to increase hydroelectricity generation capacity to 5,690 MW by 2020, quadrupling the capacity from the 2012 level. The country plans to increase hydroelectricity generation by upgrading current hydroelectric power plants and constructing new ones such as: Gurara II (360 MW), Zungeru (700 MW) and Mambilla (3,050 MW). In late 2013, the Nigerian government announced a \$1.3 billion deal with China to build the 700 MW Zungeru hydropower project (NIPP, 2014).

Renewable Energy Resources

Nigeria is endowed with abundant fossil, nuclear as well as renewable energy resources. The fossil type includes crude oil, natural gas, tar sands and coal; while the renewable energy resources include large hydro, small hydro, solar, biomass (fuel wood, animal wastes, agricultural residues, energy crops) and wind. Others are tidal and ocean waves as well as geothermal (Ajao et al., 2009).

Over the years Nigeria has overly depended on deflectable oil and gas, while totally neglecting or paying little attention to the development of the inexhaustible renewable energy resources. The annual average of daily solar radiation ranges from 3.5 kWh/m²-day in the coastal belt of the south to 7.0 kWh/m²-day in the northern arid regions, while the daily sunshine hours has an annual average of 4 to 9 hours, increasing for south to north.

Analysis of the wind pattern in the country at 10m height shows that some sites have wind speed regime between 1.0 to 5.1 m/s and this ranges from a low 1.4 to 3.0 M/S in the southern areas and 4.0 to 5.12 m/s in the extreme north. Preliminary study shows that the total actual exploitable wind energy reserve at 10m height, may vary from 8.0 MWh/year in Yola to 51.0 MWh/yr in the mountain areas of Jos plateau and is as high as 97.0 MWh/yr in Sokoto (ECN, 2014).

Table 2.2 depicts the present level of generation and short term, medium term and long term planning for renewable energy inclusion in the energy mix.

Table 2.2: Summary of Renewable Energy Supply Target¹

S/N	Resource	Present (MW)	Short term (MW)	Medium term (MW)	Long term (MW)
1	Hydro (LHP)	1938	4,000	9,000	11,250
2	Hydro (SHP)	60.18	100	760	3,500
3	Solar PV	15	300	4,000	30,005
4	Solar thermal	-	300	2,136	18,127
5	Biomass	-	5	30	100
6	Wind	10	23	40	50
All renewables		1,985.1	4,628	15,966	63,032

Nigeria's Electricity Transmission Loss Scenario

About 25% of Nigeria's 12,522 MW of installed capacity reaches the end users due majorly to transmission and distribution losses. Widespread inefficiency means that only 3,879MW of this capacity is operational with approx. 3,600MW transmitted and about 3,100MW distributed. Most of the short fall is capacity that is unavailable due to obsolete equipment and poor maintenance or to ongoing maintenance and repair activities at existing power plants. Also, 3,262MW is non-operational primarily due to gas, water, high frequency, and line constraints (APT, 2015).

Nigeria's transmission network consists of 159 substations with a total transformation capacity of about 19,000 MW and approx. 12,350 km of transmission lines. Currently, transmission capacity (approx. 5,300 MW) is higher than average operational generation capacity of 3,879MW but it is far below the total installed capacity of 13,597 MW. When operational generation capacity grows to the same level as transmission capacity, transmission will become a critical bottleneck to electricity delivery (APT, 2015).

¹ Short term 2013-2015, mid-term 2016-2020, long term 2021-2030

Different classes of data for three years pattern were gathered from Nigerian Electricity Regulatory Commission (NERC), Central Bank of Nigeria Statistical Bulletin and International Energy Agency websites. These data were collated, analyzed and projected for a future outlook on electricity, generation, consumption, transmission losses and capacity utilization in Nigeria as shown in both Table 3.1 and Figure 3.1 below

Table 3.1: Nigeria Electricity Generation, Consumption, Transmission losses and Capacity Utilization (2000 – 2013), GWh

Year	Generation	Industry	Residential	Commercial	Losses	% Lost	% Utilized	Total Consumption
2000	14727	1866	4431	2346	5618	38.1	58.7	8643
2001	15462	1914	4608	2439	5986	38.7	58.0	8961
2002	21545	1764	7715	3298	8086	37.5	59.3	12777
2003	20184	1565	7669	3538	6740	33.4	63.3	12772
2004	24275	1959	9557	4410	7545	31.1	65.6	15926
2005	23539	2119	10302	4754	5580	23.7	73.0	17175
2006	23110	3198	7832	4077	7181	31.1	65.4	15107
2007	22978	4128	10091	5252	2650	11.5	84.7	19471
2008	21110	3502	10240	4574	1989	9.4	86.8	18316
2009	19777	3109	10163	4639	1160	5.9	90.6	17911
2010	26121	3249	11962	5449	4497	17.2	79.1	20660
2011	27034	2581	13568	6180	2581	9.5	82.6	22329
2012	28706	3983	14549	6627	2485	8.7	87.6	25159
2013	28961	3899	13458	6130	4443	15.3	81.1	23487

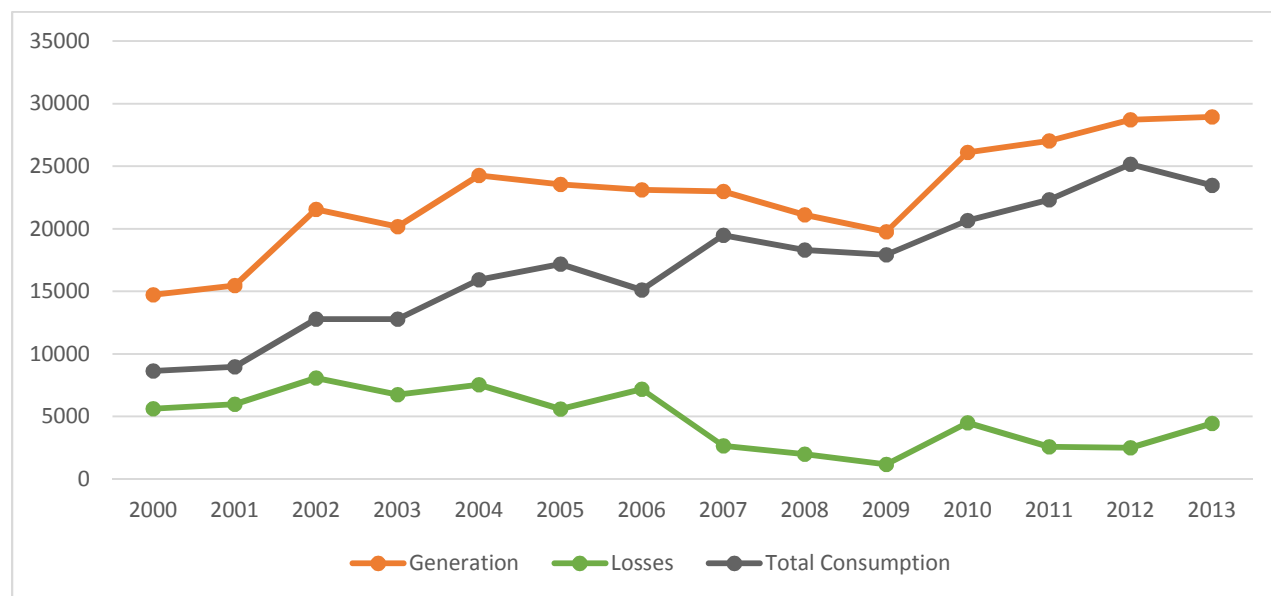


Figure 3.1: Nigeria Electricity Generation, Total Consumption and Total Losses

Then the forecasting of historical data was carried out to obtain projected values for the future using stochastic/extrapolation method as shown in Figure 3.2 below. Figure 3.2 is the projected values of total annual generation, transmission losses and consumption from 2000 to 2030. Total transmission

losses follow a downward trend up to 2017 when it is predicted to hit the zero loss level. Transmission losses account for the gap between electricity generated and quantity consumed. The trend shows that higher values of transmission losses results in lower consumption of electricity from 2000 to 2007 and lower values of

transmission losses results in higher values of electricity consumption between 2007 and 2013.

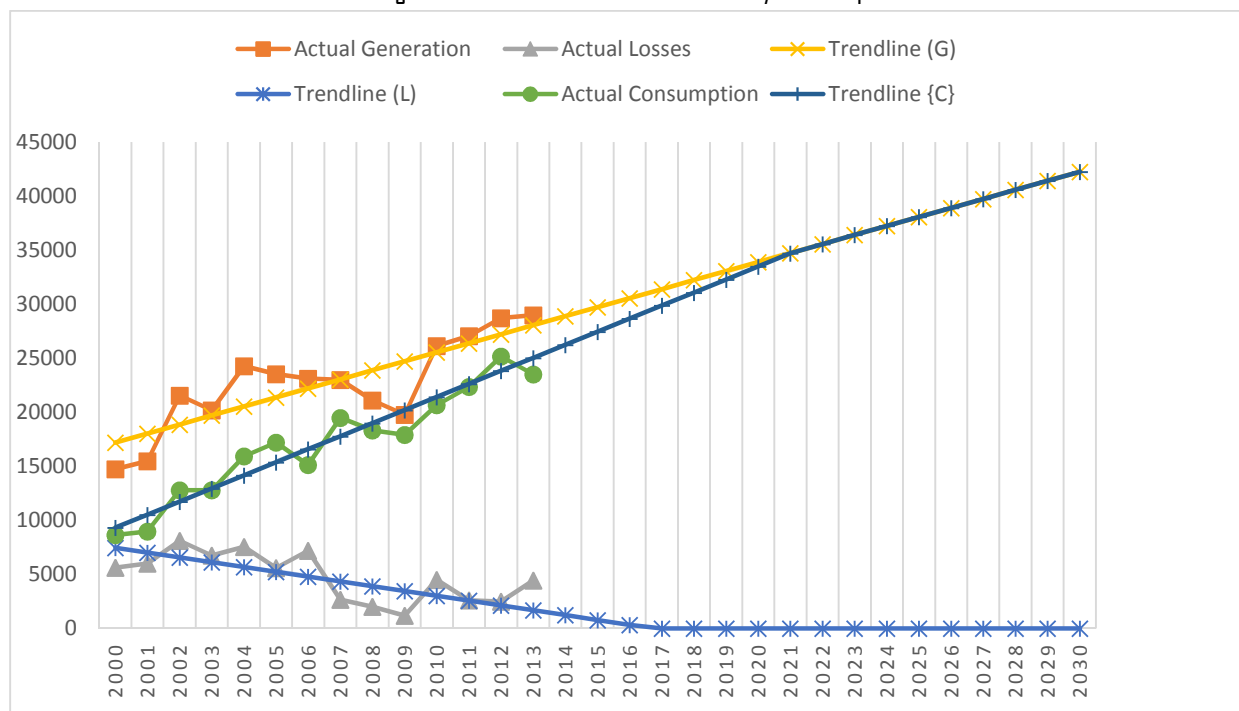


Figure 3.2: Forecasted Values for Generation, Consumption and Total Losses (GWh)

The actual values gave a trend line equation that has a negative slope, the trend line is used to forecast the future trend of transmission losses. It is expected that Nigerians be able to consume up to 99% of electricity sent out of the national grid by 2017. However, the accuracy of this forecast was calculated and mean absolute percentage error of 42.14% was obtained, this is due to wide variation in yearly values of transmission losses.

The implication of this is that despite the improved technical and management efforts of the Transmission Company of Nigeria (TCN) towards the reduction in transmission losses, Nigeria cannot achieve zero loss level in 2017 because according to (Labo, 2010), electricity transmission losses in the country are majorly due to the following factors:

- i. Radial Lines with no redundancies
- ii. Obsolete substation equipment
- iii. Overloaded transmission lines and sub-stations
- iv. Inadequate coverage of infrastructure

- v. Limited funds for development of projects
- vi. High technical and non-technical loss
- vii. Limited training opportunities
- viii. Frequent vandalism of transmission infrastructures

These issues make it more difficult to mathematically predict the trend of losses in the transmission grid but one thing that is certain is that economic development in Nigeria is strongly linked to the quantity and quality of electricity available for consumption. For Nigeria to develop its gross domestic product, transmission losses must be reduced to the barest minimum so that there can be maximum utilization of electricity by the consumers.

Transmission Company of Nigeria (TCN) Recent Challenges

Transmission Company of Nigeria (TCN) was incorporated in November 2005. The company emerged from the defunct National Electric Power Authority

(NEPA) as a product of the merger of the Transmission and Operations sectors in 2004. TCN is independent but report to Ministry of Power. Its licensed activities include: electricity transmission, system operation and electricity trading. In 2012, the evacuation capacity of TCN was about 2500 MW. The whole country is already mapped in terms of strategic transmission line network

as shown in Figure 3.3. There are about 150 on-going projects for the expansion of facilities including transmission lines, substations, transformers, switch gears etc. In February, 2016, TCN successfully evacuated highest generation of 5074 MW, translating to 109,700 MWh with a target of 6000 MW by the end of 2016 and 20,000 MW by 2021 (TCN, Newsletter, Issue No. 5, 2016).

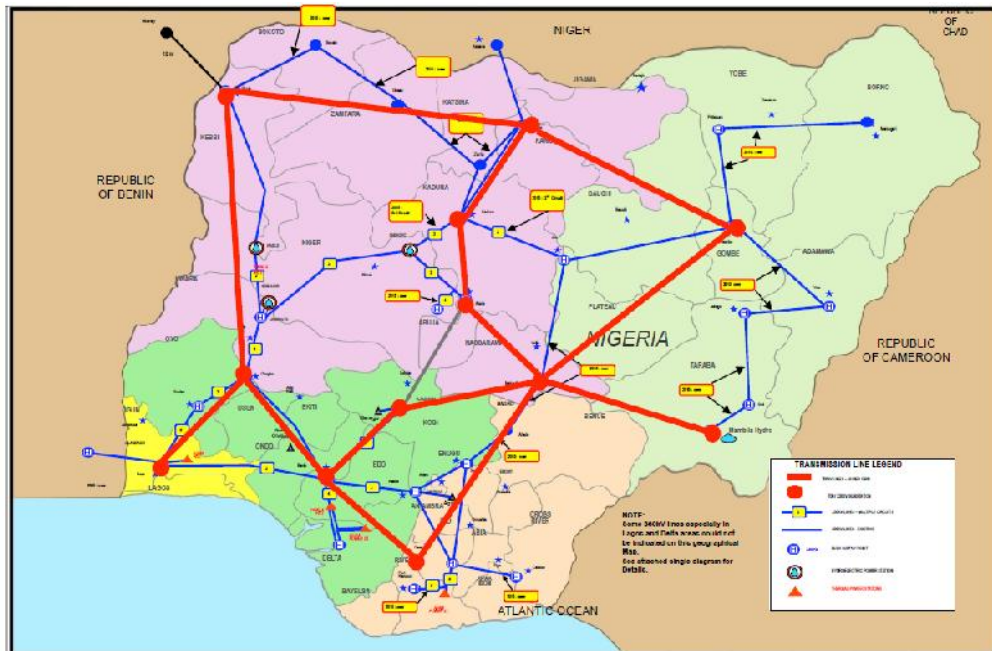


Figure 3.3: Proposed Super-Grid transmission Network (Source: (Nnaji, 2011))

Some of the most recent problems confronting the company are depicted in Table 3.2 below as adapted

from the TCN website (TCN, Transmission Company of Nigeria):

Table 3.2: Recent challenges in TCN

Issues	Planned Solution	Comments
Low voltage at Kebbi Axis	Installation of Automatic Voltage Regulator on power transformers at Birnin Kebbi Transmission Station(T.S.)	Expected to result in immediate marginal voltage improvement. Voltage control is currently by manual tap changing which does not sufficiently take care of frequent variation of grid voltage profile in Birnin Kebbi
Capacity Limitation at Power House (Kaduna Town) 195MVA is too low for the 400MW	Load re-arrangement in Kaduna. Transmission Station to fully utilize 132MW available capacity at the Substation	Present loading arrangement indicates that transformers in the station are not evenly loaded. 60MVA T2A =86% peak load, 60MVA T3 = peak 68%, 30MVA T1B =57% Peak Load and 15MVA T2B= Peak Load 34%
Faulty Metering Infrastructure CTs/VTs	Status review of metering infrastructures in Kaduna to replace defective metering facility	Bids for the procurement of new grid meters submitted and evaluation of bids in progress.
Incomplete transmission substation in Zaria/Samaru	Reinforcement of 1x40MVA and 1 x 60 MVA 132/33KV Zaria T.S with additional 40MVA mobile substation	The 40MVA Mobile substation is on ground at Zaria T.S and provision has been made for its installation in 2016 budget.
Uncompleted 132KV Makeri-Pankshin line and 132/33 KV substation in Pankshin which was started a decade ago	Completion of construction of 132KVMakeri/Pankshin 132kv lines.	To be completed in second quarter of 2016
Capacity limitation on Alaoji/Owerri/Ahoada/Yenego132KV line. The 132KV DC leg is aged and pegged to 120MW. Transformer T@40MVA at Ahoada is already overloaded	Reconductory of Alaoji/ Owerri 132KV Line.	Contract has been awarded for the reconductoring of line 1. Opening of Letter of Credit is in progress. Line 2 to be awarded.
Capacity limitation Aba/Itu 132KV SC line. The line is very old and therefore limited to 54MW to avoid snap. Full Power evacuation is constrained	Reconductory of Aba/ Itu line	Procurement of more length of conductor to complete the project.
Burnt earthing transformer at Afam Rivers IPP 1X60MVA, 132/33KV T/S.	Replacement of burnt earthing transformer at Afam Rivers IPP and clean up the two 33KV feeders at Afam.	Replacement of faulty earthing transformer completed and restored to service.
330KV Transmission line from Gombe to Maiduguri through Damaturu designed to improve service delivery to Maiduguri	Re-erect tower or improvise link the line to existing 132KV Line from Biu to Maiduguri to feed Maiduguri through Damaturu	Erection of the fallen tower has been awarded. Payment of 15% advance in progress.
330kV Circuit Breaker 3114 damaged beyond economic repair on 13 April, 2013 and requires replacement	TCN to replace damaged 330KV CB with new one. Meanwhile the available Tie Circuit Breaker is used.	Procurement of 30Nos 330KV switch gears from Original Equipment Manufacturer (OEM) is in progress.

TCN has successfully restored the Maiduguri-Damboa transmission line supplying electricity to distribution load centers in Maiduguri and the suburbs. Nigerians living in the North-Eastern part of the country are going through very turbulent times due to activities of insurgents. Aside the horrific, unending sporadic shootings which have left residents bewildered, destruction of power installations by the group has also added incessant power outage to the unfortunate situation (TCN, Newsletter, Issue No. 1, 2016).

In July 2014, Damboa 132kV substation was attacked and burnt down by the insurgents cutting off conductors in-between 6 No transmission towers. Although repairs were carried out on the affected towers, Damboa substation remained out of service.

Despite these challenges, some of the most recent achievements of TCN across the country include (TCN, Newsletter, Issue No. 1, 2016) :

- i. Restoration of power supply to Borno state in the north-east of the country
- ii. Installation of Wave Trap on R2A and RIW at Olorunsogo gas station
- iii. Commissioning of 150MVA 330/132kV Transformer at Ugwuaji transmission station
- iv. Re-strapping of New Haven-Onitsha 330kV and Ugwuaji 330kV line CTs from 800/1A to 1600/1A.
- v. Replacement of 1No 132kV exploded CT 27 on Alaoji /Aba 132kV Transmission Line at Alaoji transmission station.
- vi. Re-stringing of Delta/Benin 132KV Line 1 & 2 from T161-T163.
- vii. Completion of Lokoja 330/132/33kV transmission station
- viii. Repair and restringing of collapsed Benin-Delta 132kV Transmission line tower 512
- ix. Re-energizing of Okpai/Onitsha 330kV line after anchoring vandalized Tower 62

One hundred and twenty-six approved TCN projects worth about USD1.5 billion are underway to strengthen the transmission network and a further 118 NIPP projects have been approved. In addition, various external funding sources have been made available to finance new projects within the transmission sector. However, much funding has yet to be accessed as the number of bankable projects is low. When completed, these projects could increase grid-wheeling capacity to about 7,200 MW and the length of the network to 21,000 km (APT, 2015).

SMART GRID APPROACH

A smart grid refers to electric grid modernization using improved communication, sensing and control systems to achieve an efficient electricity delivery system. The electric power grid is the backbone of the energy supply system and it is critical to the functioning of other allied infrastructure. Several factors interact with the service life and optimum functionality of the grid to impede safe, reliable, and efficient operation. Traditional measurement and monitoring approaches is a constraint on the ability of utility company to make more effective investments in grid infrastructure and generation resources and restrict the ability of consumers to make better-informed decisions about their energy needs and consumption. Distinct from those factors is the vulnerability of the grid to other physical threats such as targeted physical attacks (NGA, 2014).

The growth of the transmission grid can improve reliability, connect lower-cost power to customers, and ensure efficient integration of renewable energy resources. Larger balancing areas, multiple transmission pathways between resource and load, and shorter scheduling windows can all help the grid function more efficiently. Increased communication capabilities and automation on the local distribution grid will ensure that utilities are able to quickly respond to outages and redirect power away from affected lines and make the

transition to greater levels of distributed generation resources easier (NGA, 2014).

The policy statement that support the modernization of the electricity transmission and distribution system to maintain reliable, secure and efficient electricity infrastructure that can adequately meet future demand growth and to achieve each of the following, which together characterize a smart grid is reproduced below (MIT, 2011):

- i. Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
- ii. Dynamic optimization of grid operations and resources, with full cyber security.
- iii. Deployment and integration of distributed resources and generation, including renewable resources.
- iv. Development and incorporation of demand response, demand-side resources, and energy efficiency resources.
- v. Deployment of real-time, automated, 'smart' technologies for metering, communications concerning grid operations and status, and distribution automation.
- vi. Integration of 'smart' appliances and consumer devices.
- vii. Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air-conditioning.
- viii. Provision to consumers of timely information and control options.
- ix. Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

- x. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

The Transmission grid carries high-voltage electrical energy over wide areas. It is a meshed grid that interconnects power plants and main consumer zones in order to guarantee suitable and redundant energy paths between the electrical energy producer and the distribution grid then to the consumers (Davoli et al., 2012). The sub-transmission grid is an optional high-voltage infrastructure that carries electricity from the transmission grid to the distribution grid or main consumers. Different layouts can be used for these networks, e.g., open loop or radial, with different characteristics of reliability and redundancy. The connections among the different grids are made in electrical substations. These substations main tasks concern the conversion among voltage levels, the topological configuration of the grids and also the protection of the electrical system in case of faults (Davoli et al., 2012).

The present day energy distribution networks were designed for unidirectional energy flow from large plants to users and are not suitable for a massive integration of small and medium power renewable energy generation units. In their architecture, the electric system is almost completely administered by the system operator that, acting on the generation side, balances the production with consumption requests in real time.

A smart grid will allow substantial integration of intermittent and unpredictable renewable sources, and distributes power highly efficiently. It is an electricity network that uses advanced communication and control technologies to deliver electricity more cost-effectively with active involvement of the customers. Advanced types of control and management technologies for the electrical grid can also contribute

to a more efficient operational running of the overall energy supply system. These technologies include devices such as smart electricity meters that show real-time use of energy and that can respond to remote communication, enabling dynamic electricity pricing related to real production and distribution costs. To provide high quality energy in this context of increased variability and complexity of the electric system requires a suitable control infrastructure based on more pervasive ICT solutions on the whole electrical supply chain (Davoli et al., 2012; Tchao et al., 2013; UN-CEB).

Modern Communication Architecture for Smart Grids

New communications infrastructures and architectures will support power system operations in the future and assist the operators to have better understanding of the network. Many methods of data transmittal are currently being used for various communication tasks on the power system, the most

common include radio, microwave, power line carrier, and fiber optics. To accommodate the high bandwidth, latency, and reliability needs of future software applications, fiber optics likely will become more prominent (MIT, 2011).

Real-time monitoring and display of power system components and performance characteristics, across interconnections and over large geographic areas will assist system operators to understand and optimize power system components, behavior and performance. Advanced system operation tools avoid blackouts and facilitate the integration of variable renewable energy resources (GRIDNEXT, 2016) as shown in Figure 4.1. Monitoring and control technologies along with advanced system analytics such as Wide Area Situation Awareness (WASA), wide-area monitoring systems (WAMS), and wide-area adaptive protection, control and automation (WAAPCA) will generate data that will inform decision making, reduce wide-area disturbances, and improve transmission capacity and reliability (GRIDNEXT, 2016; IEA, 2011).

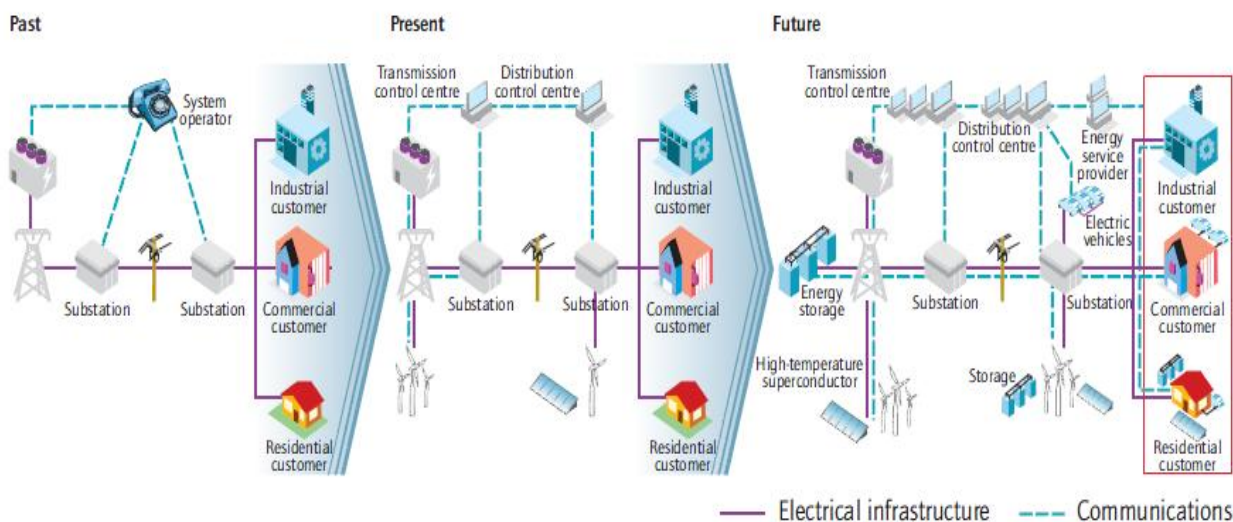


Figure 4.1: The Future of Smarter Electricity System (Source: (IEA, 2011))

The design of communication architectures for smart grids begins by breaking the whole complex system into simpler and isolated entities, and by

describing their internal system and interfaces, in order to have a clear understanding of the main actors in the system, their characteristics, objectives and the

relationships among them. Such a description may take different forms, depending on the main perspective it is addressed to: high-level conceptual models, processes and data flows, communication, information management and security, and services (Davoli et al., 2012).

To accept the variable production of new renewable generators, the actual transmission grid control system needs to evolve. In fact, the less predictable behaviour of the electrical grid needs new and more sophisticated control systems with a better wide area monitoring of the grid i.e. WASA. Synchronous phasor measurement units (PMUs) can be deployed to help develop a much more detailed outlook of the grid's dynamics for the control of the system, as well as a post-incident analysis.

Designing communication facilities in smart grids will involve dealing with several aspects as reported by (Davoli et al., 2012):

- i. software infrastructures to build distributed services and applications;
- ii. syntax and semantics of information exchange;
- iii. transport of information and networking;
- iv. communication media and technologies.

Data abstraction is needed to represent measures, events and controls of the electrical systems. Data and services are often represented in the System Configuration Language (SCL), specified by IEC 61850, which enables devices in substations to exchange configuration files and to have complete interoperability. SCL allows the description of device capabilities, system specification, substation configuration, device configuration and system exchange. A complementary data model is the Common Information Model (CIM), adopted by IEC 61970 and IEC 61968. SCL is mostly used within substations, whilst CIM is largely used in information exchanges among systems for example, energy management system, planning, energy markets and metering.

Many standards are already available for exchanging information in smart grids: standards for reliable data acquisition and control over TCP/IP networks between SCADA masters and substations (IEC 60870-5), Distribution Management System (IEC 61968), substation automation (IEC 60870, IEC 61850), distributed energy resources (IEC 61850-7-420), head-end (IEC 61968-9) and cross-domain interaction (IEC 61970, IEC 61968, IEC 61850, ETSI TS 102690) (Davoli et al., 2012).

TRANSMISSION LINES IMPROVEMENT APPLICATIONS

There are a number of new technologies and applications currently being used for the improvement of transmission system.

Flexible AC Transmission Systems (FACTS)

FACTS systems possess some of the fundamental virtues of direct current (DC) of phase independence and fast controllability to AC transmission by using electronic controllers. They can provide load flow control and, by virtue of their fast controllability, damping of power swings or prevention of sub-synchronous resonance (SSR) (Electrical Engineering Portal, 2012). FACTS systems can perform the following tasks as reported by (SIEMENS, 2012):

- i. Voltage control under several load conditions
- ii. Balance reactive power and minimize transmission losses
- iii. Increase stability of power transmission over long distances

FACTS devices are effective in controlling power flow and damping power system oscillations. By controlling power flow on an individual line, power can be redirected to or from various parts of the power grid. Managing the transmission system effectively using FACTS will require real-time coordination of the controllers to achieve the targeted objectives (McMillin et al.).

FACTS controllers present a good opportunity to regulate the transmission of alternating current, increase or diminish the power flow in specific lines and responding instantaneously to power stability problems. The unique potential of this technology is the possibility of controlling the route of the power flow and the ability of connecting networks that are not sufficiently interconnected, and thereby provide the possibility of trading energy between distant agents (Mohanty & Barik).

High Voltage DC (HVDC)

Electric power transmission was originally developed for direct current (DC). The availability of transformers and the development and improvement of induction motors at the beginning of the 20th Century led to the greater appeal for the use of alternating current (AC) transmission (Straka; Electrical Engineering Community). The use high-voltage DC (HVDC) for power transmission, in conjunction with new conversion approaches, is of great benefits for both sourcing options and system end-to-end performance. New development in advanced semiconductors and conversion topologies which function effectively in ways not previously possible are the needed catalysts that is making DC-based systems a better and available alternative to AC. As a result, HVDC systems are now practical for electricity distribution (S. Oliver & VICOR PowerBench, 2012).

HVDC is gradually becoming a veritable tool in the design of future electricity transmission grids. A classic HVDC transmission has a power rating of 1,000 MW to 3,000 MW range and HVDC systems are capable of transmitting more electrical power over longer distances than a similar alternating current (AC) transmission system. HVDC transmission is very stable, easily controlled, and can stabilize and interconnect AC power networks that are otherwise incompatible (ABB, 2014).

Dynamic Line Rating (DLR)

Line ratings are critical to prevent excessive transmission lines drooping, which could cause serious faults or outages if power lines come into contact with vegetation or other obstacles. Static line ratings provide seasonally dependent, conservative estimates of overhead transmission-line current capacity while, Direct Line Rating (DLR) provides real-time data about the effects of air temperature, solar radiation, and wind speed and direction on the power transmission lines (U.S. Department of Energy).

High-Temperature Superconductors (HTS)

As global electricity demand increases due to economic growth and new taste, more cables and conductors will be needed to increase the capacity and interconnectivity of the transmission and distribution grid to meet the new demands. Development of advanced cables and conductors that have lower losses and higher current carrying capabilities are expected to reduce transmission and distribution losses and increase energy supply to the end users (U.S. Department of Energy, 2015).

High-Temperature Superconductors (HTS) can transmit 5 to 10 times the electrical current of traditional copper or aluminum cables with significantly high efficiency. Superconducting power cable systems consist of hundreds of strands of superconducting wire wrapped around a copper core under a cryogenic cooling system to maintain proper operating conditions. In densely populated urban settings, many substations often reach capacity limits and require redundant transformer capacity to improve reliability. HTS power cables can improve grid power transmission by tying these existing substations together and avoiding very costly transformer upgrades and additional construction costs (Superconductor Technologies, Inc (STI)).

CONCLUSION

The Nigerian power sector is presently plagued with structural issues such as low generation, incessant disruption to gas supply, transmission and distribution losses and vandalism of power transmission infrastructure. The electricity sector has evolved over the years; from an initial installed capacity of less than 2000 MW in 1968 to the current capacity of about 13, 579 MW serving approx. 186 million people. In February 2016, Nigeria reached a grid-wheeling capacity of 5074 MW which was still less than the generation capacity at that time. With a target of 20,000 MW transmission capacity by 2021, Nigeria urgently need to evolve ways to minimize transmission losses and deliver quality electricity to commercial and domestic consumers for rapid economic development of the country.

The smart grid is gradually becoming a new development trend of the power grid in the world. Although the definition of the smart grid may differ, essentially the smart grid approach will be centered on the upgrading the current transmission and distribution grid and electrical equipment, using modern information, communication, monitoring, intelligent and control tools for efficient grid performance and ensure seamless renewable energy integration to network and rational energy utilization. The smart grid is capable of improving the reliability of the power grid and improve the quality of power, so as to meet consumer's demand for the security of the grid and alleviate the Nigeria's energy shortages concerns.

Integrated communications, connecting components to open architecture for real time information and control will allow every part of the grid to communicate easily with each other, sensing and measurement technologies will support rapid and more accurate response such as remote monitoring and demand-side management. Also, advanced sensors will greatly enhance monitoring and reporting line conditions

in real time and enable more power to flow over existing lines.

The ability to effectively manage load with existing transmission and distribution infrastructure will ensure that TCN could at least defer new investment in infrastructure to much later. Increased adoption of renewable energy resources will require interconnection rules, communications technologies standards, advanced distribution and reliability technologies and integration with grid planning. The electricity transmission grid will be expected to change in fundamental ways that will require careful assessment of the opportunities and costs of different technologies and policy pathways.

RECOMMENDATION

To reduce electricity losses from the national grid, Transmission Company of Nigeria (TCN) should adopt the smart grid concept as a tool for modernizing the existing grid and for future grid expansion.

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