CROSSWIND

Work package 4

List of Content

Project details

Project: CROSSWIND / CRoss-border Open-Source Small-WIND

Funding: INTERREG 5a

Project duration: 01.01.2021 – 31.12.2021

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Disclaimer

This work package started with a time delay due to the previous tasks. For that reason, the team shortened the tasks in work package 4 to finish it in time as agreed. Implementing the given geometry data of a wind turbine manufacturer afforded more time and effort than expected. Through the given data of the small wind turbine geometry, required data were missing and needed to be generated by its person in charge. So the report was finished with a time delay too. Final steps to verify this report did not take place. The final end of this report is publishing, but throughout the corona pandemic situation it wasn´t possible to do the finale verification. Additional the person in charge for verification, moved to the industrial sector of wind energy.

For those reasons, while the reader will study this report, it is to keep in mind that parts of the report are not verified or standing out.

INTERREG 5a Region

Germany	Danmark
Nordfriesland	Region Syddanmark
Flensburg	Region Sjælland
Schleswig-Flensburg	
Rendsburg-Eckernförde	
Kiel	
Plön	
Ostholstein	
Lübeck	
Neumünster	

Figure 1 - Map INTERREG Region 5a

Source: https://www.interreg5a.eu/en/

Work Package 4 – Case Study

The work package 4.0 aimed to accomplish the following targets:

- Select a commercial small wind turbine
- Model the selected wind turbine with an open-source tool
- Compare the results of the open-source tool with the results from a commercial software
- Discuss the suitability of the open-source tool to model the wind turbine

The work was then split into three sub work packages, 4.1, 4.2 and 4.3. Firstly, within work package 4.1, it was necessary to get in touch with different commercial wind turbine manufactures, evaluate the suitability of each wind turbine model and select a project partner which was willing to contribute with the CROSSWIND project.

Secondly, within work package 4.2, computational models of the selected wind turbine were built into the open-source aero-servo-elastic simulation program OpenFAST, created by the National Renewable Energy Laboratory (NREL), and the commercial aero-servo-elastic simulation program HAWC2, developed by the Technical University of Denmark (DTU). Lastly, the results obtained with OpenFAST were then compared with the ones from HAWC2 and some measure data from the wind turbine.

The following sections will go into the details of each sub work package.

Work Package 4.1 – Search for a Suitable Wind Turbine Manufacture Partner

Using the benchmark list created in Work Package 3.1, contact with different wind turbine manufactures was made. Different aspects, such as price, eagerness to collaborate with the CROSSWIND project, future cooperation and work perspective and accessibility were considered when deciding the suitable commercial partners.

One company was willing to share detailed data of their small wind turbine with the project und der terms of an NDA (non-disclosure agreement). Basic parameters of the *small wind turbine* can be seen in Table 1.

Table 1 - Basic parameters

Rated power	5,5 kW
Cut-in wind speed	3,5 m/s
Rated wind speed	13,5 m/s
Cut-out wind speed	25 m/s
Rotor rated speed	123,7 / 186 rpm
Number of blades	3
Rotor diameter	5,1 m
Generator	Asynchronous dual speed generator
Tower	17.6 m

Work Package 4.2 – Wind Turbine Computational Modelling

In this work package, computational models of the wind turbine *given small wind turbine* were built within the OpenFAST and HAWC2 environment. The following sections will discuss the implementation of the wind turbine model into the simulation software.

OpenFAST

OpenFAST is defined as a glue-code that put together different modules. Each module is responsible for the modelling of different aspects of the wind turbine and has its own required inputs. For this work the following modules were used: InflowWind module, to model the wind flow which the wind turbine is subjected; ElastoDyn module, to model the structural response of the wind turbine; AeroDyn module, to model the aerodynamic loads on the blades. ServoDyn module, to model the generator. The following sections will describe in more details what sort of inputs each module require.

InflowWind

The turbulent wind fields were generated using the program TurbSim, an open-source tool developed also by NREL. A set of 23 turbulent wind files, from 3 m/s to 25 m/s in 1 m/s steps, consistent to the IEC 61400-2 wind class I were generated. TurbSim creates a binary file which is then read by the InflowWind module.

AeroDyn

Within the AeroDyn module, information regarding the airfoil profile, blade properties such as chord distribution, airfoil profile's location, twist and so on are added. Environmental conditions such as air density, atmospheric pressure and air viscosity are also here implemented.

ElastoDyn

The ElastoDyn module requires information related to the wind turbine geometry, such as number of blades, hub radius, blade pre cone, tower height and so on; components masses and moment of inertias; structural properties of tower and blades, such as mass distribution, stiffness and so on; as well as information related to the drivetrain, such as gearbox ratio, drivetrain torsional stiffness and damping.

As mentioned before, ElastoDyn is the module responsible to determine the structural dynamics of the wind turbine. The approach used to calculate the deformation of the tower and blades relies on the mode shapes of each component, but, unfortunately, it is out of the module's capabilities to determine these structures mode shapes. Therefore, another tool developed by NREL, called BModes, a finite element code that provides dynamically coupled modes for a beam structure, is used to generate the mode shapes required by ElastoDyn.

ServoDyn

Within the ServoDyn module, the wind turbine generator was modelled as a "simple induction generator". To do so, ServoDyn requires the generator slip, synchronous speed and torque at rated speed and the generator pull-out ratio.

HAWCStab2

DTU HAWC2 [1] structural dynamics is modelled using multibody dynamics. The flexible bodies are modelled using a linear finite element formulation. The non-linear dynamics is achieved by splitting the flexible bodies, especially the blades, into multiple bodies allowing for large rotations. HAWCStab2 [2] was used to generate the power curve through an iterative process to obtain the steady-states solution.

The turbine blade sections structural properties such as radius of gyration, shear centre, moment of inertia and torsional stiffness were calculated using COMSOL [3] Beam Cross Section Interface tool assuming a full profile with constant elastic and torsional stiffness.

The airfoil lift and drag curves were generated using the software XFOIL [4] considering the Reynolds number at 0.75 blade radius at 11 m/s. The polar curve obtained was consistent with experimental values available in the literature [5]. The airfoil polar was extended for large angles of attack using the NREL AirfoilPrep [6] tool. A small set of CFD simulations was performed, but the XFOIL results were closer to the experimental results and were used.

Work Package 4.3 – Results Comparison and Discussion

The results from HAWCStab2 indicate a higher power output using the generator stage 1 up to wind speeds of 4.9 m/s, after which the power output utilizing the generator is greater up the cut-off wind speed as expected. However, the power difference between the two generator stages is very small, around 0.1 kW at 4 m/s, which indicates the use of two generator speeds increases the overall power output only marginally. The maximum power output predicted by HAWCStab2 happens at 14 m/s and with a value in good agreement with the turbine rated power indicated by the manufacturer. A comparison between power outputs predicted from HAWC2 using the blade structural properties calculated as described in the previous section and the and a stiff blade with the same geometry indicate very similar results up to speeds of 10 m/s, after which the effect of the blade flexibility reduces the power output. If in one hand the centrifugal forces act to reduce the cone angle, the lift forces counterbalance act to reduce the cone and to twist the blade in direction to reduce the blade sections angle of attack. A local minimum power output is predicted by HAWCStab2 at a wind speed of 22 m/s, after which it increases slightly.
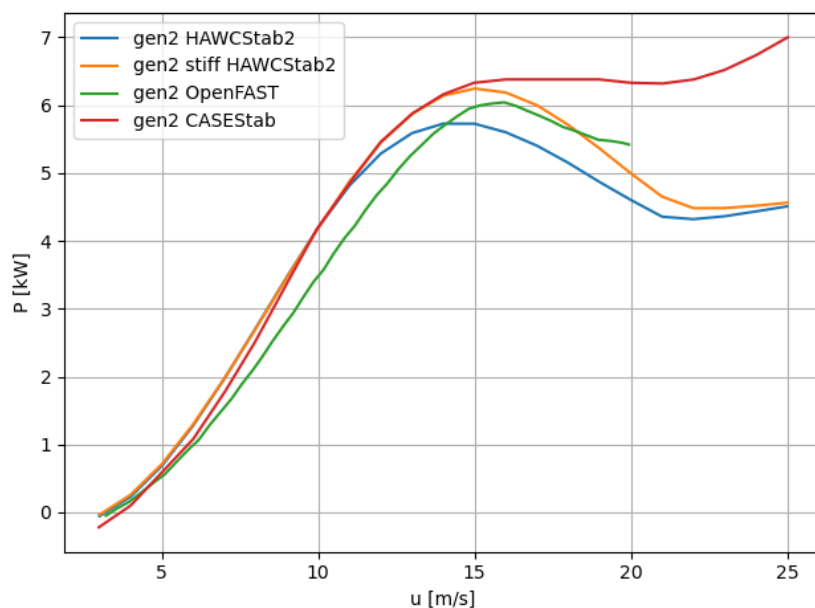
The results generated with OpenFAST indicate slightly lower power outputs - around 0.4 kW - up to wind speeds of 12 m/s, after with a higher power output is predicted by OpenFast. An important difference between the simulations in OpenFAST and HAWCStab2, is that the use of ElastoDyn in OpenFAST only includes four blade mode shapes, two flap-wise and two edgewise, but no torsional mode shape. The absence of a torsional mode shape indicates the effect of the lift force in twisting the blade and reducing the angle of attack would be absent in OpenFAST, which agrees with the power curve predicted by OpenFAST. Another difference is that OpenFAST predicts a local minimum in the power curve at lower

wind speeds, at 17 m/s against 22 m/s for HAWCStab2. This can be explained by higher angles of attack being predicted at lower wind speeds by OpenFAST. Finally, the results from CASEStab show a good agreement with HAWCStab2 up to 11 m/s. It must be noted that the blade section structural properties were approximated by of that of an ellipsis, which may explain the large stiffness.

Conclusion

The differences between the power curves predicted by HAWCStab2 and OpenFAST result from the linear reduced blade model used by ElastoDyn in OpenFAST which incorporates only two edgewise and two flapwise mode shapes. ElastoDyn doesn't include torsional mode shapes and, being a linear model, doesn't account for geometric nonlinearities.

However, in blade models where the torsional modes and geometric nonlinearities effects must be accounted for, the OpenFast structural module BeamDyn use should be considered. BeamDyn is based on geometrically exact beam theory and is designed to account for large displacements and rotations.

In order to achieve more accurate results with the OpenFAST simulation, in addition to the use of the structural module BeamDyn, further work can be done to improve the generator modelling, to include appropriate yaw bearing friction and drivetrain damping values. To perform the simulations for the CROSSWIND project, the generator was modelled as a "simple induction generator" within the ServoDyn module, which is a linear generator model, and thus doesn't capture the non-linearities of the induction generator during its non-linear stage. The presented simulation also considers an ideal yaw bearing, realistic yaw bearing friction values can be implemented with proper selection of the "nacelle-yaw spring and constant". Finally, OpenFAST considers one equivalent value for the whole drivetrain torsional damping value, while the wind turbine data sheet presents damping values for different portions of the drivetrain; further investigation in how this equivalent value should be calculated needs to be done in order to perform more accurate simulations, mainly when using highly turbulent wind fields.

The modelling of the Windstream5 within HAWCStab2, OpenFAST and CASEStab shares some similarities as well as some differences, as each aero-servo-elastic simulation program has its own specific methodology thus some variations of the simulation results are expected, but, of course, within an acceptable physical range. The report shows that the results generated with the opensource tool OpenFAST agree quite well to the ones generated with the state-of-the-art tool HAWC2, which indicates that OpenFAST can be a suitable tool to model small wind turbines.

Appendix A

CROSSWIND renewable energy calculator

An easy-to-use tool is under development to help users with making financial decisions regarding installation and use of wind turbines, solar panels and energy storage. The app analyses the economy of using renewable energies based on the location information, inputs from the user and the turbine/solar panel database. In the first panel, the user inputs

location information and by clicking on "Search" the app pulls environmental data out from the nearest weather station to the specified point as shown in Figure 2. Next, in the turbine tab, the user selects/defines the turbine as shown in Figure 3. If there is a solar system coupled to the system, the user can input the data in "Solar cells" tab. These data will be used for economy and battery size calculations.
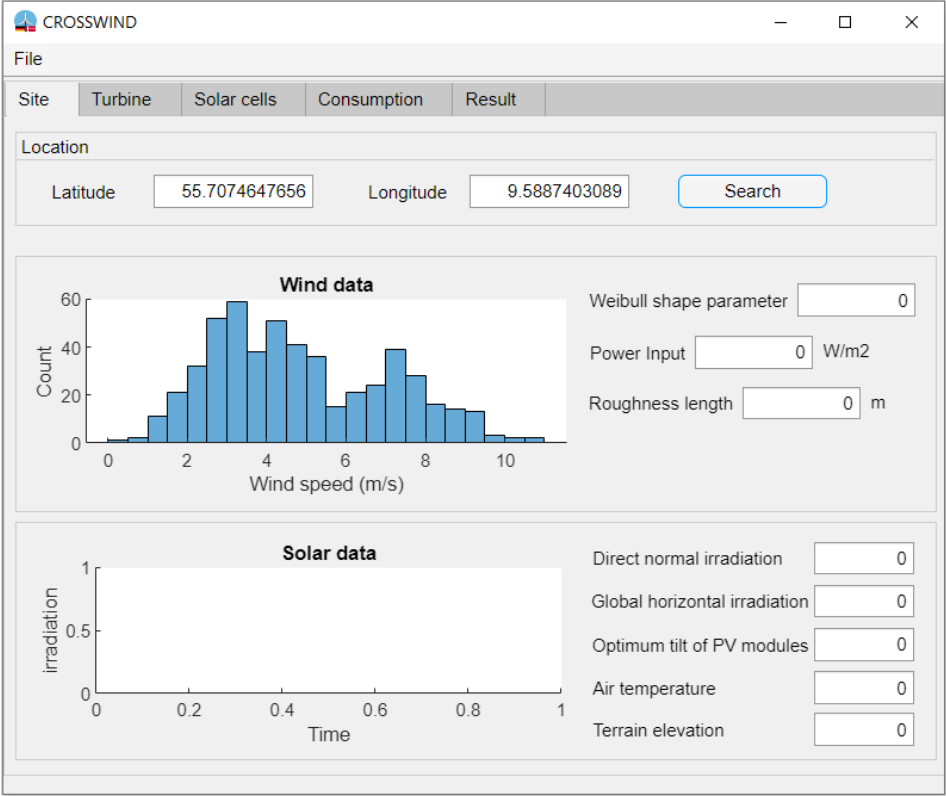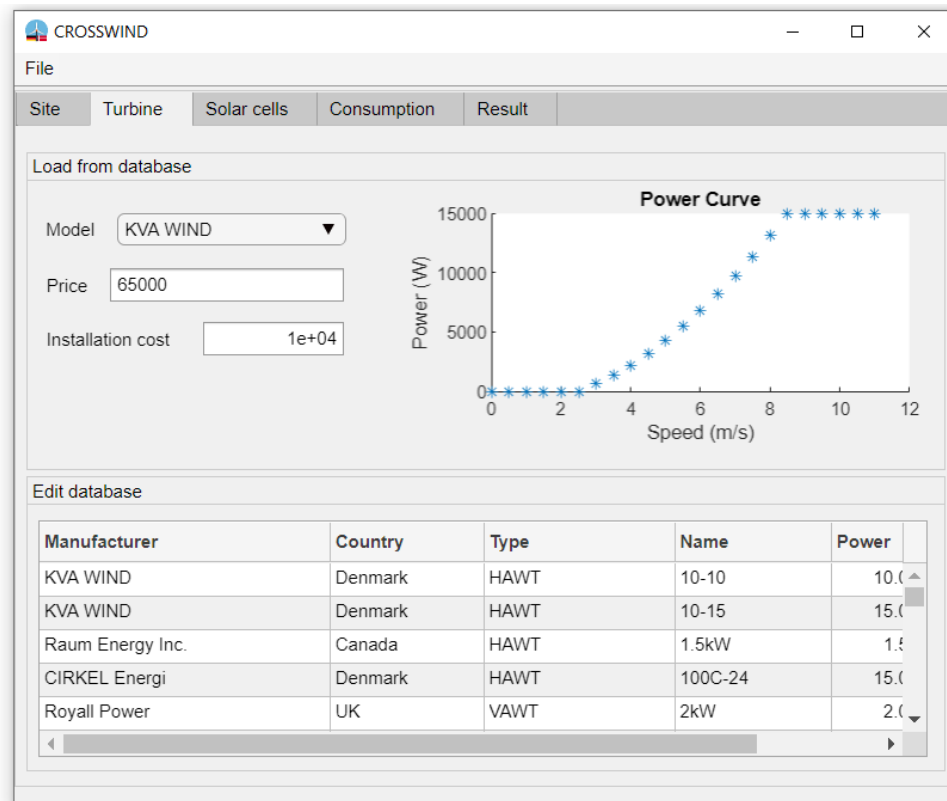

Figure 2: CROSSWIND app, site tab gathering environmental data

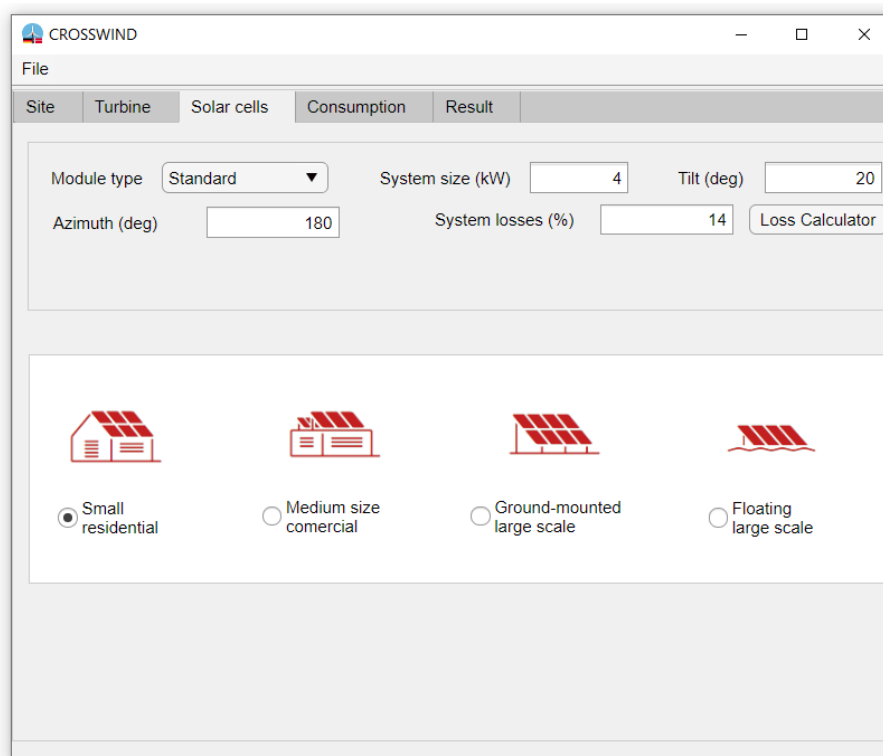*Figure 3: The user selects/defines a turbine.*

Figure 4: Solar panel information tab.

In the "Consumption" tab, the user should provide the total consumption in the household or add loads separately. Finally, after setting the electricity cost in the region, the user can see the analysis results in the "Result" tab.
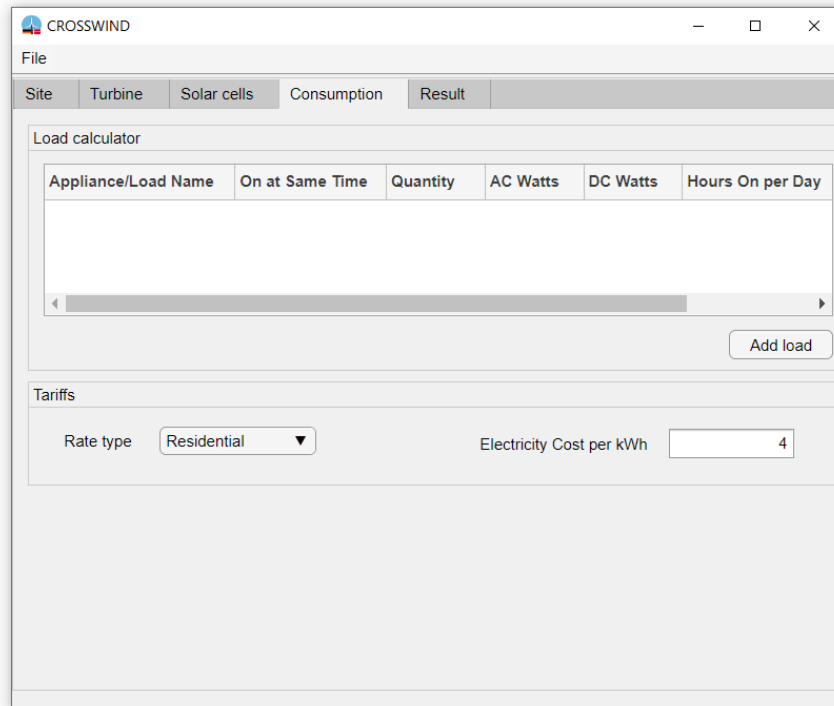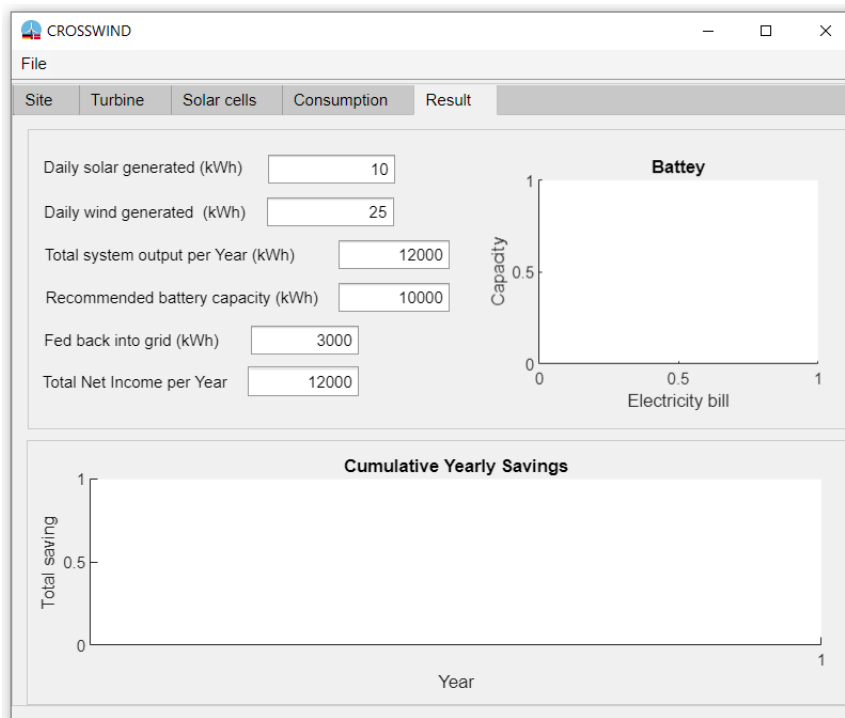
Figure 5: Consumption and tariffs set by the user.

Figure 6: The results of the analysis.

Project CROSSWIND
Work package 4
12

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