Mechanical Testing and Diagnosis
ISSN 2247 – 9635, 2021 (XI), Volume 2, pp. 18-21

A NEW METHOD TO DETERMINE THE MOST EFFICIENT ROTATION ANGLE OF A WIND TURBINE

Olena HAISHA and Eugen RUSU

Department of Mechanical Engineering, Faculty of Engineering,
"Dunarea de Jos" University of Galati, Galati, 800008, Romania

Correspondence: oleksandrgaysha1982@gmail.com

ABSTRACT

Collecting of clean wind energy is a very actual problem in our modern world of a global warming. The most popular construction of a wind energy station uses horizontal rotor and its axis must be fixed in some certain position during work process. As better by angle we fix the rotor, as more energy will be collected, so the problem of rotor's rotation angle choice can be considered significant and very actual. In this work is proposed to use the polar coordinate cardioid dependence to approximate the real rose of the wind corresponding to a certain location. Symmetry axis of such cardioid will indicate the most efficient rotor's position. For approximation is used least squares method and automated solving of non-linear algebraic equation. Developed technique allows choosing rotor's rotation angle more reasonable, based on wind statistics of certain locality.

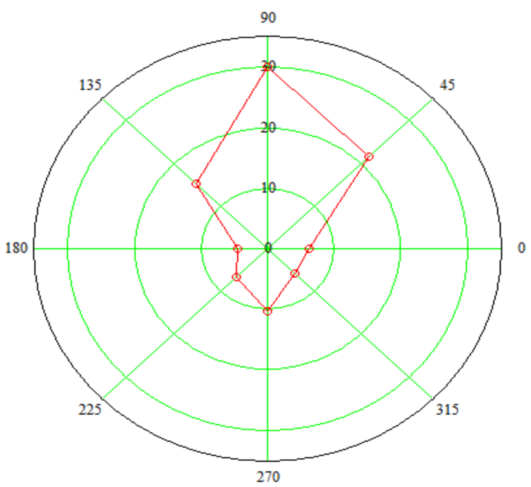
Keywords: Wind energy stations, horizontal rotor, rotor orientation, rotation angle, numerical solution

1. INTRODUCTION

During every month, the wind direction changes in a wide range of angles. It changes not only for long periods, but sometimes it happens several times a day. From the practical point of view in Horizontal Axis Wind Turbines (HAWT, [1-2]), it is not very simple process to reset the orientation of a turbine's rotor (connected to the 100-m blades) and it is not possible to carry out it very often (for example, every hour) [3-4]. Thus, it is expedient to select the most efficient position of a rotor's axis (orientation) for as longer periods as it is possible.

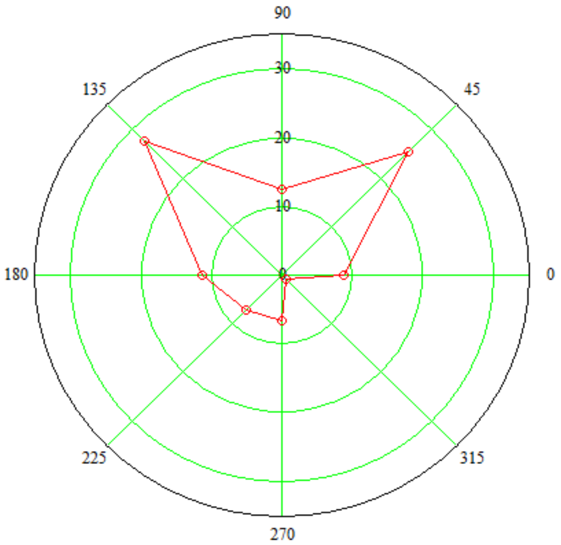
2. MATERIALS AND METHODS

The simplest way is to determine the direction of a maximum wind and to orient rotor's axis in this direction (Fig. 1).



	Direction	Percentage
↓	North	30%
↙	North-East	21.4%
←	East	6.2%
↖	South-East	5.8%
↑	South	10.3%
↗	South-West	6.6%
→	West	4.5%
↘	North-West	15.2%

Fig. 1. Example of a wind rose with one well-defined wind direction (Odessa, July 2021, values from WeatherArchive.ru [5])



	Direction	Percentage
↓	North	12.5%
↙	North-East	25.4%
←	East	8.8%
↖	South-East	0.8%
↑	South	6.7%
↗	South-West	7.1%
→	West	11.3%
↘	North-West	27.5%

Fig. 2. Example of rose of a wind with hardly defined effective rotor's axis orientation (Odessa, October 2021, values from WeatherArchive.ru)

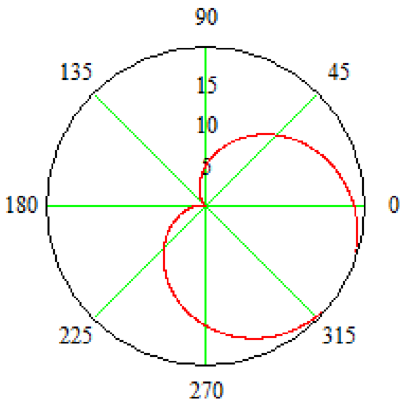


Fig. 3. Example of a cardioid dependence, with φ_0 = 30° and A = 10

But if rose of winds would be very asymmetric and without one definite maximum, like that in Fig. 2, it is expedient to turn rotor's axis to some mean windward side (to the North – on Fig. 2).

So, we need to use more complicated method to find the most effective direction of a rotor's axis. In this work, we propose to approximate wind distribution via polar coordinates dependence, known as cardioid [6]. The formula is:

$$\rho(\phi) = A(1 + cos(\phi + \phi_0)), \qquad (1)$$

where parameter φ_0 defines the angle of a graph's rotation (positive values correspond to clockwise rotation) and parameter A defines the size of a graph – Fig. 3.

So, the real wind distribution (as in Fig. 1 and Fig. 2, data from http://weatherarchive.ru)) is to be approximated with formula (1), finding current parameter φ_0 and setting rotor's axis correspondingly to this direction.

For the approximation, we have a set of φ_i values and corresponding ρ_i values, presented in tables at the right side of Fig. 1 and Fig. 2. The objective is to find the φ_0 value and it is possible to use Least Square Method (LSM) [7-8]. The objective function is the sum of the squared residuals

$$\varepsilon_i = A(1 + cos(\phi_i + \phi_0)) - \rho_i:$$

$$S = \sum_i \varepsilon_i^2 = \sum_i (A(1 + cos(\phi_i + \phi_0)) - \rho_i)^2 \rightarrow min \qquad (2)$$

Traditional minimum condition [9] is:

$$\frac{\partial S}{\partial A} = 0, \quad \frac{\partial S}{\partial \phi_0} = 0$$

Differentiating (and after reduction by 2), we will get the system of non-linear algebraic equations:

$$\begin{cases} \sum_i (A(1 + cos(\phi_i + \phi_0)) - \rho_i)(1 + cos(\phi_i + \phi_0)) = 0 \\ \sum_i (A(1 + cos(\phi_i + \phi_0)) - \rho_i)A(-sin(\phi_i + \phi_0)) = 0 \end{cases}$$

Transforming:

$$\begin{cases} \sum_i A(1 + cos(\phi_i + \phi_0))^2 - \sum_i \rho_i(1 + cos(\phi_i + \phi_0)) = 0 \\ \sum_i A^2(1 + cos(\phi_i + \phi_0))\, sin(\phi_i + \phi_0) - \sum_i A\rho_i\, sin(\phi_i + \phi_0) = 0 \end{cases}$$

Expressing *A* from the second equation and substituting it into the first one, we will get the non-linear equation of which it is possible to find parameter φ_0:

$$\sum_i \rho_i \sin(\phi_i + \phi_0) \cdot \sum_i (1 + \cos(\phi_i + \phi_0))^2 - \sum_i \rho_i (1 + \cos(\phi_i + \phi_0)) \cdot \sum_i (1 + \cos(\phi_i + \phi_0)) \sin(\phi_i + \phi_0) = 0 \quad (3)$$

3. RESULTS

Using some mathematical software (its choice is very wide because solving of non-linear algebraic equations is a standard task for such programs (Fig. 4) [10-12], it is possible to get the root of (3) (i.e., desired angle) for any real rose of winds. For example, in Fig. 5, there are shown two cases for Odessa city, 2021 year, February (φ_0 = 192°) and March (φ_0 = 259°).

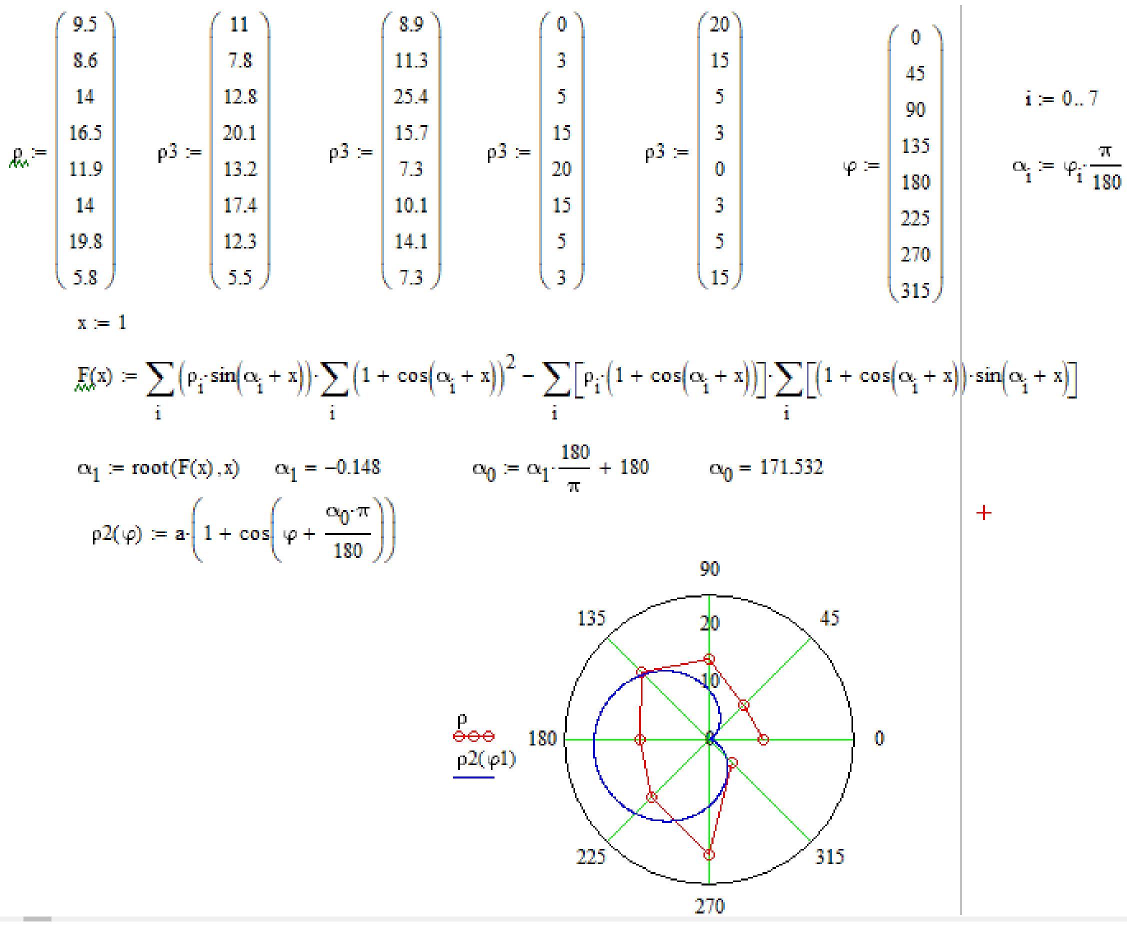
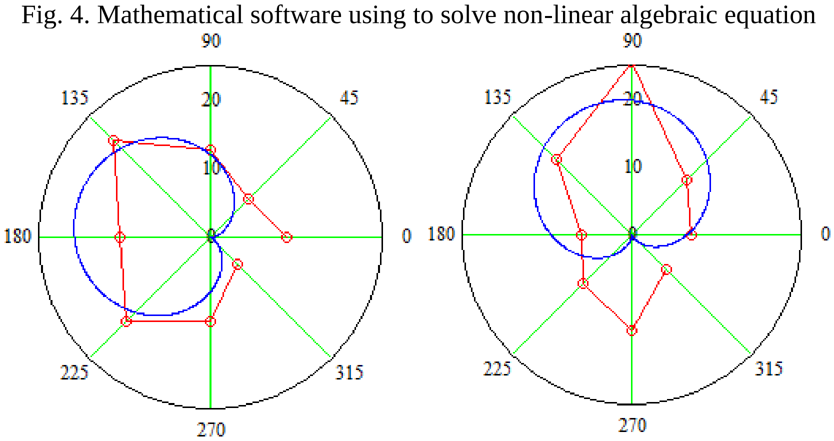


Fig. 4. Mathematical software using to solve non-linear algebraic equation



a) b)

Fig. 5. Example of proposed method using for locality of Odessa in 2021 year: a – February, b – March

4. DISCUSSION

The difference between two values of rotor's orientation angle (traditional direction to maximum wind and proposed in this work direction of an approximated cardioid axis) may be great enough. For example, in Fig. 5*a*, cardioid angle is 168° (φ_0 = 192° if it counts clockwise positive angles from the polar axis), but the maximum wind is observed on the angle of 135°, so the difference is 168° – 135° = 33°, that is great enough and it can give a noticeable difference in energy collected amounts.

CONCLUSION

So, in this work it is proposed the method to find the most efficient wind energy station rotor's orientation for any rose of winds. For this purpose, cardioid approximation with LSM method is used. In further work, it is planned to experimentally estimate the efficiency of traditional rotor's orientation on maximum wind and on the direction provided by the method proposed in this work.

ACKNOWLEDGMENT

This work was carried out in the framework of the research project DREAM (Dynamics of the REsources and technological Advance in harvesting Marine renewable energy), supported by the Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding – UEFISCDI, grant number PN-III-P4-ID-PCE-2020-0008.

REFERENCES

[1] Battisti L., design options to improve the dynamic behavior and the control of small H-Darrieus VAWTs, *Applied Sciences,* **11**, 9222, 2021. https://doi.org/10.3390/app11199222.

[2] Micallef D., Bussel G. V., A review of urban wind energy research: *Aerodynamics and Other Challenges. Energies* 11, 2204, 2018,

[3] Cashman A., A review on the historical development of the lift-type vertical axis wind turbine: From onshore to offshore floating application, *Sustainable Energy Technologies and Assessments*, **38**, 100646, 2020

[4] Bai C. J., Hsiao F. B., Li M. H., Huang G. Y., Chen Y. J., Design of 10 kW Horizontal-Axis Wind Turbine (HAWT) Blade and Aerodynamic Investigation Using Numerical Simulation // 7th Asian-Pacific Conference on Aerospace Technology and Science, 7th APCATS 2013.

[5] Weather Prognosis and Archive [Electronic resource]. – WeatherArchive, 2022, (accessed 3.04.2021), http://weatherarchive.ru.

[6] Yates R.C., *Cardioid. A Handbook on Curves and Their Properties*, Ann Arbor, MI: J. W. Edwards. pp. 4, 1952.

[7] Hastie T., Tibshirani R., Friedman J. H., *The Elements of Statistical Learning* (second ed.). Springer-Verlag. Archived from the original on 2009-11-10, 2009

[8] Bühlmann P., van de Geer S., *Statistics for High-Dimensional Data*: *Methods, Theory and Applications*. Springer, 2011.

[9] Larson R., Edwards B. H. *Calculus* (9th ed.). Brooks/Cole, 2009.

[10] Hu J., The Application of computer technology in mathematical modeling, *Journal of Physics Conference Series*, 2173 012028, 2022.

[11] Shi S., The Application of Computer Technology in Mathematical Modeling, *Electronics Technology*, **50(08)** 242-3, 2021.

[12] Huang J., Li C., Lin W., Application of Computer Technology in Advanced Mathematics Curriculum in New Engineering Background, *Computer Knowledge and Technology*, **16(18),** pp. 111-117, 2020.