Research On Improving Energy Efficiency Through Small-Scale Wind Turbine Integrated Structures

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Abstract.

The purpose of this study is to evaluate the benefits of using renewable energy in tandem with conventional sources in order to improve energy efficiency. We did our research by modelling the performance of a small-scale wind turbine and computed the performance for a specific household. The residential house in the case study had its energy consumption measured for a six-year period and was averaged. The estimated power generated by the wind turbine in the local conditions was computed and the energy reduction was obtained. Our data implies that a wind turbine integration is advisable in a windy area.

Keywords: small-scale wind energy production, residential energy efficiency, small-scale renewables.

1. Introduction

Wind turbine technology is evolving both onshore and offshore with new, larger installed capacities and more efficient solutions being presented constantly. Competitive wind turbines with less subsidies have begun to be erected due to ongoing research in the field. Small-scale wind applications also benefit from this effort as the technology is similar and this paper studies the urban possibility of implementing small-scale wind turbines. The cityscapes contain both large groups of apartment buildings as well as houses.

The current research done on wind turbines revolves around the aerodynamics of blades (Hansen, 2015) and developing a full mathematical model of the turbine in order to take into considerations all aspects of the turbine while still in the design stage (Tony Burton, 2011) and (James Manwell, 2009). Blade shapes have evolved, and several optimization configurations and schema have been proposed (Sathyajith, 2006). The main obstacle became the computational cost of having such simulations run. This impossibility has led to partial analysis of the turbines (Thomas Corke, 2018). The research was at a point bidirectional with onshore and offshore wind turbines (Letcher, 2017).

Another suggestion was to try to develop designs with the whole wind farm in mind and not just the single turbine (K. Shaler, 2019). This would have led to even more computer strain, but the solution was to simplify until we only concentrate on what is more important and not the full analysis. Building of wind farms around the world has also created problems for locals in the vicinity of the farms. Reduce noise strategies have been developed and wind turbines have become quiet but for some exceptions (B. Arnold, 2018).

Most issues have been solved and the scope is to build bigger, with reduced costs and high performance (Jain, 2010). Small – scale wind turbines have also been of interest to research with the same problems but at a smaller scale then their industrial counterpart (Chiras, 2017).

In recent research and teaching the multidisciplinary aspect of the wind turbines give the more complex nature of the subject much needed simplification (Anderson, 2020). Simplifying gives chance to identify and solve the elementary problems that occur in wind turbine design (Robert L. Jaffe, 2018). While also giving rise to specialist solutions in creating knowledge of fundamental subject in relation to the given problem (Sørensen, 2016). Horizontal - axis wind turbines as well as vertical - axis wind turbines give related problems (B. Rocchioa, 2018) allowing research to be done on a multi - objective approach (Julio Xavier Vianna Neto, 2018) and (Jie Zhu, 2020).

In the following sections we investigate how implementing the latest technology affects the overall energy efficiency of residential homes. We start with the methodology description in section 2 than in Section 3 we consider the latest small-scale wind turbine equipment available and how it performs comparatively. In Section 4 we explore the energy consumption of a home on average and we try to set up a research scenario to apply to a whole neighbourhood of houses. Section 5 is for results and discussion and in Section 6 we give our conclusion.

2. Methodology and approach

First, we considered a case study of small-scale wind turbines. A group of 5 wind turbines was considered. We chose one and used its characteristics for our later calculations on efficiency improvements. A table of technical specifications was built based on the turbine brochures available online. After a discussion we established the best wind turbine solution out of the 5 analysed.

Then, the annual energy consumption of a house was considered. We took in a six-year long string of data measurements for the electrical energy and gas energy used during the year to accommodate the house and its inhabitants. The data was matched in kWh because at first it was in cubic meters and in kWh. An average was made, and the final plotted graph shows the annual energy consumption averaged on a monthly basis.

Furthermore, the research was done with a local approach on energy efficiency needs. Calculations were derived thinking about the local availability. All the research was done by case studies and computed results.

3. A comparative study of latest small-scale wind turbine equipment to implement in residential areas

In table 1 we considered 5 models of wind turbines. The rated power considered is 50kW as this is the biggest small wind turbines by the IEC61400-2 standard and we compared their performance. The first model is the Aeolos-H 50kW, the second is the Endurance E-3120 50kW, the third is the Tuge 50kW, the fourth is the EW50 and the fifth is the Eolo-H 50kW wind turbine. As seen in table 1 we can compare their performance characteristics based on the data extracted from technical specifications in their respective brochures.

When considering the generator typology there are different options. The Aeolos-H 50kW model uses a permanent magnet synchronous generator with a direct drive system. This eliminates the need for gearing. While this is beneficial because of often failure in the gearbox area it implies the need for more power electronics. The benefit of no gearing is that less maintenance must be done also. While the Endurance E-3120 50kW model comes with a gearing system it has the benefit of direct-grid-tie without additional power electronics. The other models come in similar configurations except for the Tuge 50kW which has 2 asynchronous generators.

The rated power is the same but the rotor diameter and speed at rated power varies between the models. The active wind speed is almost the same in all model cases studied. The rated wind speed is smaller for the first 2 models which makes them better candidates in case of sites with lower wind speeds.

The swept area is the same for the first and fifth model and it also happens to be the biggest swept area among the models considered. The survival wind speed is close to 50 m/s or above. The tallest tower configuration is offered for the Endurance E03120 50 kW model with a height of maximum 42 meters.

Table 1: Wind turbine models

	1	2	3	4	5
Model	Aeolos–H 50	E- 3120 50	Tuge 50	EW50	Eolo-H 50
Typology	PMSG	ASG	ASG	ASG	PMSG

Drive Type	Direct Drive	Gearbox	Gearbox	Gearbox	Direct Drive
Rated Power	50 kW				
Diameter [m]	18	19	16	16	18
Rated rotor [RPM]	55	42	52	60	60
Active wind [m/s]	2,5-25	3,5-25	3 -25	3-25	3-25
Rated wind [m/s]	9,5	9,5	11	10,5	10
Survival [m/s]	59,5	52	50	52,5	50
Swept area m^2	254,3	290	200	199,99	254,3
Tower	24/30/36	30/36/42	36	24/27	18/24/30

In table 1 above we can also see the range in which tower support is available. The heights range from as low as 18 m for the Eolo-H 50kW to 42 meters. The Aeolos-H 50kW ranges from 24 and up to 36 meters.

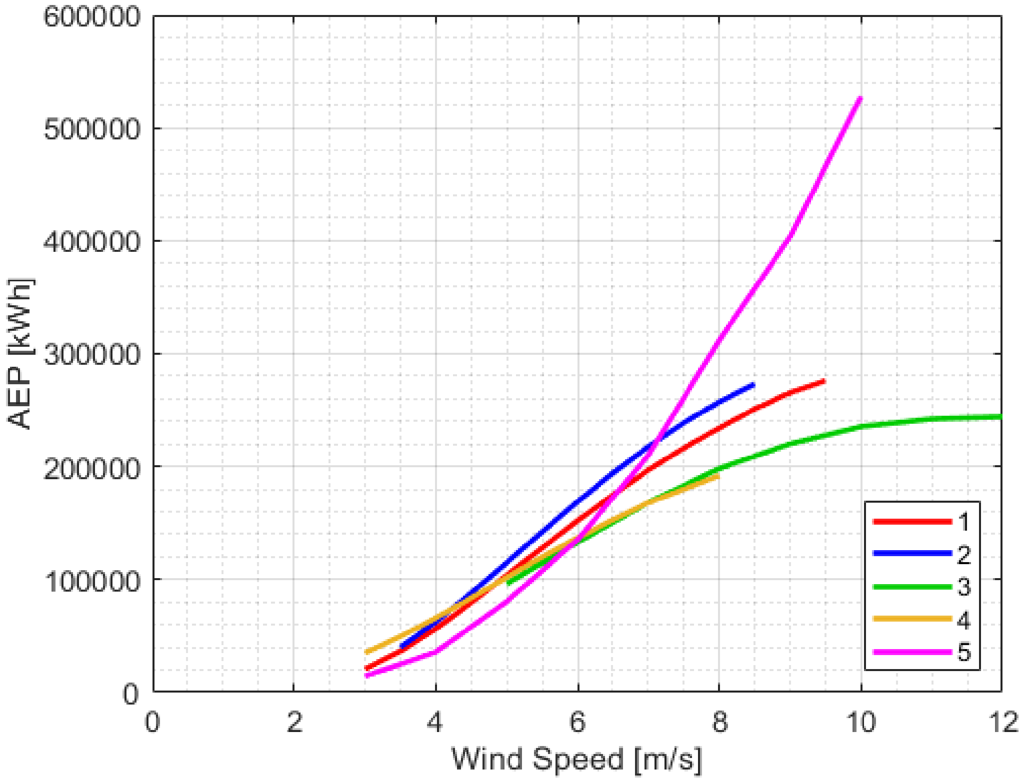

Figure 1 Annual Energy Production (AEP) for the models considered

In figure 1 we can find the Annual Energy Production (AEP) for the 5 wind turbine models considered in this study. On the X-axis we have the wind speed and on th Y-axis is the AEP. They are marked from 1 to 5 as referenced in table 1. The data is extracted from the datasheets available for the specific models online. Data was extracted from Aeolos-H 50kW datasheet Endurance E-3120 50kW datasheet, Tuge 50 datasheet, EW50 datasheet and Eolo H 50 datasheet.

Although the data extracted does not cover the entirety of the energy spectrum it can give an idea on how the wind turbines perform and compare from the annual energy production (AEP) point of view. In the low wind speed of under 6 m/s we find the leading model to be the Endurance E-3120 50kW model while at higher wind speeds of up to 10 m/s we see that the Eolo H 50 model has an advantage over the rest.

Because of the cut-in speed we do not see any production values for the 5 models that we included in the study. At 3 m/s, the wind turbines start to produce power and we can see that the EW50 leads with Aeolos and Eolo not far behind from a production point of view. At 4 m/s the Endurance model comes second place and at 5 m/s we have initial data for all 5 models. The Eolo produces the least and Endurance the most. At 6 m/s the production positions remain unchanged and at 7 m/s we can see a production tie between the Eolo and Endurance models.

We can compare all 5 models at the 8 m/s mark where data is available for all the models. The least performer is the EW50 and the best performance is reached by the Eolo H 50, with E3120, Aeolos, Tuge not far behind.

At the 9 m/s mark we can compare 3 of the models' performance and we can see in figure 1 that Eolo produces the most energy fallowed by Aeolos and Tuge. The other models have less data to work with.

We consider a performance comparison using the theoretical power and output power. The models all have specified power output at certain wind speeds and we can compare them to establish efficiency with the help of equation 1 below

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \cdot C_p \qquad (1)$$

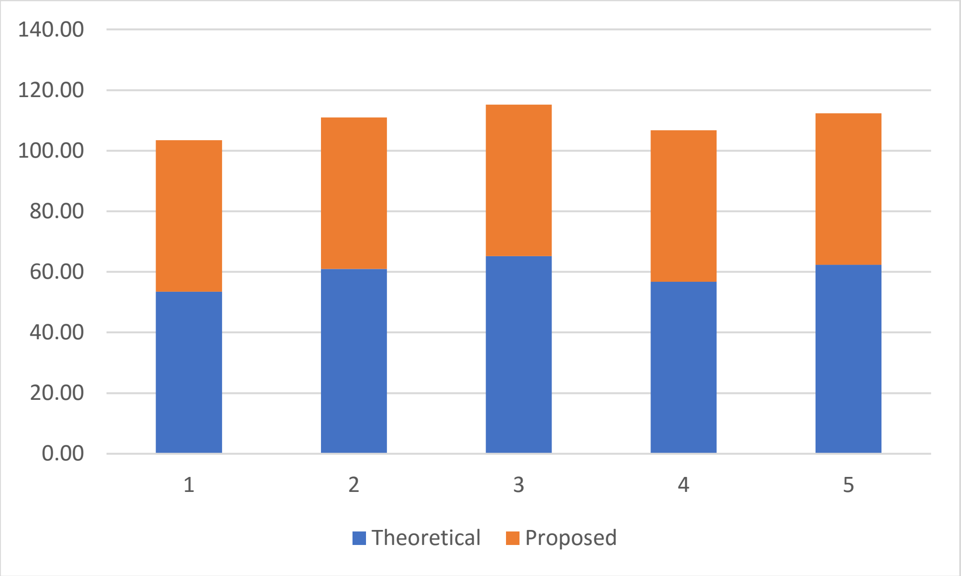

Figure 2 Proposed power output versus Theoretical power output for the 5 wind turbine models

In figure 2 above we considered the 5 models of wind turbines with their proposed power output and we computed the theoretical output at a considered power coefficient of $C_p = 0{,}4$ at their respective rated wind speeds and using their swept area to compute the efficiency in table 2 below with the help of equation 2 below.

$$\varepsilon = \frac{P_p}{T_p} \qquad (2)$$

Table 2: Efficiency of wind turbine models considered

Model	1	2	3	4	5
Efficiency	94%	82%	77%	88%	80%

In table 2 above we can see that the Aeolos model is closest to the theoretical power output with 94% followed by the EW50 model with 88%. The last 3 models are the Endurance with 82%, Eolo-H 50 with 80% and the last is the Tuge 50 model with 77% efficiency over the theoretical power that could be captured at a 0,4-power coefficient.

Given the data available and the considered situations we chose the Aeolos wind turbine model as a good candidate for our project. The wind turbine has a good performance ratio and may be used as part of a wind farm for residential use. It uses the direct drive system with no gearing. It has an overall performance advantage over the other models.

4. The average energy consumption of a house

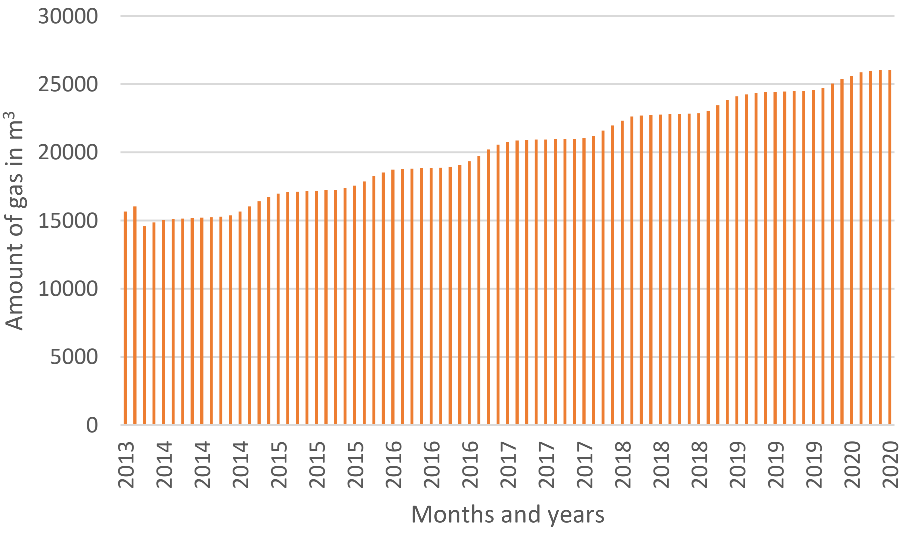

Figure 3 Measured gas consumption data

In figure 3 above we measured the gas consumption from a house during an almost six-year period in m^3. The gas meter was installed by the utility to measure consumption for billing purposes.

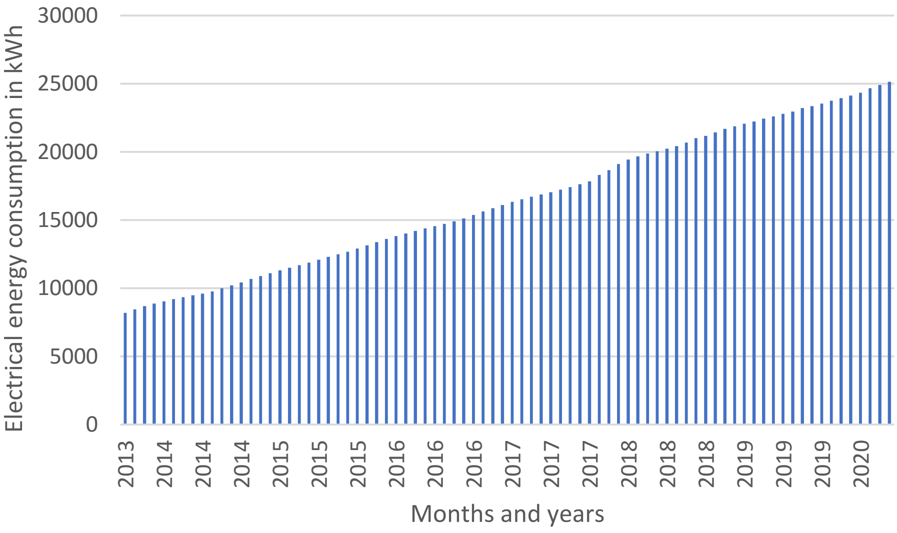

Figure 4 Measured electrical energy data from the energy meter

In figure 4 above we measured the electrical energy consumption from the same house during an almost six-year period in kWh. The energy meter was installed by the utility to measure consumption for billing purposes.

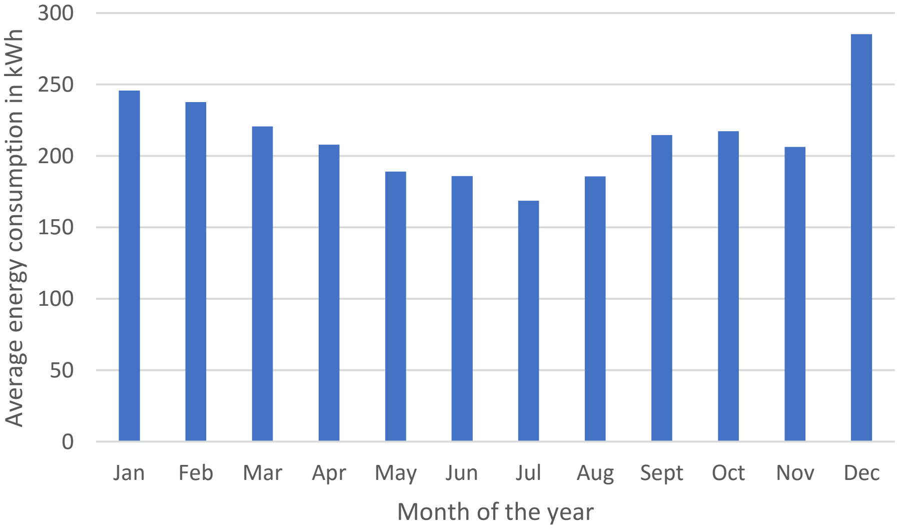

Figure 5 Average monthly electrical energy consumption for a house

In figure 5 we averaged the data from figure 4 so that we can have an estimated monthly consumption. The averages as seen above are almost the same with small variations for the summer and winter months.

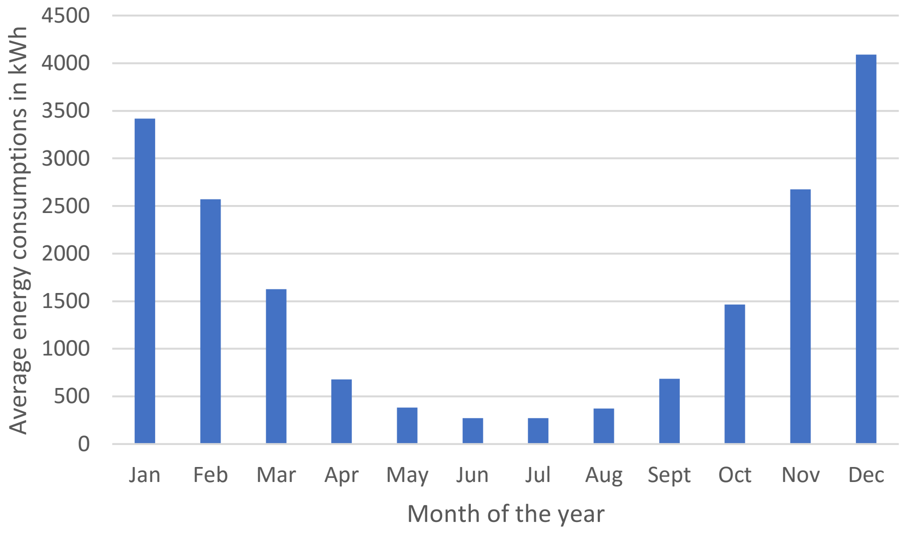

Figure 6 Average monthly gas energy consumption for a house

In figure 6 we averaged the data from figure 3 so that we can have an estimated monthly consumption. We converted the consumption from cubic meter to kWh by multiplying the amount with a factor of 10,55 to get kWh. The averages as see above are not the same because of heating and hot water consumption during the various periods of the year.

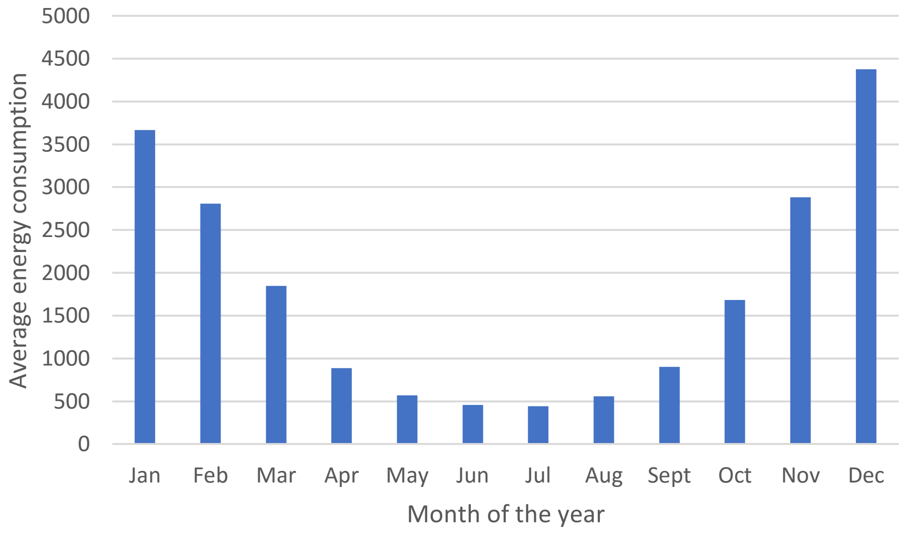

Figure 7 Average Monthly Energy Consumption for a house

In figure 7 we can see the average monthly energy consumption for a house over the period of a year. The monthly data gives a perspective on the energy consumption. We can see that in the winter months the values are higher than the summer months.

The energy measured here is for both electrical appliances as well as heating and air conditioning in the house. The data is an averaged value for a period of 6 years. We measured the electrical energy consumption and gas and averaged out the values using in equation 2 below. The plotted graph can be seen in figure 7 above.

$$A_{mec,i} = \frac{\sum_{2014}^{2020} El_{c,i}}{6} + \frac{\sum_{2014}^{2020} T_{c,i}}{6} \cdot 10.55 \qquad (2)$$

In equation 2 $El_{c,i}$ is the electrical energy consumption in the i month of the year. $T_{c,I}$ is the gas energy consumption in the I month of the year and A_{mec} is the average monthly energy consumption.

We considered the average monthly energy consumption for the house from the data in figure 7 to be computed using equation 2. Where we consider the sum of the electric energy divided by the number of years for each month. The second term is the energy derived from the amount of gas used per month multiplied with 10.55 to get the amount of energy.

The house we measured the data from is in Romania, where the climate is temperate and there are 4 seasons. Moreover, the residential area is situated on a hill in the south where temperatures are much higher than in the north and energy consumption for heat is less.

The residential complex considered is made up of family houses. The house accommodated a family of 4 during the measurements and was fully equipped with electrical appliances, heating unit for heat and hot water.

5. Results and discussion

In table 3 below we considered the average yearly consumption and the wind turbine annual energy production at an average speed of 5 m/s and we got an efficiency that suggests that we can power almost 5 such households entirely on only one turbine. For ten households we would need 2 wind turbines.

Table 3: Energy efficiency gained from wind turbine instalation

Average Energy consumpțiune [kWh]	AEP [kWh] at 5 m/s	Energy efficiency
21071	103871	492%

6. Conclusion

Implementing wind turbines to increase efficiency is practical for a residential area. The benefits grow with the growing number of houses that are connected and reducing energy consumption in households leads to more houses being connected to the same number of turbines.

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8. References

Anderson, C. (2020). *Wind Turbines: Theory and Practice 1st Edition.* Cambridge, UK: Cambridge University Press.

B. Arnold, T. L. (2018). Design of a boundary-layer suction system for turbulent trailing-edge noise reduction of wind turbines. *Renewable Energy 123.*

B. Rocchioa, S. D. (2018). Development of a BEM-CFD tool for Vertical Axis Wind Turbines based on the Actuator Disk model. *Energy Procedia.*

Chiras, D. (2017). *Power from the Wind: A Practical Guide to Small-Scale Energy Production 2nd Edition.* New Society, Canada.

Hansen, M. O. (2015). *Aerodynamics of Wind Turbines 3rd Edition* (3rd ed.). Routledge, London and New York: Taylor and Francis Group.

Jain, P. (2010). *Wind energy Engineering.* New York, New York, USA: McGraw Hill.

James Manwell, J. M. (2009). *Wind Energy Explained: Theory, Design and Application 2nd Edition* (2nd ed.). West Sussex, UK: John Wiley & Son.

Jie Zhu, Z. Z. (2020). Multi-objective aerodynamic and structural integrated optimization design of wind turbines at the system level through a coupled blade-tower model. *Renewable Energy*. doi:https://doi.org/10.1016/j.renene.2020.01.013

Julio Xavier Vianna Neto, E. J. (2018). Wind Turbine Blade Geometry Design Based on Multi-objective Optimization Using Metaheuristics. *Energy*. doi:10.1016/j.energy.2018.07.186

K. Shaler, J. J. (2019). Effects of Inflow Spatiotemporal Discretization on Wake Meandering and Turbine Structural Response using FAST.Farm. *Wake Conference 2019.*

Letcher, T. M. (2017). *Wind Energy Engineering: A Handbook for Onshore and Offshore Wind Turbines 1st Edition.* Chennai, India: Academic Press.

Robert L. Jaffe, W. T. (2018). *The Physics of Energy 1st Edition.* Cambridge, UK: Cambridge University Press.

Sathyajith, M. (2006). *Wind Energy: Fundamentals, Resource Analysis and Economics.* Kerala, India: Springer.

Sørensen, J. N. (2016). *General Momentum Theory for Horizontal Axis Wind Turbines.* Lyngby, Denmark: Springer.

Thomas Corke, R. N. (2018). *Wind Energy Design 1st Edition.* New York, New York, USA: Taylor and Francis Group.

Tony Burton, N. J. (2011). *Wind Energy Handbook 2nd Edition* (2nd ed.). West Sussex, UK: John Wiley & Sons.