Marek Hvizdoš, Ján Tkáč

Vertical axis turbines of wind power plants

This paper deals with the use of renewable energy sources with a focus on electricity generation using vertical axis wind turbines. The installed capacity of wind power plants increases with the gradual decreasing of fossil fuels reserves. Nowadays, the horizontal axis turbines are the most widely used. This paper describes the design of function models of wind turbines with a vertical axis. Characteristics of wind turbine models were verified by laboratory measurements. The results show that the rotor design has a significant impact on its parameters. The best results were achieved by the multi-stage rotors.

Keywords: renewable energy sources, wind energy, wind turbine models, measuring equipment

I. INTRODUCTION

Nowadays, humankind focuses on the use of renewable energy sources that do not pollute the environment. Energy sources, such as solar, wind, and water, are all around us. Renewable energy sources and electricity production using them are profitable because they do not violate the thermodynamic stability of the planet and reduce emissions production [1], [2]. Their advantage is the possibility of distributed electricity production at any location on the planet without the cooperation of the electric power system [3].

Utilization of the wind goes back to ancient times, when people began to use it to grind grain using windmills. It was also used in ships propulsion and so on. Today the wind is mainly used for electric power generation and wind power plants have installed capacities of MW. Their advantage is that they generate electricity obtained from a source that is free [4]. They can be integrated well with photovoltaic plants. Thus, multivalent system is created using the accumulation of produced electricity [5], [6], [7].

This paper describes the design and construction of small wind turbines of various designs. Laboratory measurements were realised to determine their properties. Models of wind turbines with various shapes will form the laboratory wind farm, and they will serve for a demonstration of wind power plants operation in the end.

II. DESIGN OF SMALL WIND TURBINES

Design of wind turbine models was based on the rotor with a vertical axis rotation. These turbines have a good starting torque and no need to rotate them by the wind direction. They start at low wind speeds and operate well under turbulent and inrush winds. It was necessary to construct models of vertical axis turbines of various kinds, which will form the laboratory wind farm. The design was based on Savonius rotor.

A. Savonius rotor

This type of rotor is a fundamental one. This low-speed rotor can start at low wind speeds, because it captures wind energy from any side by all blade area. Its blades are constructed in S-type form (Fig. 1 left). This rotor can be improved by implementation of the blades overlap (Fig. 1 right).

It was necessary to find the most appropriate material to design the models, in order to achieve the required form and mechanical properties.

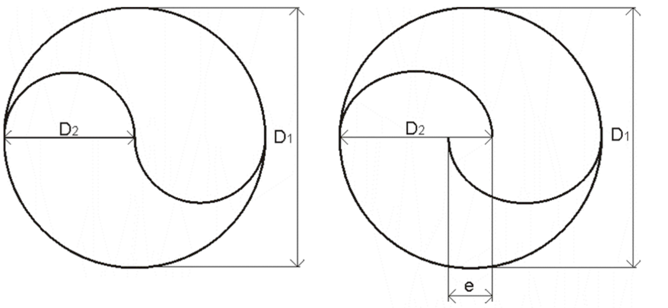

Figure 1. Savonius rotor sections without blades overlap (left) and with blades overlap (right)

Individual rotors are equally at dimensions. A plastic was used for the construction of wind turbines models, because of small weight and good strength. In the aggregate, 16 wind turbines of various shapes were constructed. All were based on the construction of Savonius rotor and its modifications with various blades overlaps and the number of stages. The diameters (D_1) of all rotors were 12 cm and height was 10 cm. Rotor dimensions had to be met for each model for accurate comparison of their properties during the measurements.

The rotors without blades overlap, and with 1 cm, 2 cm and 3 cm overlaps were constructed for properties comparison (Fig. 2). Blade height was 10 cm and its diameter (D_2) was dependent on the specific overlap (e). The blade diameter for rotor without overlap was 6 cm, for rotor with 1 cm overlap was 6.5 cm, for rotor with 2 cm overlap was 7 cm, and for rotor with 3 cm overlap was 7.5 cm. Overlapping the blades gives higher efficiency to the turbine, because rotor with overlap can start earlier and reach higher speeds than conventional rotor without overlap. It consists in the law of action and reaction.

Figure 2. Savonius rotors with blades overlap of 0, 1, 2 and 3 cm

The construction of all the rotors was based on Fig. 1. The practical implementation is shown on Fig. 2. Mutual differences pertained to only the blades overlap and the number of rotor stages. The construction of multi-stage Savonius rotors was based on Fig. 1 too. The difference was just the mutual rotation of stages.

B. Multi-stage rotors

The basic Savonius rotor supplies only two pulses of the power during one turn. Therefore, double-stage and triple-stage rotors were constructed. The stages are mutually symmetric and axially rotated. These rotors better handle turbulent airflow. They are composed of two or three simple Savonius rotors. The double-stage Savonius rotors (Fig. 3) have blades rotated by 90 °.

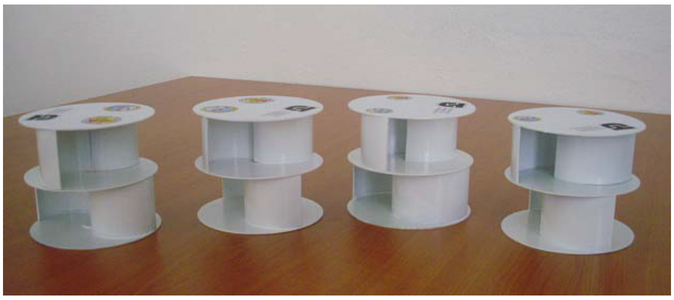

Figure 3. Double-stage Savonius rotors with blades overlap of 0, 1, 2 and 3 cm

Triple-stage rotors (Fig. 4) have the stages rotated by 120 °. The advantage of rotation of stages is that the rotor supplies more power pulses per one turn and has a better starting torque. The rotors were constructed with the same blades overlaps as in the previous case. Outer dimensions of the rotor were the same, but stages height was divided by the number of stages. It was necessary to construct the rotors with a height of 10 cm, so this height had to be divided for multi-stage rotors. Thus, height of blades for double-stage rotors was 5 cm and for triple-stage rotors 3.33 cm.

Figure 4. Triple-stage Savonius rotors with blades overlap of 0, 1, 2 and 3 cm

III. DESIGN OF THE MEASURING BASE

The measuring base was constructed following the block diagram in Fig. 5. The stand has wooden base with three small generators. The generator shafts are equipped by oscillating link with perforation to measure rotor speed. The rotors are placed on it by magnets. This method represents simple and strong mounting of the rotors. Any rotor can be easily removed at any time from the base and replaced by another rotor. Furthermore, sensors for rotor speed measuring and electronic anemometer for air flow velocity measuring are placed on the measuring base. Connection cables are installed at the bottom of the base. Wiring connects small generators and measuring sensors with printed circuit. The measuring base fulfils the condition for the location of three rotors, which can operate simultaneously (Fig. 6).

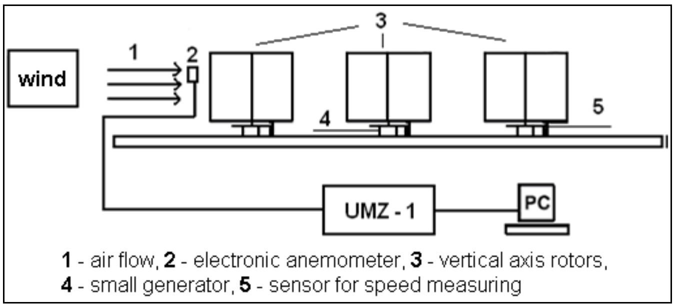

Figure 5. Schematic model of the wind park

Figure 6. The construction of the measuring base

The measurement of operating parameters was performed using a universal measuring device UMZ -1. This device includes measuring circuits and RS232 serial ports. There are two ports at the device. The first one is used for the rotor speed measuring and the second one to measure the generator voltage. The measuring equipment includes a USB port, which provides power supply to the device. The measured values are displayed using the PC.

A. Measurement of the generator voltage

Voltage measuring module provides the ability to measure the three small generators at once. Another possibility of this module is an airflow measuring. It is possible to measure the four values simultaneously. The power supply is realised with a USB port with a voltage value of 5 V. The pulses from the generator go through the LPT port to UMZ-1 device. Then they are transmitted to the computer using the serial port RS232. The pulses are processed and measured values are displayed using the software "PC Voltmeter".

B. Measurement of the rotation speed

Sensor for the rotation speed measuring works on the principle of light interruption. The rotation speed sensor sends a pulse to UMZ-1 when the light is interrupted. The light is emitted by a photodiode and received by a phototransistor. The light interrupting is done by rotating the link. 16 pulses are sent to UMZ -1 during one turn of the turbine. The sensors are placed on the measuring base and through the LPT port and cable are connected to the measuring device UMZ -1. Pulses are sent from the measuring device through the RS232 to the computer. They are processed by special software "PC Otáčkomer" [8].

C. Measurement of the air flow velocity

The speed of the airflow is necessary to know when measuring rotor parameters. Dimensions of wind turbine models are small, so measuring the wind velocity by anemometers is not be possible, because larger dimensions of anemometers can cause strong influence to the air flow towards the turbine. Consequently, electronic anemometer operating on the principle of filament resistance changes due to temperature was constructed. The advantage of this device is its small size. Air flow velocity values are displayed using special software “PC Voltmeter” [8].

IV. EXPERIMENTAL MEASUREMENTS ON WIND TURBINE MODELS

Measurement of the rotor properties were performed at various speeds of air flow. The measured values were processed to obtain graphic dependence of rotation speed, voltage and current on the air flow velocity. Measured dependences of speed for selected rotors are shown in Fig. 7. The rotors start began at wind velocity of 1.3 m/s. It confirms that these types of rotors are starting-up at low speeds.

Fig. 7 shows the impact of the stages to characteristics linearization due to the larger number of output pulses during one revolution. It follows that the best results have a triple-stage rotor with blades overlap of 3 cm. The measured dependences of output voltage and current for a triple-stage rotor are shown in Fig. 8 and Fig. 9.

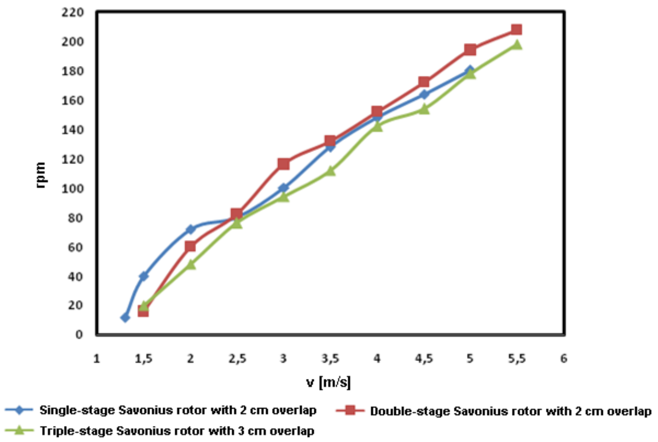

Figure 7. The dependence of the rotation speed of rotors on the wind velocity

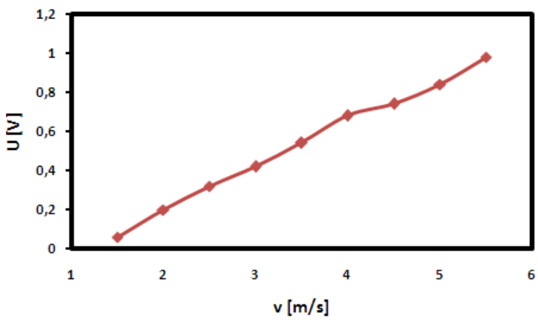

Figure 8. The dependence of the output voltage on the wind velocity

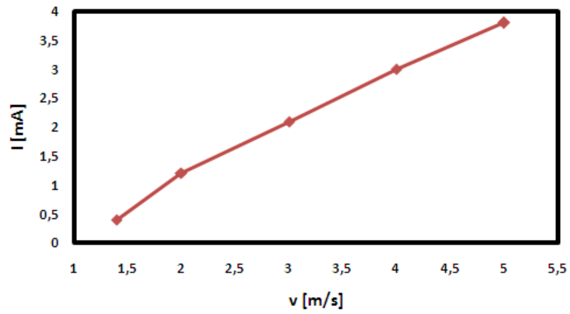

Figure 9. The dependence of the output current on the wind velocity

Following the number of measurements, the rotors catalogue was created. It contains a description of the structure, measured values and dependences of individual rotors.

V. CONCLUSION

The installed capacity of wind power plants is rapidly rising in recent years, which means higher electricity production. On principle, the kinetic energy of the wind is transformed into mechanical energy and thereafter the generator produces electricity. At the present time, horizontal axis turbines are mostly utilized. They consist of two or three blades, which are turned in the wind direction in terms of aerodynamics. The construction of these rotors is not so simple, because these rotors must be designed with respect to the best utilization.

Significantly simpler structure has rotors with a vertical axis. The best known rotors of this concept are Savonius and Darrieus rotor. They do not need to be turned in wind direction and starts-up at low wind velocity. These turbines are profitable in areas with unstable wind speed and direction.

The design of wind turbine models consisted of construction of the wind farm model. Turbines with vertical axis were constructed. The measured values show that constructed rotors are suited well to the laboratory conditions and the laboratory wind farm model has suitable parameters. The rotors start-up at the airflow speeds with values from 1.2 to 2 m/s, confirming the start-up at low wind velocity. When increasing the speed of air flow, the generator voltage is increased in addition to the rotation speed. A load of 200 Ω was connected to small generator. The generated current was calculated subsequently.

The best results showed double-stage and triple-stage Savonius rotors with a good processing of occurred turbulences. They are able to work even at higher wind speeds, as measured in the laboratory. Conventional Savonius rotors have relatively high aerodynamic resistance. It was manifested mainly at higher speeds of the air flow. Individual construction types of turbines showed good stability in the whole range of air velocity, so it was not necessary to counterbalance them. Ultimately, these turbines together with the base comprise the wind farm model. In the future, the model can be used for different measurements, or to demonstrate the operation of wind turbines with a vertical axis.

The vertical axis rotors in conjunction with photovoltaic panels are now often used in autonomous systems to secure electricity delivery. Thus, better stability and reliability of supplied electric power is achieved.

ACKNOWLEDGMENT

This work was supported by the Slovak Research and Development Agency under the contract APVV-0185-10.

This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences by the project VEGA No. 1/0487/12.

The authors wish to thank for the support to the R&D operational program Centre of excellence of power electronics systems and materials for their components No. OPVaV-2008/2.1/01-SORO, ITMS 26220120003 funded by European regional development fund (ERDF).

REFERENCES

[1] P. Horbaj, P. Čekanová, J. Selín, N. Jasminská, "*Spaľovanie fosílnych palív – jeden zo zdrojov nebezpečných emisií (1)*," in Energetika, vol. 61, no. 10, 2011, pp. 568-571, ISSN 0375-8842.

[2] R. Rybár, D. Kudelas, G. Fischer, "*Alternatívne zdroje energie 3: veterná energia*," ES/AMS Košice, 2004. 99 p., ISBN 80-8073-144-6.

[3] I. Viťaz, M. Ďulik, Z. Dostál, "*Prenos dát meraných meteorologických veličín do počítača*," in Alternatívne zdroje energie ALER 2008, Liptovský Ján, 2008, pp. 79-86, ISBN 978-80-8070-912-9.

[4] D. Kudelas, R. Rybár, M. Cehlár, "*Energia vetra: prírodné, technické a ekonomické podmienky jej využitia*," FBERG TU Košice, 2009, 215 p., ISBN 978-80-553-0169-3.

[5] M, Taušová,, P. Tauš, J. Koščo, "*Ekonomika ostrovnej FV elektrárne v podmienkach Slovenska*," in Alternatívne zdroje energie ALER 2009, Liptovský Ján, 2009, pp. 1-8, ISBN 978-80-554-0099-0.

[6] Z. Dostál, M. Bobek, J. Župa, "*Meranie globálneho slnečného žiarenia*," in Acta Montanistica Slovaca, vol. 13, no. 3, 2008, pp. 355-360, ISSN 1335-1788.

[7] P. Bača, "*Ostrovní systémy: Problematika akumulace elektrické energie z FV do olověného akumulátoru*," in 30. Nekonvenční zdroje elektrické energie NZEE, ČES, VUT Brno, 2009, pp. 70-73, ISBN 978-80-02-02164-3.

[8] Š. Hudák, S. Šimoňák, "*Programovacie techniky*," FEI TU Košice, 2010, 220 p., ISBN 978-80-553-0531-8.

ADDRESSES OF AUTHORS

Marek Hvizdoš, Technical University of Košice, Department of Electric Power Engineering, Mäsiarska 74, Košice, SK 04210, Slovak Republic, Marek.Hvizdos@tuke.sk

Ján Tkáč, Technical University of Košice, Department of Electric Power Engineering, Mäsiarska 74, Košice, SK 04210, Slovak Republic, Jan.Tkac@tuke.sk