MEECE – M0010

Demonstration of Enhanced Vortex Generators - AEP Assessment

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Document history

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A	07/12/2023	First release
B	03/01/2023	Inclusion of upgrade description and CFD analysis summary
C	29/01/2023	Final clarifications

Contents

1. Introduction

As part of the collaboration research project ‘Demonstration of vortex generators on 7MW wind turbine’ (the Project), funded under the Marine Energy Engineering Centre of Excellence (MEECE) Project, The Natural Power Consultants Limited (Natural Power) has performed a comparative performance assessment.

The assessment considers the power production performance of a small-scale turbine pre and post aerodynamic upgrades to quantify the benefit in order to validate CFD modelling and provide a methodology for assessment of upgrades for the 7MW turbine that will be instrumented within the scope of the Project. As part of this assessment, ten minute SCADA data and the long term ERA5 reanalysis dataset have been used to derive a long term wind resource profile and consider the impact of modelling assumptions and raw data corrections. The aerodynamic upgrades consist of Vortex Generators (VGs) and Gurney Flaps. It is noted the project focus, including CFD analysis considered only VG deployment.

2. Site and Data Description

Table 2.1: General site information

Item	Comment
Site location	The operational wind farm is located approximately 20 km south of Bath, UK.
Layout configuration	The layout consists of a single 850 kW Vestas V52 turbine with hub height of 40m. The base elevation of the turbine is approximately 180 m above sea level (ASL).
Terrain	The terrain of the surrounding area is undulating with some patches of forestry but is generally considered non-complex.
Neighbouring wind farms	There are no other operational wind farms in the vicinity.
Environmental and operational constraint	There were no environmental restrictions during the operational period however the turbine is restricted to 500 kW therefore comparison with the warranted power curve has not been performed
Nacelle mounted lidar	Pre-installation dates data before 2023-07-18 Post-installation dates data after 2023-07-20

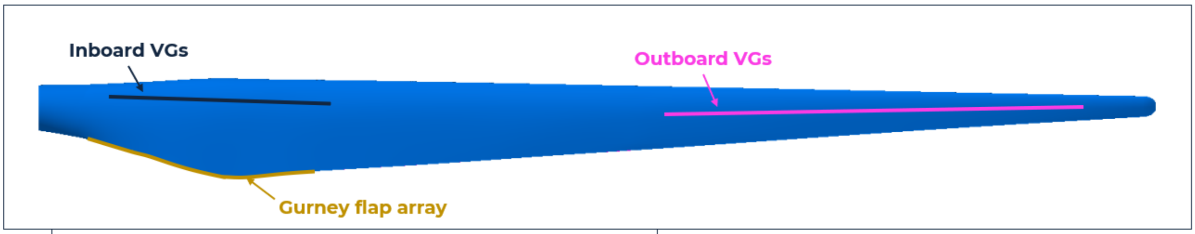
Table 2.2: Data used in analysis

Data	Period	Comments
10 Minute SCADA	01/03/2021 – 01/03/2023	Windspeed only
10 Minute SCADA combined with Nacelle Mounted Lidar	02/03/2023 – 23/08/2023	Inclusive of wind speed, active power, pitch angle, ambient temperature and turbine state. Lidar inclusive of wind speed, ‘confidence’, pressure, temperature and relative humidity
ERA5 (51.25, -2.5)	01/01/2000 – 01/09/2023	
CFD derived Lidar velocity correction values at different speed / distances	N/A	Provided for 4.5, 8 and 10 m/s for 8, 15, 29, 25, 50 and 100m distance

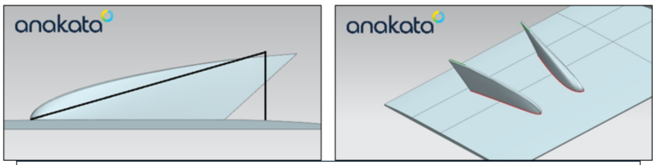
3. Upgrade pack and CFD analysis

3.1. Upgrade pack description

As part of the project, Anakata Wind Power Resources in collaboration with Swansea University and The National Technical University of Athens has defined an upgrade pack for the Vestas V52 Wind Turbine. This pack comprises of inboard and outboard Vortex Generators (VGs) and a bespoke Gurney Flap array. The pack has been developed using Blade Element Momentum (BEM) code, Computational Fluid Dynamics (CFD) Simulations and data from Wind Tunnel tests performed at the University of Swansea as part of the project. The VGs were designed, supplied, and positioned on the blade by Anakata following an Infra-Red (IR) audit and utilising data from CFD simulations. The designed upgrade pack was simulated in CFD and reviewed by the MEECE partners before install. Figure below shows an overall schematic of parts installed on the blades for the V52 turbine.



Layout of Anakata Aero-upgrade pack on the Vestas V52 blade



Anakata VG design and comparison with standard triangular VG

Figure 3.1: Anakata aero-upgrade pack overview

3.2. Numerical analysis

The flow on the turbine with and without VGs was modelled using an state-of-the-art Computational Fluid Dynamics (CFD) solver, MaPFlow [1]. MaPFlow has been extensively validated for the simulation of VG flows [2,3]. The numerical mesh consisted of 66 million cells and a detail is shown in Figure 3.2. top, shows an infrared thermography image from the field, highlighting the separated flow region near the blade root. The CFD results shown in Figure 3.2, middle agree very well with the field measurements. The surface streamlines for the case with VGs, Figure 3.2, bottom, show the successful suppression of the separated flow. The effect of VGs on the turbine performance is given in Figure 3.4. Based on these results and the site wind distribution the predicted AEP uplift for installing both inboard and outboard VGs is 4.3%.

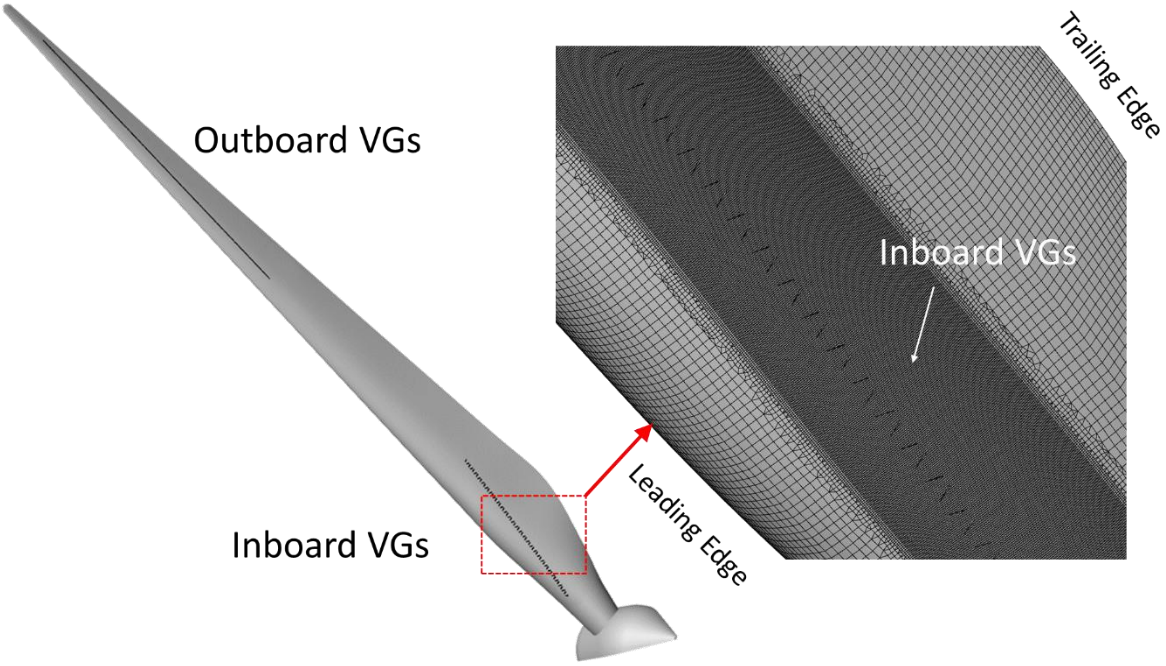


Figure 3.2: Detail of the computational mesh used in the present study.

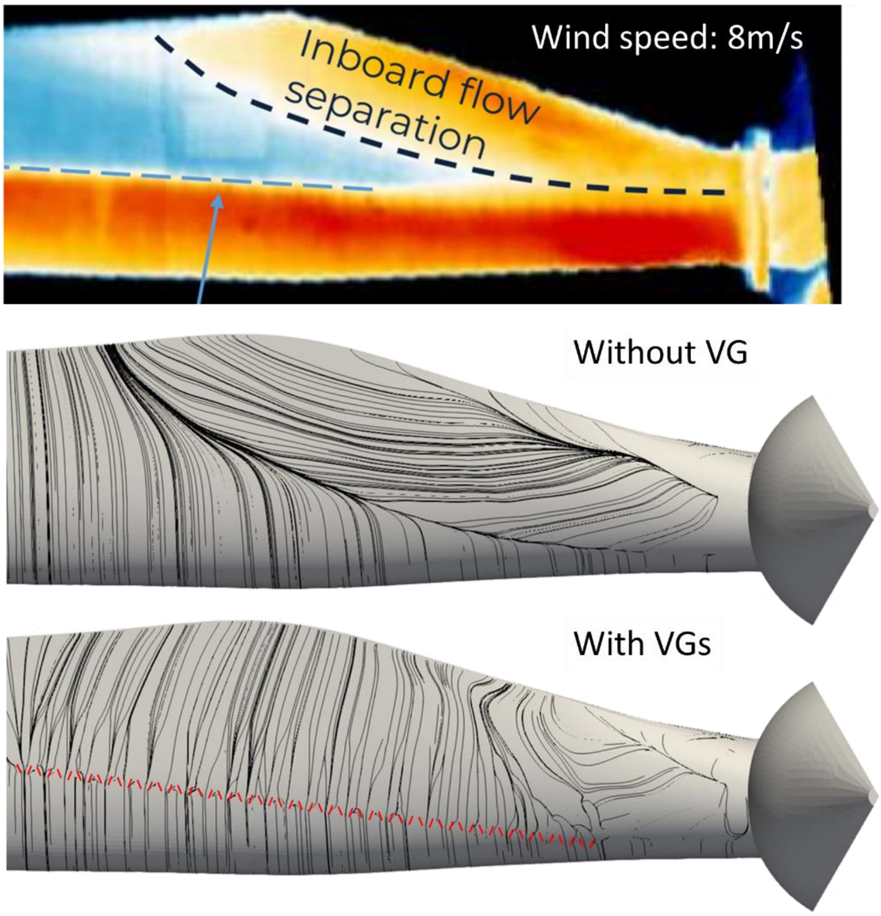


Figure 3.3:Top: Field measurements. Infrared thermography image highlighting the separated flow region for the turbine without VGs. Middle: CFD results for the turbine without VGs. Bottom: CFD results for the turbine with VGs. The separated flow is successfully suppressed.

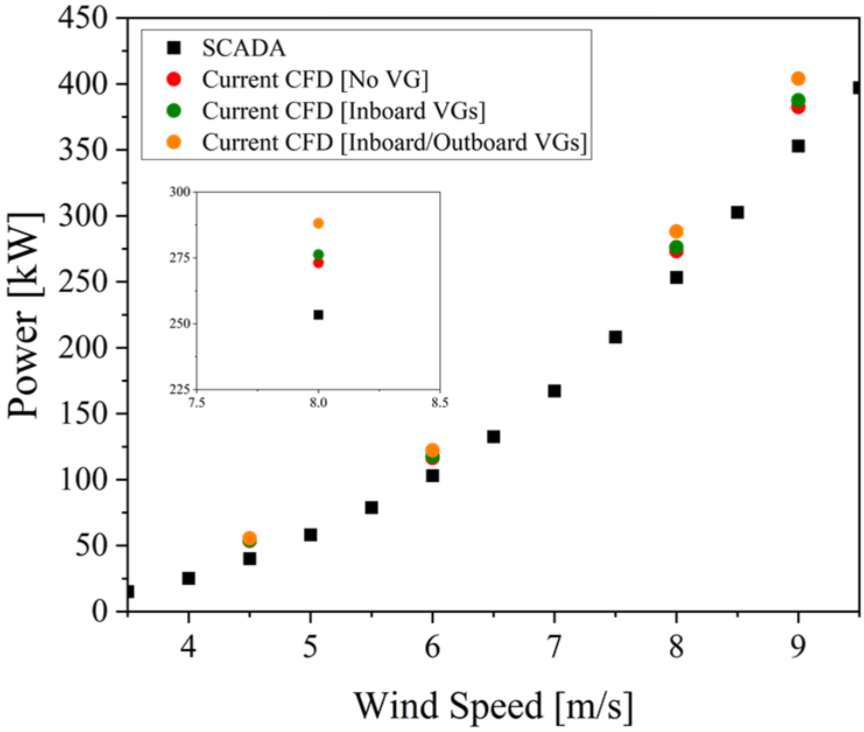


Figure 3.4: Effect of Vortex Generators on Turbine performance.

4. AEP Analysis

A high-level overview of the AEP analysis methodology is described below:

Raw Data cleaning and review

The provided data was reviewed to ensure it was as expected and basic filters were applied as follows.

- Turbine ‘state’ = 3
- Lidar ‘confidence’ > 99%
- Data flagged as ‘pre’ or ‘post’ installation based on dates in Table 2.1

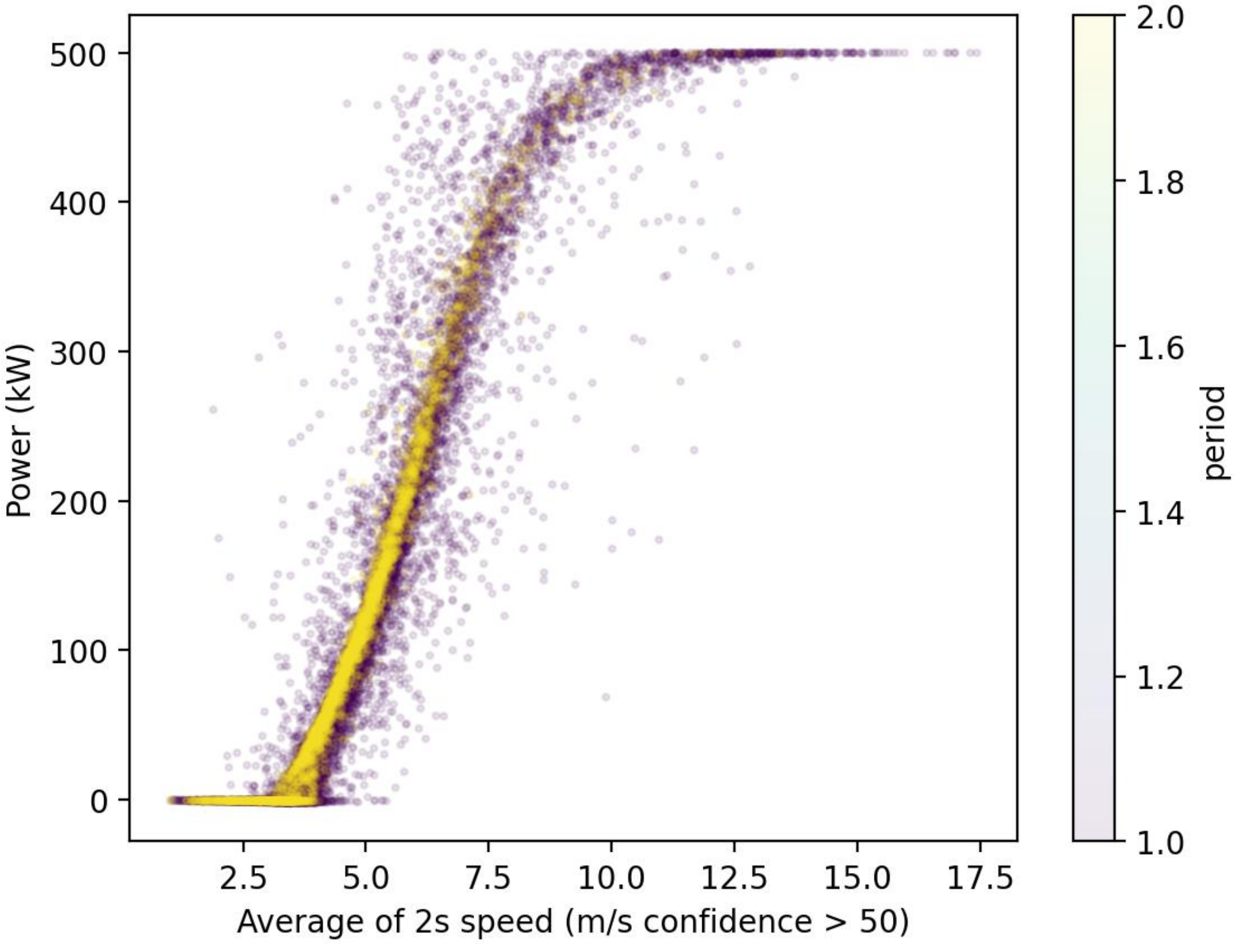


Figure 4.1: **Scatter plot of pre (1) and post (2) installation lidar wind speed vs active power**

Data correction

The Lidar data was initially corrected based on the CFD induction zone correction from the measurement distance (8m) to free stream velocity at 2.5 rotor diameters (100m):

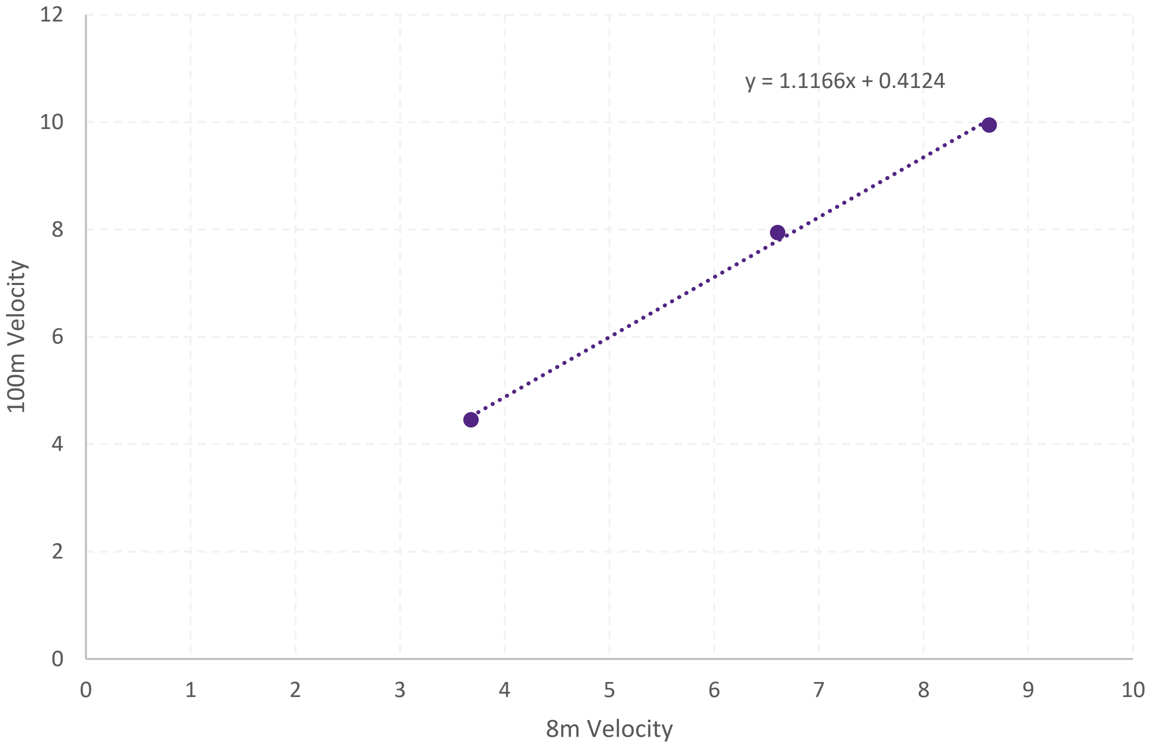


Figure 4.2: **Induction zone velocity deficit correction**

Further, a density correction was applied based on SCADA data and a density value derived from the long term reference dataset using the following equations.

Wind speed correction, where ρ_{design} has been assumed as 1.22 for the site / turbine warranted power curve:

$$U_{corrected} = U_{SCADA} * \left(\frac{\rho_{SCADA/Reference}}{\rho_{design}}\right)^{\frac{1}{3}}$$

Where density has been calculated using SCADA, the following equation has been used. Note, atmospheric pressure and temperature from the lidar has not been used directly as relevant IEC assessment methodology assumes only temperature is available in the turbine SCADA:

$$\rho_{SCADA} = 1.225\left[\frac{288.15}{T_{SCADA}}\right]\left[\frac{B}{1013.3}\right]$$

Where T_{SCADA} is temperature taken from SCADA and B has been assumed as 989.25 based on a nacelle height of 200m above sea level and lapse rate of 1.2 kPa / 100m.

The impact of induction zone and density correction were then considered visually to ensure no significant biasing or errors in the data were observed and this was observed to be consistent.

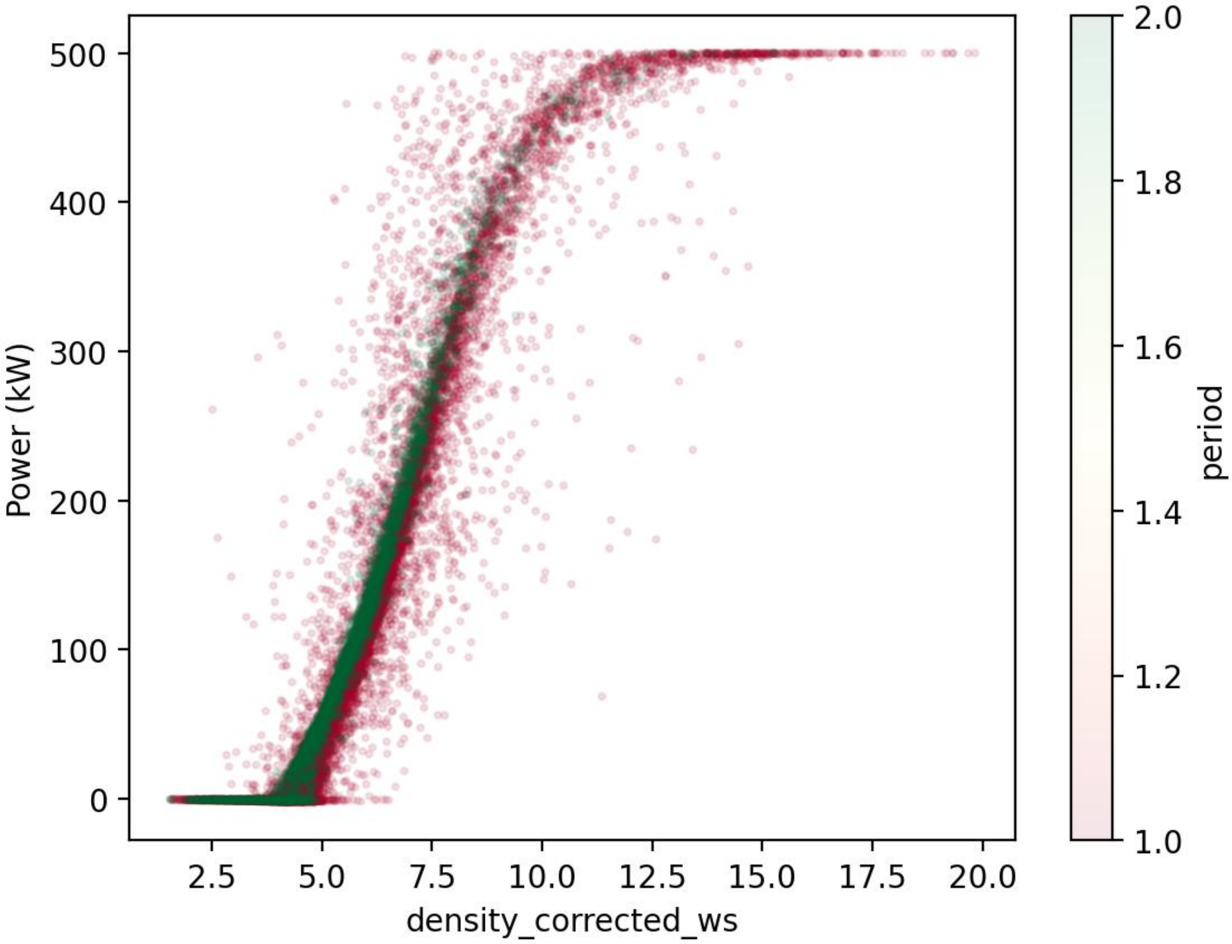


Figure 4.3: **Scatter plot of pre (1) and post (2) installation induction zone and density corrected lidar wind speed vs active power**

Operational power curve derivation

Operational power curves were then derived for the raw, induction zone only corrected data and fully density corrected values using each density approach by taking the average active power in each wind speed bin and wind direction sector for the pre and post installation periods. Example power curves are presented below. No significant sector wise variation was observed and therefore overall power curves were considered in order to maximise data coverage of each wind sector bin.

AEP assessment

Two long term wind speed distributions were derived. Firstly, by fitting a distribution to the longer period of SCADA wind speeds and secondly by considering the reference wind speed. The reference wind speed was scaled based on a scaling factor derived for the overlapping period of SCADA wind speeds such that the average of the long term wind speed for that period was equal to the average of the SCADA wind speed. The scaling factor was then applied to the long-term wind speeds and Weibull scale and shape parameters derived from this. A summary of the scaling factor and long-term wind parameters is presented in Table 4.1

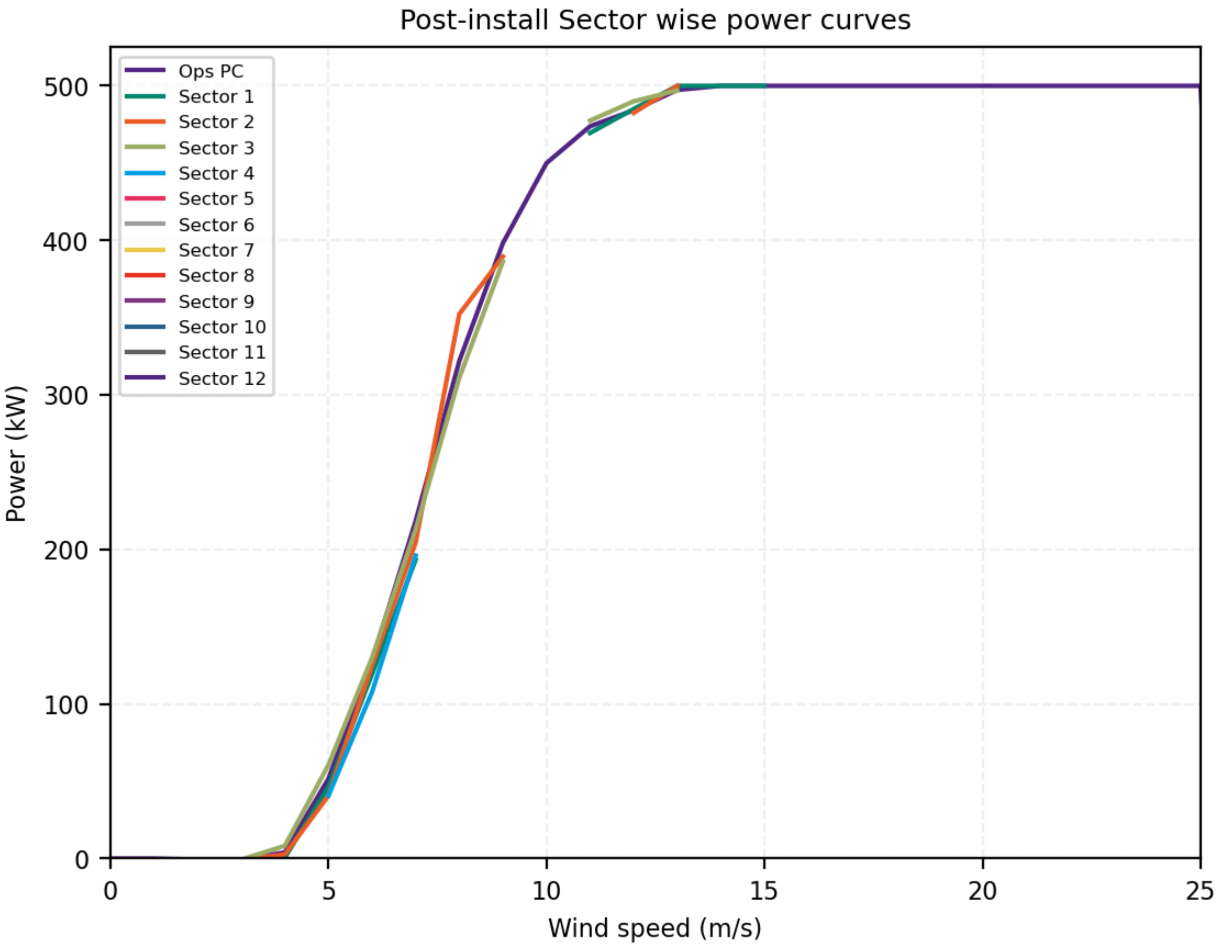


Figure 4.4: **Example power curves**

Table 4.1: Scaling and Weibull parameters

Variables	Values
Historic wind speed scale factor (m/s)	0.75
ERA5 Weibull Scale and Shape	5.90, 2.25
SCADA Weibull Scale and Shape	5.53, 1.55

5. Results and conclusions

The results are presented in Table 5.1. A figure illustrating the distributions and pre and post operational power curves is shown in Figure 5.1.

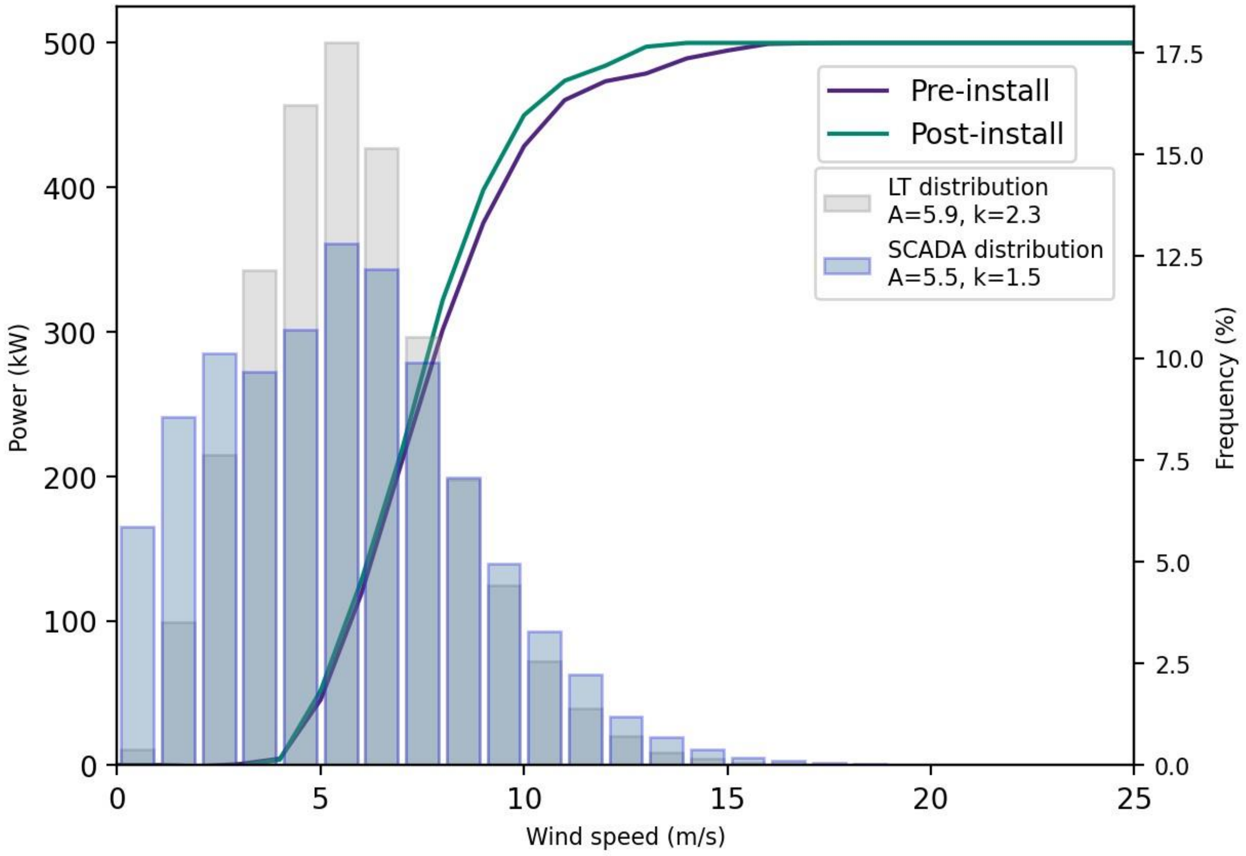


Figure 5.1: Operational power curve pre and post install and long term wind distributions

Table 5.1: AEP uplift for different inputs corrections.

	Long term reference AEP increase (%)	
Wind speed source	**SCADA**	**ERA5**
Lidar raw	3.42	3.59
Lidar induction corrected	3.51	3.70
Lidar induction and density corrected	5.32	5.77
Lidar induction with SCADA density correction	5.39	5.81

The AEP uplift ranges from 3.4 – 5.8% depending on the methodology adopted. A significant temperature gradient was observed between the pre and post installation operational periods and there is significant uncertainty in SCADA density / long term representativeness. Therefore, the most representative value for the AEP uplift associated with the upgrades has been determined as 5.77% with the alternative values considered as the minimum and maximum range for the results. The range is consistent with the numerical analysis which considered only the VGs and not the gurney flap which was also deployed on the turbine.

6. References

[1] Papadakis G, Voutsinas SG. In view of accelerating CFD simulations through coupling with vortex particle approximations. J Phys Conf Ser 2014;524:12126. https://doi.org/10.1088/1742-6596/524/1/012126.

[2] Manolesos M, Papadakis G, Voutsinas SG. Assessment of the CFD capabilities to predict aerodynamic flows in presence of VG arrays. J Phys Conf Ser 2014;524:012029. https://doi.org/10.1088/1742-6596/524/1/012029.

[3] Manolesos M, Papadakis G, Voutsinas SGG. Revisiting the assumptions and implementation details of the BAY model for vortex generator flows. Renew Energy 2020;146:1249–61. https://doi.org/10.1016/j.renene.2019.07.063.

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