

**Title:** Cost of Energy for Wind Turbines with Different Drive Train Types

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**Introduction:** Drive train configurations differ in many of the modern MW scale wind turbines available. These differences occur from manufacturer to manufacturer and even within a single manufacturer's own portfolio. The wind energy industry aims to reduce the cost of energy (CoE) for offshore wind turbines to make it cost competitive with other forms of energy generation (gas, coal, onshore wind etc.) This paper aims to assist with that CoE reduction by modelling four wind turbine types with different drive trains to determine which turbine type offers the lowest CoE.

This analysis will be carried out based on data from modern multi MW on and offshore wind turbines combined with an offshore wind farm operational model created at the University of Strathclyde [1]. Empirical operational and cost data, provided by an industrial partner, will be used for two of the drive train types analysed in this paper. As the remaining two drive train types are technologies that currently have little or no installed capacity no empirical data is available. Consequently, the inputs required to model the CoE for these two drive train types will be simulated as described in the main body of this abstract.

This analysis and paper will provide a CoE comparison for all four turbine types located at a hypothetical wind farm 40km offshore. This will allow for conclusions to be drawn on which turbine type selected at a site located 40km offshore will provide the lowest CoE. The novelty in this work is in the process of combining rare operational and cost data from a unique on and offshore population with a new operational model to determine CoE figures for current and future drivetrain types.

As this paper focuses on four different drive train types the authors feel that it is best suited to the Turbine technology (drive trains and generators section) track at EWEA 2015.

**Approach:** The following approach was taken to complete this paper:

1. Offshore operational and cost data was obtained from industrial partners for on and offshore wind farms throughout Europe
2. Data was processed (cleaned and organised)

3. Data was adjusted to represent all 4 drivetrain types, as detailed in the following section
4. O&M costs were obtained for each drive train type using the Strathclyde operational model
5. Turbine costs, energy production and balance of plant costs were modelled and taken from past publications for each drive train type.
6. Conclusions were drawn on which turbine type offers the lowest CoE

**Main Body of Abstract:** The two most widespread drive train types found in modern wind turbines and two future drivetrain types are the focus of this study. The four configurations considered are the 3 stage doubly fed induction generator (DFIG) with a partially rated converter (PRC), the 3 stage permanent magnet generator (PMG) with a fully rated converter (FRC), the direct drive (DD) PMG with a FRC and the 2 stage PMG with a FRC. All four drive train types can be seen in Figure 1.

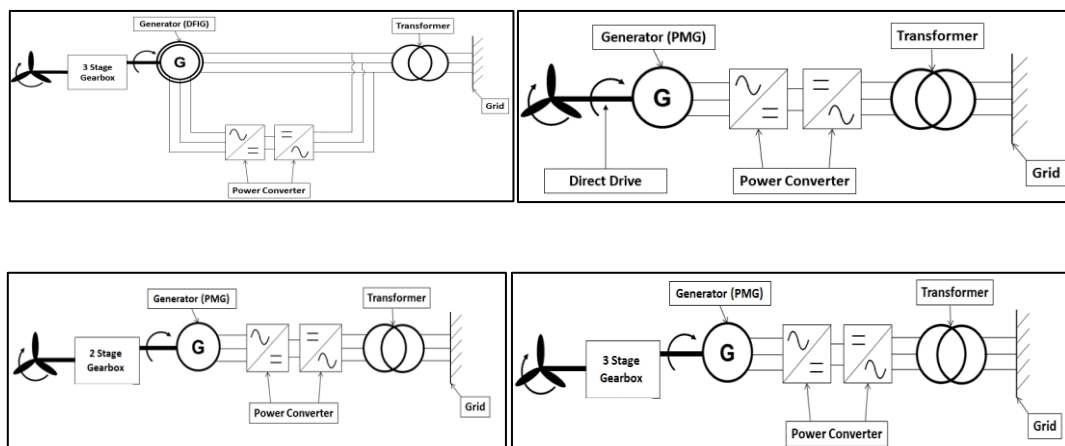


Figure 1: The four drive train types that are the focus of this paper.

The CoE was calculated using the following formula:

$$\text{CoE} = \frac{(\text{Capital Cost}) + (\text{Operating Cost}) + (\text{Cost of Capital})}{\text{Energy Production}} \quad (1)$$

For the 3 stage PMG FRC and 3 stage DFIG PRC empirical input data, the offshore operational model and balance of plant costs from [2] were used for all four variables of the CoE formula. The empirical data for the model inputs were obtained from two industrial partners who provided operational and cost data from a population consisting of over ~ 2650 modern multi MW on and offshore wind turbines. Exact population details cannot be provided for confidentiality reasons but it can be stated that all turbines in the population are between 2 and 4MW and have a rotor size of between 80 and

120m. For the DD PMG FRC and the 2 stage PMG FRC turbine types the CoE inputs were simulated as little of no operational or cost data exists for these turbine types. The capital cost and energy production inputs were obtained for these two turbine types by adjusting the 3 stage PMG operational data based on the cost of raw materials in a similar method to [3]. Cost of Capital and BoP costs were based on [2]. Operating costs were calculated by adjusting the empirical inputs from the 3 stage PMG to the operational model. These adjustments were carried out using a similar method to the adjustment methods in [4].

The results from two of the drive train types can be seen in Figure 2. The remaining drive train results will be shown in the completed paper. It can be seen that the DFIG turbine has an overall CoE of £105.57/MWh and the PMG turbine type has an overall CoE of £103.15/MWh.

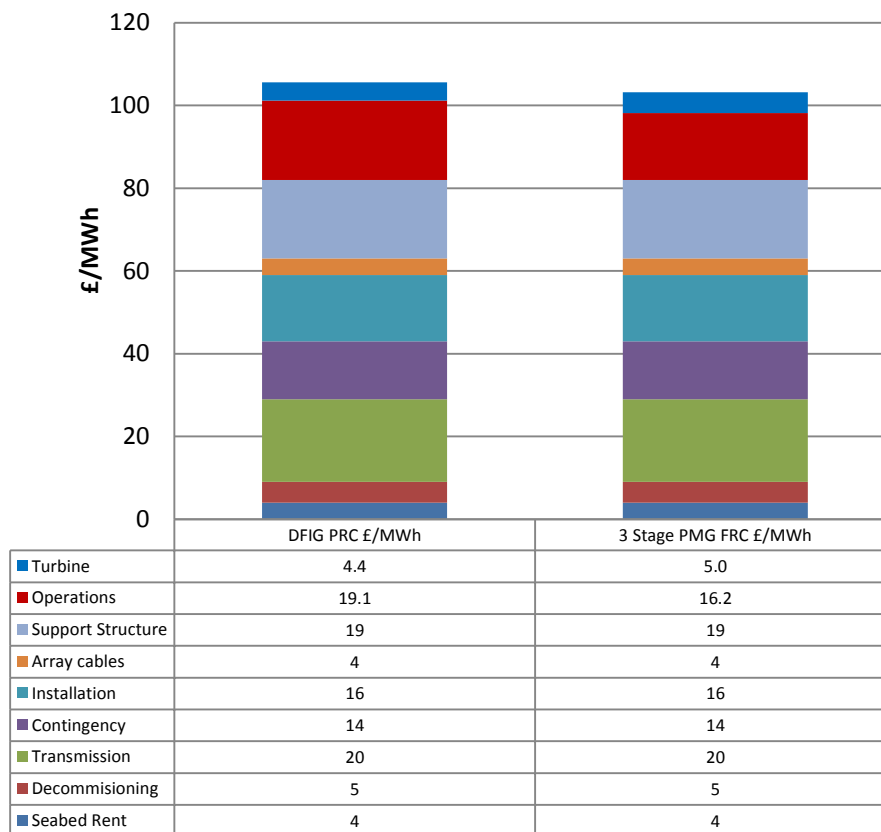


Figure 2: CoE comparison for 2 of the 4 turbine types.

**Conclusion:** As seen in Figure 2 it is assumed that certain parts of the capital expenditure, capital cost and operating cost remain the same for both turbine types as they are both located at sites 40km offshore. The cause of the £2.42/MWh difference in the two turbine types is the difference in turbine cost, O&M cost and energy production. Turbine cost and O&M cost figures in this analysis are based on operational and cost data from a manufacturer and O&M provider so the costs in Figure 2 do not include profit margins. If these profit margins were included it would lead to a higher

CoE for operators. As a means of putting the cost/MWh difference into perspective an average offshore wind farm can be used as an example. This offshore wind farm consists of 100 turbines, each producing 12,961 MWh [5] annually for a 20 year lifetime. This farm will see a cost difference of ~£65 million between the two turbine types, in favour of the PMG FRC over the lifetime of the wind farm. The paper will also provide further details and conclusions on the remaining two turbine types.

**Learning Objectives:** Following the reading of this paper the reader will be able to:

- See which turbine type provides the lowest CoE for an offshore site
- Determine if CoE savings are made on O&M costs or turbine costs for each turbine type
- Make better and more informed decisions on which turbine type to choose for offshore wind farms
- Understand the cost advantages and disadvantages of each turbine type

**References:**

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