Simulation of Electricity Production from Small Wind Turbine in locality of Košice

[1]*Jakub URBANSKÝ*, [2]*Michal ŠPES*, [3]*Daniel PÁL*, [4]*Ľubomír BEŇA*, [5]*Michal MÁRTON*

[1,2,3,4] Department of Electrical Power Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Slovak Republic
[5] Department of Electronics and Multimedia Telecommunications, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Slovak Republic

[1]jakub.urbansky@tuke.sk, [2]michal.spes@tuke.sk, [3]daniel.pal@tuke.sk, [4]lubomir.bena@tuke.sk, [5]michal.marton@tuke.sk,

***Abstract* — Due to pollution caused by conventional electricity production, such as coal power plants, it is possible to notice increased demand for application of new clean energy sources. Typical representatives of this sources are wind turbines and photovoltaic panels. This sources can be utilized in various forms, from household usage to usage in large power plants. Therefore, estimating their production is relevant task. The main purpose of this article is to investigate possibilities of electricity production from small wind turbine in locality of Košice. Small wind turbine was implemented in computer software Matlab Simulink. Based on carried out simulations with usage of real data of wind speed measured at our department we can state practical usage of small wind turbine as supplementary energy source in household application.**

***Keywords* — electricity production, simulation, wind turbine, renewables**

I. 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. It was a significant decrease compared to 17.1 GW in 2017 which was record year for 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.

II. 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]:

$$E_k = \frac{1}{2}.m.v^2 \left(J\right) \tag{1}$$

Where:
m - mass (kg)
v - moving mass velocity (m.s^{-1})
The following equation (2) applies to mass [3]:

$$m = \rho.V = \rho.A.s\left(kg\right) \qquad (2)$$

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]:

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

A. 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. 1) [3]:

- vertical,
- horizontal.

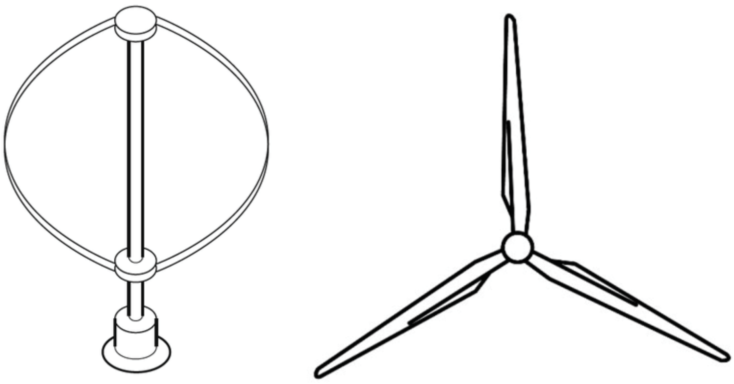

Fig. 1 Vertical (left), horizontal (right) turbine

B. Model description

Due to low average wind speeds in location of Košice, turbine, Airdolphin PRO Z-1000-48 (Fig. 2) with low cut-in wind speed (see Tab. 1.) was chosen. [4]

Fig. 2 Examined wind turbine [4]

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

Table 1
Technical specification of 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}

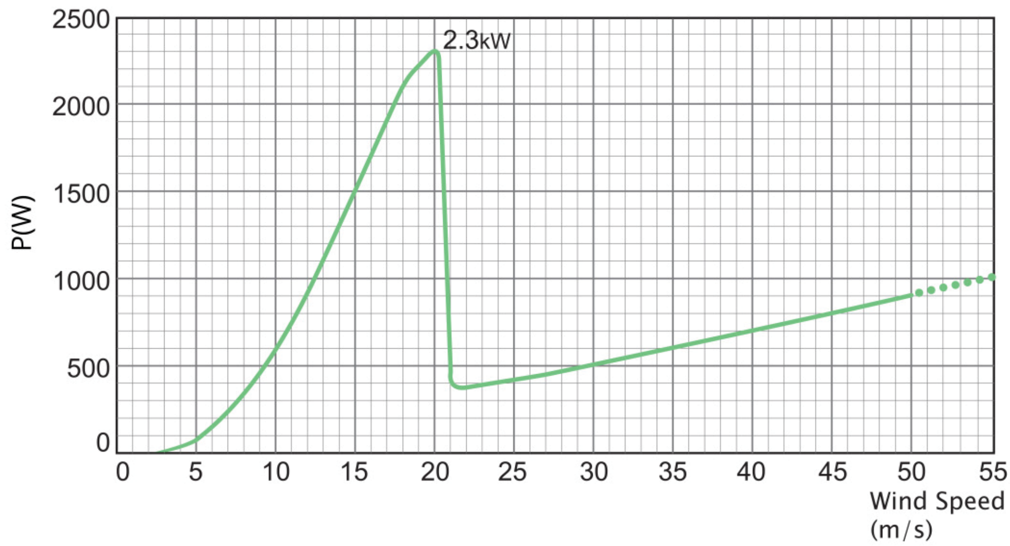

Fig. 3 Examined wind turbine [4]

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

C. Implementation in Simulink

Wind turbine is implemented in Matlab Simulink based on power output characteristic shown on Fig. 3 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, it was found that wind speed of 55 m.s^{-1} should be adequate boundary value, and this value was set as cut-of wind speed in simulation.

$$P(v) = \begin{cases} P = P_{0-2,5};\, v<2,5 m.s^{-1} & (4) \\ P = P_{2,5-20};\, 2,5 m.s^{-1} \leq v < 21 m.s^{-1} & (5) \\ P = P_{21-55};\, 21 m.s^{-1} \leq v < 55 m.s^{-1} & (6) \end{cases}$$

For wind speeds 0 – 2,5 m.s-1 is power output based on Fig. 3 defined as 0W.
Therefore, for (4) can be mathematically stated as:

$$P_{0-2,5} = 0\,W \tag{7}$$

For wind speeds 2,5 – 20 m.s-1 is power output based on Fig. 3. defined as approximated curve with polynomial equation of fourth order.
Therefore, for (5) can be mathematically stated as:

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

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

For wind speeds 21 – 55 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 – ∞ m.s^{-1} is power output set to 0 W.

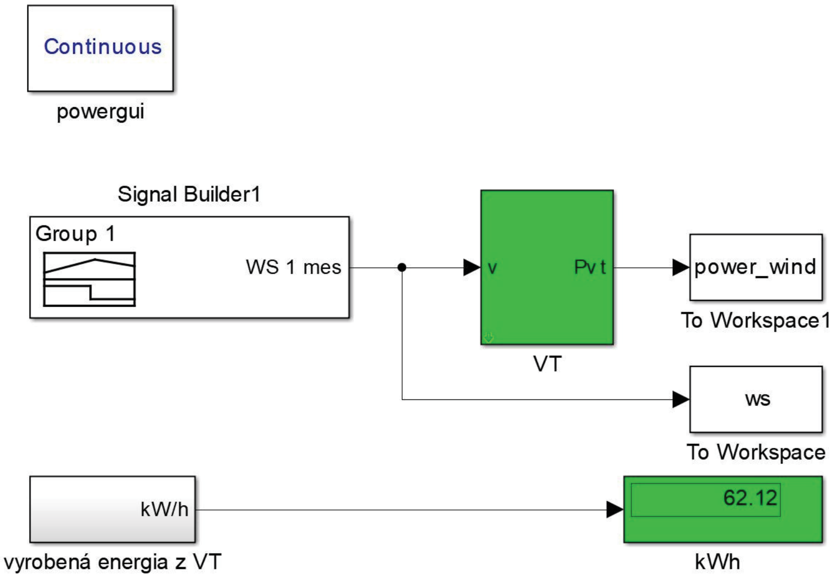

Fig. 4 Implementation of model in environment of software Matlab Simulink

At Fig. 4. 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.

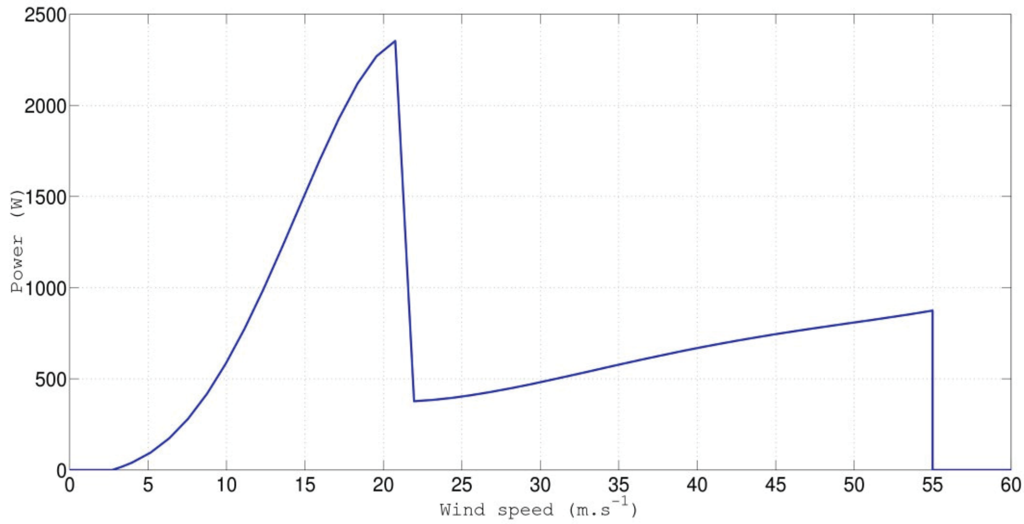

Fig. 5 Implementation of power output characteristic in Simulink model

Final implementation of power output characteristic based on (7), (8) and (9) is shown at Fig. 5.

III. 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 m.s^{-1}. Time course of measured wind speed is shown at Fig. 6. Based on model calculation wind turbine produced 62,12 kWh of electricity (Fig. 4).

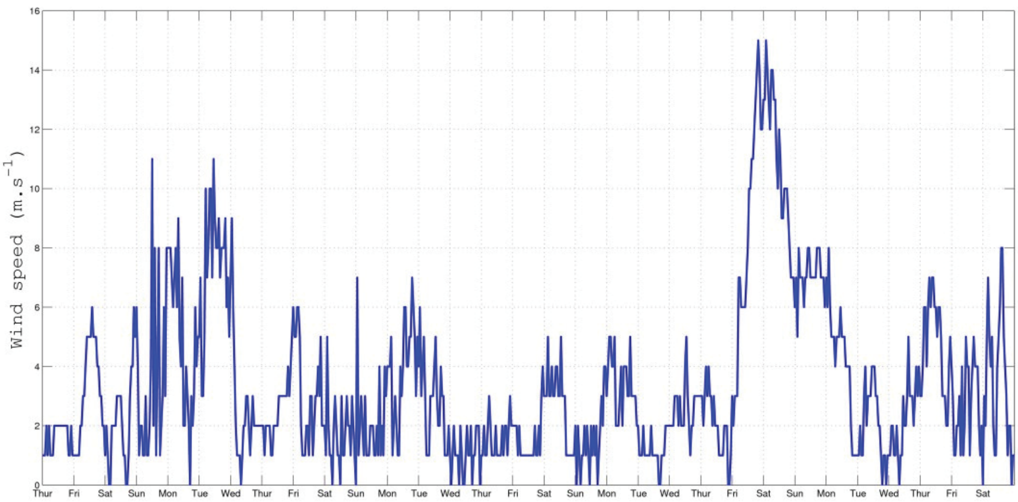

Fig. 6 Time course of measured wind speed for month January of 2015

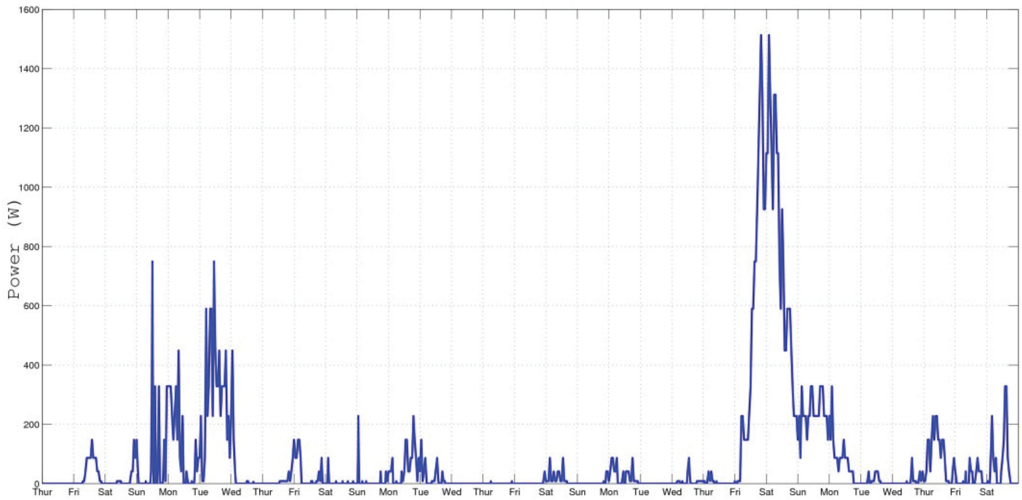

Fig. 7 Time course of calculated wind turbine power output for month January of 2015

At Fig. 7 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 22^{th} and 23^{th} from Fig. 6., that peak in wind electricity production also match 22^{th} and 23^{th} day of January of year 2015.

IV. Conclusion

In this article we have 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 cloud be purchased for similar prica, and produce much more carbon free electricity this way.

ACKNOWLEDGMENT

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