Renewable Energy 44 (2012) 414–422

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

# Simplified site-screening method for micro tidal current turbines applied in Mozambique

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## ARTICLE INFO

*Article history:*
Received 2 August 2011
Accepted 6 February 2012
Available online 27 February 2012

*Keywords:*
Tidal energy
Ocean energy
Decentralized power production
Off-grid electrification
Site characterization
Energy resources

## ABSTRACT

A variety of tidal current turbines (TCT) are emerging, the majority focussing on large-scale extraction of renewable energy at global tidal hot-spots. Concurrently, some turbines are small and may be suitable also for micro-scale applications (micro-TCT) in remote areas, such as decentralized electrification in countries where fuel-independent energy systems with high power predictability are particularly important. In shallow waters the force of tidal currents varies considerably over short distances and very site-specific measurements are important for assessment of localization, but are also expensive. For micro-TCT to be of interest site-screening and evaluation must be inexpensive, and low-cost methods are thus required. This study proposes a simplified tidal model that is calibrated to site-specific conditions by short-term observations using lightweight equipment. By measurements comprising down to 8% of the monthly tidal period the potential power output can be estimated, with uncertainty intervals up to ±20%, for currents applicable for micro-TCT. This site-screening method was tested at five sites in Mozambique where near-shore tidal currents were measured with lightweight current meters. At three of the sites, currents were estimated to exceed 1 m $s^{-1}$ and power output was calculated based on technical assumptions for a micro-TCT device. Results are discussed from the perspective of micro-TCT development and decentralized remote area electrification.

## 1. Introduction

Tidal current turbines (TCT) convert kinetic energy from fast-flowing tidal currents into electricity. The TCT technologies are still at a formative stage and comprise a wide diversity of different designs [1–5]. The predictability of tides provides a great advantage and is one major reason for the substantial interest that lately has been given to tidal power [3,5–8]. Despite limited knowledge of the occurrence of strong tidal currents in most parts of the world the global extractible resource is presumed to be substantial [5,9] and projections for TCT technology suggest an extensive growth from 2020 [10,11]. Being both a renewable and a predictable energy source tidal power may become one of many important pieces in the jigsaw of cleaner global energy supply. More modestly, it has been suggested that the immediate opportunities for TCTs reside in providing power to rural and island communities [2].

Most of the different TCT technologies rely on submerged or floating generators driven by horizontal or vertical turbines, with rotors forced by the currents. The rotor dimensions are heavily influential on energy capture, but large rotors produce massive loads from currents, involving large foundations and stress on materials. Within TCT development the main focus has been on relatively large solutions with tidal farms of tens to hundreds of units, each with a capacity from about 300 kW to 2 MW, operating in fast-flowing currents above 2 m $s^{-1}$ [12]. Devices set for these conditions require weight dimensions of up to hundreds of tons per unit [13] which implies high costs of manufacturing and installation.

Distinguishable from the large-scale approach are small units rated at about 5–25 kW, here referred to as micro-TCT. Of the 39 TCT devices reviewed by the International Energy Agency [12], a handful can be classified as micro-TCT. Micro-TCTs are lightweight, can be deployed in shallow waters, and may be adapted to

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doi:10.1016/j.renene.2012.02.010

the conditions of less harsh sites and slower current velocities. One example is the vertical axis turbine presented in [14], where low cut-in speed and high generator efficiency at low speed increase the period of power generation as it operates over a larger part of the tidal cycle. Another example is the Gorlov helical turbine which is scalable based on units rated at a few kW [15].

If smaller and less harsh sites can be utilized, the number of potential sites increases. In a review of the Norwegian tidal current resource 13% of the theoretical resource was estimated to reside in sites shallower than 20 m [8]. Although the extractable energy is relatively small at modest currents ($<2$ m $s^{-1}$ mean maximum spring speed) such currents constituted about one third of the number of potential sites in the same resource assessment. Micro-scale extraction may typically be of interest where access to predictable renewable energy is of particular value, such as remote and less developed locations [15]. As noted by [16] on small-scale wave power, along with benefits of fuel independence the *access* to electricity can *per se* be regarded as important additional values in some developing countries.

Decentralized electrification is an issue of great importance both for remote island communities and countries where the costly extension of national transmission grids is still under development [17,18]. For example, low rural electrification levels and expensive fuel for diesel generators in Tanzania have motivated a rise in the standardized purchase tariff for electricity sold by small producers to decentralized grids to 25¢ per kWh, which is >300% of the purchase tariff for electricity sold to the main grid [19,20].

With local use of renewable energy the running costs are basically limited to maintenance. Micro solar PV systems have frequently been used in off-grid applications, but more power-intense sources are often needed if electricity is to be used for economically productive purposes [21,22]. The use of micro tidal barrages is since long proven [23], and another suggestion has been micro-scale river current energy conversion [24]. Similarly, micro tidal power could contribute where strong currents are available. China is a good example of early action in the field of tidal power, where research and development has risen expectations on future expansion [25]. Another recent example comes from Mozambique where local fishermen are assisted by university personnel in deploying a <1 kW vertical axis micro-TCT in the mouth of the Zambezi river in order to power a refrigerator and charge phones, with the ambition of increasing revenue from fishery [26]. A first turbine was destroyed but a second is under construction.

As tidal currents are very confined and directly dependent on local bathymetry it is not straightforward to indentify appropriate sites. At a strategic level, tidal current resources can be estimated either by modelling water movements based on tidal range (water level) data and coastal morphology [27–29], or by using existing information of the peak current velocities at specific sites [8,13]. Assumptions are necessary in all modelling and uncertainties increase when large-scale assessments are transferred to site-specific evaluations. For adequate calculation of potential power output at a specific site a detailed characterization of the local currents is required [30–32], with suggested lowest sample series of one synodic period (29 days) [7]. In near-shore shallow waters, where the spatial variation of currents is particularly high, several nearby sites may have to be investigated to identify the most potent.

In remote areas, however, long-term field measurements with expensive equipment are logistically complicated and costly, even more so if the project takes place in a developing country. One month of measurements with acoustic Doppler current profiler (ADCP) equipment at a remote location, including safeguarding of equipment and a vessel for deployment and recovery, would imply huge costs in relation to the output and economic return of any micro-TCT. Here, initial data sampling will inevitably consume a disproportionally large share of the project and for this reason adapted low-cost methods for site-screening and preliminary evaluation will likely be important for micro-TCT technology to become of interest at the niche market of remote area electrification.

In this paper we have developed and tested a simple low-cost method for site-specific evaluations of the potential for micro-TCT. Short-term observations were collected by lightweight current meters in five shallow straits; the most influential site-specific tidal characteristics were then extracted and used to calibrate a basic tidal model, in turn producing site-specific and time-resolved estimations of electric power output. The resulting power output and availability over time were examined in terms of usefulness for remote rural villages. The study aims to exemplify how site evaluations for micro-TCTs can be conducted with a fraction of the effort required for fulltime measurements.

## 2. Methods

### 2.1. Main characteristics of tides

Tidal currents are induced by water level fluctuations originating from the Earth's rotation in combination with the gravitational forces between the Earth, the moon, and the sun. The magnitude of tides at a specific location is further determined by coastal geometry, i.e. shoreline and bathymetry [15,33]. Although weather conditions have some influence, tidal elevations and their induced currents are essentially predictable. The dominant astronomical force, the moon, creates a tidal lunar day cycle of 24 h 50 min. Each lunar day comprises one or two tidal periods for diurnal and semidiurnal tides respectively. The moon position in relation to Earth and sun adds a monthly cycle (29.5 days). The tides are magnified when the three astronomic bodies are positioned in line (spring tides) and are weakened when they form an angle close or equal to 90° (neap tides); a monthly cycle covers two periods of spring and neap tides. Typically, spring tides create a tidal range twice the size of the neap tidal range [7]. Altogether, these major constituents produce a double sinusoid tidal pattern. In addition, the first and the second tide each lunar day differ in consequence of the Earth's rotation, and the moon's altitude over Earth affects the magnitude of spring and neaps tides.

The tidal fluctuations induce flood currents towards the coast and receding ebb currents in the opposite direction. Flood and ebb currents are thus variable but predictable over time. Exaggerated currents are typically found in association with straits and peninsulas [30].

The rate of kinetic energy in flowing water varies as the cube of the velocity, and the conversion into electric power ($P_e$) can be calculated by Equation (1):

$$P_e = \frac{1}{2} \cdot A_t \cdot \rho \cdot \eta(v) \cdot v^3 \quad \forall \ v \geq v_{cut-in} \tag{1}$$

where $A_t$ is the swept area ($m^2$) of the specific turbine, $\rho$ is the density of water, $\eta$ is the efficiency of the device, and $v$ is the current speed (m $s^{-1}$). Electricity is generated as long as the water speed exceeds the device-specific cut-in speed, $v_{cut\text{-}in}$. For estimations of potential power output at a specific site $v$ should be determined and technical assumptions must be made.