Online Journal of Renewable Energy, 2018, 1, 13 -22

ELECTRICITY PRODUCTION FROM HYDROELECTRIC SOURCES IN NIGERIA: ANY PROSPECT

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ABSTRACT

Hydroelectric energy is produced by the force of falling water. The capacity to produce this energy is dependent on both the available flow and the height from which it falls. Building up behind a high dam, water accumulates potential energy. This is transformed into mechanical energy when the water rushes down the sluice and strikes the rotary blades of turbine. The turbine's rotation spins electromagnets which generate current in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines.

Keywords: Dam, Turbine, Generator, Penstock

Introduction

Hydroelectric generated mainly from dams, is a clean, renewable, non-emitting source of energy that provides low-cost electricity and helps reduce carbon emissions. Hydroelectric generation is the second largest in the world, providing 7% of domestic electricity production and much larger percentages in the western states. It is more efficient than any other form of electricity generation and offsets more carbon emissions than all other renewable energy sources combined. Hydropower accounts for approximately 75% of the nation's total renewable electricity generation, making it the leading renewable energy source of power.

*Madu, K. E. and Nwankwo, E. I. (2018). Electricity Production from Hydroelectric Sources in Nigeria: Any Prospect. *Online Journal of Renewable Energy,* 1 (1): 13 – 22.

The annual hydropower output is equivalent to the energy produced from burning 200 million barrels of heating oil (IWAIG, 2010). Hydropower turbines (Figure 1) are capable of converting more than 90% of available energy into electricity, making it the most efficient form of electricity generation.

Since the early 20th century, the term has been used almost exclusively in conjunction with the modern development of hydroelectric power. International institutions such as the World Bank view hydropower as a means for economic development without adding substantial amounts of carbon to the atmosphere, but dams can have significant negative social and environmental impacts (EURELECTRIC, 2011).

Advantages to hydroelectric power:

1 Fuel is not burned so there is minimal pollution.
2 Water to run the power plant is provided free by nature.
3 Hydropower plays a major role in reducing greenhouse gas emissions.
4 Relatively low operations and maintenance costs.
5 The technology is reliable and proven over time.
6 It's renewable - rainfall renews the water in the reservoir, so the fuel is almost always there.

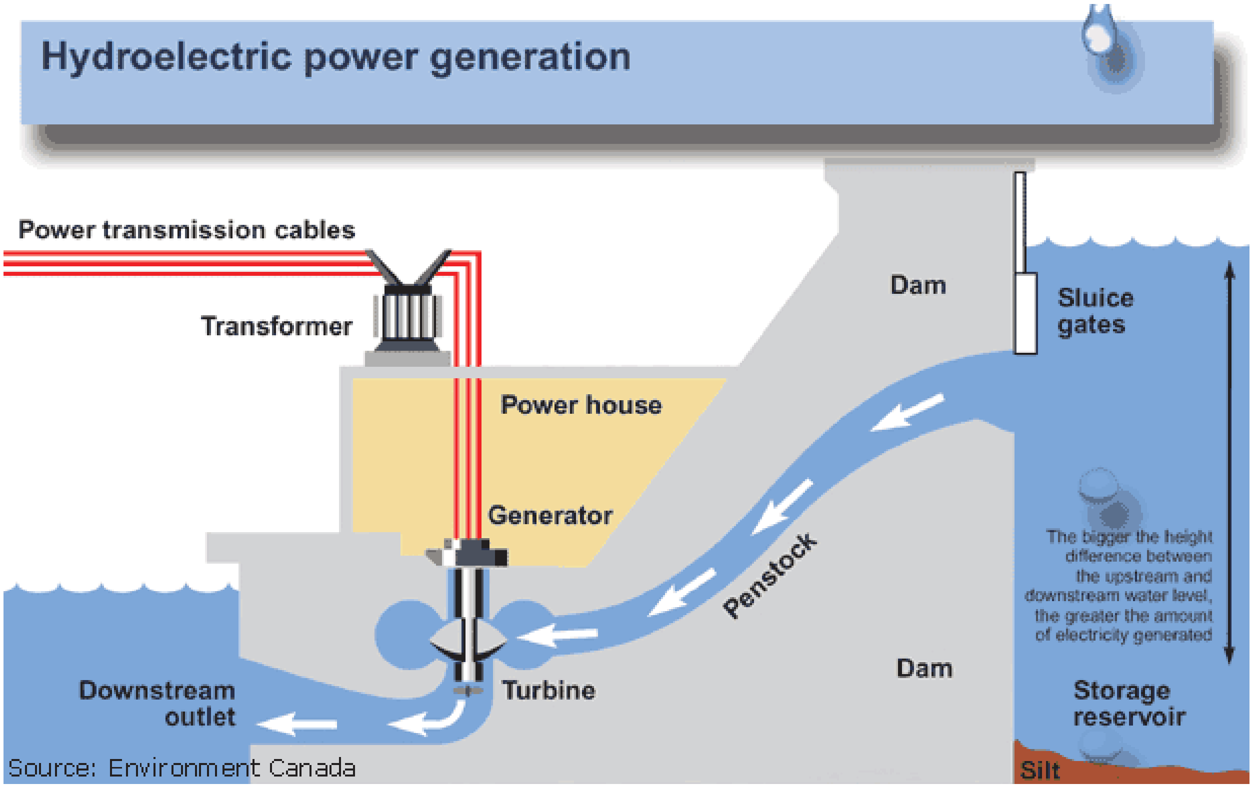


Figure 1: Hydro-Power Plant

Hydropower Development in Nigeria: The Beginning

The development of large hydroelectric power generation in Nigeria, started in the early 1960s after hydrological surveys commissioned to study the energy potential of Nigeria's river system, by the Federal and the Northern Regional governments, acting separately in the preceding decade. The initial surveys took place in the Niger River and its tributary, the Kaduna River. This is because the Niger and its tributaries drain more than 50% of the country. The surveys led to the establishment of the Niger Dams Authority, NDA, to develop the Kainji Dam and to run the power station as well as to oversee all future development of hydropower in the country. According to the initial plans, Kainji was associated with a national grid. The Authority planned it to be sufficient until 1980 when other dams, namely Jebba on the Niger and Shiroro on the Kaduna rivers would complement it. Jebba was to come in ten years later and Shiroro after that, to bring total hydro capacity to 1730 MW.

By 1990, hydropower capacity in Nigeria (Table 1) was about 1900 MW. The NDA Commissioned Kainji in 1969 with an initial installed capacity of four 80-MW Kaplan sets. Later, it installed four more sets and by 1978, the installed capacity was 760 MW. NEPA planned new plants at Jebba and Shiroro. However, political and economic circumstances delayed them and they could not come on stream in quick succession to meet fast growing demand, as NEPA had planned. The 540 MW Jebba scheme came on line in 1985. NEPA commissioned Shiroro 600 MW scheme, in 1989. With the 1972 merger of the Electricity Corporation of Nigeria, ECN, and the Niger Dams Authority, NDA, to form the National Electric Power Authority, NEPA, development of Nigeria's hydro resources became the responsibility of the NEPA. The decade witnessed generation capacity stagnation, though NEPA had perceived in 1975 that demand was growing at about 20.5% per year. In a 10-year development plan in 1979 to cover a decade up to 1990, NEPA's hydro capacity increases were as follows: Lokoja, 1950 MW Shiroro, 600 MW Makurdi, 600 MW Jebba, 545 MW Ikom 400 MW.

However, Nigeria's hydropower development was slow. Between 1979 and 1983, the FGN disclosed that the Lokoja hydro station would not cost less than N2000 million.That apart, thousands of people on the banks of the Niger and Benue would be displaced by the project. People on the Benue would feel the effects as far as Makurdi and along the Niger as far as Rabba. Eight Local Governments in Niger, Kwara, Benue and Plateau States would bear the brunt. Despite the hydropower potential, the environmental impact was severe and the FGN suspended the project. In my opinion FGN action lacked courage. Perhaps, they might have acted differently if they understood two facts. First, the country's energy resource is finite. Secondly, the future of the country's economic hopes and aspirations depended on energy. Therefore, Nigeria's politicians might have been more courageous. With hindsight, if they acted differently then, Nigeria would have paid off the debt in her boom years.

Hydropower technologies

There are three main categories of hydropower technologies: run of river, impoundment, and pumped storage. The run-of-river technology relies on the flow of the river at an elevated point, which, through gravity, is fed to a turbine generator. Impoundment hydropower systems employ one or more dams to store water. The potential energy stored in the dam is converted to electricity by passing the stored water from an elevated point through a turbine generator located at the lower point (EREC, 2010). Pumped hydropower is a two-dam system, where one dam is installed at a higher point to the other. During off-peak hours when the cost of electricity is low, the water from the lower reservoir is pumped up to the elevated reservoir using electricity from the grid. When the cost of electricity is high during peak hours, the water is released from the upper dam to generate electricity. Pumped hydropower is the only hydropower system that produces a non-renewable form of hydroelectricity.

Hydro energy is available in many forms, potential energy from high heads of water retained in dams, kinetic energy from current flow in rivers and tidal barrages, and kinetic energy also from the movement of waves on relatively static water masses. Many ingenious ways have been developed for harnessing this energy but most involve directing the water flow through a turbine to generate electricity (Frost and Sullivan, 2011; Goldberg and Lier, 2011).

Materials and method

Pipelines

A hydroelectric turbine operates from the pressure at the bottom end of a pipeline. This pressure, usually measured in pounds per square inch (PSI), is directly related to the head or vertical distance from where the water goes into the pipe at the top of the pipeline, to the turbine located at the bottom of the pipeline. The pressure at the lowest point of a pipeline is equal to 0.433 times the vertical distance in feet, called head. Pressure is important because it is a determining factor in how much power is available and what type of pipe is required. Polyethylene pipe can be used for pressures up to 100 PSI, PVC pipe is available with pressure ratings from 160 to 350 PSI and steel pipe can withstand 1000 PSI or more (Hall, 2003). Pipe diameter is very important. All pipelines will cause the water flowing in them to lose some energy due to friction. The pipe must be large enough for the maximum quantity of water it will carry. The pressure at the bottom of a pipeline when water is not flowing is called static pressure. When water is flowing through the outlet or nozzle of the hydroelectric turbine, the pressure at the outlet is the dynamic pressure or running head. See graph below in Figure: 2 for pipe losses.

If you install a gate valve on the pipeline just above the turbine and a pressure gauge on a "T" fitting just above the gate valve, you will read the static pressure on the gauge when the valve is closed and the dynamic pressure when the valve is opened. The maximum power that can be delivered by a pipeline will occur when the dynamic pressure is approximately 2/3 of the static pressure. The actual flow rate of the water in a hydroelectric system is determined by the diameter of the nozzle. We will supply a turbine with the proper size nozzle for your site, depending on the head, flow, length and diameter of the pipe.

Table 1: Hydro Power Capacity in Nigeria

Hydroelectric station	Community	Coordinates	Type	Capacity (MW)	Year completed	Name of reservoir	River
Kainji Power Station			Reservoir	800	1968[6]	Kainji Lake	Niger River
Jebba Power Station			Reservoir	540	1985	Lake Jebba	Niger River
Shiroro Power Station			Reservoir	600	1990	Lake Shiroro	Kaduna River
Zamfara Power Station			Reservoir	100	2012[7]	Gotowa Lake	Bunsuru River

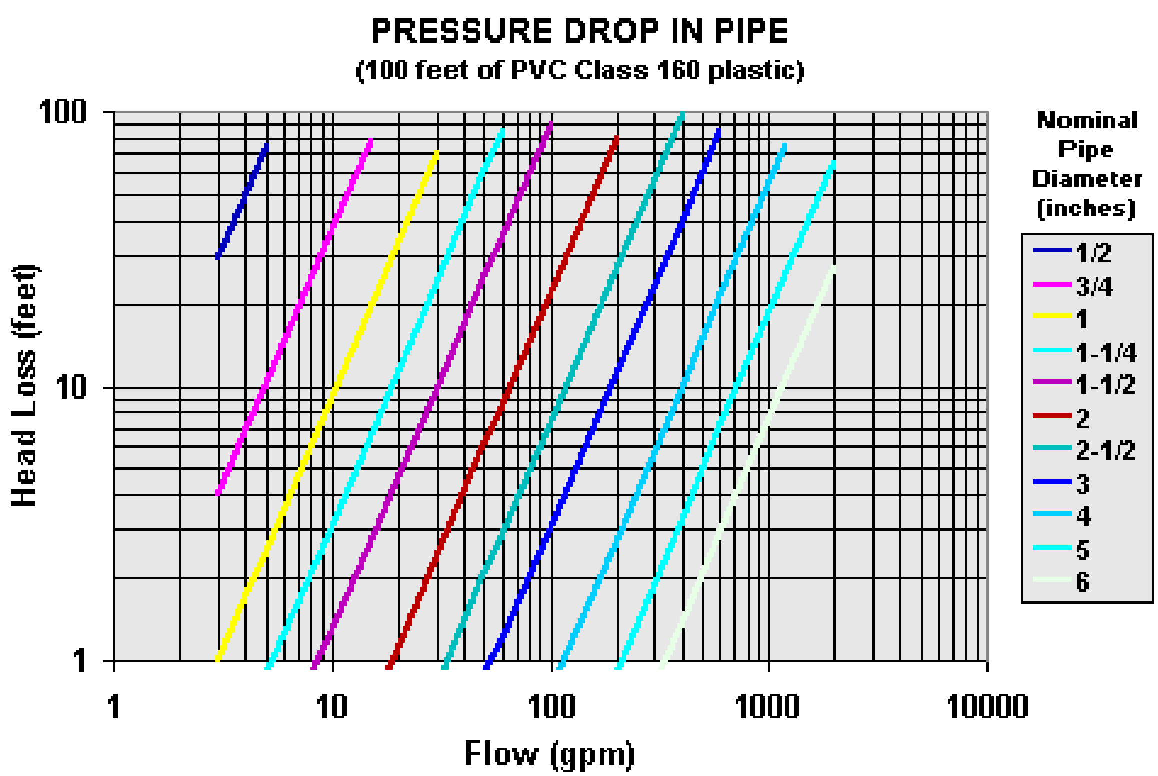


Figure 2: Pressure Losses in the Pipe

Nozzle Selection

Power output of a hydroelectric generator is determined by the pressure of the water at the nozzle and the amount of water flowing out of the nozzle. The larger the nozzle, the greater the flow will be. The nozzle must also be sized small enough to keep your pipeline full and keep the speed of the water in the pipe below 5 feet per second.The nozzle selection chart below shows water flow through various size nozzles at given pressures. Use this chart (Figure 3) to determine what size nozzle and how many nozzles you need to accommodate the flow of water you have and to deliver the amount of power you need.

The choice of an appropriate hydropower technology is site-specific. Hydroelectric plants fall under three general classifications based on construction: run-of-the-river hydro, storage (or pondage) hydro and pumped storage hydro.

Nigeria's hydro plants fall almost exclusively under the storage hydro classification.

Water Turbines

Like steam turbines, water turbines may depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the blades to turn the turbine shaft which in turn drives the generator. Several different families of turbines have been developed to optimize performance for particular water supply conditions.

All that matters is the change in angular momentum of the fluid between the turbine's input and output. The type of turbine used in a hydroelectric plant depends primarily on the design head for the plant. By far the largest number of hydroelectric projects uses reaction-type turbines. Only two types of reaction turbines are now in common use. For medium heads (that is, in the range from 20 to 300 metres), the Francis turbine is used exclusively. Shiroro Power Station with a design head of 97 metres falls into this category.

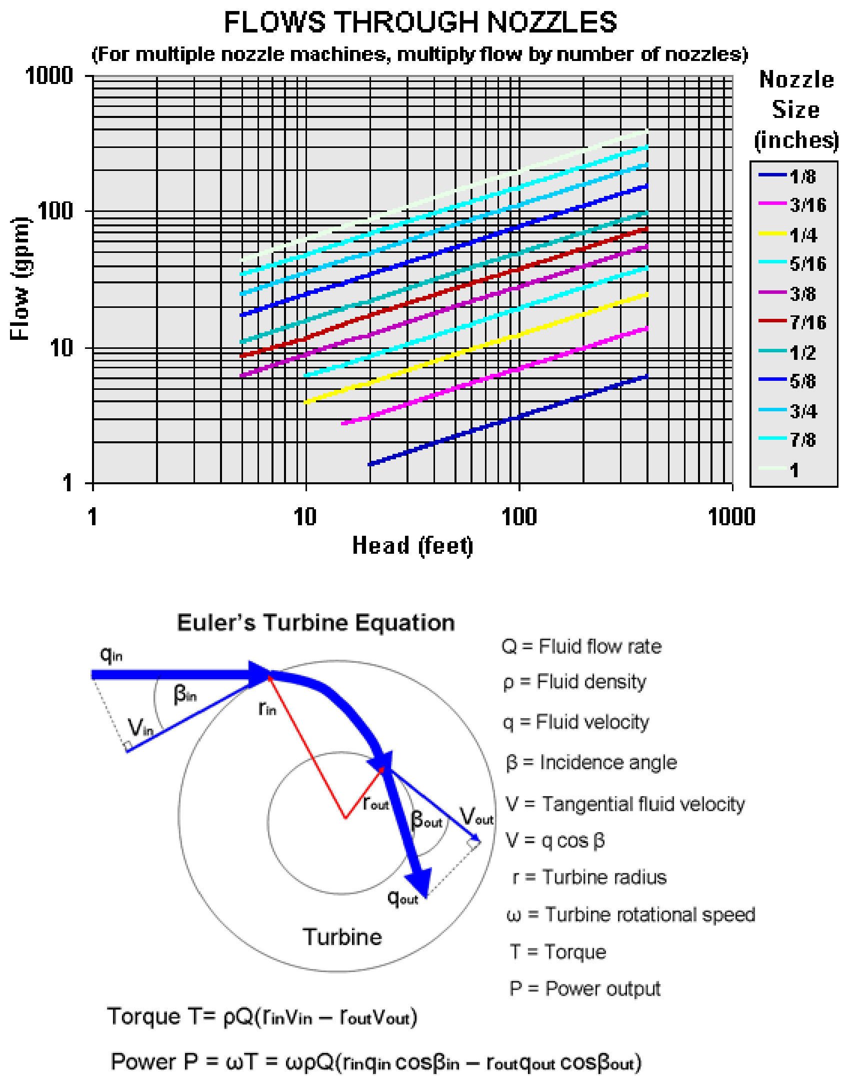
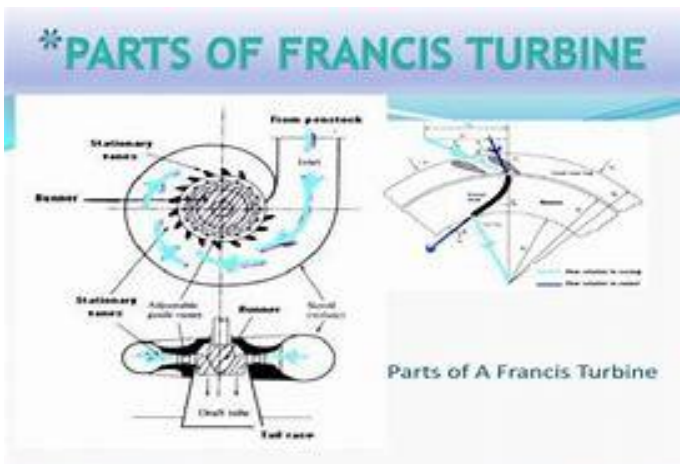
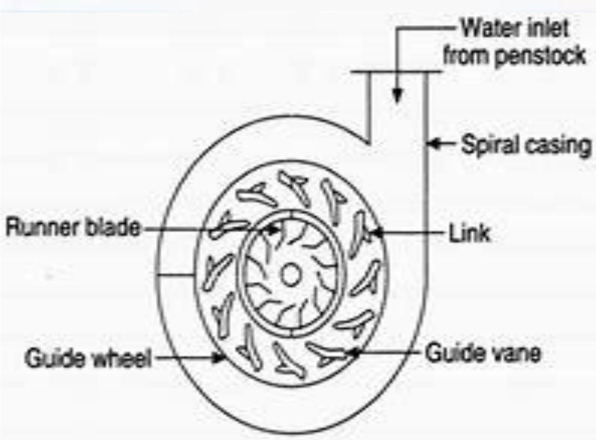


Figure 3: Flow of Water through Nozzles

For the low-head plants (that is, for design heads in the range of 3 to 20 metres), the propeller turbine is used. The more modern propeller turbines have adjustable pitch blading (called Kaplan turbines) to improve the operating efficiency over a wide range of plant head. The plant at Kainji Power Station comprises both Kaplan and the fixed propeller turbines. Typical turbine performance results in an efficiency at full gate loading of between 85 to 90%. The Francis turbine and the adjustable propeller turbine may operate at 65 to 125% of rated net head as compared to 90 to 110% for the fixed propeller. Shiroro Power Station maintains an operating policy at 93 to 113% of rated head.High-head plants (typically over 300 metres) use impulse or Pelton turbines. In such turbines, the water is directed into spoon-shaped buckets on the wheel by means of one or more water jets located around the outside of the wheel. As we have already noted, the proposed Mambilla hydroelectric project, which will operate under a net head of 927 metres, will be equipped with Pelton turbines.Once a choice of hydropower technology is made, it can be used with advantage to adapt to the service requirements expected from the plant. Where the main requirement especially for plants with a relatively higher capacity factor is to operate for much of the period in a year to serve a base load, the Francis turbine (Figure 4) offers the advantage. If on the other hand the plant is to be deployed for “peak lopping” duty most of the time, the Kaplan turbine, will be the obvious choice.





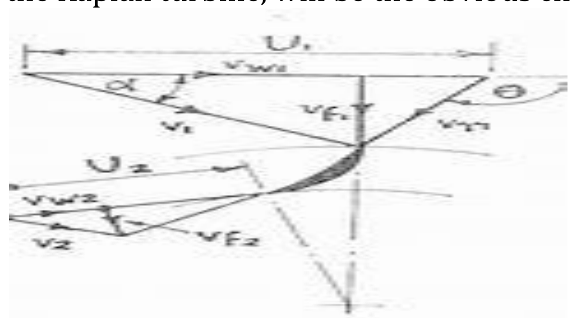


Figure 4: Parts of the Francis Turbine

However, apart from the basic functions of producing and delivering electric energy and power to customers, generating companies are required to pay equal attention to the issue of security and reliability of supply. In order to satisfy this requirement, generators nowadays, have to fulfil both the commercial obligations in the Power Purchase Agreements, PPAs, as well as the technical requirements that are prerequisites for connection to the grid, as set out in the Grid Code. These are ancillary services.

They enable the System Operator to keep the system’s supply and demand in balance by keeping the voltage and the frequency at the right level and preventing system collapse as well as restarting the system after collapse. In order to cope with this onerous duty, selecting the right turbine and generator is a priority. That gives stable operation over the full range of plant head and loading condition.

The above considerations informed the philosophy of the selection of the turbines at Kainji Dam. The initial installation of 4 x 80 MW units was equipped with Kaplan turbines which in addition to supplying the national demand at the time, also had the flexibility to control frequency and thus provide the required ancillary services. Conversely, the 2 x 100 MW and 2 x 120 MW units installed in the subsequent phases of the project, were equipped with the fixed propeller type turbine which provided the station with the much needed capability to supply the system base load, for most of the time.

At Shiroro, the generator can operate as a synchronous condenser to provide the system with increased voltage support, by generating or absorbing reactive power. Considering the position Shiroro occupies in the network, this utility is of great value especially during the dry season period in the year, when energy production is reduced from the plant, with severe consequences to voltage profile in the northern part of the country. Together with its black-start capability, that forms the nucleus of the ancillary services the plant renders to the national grid.For small hydropower schemes, especially below 30 MW, there are wide varieties of options for turbine arrangement. The costs, operating efficiency, maintenance and flexibility differences are large and need careful consideration.

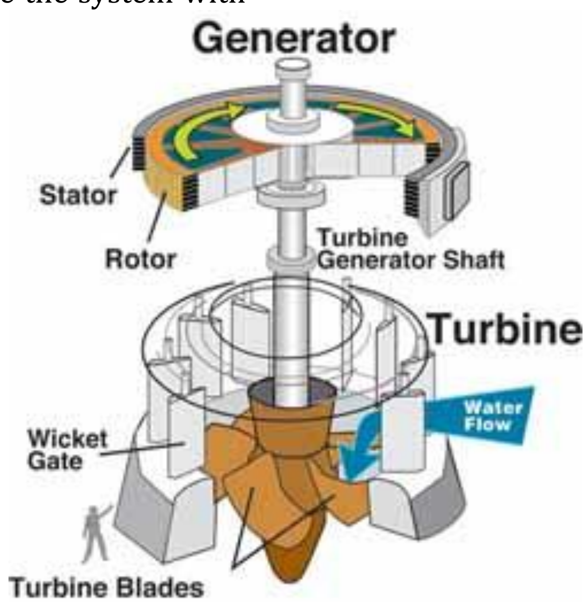


Figure 5: A Typical Turbine

Hydroelectric Power Generation Efficiency

Hydroelectric power generation is by far the most efficient method of large scale electric power generation. Energy flows are concentrated and can be controlled. The conversion process captures kinetic energy and converts it directly into electric energy. There are no inefficient intermediate thermodynamic or chemical processes and no heat losses. The overall efficiency can never be 100% however since extracting 100% of the flowing water's kinetic energy means the flow would have to stop.The conversion efficiency of a hydroelectric power plant depends mainly on the type of water turbine employed and can be as high as 95% for large installations (Hydro World, 2011). Smaller plants with output powers less than 5 MW may have efficiencies between 80 and 85 %.It is however difficult to extract power from low flow rates.

A hydroelectric dam installation uses the potential energy of the water retained in the dam to drive a water turbine which in turn drives an electric generator. The available energy therefore depends on the head of the water above the turbine and the volume of water flowing through it. Turbines are usually reaction types whose blades are fully submerged in the water flow. The diagram opposite (Figure 5) shows a typical turbine and generator configuration as used in a dam.

Results and Discussion

Before embarking on any hydro power generation project it is essential to survey the proposed site to calculate the amount of available hydro power.

The two vital factors to consider are the flow and the head of the stream or river (Figure 6). The flow is the volume of water which can be captured and re-directed to turn the turbine generator, and the head is the distance the water will fall on its way to the generator. The larger the flow – i.e. the more water there is, and the higher the head – i.e. the higher the distance the water falls – the more energy is available for conversion to electricity. Double the flow and double the power, double the head and double the power again. A low head site has a head of below 10 meters. In this case you need to have a good volume of water flow if you are to generate much electricity. A high head site has a head of above 20 meters. In this case you can get away with not having a large flow of water, because gravity will give what you have an energy boost. The key equation to remember is the following:

Power = Head x Flow x Gravity [1]

Where power is measured in Watts, head in meters, flow in litres per second, and acceleration due to gravity in metres per second per second. The acceleration due to gravity is approximately 9.81 meters per second per second – i.e. each second an object is falling, its speed increases by 9.81 meters per second (until it hits its terminal velocity).

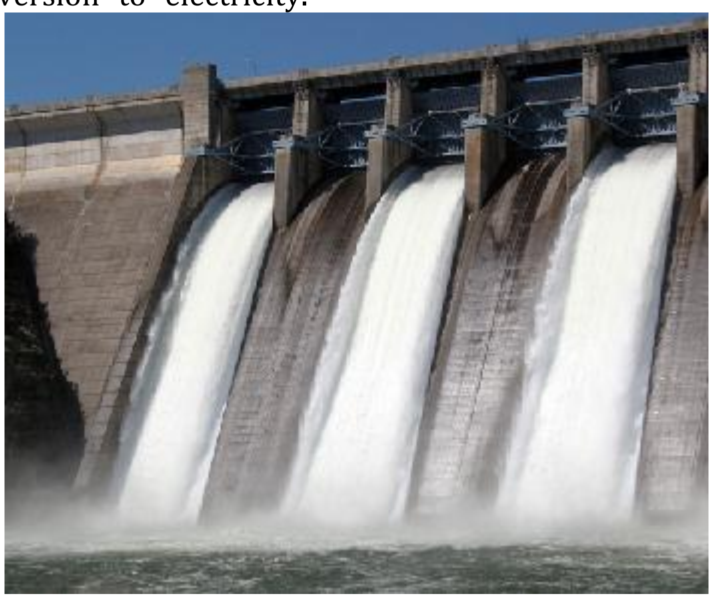


Figure 6: Flow and Head of the Stream/River

Therefore it is very simple to calculate how much hydro power you can generate. Let's say for example that you have a flow of 20 litres per second with a head of 12 metres. Put those figures in the equation and you will see that:
x 20 x 9.81 = 2,354 Watts

Available Power

Potential energy per unit volume = ρgh
Where ρ is he density of the water (10^3 Kg/m^3), h is the head of water and g is the gravitational constant (10 m/sec^2)
The power P from a dam is given by

$$P = \eta \rho g h Q$$

Where Q is the volume of water flowing per second (the flow rate in m^3/second) and η is the efficiency of the turbine.
For water flowing at one cubic meter per second from a head of one meter, the power generated is equivalent to 10 kW assuming an energy conversion efficiency of 100% or just over 9 kW with a turbine efficiency of between 90% and 95%. To calculate output power of a hydroelectric turbine, the simplest formula is(8):

$$P = Q * \rho * g * H * \eta$$

Where P = electric power in kVA; Q = flow rate in the pipe (m3/s); ρ = density (kg/m3); g = Acceleration of gravity (m/s^2); H = waterfall height (m); η = global efficiency ratio (usually between 0,7 and 0,9)

Available Power

The maximum power output from a turbine used in a run of river application is equal to the kinetic energy ($\frac{1}{2}mv^2$) of the water impinging on the blades. Taking the efficiency η of the turbine and its installation into account, the maximum output power P_{max} is given by

$$P_{max} = \frac{1}{2}\eta\rho Q v^2$$

Where v is the velocity of the water flow and Q is the volume of water flowing through the turbine per second.

Q is given by $Q = A\, v$

Where A is the swept area of the turbine blades.
Thus

$$P_{max} = \frac{1}{2}\eta\rho A v^3$$

The power generated by one cubic meter of water flowing at one meter per second through a turbine with 100% efficiency will be 0.5 kW or slightly less taking into account the inefficacies in the system. This is only one twentieth of the power generated by the same volume flow from the dam above. To generate the same power with the same volume of water from a run of river installation the speed of the water flow should be $\sqrt{20}$ meters per second (4.5 m/sec).

Conclusion

With only 26% of the country's technically feasible hydropower potential exploited, the future holds great promise for the exploitation of this important renewable energy resource. To make a success of it, the right policies and a favourable environment must be in place. The recent power reform programs should be the catalyst for positive change especially in the area of small hydropower development.Hydropower development in Nigeria has been at a snail's pace with no capacity addition since Shiroro came on stream in 1989. For the country to take full advantage in harnessing this cheap and renewable source of energy, she needs to implement the development programmes set out in the new National Energy Master Plan, with a lot more vigour. The REMP is heavy on where to go but light on how to get there. What are the other projects apart from Zungeru and Mambilla that will make Nigeria achieve the targets? Has she identified other large hydro potential sites since NEPA released the last development plan in 1986? What is happening to Makurdi? If the FGN decides to go ahead and develop the proposed sites at Makurdi, Gurara, and Ikom, they will add only about 1,800 MW to the country's resource. Add Zungeru and Mambilla and the country, will have just enough to meet the long-term target, based on the 7% GDP growth rate scenario. There is an urgent need to rethink Lokoja and to investigate new potential sites for Nigeria's power development.

We conclude with a comment on Nigeria's approach to small hydropower development. Small hydro is accepted as a proven technology for cost-effective power supply to isolated areas and rural communities. The success story of NESCO is Nigeria's evidence of that. Fixation with the idea of being "connected to the national grid" appears to have resulted in the smallest hydro project, being connected to the national grid. From Challawa Gorge to Tiga, Gurara, Dadinkowa, with capacities ranging from 30 to 40 MW have been connected to the national grid using expensive evacuation 132-kV power lines. We acknowledge the merit of HV line connection in the reduction of I2R losses, but there is the problem of reactive power requirement and the demand for line charging. In a 132-kV line, that could be as high as 3.25 MVA, 4.86 MVA and 6.46 MVA for 60-km, 90-km and 120-km HV line respectively. Serving that demand can be quite onerous for a small plant. Apart from adding high cost to the project, this mode of evacuation introduces delays and right of-way issues, which increases the cost payable by the consumer. Besides, there are water management issues to consider too. These dams are multipurpose dams primarily for irrigation and water supply. Power generation is a spin-off and should be seen as that. I hope that the foregoing points will influence future decisions in similar projects. The program designed by the Presidential Task Force on Power for these types of projects is the right approach.

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