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Economic cost evaluation on the viability of offshore wind turbine farms in Nigeria

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ABSTRACT

The paper presents an economic cost evaluation on the feasibility of offshore wind turbine (OWT) farms development in Nigeria, using a 500 MW OWT farm as an incident study. A developed model was used to evaluate the economic cost of the OWTs at different phases of the project. Additionally, the effect of the cost drivers at the changed phases of the OWTs was studied correspondingly. Results obtained showed that over 50% of the OWT project cost emanated from CAPEX while a value less than 50% came from OPEX. However, further analysis indicates at maximum power of 4 MW a 4.95% diminution in LCOE. For comparable power rating (PR) between $5 \leqslant PR \leqslant 6$ MW, a 2.7% reduction in LCOE exists. Cost stability was apparent at a growth of WTs between $300 \leqslant WT \leqslant 500$ MW. The study also observed a decrease in LCOE for all development stages of the OWT while a decrease in the CMS detectability was considered marginal. Subsequently, it can be inferred that Nigeria has the potential for OWT farm expansion. However, the demonstrated model was appropriate for handling preliminary variations in OWT studies.

1. Introduction

Over the past years, Nigeria had faced insufficient electricity supply due to poor infrastructure as well as inadequate gas supply to power generating turbines. The latter is culminated by youth restiveness especially in the regions where the power generating stations are domiciled. Furthermore, apart from these factors, the dwelling oil reserves and the environmental complications arising from fossil fuel utilization necessitates the need for greener energy development (Abam and Ohunakin, 2015). Additionally, onshore wind power in recent times is receiving wider acceptability as an alternative for fossil energy derivatives. For example, the Global Wind Energy Council (GWEC) in 2014 has projected a 3.4% annual increase with a cumulative increase of 14.9% and growth installed capacity of 47 GW. South Africa, Mexico, and Ethiopia all developing economies have projected an increase of 9 GW installed capacity by 2030, 2 GW by 2024 and 7 GW in 2030, respectively (GWEC, 2014; Pineda et al., 2014).

Moreover, development and application of offshore wind turbine farm appears to be increasing across the world particularly in the developed economies. In Europe, for instance the installed capacity of OWTs has grown rapidly in the last decade with an average annual growth of 50% (Pineda et al., 2014; Esteban et al., 2011; Green and Vasilakos, 2011). OWTs have great potentials and advantages over onshore wind turbines, these include high power rating, high yield energy, high offshore wind and unlimited space which make the installation of bigger OWT possible. Nonetheless, the drawback of the OWT technology is the additional cost that has to do with capital cost, operation and maintenance cost (O&M). The additional cost is associated with customized vessels, transmission system and weather (Bilgili et al., 2011; Dicorato et al., 2011; Madariaga et al., 2012). Likewise, OWTs farm or project development is technically and economically involving. For this reason, they require economic cost evaluation tools for adequate analysis. One of the most applicable tools, is the levelized cost of energy (LCOE) model. The LCOE relates the energy yield from the turbines with the generating cost. This measure takes care of the cost from the predevelopment phase to the decommissioning stage of the OWT project. By this, the key areas where cost can be reduced in the different phases of the OWT project are identified. Additionally, the investment decision-making process for a possible cost before purchase is made flexible (Madariaga et al., 2012). At present, Nigeria appears to be into the vortex of energy crisis, a situation that has generated economic disproportion and thus slowed industrialization (Abam and Ohunakin, 2015). Optimal energy utilization through a viable

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energy mix framework is opined as an effective measure to ensure energy security in Nigeria. The present study therefore aims at adopting the framework in Madariaga et al. (2012) to economically estimate the viability of all the associated OWT costs and its implementation in Nigeria. The key cost drivers for the application of the OWT technology will be identified. Moreover, the upshot from the study may constitute the basis for preliminary cost reduction to any agency, governments and organizations, who intend to adopt the OWT technology for development specifically in Nigeria

2. Methodology

The methodology adopted in this study includes the cost breakdown structural approach and the simple levelized cost of energy method (Bilgili et al., 2011; Gielen, 2012; Tegen et al., 2012). The latter is used in evaluating the life cycle cost (LCC) of each phase of the OWT farm project. The methodology for the economic cost evaluation was divided into five project stages which include: the predevelopment and consenting (P&C), production and acquisition (P&A), installation and commissioning (I&C), operation and maintenance (O&M), and decommissioning and disposal (D&D). The general expression for the economic viability cost (EC_v) of an OWT farm project is expressed in Eq. (1) (Green and Vasilakos, 2011; Bilgili et al., 2011).

$$EC_v = \sum \left(C_{P\&C}, C_{P\&A}, C_{I\&C}, C_{O\&M}, C_{D\&D}\right) \tag{1}$$

where C is the total cost per year while the present value and the levelized cost of energy (LCOE) are presented in Eqs. (2) and (3) (Gielen, 2012; Arwas et al., 2012).

$$\mathrm{Pv}\,(x) = \frac{x}{(1+d)^n} \tag{2}$$

$$\mathrm{LCOE} = \frac{\sum_n \frac{C_n}{(1+d)^n}}{\sum_n \frac{E_n}{(1+d)^n}} \tag{3}$$

where d is the discount rate, and n is the year the revenue or cost takes place

2.1. Predevelopment and consenting

It takes about five years to develop any OWT project afore the time of installation. During this period, a lot of paperwork including, the cost implications, and legal framework are established to certify the feasibility of the OWT project. The cost segment entails: the cost of managing the project C_{pm}; the legal authorization process cost C_{leg}; the cost of surveys carried out C_{sur}; the cost of engineering activities C_{eng}; as well as the contingencies cost, C_{com}. The component cost are defined in Eq. (4) (Dicorato et al., 2011; Castro-Santos and Diaz-Casas, 2014; Offshore Design Engineering Ltd., 2007).

$$C_{P\&C} = \sum \left(C_{pm}, C_{leg}, C_{sur}, C_{eng}, C_{con}\right) \tag{4}$$

where C_{pm} is assumed to be 3% of the total capital expenditure.

The cost of surveys to be conducted and installation capacity of the OWT is given by Eqs. (5) and (6) (Bjerkseter and Agotnes, 2013; BVG Associates, 2010; Kaiser and Snyder, 2012)

$$C_{\mathrm{sur}} = \mathrm{IC}\left[\sum \left(C_{\mathrm{sur}_e}, C_{\mathrm{sur}_c}, C_{\mathrm{sur}_s}\right)\right] + C_{\mathrm{sur}_m} \tag{5}$$

$$\mathrm{IC} = \mathrm{PR}\left[\sum_{i=1}^{n} N_{\mathrm{WTi}}\right] \tag{6}$$

where C_{sur_e}, C_{sur_c}, C_{sur_s} and C_{sur_m} are the environmental, coastal processes, sea bed, and met-ocean survey costs while N_{WTi} is the network produced by the offshore wind turbines and PR is the power rating of OWT in the wind farm.

Eq. (7) expresses the cost of engineering activity which include the material selection and structural design of the OWT project.

$$C_{eng} = \sum \left(C_{eng_m}, C_{eng_v}\right) \tag{7}$$

where C_{eng_v} represents the cost associated with the critical verification by a third party and C_{eng_m} represents the main engineering activities cost dependent on the OWT project size (Bjerkseter and Agotnes, 2013; Maples et al., 2013). The C_{eng_v} is a linear function of the installation capacity and it can be expressed as in Eq. (8) (Garrad Hassan, 2013; Tavner, 2013)

$$C_{eng_m} = \left[\sum \left(C_{base}, C_{eng_l}\right)\right] \times (IC - 108) \tag{8}$$

where C_{base} is the independent base cost, set at a base case of 108 MW offshore wind farm (Offshore Design Engineering Ltd., 2007).

2.2. Procurement and acquisition

Wind turbine generator (WTG), the support structure/foundation, the power transmission system (PTS) and the monitoring systems are the key components of the OWTs. Therefore, the costs associated with these components makes up the cost for the procurement and acquisition stage. This cost is expressed in Eq. (9). Their detailed expressions are contained in Dicorato et al. (2011), Gielen (2012), BVG Associates (2010), Kaiser and Snyder (2012), Maples et al. (2013), Garrad Hassan (2013) and Tavner (2013).

$$C_{P\&A} = \sum \left(C_{WT}, C_f, C_{PTS}, C_{mon}\right) \tag{9}$$

where

C_{WT} = procurement cost of the OWT sub-assemblies

C_f = procurement cost of the support structure/foundation

C_{PTS} = procurement cost of the electrical power transmission systems

C_{mon} = procurement cost of the systems used to monitor the OWT farm .

2.3. Installation and commissioning

This stage has to do with all the allied installation works of the OWT beginning from the time the procured components are delivered to the commissioning of the OWT. The cost associated with the installation and commissioning stage is expressed as:

$$C_{I\&C} = \sum \left(C_{I\&Cport}, C_{comp}, C_{com}, C_{I\&Cins}\right) \tag{10}$$

where:

$C_{I\&Cport}$ = the cost incurred in the port,

C_{comp} = the component installation cost,

C_{com} = the cost of commissioning the OWTs and electrical system

$C_{I\&Cins}$ = the cost of construction insurance.