DETERMINATION OF LOADING CHARACTERISTICS OF A GENERATOR FOR A BLADELESS TURBINE

Z. Vondrášek, L. Dlabal

Department of Electrical Engineering and Automation, Faculty of Engineering, Czech University of Life Sciences Prague, Czech Republic

Abstract

The article summarises the results of experimental measurements on an electricity generator performed on the SETUR DVE 120, a commercially available set equipped with a bladeless turbine. Generator loading characteristics were compiled from the measured data. The measurements were performed in a closed hydraulic testing circuit in a laboratory of the Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences in Prague. The first part of this article describes the measuring station, the measuring method and determination of operating, technical and other associated parameters. The following part deals with the verification of the machine type (synchronous), determination of the number of the generator's pole pairs and its loading characteristics. The loading characteristics describe the dependence of the line voltage on the phase current or on the electrical output power. Knowledge of the operating characteristics is needed for the efficient utilisation of a small hydro-electric set.

Key words: line voltage, electric current, generator speeds.

INTRODUCTION

Climate change is resulting in numerous unknown effects. Many questions are being raised, especially concerning threats to agriculture. The issue of watering crops is of particular interest in this respect (KUCHAR, 2011). Rural areas on the world frequently struggle with a lack of water for irrigation systems or a complete absence of mains electricity. Reports state that around 1.6 billion people live in rural areas without access to electricity (IEA, 2006; LAHIMER, 2012). This number will not fall unless there are solutions available, especially for less-developed countries. Electrification and computerization of the private activities of people increases the rate (phones, cameras, PC's) and the demands on the availability of electrical power. Using the energetic potential of small water streams by means of a micro-turbine is a possible solution in some cases. This alternative is becoming very attractive in the field of local renewable energy sources for electricity generation (BHUSAL 2007). The newly developed bladeless turbine is one such. In order to operate and utilise a bladeless-turbine-based energy source efficiently, knowledge of its functionality is necessary. For this reason, both the turbine and its generator are currently subject to further investigation.

The aim study was to analyse the parameters measured at the generator for turbine and to determine its loading characteristics. Electricity from the SETUR DVE 120 equipment is generated by a synchronous generator with permanent magnets. These electrical units feature a relatively high efficiency and a high momentum density (GIERAS, 2010; HÖLL, 2014). The weak point of these generators operated with uncontrolled rectifiers is their inability to control their output voltage, which depends not only on the running speed and on the generator's momentary electrical output, but also on the unit's current operating temperature (HÖLL, 2014). On the other hand, their ability to operate in 'island mode' is a significant strength, supporting the versatility of their application (POLÁK, 2013). This strength is enabled by the already mentioned permanent magnets.

MATERIALS AND METHODS

The operating measurements were performed on a synchronous generator in a laboratory of the Department of Mechanical Engineering, Faculty of Engineering, Czech University of Life Sciences in Prague. The measurements of this generator (Fig. 1) were performed using a measuring electrical circuit.

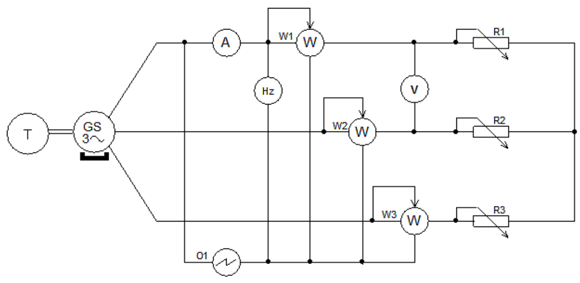

Fig. 1. – Electrical circuit for synchronous generator measuring

T – turbine, GS – synchronous generator, A – ammeter, W – wattmeter(W1, W2, W3), V – voltmeter, Hz – electronic frequency meter,O1 – oscilloscope, R1, R2, R3 – loading rheostats

A bladeless turbine (T) was the source of mechanical energy for the generator. The generated electricity flowed in a three-phase system through a wattmeter (W1, W2, and W3) into an electrical load formed by a rheostat (R1, R2 and R3) in each phase. The generator was loaded symmetrically in all phases during measuring. Generator speeds were controlled by amounts of water running through the turbine, reflecting the generator loading by active resistance (island-type loading).

The line voltage had to be measured with a voltmeter (V) to determine the loading characteristics. The phase current was measured with an ammeter. The measured values of the line voltage and the phase current were also used for correct setting of the measuring range in all the wattmeters. An oscilloscope (O1) was used for determining the voltage/time behaviour. The frequency within the electrical system was measured by an electronic frequency meter (Hz). The frequency measurements confirmed that the generator was synchronous. Further text comments on the procedure for this finding.

Determination of Generator Operating and Technical Parameters

Verification of whether the generator was synchronous was carried out at several generator speeds n. If the electrical system frequency f grows linearly with speed, the generator is synchronous. Then the number of pole pairs p was determined from the following formula (1): (HÖLL, 2014)

$$p = 60 \cdot \frac{f}{n} \qquad (-) \qquad (1)$$

The set's total output power P_{el} under a symmetrical load can be calculated by the following formula (2): (Polák 2015)

$$P_{el} = P_1 + P_2 + P_3 \qquad (W) \qquad (2)$$

where: P_1, P_2 and P_3 are output powers of individual phases of generator

The main criteria characterising an alternator are control and loading characteristics. As the alternator is excited by permanent magnets, the control characteristics cannot easily be found. The measured parameters are used for compiling the loading characteristics, i.e. the dependence of the voltage U_{sd} at terminals on the loading electrical (stator) current I - at a constant generator speed n, frequency f and power factor cos φ. These characteristics are sometimes termed external.

The generator fed a resistance load during measuring. The power factor was cos $\varphi = 1$ throughout the measuring. (GAMPA, 2016)

RESULTS AND DISCUSSION

The determination of operating and technical parameters confirmed that the unit was synchronous. This conclusion was based on the electrical system frequency being dependent on the generator speed. It is obvious from Fig. 2 that the electrical system frequency grows linearly with growing generator speed.

It was calculated by means of formula (1) that there were 10 pairs of poles in the synchronous generator, i.e. it was a 20-pole unit.

Loading characteristics were compiled for the synchronous generator (Fig. 3). Curves were drawn for selected generator speeds. It is clear on first sight that the curve lines rather presented a linear decrease with growing load. The growing generator load increased the electrical (stator) current and decreased the line voltage.

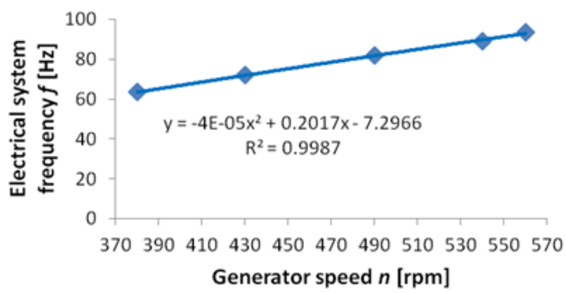

Fig. 2. – Electrical systém frequency – generator speed relationship

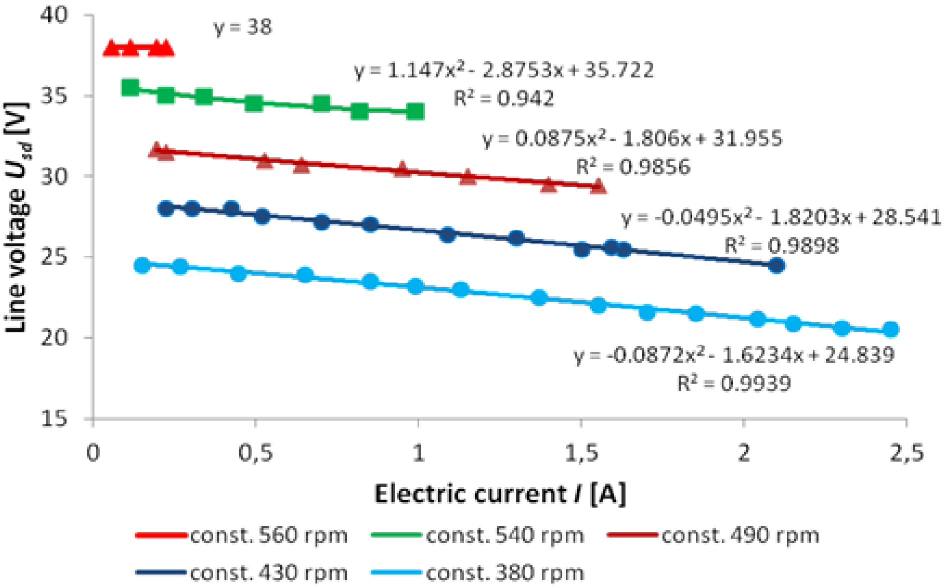

Fig. 3. – Generator loading characteristics – line voltage dependence on the electric current

POLÁK (2013) mentions the possibility of using sets DVE 120 to charge the batteries, but without additional experimental findings. Fig. 3 shows a relatively high dependence of the electrical line voltage U_{sd} on generator speed n, or used electrical current I. An individual stabiliser would be needed to eliminate voltage changes for a particular appliance.

Fig. 3 presents somewhat difficult to read characteristics for n = 560 rpm. For that reason Fig. 4 shows these characteristics in detail. When the generator was gradually loaded at this speed, its line voltage remained virtually unaltered, reaching 38 V.

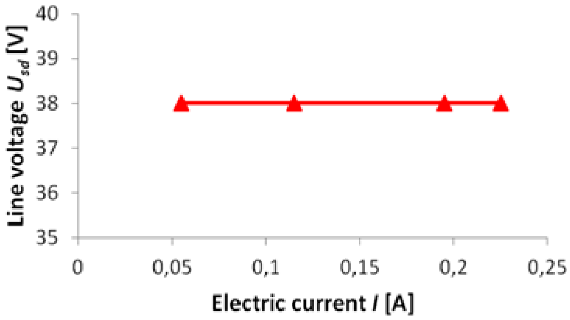

Fig. 4. – Generator loading characteristics for n = 560 rpm

The line voltage behaviour over time was determined with an oscilloscope (Fig. 5). At the same time the generator's electrical system frequency was recorded by means of an electronic frequency meter.

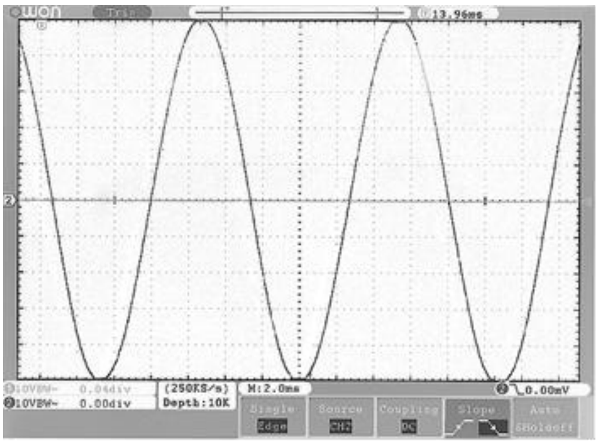

Fig. 5. – The line voltage U_{sd} behaviour at a generator speed n = 560 rpm and an electrical system frequency of f = 93.3 Hz

To summarise, the electrical system frequency was f = 93.3 Hz and the line voltage amplitude $U_{sd;max}$ = 53.5 V at a generator speed of n = 560 rpm and an effective voltage of U_{ef} = 38 V – as measured by a voltmeter.

The dependence of the line voltage on the electrical power (Fig. 6) further documents the applicability of this generator. The loading characteristics (at constant speed) featured a linear voltage decrease with increasing load. The curve lines had rather a slightly negatively-logarithmic shape at lower speeds.

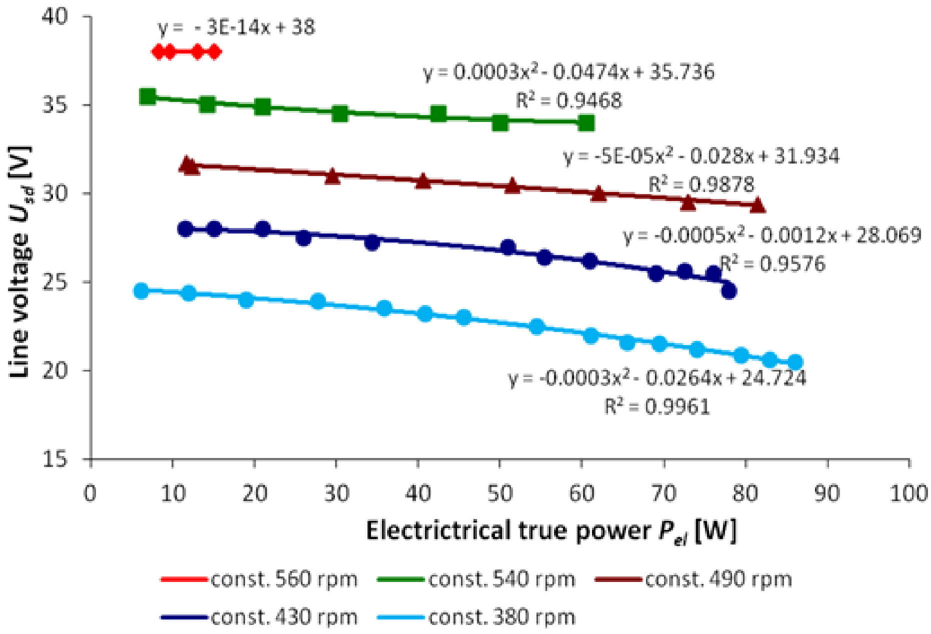

Fig. 6. – Generator loading characteristics – line voltage dependence on the electrical true power

CONCLUSIONS

The objective of the experiment was to determine the operating and technical parameters of a generator linked to a bladeless turbine. The measured values of the generator's peripheral parameters were influenced by the mechanical power supplied by the bladeless turbine. The process found that the DVE 120 set contained a synchronous generator with 10 pole pairs, i.e. it was a 20-pole unit. The output line voltage changed linearly with changing current (decreasing with growing loads) in the set's operating mode. Line voltages generated clear sinusoids, free of any visible deformations. When the synchronous generator (speed of 560 rpm) load was reduced, the electrical system frequency was $f = 93.3$ Hz, which corresponded to a line voltage amplitude $U_{sd;max} = 53.5$ V at an effective voltage of $U_{ef} = 38$ V – as measured by a voltmeter. The generator was operated at different additional speeds, which corresponded with values of line voltage $U_{sd} = 34 \div 35.5$ V, electrical current $I = 0.115 \div 0.99$ A and maximum overall electrical true power of $P_{el} = 60.5$ W achieved at a generator speed of $n = 540$ rpm; of line voltage $U_{sd} = 29.4 \div 31.7$ V, electrical current $I = 0.195 \div 1.55$ A and maximum overall electrical true power of $P_{el} = 81.4$ W achieved at a generator speed of $n = 490$ rpm; of line voltage $U_{sd} = 24.5 \div 28$ V, electrical current $I = 0.225 \div 2.1$ A and maximum overall electrical true power of $P_{el} = 78$ W achieved at a generator speed of $n = 430$ rpm and of line voltage $U_{sd} = 20.5 \div 24.5$ V, electrical current $I = 0.15 \div 2.45$ A and maximum overall electrical true power of $P_{el} = 86$ W achieved at a generator speed of $n = 380$ rpm.

Based on the determined loading characteristics, we can now predict the generator's electrical output parameters when working together with a bladeless turbine under various local conditions. If the generator is operated in conjunction with the above turbine, the characteristics of such a water turbine need to be known – work is still underway to clarify these.

The DVE 120 set is equipped with a bladeless turbine and a generator featuring permanent magnets. It is therefore suitable for electricity generation in "island mode", i.e. independent of electrical infrastructure.

The speed of the set changes with the current offtake in island operation as well as the output current frequency and voltage. This feature is inconvenient for appliances fed by an alternating current system. Output current rectification seems to be more beneficial. Such a set is suitable for charging rechargeable batteries.

ACKNOWLEDGEMENT

This work has been supported by the Internal Grant Agency of the Faculty of Engineering, Czech University of Life Sciences Prague, Project 2014:31130/1312/3114 (Determination of bladeless turbine operating characteristics from the user's perspective).

REFERENCES

1. BHUSAL, P., ZAHND, A., ELOHOLMA, M., HALONEN, L.: Energy efficient innovative lighting and energy supply solutions in developing countries. International Review of Electrical Engineering (I.R.E.E.), 2007: pp. 665 - 670.
2. GIERAS, J. F.: Permanent magnet motor technology. 3rd edition. New York: CRC Press. 2010: ISBN 978-1-4200-6440-7.
3. HÖLL, J., WILDA, L.: PM generator s různým počtempólů a typem vinutí pro použití v manipulační technice. Elektrorevue, Volume 16, Issue 2, April 2014: pp. 100 - 104. ISSN 1213-1539.
4. IEA, I. E. A.: World Energy Outlook 2006. Paris, France, November 2006: pp. 567.
5. KUCHAR, L., IWAŃSKI, S.: Rainfall Simulation for the Prediction of Crop Irrigation in Future Climate. Infrastrukturai Ekologia Terenów Wiejskich. 2011: Nr 2011/05.
6. LAHIMER, A. A., ALGHOUL, M. A., SOPIAN, K., ET AL.: Research and development aspects of pico-hydro power. Renewable and Sustainable Energy Reviews, Volume 16, Issue 8, October 2012: pp. 5861 - 5878. ISSN 1364-0321.
7. POLÁK M., ET AL.: Bezlopatková miniturbína. Praha: Nakladatelství ČVUT, 2013: pp. 57 - 59. ISBN 978-80-01-05233-4.
8. POLÁK, M., DLABAL, L.: Operating characteristics of a bladeless turbine for irrigation purposes. Soil and Water Research, Volume 10, Issue 4, December 2015: pp. 278 - 283.
9. GAMPA S. R., DAS D.: Optimum placement of shunt capacitors in a radial distribution system for substation power factor improvement using fuzzy GA method, International Journal of Electrical Power & Energy Systems, Volume 77, May 2016: pp. 314 - 326, ISSN 0142-0615.

Corresponding author:

Ing. Zbyněk Vondrášek, Ph.D., Department of Electrical Engineering and Automation, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3194, e-mail: vondrasek@tf.czu.cz