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ISSUES OF WINDMILL EFFICIENCY MEASUREMENT IN THE FIELD

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Abstract

Wind turbines become more and more popular worldwide recently as any other renewable energy sources, therefore evaluation of specific turbine efficiency is a significant scientific and technical scope. Direct comparison of windmill efficiency in general is not correct because of the versatile nature of a real wind. In permanently varying wind speed the rotational speed is changing greatly causing the appropriate variety spectrum of generating power. The goal of our latest research was to explore a ways of calculation of wind turbine efficiency and performance characteristics based on parameter information received in real wind conditions. Modern modeling of wind turbine operation was made using Matlab/Simulink software. Results showed the importance of the scope and proved its worthiness. Per our opinion the presented paper will be useful for turbine efficiency analysis and would help in the development of methodology for measurement and comparison of different turbines operating in the field.

Keywords: renewable energy, wind power, turbine performance, mathematical modeling, turbine efficiency

Introduction

Wind power utilization becomes more and more valuable, various types of wind turbines appear on the World market presenting diverse technical solutions intended on the improvement of performance which in turn should be evaluated. Surely the specific design could be tested in real wind conditions but the further comparison of testing data is not as easy as it could be imagined at once. The reason is the unstable wind speed caused by versatile nature of real wind flow giving different yield under different conditions for the same turbines. Therefore we see the demand of technique for correcting the interpretation of testing results based on data taken in real wind conditions [1].

Assumed the main characteristic of turbine is the efficiency also called coefficient of power i.e. a ratio between generated mechanical power and aerodynamic power of wind flow across the swept area of wind turbine rotor.

Our research was focused in the investigation of capability to measure the wind turbine efficiency in real conditions when the wind speed is changing continually.

Windmill model description

Basic differential equation, describing the rotation of wind turbine is $J_t \frac{d\omega}{dt} = M_{air} - M_{load}$, where J_t – inertia of wind turbine; M_{air} – aerodynamic torque; M_{load} – load torque.

Aerodynamic torque: $M_{air} = c_P(Z)\frac{\rho * V^2}{2} S * R$, where $C_P(\lambda)$ – power coefficient (depends on tip speed ratio Z); ρ – air density; V – wind speed; S – swept area.

Power coefficient C_P depending on tip speed ratio Z could be approximated by equation $c_P(Z) = (\frac{c_1}{Z} - c_2) * e^{-\frac{c_3}{Z}} + c_4$, where $c_1 \dots c_4$ – constants, Z – tip speed ratio: $Z = \frac{\omega r}{V}$, where ω – angular speed; r – radius of turbine.

Torque of load is $M_{load} = \frac{P_M}{\omega}$, where P_M – mechanical power of the alternator shaft. Based on C_P (Z) equations we were able to find the dependence of aerodynamic power on wind speed and rotation speed [2] so we can declare that for each given wind speed value there is a rotational speed where mechanical power of wind turbine is maximal.

Mathematical model of alternator consists of the following equations:

Electric power in alternator for one phase is $P_{phase} = \frac{P_M}{3}$.

EMF in the phase is proportional to rotational speed: $E_{phase} = \omega * k_1$, where k_1 is a constant. Current in phase: $I_{phase} = \frac{P_{phase}}{E_{phase}}$. Then the losses in winding: $P_{losses} = I_{phase}^2 * R_{phase}$, and losses in alternator: $P_{losses\ total} = 3 * I_{phase}^2 * R_{phase}$, where R_{phase} is the winding resistance. Voltage on winding terminals is $V_{phase} = E_{phase} - R_{phase} * I_{phase}$. "Star" connection of coils and bridge rectifier makes output voltage is $V_{out} = 2{,}34 * V_{phase}$, and output power is $P_{out} = P_M - P_{losses\ total}$. Rectifier output is connected to power converter, which adjusts the current in alternator changing load impedance so that the tip speed ratio Z provides maximum power coefficient C_P at current wind speed V. At the same time the whole of electric power P_{out} flows to the battery of infinite capacity.

For better testing evaluation the model of wind turbine was realized in Matlab/Simulink software [3]. General view of the model is presented on figure 1.

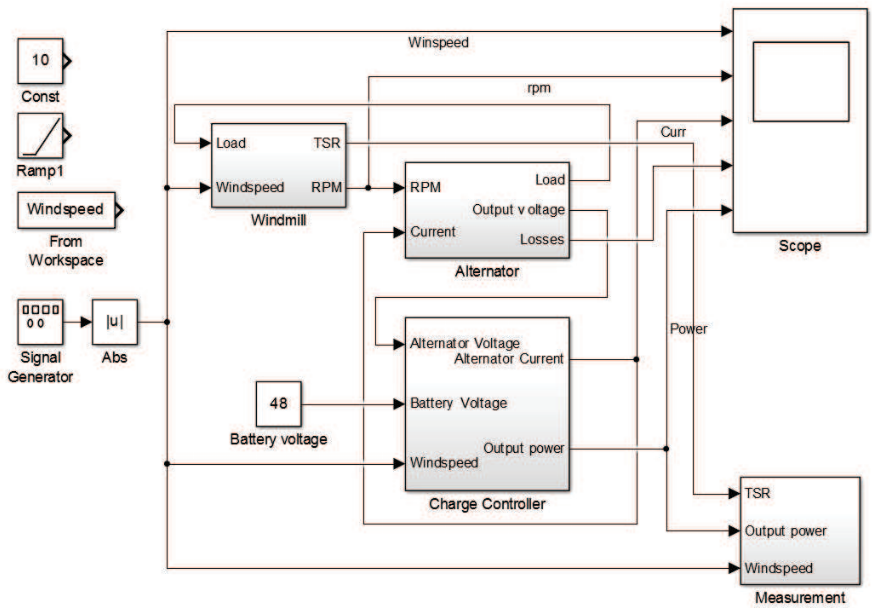

Fig. 1. General view of wind turbine Matlab/Simulink model

The model was tested using different signal generators simulating wind speed source, and finally adjusted for further research procedures [4].

Results and discussion

Next stage of the research was to analyze the developed model for applying different methods of efficiency measurement. It was assumed as working hypothesis that the direct measurement of instantaneous wind speed and output power in real wind conditions allows calculation of power coefficient C_P. The result of these calculations is presented on figure 2.

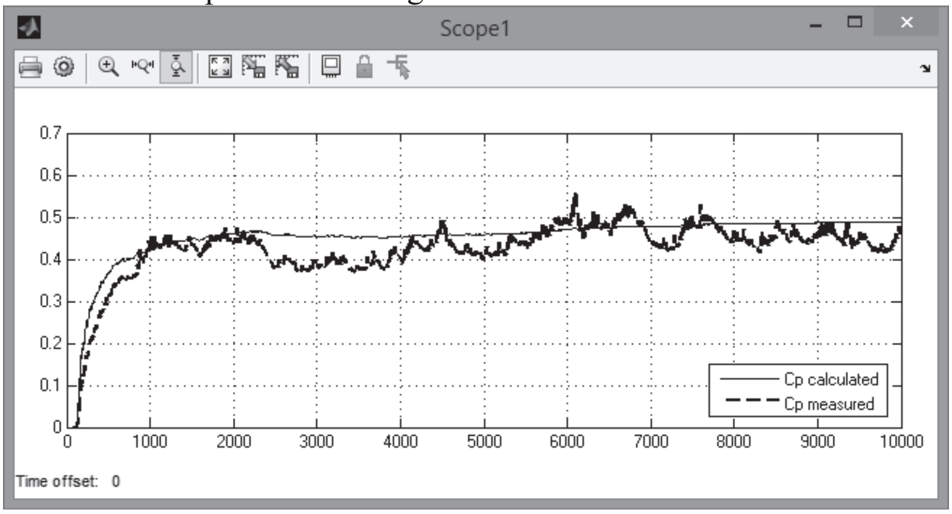

Fig. 2. Calculation of C_P based on current values of measured parameters

Diagram shows that power coefficient C_P differs from the expected values. This fact can be explained by processes in power controller of wind turbine which are changing the output power according to special algorithm providing the maximum yield [5].

Thereby to get the adequate numbers we had to use two different algorithms of processing the measured data. The first algorithm is based on the processing of the numbers using the low-pass filter. Second algorithm controls the integrating of the weighted values of Cp in time. Contribution of Cp should be proportional to output power, and average value is as follows: $Cp = \frac{\sum(P_{out}(i)*Cp(i))}{\sum P_{out}(i)}$, (14) where $P_{out}(i)$ – current output power, $Cp(i)$ – current coefficient of power. Power coefficient Cp curve at periodically variable wind speed for both methods is shown on figure 3.

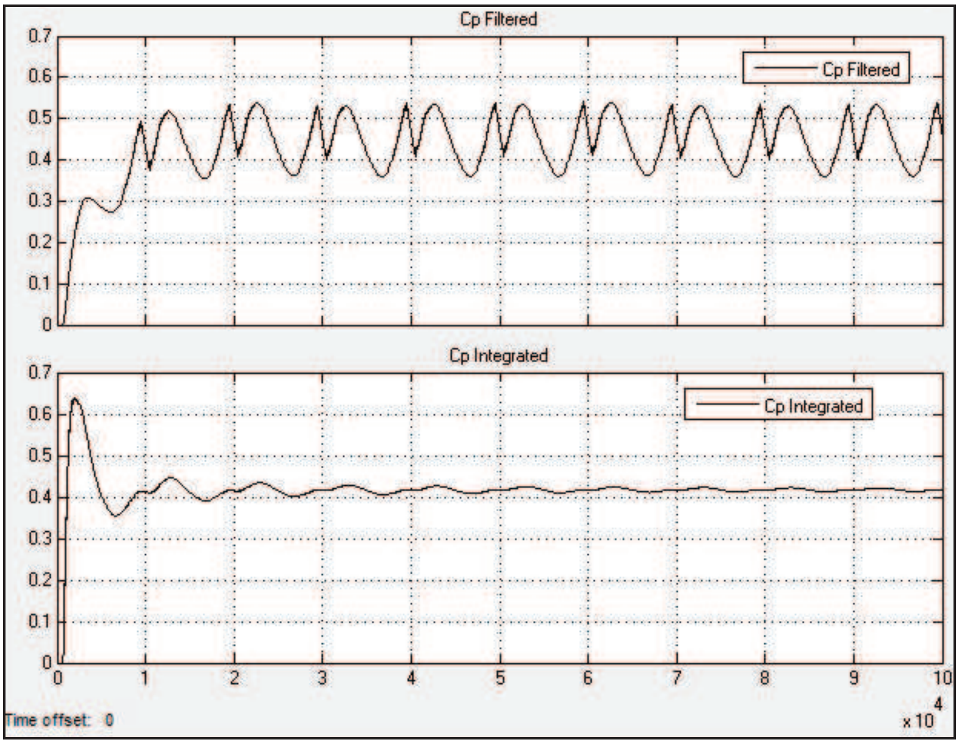

Fig. 3. Power coefficient Cp at periodically variable wind speed for both methods

From diagrams on Fig. 3 it is obvious that both methods help to increase the precision of power coefficient value comparing to the defined by model. The difference between two methods is in accuracy of numbers. First method works better with the big number of short-time wind speed fluctuations. The second one is more suitable for the stable wind speed conditions and provides more accuracy at long-term testing.

The model was also tested by samples of real wind speed values collected during the field testing, figure 4.

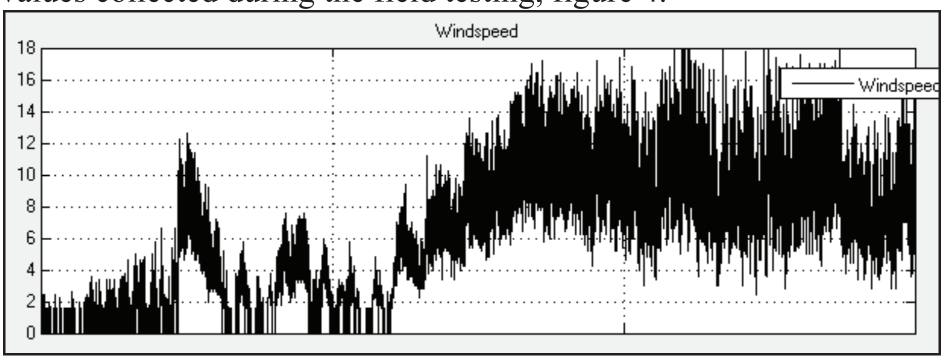

Fig. 4. Real wind speed recorded in the field

Power coefficient C_P at a sampled wind speed is shown on Figure 5.

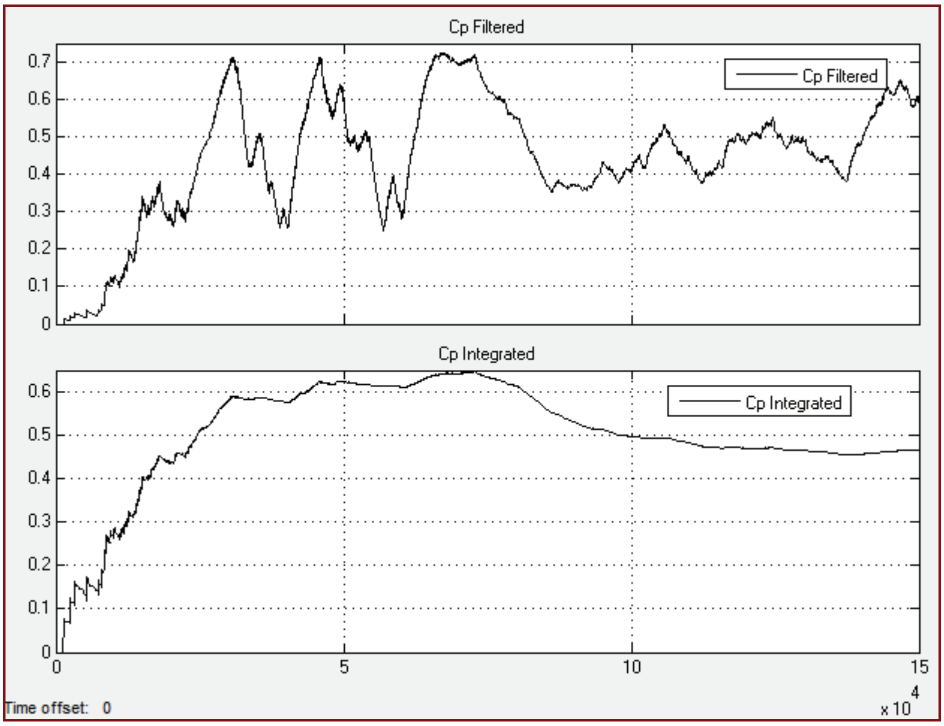

Fig. 5. Calculated power coefficient C_P at sampled wind speed

Diagram shows the difference from previous results. It can be explained with the following arguments: inertia of wind turbine does not allow adjusting the rotational speed on time [6]. The research showed that determination of power coefficient in real operating conditions doesn't have a simple solution; therefore there is a demand for special techniques of measuring the efficiency of turbine using the wind speed and generated power samples.

Conclusions

1. Calculation of power coefficient based on current wind speed and generated power is limited in practice by the stability of parameters collected during measurement.

2. Calculating the C_P based on current wind speed and generated power it is important to take into account not just current but also previous values.

3. There is a bunch of reasons introduced above showing a necessity for the development of methodology for measurement of performance characteristics of wind turbines in real wind conditions.

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