

Implementation of Small Wind Turbine in Matlab Simulink

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Abstract. Nowadays we can notice the increasing interest in practical application of renewable energy sources around the world. The most common types are photovoltaics panels and wind turbines. They can be utilized in large farms but also in households in form of off-grid systems or as supplementary energy sources. Therefore, estimating their electricity production is important task. The main goal of this article is investigate theoretical background of small household wind turbines and create a computer simulation of one turbine energy production. In order to carry out needed simulations, the computer model of wind turbine was implemented in Matlab Simulink environment. Based on carried out simulations with usage of real wind speed measurement realized at department of electrical power engineering we can state potential of small wind turbine in household application.

Keywords

Wind turbine, Implementation, Renewable energy sources, Computer simulation, Matlab Simulink.

1. Introduction

With the ever-increasing number of the world's population, the demand for energy is increasing, especially for electricity. It is widely known fact that the energy stored in fossil fuels will be depleted over the next few years. It is therefore important to develop new sources of energy and to deploy already existing alternative and renewable resources to meet the global demand for energy with the least possible burden on the environment.

At present, the production of electricity from renewable sources, both in large photovoltaic and wind power plants, as well as in local conditions such as production halls, large settlements, family houses, etc., is gaining popularity at both domestic and international levels.

In year 2018 gross annual wind installations in Europe decreased to 11.7 GW, with 0.4 GW being decommissioned (see Fig. 1.). It was a significant decrease compared to 17.1 GW in 2017 which was record year for Europe. [1]

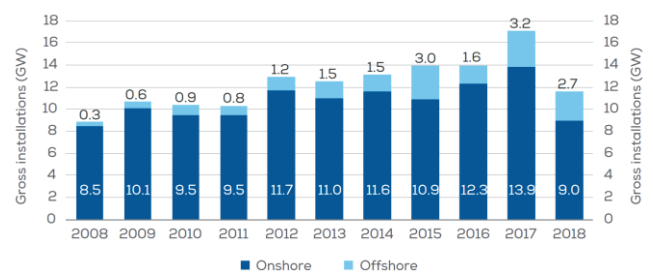


Fig. 1. Gross annual onshore and offshore wind installations in Europe [1]

The main aim of this article will be investigate possibilities of electricity generation from small wind turbine in locality of Košice.

The primary goal is to create model of the particular wind turbine in simulation software Matlab Simulink. The secondary goal will be carry out simulation based on real wind speed measurements realized on Department of Electrical Power Engineering.

2. Wind energy

Solar radiation heats both the Earth's surface and the atmosphere. The temperature difference between the atmosphere and the earth's surface causes air to flow that is the source of wind energy. [2]

The energy of moving air mass can be expressed by the kinetic energy equation (1) [3]:

$$E_k = \frac{1}{2} m \cdot v^2 (J) \quad (1)$$

Where:

m - mass (kg)

v - moving mass velocity (m.s^{-1})

The following equation (2) applies to mass [3]:

$$m = \rho \cdot V = \rho \cdot A \cdot s \quad (\text{kg}) \quad (2)$$

Where:

A - area by which the given air volume flows (m^2)

s - distance which the moving air passes (m)

From (1) and (2) for wind power flowing through the unit area is possible to establish equation (3) [3]:

$$P_v = \frac{E}{A \cdot t} = \frac{1}{2} \cdot \rho \cdot \frac{A \cdot s}{A \cdot t} \cdot v^2 = \frac{1}{2} \cdot \rho \cdot v^3 \quad (\text{W.m}^{-2}) \quad (3)$$

2.1 Wind Turbine

A wind turbine is a device that converts the wind's kinetic energy into mechanical energy. In wind power plants, kinetic energy is converted into mechanical energy, which is then transformed into electrical energy. [3]

By axis rotation is possible to divide wind turbines as (see Fig. 2.) [3]:

- vertical,
- horizontal.

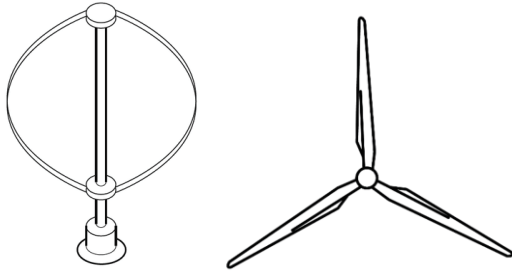


Fig. 2. Vertical (left), horizontal (right) turbine

3. Model description

Due to low average wind speeds in location of Košice, turbine, Airdolphin PRO Z-1000-48 (Fig. 3.) with low cut-in wind speed (see Tab. 1.) was chosen. [4]



Fig. 3. Chosen wind turbine [4]

| Wind Turbine Type | Horizontal axis, up-wind |
|---------------------|-------------------------------|
| Rotor Diameter | 1800 mm |
| Mass | 17,5kg |
| Number of Blades | 3 |
| Cut-in Wind Speed | 2,5 m.s^{-1} |
| Cut-out Wind Speed | - |
| Survival Wind Speed | 65 m.s^{-1} |
| Rated Power | 1kW at 12,5 m.s^{-1} |
| Rated Rotor Speed | 1000 rpm |
| Maximum Power | 2,3kW at 20 m.s^{-1} |

Tab. 1. Technical specification of wind turbine [4]

Technical specifications of chosen wind turbine are listed in Tab. 1. Nominal power of wind turbine is 1kW at wind speed of 12,5 m.s^{-1} .

Power Output (W)

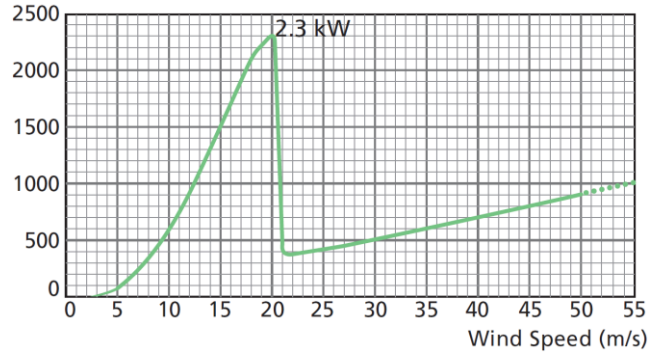


Fig. 4. Power output characteristic of wind turbine [5]

Power output characteristic of Z-1000-48 is shown at Fig. 4. with peak power of 2,3 kW at wind speed of 20 m.s^{-1} .

4. Implementation in Matlab Simulink

Wind turbine is implemented in Matlab Simulink based on power output characteristic shown on Fig. 4. Cut-in wind speed of turbine is 2,5 m.s^{-1} and survival wind speed is 65 m.s^{-1} , such high wind speed isn't common for the local climatic conditions. Thus, 55 m.s^{-1} is enough, and was set as cut-of wind speed in simulation.

$$P(v) = \begin{cases} P = P_{0-2,5}; & v < 2,5 \text{ m.s}^{-1} \\ P = P_{2,5-20}; & 2,5 \text{ m.s}^{-1} \leq v < 21 \text{ m.s}^{-1} \\ P = P_{21-55}; & 21 \text{ m.s}^{-1} \leq v < 55 \text{ m.s}^{-1} \end{cases} \quad (4)$$

For wind speeds 0 – 2,5 m.s^{-1} is power output based on Fig. 4. defined as 0W.

Therefore, for (4) can be mathematically stated as:

$$P_{0-2,5} = 0 \text{ W} \quad (7)$$

For wind speeds 2,5 – 20 m.s^{-1} is power output based on Fig. 4. defined as approximated curve with polynomial equation of fourth order.

Therefore, for (5) can be mathematically stated as:

$$P_{2,5-20} = -0,04v^4 + 1,33v^3 - 5,69v^2 + 30,92v - 65,88 (W) \quad (8)$$

With accuracy of $R^2 = 0,99$

For wind speeds $21 - 55 \text{ m.s}^{-1}$ is power output based on Fig. 4. defined as approximated curve with polynomial equation of fourth order.

Therefore, for (6) can be mathematically stated as:

$$P_{21-55} = 0.0008v^4 - 0.1332v^3 + 7.9905v^2 - 187.79v + 1872.2 (W) \quad (9)$$

With accuracy of $R^2 = 0,96$

For wind speeds $55 - \infty \text{ m.s}^{-1}$ is power output set to 0 W.

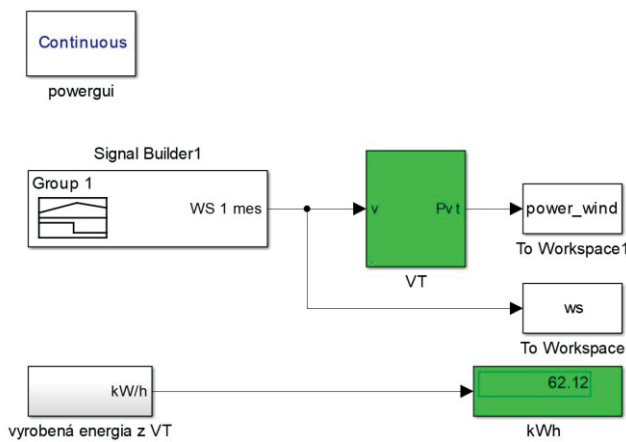


Fig. 5. Implementation of model in Simulink

At Fig. 5. is shown final model implemented in Matlab Simulink. Input parameter is wind speed in m.s^{-1} and output is in watts. Model is also calculating produced electric energy in kWh.

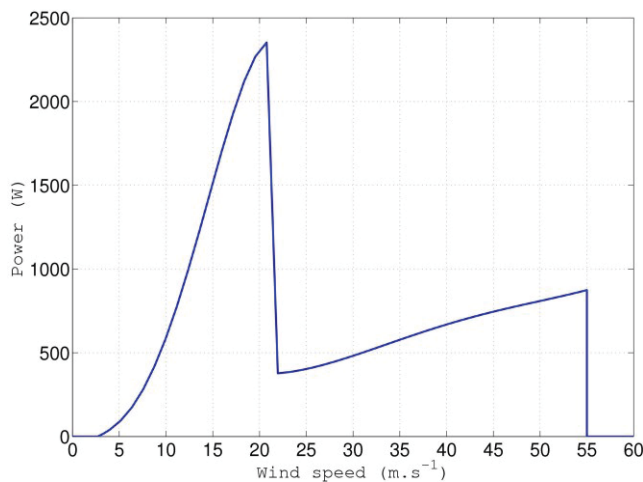


Fig. 6. Implementation of power output characteristic in Simulink model

Final implementation of power output characteristic based on (7), (8) and (9) is shown at Fig. 6.

5. Simulations

Simulation was running in continuous mode with ode45 solver which is capable of solving nonstiff differential equations — medium order method, with simulation step of 1s.

Input parameter was values of wind speed measured at Department of Power Engineering for period of one month. Specifically, month January of 2015 was selected, with average wind speed of $3,176 \text{ m.s}^{-1}$. Time course of measured wind speed is shown at Fig. 7. Based on model calculation wind turbine produced 62,12 kWh of electricity (Fig. 5.).

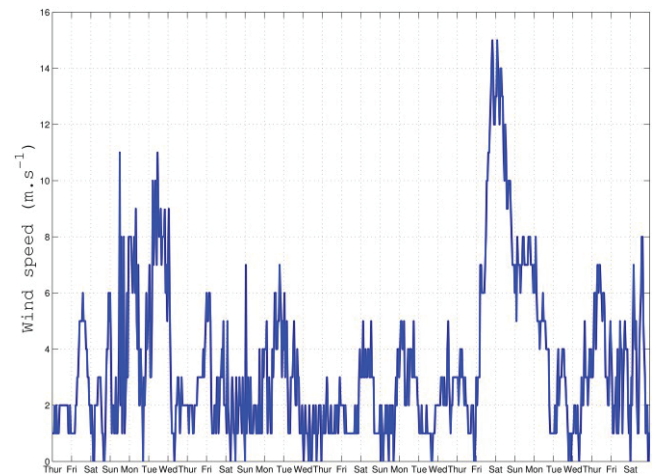


Fig. 7. Time course of measured wind speed for month January of 2015

Measuring sample time was 3600s (1h), thus it has to be corrected before inserting in Matlab. As simulation time in Matlab was 1s, more suitable sample time of wind speed measurements would be 1s as well to get as accurate results as possible.

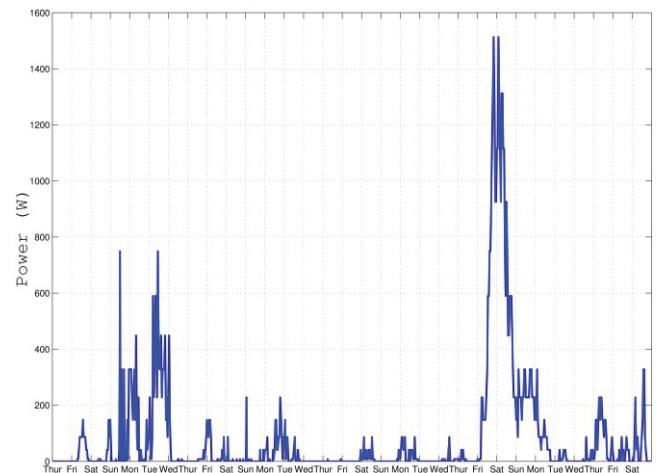


Fig. 8. Time course of calculated wind turbine power output for month January of 2015

At Fig. 8. time course of calculated wind turbine power output for month January of 2015 is shown. It is possible to conclude based on peak wind speeds for 22th and 23th from Fig. 6., that peak in wind electricity

production also match 22th and 23th day of January of year 2015.

Conclusion

At present time it is possible to notice the increasing interest in practical application of renewable energy sources around the world. Since the most common types of these energy sources are photovoltaics panels and wind turbines. We've decided to investigate possibility of electricity production from wind in local conditions.

The main goal of this article was to investigate theoretical background of small household wind turbines and create a computer simulation of one specific wind turbine energy production. Since most of the wind turbines have high cut-in wind speeds, turbine with one of lowest possible cut-in speed was chosen.

This turbine power out characteristic provided by manufactures was successfully implemented in to Matlab Simulink environment via polynomial approximation where we specified 2 stages with mathematical equations and 2 via constant 0 W value. Established model is dynamically calculating power output of wind turbine based of wind speed on input. It would be interesting to verify this modeling approach with real wind turbine and wind speed measuring sample time of 1s.

It is possible to conclude that such wind turbine in our local conditions wouldn't make sense. Produced electricity wasn't sufficient enough to justify purchase costs. Price of such turbine is circa 3600€, it is possible to buy similar wind turbines from China for fraction of cost, however with questionable durability and reliability. For that price would be in our local conditions much more reasonable to invest financial resources in to photovoltaic panels, circa 18 panels or more could be purchased for similar price, and produce much more carbon free electricity this way.

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