ADVANCING INDUSTRIAL ENGINEERING IN NIGERIA THROUGH TEACHING, RESEARCH AND INNOVATION

A BOOK OF READING

Edited By
Ayodeji E. Oluleye
Victor O. Oladokun
Olusegun G. Akanbi

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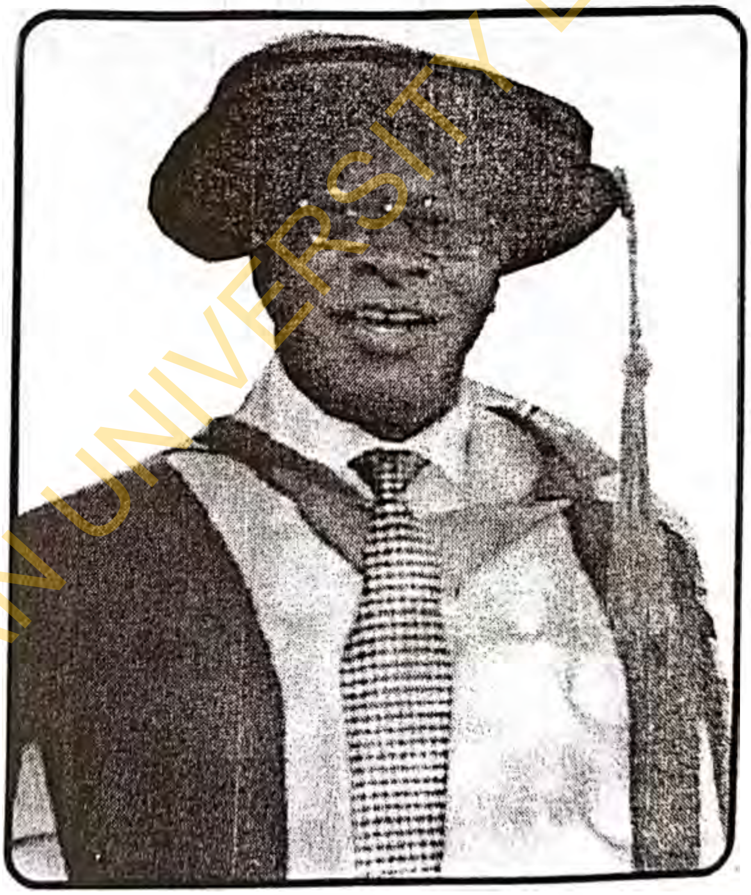
(A Festchrift in honour of Professor O. E Charles-Owaba)



Professor O. E. Charles-Owaba

Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation.

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FOREWORD

It gives me great pleasure writing the foreword to this book. The book was written in recognition of the immense contributions of one of Nigeria's foremost industrial engineers, respected teacher, mentor, and lover of youth – Professor Oliver Charles-Owaba.

His commitment to the teaching and learning process, passionate pursuit of research and demonstration of excellence has prompted his colleagues and mentees to write this book titled – Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation (A Festschrift in honour of Professor O. E Charles-Owaba) as a mark of honour, respect and recognition for his personality and achievements.

Professor Charles-Owaba has written scores of articles and books while also consulting for a medley of organisations. He has served as external examiner to various programmes in the tertiary educational system. The topics presented in the book cover the areas of Production/Manufacturing Engineering, Ergonomics/Human Factors Engineering, Systems Engineering, Engineering Management, Operations Research and Policy. They present the review of the literature, extension of theories and real-life applications. These should find good use in the drive for national development.

Based on the above, and the collection of expertise in the various fields, the book is a fitting contribution to the corpus of knowledge in industrial engineering. It is indeed a befitting gift in honour of erudite Professor Charles-Owaba.

I strongly recommend this book to everyone who is interested in how work systems can be made more productive and profitable. It represents a resourceful compilation to honour a man who has spent the last forty years building up several generations of industrial engineers who are part of the process to put Nigeria in the rightful seat in the comity of nations. Congratulations to Professor Charles-Owaba, his colleagues and mentees for this festschrift.

Professor Godwin Ovuworie
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CHAPTER 7

The Role of Renewable Energy in Nigeria's Energy Transformation

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Abstract

The domination of the energy mix of most countries across the globe by fossil fuel has been having serious effects on the climatic conditions, resulting from constant emission of greenhouse gases, GHG. It has also been found to be detrimental to human health, and as such, not less than 5 million cases of premature deaths due to local air pollution are annually recorded. Therefore, to combat GHG emissions and air pollution, there is an urgent need to adopt clean sources of energy generation, such as the renewables. This chapter discusses the meaning, history and benefits of renewable energy, highlights the common forms and sources, dwells on energy trends in Nigeria, reflects on hydropower plants in relation to technology, material selection and efficiency, as well as draws conclusions from areas covered.

Renewable energy – What does it mean?

Renewable energy, also called clean energy, is that source of energy that is being constantly replenished, originates from natural sources or processes and does not bring any harm to nature (Shinn, 2018; Project Solar, 2018 and Quaschning, 2019). As defined in the national renewable energy and energy efficiency policy (NREEEP) of Nigeria, renewable energy is that energy obtained from energy sources whose usage will not lead to the depletion of the earth's resources (Kehinde *et.al*., 2018). Examples are solar, hydro, wind, biomass energy and geothermal power. Another typical example is the bioenergy, which include biofuels, biopower and bioproducts (Bolarinwa, 2018). However, biofuel usage has been gaining popularity by the day, as biogas, a typical biofuel, is being increasingly used in both developed and developing countries. A major advantage of the renewable energy types is that they cannot undergo depletion (Shinn, 2018 and Project Solar, 2018).

As the world continues to move away from fossil fuel (oil, gas, coal and so on), into the clean energy era, consumption of renewable energy types increasingly gain global recognition (Bolarinwa, 2018). Although entirely new to many parts of the world in advanced forms, humans have been using renewable energy in different forms for heating (sunlight), as means of transportation (wind for sailing) and grinding (windmills) to mention a few (Shinn, 2018). Energy is of paramount importance, as it continuously plays key roles in the technological, industrial, economic and social advancement of any nation (Bolarinwa, 2018). Historically, adoption of renewable energy started in Europe more than two thousand years ago in the form of water wheels, which forms the principles guiding the hydropower (Project Solar, 2018). Although its use dated back to around 635 AD in the Middle East and Central Asia, its perfection took place in Netherlands. Table 1 shows the historical development of renewable energy across time.

Table 1: Historical development of renewable energy (Source: Richie, 2017; Project Solar, 2018; Nunez, 2019; OECD/FAO, 2019; Folk, 2020)

Year	Development that took place in relation to renewable energy.
1590	Windmills were the order of the day in Netherlands.
1839	Discovery of photoelectric effect by Edmond Becquerel.
1860	A famous French inventor, Augustin Mouchot perfectly developed the first solar energy system in the world.

1876	Kings College, London's professor of natural philosophy, William Grylls Adams used selenium to trap sunrays for electricity generation.
1882	The world's first hydroelectric power plant was in the United States, situated along the Fox River in Appleton, Wisconsin was commissioned.
1887	Wind turbines were built in Europe
1888	Charles F. Brush developed the first windmill for electricity generation. A total of 72 electricity generating wind turbines were available back then in Denmark.
1921	Perfection of photoelectric effect by the famous physicist, Albert Einstein.
1927	Wind turbines were commercialised in the United States to aid farming.
1930	Electricity generating wind turbines had widely spread across the United States.
1935	United States's largest hydroelectricity system, Hoover Dam was built in Colorado for water supply to South California, Arizona and later to Connecticut.
1958	The first United States's solar-powered satellite (Vanguard 1) was launched.
1978	The whole of Tohono Oodam reservation in Arizona was solar-electrified.
1996	Sodium nitrate and potassium nitrate were combined to enhance storage of solar energy for a longer time, especially after sunset.
2013	The world's largest solar plant (Ivanpah) was built in the Mojave Desert of South California on about 4,000 acres of land (with construction cost of about 2.2 billion dollars).
2016	About 341,320 electricity generating wind turbines were already functioning across the globe, creating up to 1.55 million jobs across the globe.
2019	7%, 2% and 1% of the World's energy; together with 16%, 5% and 2% of the World's electricity supply were

	respectively coming from hydropower, wind and solar energy.
2019	77% of the total biodiesel production, and 60% of the bioethanol production were already coming from vegetable oils and crops respectively.

Forms and sources of renewable energy

Renewable energy can come in different forms, depending on the primary source of the energy in question.

Solar energy is obtained by arresting the radiant energy from sunlight and transforming it into heat, electricity, or hot water (Just Energy, 2020). The use of photovoltaic (PV) systems help to convert direct sunlight into electricity through the use of solar cells (Just Energy, 2020). This form of energy has continued to gain global attention, that is, it is the fastest growing and most widely acceptable nowadays, due to its efficiency and convenience (Richie, 2019; Tesla, 2020).

Wind power is created when sunlight hits the earth's surface, causing a difference in temperature across different regions of the earth surface and resulting to movement of air molecules in the atmosphere (Nelson & Starcher, 2018). It is naturally harnessed using wind turbines, but requires a large region of area fields (Nelson & Starcher, 2018). In simple terms, mechanical energy is created with the wind going into the wind turbine and this energy is finally transformed to electricity (Tesla, 2020).

Hydroelectric power is the form of energy that can be harnessed using the kinetic energy of water to turn a turbine, which then generates electricity from the mechanical movement of the turbine blades, usually aided by generator in most cases (Grigsby, 2018; Tesla 2020). Although about a quarter of World's total electricity generation comes from renewables, hydropower is the biggest source of renewable energy, accounting for more than 60% of renewable energy generation (Ritchie, 2017). Hydropower energy is not only continuous, but can be predicted for proper management (Tesla, 2020).

Geothermal energy comes from heat trapped underneath the earth's crust and possibly from radioactive decay (Just Energy, 2020). This heat can cause volcanic eruptions and geysers when released at once naturally. It can however be arrested and used to generate geothermal energy, using the steam coming from the heated water pumping below the surface and rising to the top to operate a turbine (Just Energy, 2020; Tesla, 2020).

Other forms of renewable energy include biomass, hydrogen, fuel cells, hydrogen fusion, and ocean tides (Johansson *et. al.* 1993). The use of biomass, as renewable energy is not only common, but ancient (Ogunsola, 2007: Tesla, 2020). A typical example is the burning of wood. It involves using both organic and natural materials, which are later transformed into some other utilisable forms. The technologies adopted today are such that tend not generate CO_2 gas. Renewable energies supply up to 26% of the entire electricity presently available worldwide (Folk, 2020). This has been estimated by IEA to increase to about 30% by the year 2024. Figure 1 shows some common forms of renewable energy.

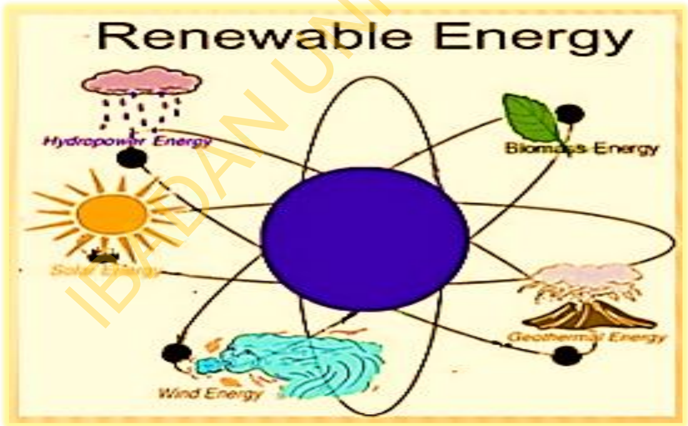

Fig. 1: Common forms of renewable energy (Source: Pazhamkavil, 2014)

Benefits of renewable energy

The major benefit of renewable energy is that since it does not undergo depletion, the problem of emission of greenhouse gases, hence global warming is not there (Bolarinwa, 2018; Tesla, 2020). This makes both the atmosphere and environment to be free from pollution. It also plays vital roles towards the survival of mankind. For instance, it is equally useful for cooking, heating of water and space, electrification, farming, industry, food processing and storage, education, mineral extraction and processing, water damming to mention a few (Asokoroogaji, 2011; Project Solar, 2018). Biomass helps to minimise landfills and produces no greenhouse gases (GHG). In more specific terms, benefits of renewable energy are numerous and include:

(1) Improved public health and environmental conditions.
(2) Constant availability and limitless supply.
(3) Reduction of energy costs.
(4) Creation of more employment opportunities.
(5) Possibly embarked upon on both small and large scales to cater for both domestic and industrial energy consumptions.

Nigeria and energy trends

While attainment of clean energy is one of the 17 sustainable development goals of the United Nations, of which Nigeria is a member, energy demand in Nigeria is still higher than the present supplies (Kehinde *et. al.*, 2018). Setbacks keep recurring in her energy sector (Nwagbo, 2017; EIA, 2020). In 2017, energy consumption in Nigeria was estimated to 1.5 quadrillion British thermal units, BTU (EIA, 2020). This is mostly derived from natural gas, petroleum and other liquids (97%).

The remaining quota (3%) came from renewables, coal, biomass and waste. While Nigeria's electricity generation capacity was about 12,664 MW in 2017; 10,522 MW (83%) came from fossil fuels, 2,110 MW (about 16%) was from hydroelectricity. Only 32 MW (1%) came from solar, wind, biomass and waste (EIA, 2020). As a result of this under-capacity electricity generation, up till the end of 2018, just about 60% of Nigerians had access to electricity supply. In 2018, Nigeria was the highest producer of oil and natural gas in Africa, and was the fifth-largest exporter of liquified natural gas worldwide, coming after Qatar, Australia, Malaysia and United States (EIA, 2020). Her exportation of about 982 Bcf of LNG accounted for about 6.5% of the global LNG trade. While India was the largest importer of Nigerian crude oil, Spain emerged as the largest importer of her LNG, followed by India and France (EIA, 2020). The 2018 estimate of EIA indicated that while crude-oil is mainly used for backup power generation in Nigeria, most of the electricity generation coming from fossil fuel is from natural gas (EIA, 2020). These 2 products have remained the country's main source of income. IMF estimated that alone in 2018, Nigeria realised about $55billion from the sales of oil and gas. Unfortunately, the non-oil revenue constitutes just about 3.4% of gross domestic product (GDP), about the lowest in the world (EIA, 2020). Towards the end of 2019, while Nigeria's proved crude oil reserves was estimated to 37 billion barrels, her proved natural gas was estimated to 200.4 trillion cubic feet (Tcf), and marketed natural gas of about 1.6 Tcf (EIA, 2020). The country has since increased her LNG by about 365 billion cubic feet (Bcf). On the other hand, Nigeria ranked the 7^{th} largest natural gas flaring nation in 2018, flaring up to 26.1 Bcf (EIA, 2020). Renewable energy from hydropower, which is the bedrock for electricity generation into the Nigeria national grid, has been in existence since around the middle of the twentieth century (IIED, 2012). Presently in Nigeria, there are three major hydropower plants all together generating about 1.9 GW hydropower capacity (Ufondu *et. al*., 2019). These are located at Kainji, Jebba and Shiroro. Whereas, the extent of the industrial growth of a nation largely depends on available energy and its utilisation. Prospects exist for renewable energy in Nigeria due to its ability to provide energy in the remote areas (IIED, 2012). For instance, the technical potential of solar energy in Nigeria is estimated at 1.50 x 10^8 joule of useful energy annually on a 5% device conversion efficiency, which almost equals 258.62 million barrels of oil on annual basis (Nwagbo, 2017). Nigeria also has the capability to harness wind for electricity generation. While a wind data survey was conducted between 1979 and 1988, as at 2017, about 30 wind stations have been developed (Nwagbo, 2017). In the case of hydroelectricity, recent studies by experts show that only 24% of large and 4% of small possible hydropower generation in Nigeria have been embarked upon. Although renewable energy is undoubtedly available in Nigeria, it is yet to take its full course! Government policies are regularly put in place to coordinate the activities of this sector. For instance, the Nigerian government, in 2003 introduced renewable into the national energy grid. This came up again in the 2005/2006 renewable energy master plan (REMP), whose successful implementation means adequate wind, solar PV, solar thermal and hydroelectricity sources by 2025 in providing an equivalent of the capacity available in Nigeria today (Nwagbo, 2017; Ufondu *et. al*., 2019). NREEEP to actualise the objectives of REMP and REAP (renewable energy activation plan). The government also came up with the national biofuel policy in 2007 and incentive for integrating the agricultural sector in order to improve the quality of automotive fossil-based fuels in Nigeria. Other governmental efforts put in place to develop the country's energy sector include the rural electrification strategy and implementation plan (RESIP) and the building energy efficiency code of 2017 to control the cost and availability of energy at domestic and industrial levels, as well as minimising wastage (Ufondu *et. al*., 2019). Nigeria's energy problems are created by very poor maintenance of her power sector, especially the electricity facilities; bad electricity transmission and distribution network; as well as shortages in natural gas supply (EIA, 2020). Table 2 shows some of Nigeria's energy resources (Akorede *et. al*., 2017).

Table 2: Energy Resources in Nigeria (Source: Akorede *et. al*., 2017)

Resource	Reserves (natural units)	Production level (natural units)	Utilisation (natural units)
Crude oil	36.22 billion barrels	2.06 million bpd	445,000 bpd
Natural gas	187 trillion SCF	7.1 billion SCF/day	3.4 billion SCF/day
Coal and lignite	2.734 billion tonnes	Insignificant	Insignificant
Tar sands	31 billion barrels of oil equivalent	0	0
Large hydropower	11,250 MW	1,938 MW (167.4 million MWh/day)	167.4 million MWh/day
Small hydropower	3,500 MW	30 MW (2.6 million MWh/day)	2.6 million MWh/day
Solar radiation	3.5 – 7.0 kWh/m2/day	excess of 240 kWp of solar PV or 0.01 million MWh/day	excess of 0.01 million MWh/day solar PV
Wind	2 – 9 m/s at 10 m height	-	-
Biomass (Fuelwood)	11 million hectres of forest and woodland	0.12 million tonnes/day	0.12 million tonnes/day
Biomass (Animal waste)	245 million assorted animals in 2001	0.781 million tonnes of waste/day in 2001	not available
Energy crops and agric. residues	72 million hectares of	excess of 0.256 million tonnes of assorted	not available

	agric. land and all waste lands	crops residues/ day in 1996	

* SCF – standard cubic feet * bpd – barrel per day

Hydropower plants and available technology

Hydropower, produced from water's kinetic energy is one of the most reliable and efficient sources of renewable energy. (Elbatran *et. al.*, 2015). The amount of electricity possibly generated by one hydropower plant depends on the head and flow rate of the river being used, in addition to turbine efficiency and depth (Jawahar, 2017). The existence of hydropower can be traced back to the era during which it was used to grind millet and grain (Lewis *et. al.* 2014). The technology involved determines the resulting hydropower plant (Yaakob *et. al.*, 2015). Possibly available technology can be: (1) Run of River (RoR) (2) Pumped storage (3) Dammed reservoir.

(1) Run of River: This produces electricity by means of the water flowing from the natural range of the river topography, and as well utilises other components within the area. (Egré & Milewski, 2002).
(2) Pumped storage: This pumps water during off-peak hours when electricity is in excess, into an upper storage basin (Hadjipaschalis *et. al.*, 2009). Afterwards, the water flow is reversed, and as such, the water falling through a height creates enough kinetic energy to turn the turbines at the base and generate electricity during peak load. (Mahlia *et. al.*, 2014).
(3) Dammed reservoir: This utilises constructed dam(s) to generate electricity by creating a large mass of standing water known as a reservoir, once this body of water is released through the dam gates, electricity is generated by converting resulting kinetic energy and mechanical energy from the flowing water using turbine and generators. (Cernea, 1997).

In terms of capacity, the quantity of energy generated by the plant determines the size of the hydropower plant in question (Sopian and Razak, 2009). Based on this, hydropower plants can be categorized as:

1. Large hydropower plant: Capacity greater than 10 MW.
2. Small hydropower plant: Capacity ranging between 1 and 10 MW.
3. Mini hydropower plant: Capacity of 100 KW to 1 MW.
4. Micro hydropower plant: Capacity of 5 Kilowatt to 100 KW.
5. Pico hydropower plant: Capacity less than 5 KW.

The Pico hydro energy source is simple and economical to set up (does not require a dam) and with high efficiency rate (Basir and Othman, 2013). It is a form of clean energy source that does not rely on non-renewable energy sources, and most times use the run of river (ROR) technology. It can exhibit up to a maximum of 5 KW output of electricity output (Zainuddin *et. al*., 2007; Basir and Othman, 2013). This energy source is useful for indoor and streets lightning, powering of TV and radio sets, telephones, refrigerators, farming purposes and poultry rearing, charging of mobile phones and so on. It can be adapted in communities wherein the energy consumption is not much, especially in villages and remote areas to which it is impossible or expensive to extend the national grid (Basir and Othman, 2013). The Pico hydropower system of electrification has widely adopted in Malaysia (Basir and Othman, 2013), Thailand (Chuenchooklin, 2006) and Rwanda (Kabeja, 2018) in recent times. It is known as a versatile source of power (Chuenchooklin, 2006). Figure 2 shows the setup of a typical Pico hydropower plant.

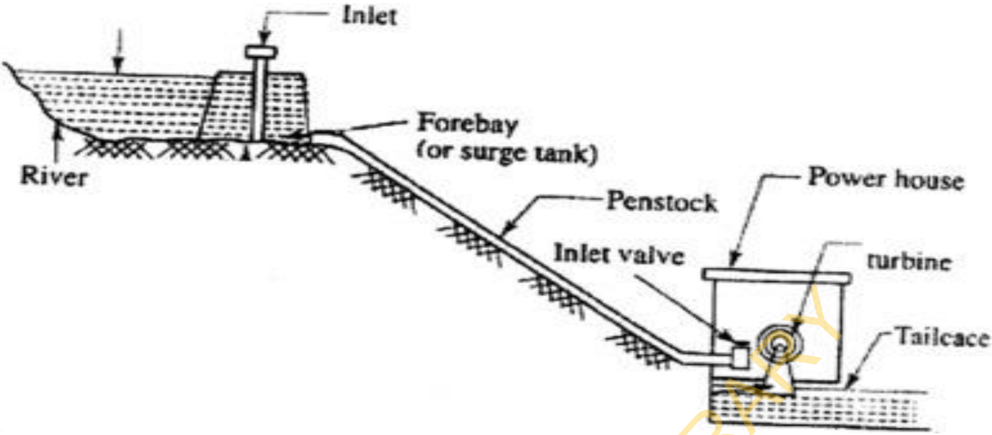

Fig. 2: The Pico hydropower plant (Source: Jawahar and Michael, 2017)

Components of the hydropower plant

The hydropower plant consists of the following components (Anupoju, 2020):

1) Forebay: Basin area of the hydropower plant which temporarily stores water before it is transported to the intake chamber.
2) Intake structure: Directs the water coming from the forebay to the penstock.
3) Penstock: Laid pipes, usually large, for sending water to the turbines.
4) Surge chamber: An open top cylindrical tank for controlling pressure in the penstock.

5) Turbines: Converts the resulting kinetic energy to mechanical energy.
6) Powerhouse: The building that houses the hydraulics and electrical parts for protection.
7) Draft tube: Particularly used with reaction turbines to connect the turbine outlet to tailrace to enable water discharge with safe velocity.
8) Tailrace: Channels the water from turbines to the stream to avoid plant damage, in the form of lowered efficiency, cavitation, damaged turbine blades, due to silting or scouring resulting from unguided flow of water from the powerhouse.
9) Generator: Converts generated mechanical energy to electrical energy.

The Turbine as a critical component

Without the turbine, generation of electricity would not have been possible. The reason is that it converts available mechanical energy to electrical energy by coupling to the generator, the shaft of turbine. It operates in such a manner that high pressure is generated, which in turn rotates the shaft and makes the generator to produce electrical energy (Anupoju, 2020). Turbine types can be:

1) Impulse turbine: Otherwise known as the velocity turbine. Example is the Pelton wheel (Figure 3). The impulse turbine operates by a principle based on the Newtons second law of motion, in which a water jet coming from a nozzle standing-still touches a properly designed blade which subsequently generates a turning force that spins the turbine, thus removing the kinetic energy of water touching the blade of the turbine. The blade movement then converts pressure into kinetic energy. The discharge the water pressure at atmospheric pressure (Benzon *et. al.*, 2016). The performance of impulse turbine is at its best when water head is high but water-flow is low. (Norman, 2003).
2) Reaction turbine: Otherwise known as the pressure turbine. Example is the Francis turbine. A reaction turbine builds torque as a result of the interaction between pressure and the weight of

water. The principle of operation here is guided by Newton's third law of motion. (Paish, 2002). Reaction turbines become useful at sites with low head but high flow of water, unlike the impulse turbines. (Norman, 2003).

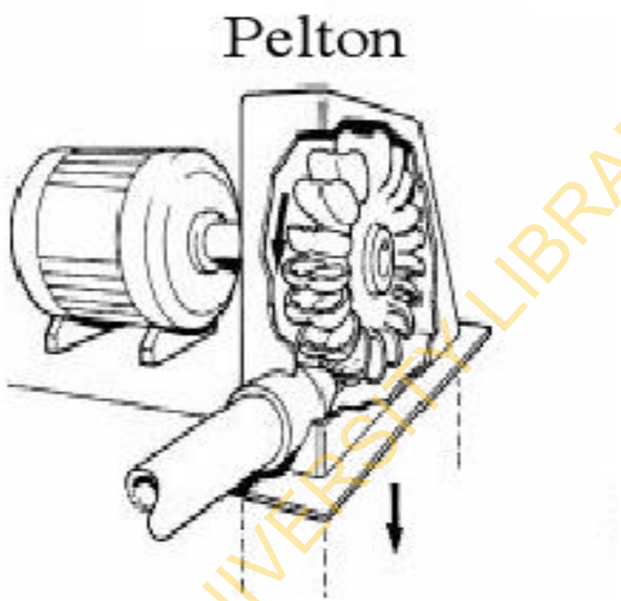

Fig. 3: The Pelton turbine (Source: Basil and Keroh, 2013)

Hydropower plant and material selection

Materials can be selected from a wide category of materials, such as metals, ceramics, polymers and composites. Selected materials must be able to serve the purpose for which they have been selected, and leave behind no limitations (Saidi *et. al.*, 2019). For example, in designing the turbine, selected material must be able to ascertain resilience and possess a high load bearing capacity. Where necessary, thick aluminium blades are utilised to resist wear and tear. Moreover, in order to reduce maintenance cost acquired from periodic painting, frames may be made with galvanised steel to avoid corrosion, at the expense of weight. In a nut shell, material selection is very crucial in the manufacture of hydropower plants, in order to ascertain good quality, durability, sights appeal, adequate in-built properties (physical and mechanical) and reasonable production cost. The selection is guided by number of factors, such as available technology, cost, available materials, product safety, expected functions and so on (Saidi *et. al.*, 2019). It is best done at the early stage of product development, especially when the expected functions of the system are being considered.

Hydropower plant and efficiency

Efficiency of the hydropower plant can be affected by the efficiency of the generator, penstock, design of the tailrace, as well as efficiency of the turbine, which itself is dependent on the nature of the water source available, that is, on the head and flow rater of the river in question (Basir and Othman, 2013; Anupoju, 2020). For instance, to maximise the output, a step-up transformer may be introduced in order to raise the output voltage. Also, the blades of the turbine can be provided with metal enclosure to increase efficiency. Where necessary, well lubricated ball bearings are to be used to overcome friction.

Nigeria and renewable energy

Despite the fact that renewable energy from hydropower has been in existence since around the middle of the twentieth century in Nigeria, serious explorations in different dimensions did not commence until around the end of the same century, particularly in the area of photovoltaic (PV) panel solar power (IIED, 2012). Although electricity generations from Nigeria's gas power stations would have overtaken that of her hydropower plants in terms of quantity, the gas stations continue to encounter problems due to unstable gas supplies and poor state of the national grid (IIED, 2012). The history of renewable energy in Nigeria is somehow short, with the public's opinion of seeing solar energy and wind power as the only available sources of alternative energy (IIED, 2012). Some of the achievements, successes and limitations of associated with renewable energy in Nigeria have been identified.

Achievements and successes of renewable energy in Nigeria

Water pumping: The use of renewable energy to power boreholes for the provision of clean and safe drinking water. This has come a long way in overcoming the problem of unstable electricity from the grid with which to operate boreholes, especially in towns and villages, as well as fueling generators where present. For example, the water borehole drilling projects of the Niger Delta Wetlands Centre (NDWC), using solar power since the mid-1990s (IIED, 2012). Figure 4 shows the basic components of a typical DC solar water-pumping system.

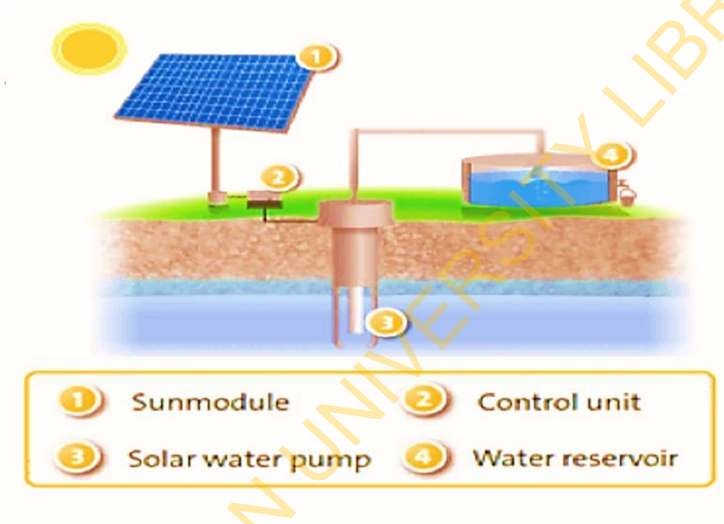

Fig. 4: Basic components of a DC solar water-pumping system (Source: IIED, 2012)

Lighting projects: Renewable energy has been in use for a while now in Nigeria for powering street lights, security lights around banks, schools, campuses, organisations, laboratories, hospitals and research institutes. This has helped to reduce the use of generators, hence noise and air pollution, as well as fueling and maintenance costs.

Hospitals and medical stores: Renewable energy has been useful in powering the theatre for surgical operations as well as refrigerating certain medicines and vaccines that require being stored well below room temperature in Nigeria. An example of such vaccine is the polio vaccine (IIED, 2012).

Household usage: Renewable energy is commonly used as an alternative to the national grid supply in some urban homes in Nigeria, and as source of electricity supply in rural areas not having access to the existing national grid to light house bulbs and power TV sets, radios, fans, *etc*.

Bank and office usage: Renewable energy is also used in Nigeria as an alternative to both national grid and generators for electricity supply to banks and offices to power computers, type-writers, printers, projectors, telephones, security doors and safes, fans, *etc.*

Information and communication technology: The use of renewable energy in Nigeria has been aiding information and communication networks by improving access to the internet. Without renewable energy as a stable option of electricity supply, eased access to the internet using band-widths, modems, WIFI, *etc*. would not have been possible.

Surveillance and security checks: Renewable energy has been used to power CCTV in some homes, offices, streets, banks, religious and other institutions in Nigeria for surveillance and security checks.

Job opportunities: Renewable energy installations continue to create jobs for the willing unemployed in Nigeria, especially those with skills along that area and others that have been able to acquire necessary skills through training by experts.

Some limitations associated to renewable energy in Nigeria

Set-up cost: The initial set-up cost is usually high, that is, it is capital-intensive and as such, not many people can afford it in Nigeria.

Maintenance cost: The maintenance cost is also on the high side, especially with solar systems in which batteries need to be replaced periodically.

Awareness: Renewable energy is still relatively new to many Nigerians, as a result of this, it is not wide-spreading as expected.

Destruction of aquatic lives: Aquatic lives are usually endangered or destroyed in places where the source of renewable energy is by means of river or dam.

Solution development to renewable energy problems in Nigeria

1) The government must pay special attention towards strengthening the growth of renewable energy in Nigeria by integrating existing projects and widening research scopes in the area of renewable energy (IIED, 2012).
2) Government can also release funds for the pursuit of major pilot projects, and incentives to researchers to boost their morale.
3) The general public need to be well sensitized by the government to increase awareness so that consumers can show better interest in digressing to renewable energy and investing therein.
4) Both policymakers and renewable energy experts need to work together to come up with best practices of renewable energy that will function effectively in specific areas, in particular the rural areas to cater for the necessary amenities, such as water, hospitals and schools (IIED, 2012).
5) Renewable energy education may as well be incorporated into schools curricular in order to encourage wide participation of the public towards developing renewable energy projects (IIED, 2012).

Conclusion

While availability of energy remains crucial towards the development of a nation's economic and industrial growth, means of overcoming the problems associated with fossil fuel consumption for energy generation have been traced to using renewable energy in its place. With examples including solar, hydroelectric power, wind, biomass energy and geothermal power, renewable energy is a safe source of energy because it is clean (neither harms nature nor undergo depletion) and also readily available. The consumption of renewable energy continues to increase as the world gradually digresses from the use of fossil fuels. Nigeria, although with 3 major hydropower plants still suffers from energy shortage due to under-capacity production of electricity and improper maintenance of available electricity facilities; poor electricity transmission and distribution network; as well as shortage of natural gas supply, as a result of gas flaring. Hydropower, as a renewable energy source is very reliable and efficient. The smallest available capacity, which is the Pico hydropower plant can be established on a small scale, especially in remote areas as it is simple to construct, economical, yet a very clean source of energy. To ensure high quality, durable and efficient hydropower plants, materials must be carefully selected, bearing in mind product safety, available technology, cost and expected functions at the early stage of the design. Aside renewable energy from hydropower, other notable projects did not kick until towards the end of the twentieth century. Despite the limitations of poor awareness and inadequate funding, the successes recorded so far with respect to renewable energy development in Nigeria have greatly contributed to provision of clean water supply, streets and security lights where desired, rural and urban electrification, improved ICT facilities, better surveillance and security systems and more jobs creation.

Finally, government, stakeholders, researchers/developers and the general public must all arise and diligently play their parts to encourage the full growth of renewable energy in Nigeria, for a successful energy transformation.

References

Akorede, M.; Ibrahim, O.; Amuda, S.; Otuoze, A. and Olufeagba, B. (2017). Current status and outlook of renewable energy development in Nigeria. *Nigerian Journal of Technology* (NIJOTECH). 36(1). Pp 196-212. Retrieved from, http://dx.doi.org/10.4314/njt.V36i1.25

Anupoju, S. (2020). Components of a hydropower plant and their functions. Retrieved from, https://theconstructor.org/structures/hydropower-plant-components-functions/19705/

Asokoroogaji, C. (2011). Importance of energy to the Nigerian economy. Retrieved from, http://www.comfortasokoroogaji.wordpress.com

Basir, M. F. and Othman, M. M. (2013). An overview of the key components in the Pico hydropower generating system: *Latest trends in renewable energy and environmental informatics.* RESEN-first.doc.

Basir, M. F. and Keroh, A. (2013). An overview of the key components in the Pico hydropower generating system. Retrieved from, https://www.wseas.us/e-library/conferences/2013/Malaysia/RESEN/RESEN-34.pdf

Benzon, D. S.; Aggidis, G. A. And Anagnostopoulos, J. S. (2016). Development of the Turgo Impulse turbine: Past and present. *Applied Energy*. 166. 1-18.

Bolarinwa, M. A. (2018). Techno-economic evaluation of biogas generation from selected substrates in a teaching and research farm in Ibadan, Oyo State, Nigeria. *International Journal of Innovative Science and Research Technology*. 3 (7) Pp 699-704. Retrieved from, http://www.ijist.com

Cernea, M. M. (1997). *Hydropower dams and social impacts: a sociological perspective*. The World Bank.

Chuenchooklin, S. (2006). Development of pico-hydropower plant for farming village in upstream, Thailand – Prosperity and poverty in globalised world. "Challenges for agricultural research". Tropentag 2006, Bonn. Retrieved from, http://dox.doi.10.1.1.543.5497 PICO IN THAILAND.pdf

Egré, D. and Milewski, J. C. (2002). The diversity of hydropower projects. *Energy Policy*. 30.14; 1225-1230.

Elbatran, A. H.; Abdel-Hamed, M. W.; Yaakob, O. B. and Ahmed, Y. M. (2015). Hydro power and turbine systems reviews. *Jurnal Teknologi*.74.5.

Folk, E. (2020). The growth of renewable energy: What does the future hold? Retrieved from, https://earth.org/the-growth-of-renewable-energy-what-does-the-future-hold/#

Grigsby, L. L. (2018). *The Electric Power Engineering Handbook-Five Volume Set*. CRC press.

Hadjipaschalis, I.; Poullikkas, A. and Efthimiou, V. (2009). Overview of current and future energy storage technologies for electric power applications. *Renewable and sustainable energy reviews*. 13.6-7; 1513-1522.

International Institute for Environment and Development (IIED). (2012). Renewable energy potential in Nigeria: Low carbon approaches to tackling Nigeria's energy poverty. The Sungas project. Retrieved from, http://pubs.iied.org/GO3512.pdf.

Jawahar, C. P. and Michael, P. A. (2017). A review on turbines for micro hydro power plant. *Renewable and Sustainable Energy Reviews*. 72. 882-887. Science Direct. Retrieved from, https://www.sciencedirect.com/science/article/pii/S1364032117301454 https://doi.org/10.1016/j.rser.2017.01.133

Johansson, T. B., Kelly, H., Reddy, A. K., and Burnham, L. (1993). *Renewable energy: sources for fuels and electricity*. Island press.

Just Energy Group. (2020). 7 types of renewable energy: The future of energy. Retrieved from, https://www.justenergy.com/blog/7types-energy-future-of-energy.

Kabeja, B. B. (2018). Pico-hydro, a new source of energy in Rwanda. Energy, Work. Retrieved from, https://cleanleap.com/pico-hydro-new-source-energy-rwanda.

Kehinde, O.; Babaremu, K.; Akpanyung, K.; Remilekun, E.; Oyedele, S. and Oluwafemi, J. (2018). Renewable energy in Nigeria: A review. *International Journal of Mechanical Engineering and Technology*. 9(10). Pp 1085-1094. Retrieved from, http://www.iaeme.com/IJMET/index.asp

Lewis, B. J.; Cimbala, J. M. and Wouden, A. M. (2014). Major historical developments in the design of water wheels and hydroturbines. In *IOP Conference Series: Earth and Environmental Science*. 22.1. p. 012020. IOP Publishing.

Mahlia, T. M.; Saktisahdan, T. J.; Jannifar, A.; Hasan, M. H. and Matseelar, H. S. (2014). A review of available methods and development on energy storage: Technology update. *Renewable and Sustainable Energy Reviews*. 33. 532-545.

Nelson, V. and Starcher, K. (2018). *Wind energy: Renewable energy and the environment*. CRC press.

Norman, J. (2003). The world of hydropower. Retrieved from, https://www.tande.com.tw/rn-hydro/alaskan.pdf.

Nunez, C. (2019). Hydropower, explained: Benefits and pitfalls of generating electricity from waterways. Hydropower facts and information. National Geography. Retrieved from, https://www.nationalgeographic.com/contributors/n/christina-nunez.html.

Nwagbo, G. (2017). Renewable energy in Nigeria. Retrieved from, https://large.stanford.edu/courses/2017/ph240/nwagbo2/#

OECD/FAO. (2019). Agricultural outlook, 2019 –2028. Retrieved from, https://www.fao.org/CA4076EN_Chapter9_Biofuels/pdf

Ogunsola, O. I. (2007). History of energy sources and their utilisation in Nigeria. *Energy sources*. 12(2). Taylor and Francis online. Retrieved from, https://www.tandonline.com/action/showCitFormats?doi=10.1080%2F00908319008960198

Paish, O. (2002). Small hydro power: Technology and current status. *Renewable and sustainable energy reviews*. 6(6). Pp537-556.

Pazhamkavil, S. (2014). Concept of renewable energy: Various forms of renewable energy – renewable energy sources. *Engineering, Technology, Business*. Retrieved from, https://www.slideshare.net/featured/category/engineering

Project Solar UK Limited (2018). The History of Renewable Energy: Where It All Began. Retrieved from, https://www.projectsolaruk.com

Quaschning, V. V. (2019). Renewable energy and climate change. Wiley.

Richie, H. (2017). Renewable energy. Published online at OurworldInData.org. Retrieved from, https://ourworldindata.org/renweable-energy

Saidi, T.; Dare, A. A.; Fasogbon, S. K.; Ewemoje, O.; Anyaeche, O.; Bolarinwa, M.; Adetoyi, O., Adewole, K.; Lawal, O. and Coker, A. O. (2019). Materials for Medical Devices. In Biomedical Engineering for Africa. T. S. Douglas Ed., Cape Town: University of Cape Town Library. Pp 55-61.

Shinn, L. (2018). Renewable energy: The clean facts. Retrieved from, https://www.nrdc.org.stories/renewable-energy-clean-facts/

Tesla, N. (2020). Other forms of renewable energy. Retrieved from, http://www.progressivesolarenergysystemsllc.com

Ufondu, I.; Ibeku, I. C. and Obetta, Felix (2019). Renewable energy in Nigeria. Retrieved from https://www.lexology.com/gtdt/workareas/renewable-energy

United States Energy Information Administration (EIA). (2020). International: Nigeria. *Independent Statistics and Analysis*. Retrieved from, https://www.eia.gov/international/#menu

Yaakob, O. B.; Elbatran, A. H.; Ahmed, Y. M. and Shabara, H. M. (2015). Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: a review. *Renewable and Sustainable Energy Reviews*. 43. 40-50.

Zainuddin, H.; Yahaya, M.; Lazi, J.; Basir, M. and Ibrahim, Z. (2009). Design and development of pico-hydro generation system for energy storage using consuming water distributed to houses. International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering. 3(11). World Academy of Science, Engineering and Technology. Retrieved from, https://www.researchgate.net/publication/280688181-Design-and-Development-of-pico-hydro-generation-system-for-energy-storage-using-consuming-water-distributed-to-houses/citation/download