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DEVELOPMENT OF RIG HANGING HYDRO TURBINE BASED ON WASTE WATER DISCHARGE AT CHALLAWA INDUSTRIAL AREA OF KANO STATE

[1]F. A. Umar [1,*], S. M. Lawan, [2]C. N. Okpala[1] and A. Aminu

[1]Department of Electrical Engineering, Kano University of Science and Technology, Wudil
[2]Department of Physics, Federal University Dutsin - Ma, Katsina State, Nigeria
*Corresponding Author's email: salisumuhdlawan@gmail.com

ABSTRACT

Design of hydroelectricity system is employed here in an effort to produce electric energy using an exhaust waste water of steam power plant. The major concern in this work is how the system is designed, selection of site and resources. The system after designed and fabricated was mounted at waste water outlet for proof run for about three months period. The result obtained exhibit the overall design is feasible for the sensitive site application.

Keywords: Hydro; micro hydro; renewable energy; waste water

INTRODUCTION

It is accepted that there was shortage of network electricity supply to rural district in underdeveloped nations and as a result, RE mechanization like hydro, wind, and solar are to be expanded and executed **(Abidin & Othman, 2005; Evers, 2010).** Wide execution of RE technologies donate durably to the sustainable development of the economy which lead to the protection of the environment, although the type of renewable energies has made them differently inefficient and economical when working separately in providing sustainable and steady electricity to consumers **(Deichmann, Meisner, Murray, & Wheeler, 2011)**. Usually, the mixing of RE and convention fuel are seen to be workable for the solution of off-grid electricity **(Madlener, Kumbaroğlu, & Ediger, 2005; Mathew, 2006; Ngan & Tan, 2012; Nguyen & Ha-Duong, 2009)**.

Among different types RE mechanization, micro hydro and wind-drive system are consider as the highest reliable sources **(Albani, Ibrahim, Yong, & Muzathik, 2013; Ibrahim, 2012)**. The availability of wind power is almost anywhere in the world but varies base on the location. Micro hydro model make use of moving water from rivers to generate electricity, mostly these natural water resources are not steady and foreseeable**(Mohibullah, Radzi, & Hakim, 2004).**Furthermore, nearly all rural areas and settlements have access to water within around because of its prerequisite for all living and organism**(Olivier, Peters, & Janssens-Maenhout, 2012;&Shekarchian, Moghavvemi, Mahlia, & Mazandarani, 2011).**Really it has been shown to be so effective but economic solution to off-grid electrification in rural villages **(Bekele & Tadesse, 2012; Liming, 2009; Pereira, Freitas, & da Silva, 2010; Yeo, Chen, Shen, & Chua, 2014)**.In addition, it practically showed the fitness and efficiency of rig turbine with arms**(Tian, Jaffar, Ramji, & Abdullah, 2015).**

Based on the literature study above, the study presently reason to adopt this concept, with modification, and also the site is different, in this case wastewater discharge weir in the Nigeria bottling company (NBC), PLC, Challawa factory, Kano State, with a plant located at seaside is considered. NBC has a power plant which is located near the estuary connected to Challawa River. There are two reasons why steam-fired power generators are cooled from the estuary using water pumps: (a) plant-wide heat rejection applications due to the availability of the water, and (b) it does not change with time over the year, that is to say no considerable adverse effect due to drought on the supply of the water. The waste water is then discharged back to the estuary. An artificial waterfall is observed at the discharge weirs due to sharp drop of the waste water as shown in Figure 1. The waste energy recovery of the waterfall is quite possible. Therefore, this work is aimed at recovering the waste energy by designing, developing and installing a waste water power generation system. Based on the aforementioned reasons, the present study was initiated.

Figure 1: Waste water discharge weir

METHODOLOGY

For the hydro, a drop of h = 2.0 m was observed at the waste water discharge weir. The waste water is supplied to the power plant via a pair of pumps, each with the capacity of 2.6 m^3/s. Therefore, the volume flow rate of the waterfall inside the discharge weir is constant at Q = 5.4 m^3/s – except during maintenance, where either of the pumps will be reduce to switched off and the volume flow rate to half. It is a common practice in micro hydro design to assume the efficiency to be e = 50% **(Ibrahim, 2012**).

SITE FOR ENERGY RECOVERY

With both head and volume flow rate known, the potential of the site is calculated to be P = 12 eQh = 70.2 kW. However, 70.2 kW is the maximum available power offered by the site. In reality, the actual power that can be tapped into is a portion of the maximum available power, depending on various design and operating factors **(S. M. Lawan, Abidin, Masri, Chai, & Baharun, 2015 & S. Lawan, Abidin, Masri, Chai, & Baharun, 2017)**

RESOURCE

The waste water is essentially raw river water **(Ibrahim, 2012).** The waste water is used to cool the turbines after undergoing filtration process in order to separate out logs, debris and marine lives. Apart from filtration, no 7.5 – 7.9 meaning it was slightly alkaline. The chloride content was measured to be 26.64 mg/L, and the particle counts were around 600 – 1000 mg/L.

Ideally, the system needs to be constructed using marine-grade material due to the corrosive nature of the selected site but because of the unavailability of the material and

purification is done to make the wastewater clean. By channelling the waste water into the estuary one more time through discharge channels and two discharge weirs. The temperature of the sea water at the intake was measured to be around 30 – 31°C. The pH of the water was between

also cost implication, 316L stainless steel was used to construct the turbine while 304L stainless steel was used to built the arm.

The schematic diagram of the system is shown in Figure 2 below.

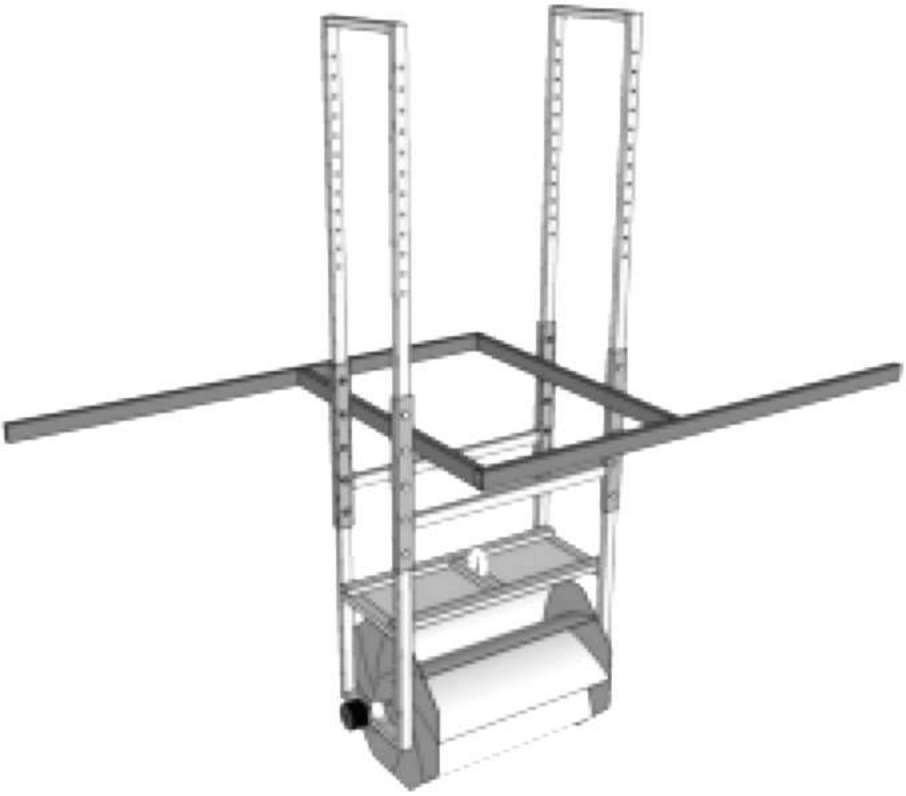

Figure 2: Modelled Rig hanging Hydro turbine

REQUIREMENTS OF THE HYDRO DESIGN

The availability of different types of micro hydro turbines across the globe makes it easier for professionals to design and select the most suitable for their function while considering the available space for installation. Because of the condition attached by NBC that no civil work is allowed in the site, an integrated and comprehensive system has to be developed and which a crane can be used to install it (as shown in Figure 3). The characteristics of the water at the site are high flow and low head. Also the authority of the company needs adjustable system so that various heads and flows can be connected at ease. These two considerations necessitate, a comparative study, as shown in Table 1 **(Ibrahim, 2012;&Mohibullah et al., 2004**), of various types of micro hydro turbines and waterwheels available in the market was made to decide on the type of turbine best suit the system. Through this relative work, after careful comparison, a hybrid design based on cross flow turbine and breast shot waterwheel is considered to be the most suitable micro hydro turbine for the site.

Figure 3: Installation of the system using a crane

Table 1: Comparison of different types of micro hydro turbines and waterwheels available in the market

Characteristics	Waterwheel			Impulse turbine		Reaction turbine	
	Breast shot	Overshot	Buckshot	Multi-jet Peloton	Cross flow	Francis	Propeller
Possible Variation	Blade Design	Blade Design	Blade Design	Number of Nozzle	Length	Nil	Number of Blade
Direct coupling	No	No	No	No	No	Yes	Yes
Low head run	Good	Good	Good	Poor	Moderate	Poor	Good
Turbine size	Large	Large	Large	Medium	Medium	Small	Small
Intake control structure	Minimal	Minimal	Some	Complex	Some	Complex	Complex
Particle tolerance	High	High	High	Moderate	Moderate	Low	Low
Cavitation possibility	Low	Low	Low	Low	Low	Moderate	Moderate
Fabrication	Simple	Simple	Simple	Moderate	Simple	Difficult	Moderate
Installation difficulty	Moderate	Moderate	Moderate	Difficult	Moderate	Difficult	Moderate
Parts accessibility	Good	Good	Good	Moderate	Moderate	Little	Little
Expected maintenance cost	Minimal	Minimal	Minimal	Minimal	Minimal	Some	Some
Direct coupling	No	No	No	No	No	Yes	Yes

TECHNO-ECONOMICAL ANALYSIS

RECOVERY OF THE ENERGY

The waste water supplied by the pumps to cool the steam-fired gas turbines are recovered by the system inform of waste energy which is inside the power plant. Despite the fact that, the system can't recover thermal energy from the waste water but it can salvage mechanical energy (both potential and kinetic energy). The ratio of power recovered from the waste water to the power used to supply the waste water is known as Energy Recovery Efficiency (ERE) as used in this study. As in all cases, the numerical value is always less than or equal to 100%. The rating of the power used to supply the waste water is written on the pump's plate and in this case the power is 658 kW. Since two pumps are used to accommodates waste water from discharge weir, the ideal ERE is 69.6/1316 = 5.3%, while the actual ERE is 10/1316 = 0.76%. Comparing the above values of actual and ideal percentages, an improvement can be made in order to have reasonable value.

PAYBACK PERIOD

The payback period is an important factor that is used to know the time period within which the system can payback the amount of money invested. For this particular system, the payback period is about 45 months. This means that the system will regain all its cost and starts to generate revenue after running accordingly for 3 years and 9 months. In this study, the present-worth method of analysis is used with the following data:

Capital Cost, $C = NGN5{,}000{,}000{:}00$

Annual operation and maintenance cost, $A_c = NGN15{,}000{:}00$

Annual revenue generated, $A_r = (NGN17/kWh)(10)(24)(365) = NGN1{,}489{,}200$

Interest rate, $r = 4\%$

The payback period, n was calculated using the formula below:

$$C = (A_r - A_c)\left[\frac{(1+r)^n-1}{r(1+r)^n}\right] \qquad (1)$$

$$n = \frac{1}{\log(1+r)} log\left[\frac{(A_r-A_c)}{(A_r-A_c)-rC}\right] \qquad (2)$$

The economic valuation process of a commercial-scale wind turbine in this paper considers only two parameters: the net present value (NPV) and simple payback period (SPP). The calculation of the net present value (NPV) requires the present value (PV).

The annual saving or the avoided electricity cost is a key input in determining the PV, NPV, and SPP. Equation 3 shows how variable cost (in Naira/kWh) from a utility company is normally applied to convert the AEO to the annual saving (A).

AA= AEO (in kWh) x variable cost (in NairaWh) (3)

Equation 4 relates PV and A, where *i* is the interest rate (%) and *n* is the estimated lifetime (years).

PPPP=AA (1+*ii*)*nn*−1(*ii*)(1+*ii*)*nn* (4)

DURABILITY

Although the system was made from different materials, the durability test was successful over the year of proof run. The corrosion rate is rapid and aggressive because the system is in direct contact with warm sea water and vapour (measuring around 37 - 39°C). The system was also observed to have different degrees of rust at various parts that were not constructed with 316L stainless steel during the three months of proof run. This can be seen by comparing figure 4(a) and 4(b). Bolts and nuts, bearings, sprockets and chains were not constructed with 316L stainless steel that is the reason why the rust affects them severely. Effort was made to put grease, paint and coat in order to protect them but prove abortive because the system is in contact with the elevated sea water and vapour. Figure 5 below shows the condition of the system as the result after one year's proof run.

(a) (b)

Fig. 4: (a) Hanging waste water power generating system before installation; (b) Hanging waste water power generating system after three months of proof run.

Fig. 5: Hanging waste water power generating system after one year of proof run

RESULTS AND DISCUSSION

RESULTS

Considering the importance of safety matters, on-site test was not conducted. This resulted in obtaining only a finite data at the time of proof run. Data obtained during proof run is shown in Table 2 below. The study considered only two types of drive systems, namely: pulley and timing belt, and then sprocket and chain. Since the terminal voltage varies directly with the speed of the generator for all permanent magnet ac synchronous generators, the efficiency can be calculated by dividing the recorded voltage to 400V, the designed optimum voltage for the generator. Therefore, the efficiency range is: $210/400 < \eta < 280/400 = 0.525 < \eta < 0.70$

Table 2: Data obtained during the 3 months test run

	Timing belt and pulley	Chain and sprocket
Turbine rpm when not connected to a generator	68 – 70 rpm	106 – 109 rpm
Turbine rpm when connected to a generator	45 – 47 rpm	85 – 87 rpm
Voltage generated at the generator	150 – 180V	210 – 280V
Current generated at the generator	18.1A	18.1A

DISCUSSION

Design, resource and site are the major factors that differentiate the existing micro hydro from the present waste water power generating system. In terms of resource, micro hydro deals with cool fresh water while in this study, heated sea water is used. To minimize the corrosion, not all methods can be applied because of the rotating parts; therefore, methods such as surface treatment, coating and galvanization are inappropriate in this study. Marine-grade materials are best suitable for this application.

It is quite fortunate that locally and inexpensive marine-grade material (316L stainless steel) was used to construct the rig and turbine used in this study, but 304 stainless steel was used to construct the arm, though not a marine-grade material, but can resist corrosion in comparison with steels and irons. Steels and irons are used in other parts of the system such as: bearings, generator and drive system (sprocket-chain and pulley-belt) but they are also protected from corrosion using grease and paint, unfortunately, the protection did not last long.

The continuous supply of waste water to the coal-fired gas turbine by the discharge weir makes it necessary not to halt the waste water for the purpose of proof run. All the civil works were avoided at the site during the installation of the system for safety purpose and therefore, all the parts were comprehensively integrated. Lastly, the design was made purposely for the site unlike the sites for existing micro-hydro power plants (river and stream). This makes the hanging design appropriate for industries with similar type of setup.

CONCLUSION

The study have been completed and undergone a proof run of about three months, the system was found to have operated according to the design. Although it is a system that converts waste to energy with no fossil fuel consumption and no carbon emission observed. Less than four years was calculated as the system's payback time. The range of 53% to 70% was obtained as the efficiency during testing. The river water available in this study is corrosive and can course damage to iron and steel parts of the system. The best option is stainless steel (marine-grade), although it is very expensive to be used in this project, this makes the design and fabrication of the system to have some drawbacks. Although the system can run, the design can still be improved.

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