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Offshore wind energy storage concept for cost-of-rated-power savings

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HIGHLIGHTS

- Investigated CAES + HPT system concept for offshore wind energy;
- Validated cost model for offshore wind farm including CAPEX and OPEX items;
- Quantified cost-of-rated-power savings associated with CAES + HPT concept;
- Estimated savings of 21.6% with CAES + HPT for a sample $2.92 billion project.

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ABSTRACT

The size and number of off-shore wind turbines over the next decade is expected to rapidly increase due to the high wind energy potential and the ability of such farms to provide utility-scale energy. In this future, inexpensive and efficient on-site wind energy storage can be critical to address short-time (hourly) mismatches between wind supply and energy demand. This study investigates a compressed air energy storage (CAES) and hydraulic power transmission (HPT) system concept. To assess cost impact, the NREL Cost and Scaling Model was modified to improve accuracy and robustness for offshore wind farms with large turbines. Special attention was paid to the support structure, installation, electrical interface and connections, land leasing, and operations and maintenance cost items as well as specific increased/reduced costs reductions associated with CAES + HPT systems. This cost model was validated and applied to a sample $2.92 billion project Virginia Offshore case It was found that adaption of CAES + HPT can lead to a substantial savings of 21.6% of this 20-year lifetime cost by dramatically reducing capital and operating cost of the generator and power transmission components. However, there are several additional variables that can impact the off-shore energy policy and planning for this new CAES + HPT concept. Furthermore, these cost-savings are only first-order estimates based on linear mass-cost relationships, and thus detailed engineering and economic analysis are recommended.

1. Introduction

The DOE projected US wind energy ramp-up by 2030 is expected to lead to large offshore turbines, as these systems can capture higher wind speeds aloft and provide utility-scale energy. A recent study predicts a sustained growth in wind generation in the United States to 35% of end-use demand by 2050 [1,2]. However, fabrication and assembly of such wind turbines presents a host of issues. For example, a 5 MW turbine with a conventional rotor design and a tower-mounted electric generator requires: (1) hoisting and mounting 70 m long blades which weigh 50,000 kg (more than a 50 tons), (2) requires hoisting and mounting a 5 MW electric generator at 100 meters in height. These requirements may yield to increased costs that can substantially reduce much of the cost-of-energy savings for large-scale systems.

In 2013, Virginia Electric and Power Company (d.b.a. Dominion Virginia Power) leased an offshore section of land off the coast of Southeast Virginia with an aim to develop this land into an offshore wind farm resource. This parcel of land is situated in 30–50 m water depths, roughly 27 miles east off the coast of Virginia Beach, VA, with an area of 112,799 acres. At this site, reliable wind speeds and the necessary space for an offshore wind farm project are readily available [3]. Furthermore, neither the visibility nor noise of a wind farm should concern residents on the coast. In offshore wind farm installations such as the one proposed here, studies suggest that large-scale wind turbines be installed instead of many small-scale equivalents. Due to economics of scale, the cost per megawatt of wind turbine energy decreases with an increase in wind turbine capacity thanks to the shrinking, fractional costs

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Nomenclature

AEP	annual energy production (kW∗h)
COE	cost of electricity (2015$/kW∗h)
C	cost (2015$)
d	distance from shore (km)
K	capacity factor
L	expected lifetime of project (yr)
M	mass (kg)
N	number of turbines in a farm
P_r	rated power (kW)
R	mass reduction factor

Subscripts

CAES + HPT	CAES + HPT system item
CAPEX	CAPEX item
conv	variable associated with a conventional farm
E	electrical interface and connections item
G	generator item
gearbox	gearbox item
I	installation item
leasing	land leasing item
O&M	operations and maintenance item
OPEX	OPEX costs
support	support structure item
T	tower item
transport	transportation to shore item

associated with offshore substructures, installation, operation and maintenance, and electrical infrastructure [4]. However, these costly requirements can be potentially eliminated with systems involving two new technologies [5–7]: hydraulic power transmission (HPT) and compressed air energy storage (CAES).

The HPT technology employs a lightweight and highly-compact hydraulic pump in the nacelle at the top of the tower which extracts the wind power and delivers it to the wind platform base at sea level, as shown in Fig. 2 with comparison to a conventional technology shown in Fig. 1. The extra energy can be stored as compressed air inside the tower. When re-generating the power, the compressed air expands through the CAES system and the stored energy gets back. Herein, the tower is employed as a pressure vessel to store the compressed air, previous analysis based on cross-over pressure for the design limit indicates that this concept can provide considerable energy storage capability, but the influence of pressurization on the tower stresses needs to be further determined [7]. This CAES/HPT technology reduces head mass, eliminates the need for a gearbox, and likely simplifies maintenance. The CAES also has low capital cost per kWh among many energy storage technologies [8] and it is suitable to wind energy storage applications [9]. Additionally, the whole system can be combined with a CAES system prior to electricity generation in order to reduce peak energy transmission and associated costs without limiting the total energy produced [10–12]. Although the installation of a HPT and a CAES system would result in additional capital expenditures (CAPEX), the use of both would beneficially result in a decrease or completely eliminate costs associated with the gearbox, the generator, and larger head masses, as well as allowing for the use of cheaper, lower-capacity electrical cables. Due to these changes, the operating expenditures (OPEX) can potentially be reduced. It is the goal of this present study to determine whether the combination of both increased and decreased costs associated with CAES + HPT is beneficial or detrimental to a proposed off-shore wind farm located at the Dominion lease site.

There have been several previous studies to develop a cost model applicable to offshore wind turbines. Chief among offshore wind farm cost models is the NREL Cost and Scaling Model [13] developed in 2006. The NREL Cost and Scaling Model is designed for a wind farm with a very specific setup. That is, a 500 MW wind farm utilizing 167, 3-MW turbines with a rotor diameter of 90 m, a hub height of 80 m, spaced on a 7 rotor diameter by 7 rotor diameter grid placed in 10 m depths roughly 5 miles from shore. Therefore, this model requires adaption to consider turbines that are

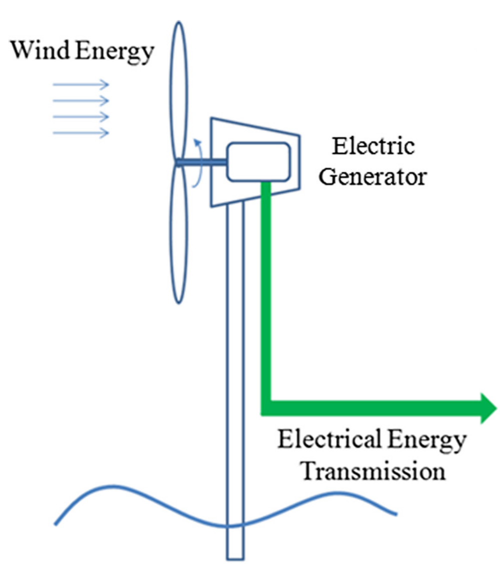

Fig. 1. Conventional wind turbine system architecture with a generator located on top of the tower in a nacelle.

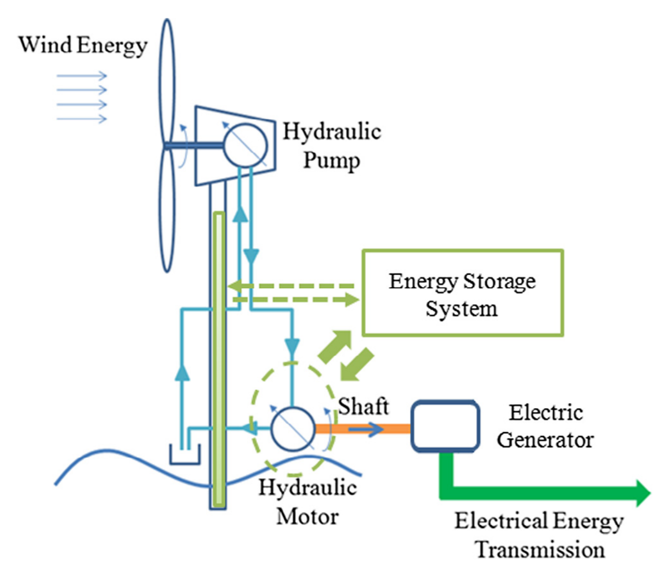

Fig. 2. HPT + CAES wind turbine system architecture with a hydraulic pump in the nacelle at the top of the tower allowing a motor and the generator to be located on a platform much closer to sea level (for improved acceability for installation and maintence).