FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

POWER SYSTEM INSTABILITY, A BANE OF INDUSTRIALIZATION AND ECONOMIC GROWTH OF A NATION: NIGERIA AS A CASE STUDY

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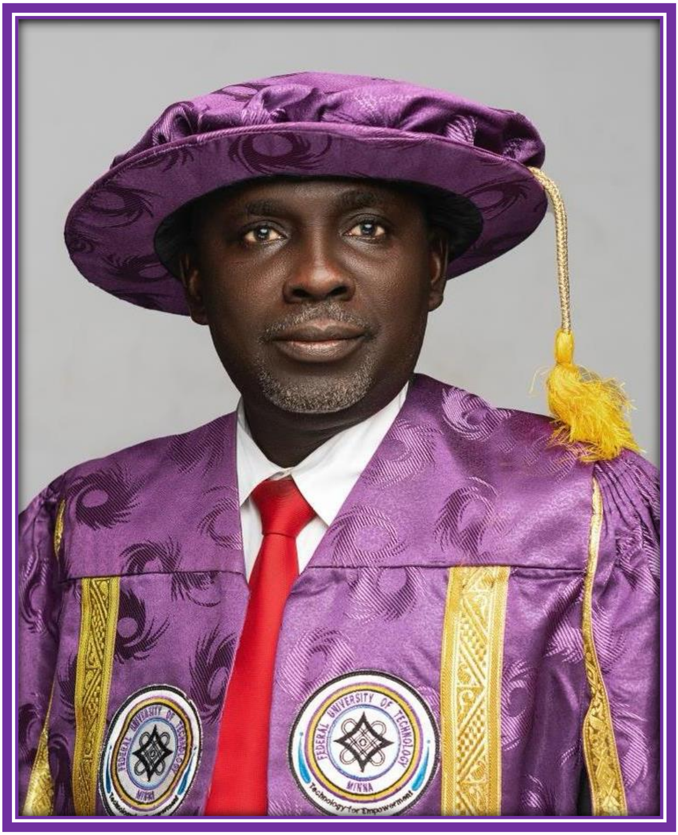

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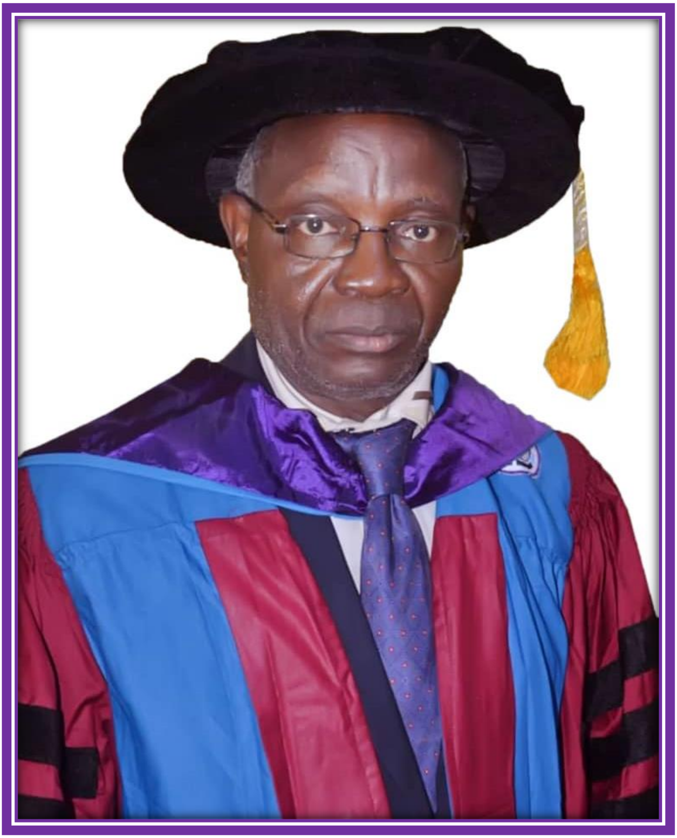

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PREAMBLE:

I give praise and thanks to the Almighty God for His mercies and love lavished on me to have made me who I am and caused my academic dreams to be actualized. At the beginning of my life, I often, imperceptibly, got involved in connecting batteries to bulbs just to excitingly see the bulb lit with some electrical scraps which subsequently drew my interest in the field of Electrical Engineering. I never knew that the ecstasy of playing around with those electrical scraps will culminate in becoming a Professor of Electrical Engineering. However, when I started my career in this field, I was faced with the challenge of an option of Electrical Engineering to choose. Later, the choice I made was elicited by Engr. Dr. A. O. Ekwue (now a professor) who would always say "These are the things you see around you". The mentorship, expertise and scholastic pursuit of this don exhilarated me to toe the path of excellence in academics.

1.0 Introduction:

Electricity is a prerequisite for the socio-economic development of any nation where the welfare and security of the citizens are guaranteed. Inadequacy of it, manifesting as unstable supply and frequent blackouts, reflects the ineffectiveness of governments.

Therefore, with a view to achieving stability and sufficiency, the Nigerian power sector has witnessed a series of successive government interventions since Independence and, similarly, enjoyed the government's monopoly until recently.

Several efforts have been made to boost and improve power supply in order to meet the astronomical demand for electricity by the teeming population of our country. In 2004, the National Integrated Power Project (NIPP) scheme was initiated to launch gas-powered stations, towards boosting the power supply.
Consequent to the implementation of the National Electric Power Policy (NEPP) of 2001, the Electric Power Sector Reform Act of 2005 was enacted, leading to the establishment of the Nigerian Electricity Regulatory Commission (NERC). Subsequently, the Road Map for Power Sector Reform was formulated, and its implementation on November 1, 2013, resulted in the eventual privatisation of the power sector, which is where we are today (Folorunso and Oluwu, 2014).

With the privatisation, two of the three segments of the sector, comprising the six-generation companies (Gencos) and 11 distribution companies (Discos), were officially handed over to investors. The government retained the third arm, operating it as the Transmission Company of Nigeria (TCN). No doubt, the socio-economic deliverables from this measure were to ensure efficient and competitive services that would guarantee sustainable power supply for businesses and households. However, the stride to achieve the objective of attaining

sustainable electricity supply has not been realised despite the huge amount of money spent annually on the power sector and the unfeasible policies enacted.
Meanwhile, the inept management had escalated prices paid by consumers under the Multi-Year Tariff Order (MYTO), introduced in June 2012 to allow tariffs gradually grow as the cost of operations does, just to attract private investment.

But despite these creative and innovative solutions aimed at attaining sufficient availability of electricity, the situation is retrogressing day by day, even with continued government subsidies for some users. The infrastructures are poor and decaying because the operators, apparently, refuse to reinvest, suggesting that most of them were not actually prepared for the business, be it in relation to patriotism, capacity and funding.

Consequently, today, Nigeria is at a crossroad concerning power supply. People are made to pay for power not consumed either by over-billing or billing without supply. Businesses are folding up and jobs are being lost rapidly. Health hazards arising from emissions from power-generating sets and transmission lines are on the increase. Communication, information access and quality of education are threatened. Pressures of urban migration are growing daily. Poverty and insecurity are multiplying exponentially. At a time when her contemporaries are making exploits in science and technology, including advancements in politics and governance, Nigeria is still struggling with self-discovery. All these are because Nigeria's power sector is not driving the economy.

Reflecting the grievances of frustrated Nigerians, including businesses that have suffered years of an incessant power outage and suppression of productive activities sequel to this dismal performance, erstwhile Senate President, Ahmad Lawan lamentably said: "*if there's any sector* *of our economy that is so important and yet so challenged, it is the power sector. I believe that this is a sector that needs a declaration of emergency. The truth is that we all know what is wrong. What we really need to do is to have the political will to take on the challenges generally. From the electricity power reform of 2005 to the privatisation of Gencos and Discos and to what is happening today, we know that everything is a fraud. If we play the ostrich, in the next 10 years we will be talking about the same things. I think the time has come for us to have courage*" (Daily Sun, July 8, 2020). So then, Nigerians are justifiably pained that nothing significant has been delivered to even rationalise the privatisation in the first place since the status quo of erratic power supply in our country has not changed. Of course, that is what informed the choice of the subject for consideration in this lecture today.

2.0 **Effects of Power System Instability on Industrialization and Economic Growth**

First, we look at what is meant by power system instability before we discuss the effects on the economy of our country and industrialization.

2.1 **Definition of Power System Instability**

Power system instability is the attribute of the system or part of the system which enables it not to be in equilibrium or balance, that is, lack of maintaining synchronism. In a power system, when the real power generated exceeds, the real power demanded by loads or vice versa, the system becomes unstable or unbalanced. Consequently, the normal frequency of 50 Hz is distorted. As the load exceeds generation, the frequency goes down. The rate of decline depends on the inertia of the generators within the system. In such a situation, under frequency load shedding schemes (UFLS) on the utility are adopted so that stability or equilibrium can be attained (Gupta, 2019; Charles, 2015).

2.2 **Electricity – A Panacea to the Development of Industries and Economic Growth**

There is a consensus that access to electricity relates positively to the development of industries and, hence, the economic growth of a nation. It should be noted that industries are major users of electricity and therefore its deficit will lead to many losses though with normal labour costs in these industries. Statistics reveal the amount of electrical energy required for the effective operation of most industries and per capita consumption of Gross Domestic Product (GDP) that reflect the economic realities of a nation. Table 1 shows at a glance the rankings of about twenty-three (23) countries based on their gross domestic product, population and power generation. According to the International Monetary Fund (IMF), the three largest economies in the world as measured by nominal GDP are the United States of America, China and Japan. Economic growth and prosperity of these countries are determined by a wide range of factors, namely, investment in workforce education, production output (as determined by investment in physical capital), natural resources and entrepreneurship. Nigeria, being the focus of this study, is ranked 27th with a GDP of 0.51 (US$ Million), power generation of 27.0 (TWh) and population size of 211,400,708. By way of comparison with Brazil which is in the same population bracket (213,993,437), there is a clear difference between power generated in Nigeria and power generated in Brazil (Ebele, et al., 2017).

Table 1: Rankings of some countries based on their GDP, Population and Power Generation

Country	Ranking	GDP (US$ Million)	Estimated Population Size	Power Generation (TWh)*
USA	1	22.67	332,915,073	4,326.6
China	2	16.64	1,444,216,107	4,715.7
Japan	3	5.37	126,050,804	1,042.7
Germany	4	4.31	83,900,473	602.4

United Kingdom	5	3.12	68,207,116	364.9
India	6	3.04	1,393,409,038	1,052.3
France	7	2.93	65,426,179	556.9
Italy	8	2.10	60,367,477	300.6
Canada	9	1.88	38,067,903	636.9
South Korea	10	1.81	51,305,186	520.1
Russia	11	1.71	145,912,025	1,053.0
Australia	12	1.62	25,788,215	252.6
Brazil	**13**	**1.49**	**213,993,437**	**588.0**
Spain	14	1.46	46,745,216	289.0
Mexico	15	1.19	130,262,216	295.8
Indonesia	16	1.16	276,361,783	182.4
Saudi Arabia	19	0.80	35,340,683	250.1
Poland	21	0.64	37,797,005	163.1
Sweden	23	0.63	10,160,169	150.3
Nigeria	**27**	**0.51**	**211,400,708**	**27.0**
UAE	30	0.40	9,991,089	99.1
Malaysia	35	0.39	32,776,194	130.1
South Africa	38	0.33	60,041,994	259.6

Source: IMF World Economic Outlook database as of September 2021; *World Development Indicators: Electricity production, sources and access, 2020.

A critical view of the foregoing speaks more of the drawbacks in the Nigerian power sector that is evident in its economic growth retardation. Little wonder, the Executive Director, Association of Nigerian Electricity Distributors from his excerpts in Punch Newspaper asserted that the demand for electricity by the teeming population of Nigeria can be met if only Nigeria will generate at least 180, 000 Megawatts of electricity. He pointed out that low power generation in the country has been the major cause of mismatch in power demand and therefore should be stepped up in order to maintain power system stability (Punch, June 21, 2018). Three decades ago, Iran and Nigeria both had about 6,000 MW power generating capacity and similar population growth rates. As of 2010, Iran generated over 70,000 MW of electricity as compared to the then Nigerian 4,000 MW generating capacity (Adelaja, 2020). However, for such an anticipated capacity of electricity to be generated, then the transmission infrastructure by which it is wheeled to all parts of the country should be re-constructed and expanded in order to be technically fit for effective transmission of power (Sadiq, *et al*., 2014; Ahmad, *et al*., 2015). The transmission system currently has the capacity to transmit a maximum of about 6,000 MW and anything beyond this will precipitate instability in the entire power system (Sambo, *et al*., 2012). Though looking at the trajectory of efforts made to improve this power sector, it is hoped that with time power crisis would have fizzled into history.

2.3 **Impact of Power Instability on Industrialisation and Economic Growth**

Regrettably, Nigeria's persistent power crisis has weakened the industrialization process and significantly undermined the effort to achieve sustained economic growth as well as reduced the competitive capacities of domestic industries in regional and global markets (Ohiobrain, 2015). From the World Bank in the year, 2010, electric power consumption in Nigeria was 756.35kg of oil equivalent. In September 2020, the price of electricity was US$0.060 per kWh for households and US$0.098 per kWh for businesses which includes all components of the electricity bill such as the cost of power, distribution, taxes and other fees. For comparison, the average price of electricity in the world for this period is US$0.137 per kWh for households and US$0.123 per kWh for businesses (World Bank, 2010). In Nigeria, we have a catalogue of industries that are no longer functional because of huge losses incurred as a result of unstable electricity supply. Most of them have relocated to other countries that have a fairly constant supply of electricity. While the multi-national company like Shell Petroleum Development Company, Ajaokuta Steel and Rolling Mill, African Timber and Plywood Limited at Sapele, Nigeria Electricity Supply Company (NESCO) at the mining site in Jos opted for licenses to be granted for authorization to generate electricity because of the vulnerability of colossal waste at power failure and minimal losses at proximity along the transmission line.

Thus, the middle-income economic status of Nigeria that required over 15, 000 MW cannot be sustained any longer. This underpins the Government's goal of increasing installed power generation capacity from about 5,566 MW to 17,108 MW by 2020 which was not achieved. Moreover, the government is assiduously working towards the diversification of the energy mix in order to achieve the set goals. In this regard, the nation's vast resources of coal, wind, solar, biomass and hydropower potentials are being fully exploited (Adetoro, *et al*., 2022). Notwithstanding, the challenge has been how to attract investments to build the necessary infrastructure for the generation, transmission and distribution of electricity throughout the country in order to surmount the deficit of electric power (Federal Ministry of Power, 2013). Because of this challenge, the country is seen as one of the poorest countries in the world despite human resources and huge resources from crude oil export (Nwankwo & Njogo, 2013), and concerted efforts are made to explore new technology with which to improve the stability of power system. Amongst the new technology considered and applied to the Nigerian power system include Flexible Alternating Current Transmission System (FACTS) which is discussed in sub-section 3.

3.0 **Milestone in Power System Stability improvement**:

3.1 Definition of Power System Stability

Power System Stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance. That is the ability of the system to maintain synchronism so that the electricity being generated is equal to the electricity demanded by loads under a normal frequency of 50Hz.

3.2 Headways in power system stability improvements

Over the years, strenuous efforts have been made by the government of Nigeria to ameliorate power supply through huge financial investment in the power sector yet the power infrastructure in Nigeria has not been properly managed and that leads to frequent equipment breakdown and very low system availability and reliability. This situation became a financial drain on the country's treasury as there have been unabated corrupt practices and neglect of potential technical approaches to alleviate power instability (Eke, 2014; Nwohu, 2007a; Nwohu, 2011c).

3.2.1 Journey so far by the Government to minimize power outages

Kudos to successive governments that built and commissioned power stations in various states without due consideration of expanding transmission corridor by which power is evacuated to all parts of the country yet quite a good number of electricity consumers are deprived of good quality of electricity. The reason is not far-fetched. The government should therefore be thinking of reconductoring the entire transmission matrix or adopting the use of the Flexible Alternating Current Transmission System (FACTS) for equitable distribution of power in as much as various power stations are built. Suffice to say that frequent power outages have not been effectively handled when the effects preceding the outages are not critically examined and appropriate technical procedures are not adopted.

3.2.2 Deployment of state-of-the-art modern technology

Sometimes, the disruption of electricity may not be an outright component outage by vandalism (see Figure 1) leading to a power cut, but rather a brownout that has hazardous effects on the appliances of electricity users. Low voltage and power losses are characteristic of such a phenomenon.

Figure 1. Nemesis caught up with the man vandalizing a transformer in a community in Ebonyi State.
Source: *National Daily Mirror, 26th June 2018*.

However, several efforts have been made by researchers to improve voltage profiles of power system networks and reduce losses along transmission lines. Nwohu, in his research papers, explored various ways the low voltages can be improved thereby stabilizing system voltage profiles (Nwohu, 2009; Nwohu, 2015; Mbunwe, *et al*., 2015; Ambafi, *et al*., 2012; Olanite, *et al*., 2022; Nwohu, 2011d).
Often, voltage instability leads to poor quality of electricity supply that consequently halt normal operation of these industries and damage equipment or appliances in domestic dwellings. Of course, these damages can be quantified by the great financial losses incurred. Since power quality is a function of stable electricity supply then this situation eventually should necessitate the deployment of end-user equipment that are highly sensitive to poor quality control of electricity supply. Such equipment as Dynamic Voltage Restorer (DVR) and Solid-State Transfer Switch (SSTS) are used to protect critical (sensitive) loads

against voltage sags and swells or any electrical disturbances (Nwohu, 2008a & 2008b).

In recent years, with the advent of power electronics, Custom Power Technology at the distribution level and its counterpart, Flexible Alternating Current Transmission System (FACTS) in the transmission section have secured prominence globally, and wide applications in power system stability. Technically, successful attempts have been made in the use of these devices to improve voltage stability and reduce losses in Nigerian power networks, however, the real implementation in Nigerian networks has not been done for the following reasons:

- lack of political will,
- misplacement of national priority,
- inept management,
- incredible and evasive policies,
- endorsement of corrupt practices and
- reluctance to adopt new technology, perhaps, for the initial high cost of installation of these devices despite the outweighed benefits to be accrued to our country.

Although capacitor banks are commonly used in Nigerian power networks to enhance the power factor thereby increasing the reactive contents on the network to some extent, the impact of the application of either custom power devices or FACTS devices is more pronounced in the network if optimally sited than the installation of capacitor banks. So, the credence in the use of these devices inspired me to have a special interest in my research work to improve the stability of the Nigerian power network with these devices.

3.3 Nigerian Power System Network

The radially structured network of the Nigerian Power System with long transmission distance makes it susceptible to faults and system instability. Often, loads at some distances from the power source suffer from an inadequate power supply, simply because of losses along the transmission line (Nwohu, *et al*., 2017; Dodo, *et al*., 2020). This is typically observed in the Nigerian Power Network where electricity consumers in the following States, Gombe, Adamawa, Taraba, Yobe and Maiduguri experience very low voltage because of their remoteness with regard to the power source which is accompanied by many losses along their transmission lines (See Figure 2). Therefore, proper placement of FACTS on the Nigerian power network will certainly stabilize the system and afford adequate power supply to the northeast of the country that demands increased reactive power of the system network.

The substantial increase in power demand has been noticed for decades with the increase in population while the expansion of power generation and transmission has been severely limited due to limited resources. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor.

Figure 2: Nigerian 330 kV Network (Blue line)
Source: *Federal Ministry of Power, 2013*

Various techniques have been used for solving various power system steady state control problems, ranging from conventional equipment deployment to the use of Flexible AC transmission systems (FACTS) controllers. In Nigeria, conventional equipment has been in use although not much impact has been made on system stability. An incessant power failure has been the order of the day. Hopefully, the emergence of FACTS which has received global recognition in recent times will aptly tackle the issue of power outages and significantly improve power system stability in the Nigerian power network if its installation is welcome (Nwohu, *et al.*, 2015; Nwohu, *et al.*,2016; Alok and Amar, 2020).

Flexible AC transmission systems are devices which allow flexible and dynamic control of power systems and a few examples are given below (Hingorani and Gyugyi, 2000). Examples of FACTS Controllers for enhancing Power System Control include

- Static Synchronous Compensator (STATCOM) -Controls voltage
- Static VAR Compensator (SVC) -Controls voltage
- Unified Power Flow Controller (UPFC)
- Convertible Series Compensator (CSC)
- Inter-phase Power Flow Controller (IPFC)
- Static Synchronous Series Controller (SSSC)

Each of the above-mentioned controllers has impact on voltage, impedance, and/or angle (and
power)

- Thyristor Controlled Series Compensator (TCSC)-Controls impedance
- Thyristor Controlled Phase Shifting Transformer (TCPST)-Controls angle
- Super Conducting Magnetic Energy Storage (SMES)-Controls voltage and power

4.0 **My Contribution to Power System Stability Enhancement**:

Mr. Chairman, sir, my research interest has been on the improvement of Nigerian Power System stability. In as much as the stride made by the government to provide an adequate supply of electricity is remarkable and commendable, the country has been left in the destitution of power and therefore enough provision should be made in the evacuation of power generated. This can be feasible by reconductoring or expanding the existing transmission corridor. Often, there have been drawbacks to the provision of rights-of-ways for organised public opposition and eco-friendly reasons that are effectively tackled through the use of FACTS on transmission lines or Custom Power devices at the distribution level. The global use of FACTS aroused my interest and inspired me to research and see the applicability of this technology to the existing Nigerian power system, particularly, the states that uniquely suffer brownout because of their remoteness. Most of my research work has to do with the voltage stability of the entire Nigerian power network, especially as it affects those states located far from the power generating stations.

In one of my research projects where voltage stability and transmission line losses were studied to characterize the performance of the entire power system in order to infer at what point or under what condition, the system can suffer from emergency voltage instability. North-east and part of North-central of the Nigerian grid system are considered for case studies as shown in Figure 3.

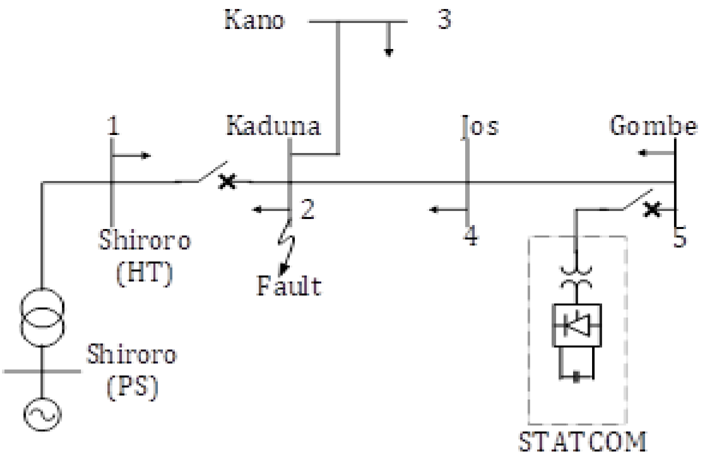

Figure 3: Northeast and part of Northcentral Nigerian grid system

Source: (Nwohu, 2011b)

The network was modelled in Power System Computer Aided Design (PSCAD) based on detailed Electromagnetic Transients Direct Current (EMTDC) simulation results to validate the Static Synchronous Compensator (STATCOM) model used. At a steady state, this network was evaluated and observed to be prone to voltage instability at loads above 200MW. A three-phase to ground fault was initiated at bus 2 at 300ms which triggers the circuit breaker at 400ms to clear the fault without STATCOM and the voltages obtained were as shown in Table 2. It was generally observed that the voltage at which bus 5 operated was very low but considerably improved at the connection of STATCOM (see Figure 4) (Nwohu, 2011b; Aribi and Nwohu, 2014).

Table 2: Bus Voltage Profiles with and without STATCOM
Source: (Nwohu, 2011b)

Bus Number	Bus Name	Load Demand (MW)	Without STATCOM (kV)	With STATCOM (kV)
1.	Shiroro	61.5	332.87	329.8
2.	Kaduna	166.2	315.00	314.9
3.	Kano	184.9	309.40	310.8
4.	Jos	58.4	302.10	313.6
5.	Gombe	102.9	268.90	330.0

Table 3. Voltage output with variation in load demand at Gombe bus
Source: (Nwohu, 2011b)

Bus No.	Bus Name	Load Demand (MW)	Voltages (kV) Without STATCOM	Voltages (kV) With STATCOM	Load Demand (MW)	Voltages (kV) Without STATCOM	Voltages (kV) With STATCOM
1.	Shiroro	61.5	333.1	332.4	61.5	330.9	330.0
2.	Kaduna	166.2	312.6	311.8	166.2	308.6	306.8
3.	Kano	184.9	289.5	303.6	184.9	300.3	301.6
4.	Jos	58.4	327.4	329.7	58.4	301.7	310.4
5.	Gombe	67.9	323.7	330.4	215.0	221.4	329.9

Consequently, the power losses along the transmission line were also read and recorded as shown in Table 4. However, the transmission line losses were reasonably high. But with the STATCOM embedded on the line, the losses were drastically reduced as shown in Figures 5 and 6. Furthermore, the loading of the system was varied at bus 5 in order to examine the robustness of the STATCOM in the reduction of the system losses and voltage stability enhancement. The results obtained of the system voltages and losses were depicted in Tables 3 and 5 respectively.

The effects of STATCOM can be appreciated as it is connected to the variation of the loads at Gombe bus (see Figures 7a, 7b, 8a, 8b, 8c and 8d).

Table 4: Transmission Losses with and without STATCOM

Lines	Names	Distance (Km)	Real power losses (MW) With STATCOM	Real power losses (MW) Without STATCOM	Reactive power losses (MVar) With STATCOM	Reactive power losses (MVar) Without STATCOM
1-2	Shiroro-Kaduna	96	0.873	1.047	2.11	7.87
2-3	Kaduna-Kano	230	2.980	3.137	11.46	23.59
2-4	Kaduna-Jos	197	1.098	2.274	6.89	17.13
4-5	Jos-Gombe	265	3.512	4.738	11.86	35.57

Source: (Nwohu, 2011b)

Table 5: Transmission losses with variation in load demand at Gombe bus (i.e. bus 5)

Lines	Names	Load Demand @ bus 5	Real power losses (MW) With STATCOM	Real power losses (MW) Without STATCOM	Reactive power losses (MVar) With STATCOM	Reactive power losses (MVar) Without STATCOM
1-2	Shiro-Kad	67.9	0.098	0.176	0.647	3.698
2-3	Kad-Kano		1.437	2.178	4.021	18.948
2-4	Kad-Jos		0.426	1.058	1.692	12.354
4-5	Jos-Gombe		1.637	3.352	7.501	27.183
1-2	Shiro-Kad	215.0	1.098	3.176	1.647	13.698
2-3	Kad-Kano		3.437	4.178	5.021	38.948
2-4	Kad-Jos		1.426	2.058	3.692	22.354
4-5	Jos-Gombe		4.637	6.352	17.501	87.183

Source: (Nwohu, 2011b)

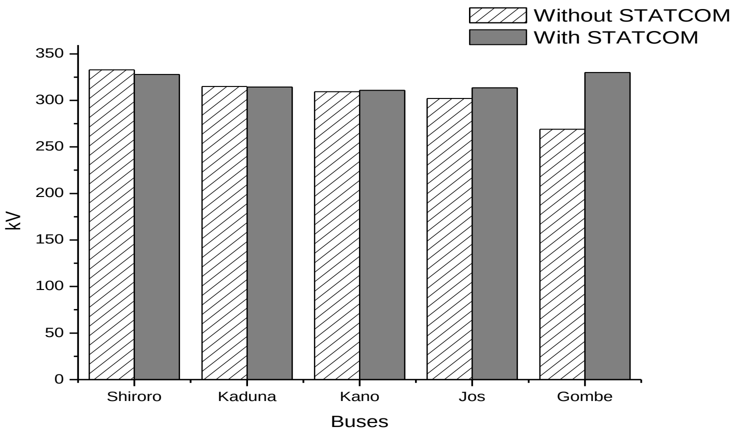

Figure 4: Voltage output with and without STATCOM

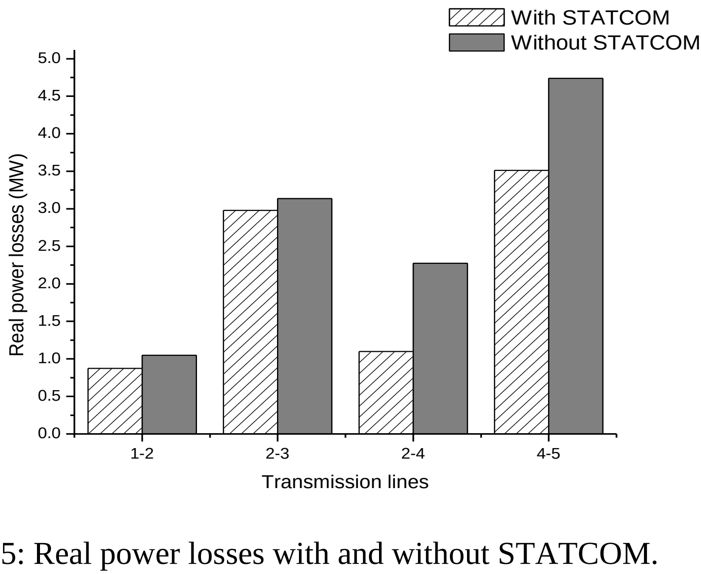

Figure 5: Real power losses with and without STATCOM.

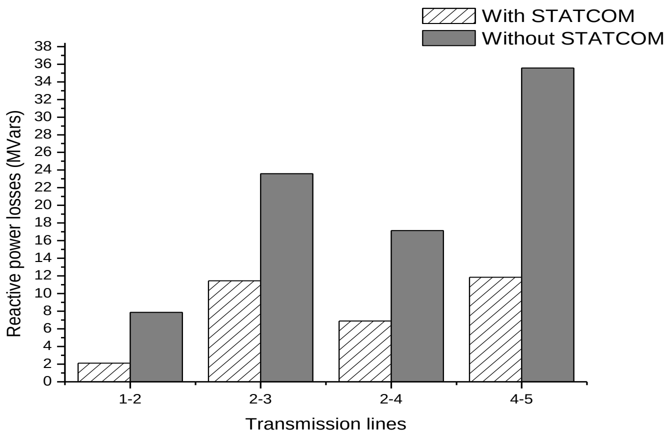

Figure 6: Reactive power losses with and without STATCOM

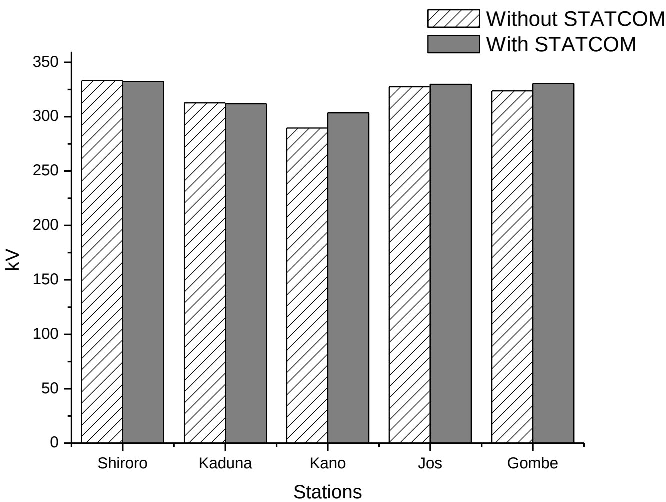

Figure 7(a): Voltage output at the load of 67.9 MW in Gombe bus

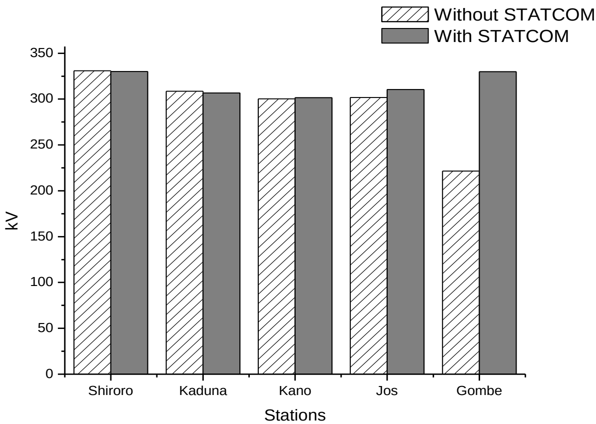

Figure 7(b): Voltage output at the load of 215 MW in Gombe bus

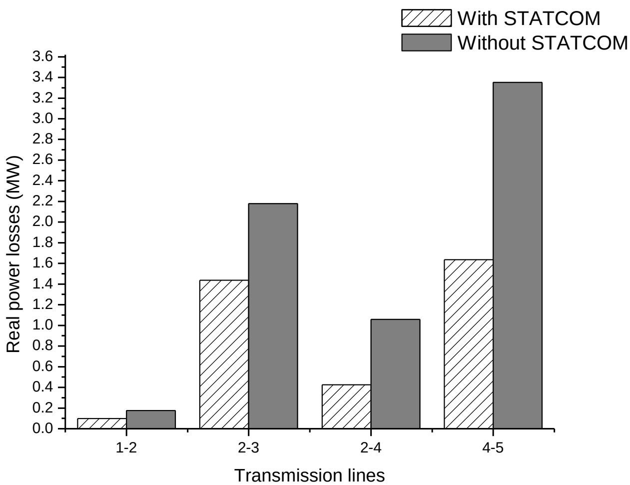

Figure 8 (a) Real power losses at 67.9 MW load.

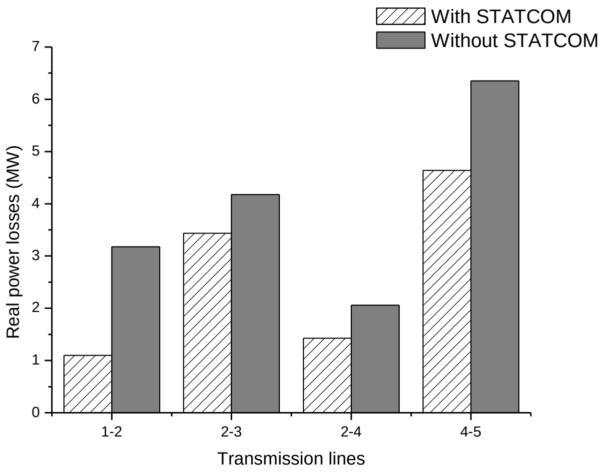

Figure 8(b): Real power losses at 215 MW load.

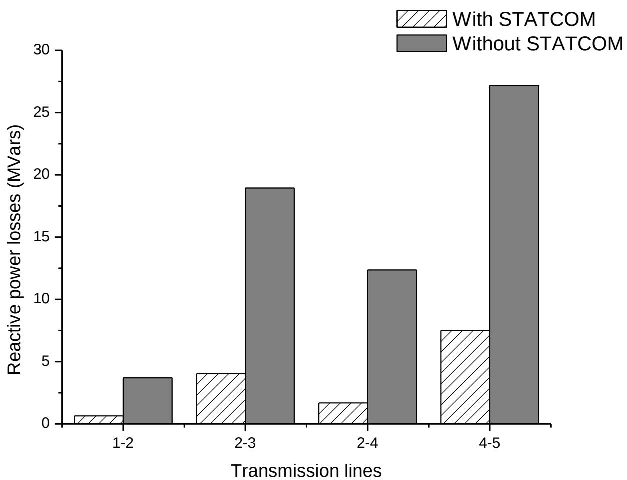

Figure 8(c): Reactive power losses at 67.9 MW.

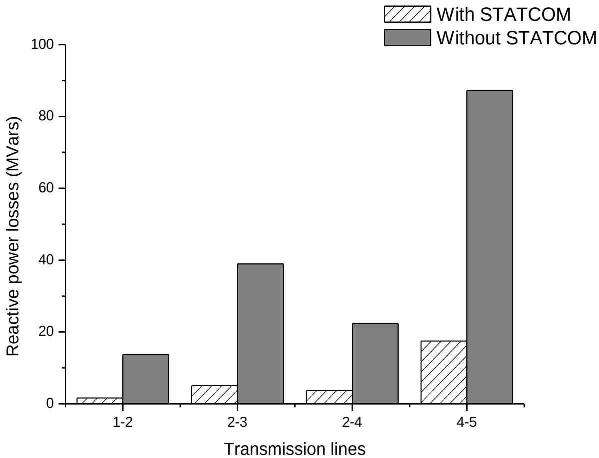

Figure 8(d): Reactive power losses at 215 MW load.

Moreover, the operation of the power system and its control is not limited to the transmission section but rather extends to the distribution system where the end-users are connected. However, the issue of power quality that affects adversely domestic appliances would have to be tackled by the use of custom power devices. Hence, the consideration of the Distribution Static Compensator (D-STATCOM) that enhances the system's stability. D-STATCOM is one of the custom power devices harnessed with power electronics components that are based on the principle of voltage-sourced converters (Nwohu, 2011a; Nwohu, 2007b; Nwohu and Sadiq, 2015).

The studied system comprises a 132kV transmission system feeding into the primary side of a 3-winding transformer as shown in Figure 9. A varying load is connected to the 11kV secondary side of the transformer. A 2-level D-STATCOM is connected to the 11kV tertiary winding to provide instantaneous voltage support at the load point. A 750μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. The studied system is implemented in PSCAD/EMTDC to carry out simulations for the D-STATCOM.

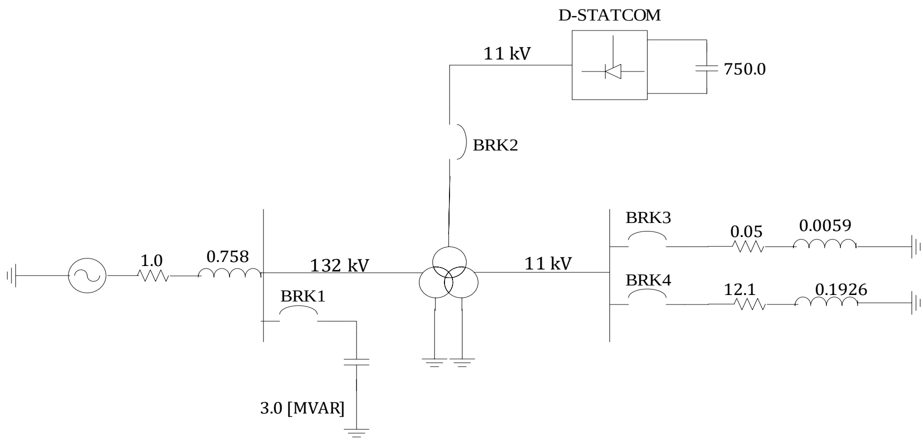

Figure 9: A hypothetical distribution system

Source: (Nwohu, 2011a)

A set of switches shown in Figure 9 was used to assist different loading scenarios being simulated with ease. The effectiveness of this controller in providing continuous voltage regulation was determined by simulations carried out with and without D-STATCOM connected to the system:

1. At the load when BRK3 is opened and remains so throughout the rest of the simulation. The load voltage is observed to be 0.9915 p.u., very close to the reference value (i.e., 1.0 p.u.) as shown in Figure 10.

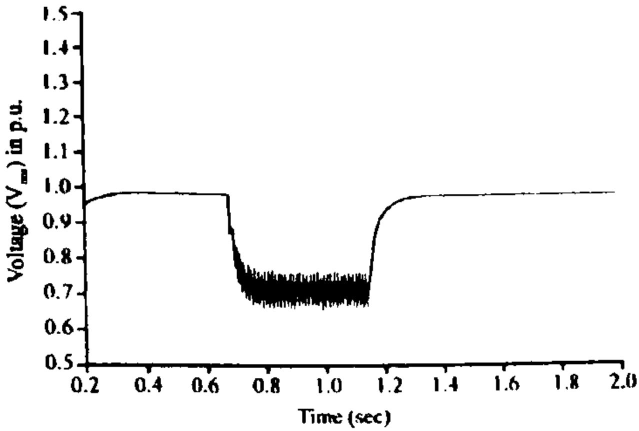

Figure 10: Voltage at load point without D-STATCOM having BRK3 and capacitor bank opened.

2. When the load is increased (i.e., BRK3 is closed), the voltage drops by 23% (i.e., load voltage becomes 0.7641 p.u.) with respect to the reference value (see Figure 11).

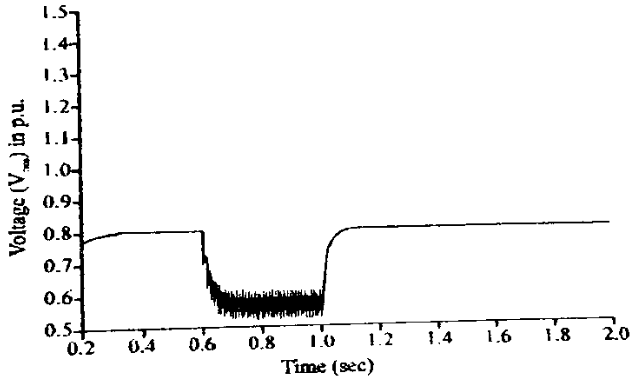

Figure 11: Voltage at load point without D-STATCOM having BRK3 closed and the capacitor bank opened.

3. When BRK3 is opened at 800 ms and remains so throughout the rest of the simulation. The load voltage (i.e., 0.9915 p.u) is very close to the reference value as depicted in Figure 12.

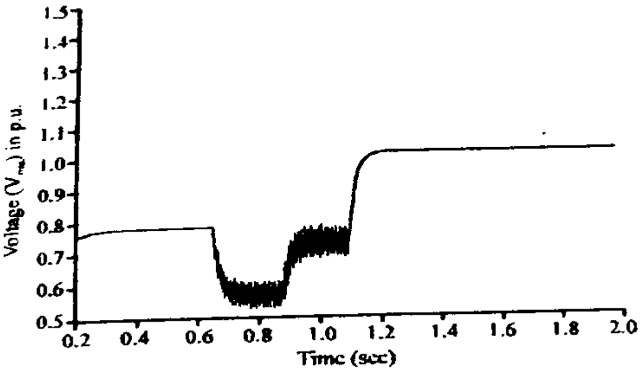

Figure 12: Voltage at the load point without D-STATCOM having BRK3 opened at 800 ms and the capacitor bank opened.

4. When the capacitor bank is connected to the high voltage side of the system network at 1200 ms. The load voltage increases (i.e., 1.2787 p.u.) approximately by 28% with respect to the reference voltage (see Figure 13).

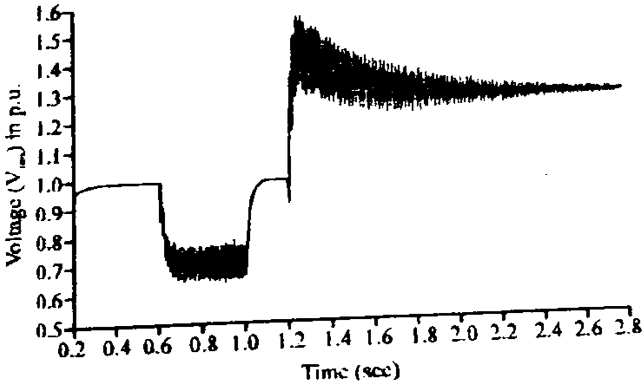

Figure 13: Voltage at load point without D-STATCOM having BRK3 opened and the capacitor bank closed at 1200 ms.

Figures 10-13 show the rms voltage at the load point for the case when the system operates with no D-STATCOM connected. Similarly, a new set of simulations was carried out but now with the D-STATCOM connected to the system and the results are as shown in Figure 14. In spite of sudden load variations, the regulated rms voltage shows a reasonably smooth profile without transient overshoots as D-STATCOM is connected.

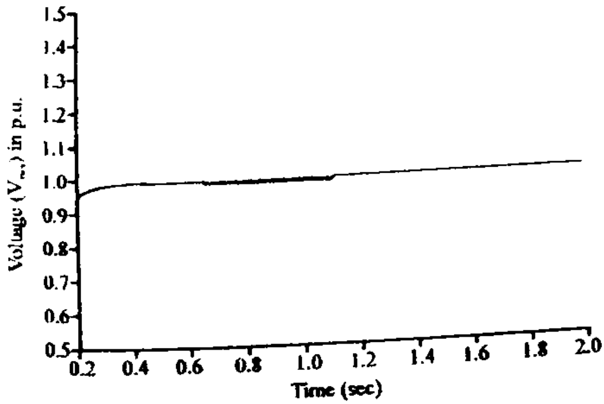

Figure 14: Voltage at load point with D-STATCOM having 750 μF capacitor size.

It should be noted that capacitor size has a great effect on the performance of D-STATCOM. However, adequate precaution should be taken in order to identify the most suitable capacitor size, aiming at minimizing waveform distortion and keeping transient overshooting at minimum values. Now with the use of a 750μF capacitor, a rapid regulation response is obtained and transient overshoots are almost non-existent. This, however, contrasts with cases where the capacitor is undersized (e.g., 75μF) that is a sluggish response and large transient overshoots are observed or oversized (e.g., 7500μF) where the D-STATCOM exhibits a very different harmonic generation behaviour.

Conclusion or Concluding Remarks:

Electricity is pivotal in the economic growth of a nation and its industrialization. Any disruption of the electricity supply adversely affects the functionality of industries and the economic realities of that nation. Therefore, proactive measures that should be taken were discussed in this lecture to curb this menace and rightly place the economic indices that juxtapose the development of our country. Of course, this is in tandem with various efforts made by research and government intervention to ameliorate the production of electrical power in order to reach the set goals.

Generally speaking, Nigerian network capacity expansion has been very slow due to environmental restrictions, expenses incurred for rights-of-way and the inability to keep pace with the growing demand for power supply. Thus, power generation, transmission and distribution infrastructure become overloaded resulting in frequent power outages. But with the limited power supplied, the old-fashioned load-shedding technique is employed as means of rationing the power among electricity consumers.

Notwithstanding, the poor quality of electricity supply becomes another issue to combat with leading to brownout of power culminating in huge damages to domestic electrical appliances. This informed the reason for devising ways of stabilizing power systems by conventional methods and the recent deployment of FACTS technology. Although the stride to stabilize the power sector with conventional methods has not brought much change considering the complexity and vastness of the Nigerian network. Hopefully, the deployment of FACTS to the Nigerian power network would not have only enhanced the stability of the entire power network but ensured quality distribution of power to all consumers of electricity if all those avoidable impediments to actualizing FACTS installation on the Nigerian power network are eliminated. Finally, classical case studies are considered to validate the use of FACTS on the Nigerian power network to stabilize the system and achieve the long-expected dream of constancy in electricity production.

Acknowledgements:
First and foremost, I wish to express my profound gratitude to God Almighty who spared my life and has enabled me to actualize the long-conceived dreams of my life. I never knew that I would be privileged to study at university with a view to becoming a Professor of Electrical Power Systems Engineering, considering my poor family background. Indeed, it was by divine providence that made me jump over hurdles of life to get to the pinnacle of my academic career. May His name be glorified and exalted.

I am highly indebted to my late parents, Mr. Emmanuel Irokazi Nwohu and Mrs Margaret Iheoma Nwohu that were instrumental to my earthly existence, upbringing and training, up to the level that I ran into a fortune of securing a scholarship for the completion of my educational career. I appreciate their sacrifices and self-denial exhibited in nurturing me and establishing a platform on which the edifice of my life is built, though they could not live to reap what they had sown. May their souls continue to rest at the bosom of Christ.

My deep appreciation goes to my wife, Mrs Cordelia Nwakuru Nwohu for her patience and tolerance when this work takes me late in the night in the comfort of our companionship. Also, I thank my children for sparing their leisure to support me while collecting relevant information for this work. Undoubtedly, their words of comfort and encouragement exhilarated me when my laptop was stolen where I first saved most of the work done preparatory to this inaugural lecture.

I wish to acknowledge the mentorship and motivation received from some of my teachers who set me on the footpath which I have strived

to walk for the past thirty-seven (37) years. As the saying goes, "The child is born with wings but the teacher helps him/her to fly". First on the list is Engr. Prof. A. O. Ekwue who was my lecturer in Power Systems Engineering and whose conscientious effort inspired me to make the right choice of option in the area of specialization in Electrical Engineering. I am indebted to late Engr. Prof. P. A. Kuale and Dr. G. O. Anderson that supervised my Master's thesis and their meritorious guide greatly influenced me in the style of supervision of postgraduate students. Kudos to Engr. Prof. U. O. Aliyu (Emeritus) who drilled me during my PhD programme at ATBU evidenced in his censorship and meticulous vetting of my PhD dissertation. Of course, this rare trait exhibited by him has much to inculcate in me the competence of accessing any scholar on the basis of promotion or award of a diploma. Thank you, Prof.

I am sincerely grateful to the Vice Chancellor, Prof. Faruk Adamu Kuta and his management team for giving me the opportunity to present my inaugural lecture. The arrangements and participation of the principal officers of this university in my inaugural lecture are highly appreciated.

Suffice it to say that some individuals who are behind the scene at their secret chambers upheld me in prayers and whose spiritual commitment to God on my behalf has made this occasion a huge success. Such individuals as the State Overseer of Deeper Christian Life Ministry, Ogun-East in Ogun state, in the person of Pastor T. Araromi, Professor M. A. Abolarin, Brother Taye Olaniyi and brethren of like precious faith. Many thanks to all of you.

Finally, my appreciation goes to the Ag. Dean, School of Electrical Engineering and Technology and all my colleagues who assisted in one area or the other to ensure a hitch-free inaugural lecture. Thank you for standing by me at this crucial time. Also worthy of thanks are the

distinguished Professors of this university, special guests present and online via zoom as well as students that graced this occasion, thereby making it an interesting one. May God bless all of you.
Mr. Chairman, sir, I am done!

The Brief Profile of the Inaugural Lecturer

Engr. Prof. M. N. Nwohu was born on October 5, 1959, in Idiaraba Lagos State, Nigeria. He hails from Itaja Olokoro, Umuahia-South Local Government Area, Abia State, Nigeria. He is happily married to Mrs. Cordelia Nwakuru Nwohu and is blessed with four children- Esther, Henry, Priscilla and Matthew.

He started his educational pursuit at Umutowe Community School, Olokoro until June 1975. The same year he passed the National Common Entrance Examination and was admitted into Olokoro High School, Olokoro, Umuahia. He graduated in 1980. In his quest to update his knowledge and advance his career, he got admission into Alvan Ikoku College of Education, Owerri to study Mathematics/Chemistry Education in 1982 and in 1983, he secured admission into the Federal University of Technology, Owerri under the auspices of Joint Admission Matriculation Board (JAMB). He received his bachelor of Engineering (B.Eng.) in Power Systems Engineering Technology from the Department of Electrical and Electronics Engineering, Federal University of Technology, Owerri, Nigeria, in 1988 and subsequently, proceeded for his National Youth Service Corp (NYSC) in Ogun State until September 1989. He got his Master’s degree in Power and Machines from the Electrical and Electronics Engineering Department, University of Benin, Nigeria in 1994. In 2007, he badged on his Doctor of Philosophy (PhD) Degree in Power Systems Engineering from the Electrical and Electronics Engineering Programme, Abubakar Tafawa Balewa University, Bauchi, Nigeria.

At the completion of his Master's degree programme from the University of Benin, Engr. Prof. M. N. Nwohu secured an appointment with Nigeria Defence Academy, Kaduna in 1994 where he began his academic career as a Lecturer II. In September 1999, he joined the services of the Federal University of Technology, Minna as Lecturer I in the Electrical and Computer Engineering Department. Subsequently, he was appointed as acting Head of the Department of Electrical and Computer Engineering, Federal University of Technology, Minna in the 2002/2003 session and Head of the Department of Computer Engineering of the same University in the 2011/2012 session. Based on the strength of his scholarly publications, Engr. Prof. M. N. Nwohu was promoted to Senior Lecturer in October 2009. In October 2012, he was promoted to Associate Professor having satisfied the minimum number of years stipulated in the promotion guidelines. In October 2016, he got to the pinnacle of his educational career as a Professor of Electrical Power Systems Engineering. He has over 29 years of teaching and consultancy experiences.

His research interests include Power System Analysis, Power System Stability and Control, Application of FACTS devices and Artificial Intelligence to Power Systems, System Simulation, Power Quality, and Numerical Analysis. He has been involved in ground-breaking international and local researches.

Engr. Prof. M. N. Nwohu belongs to different professional bodies among which is the Institution of Electrical Engineering and Technology (IET), UK, Nigerian Society of Engineers (NSE), International Association of Engineers (IAENG), USA and the International Society for Development and Sustainability (ISDS), Japan. He is a registered, practicing Engineer with the Council for the Regulation of Engineering in Nigeria (COREN).

He is a regular reviewer of reputable journals, both National and International journals and a member of the Editorial Board of eight journals, viz, Nigerian Journal of Engineering and Applied Sciences (NJEAS), International Journal of Electrical and Electronics Engineering, Universal Journal of Electrical Engineering and Informatics, International Journal of Engineering and Science, International Organization of Scientific Research-Journal of Electrical and Electronics Engineering, International Research Journal of Engineering and its Applications (IRJEA), International Journal of Latest Research in Engineering and Technology (IJLRET), International Journal of Research Studies in Electrical and Electronics Engineering (IJRSEEE)

In his proclivity for scholastic excellence that is evident in his extensive research, he has over 60 refereed publications to his credit in both local and international journals excluding two textbooks, viz, Voltage Stability Enhancement of the Nigerian Grid System using FACTS Devices and Computational Mathematics for Electrical Engineers in press. As a team player and a mentor, he has supervised over 300 Undergraduate projects, 25 postgraduate Diploma projects, 20 Master’s Degree Theses and 4 PhD Dissertations, and has so far assessed 10 candidates for professorial positions. There is a saying that “Legacy is about preserving all that you have built by raising other people” and by the grace of God, Professor Nwohu can look back to see and confidently say that through his mentorship, a professor, an associate professor and two senior lecturers have been raised in his department.
Remarkably, he was also an External Examiner to the following Universities, viz, Michael Okpara University of Agriculture, Umudike (2017-2020), University of Nigeria, Nsukka (2020-2024), Bayero University, Kano (2021), University of Abuja, FCT (2020), Federal University of Technology, Owerri, (2024), Baze University, Abuja (2021) and Covenant University, Ota (2023)

Interestingly, Professor Nwohu has held several Administrative positions/Responsibilities which include Permanent Member of the Senate, Federal University of Technology, Minna since 2016, Member, University Central Admission Committee, Federal University of Technology, Minna (2018-2022), Acting Head of Department, Electrical/Computer Engineering (2002-2003), Federal University of Technology, Minna, Head of Department, Computer Engineering (2011-2012) of same University, Member, Students Disciplinary Committee of the University (2018-2022), Chairman, Committee on Curriculum Development of Mechatronics Engineering (2010-2011), Member, University Health Services Management Board (2023-2025).

Professor Nwohu is a recipient of many Awards/Honours, including the award of excellence in Research Gate for his publications in Power Systems Engineering.

Engr. Prof. M. N. Nwohu as a compatriot is proactive to the welfare of his community and therefore committed to the development of his community and country at large. His resourcefulness has availed him the opportunity to serve the university community in various capacities, besides headship of the aforementioned Departments. He has been involved in the training and development of pupillage Engineers in the professional organizations he is affiliated with. His expertise has brought him to the level of consultancy and supervision of electrical engineering works and services outside university community.

Worthy of note is the spiritual life of Engr. Prof. M. N. Nwohu who began his walk with God early in his teenage as he was conscripted into the universal church as a soldier of Jesus Christ on 17th December 1979. As a child of God, he identified with many Christian organizations where he held various positions by his commitment and zeal to the work of God. He was a secretary of a defunct inter-denominational Christian Group known as Believers' Central Fellowship, Olokoro in March 1980. He was a maintenance coordinator with Deeper Life Campus Fellowship in 1982 as he was spotted by the grace of God found in his life while at Federal University of Technology, Owerri. In 1999, when

Engr. Prof. M. N. Nwohu relocated to Minna, Niger State, he was asked to lead a District Church of Deeper Life Bible Church at Dutsen-Kura Gwari. Since then, he has been on the pastoral work overseeing the affairs of District churches at Kpankungu and Bosso alongside his secular job. By the grace of God, Engr. Prof. M. N. Nwohu has left a good legacy that bears persuasive credence to his commitment and establishment of souls in God's kingdom which left many Christians aflame in the work of God.

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