American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-8, Issue-1, pp-282-290
www.ajer.org
Research Paper Open Access

Application of Fuel Cell as an Alternative Source of Electricity Generation in Nigeria

Revelation J. Samuel[1], Zekieni R. Yelebe[2], Blessing Z. Yelebe[2] and Ruth E. Ekperiware Emberru[3]
[1](Department of Chemical Engineering, University College London, WC1E 7JE, United Kingdom)
[2](Department of Chemical/Petroleum Engineering, Niger Delta University, Bayelsa State, Nigeria)
[3](Center for Petrochemical, Energy and Environmental Studies, Federal University Otuoke, Bayelsa State, Nigeria)
Corresponding Author: Revelation J. Samuel

ABSTRACT : *The Nigerian Energy Sector has been struggling to supply electricity in excess to the nation's population. As a result of this problem, to generate, transmit and distribute electricity has fallen short of the required standard. However, the shortage of electricity supply cannot be placed into a general context. The factors that contribute to this problem include the present state of Nigerian economy, which mainly centres on agricultural production and crude oil extraction. The poor or near absence of physical infrastructure is also identified as a major problem of the power sector. Based on several years of electricity research on the need of the nation, the idea to assess the supply of constant electricity to improve industrial development in Nigeria would greatly benefit the Nigerian energy sector in achieving the nation's industrial development goals. This paper shows fuel cell model and identifies fuel cell technology application as an alternative means to address the problem of electricity generation in Nigeria. Fuel cells are advantageous because of their high energy efficiency, lower or no emissions, no moving parts and are scalable from mini-watts to mega-watts. The study also shows that making use of a simple fuel cell locally could create employment for the people, and improve the economy through the building of new plants, manufacturing of parts and marketing of equipment*
KEYWORDS: *energy, electricity, electrochemical reaction, fuel cell, Nigeria, polarisation curve*

Date of Submission: 16-01-2019 Date of acceptance: 30-01-2019

I. INTRODUCTION

The history of electricity generation in Nigeria dates back to 1896 when electricity was first produced in Lagos, fifteen years its introduction in England [1]. The total capacity of the generators used was 60 kW. In other words, the maximum demand then was less than 60 kW. In 1946, the Nigerian Government electricity undertaking was established under the jurisdiction of the Public Works Department (PWD) to take over the responsibility of electricity supply in Lagos State [2].

In 1950, a central body was established by the legislative council which transferred electricity supply and development to the care of the central body known as the Electricity Corporation of Nigeria (ECN) [3]. Other bodies like Native Authorities and Nigerian Electricity Supply Company (NESCO) also had licenses to produce electricity in some locations in Nigeria. There was another body known as Niger Dams Authority (NDA) established by an act of parliament. The Authority was responsible for the construction and maintenance of dams and other works on the River Niger and elsewhere generating electricity by hydro-power, improving navigation and promoting fish brines and irrigation [3]. The energy produced by NDA was sold to ECN for distribution and sales at utility voltages.

In April 1972, the operation of ECN and NDA were merged in a new organisation known as National Electric Power Authority (NEPA). Since ECN was mainly responsible for distribution and sales whereas NDA was to build and run generating stations and transmission lines, the primary purposes for the merger were [2]:

- Vesting the production and distribution of electricity throughout the country to one organisation which will assume responsibility for the financial obligations.

- Effective utilisation of human, financial and other resources available to the electricity supply industry throughout the country.
- To develop and maintain an efficient co-ordinate and economical system of electricity supply throughout the Federation.

Since the inception of NEPA, the authority expands annually in order to meet the increasing demand of the populace. Unfortunately, majority of Nigerians have no access to electricity and the supply of those provided is not regular [4]. Due to this backdrop the Federal Government has embarked on aggressive power sector reforms with the intention of resuscitating NEPA and making it more efficient, effective and responsive to the yawning of the teeming populace through the introduction of State-owed Power Holding Company of Nigeria (PHCN) and Local Electric Distribution Companies or Local Distribution Companies (LDC) among the regions.

In March 2005, the Federal Government enacted the Electric Power Sector Reform Act (EPSR Act), which called for unbundling the national power utility company into a series of 18 successor companies: six generation companies, 11 distribution companies covering all 36 Nigerian states, and a national power transmission company [5]. The act stipulated that ownership of these companies be granted to the Bureau of Public Enterprises (the privatization arm of the Federal Government) and the Ministry of Finance Incorporated. This unbundling paved the way for an ambitious privatisation program to be carried out by the Bureau of Public Enterprises in Nigeria. In 2007, the Bureau of Public Enterprises hired CPCS Transcom Limited, an international consulting firm based in Ottawa, Ontario, to provide advice about the best ways to move forward with the privatisation of the country's 11 distribution companies and the 6 generation companies [6]. In 2010, CPCS was consulted again in order to provide advice on the Nigerian government's privatisation program. PHCN ceased to exist from 30th September 2013 following a successful privatisation process by the Goodluck Jonathan government [7].

For several years, despite consistent perceived cash investment by the Federal Government, power outages have been the standard for the Nigerian populace, however citizens of the country still do not see this as normal. In spite of considerable achievements of recent times with regards to electricity generating capability, additional power plants need to be committed to cover expected future loads. At present, efforts would be made to complete the on-going power plant projects. Plans are already nearing completion for the extension and reinforcement of the existing transmission system to ensure adequate and reliable power supply to all parts of the country [8].

For over two decades, Nigeria has experienced problems in the area of electricity generation, transmission and distribution. The extent of this is underlined by the fact that Nigeria is the largest purchaser of standby electricity generating plants in the world [9]. A country where importing of electricity generators has become a traditional norm in the society shows the level of problem the Nigerian Government is facing. Recent reports show that highly placed political figures are behind the importation of these electricity generators to Nigeria [10].

This potential eradication is tied to improving the current energy sector, although we can point out that the Government is more concerned with the effect of pollution and other hazardous and harmful effects these generators cause to the society. However, eradicating or minimizing generator importation is mainly not the solution to Nigeria’s electricity problem. The Federal Government of Nigeria should gather resources and focus more on tackling the problem that leads to the importation of generators, which is Power Supply. In addition, the Federal Government of Nigeria need to consider other alternative energy sources such as Fuel Cell Technology, which addresses pollution concerns. The key point is focusing on solution, not fringe issues that will not benefit the Nigerian society.

Fundamentally, the power sector, a component of which is the electricity sector of the economy has a great importance to our lives and takes central role in the economic transformation process. Currently power generation capacity in Nigeria is estimated to be around 6,000 megawatts, with average working capacity of 2,000 megawatts, to provide electricity for over 150 million people while in Finland the current megawatts is estimated to be around 36,000 megawatts, providing electricity for 5.5 million people [10]. Over the last two decades the Nigeria Energy Sector has been struggling to supply electricity in excess to the Nigeria population, as a result of this problem, to generate, transmit and distribute electricity has fallen short of the required standard [24]. However, the shortage of electricity supply cannot be placed into a general context. Other factors include the present state of Nigerian Economy, which mainly focusses on agricultural production and crude oil extraction. The poor or near absence of physical infrastructure was also identified as a major problem of the power sector.

Based on several years of electricity research on the need of the nation, the idea to assess the supply of constant electricity to improve industrial development in Nigeria would greatly benefit the Nigerian energy sector in achieving industrial development and national electric power supply goals which entail raising the capital energy consumption over a period of 10 years [10].

II. ELECTRICITY GENERATION IN NIGERIA AND ITS CHALLENGES

Electricity generation in Nigeria over the last 40 years varied from gas-fired, oil-fired, hydroelectric power stations to coal-fired station with hydroelectric power system taking precedence. This is predicted by the fact that the primary fuel sources (coal, oil, water and gas) for these power stations are readily available. The country has large coal reserves estimated at 2 billion metric tonnes of which 650 million tonnes are proven reserves [23]. About 95% of Nigeria's coal produced has been consumed locally, mainly for railway transportation, electricity production and industrial heating in cement factory [11]. Nigeria also has abundant reserve of natural gas. In energy terms, the quantity of natural gas is at least twice as much as the crude oil, and the horizon for the availability of natural gas is definitely longer than that of crude oil. The known reserves of natural gas have been estimated at about 2.4 trillion cubic metres and are expected to last for more than a century as a domestic fuel and major export [11].

Power Sector reforms in a developing economy such as Nigeria poses great challenges not only to the government that initiated the programme but also to the populace who are the consumer of energy and to the electricity governing bodies. These challenges can be classified into four categories [12]:

- Economic and Social factors,
- Technical Issues,
- Political Issues and
- Environmental factors

It is no longer debatable that the primary aim of the power sector reform by the Federal Government is to enhance the efficiency of the nation's power industry as well as make energy affordable and available to consumers. This means generating more power to the national grid and reactivating most of the 'dead' units in the nation's power sector.

For economic stability, and in order to satisfy the demand of electricity by consumers, new power stations must be constructed by the Federal Government, PHCN and Independent Power Producers (IPPs). Construction of new power stations and comprehensive maintenance of dysfunctional already existing units are usually capital intensive [22]. Hence, there is a price to pay for constant power supply in homes, which translates to more money being given out to utility companies by end users since the former primary concern will be to make profits. There are likely to be job losses following the mergers and takeovers of the utility companies [23].

Again, for the overall interest of both the distribution companies and the consumers, it is not enough to generate power adequately without recourse to the strength of existing transmission line capabilities as well as how the power could be used. The former emphasised re-enforcement and construction of additional transmission lines in order to ease evacuation of energy especially in areas where IPPs cluster as a result of proximity to energy sources whereas the latter calls for establishment of Demand Side Management (DSM) program [13]. DSM program usually consists of planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify their level and pattern of electricity usage instead of building new power plants to respond to increasing consumer demand. Electricity producers can also endeavour to minimise their customer's demand for power by offering special programmes for home owners, businesses, institutions and industries. To determine the success of such programmes, the costs and benefits of DSM opportunities should be directly compared with the costs and benefits of building new power plants and transmission lines [14].

There is a need of creating and ensuring a level playing field for all stakeholders in the merging power sector reform if the desired objectives are to be achieved. By the reform programme, it is expected that the power sector will open itself to key players within and outside the country. This means that the IPPs should expect a conducive political atmosphere before they agree to invest their money. Majority of the IPPs will like to construct their plants within the Niger Delta Area where sources of energy required to run their plants are guaranteed [22]. At present, the hostile environment in the Niger Delta predicated by armed ethnic militia and youth restiveness will definitely scare intending power investors. This brings to fore the need to sustain the nation's democratic structures with the view of ensuring government policy stability. By so doing, the envisaged comprehensive national energy policy that will take care of conservation, storage, consumption, construction and distribution will be sustained when it becomes operational [24].

The nature of power plant to be built in a given locality is dependent upon the nature of the environment. For instance, a city that already has cement and chemical industries may fraud at hosting thermal power plant because of high level of carbon dioxide emissions and other environmental issues. In order to guard against environmental pollution, government must create Environmental Inspection Agency (EIA) to monitor and regulate the extent of damage caused by pollution to the environment and the inhabitants. Also, the IPPs may be confronted with high compensation fees for economic trees, properties and right of ways in their quest to erect a power plant in any given city. These compensation fees may be in millions and can invariably pose as a deterrent to potential IPPs [23]. Therefore, fuel cell technology application can serve as an alternative means to address the problem of electricity generation in Nigeria. Since making use of a simple fuel cell locally could create employment for the people and encourage people to venture into engaging in this mode of electricity generation.

III. FUEL CELL TECHNOLOGY

A fuel cell is a device that converts chemical energy directly into electrical energy [15]. Fuel cell is a device that generates power by the combination of fuel and oxygen. It is a cross between an engine and a battery – it is an electrochemical engine. Fuel Cells, although they are considered as a fairly new concept, have been in existence for many years. They consist of one positive electrode and one negative electrode (one cathode and one anode) that produces energy. The fuel cells also contain an electrolyte which carries the charged particles from the electrode to electrode and a catalyst. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, and can produce electricity continually for as long as these inputs are supplied.

Historically, the principle of fuel cell was discovered by German scientist Christian Friedrich Schonbein in 1838 published in one of the scientific magazines of that time [16]. Based this work, the first fuel cell was demonstrated by Welsh scientist and Barrister Sir William Robert Grove in the 1839 edition of the philosophical magazine and journal of science [17] and later sketched in 1842, in the same journal [18]. The fuel cell he made used similar materials to today’s phosphoric-acid fuel cell. Fig. 1 shows a brief historic development of fuel cell from 1839 till present.

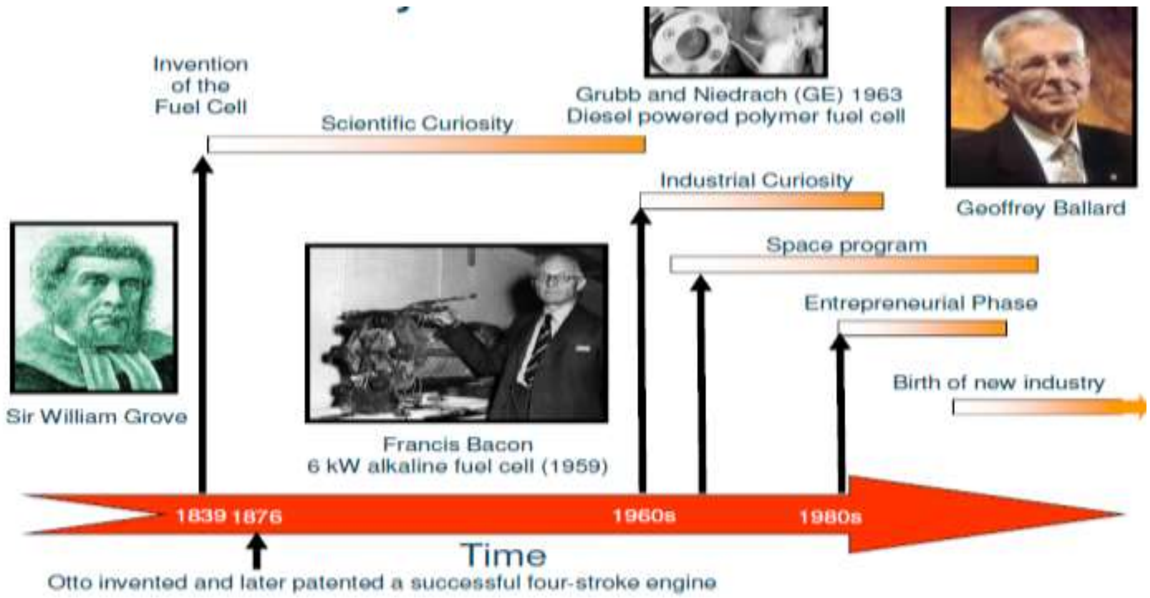

Figure 1: History of Fuel Cell Development [15]

Unit cells form the core of a fuel cell. These devices convert the chemical energy contained in a fuel electrochemically into electrical energy. The basic physical structure or building block of a fuel cell consists of an electrolyte layer in contact with anode a cathode on either side as shown in Fig. 2.

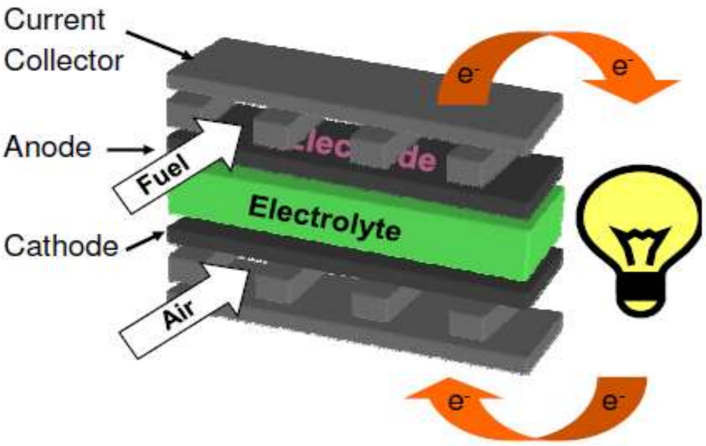

Figure 2: Basic Structure of a Typical Fuel Cell [15]

In a typical fuel cell, fuel is fed continuously to the anode (negative electrode) and an oxidant (often oxygen from air) is fed continuously to the cathode (positive electrode). The electrochemical reactions take place at the electrodes to produce an electric current through the electrolyte, while driving a complementary electric current that performs work on the load. Although a fuel cell is similar to a typical battery in many ways, but it differs in several respects. The battery is an energy storage device in which all the energy available is stored within the battery itself. The battery will cease to produce electrical energy when the chemical reactants are consumed (i.e. discharged). A fuel cell on the other hand, is an energy conversion device to which fuel and oxidant are supplied continuously. In principle, the fuel cell produces power for as long as fuel is supplied.

Fuel cells are classified according to the choice of electrolyte and fuel, which in turn determine the electrode reactions and type of ions that carry the current across the electrolyte. It is possible to distinguish six major types of fuel cells depending on the type of their electrolyte [19]. They are proton exchange membrane (PEM) or polymer exchange membrane fuel cells (PEMFCs), alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), molten carbonate fuel cells (MCFCs), solid oxide fuel cells (SOFCs), and direct methanol fuel cells (DMFCs) [19]. Fuel cells are named according to their electrolyte material. Fuel cells range in temperature of operation from room temperature to over 1000°C as shown in Fig. 3.

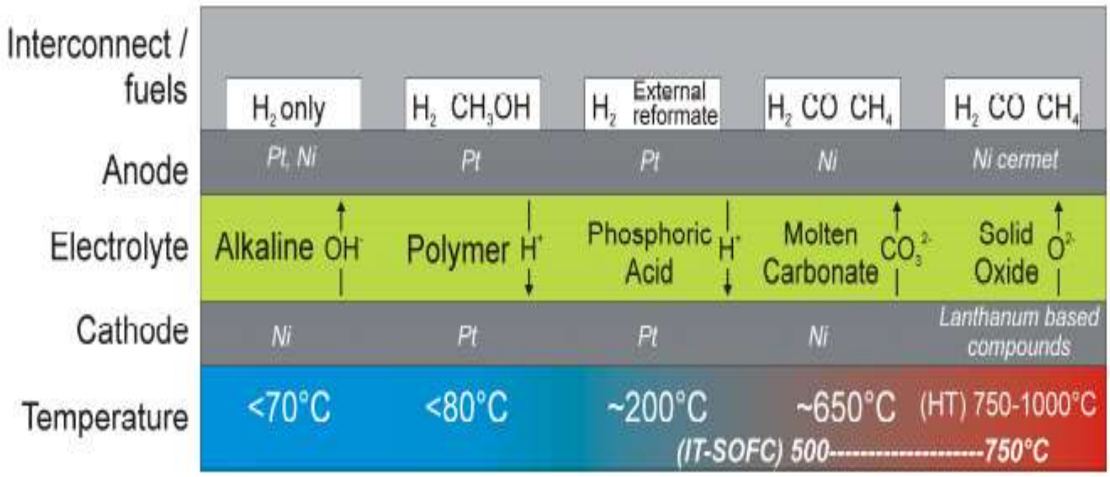

Figure 3: Fuel Cell System and Operating Temperature Range [15]

Broadly, the choice of electrolyte dictates the operating temperature range of the fuel cell. The operating temperature and useful life of a fuel cell dictate the physicochemical and thermomechanical properties of material used in the cell components (i.e. electrodes, electrolyte, interconnect, current, collector, etc.). Aqueous electrolytes are limited to temperatures of about 200 0C or lower because of their high vapour pressure and rapid degradation at higher temperature [20]. The operating temperature also plays an important role in dictating the degree of fuel processing required. In low-temperature fuel cells, all the fuel must be converted to hydrogen prior to entering the fuel cell. In addition the anode catalyst in low-temperature fuel cells (mainly platinum) is strongly poisoned by carbon monoxide. In high-temperature fuel cells, carbon monoxide poisoning is limited with the used of nickel and even methane directly used is internally converted to hydrogen or oxidized electrochemically.

Fuel cells are advantageous because of their high energy efficiency and much lower emissions due to the direct conversion of free energy in the fuel into electric energy, without undergoing combustion. The main features of fuel cells are [15]:

- High efficiency
- Low or no emissions
- Quiet, no moving parts, potentially highly reliable and
- Scalable
- Applications from mW to MW

IV. APPLICATION OF FUEL CELL FOR ELECTRICITY GENERATION

A fuel cell is a galvanic cell in which the chemical energy of a fuel is converted directly into electrical energy by means of electrochemical processes [21]. The fuel and oxidizing agents are continuously and separately supplied to the two electrodes of the cell, where they undergo a reaction. An electrolyte is necessary to conduct the ions from one electrode to the other as shown in Fig. 4. The fuel is supplied to the anode or positive electrode, where electrons are released from the fuel under catalyst. The electrons, under the potential difference between these two electrodes, flow through the external circuit to the cathode electrode or negative electrode, where, in combination with positive ions and oxygen, reaction products, or exhaust, are produced.

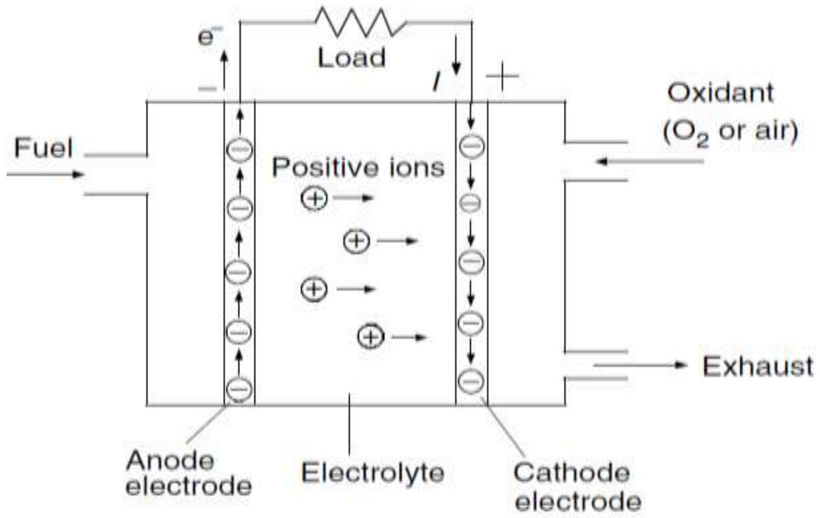

Figure 4: Basic Operation of a Fuel Cell [21]

The chemical reaction in a fuel cell is similar to that in a chemical battery. The thermodynamic voltage of a fuel cell is closely associated with the energy released and the number of electrons transferred in the reaction. The energy released by the battery cell reaction is given by the change in Gibbs free energy, ΔG, usually expressed in per mole quantities. The overall reaction and reactant flow using the polymer electrolyte as an example is shown in Fig. 5. An electrochemical reaction circulates current through a continuous circuit to complete the reaction. A purely chemical reaction does not. For an electrochemical reaction to occur, we need: electrodes, oxidation to occur at the anode, reduction to occur at the cathode, electrolyte to conduct ions from one electrode to another (but not electrons) and an external connection between the electrodes for the current to flow between. Electrochemical reactions that produce electric current are galvanic (i.e. fuel cells and batteries).

Globally [15],

Hydrogen Oxidation Reaction (**HOR**)
Oxygen Reduction Reaction (**ORR**)

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O \quad (1) \qquad (1)$$

But electrochemically,

$$H_2 \rightarrow 2H^+ + 2e^- \quad \text{(HOR)} \qquad (2)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad \text{(ORR)} \qquad (3)$$

Charge neutrality (an excess of charge cannot be maintained in equilibrium):

$$H_2 \rightarrow 2H^+ + 2e^- \quad \text{(HOR)} \qquad (4)$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow 2H_2O \quad \text{(ORR)} \qquad (5)$$

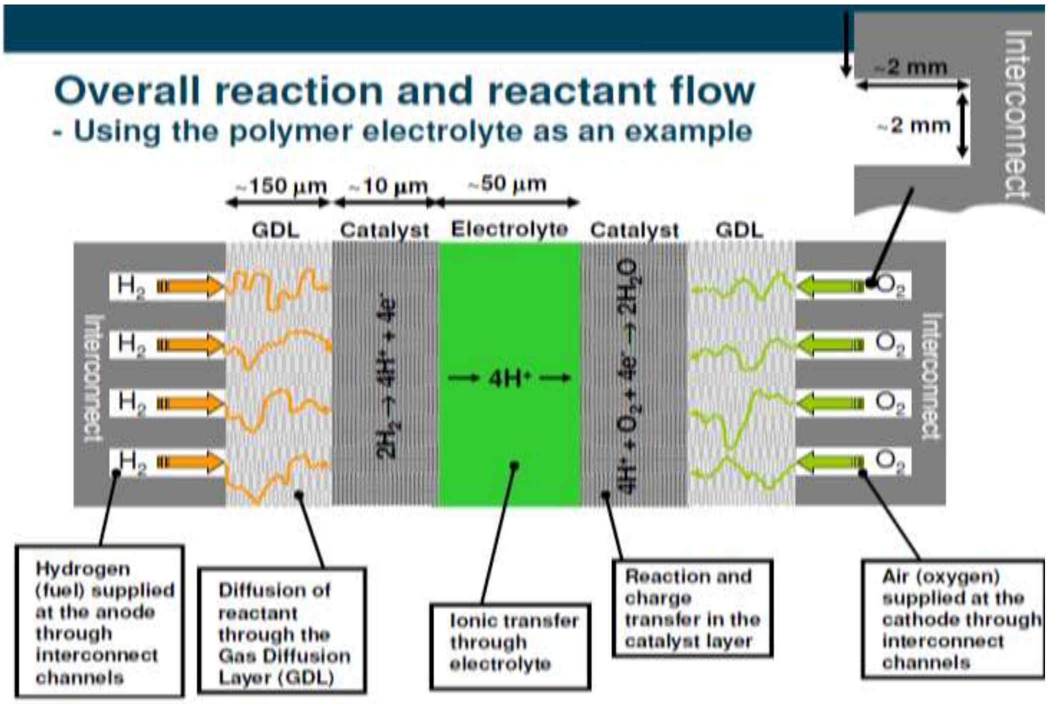

Figure 5: Overall Reaction and Reactant Flow using Polymer Electrolyte [15]

Fuel Cell Model

To calculate the maximum possible open-circuit (zero cell current) voltage of the fuel cell as a function of temperature and pressure, the Nernst Equation below is applied:

$$E = E^o + \frac{RT}{nF} ln \frac{\Pi a_{reactants}^{v_i}}{\Pi a_{products}^{v_i}} \qquad (6)$$

Where $E^o = \frac{-\Delta G^o}{nF}$, $\Pi a_{reactants}^{v_i} = a_{H_2}(a_{O_2})^{\frac{1}{2}}$ *and* $\Pi a_{products}^{v_i} = a_{H_2O}$

$$E = \frac{-\Delta G^o}{nF} + \frac{RT}{nF} In \frac{a_{H_2}(a_{O_2})^{\frac{1}{2}}}{a_{H_2O}} \quad \text{but} \quad a_i = \frac{P}{P^o} y_i \qquad (7)$$

$$E = \frac{-\Delta G^o}{nF} + \frac{RT}{nF} In \frac{\left(\frac{y_{H_2} P_{anode}}{P^o}\right)\left(\frac{y_{O_2} P_{cathode}}{P^o}\right)^{\frac{1}{2}}}{\left(\frac{y_{H_2O} P_{cathode}}{P_{sat}}\right)} \qquad (8)$$

From thermodynamics:

$$-\Delta G^o = \Delta H - T\Delta S\,, \quad \Delta H = \int_{T_o}^{T} C_p(T)dT \quad \text{and} \quad \Delta S = \int_{T_o}^{T} \frac{C_p(T)}{T} dT \qquad (9)$$

To model the cell, activation, ohmic and transportation losses must be accounted by modifying the maximum electric voltage and thus the fuel cell model is given as:

$$V = E^0 - \eta_{act} - \eta_{ohmic} - \eta_{conc} \qquad (10)$$

We need to understand and derive expressions for each of these losses in order to be able to model a fuel cell and predict how the fuel cell will work. Thus:

$$\eta_{act} = [a_A + b_A \ln(j + j_{leak})] + [a_C + b_C \ln(j + j_{leak})] \quad (11)$$

$$\eta_{ohmic} = j \cdot ASR_{orhmic} \quad \text{and} \quad \eta_{conc} = c * ln \frac{j_L}{j_L - j - j_{leak}} \quad (12)$$

Substituting equations 10 and 11 into 9 gives an overall equation

$$V = E^0 - [a_A + b_A \ln(j + j_{leak})] + [a_C + b_C \ln(j + j_{leak})] - (j \cdot ASR_{ohmic}) - \left(c * ln \frac{j_L}{j_L - j - j_{leak}}\right) \quad (13)$$

Where
ASR_{ohmic} = Area specific Resistance; A_f = Frontal area;
C_D = Aerodynamic drag coefficient; E_{cell} = Electric potential of the cell;
E^{oo}= Thermal Voltage; f_r = Rolling resistance coefficient;
g = Acceleration due to gravity; c = Empirical constant from Mass transport losses;
ΔG^o= Gibbs free energy; ΔH = Change in Enthalpy;
ΔS = Change in Entropy; F = Faraday's Constant;
j_o = Exchange current density; n = Number of moles;
η_t = Transmission efficiency; ρ_a = Air density;
α = Charge Transfer Coefficient; V = velocity

Fuel cell operation and performance is predicted using the polarisation curve (see Fig. 6) showing irreversible losses and departure from the Nernst voltage due to species crossover through the electrolyte, internal currents from electron leakage, contaminants. Typical fuel cell performance is affected by acceleration of kinetic losses due to reaction at electrodes, Ohmic (IR) losses due to electronic and ionic conduction losses and concentration polarisation due to mass transport limitation.

These losses are the main disadvantages of using a fuel cell in electricity generation. The cell performance may be limited if the losses incurred becomes enormous. The operating cell volt is from 0.65 to 1.0 volt.

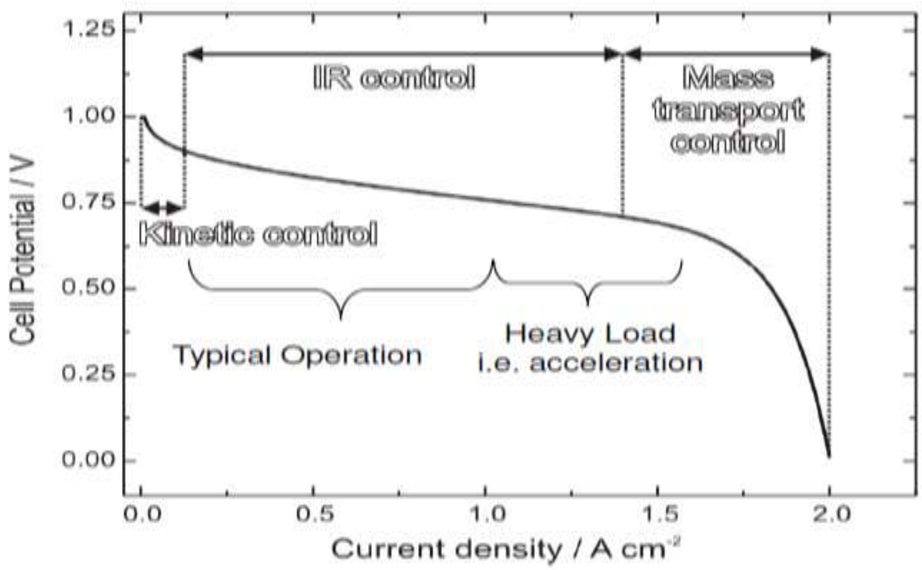

Figure 6: Fuel Cell Polarisation Curve [15]

V. CONCLUSION

In this paper, a comprehensive study of fuel cells and its applications in Nigeria was undertaken. The characteristics of fuel cell technology of being highly efficient, and generate much less pollutants than do traditional methods indicates that fuel cells have a very good potential to be used as electrochemical devices to generate electricity in Nigeria. Moreover destructive activities as a result of youth restiveness will have little or no effect on the applicability of fuel cells unlike gas powered electricity generators. If required attention is given to this new technology and suitable areas in which the technology is applicable are explored, it will go a long way in making this technology a source of wealth for the nation. Therefore, energy production in the country will eventually increase and change to hydrogen based economy and could create thousands of industrial and scientific jobs. Also, the building of new plants, manufacturing of parts and marketing of equipment could be highly profiting investments that stimulate jobs and economic growth.

The technology proposed in this paper maybe limited in applications. Fueling of the fuel cells is still a major problem to the difficulty of producing, transporting, distributing and storing of hydrogen. Reforming hydrocarbons via reformer to produce hydrogen is technically challenging and not clearly environmentally friendly. The period of refueling and starting of fuel cell vehicles are longer and the driving range is shorter than in an internal combustion engine car. Fuel cells are in general slightly bigger than comparable batteries or engines. However, the size of the units is decreasing. Fuel cells are currently very expensive to produce, since most units are hand-made. The technology is not yet fully developed and only few products are currently available.

REFERENCES

[1] Niger Power Review (1985) Development of the Electricity Industry in Nigeria (1960-1985), pp. 1-6
[2] Niger Power Review (1989) Development of the Electricity Industry in Nigeria (1960-1989), pp. 10-15.
[3] Manafa, N., Electricity Development in Nigeria. Rasheen Publisher, Lagos, 1995, pp.37-51.
[4] Okoro, O. I. and Madueme, T.C., Solar Energy Investments in a Developing Economy, Renewable Energy, Vol. 29, 2004, pp. 1599 -1610.
[5] Nwabueze, U.B., Power Reform and Electricity Generation. Otsego, Michigan p. 36. ISBN 1589613376, 2005.
[6] Perry H. Robert, Chemical Engineering Handbook, 7th edition, McGraw Hill, New York, 1997
[7] Nwabueze, U.B., (2013) Power Reform and Electricity Generation. Available at www.nigeriaelectricityprivatisation.com
[8] Ifedi, V., Power Reform and Electricity Generation in Nigeria. Dawodu.com. Retrieved March 2nd, 2014.
[9] Braimoh and Okedeyi, Energy and Power Generation, Transmission and Distribution in Lagos state. Retrieved March 2nd, 2014, from http://cefolassaocoed.net/index.php?option=com_content&view=article&id=83&Itemid=88&limitstart=4
[10] Biodun, A.A., The Power Sector and Industrial Development in Nigeria. Thesis of Bachelor of Business Administration, Lahti University of Applied Sciences, 2011.
[11] Bustros, A.O., Petroleum in Nigeria. Oxford University Press, Ibadan, 1983, pp.3-6.
[12] Samuel H. Maron and Carl F. Prutton, Principles of Physical Chemistry, 4th edition, Mac Millan Company, 1965, pp 143.
[13] Inugonum, T., Challenges Facing the Development of Independent Power Producers in a Deregulated Power Sector in Nigeria. (NEPA as a case study), 6th International Conference on Power System Operation and Planning (ICPSOP), May 22-26, Cape Verde, 2005, pp. 33-37.
[14] Donald, C., US Electric Utility Demand Side Management. Available at www.eia.doe.gov/cneaf/pubs_html/feat_dsm/contents.html 1997, pp.1-26.
[15] Brett, D., Fuel Cells and Systems. Energy Systems and Sustainability Lecture Notes, Department of Chemical Engineering, University College London, 2013.
[16] George, W., Fuel Cell History, Part 1. Available at www.fuelcelltoday.com accessed March 2nd 2014.
[17] Grove, W.R., On Voltaic Series and the Combination of Gases by Platinum. 1839 Edition of the Philosophical Magazine and Journal of Science, 1839.
[18] Grove, W.R., On a Gaseous Voltaic Battery. 1842 Edition of the Philosophical Magazine and Journal of Science,1841.
[19] Berlowitz, P.J., and Darnell, C.P., Fuel choices for fuel cell powered vehicles, Society of Automotive Engineers (SAE) Journal, Paper No. 2000-01-0003, Warrendale, PA, 2002.
[20] Kakati, B.K., and Deka, D., Differences in Physico-mechanical Behaviours of Resand Novolac Type Phenolic Resin Based Composite Bipolar Plate for Proton Exchange Membrance (PEM) Fuel Cell. Available at www.fctec.com, 2007.
[21] Mehrdad Ehsani, Yimin Gao, Sebastien E. Gay, and Ali Emadi, Modern Electric, Hybrid Electric, And Fuel Cell Vehicles: Fundamentals, Theory, and Design. CRC PRESS Boca Raton London New York Washington, D.C., 2004
[22] Practice, W. A. (2016). Nigerian Power Sector : Opportunities and Challenges for Investment in 2016, (1930), 1–15.
[23] Okoro, O., & Chikuni, E. (2007). Power sector reforms in Nigeria: opportunities and challenges. Journal of Energy in Southern Africa, 18(3), 52–57.
[24] Enterprises, B. of P. (2016). Overview of the Nigerian Electricity Industry (Roles , Responsibilities , Structure , Expectation) The power sector reform programme.

Revelation J. Samuel" Application of Fuel Cell as an Alternative Source of Electricity Generation in Nigeria" American Journal of Engineering Research (AJER), vol.8, no.01, 2019, pp.282-290