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Research paper

Small 500 kW onshore wind farm project in Kribi, Cameroon: Sizing and checkers layout optimization model

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ABSTRACT

For the purpose of providing cheap, affordable and reliable electrical energy to communities in need and power-up new industries and enterprises, a small onshore wind farm with an estimated capacity of 500 kW is designed and studied. With the help of a wind rose, wind resource map, and results from Weibull statistics, a potential site is selected and the wind farm is positioned along Cameroon's coastline for maximum energy capture. Using the PARK model for wind turbine layout optimization, two different layout patterns (Checkers pattern and column pattern) are studied for the purpose of minimizing the wake effect and thereby, maximizing the output power from the farm. The Checkers model was found suitable as compared to the column model to be used on Grand Batanga, a small locality South of the city of Kribi, Cameroon.

1. Introduction

The quest to become an emerging state by the year 2035 has pushed Cameroon's government to heavily invest in the energy sector, as energy is the driving force behind the rapid development of any country. Significant progress has already been made with a newly constructed dam in the south region of the country. But giving that dams are not ecologically friendly and also given problems posed by global warming with the earth warming by 1° every 10 years, has caused most sub-saharan African countries like Cameroon to be affected by droughts. Long periods of droughts or dry season as is often the case in the tropics give rise to seasonal rivers. Hence there is usually very low energy output from these dams during the dry seasons which causes some large communities to go days and sometimes weeks without electricity.

Our objective in this work is to contribute in the energy sector by identifying potential renewable energy sources, sites and propose efficient ways of harnessing them that can add significant megawatts to the national grid. Which will go a long way to make electrical energy available in rural areas that are often forgotten or deprived of basic energy and water.

For a larger and more industrious community like Kribi, wind energy has been found suitable as an alternative energy source compared to solar in Cameroon because it is cheaper and yields more power per square area of land than solar.

To select the best site for the installation of a small wind farm, the first step is to carry out a wind energy assessment which is usually done using wind resource maps. A wind resource map for Cameroon is shown in Fig. 1 (Anon, 2014). Here we see that favourable wind speeds to support a small wind farm are mostly available in the Northern parts of the country and the coastal regions. Also given that the population density in the coastal regions is increasing in an alarming rate and more industries and enterprises are being created in these regions, we choose to look for a potential wind energy site for the installation of a small wind farm along the coast.

Next we have applied the Weibull statistics to estimate and compare the wind power densities, average wind speeds, most probable wind speeds and wind speed carrying maximum energy of three different locations in three different coastal regions to select the best site with sufficient wind speed (Arreyndip et al., 2016). When the best site is selected, next step is to select an appropriate wind turbine with wind speed characteristics capable of fully functioning on the chosen site and finally given the energy needs of the consumer, a wind farm is constructed to satisfy these energy needs.

To construct a wind farm, wind turbines layout within the farm is a very crucial step towards harvesting higher energy from the farm as wrong positioning leads to maximizing the wake effect and minimizing power capture. The problem of wake (which is a low wind field created by a wind turbine that is sometimes

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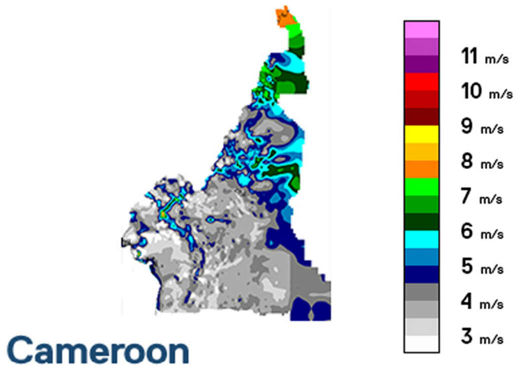

Fig. 1. Wind resource map of Cameroon showing distribution of wind speed over the territory (Anon, 2014).

experienced by another wind turbine downstream) elimination in a large wind farm with clusters of large wind turbines still remains a challenge (Wang et al., 2016b; Kusiak and Song, 2010; Song et al., 2013). But this challenge can equally be eliminated by the constructing stand-alone wind turbines farm that will definitely take an incredible land space. Hence given that we are constrained in a particular land surface area, researchers have developed and simulated complex wake models to solve the wake problem (Wang et al., 2016b; Kusiak and Song, 2010; Song et al., 2013). They have shown that an efficient wind farm design can be carried out through optimization of wind farm layout and also carrying out some control strategies (Wang et al., 2016b; Kusiak and Song, 2010; Song et al., 2013). Which can go a long way to minimize the wake effect by cutting down power loses due to turbulence and maximize the wind farm output power.

Here, we will limit ourselves to simple analytic wake models without going deeply into Computational Fluid Dynamics (CFD) simulation since we do not have access to the software. More complex wake models have been developed like the Ainslie-based models, the parabolic Navier–Stokes (N–S) equation and the complete 3D (N–S) models (Wang et al., 2016b). Researchers who have already developed and studied different analytic models for wind farm layout optimization are; Longyan et al. applied and compared the effectiveness of three different analytic wake models (PARK, Larsen and B–P model) for wind farm with variable and constant hub heights. One of their result is that, when using PARK model, the surface roughness value must be carefully tuned to achieve good performance in predicting the wind farm power production (Wang et al., 2016b). Kusiac and Song also applied the PARK model for the purpose of maximizing output power from a circular shape wind farm. Their complex nonlinear model was solved by the evolutionary strategy algorithm with the quality of the generated solutions acceptable for industrial applications (Kusiak and Song, 2010).

In this work, we will limit ourselves to the most popular and widely used wake model for wind farm layout optimization which is the PARK model and focus more on wind turbine sizing and the layout patterns with minimal wake effects. The remaining sections are organized and explained as follows. In Section 2, we will revisit the widely used Weibull model for wind energy assessment, the actuator disc concept and the PARK model. We will also make use of the wind rose which will help us in positioning wind turbines in the farm. Sizing and layout patterns over the selected site for maximum energy capture are also discussed. Wind power output will also ba calculated and compared using the different layout patterns. Section 3 is dedicated to discussing the results of our findings and we will end with a conclusion in Section 4.

2. Methods

We will start this section with a brief review of the widely used Weibull statistics for wind energy assessment in which we have already presented some results which are stated here-in in our previous work. We will also revisit the actuator disc concept and the PARK model which will help readers without a background in wind energy to know how and where some constants and parameters like the axial induction factor, power coefficient are derived and assigned values.

2.1. Weibull statistics

The Weibull distribution with probability density function, cumulative probability distribution and quantile distribution given by (Arreyndip et al., 2016; Fagbenle et al., 2011; Oyedepo et al., 2012; Kollu et al., 2012; Ozerdem and Turkeli, 2003; Carta et al., 2009; Montgomery and Runger, 2003; Akpinar and Akpinar, 2005; Arreyndip and Joseph, 2016):

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right], \tag{1}$$

$$F(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^{k}\right), \tag{2}$$

$$Q(v) = [-\log(1-v)]^{\frac{1}{k}}. \tag{3}$$

The mean value of the wind speed v_m and standard deviation ν is defined in terms of the Weibull parameter k and c are given as (Arreyndip et al., 2016; Fagbenle et al., 2011):

$$v_m = c\Gamma\left(1+\frac{1}{k}\right), \tag{4}$$

where $\Gamma()$ is the gamma function. and

$$\nu = \sqrt{c^2\left[\Gamma\left(1+\frac{2}{k}\right) - \left[\Gamma\left(1+\frac{1}{k}\right)\right]^2\right]}. \tag{5}$$

2.1.1. Mean power and energy densities

When assessing the wind energy potential of a site, there are two wind speeds that are of interest and must therefore be taken seriously into consideration. These are the most probable wind speed v_{mp} and the wind speed carrying maximum energy v_{Emax}. They are given by the expression (Oyedepo et al., 2012; Kollu et al., 2012):

$$v_{mp} = c\left(\frac{k-1}{k}\right)^{(1/k)}, \tag{6}$$

and

$$v_{Emax} = c\left(\frac{k+2}{k}\right)^{(1/k)}. \tag{7}$$

Theoretically, the mean power density is proportional to the cube of the mean velocity given by,

$$P_D = \frac{P(v_m)}{A} = \frac{1}{2}\rho v_m^3. \tag{8}$$

It can also be calculate from the Weibull probability density function given by,

$$P_D = \frac{P(v)}{A} = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right), \tag{9}$$

and the energy density is given by,

$$E_D = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) T. \tag{10}$$