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Characteristics of Calabar Tidal Resource: Patterns and Relationship to Sustainable Clean Energy.

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ABSTRACT

The ability of tidal power to reliably contribute energy to electricity networks is directly related to the characteristics of the tidal resource. This research presents an investigation on the tidal energy potential of Calabar, Cross-River State (Latitude 4.9667°N, Longitude 8.3167° E) a coastal region of Nigeria along the Atlantic Ocean. An analysis of the characteristics of the tidal power resource of Calabar in Southern Nigeria has been carried out, based on daily observed tidal height for the period of ten years (2001 – 2010). Patterns of tides availability are presented, with data demonstrating distinct patterns of daily, monthly and yearly variability – tides exhibited a sinusoidal trend over the ten-year period. The average yearly tidal height range of Calabar was 2.65 – 3.02 meters.

Keywords Tides; Electricity; Tidal power; Clean Energy.

INTRODUCTION

The demand for energy has been rising from the time of the primitive man who needed very little daily energy consumption, to today, when the need for energy is vast (Sambo, 2000; Holm, 2005). Nigeria is one of the developing countries and its dependence on fossil fuels can only be offset by the sustained exploitation of other energy resources. Tidal energy is renewable and can be harnessed for various end-uses. A precise knowledge of tidal wave pattern is a pre-requisite for the efficient planning and implementation of any tidal energy project [Deign, 2014; Twidell and Weir, 2006; Cheremisinoff. 1979; Bahai and Myers, 2003).

History of Tidal Power

Tidal power is the harnessed kinetic energy from tidal flow to generate electricity. Use of tidal power dates back to the 11th century, where primitive tidal mills were used in England. In the 18th century, others were built in Western Europe, Canada and USA.

As a result of the industrial revolution and subsequent widespread use of electric power, tidal mills became obsolete. With the growing demand for electrical power the U.S. Army Corps of engineers was authorized in 1935 to construct a 65 MW tidal power project in Cobscook Bay, Maine (Herbich, 2000; Hagerman and Polagye, 2006; Blanchfield, 2007;).

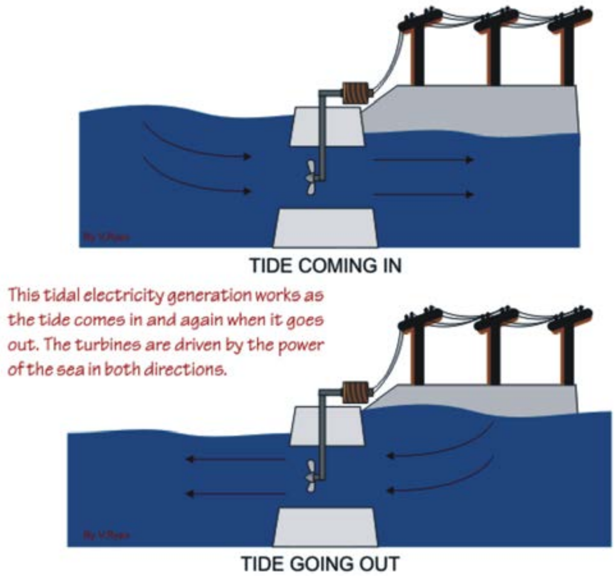

FIG. 1: How Tidal Power stations work.

Tidal Power Assessment

This section presents Calabar's coastal belt as the primary study area. Calabar is in

Cross-River State, Nigeria, with Lat. 4.96°N, Long. 8.31° E). For a satisfactory assessment of the tidal energy potential of Calabar, details of tidal height for ten years were obtained. It is essential to assess tidal energy potential of a site before any tidal energy based system is set up.

Energy is extracted from the movement of the tides; from the differences in tidal height and from the fast-moving tidal streams and currents (tidal speed). Since, movement of the tides is of primary concern, the tidal height data will be used for the assessment, because it is readily available (SEA, 2004; SDC, 2007; Nwaokocha and Laveni, 2013).

The following evaluations were derived from the tidal height data:

Daily Average: This is the average of the tidal height measured per day. Denoted as $\bar{h}$

$$\bar{h} \; \frac{1}{N} \quad \sum_{i=1}^{N} hi \qquad (1)$$

where, $\bar{h}$ is the average value, and

N is the total number of tidal heights in a day.

Monthly mean: This is the average of the daily means in a month. Denoted as $\bar{d}$

$$\bar{d} \; \frac{1}{N} \quad \sum_{i=1}^{N} di \qquad (2)$$

where, $\bar{m}$ is the average value, and

N is the total number of days in a month.

Yearly mean: This is the average of the monthly means in a year. Denoted as $\bar{m}$

$$\bar{m} \; \frac{1}{N} \quad \sum_{i=1}^{N} di \qquad (3)$$

where, $\bar{m}$ is the average value, and

N is the total number of months in a year.

Tidal power represents the potentially available tidal energy flux per unit area of flow. It is related to the tidal pressure head (water level above mean sea level) and flow. Tidal power, P, per square metre of flow area is given by:

$$P = \varrho g h Q \qquad (4)$$

where ρ = density of water

g = acceleration due to gravity

h = tidal height, and

Q = tidal flow per unit area.

This formulation is applicable where tidal power is to be derived from large ranges in tidal elevation. Typical peak tidal variation in Bass Strait is approximately 2.5m (SEA, 2004; SDC, 2007; Nwaokocha and Laveni, 2013).

A second formulation for tidal power relates to current speed where the extraction of power is via the use of tidal turbines [14-19]. In this case, tidal power is given by:

$$P = \frac{1}{2} \rho \upsilon^2 \; Q \qquad (5)$$

Where ρ = density of water

v = tidal current velocity

Q = tidal flow per unit area.

Historically, the energy flux method has been the primary method for estimating the resource potential of a tidal stream (Hagerman and Polagye, 2006; Blanchfield, 2007). This method assumes that the extractable power is directly proportional to the kinetic energy flux through the most constricted cross-section of the channel in the undisturbed state. The head difference across the channel is assumed to have a negligible impact.

In deep water, the wave energy flux is expressed as (Hagerman and Polagye, 2006; Blanchfield, 2007), with P the wave energy flux per unit of wave-crest length, H_{m0} the , T the wave period, ρ the water density and g the acceleration by gravity.

$$P = \frac{pg^2}{64} \; H^2 moT \; = 0.5 \; \frac{\text{kW}}{\text{m}^3 .\ \text{s}} \; H^2 moT$$

The above formula states that wave power is proportional to the wave period and to the square of the wave height. When the significant wave height is given in metres, and the wave period in seconds, the result is the wave power in kilowatts (kW) per meter of wavefront length (Herbich, 2000).

Probability of Exceedence

The Probability of Exceedence is a statistical tool which analyzes the distribution of annual mean values for a particular tidal height data, and estimates the probability that the annual mean will exceed certain values. This estimate becomes more accurate with more years of data.

The Probability of Exceedence graph shows both the measured values and the normal distribution that best fits those values. The y-axis indicates the probability that the annual mean value will exceed a particular value.

RESULTS AND DISCUSSIONS

The data collected was analyzed to get the daily, monthly and yearly mean tidal height for the locations. Fig. 2 presents the typical daily average tidal height for the Months of March, June, September and December for year 2010 in Calabar, Cross-River State, Nigeria. Fig. 3 also presents typical monthly average tidal height versus months for the years 2002, 2004, 2006, 2008 and 2010. Similar patterns of flow is also observed over the years.

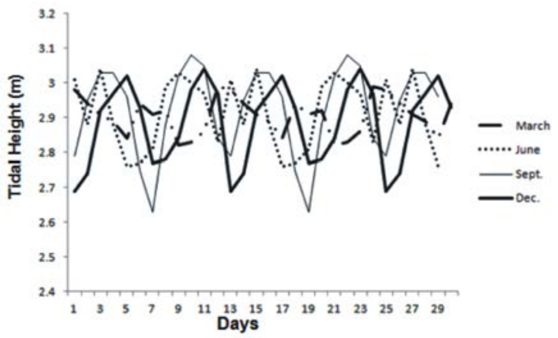

FIG. 2: Typical daily average tidal height for the months of March, June, September and December for year 2010 for calabar, cross-river state, Nigeria.

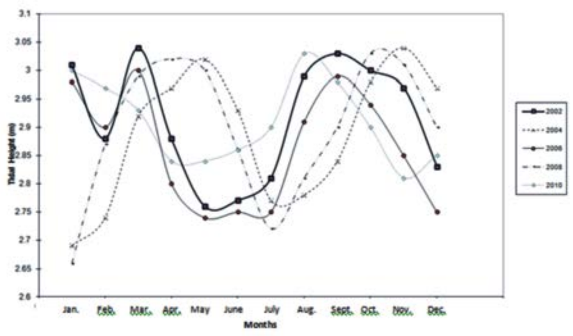

FIG. 3: Typical monthly average tidal height versus months for 2002, 2004, 2006, 2008 and 2010 for calabar.

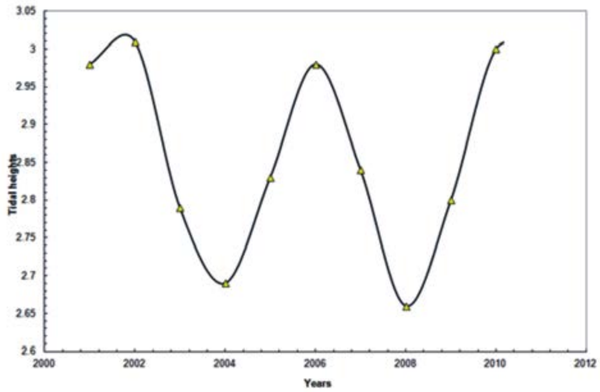

Fig. 4: Yearly Average Tidal Heights for Calabar.

Figure 4 shows typical yearly average tidal heights for Calabar, Cross-River State, Nigeria. Figure 5 presents the comparison of the maximum, minimum and mean tidal height for Calabar, Cross-River State, Nigeria. The maximum tidal height is the highest tides per day, while the minimum tidal height is the lowest tides per day.

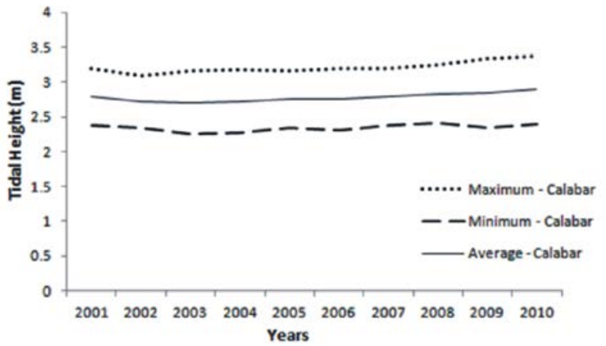

Fig. 5: Comparison Of The Maximum, Minimum and Average Tidal Height for Calabar.

Figure 6 is the variation of yearly average tidal height for the months of January between the years 2001 to 2010 in Calabar. The figure depicts the tidal height ranging between 2.66 metres and 3.03 metres for years 2001 to 2010.

Figure 7 presents the probability of exceedence for Calabar, which is derived from the daily tidal height data. The graph shows that for any particular year, the probability that the mean annual tidal height will exceed 2.60 metres is 75% and the probability that it will exceed 2.80 metres is about 25%.

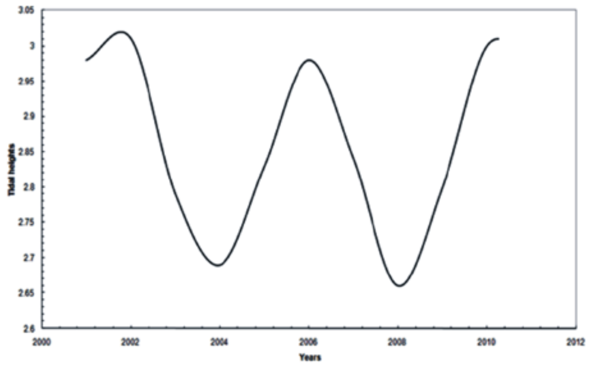

Fig. 6: Variation of Yearly Average Tidal Height for The Months of January (2001 - 2010) for Calabar, Cross-River State, Nigeria.

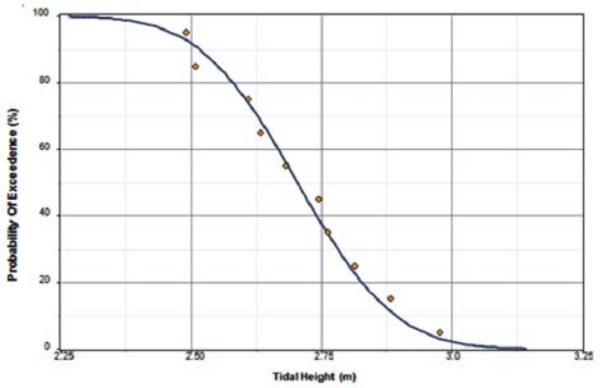

Fig. 7: Probability of Exceedence for

Using a Regression method for the analyzed data, the following equation of line was generated:

$y = 3E\text{-}05x^6 - 0.0013x^5 + 0.0187x^4 - 0.1296x^3 + 0.4187x^2 - 0.548x + 3.1014$

$R^2 = 0.9068$

The co-efficient of Determination, R^2 depicts the viability of the data.

TABLE 1: COMPARISON OF TIDAL HEIGHTS

COUNTRY	SITE	AVERAGE TIDE (m)	ESTIMATED POWER
USA	TACOMA	2.5	6.75 MW
RUSSIA	KISLAYA GUBA	2.3	0.4 MW
CHINA	JIANGXIA	5.08	3.9 MW
AUSTRALIA	BASS STRAIT	2.5	20 kW/m
CANADA	ANNAPOLIS	6.4	18 MW
NIGERIA	CALABAR	3.07	36 kW/m

Results showed that the tides exhibited similar trends over the ten-year period. The yearly tidal heights for Calabar, Bonny, Akassa and Lagos were 3.07, 2.40, 1.80, 1.30 metres respectively.

By comparison, the tidal technology in use in the Tacoma region (USA) with average tidal height of 2.5 metres, produces 6.75 MW electric power and has an estimated annual energy capacity of 13 GWh – thus Calabar coastal site with an average tidal height of 3.07 metres will do better. Since the percentage of time the tidal height exceeds 2.50 metres is 92% and that it will also exceed 2.60 metres is 75%.

CONCLUSIONS

It was discovered that tidal energy availability in Calabar is favoured with the yearly average tidal height of 3.07 metres. This paper posit that a tidal power plant can be established in Calabar. The need to proactively reduce the damage on our environment has been the fulcrum of this study. The following conclusions were drawn:

yearly tidal height is the same over the years.

- Charts of recorded tides exhibit a sinusoidal trend over the ten years period: the observed frequencies rise steadily, reaching a maximum value of tide height for each location, and then drop more or less slowly.

Then on this premise, it is recommended that the establishment of tidal power plant for clean energy generation be integrated into the new energy policy being drafted by the Federal government.

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