

Cantilever Direct River Hydropower Plant

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Abstract: Water power offers big advantages to the communities they serve because of its cleanness and sustainability. Though unevenly distributed over the country, Nigeria boasts of abundant water resources covering an enormous and diverse landscape across the length and breadth of the country. Effective exploitation of these resources is favored through very small hydropower technologies. Hitherto hydropower plants in Nigeria have been constructed in the very large scale basis where a dam is first built to hold the water and render the necessary head required to drive the turbine. Apart from the great ecosystem disruption caused by conventional hydropower installations, the equipment are very expensive and far beyond the financial strength of communities and individuals. Currently most hydropower installations in Nigeria were built by government. Energy scarcity bedeviling the country can be addressed through very small hydropower plants. Run of River (ROR) hydropower plant, a form of hydropower system using energy of diverted water to drive a turbine comes handy with less cost and less ecosystem disruption than conventional gigantic systems. But ROR construction is not portable and cost effective enough for individual with available hydro potential within their reach to own. This invention contrives a Direct River sinking of a cantilevered turbine unto the free flowing water wherefore the force of flowing water rotates the turbine which in turn rotates an alternator connected to it to generate electricity. This novel machine is envisaged to be the Nigeria's revolution in hydropower harnessing.

Keywords: Water, Resources, Hydropower, Run of River, Direct River

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I. Introduction

Energy plays the most vital role in the economic growth, progress, and development, as well as poverty eradication and security of any nation. Uninterrupted energy supply is a vital issue for all countries today. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly. Security, climate change, and public health are closely interrelated with energy. Energy is an important factor in all the sectors of any country's economy. Access to clean modern energy services is an enormous challenge facing the African continent because energy is fundamental for socioeconomic development and poverty eradication. Today, 60% to 70% of the Nigerian population does not have access to electricity. There is no doubt that the present power crisis afflicting Nigeria will persist unless the government diversifies the energy sources in domestic, commercial, and industrial sectors and adopts new available technologies to reduce energy wastages and to save cost (Oyedepo, 2012).

Most states in Nigeria have one or two rivers flowing through them. Some of these rivers have great potential to generate electricity. A good number of these sites have not been harnessed for energy production. This may be due to the availability of cheaper electricity from the national grid and by the availability of portable, flexible, low cost diesel generators. Although, diesel generators are cheap to buy, the rise in the cost of oil has made diesel generators expensive to operate. The National electric grid does not include a number of small communities, resources-based businesses, farmers, and lodge owners: people that are connected to the national grid who are paying huge amount of money for their independent way of life. Such people, who are close to a flowing river around them may consider very seriously hydropower, which offers a stable, inflation-proof source of electricity, using proven technology (Aguda, 2014).

Before 1960, the bulk of power production in Nigeria was from coal as the source of fuel for thermal power system. Construction activities on the first hydropower station in Nigeria commenced in 1964 at Kainji

on River Niger. The dam was commissioned in 1968 with an installed capacity of 320MW, and by 1978, the station had 8 plants with capacity of 760MW. Later on, the tail water from Kainji Dam was utilized to generate 540MW at Jebba Dam, 97 km downstream of Kainji Dam. The third Hydro-Electric Power (HEP) station, the Shiroro Dam was commissioned in 1990 with an installed capacity of 600MW bringing the total installed capacity of Hydro Electric Power (HEP) in Nigeria to 1900MW. There are a number of small hydropower stations, such as 3MW plant in Bagel, 8MW plant in Kura and 8MW in Lere, 2MW Station at Kwall fall on N'Gell River (River Kaduna) and 8MW station at Kurra fall. The cumulative capacity of hydropower stations (small and large) is about 2000 MW. This accounts for 32% of the combined installed capacity of hydro, thermal and gas power stations in Nigeria. The development of 2500MW Mambilla hydropower station is in progress and the country still has potential for about 6000MW hydropower stations. Nigeria has just developed 23% of her feasible hydropower. This is very low compared to other African countries such as Lesotho which has developed 50% of her hydropower potential; Burkina Faso developed 46%, while Kenya has developed 34% of her hydropower potential (Abaka *et al.*, 2017).

There is an increasing need to develop clean energy technologies to cope with the problems relating to climate change, sustainable development, and energy security. Although hydropower is currently the principal renewable electricity generation source, its development would require overcoming some barriers concerning environment, public acceptance, and economic aspects. Contrary to apparent benefits, large scale hydroelectric development produces a broad range of environmental impacts. Chief among these impacts are landscape destruction, contamination of food webs by mercury, and possibly the evolution of greenhouse gases (Rosenberg *et al.*, 1995). Very small hydro plants do not suffer from such environmental and social problems as larger ones generally due to the scale of the technology the insignificant storage of water. Normally these schemes do not form a barrier to the passage of aquatic life, especially fish.

Hydropower plants capture the energy of falling water to generate electricity. A turbine converts the kinetic energy of falling water into mechanical energy. Then a generator or alternator converts the mechanical energy from the turbine into electrical energy. Hydropower plants range in size from "micro-hydros" that power only a few homes to giant dams like Kanji Dam Plant that provide electricity for millions of people. Plate 1 is a pictorial section of conventional hydropower plant. The dam creates a water reservoir storing potential energy. When the intake valve is opened, the potential energy is converted to kinetic energy as the water flows through the penstock to the turbine. The kinetic energy of the water is turned to mechanical energy by the turbine which rotates the generator to produce electricity. Transmission lines take the electricity to the consumers. Most conventional hydroelectric plants include four major components namely:

- i. Dam: The dam is used to raise the water level of the river to create falling water. It enables easy control of water flow. The reservoir that is formed is, in effect, stored energy.
- ii. Turbine: The force of falling water pushing against the turbine's blades causes the turbine to spin. A water turbine is much like a windmill, except the energy is provided by falling water instead of wind. The turbine converts the kinetic energy of falling water into mechanical energy.
- iii. Generator or Alternator: When the alternator is rotated by the turbine, electricity is produced. It is usually connected to the turbine by shafts, belts and possibly gears. When the turbine spins it causes the generator to spin also; thereby converting the mechanical energy from the turbine into electric energy. Generators in hydropower plants work just like the generators in other types of power plants.
- iv. Transmission lines: Transmission lines are used to transmit electricity from the hydropower plant to homes and business.

Conventional hydropower has advantages and disadvantages as an energy source. Its advantages include its ability to be a continuous power source that releases minimal air pollutants during power generation relative to fossil fuels. Its disadvantages include high initial capital costs, ecosystem disruption, and reduced generation during low water years and seasons (Bracmort *et al.*, 2015). The fact of high initial capital costs in building dams and constructing channels to the turbine implies that individuals and small communities would find it difficult harnessing this abundant renewable energy in their nearby streams and rivers.

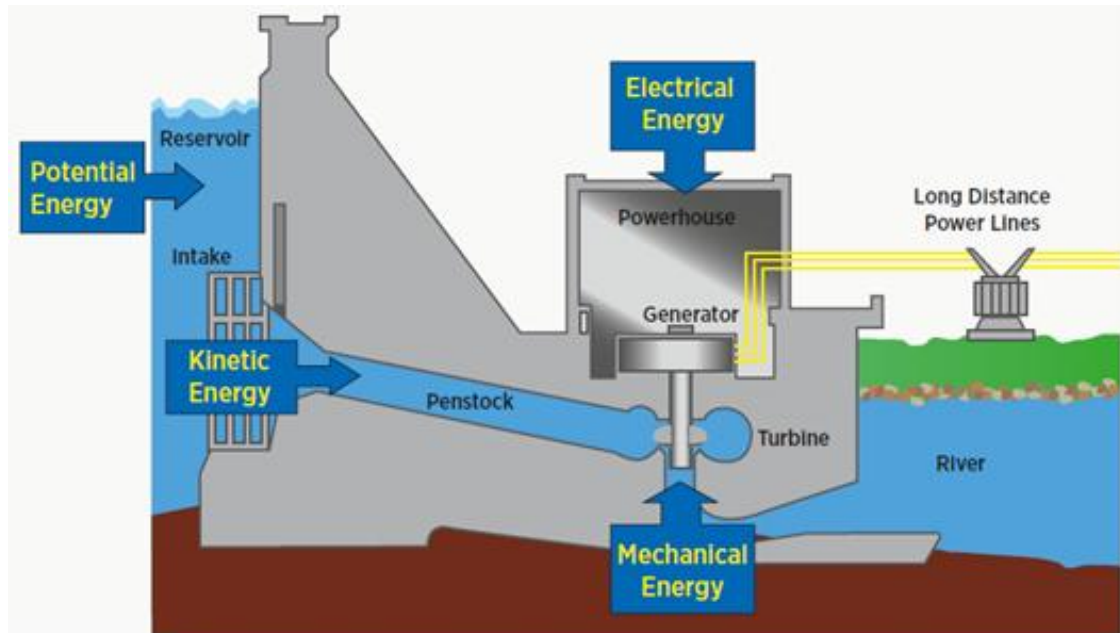


Plate 1: Pictorial section of a Conventional Hydropower Plant.

Hydropower is also being generated without a dam by diverting the river from a side to a turbine located downstream. This method is called Run of River (ROR). In ROR, the volume and speed of water is not augmented by a dam. ROR hydropower schemes operate without water storage, using the flow within a river channel. Channel obstructions (typically weirs) regulate water levels, allowing a proportion of flow to be diverted down a secondary channel to a turbine before it is returned to the main channel further downstream. Such schemes vary in size; some larger installations located on major rivers can have peak capacities of >1 MW, whereas the smallest ROR schemes on streams have peak capacities of <10 kW. In Europe, the majority of ROR schemes are mini (<1 MW) and micro (<100 kW) schemes installed on smaller river systems, with relatively few multiple megawatt schemes (Anderson *et al.*, 2015). Figure 1 is a schematic diagram depicting the diversion, turbine position and the water way back into the river main route.

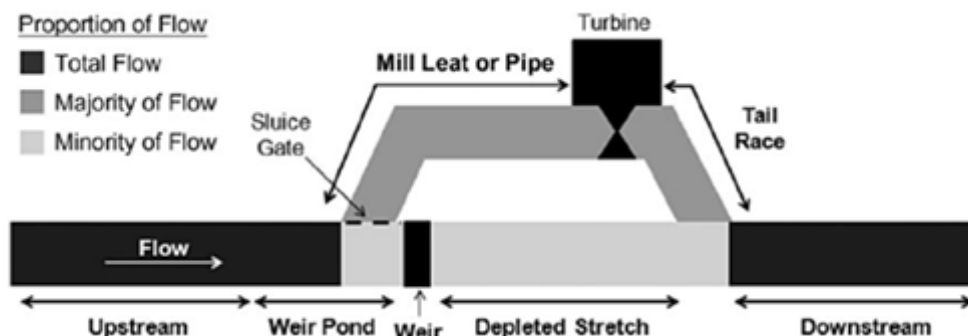


Figure 1: Schematic representation of Run of River Hydropower highlighting the key components present for both high and low head diversion schemes.

ROR schemes vary considerably in design, as they are tailored to the site geography. However, three basic classifications can be identified: high-head schemes, low-head diversion schemes and low-head in-weir schemes. High-head schemes use relatively small volumes of water, diverted over long distances (typically >1 km) and are confined to high-gradient, upland rivers. The head (vertical fall) is usually provided by natural waterfalls or cascades, but small (<0.5 m) weirs are still required to divert water. Low-head schemes occur in lower gradient river reaches and are often retrofitted to existing structures. In both cases, relatively large volumes of water are diverted, but the distance between diversion and return of the water is typically much greater in the former (0.1–1 km) than the latter (<0.05 km) (Anderson *et al.*, 2015).

Conventional high head hydropower installations and the ROR systems generally disrupt the ecosystem though in varying degrees. Cost variations also exist with large hydropower systems costing much more than ROR systems. It is opined that it will be very cost effective with minimal ecosystem disruption if a water wheel is sunk directly into a river or stream. This invention contrives a direct sinking of a cantilevered turbine unto the free flowing water wherefore the force of flowing water rotates the turbine which in turn rotates an alternator connected to it to generate electricity. No dams or penstocks are needed though the power generated would be small but it can be useful to individual homes and small communities.

The absence of a major reservoir has two main implications for ROR systems and the novel Cantilever Direct River Hydropower system. The first is that if or when the river's water levels are depleted because of drought or water extraction, the 'fuel' for the Hydropower system is reduced or becomes entirely unavailable. Without a dam for storing water, there is no stored power. This means the capacity factor of ROR or Direct River Hydropower Plant could vary between 40% and 80%. By comparison most of large hydroelectric dams with big reservoirs have capacity factors closer to 85-90%.¹ The lack of a reservoir also puts an upper limit on the size of the Run of River and Direct River plants so that they are only really feasible on rivers with large year-round flow-rates. The second implication is that the lack of a major reservoir reduces the environmental footprint of Run-off River and Direct River plants (Whiticar, 2015). Whereas it would deliver smaller power for same size of conventional turbine, the novel Cantilever Direct River Hydropower Plant is cost effective and renders very minimal disruption to the ecosystem.

II. Nigeria Hydro Potential

Of all the renewable sources of energy, water is the better choice because a small-scale hydropower is one of the most cost-effective and reliable energy technologies to be considered for providing clean electricity generation. Hydro power is a renewable, economic, non - polluting and environmentally benign source of energy. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations and help in improving reliability of power system. Hydro stations are the best choice for meeting the peak demand. The generation cost is not only inflation free but reduces with time. Hydroelectric projects have long useful life extending over 50 years and help in conserving scarce fossil fuels. They also help in opening of avenues for development of remote and backward areas (Edeoja *et al.*, 2015).

There are over 278 unexploited hydropower sites with total potentials of around 734.3MW. So far about eight (8) small hydropower stations with aggregate capacity of 37.0MW have been installed in Nigeria by private companies and the government. The hydropower potential of Nigeria is very high and hydropower currently accounts for about 29% of the total electrical power supply. The first hydropower supply station in Nigeria is at Kainji on the River Niger where the installed capacity is 836MW with provisions for expansion to 1156 MW. A second hydropower station on the Niger is at Jebba with an installed capacity of 540 MW. It has been estimated since the 1990s that for Rivers Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom, respectively) the total capacity stands at about 4,650 MW. Only the Shiroro site has been exploited till date. Estimates for the rivers on the Mambila Plateau are put at 2,330MW. The overall hydropower resource potentially exploitable in Nigeria is in excess of 11,000MW. The foregoing assessment is for large hydro schemes which have predominantly been the class of schemes in use prior to the oil crisis of 1973. (Edeoja *et al.*, 2015). Nigeria has abundant water resources covering an enormous and diverse landscape, although they are unevenly distributed over the country. Figure 2 is Map showing rivers in Nigeria. The four major drainage systems in Nigeria are:

- i. The Niger River Basin Drainage System with its major tributaries of Benue, Sokoto-Rima, Kaduna, Gongola, Katsina-Ala, Donga, Tarabe, Hawal and Anambara Rivers.
- ii. The Lake Chad Inland Drainage System comprising the Kano, Hadejia, Jama'are Misau, Komadougou-Yobe, Yedoseram and Ebeji Rivers.
- iii. The Atlantic Drainage System (east of the Niger) comprising the Cross, Imo, Qua Iboe and Kwa Rivers.
- iv. The Atlantic Drainage System (west of Niger) made up of the Ogun, Oshun, Owena and Benin Rivers (Taiwo *et al.*, 2012)

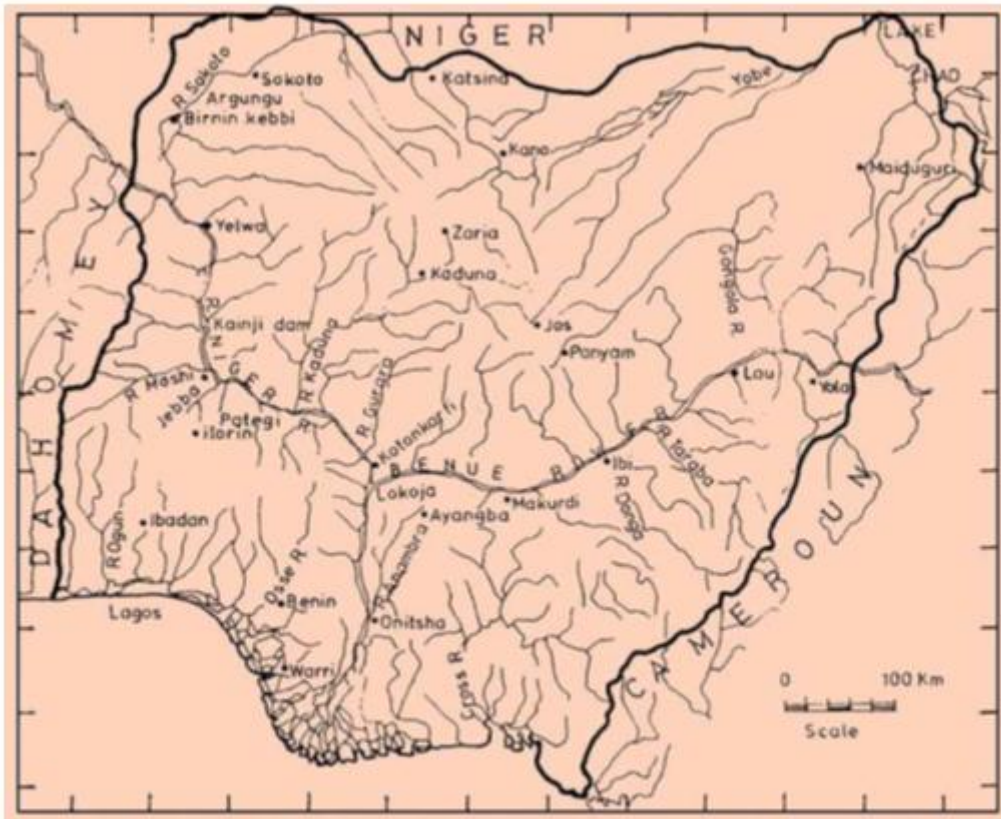


Figure 2: Map showing rivers in Nigeria.

(Source: Taiwo *et al.*, 2012)

Assuredly, there are uncountable rivers and streams sites which are favourable for Cantilever Hydropower Power Plant as the equipment can be installed at any locations along their entire lengths wherever there is a strong riverbank for stanchion installation. Small hydro power is being generated from small rivers. A small River is universally defined as the river with catchments area less than 500km² or in a precise sense, less than 300 km². From the point of view of small hydro power development, any river or stream with catchments area less than 100 km² is quite of interest (Kela *et al.*, 2012).

III. Hydro-Power Equations

The generated electric power output of a hydroelectric plant is given by the equation:

$$P(kW) = \frac{\eta \gamma Q (m^3 / s) H (m)}{1000}$$

..... (1) (Abd El-Aziz and Abd El-Salam, 2007).

Where:

P = Generator output in (kW)

Q = Water flow through the turbine (Discharge) in (m³/sec)

H = net head of water (m) (the difference in water level between upstream and downstream of the turbine)

η = Station Efficiency

g = specific weight of water (N/m³)

To calculate the available energy that can be generated within 24 hours in (GWh), the following form will be used:

$$E (GWh) = \frac{P (kW)}{1000 * 1000} * (24)$$

..... (2) (Abd El-Aziz and Abd El-Salam, 2007).

For large hydropower systems where dams are used to provide water reservoir, equation (1) would apply directly since (H), the net head of water can be easily computed. The unique set of geographical factors associated with Direct River and Run-off River plants means that power output is never identical across sites and the suitability must be measured using this formula:

$$P = Q \times H \times 7.83 \dots\dots\dots (3). \text{ (Whiticar, 2015).}$$

Where:

- P** is the power produced (in kW)
- Q** is the water flow in cubic meters/second
- H** is the hydrostatic head of the water in meters

Thorough fieldwork is required to accurately determine all the values in the above equation for a given site. Daily and seasonal fluctuations in flow mean that observations must be carried out over time to determine river flow averages. When the plant is not hooked up to a grid but used to power a small remote community, than the minimum year-round flow-rate must exceed the power requirements of the community or else they will have to rely on a source of back-up power like diesel generators (Whiticar, 2015).

IV. Equipment Description

The water wheel of this invention is a sized squirrel cage bladed turbine on bearings (Figure 3). It is hung at the end of a long hollow shaft running inside journals held by a well bedded stanchion at the bank of a river or stream. The cantilever end of the hollow shaft extending into the river carries the hydro turbine which can be lowered into the river by turning the end of the shaft from the riverbank. The concrete base and stanchion, the weight of the shaft and turbine are matched in such a manner that the turbine at the cantilever end does not overturn the concrete work and that when the turbine is lowered into the river, the blades are well positioned and driven by the flowing water. Motion of the turbine generated by the flowing water is transmitted to an electric alternator directly or through intermediate shafts mounted on the hollow shaft to produce electricity. The electricity is tapped from the alternative and delivered to consumers. The isometric, orthographic and exploded views of the invention are displayed in figures 4, 5 and 6 respectively.

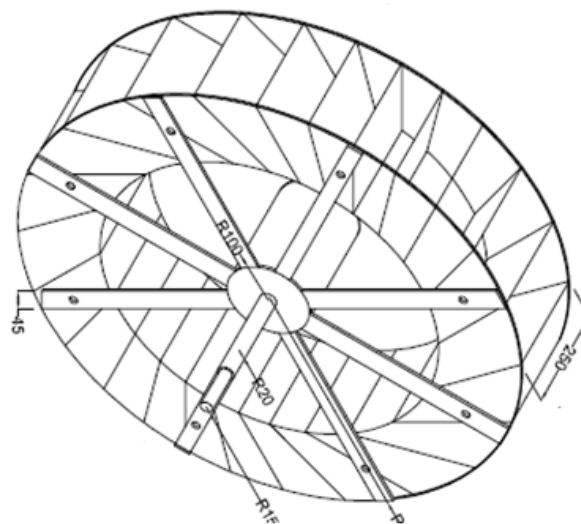
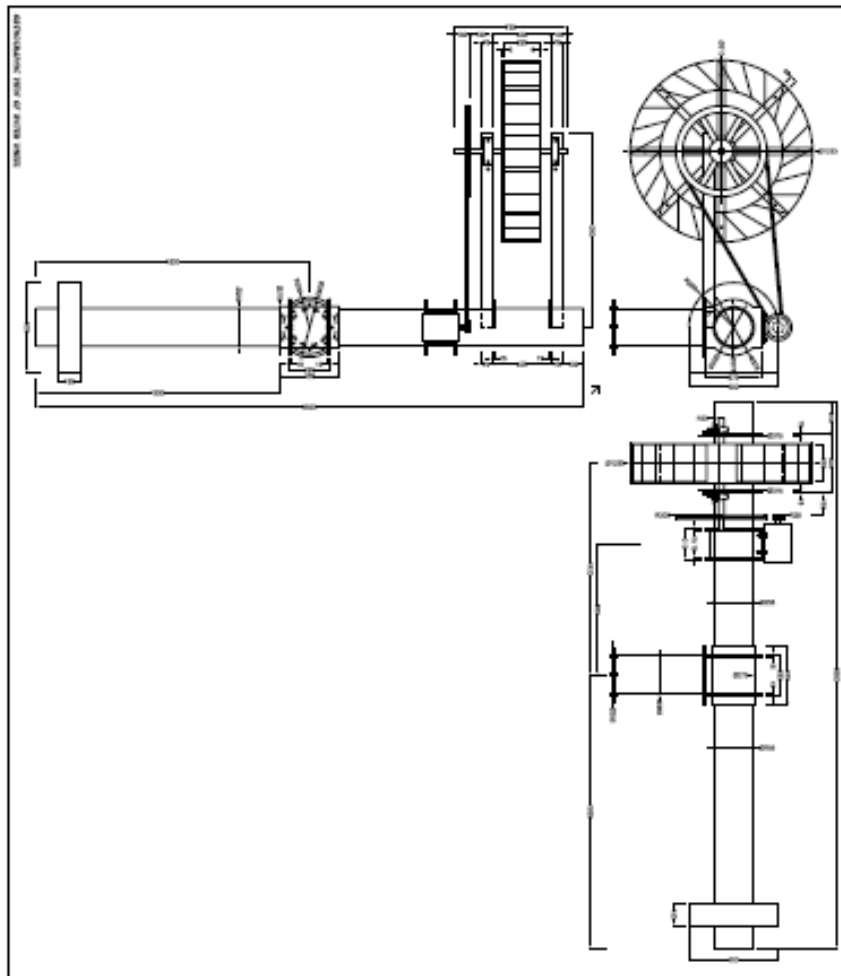
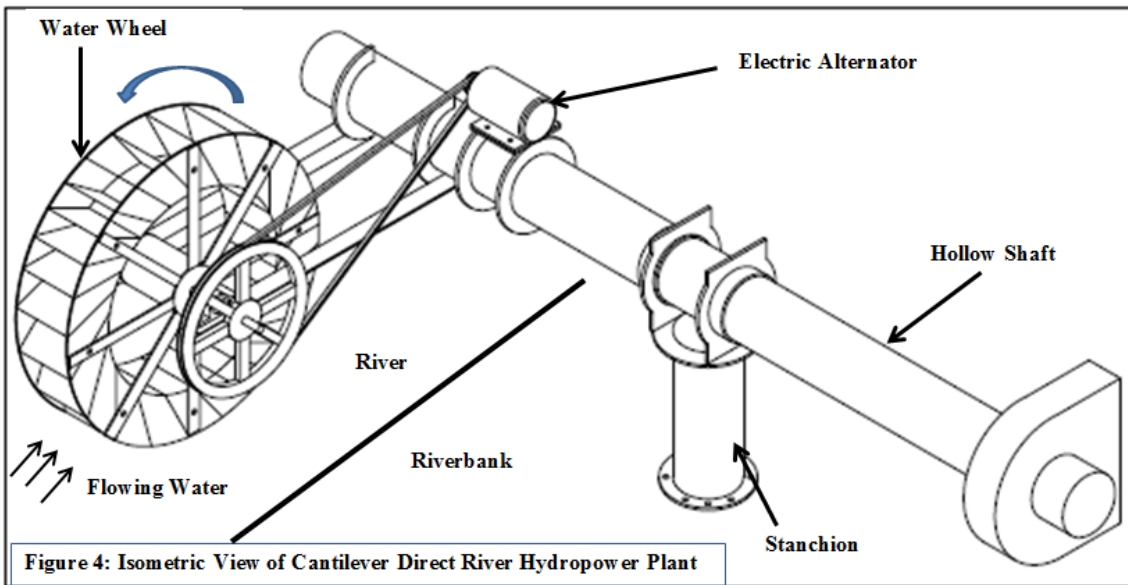
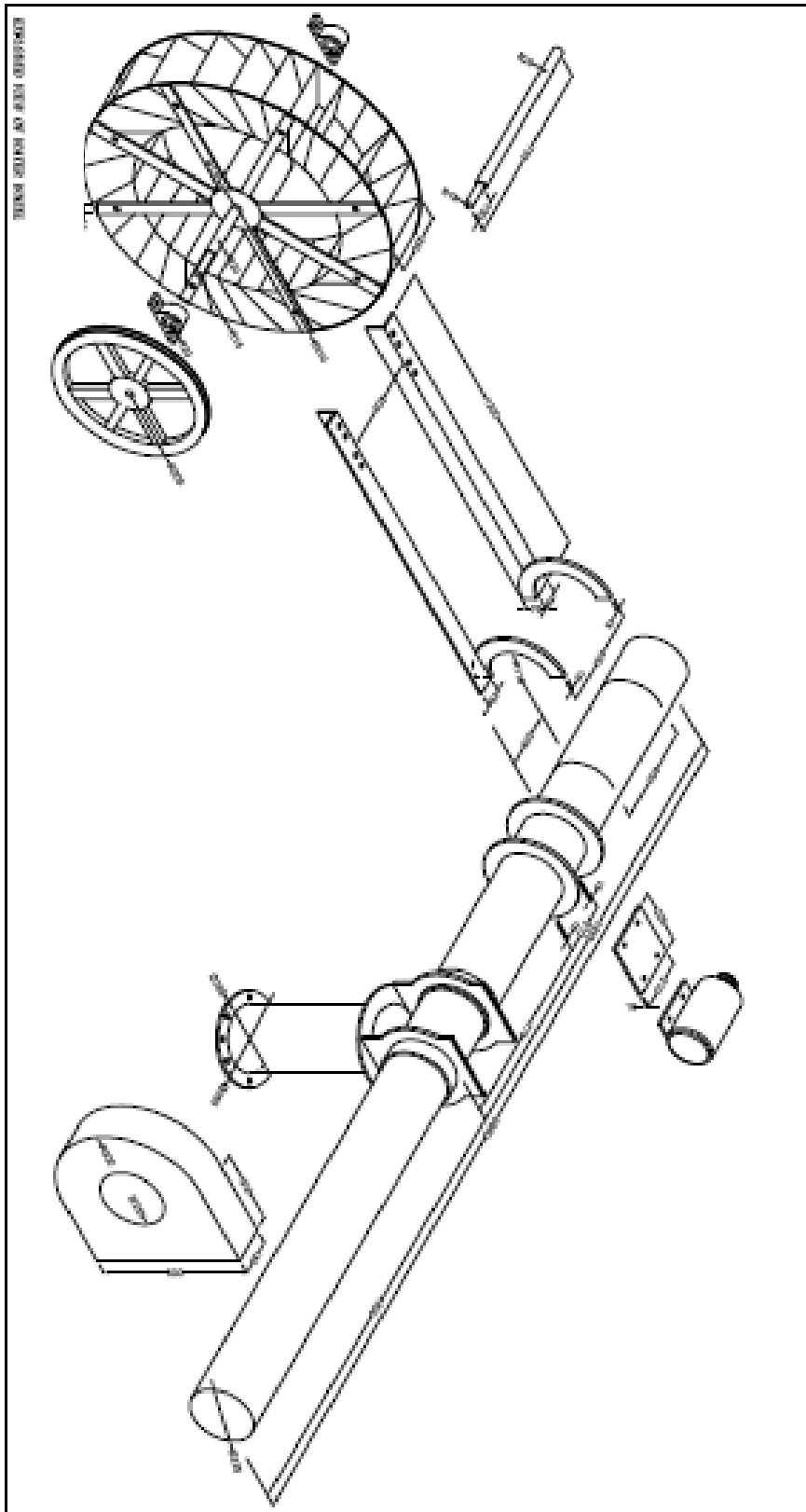


Figure 3: Squirrel Cage Turbine





V. Conclusion

Much of the developments in hydropower exploitation in Nigeria had focused on very costly gigantic systems which are unsustainable in most cases because of its destruction of aquatic life and the attendant erosion caused by diversion of natural water routes. Cantilever Direct River Hydropower Plant does not disrupt the

ecosystems as the turbine is simply installed at the center of flow. Many positions along the water routes of the many rivers across the country are feasible for the installation of the novel plant for energy generation from 5kW and above. The cost-effectiveness and portability of the project enhances private participation in hydropower generation. The project is a tripartite collaboration of Sokoto Energy Research Centre, Energy Commission of Nigeria, Usman Danfodiyo University, Sokoto, Hydraulic Equipment Development Institute, National Agency for Science and Engineering Infrastructure, Federal Ministry of Science and Technology, Abuja and National Board for Technology Incubation (NBTI), Federal Ministry of Science and Technology, Abuja. With scholarly input from Institute for Agricultural research (IAR), Agricultural and Water Resources Engineering Department, Ahmadu Belo University, Zaria.

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