Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 9 (2023) 284–289
www.elsevier.com/locate/egyr

7th International Conference on Renewable Energy and Conservation, ICREC 2022 November 18–20, 2022, Paris, France

Digital twin-driven energy modeling of Hywind Tampen floating wind farm

Muhammad Talal Qaiser, Jasim Ejaz, Ottar Osen, Agus Hasan*

Department of ICT and Natural Sciences, Norwegian University of Science and Technology, Ålesund 6009, Norway

Received 15 August 2023; accepted 3 September 2023
Available online 11 September 2023

Abstract

This paper presents energy modeling of Hywind Tampen floating wind farm based on digital twin technology. Upon its completion, the Hywind Tampen wind farm is the largest floating wind farm in the World and the first floating wind farm to supply electricity for oil and gas fields. The wind farm is located about 140 km off the Norwegian coast with water depth between 260 and 300 m and consists of eleven wind turbines with a capacity of 8.6 MW each. Together with ten gas turbines, it will supply electricity for two oil and gas fields at the Norwegian Continental Shelf (NCS), namely the Gullfaks field with three platforms and the Snorre field with two platforms. In this paper, digital twins of the wind turbines and the oil platforms are created in Unity 3D. Energy from the wind farm is modeled from the first principle and is calculated using inputs from the historic weather data all year round. Simulation results show the wind farm can supply up to one-third of the total electricity needed by the oil and gas platforms almost constantly, which associated with reduction of 200,000 tonnes of CO2 emissions and 1000 tonnes of NOx emissions annually.

Peer-review under responsibility of the scientific committee of the 7th International Conference on Renewable Energy and Conservation.

Keywords: Digital twin; Wind farm; Renewable energy

1. Introduction

Hywind Tampen is a floating wind farm intended to provide clean energy solutions for the Snorre and the Gullfaks oil fields at the Norwegian Continental Shelf (NCS). The farm is located about 140 km off the Norwegian coast with water depth between 260 and 300 m. The two oil fields are consisting of five oil platforms: Snorre A, Snorre B, Gullfaks A, Gullfaks B, and Gullfaks C. Currently, all rigs are powered by gas turbines [1]. They are expensive to operate and are the main source of significant amount of carbon and nitrogen emissions. The floating wind farm consists of eleven floating wind turbines supplied by Siemens Gamesa with a combined capacity of 94.6 MW (8.6 MW each) and is planned to provide about one-third of the total energy needed by the oil fields. The

* Corresponding author.
E-mail address: agus.hasan@ntnu.no (A. Hasan).

https://doi.org/10.1016/j.egyr.2023.09.023

Peer-review under responsibility of the scientific committee of the 7th International Conference on Renewable Energy and Conservation.

clean energy provided by the Hywind Tampen will help to reduce up to 200,000 tonnes of CO2 emissions and 1000 tonnes of NOx emissions annually. The idea behind the Hywind Tampen development is to run in parallel with the gas turbines to deliver a constant supply of electricity for the oil and gas platforms, as can be seen from Fig. 1. Furthermore, the wind farm will be used as a laboratory for development of future floating wind turbine design. The wind farm is scheduled to start its operation in the third quarter of 2022 and upon its completion is the largest floating wind farm in the world.

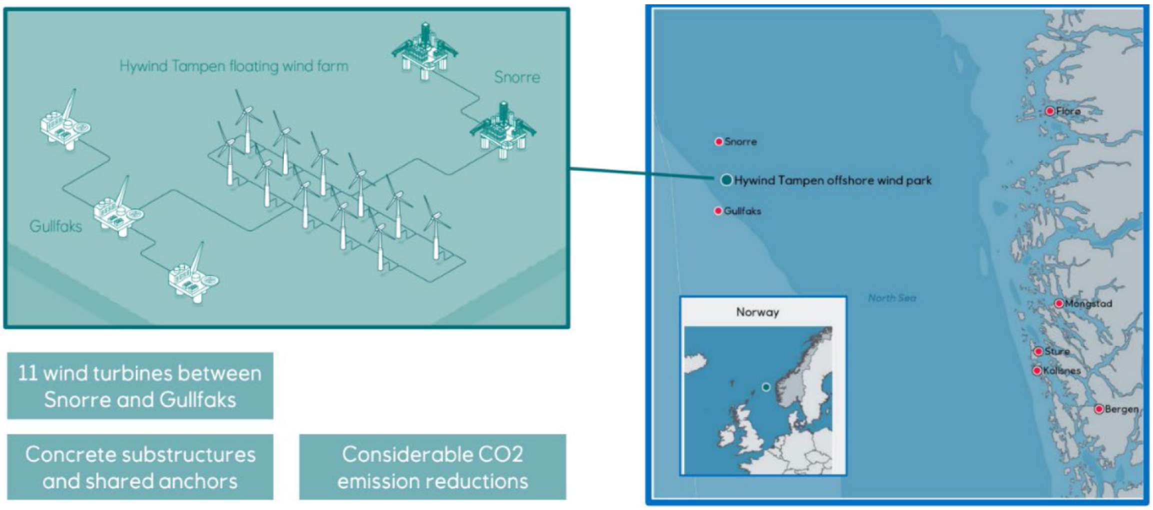

Fig. 1. Illustration of Hywind Tampen wind farm.
Source: Courtesy of Equinor ASA.

Since the energy output from the wind farm is heavily dependent on the weather conditions, there is an incentive to model the energy system and to simulate the wind farm based on the historic data of the weather at the Tampen area. To model and simulate the energy system and to incorporate the weather data, in this paper we propose a simulation environment based on digital twin technology. Digital twin is one of the fastest growing technological trends in Industry 4.0. It enables the industries to monitor the assets in real-time, predict their remaining lifetime, and even to test and validate the assets without having built them. This emerging technology has made it easy to research and test other technologies with minimum effort and cost to get maximum efficiency out of it. Thus, the objective of this paper is to utilize digital twin technology to model, simulate, and evaluate the energy system of the Hywind Tampen wind farm, for which the result can be used by the operator to develop the farm in a more optimal manner.

The contributions of this paper are threefold. First, development of a digital twin platform based on Unity 3D to model and simulate the energy system of the Hywind Tampen floating wind farm. Second, integration of the historic weather data to simulate real-world scenarios in the digital twin platform. Third, estimation of the electrical energy produced from each wind turbine.

2. Wind turbine energy modeling

A wind turbine normally consists of a turbine rotor, which can be controlled such that it always facing the wind direction, a nacelle, blades, and a tower. When air passing through the blades, it forces the blades to rotate. This mechanical rotation is then connected to a gear train using a low-speed shaft. The gearbox is used to convert the low rotation of the rotor to high-speed rotation in the generator using a high-speed shaft. The generator in turn converts this mechanical energy into electrical energy. The total energy output of a wind turbine is dependent of the wind speed, wind direction, and the size of the blade. Longer blade produces higher output. The longest wind turbine blade diameter as of 2022 is 222 m, designed by Siemens Gamesa [2]. This colossal turbine can produce up to 15 MW with power booster.

It has been known that the available power in the wind can be calculated as [3]

$$P_w = \frac{1}{2}\rho A v^3 \tag{1}$$

where ρ is the air density, A is the swept area of the blades, and v is the mean wind speed over a time period. Not all available power can be converted into electrical energy since there are various aerodynamic losses, for example due to the wake rotation, blade-root, and blade-tip. The power efficiency of the wind turbine can be expressed by the power coefficient, and is given as the ratio between the captured mechanical power to the available power as follows

$$C_p = \frac{P_{out}}{P_w} \tag{2}$$

According to Betz [4], the power output of the mechanical energy captured by the wind turbine blades is given by

$$P_{out} = \frac{1}{2}\rho A v^3 4a\,(1-a)^2 \tag{3}$$

where a is the axial induction factor. From Eqs. (2) and (3), we can conclude that the power efficiency is given by

$$C_p = 4a\,(1-a)^2 \tag{4}$$

From here, it is easy to see that the maximum power efficiency is obtained when $a = \frac{1}{3}$, which associated with $C_p = \frac{16}{27} \approx 59.3\%$. This is known as the Betz limit (or Lanchester-Betz limit). Indeed, Betz limit is the theoretically maximum efficiency that a wind turbine can achieve. The value was introduced by a German physicist Albert Betz in 1919.

3. Digital twin technology

A digital twin is a virtual representation of a physical asset to perform real-time modeling, simulations, and predictions for improved decision-making processes throughout its life cycle [5]. Digital twin monitors, controls, and optimizes these assets to enable itself for decision making. A digital twin is composed of three minimum components: modeling, simulation, and visualization. A virtual twin is created in a virtual environment to represent the physical assets. The next step is to make a predictive twin. It predicts the behavior of the physical asset based on its physics or on some data-driven hybrid model in the virtual environment. We get the insights of operations from the prediction twin and these insights are integrated into processes using twin projection. Once the digital twin is fed with data, it can be used to perform simulations, study performance issues, and generate possible improvements.

The physical asset under study is outfitted with the data using different sensors. These sensors produce different measurements related to the performance of the system such as power output, temperature, weather conditions, and wind speed. This data is then processed and applied to the digital model. Using digital twins, engineers and researchers can have better design and operation of their systems. It enables more effective research with the abundance of data, which is more likely to have a similar effective performance outcome. It has a greater impact especially for large projects, where building a prototype just for experimentation is not feasible. Decisions become much easier even before large-scale manufacturing. Digital twins help us to mirror and monitor the performance of products even during production to achieve and maintain peak efficiencies.

3.1. modeling

Modeling is the representation of a body, asset, or process. It is used to simplify a real-world problem; such that relevant aspects can be analyzed. A model can be a representation of a physical asset, a mathematical model, or it can be an algorithm to replicate a phenomenon. For digital twin to work, a digital model is required to be like the actual physical asset. Physics can be applied to it such that it can replicate the actual behavior of the physical asset.

A digital twin can use any sort of model, provided it is a sufficiently accurate representation of the physical object whose model is to be replicated. To keep it computationally instantaneous and at acceptable level of accuracy, a digital twin can use models that are directly derived from the physics of the actual body. For instance, a digital twin of a wind farm contains several wind turbines, all generating electricity by showing the movement of blades. If we make a perfectly accurate model, then it would have a high computational cost, so we need to balance it out.

A general model of a digital twin should have three main features: (i) it should be sufficiently physics-based, such that by updating parameters, the model should reflect the changes being done, (ii) it should be accurate enough that changing the parameters will provide useful insights for the application, and (iii) it should be sufficiently fast such that the decisions can be made within the available period. In this paper, the energy generated by each turbine in the Hywind Tampen is modeled using Eq. (1). With a 167-meter rotor diameter, each turbine will have a swept area of 21,900 m2.

3.2. Simulation

Simulation is a process of imitating real processes or situations that can show different outcomes by experimenting with different scenarios. While the model represents key behavior and characteristics, simulation represents how the model will evolve and react to different conditions when applied to it. It mimics the operations of an already existing or a proposed system. Simulation can be applied to a variety of scenarios. There are different advantages that can be achieved through simulation. It includes less financial risk since experimentation is carried out on a computer model instead of an actual prototype. It can also be used for testing different theories and ideas against the same exact conditions without any deviations. To simulate the energy generated by the Hywind Tampen wind farm, we use a historical weather data from 1st January 2021 to 31st December 2021 obtained from a weather station at Gullfaks C.

3.3. Visualization

Previously, visualizing a CAD model in basic software with some tables or graphs was considered enough. There are many tools now that can provide realistic graphs and visuals which are very close to the actual objects available. Affordable options for Virtual Reality and Augmented Reality are also available to visualize models in a more comprehensive manner. The platform used for this project is based on Unity 3D. The platform was developed at the Norwegian University of Science and Technology (NTNU) and has been used for teaching and research. The platform architecture is presented in Fig. 2.

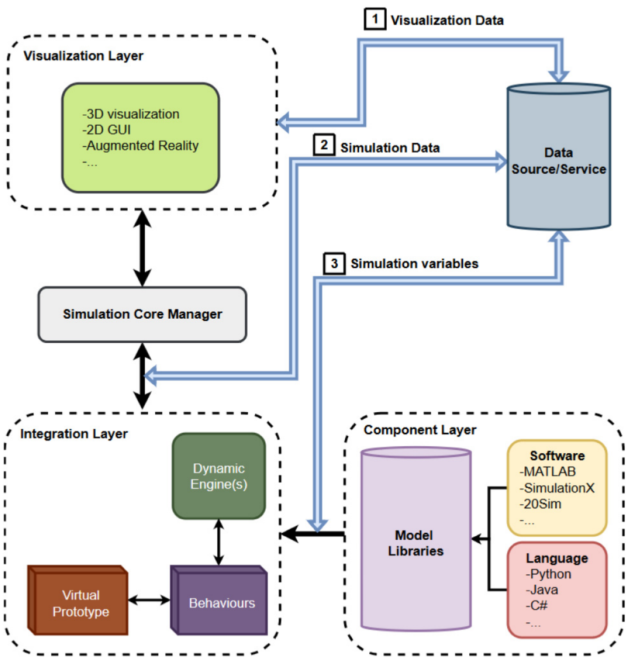

Fig. 2. Digital twin platform architecture developed at NTNU.

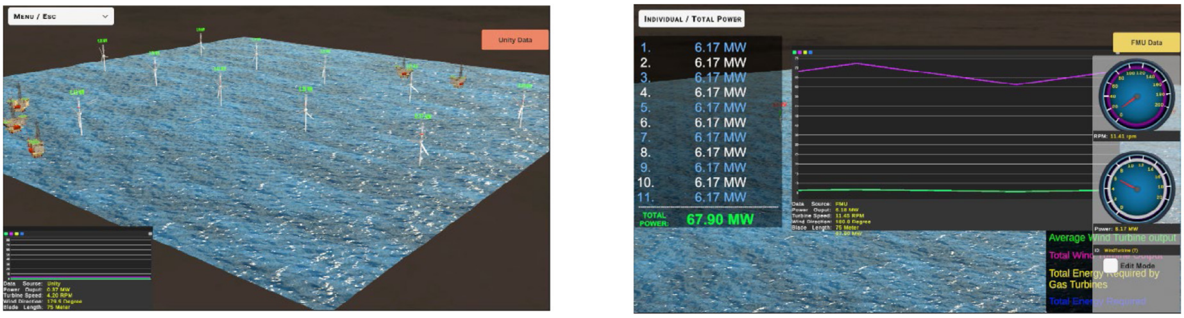

Fig. 3. Digital twin visualization interface.

The platform combines data-driven and model-driven architectures. To collect raw data from various sources, the platform uses a single database and a service management center. When the script variable is mapped to the data, it can be used to visualize the data directly (visualization data), simulate different scenarios (Simulation data), and exchange the data with the model (Simulation variables). With the simulation and visualization platform, it is more flexible to link the data to any object. The snapshoot of the digital twin visualization can be seen from Fig. 3. The left figure shows the configuration of the Hywind Tampen wind farm, while the right figure shows the information regarding the total energy output of the individual wind turbine.

4. Simulation study

A simulation study is conducted to show the feasibility of the Hywind Tampen floating wind farm to supply electricity for the five oil and gas platforms. The simulation uses weather station data located at the Gullfaks C oil platform. In this simulation, the wind speed and wind direction data are used as inputs for the digital twin. The digital twin calculates the energy production based on formulas provided in Section 2. Fig. 4 shows the energy production from the wind farm and its associated mean wind speed and temperature. It can be observed that the mean wind speed at the Gullfaks area is relatively stable. Higher speed typically happens during winter and spring. Furthermore, we assume the cut-in speed is 4 m/s and the cut-off speed is 15 m/s. These thresholds are applied to protect the turbines from damage. Thus, when the wind speed is lower that the cut-in speed, the turbine is not rotating, and the energy is zero. On the other hand, if the wind speed is above the cut-off speed, then the pitch control will be activated to maintain the energy level.

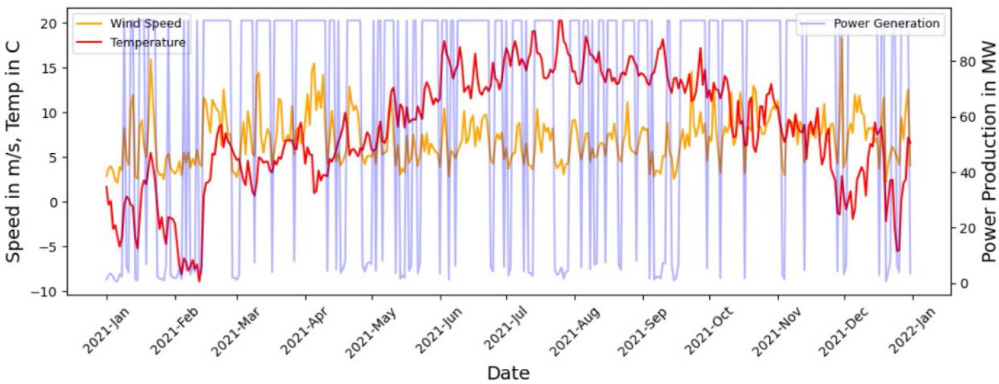

Fig. 4. Wind energy production from the Hywind Tampen.

Since every oil platform has two gas turbines, the total number of gas turbines is ten. The ten gas turbines are working together with the wind farm to ensure the amount of energy is always enough at any given time during the year. Fig. 5 shows how this can be achieved. If the wind speed is low, the gas turbines will be turned on to ensure the energy is sufficient.

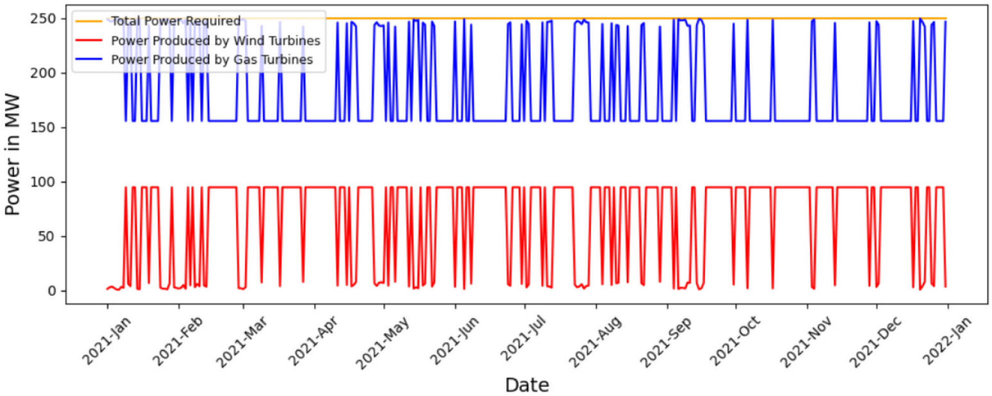

Fig. 5. Combination of energy produced by the wind and gas turbines.

5. Conclusion and future works

In this paper, a digital twin platform has been created and used to model and evaluate the energy system of the Hywind Tampen floating wind farm. Using historical weather data, we show that the wind farm is a reliable option to reduce the use of gas turbines, hence, reducing the emission. The main reason that the Hywind Tampen is feasible is because the stable supply of the wind in the Norwegian Continental Shelf. Future work could include development of high-fidelity wind turbine model including modeling of the floating structure dynamics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[1] Nysæther Jon. Experiences from hywind scotland and the way forward for floating offshore wind. In: EERA deepwind, Trondheim. 2019.
[2] Rolink Amadeus, et al. Methodology for the systematic design of conical plain bearings for use as main bearings in wind turbines. Forschung im Ingenieurwesen 2021;85:629–37.
[3] Tong Wei. Fundamental of wind energy. WIT Trans State Art Sci Eng 2010;44.
[4] Betz Albert. Das maximum der theoretisch möglichen ausnützung des windes durch windmotoren. Z das gesamteTurbinewesen 1920;307–9.
[5] Rasheed Adil, San Omer, Kvamsdal Trond. Digital twin: Values, challenges and enablers from a modeling perspective. IEEE Access 2020;8.