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Cite as: AIP Conference Proceedings **2449**, 030009 (2022); https://doi.org/10.1063/5.0090961
Published Online: 01 September 2022

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Piezoelectric Springy Wind Generator

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Abstract. The article discusses a piezoelectric springy wind energy generator with a vertical propeller, having three piezoelectric plates, connected in parallel or in series. The impact force on the mechanical system, consisting of a spring and a two-component structure, comprising a piezoelectric plate and a brass substrate, has been simulated in ANSYS R19.1. With the help of the equivalent electromechanical circuit and Simulink, the voltages on the piezoelectric plates at idle run have been obtained. Experimental studies and modeling have been performed, determining the influence of the propeller's revolutions per minute and the connection scheme of the piezo-plates on the output electrical parameters of the wind energy generator.

INTRODUCTION

The consequence of the miniaturization of industrial products is a reduction in energy consumption. This creates opportunities for the use of micro-power generators, such as piezoelectric water and wind energy generators [1-4].

Piezoelectric wind generators are of two main types: rotary and linear [4, 5, 6]. In turn, rotary piezoelectric generators are divided into two main types: with a horizontal or a vertical axis [4]. Vertical-axis generators have a significant advantage, as they do not require directing of their propeller when the wind direction changes [4].

The present work studies and models a piezoelectric wind generator with a vertical-axis propeller and three piezo-plates, connected in parallel or in series. The aim is to determine the influence of both the number of revolutions per minute and the connection scheme of the piezo-plates on the output electrical parameters of the wind generator.

EXPOSITION

In this study a piezoelectric wind generator with a vertical-axis propeller, consisting of the following elements, was investigated and modeled (Figure 1): 1 - base, 2 - bearing, 3 - vertical axis, 4 - propeller, 5 - rod, 6 - brass base, 7 - spring and 8 – piezo-plate. As the propeller rotates, the rod 5 strikes successively the free ends of the three springs, which begin to move with attenuating sinusoidal oscillations. The oscillations are transmitted to the two-component mechanical structure, containing a brass base and a glued to it piezoelectric plate. Thus, the mechanical energy of the propeller is transmitted through the springs to the piezoelectric plates and converted into electrical energy, thanks to the direct piezoelectric effect.

Plates, made of piezo-ceramics PZT 5A with diameter D_p = 20 mm and thickness T_p = 0.3 mm, rectangular brass bases with dimensions 28x20x0.3 mm, springs with diameter D_s = 4.63 mm, wire diameter d_s=0,63 and length l_s=20 mm were used for producing the considered wind generator. The vertical-axis propeller has a diameter of 100 mm and a height of 90 mm.

10th International Scientific Conference "TechSys 2021" – Engineering, Technologies and Systems
AIP Conf. Proc. 2449, 030009-1–030009-8; https://doi.org/10.1063/5.0090961
Published by AIP Publishing. 978-0-7354-4397-6/$30.00

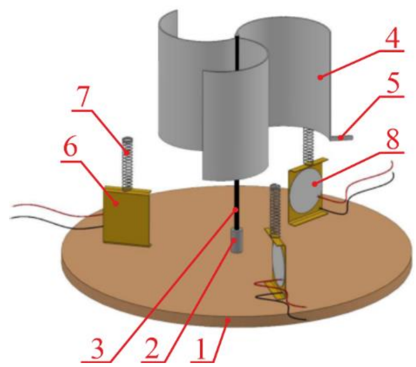

FIGURE 1. Piezoelectric wind generator.

In the process of modeling with ANSYS R19.1, the impact of the force reaction 2- F, resulting from the rotation of the propeller, was simulated on the mechanical system spring – two-component structure, comprising a piezo-plate and a brass substrate - Figure 2.

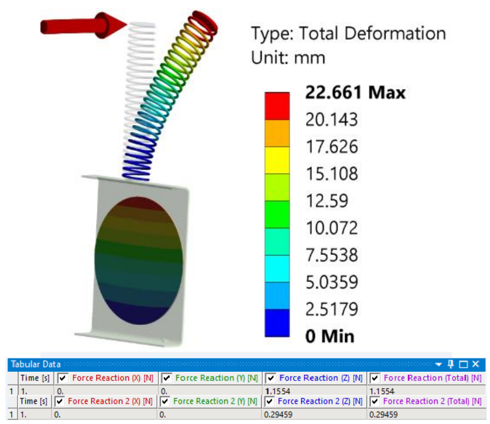

FIGURE 2. Impact force reaction 2 simulation in ANSYS.

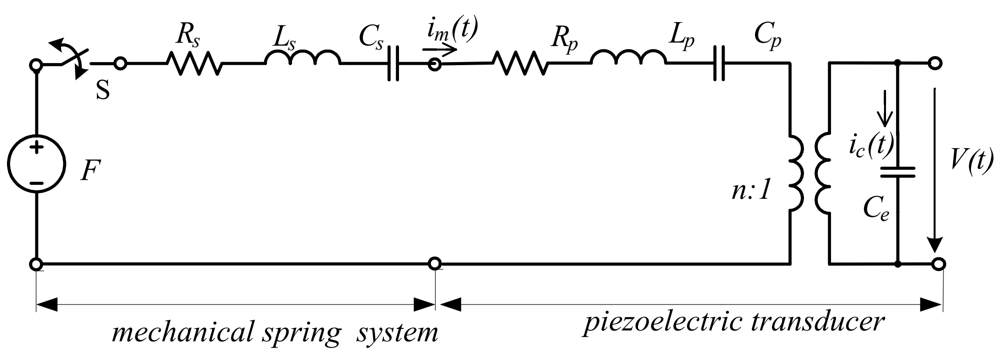

FIGURE 3. Equivalent electromechanical circuit diagram of the piezoelectric wind generator.

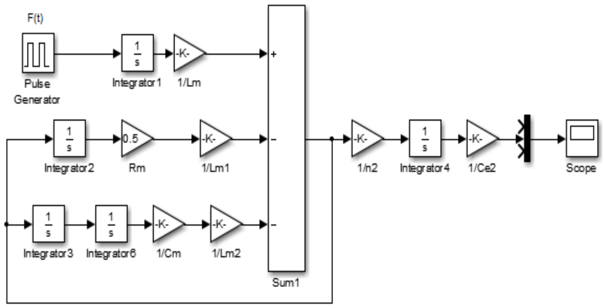

FIGURE 4. Simulation scheme in MATLAB environment.

The equivalent electromechanical scheme (Figure 3) was made, taking into account the mechanical and electrical parameters of the system, composed of a spring and a two-component structure, comprising a piezoelectric plate on a brass substrate. A model of the generator in MATLAB was created with Simulink (Figure 4) and the simulated attenuating sinusoidal voltages of the piezo-plates were obtained (Figure 5).

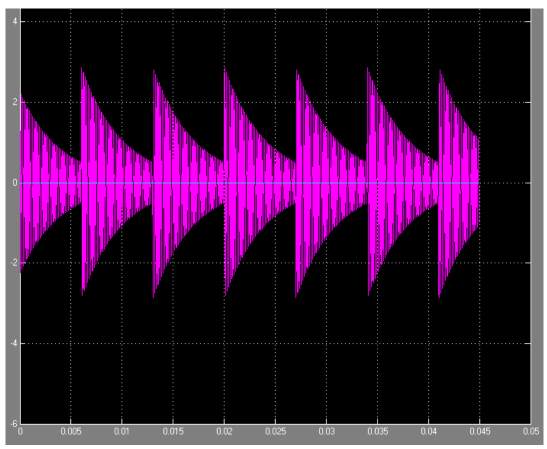

FIGURE 5. Simulated attenuating sinusoidal voltage at idle run in MATLAB environment.

When an impact force acts on the free ends of the springs, a transient process develops. Exponentially attenuating sinusoidal mechanical oscillations are obtained, which, thanks to the straight piezoelectric effect, are converted into electrical voltage.

The transient process has a duration Δt and at the beginning of it the voltage in the piezoelectric plate has a maximum amplitude V_{m1}, while at the end of the attenuation process the amplitude is V_{mn} (amplitude for the n-th oscillation) - Figure 6. Due to the inertia of the mechanical part, the electric voltage V(t) decreases exponentially for time Δt [7].

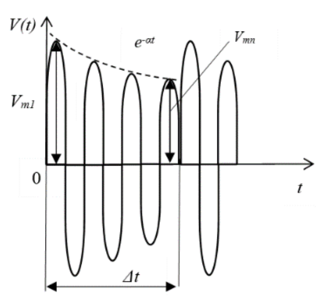

FIGURE 6. Attenuating sinusoidal voltage at idle run.

The voltage on the piezoelectric plate $V_L(t)$ in instantaneous form is equal to

$$V(t) = V_{m1} e^{-\alpha \Delta t} \sin \omega t \tag{1}$$

The attenuation coefficient α can be calculated with the help of

$$\alpha = \frac{1}{\Delta t} \ln \frac{V_{mn}}{V_{m1}} \tag{2}$$

The rectified voltage at idle run is equal to

$$V = \frac{V_{m1}}{\sqrt{2}} e^{-\alpha \frac{\Delta t}{2}} \tag{3}$$

The charge Q on the plates of the piezoelectric plate with capacity C_p, is

$$Q = C_p V \tag{4}$$

In the equivalent circuit diagrams of the piezoelectric plates - Figure 7 and Figure 8 - the equivalent sources of current are indicated.

$$J(t) = \frac{dQ}{dt} \tag{5}$$

The active power can be determined from (3), where by R_L the active load is denoted

$$P = \frac{V^2}{R_L} = \frac{U_L^2}{R_L} \tag{6}$$

The three piezoelectric plates are connected in parallel with a common rectifier or in series with separate voltage rectifiers [8].

The equivalent circuit diagram of the three piezo-ceramic plates, connected in parallel with one common voltage doubler, is shown in Figure 7. Figure 8 shows the electric circuit diagram of the three piezo-ceramic plates when a voltage doubler is connected in series to each plate.

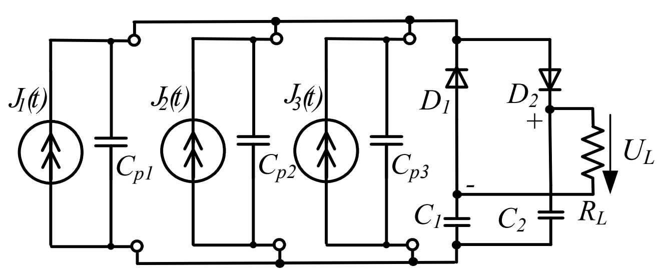

FIGURE 7. Equivalent circuit diagram with parallel-connected piezo-plates.

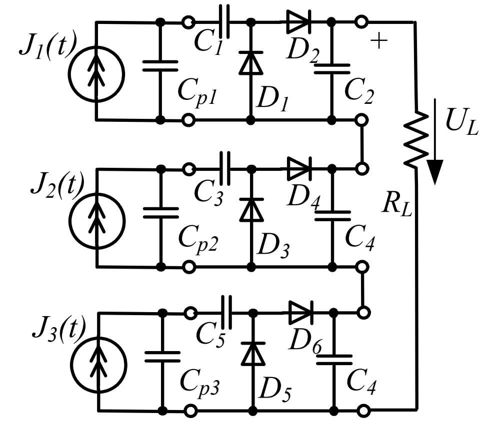

FIGURE 8. Equivalent circuit diagram with series-connected piezo-plates.

EXPERIMENTAL STUDIES

Experimental studies were performed for the two connection schemes of the piezoelectric plates. The DC voltages, currents and powers, measured for the range of revolutions per minute of the generator propeller from 400 to 1400 min^{-1}, are presented in Figures 9, 10 and 11 for the parallel-connection scheme of the three piezo-plates, and in Figures 12, 13 and 14 - for the series-connection scheme of the three piezo-plates, respectively.

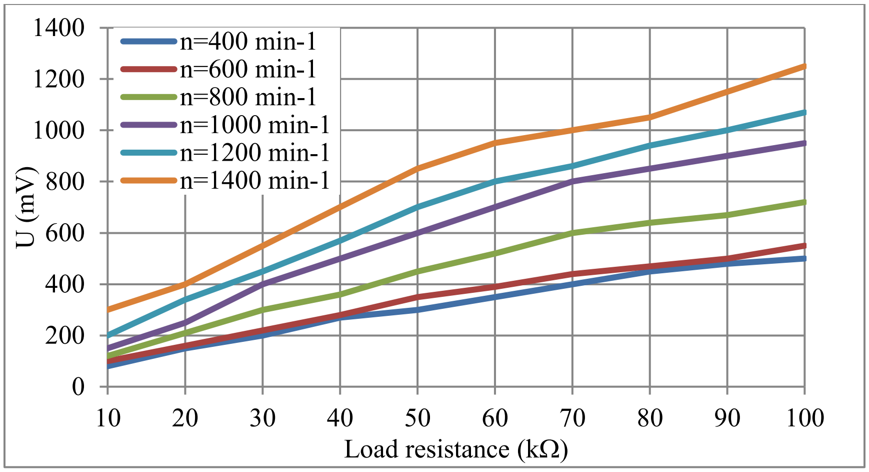

FIGURE 9. Voltages in the case of parallel-connected piezo-plates.

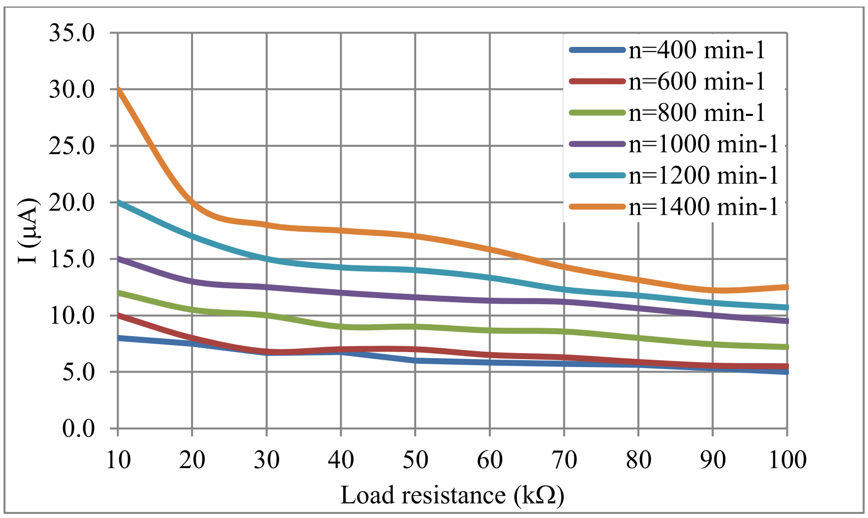

FIGURE 10. Currents in the case of parallel-connected piezo-plates.

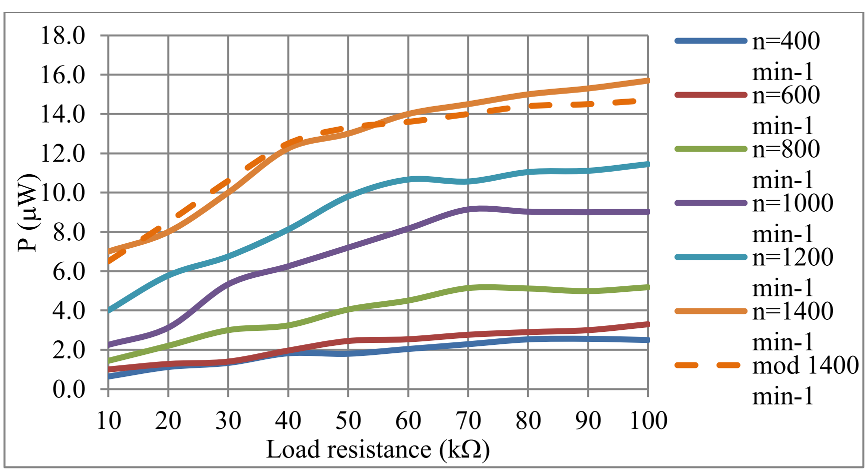

FIGURE 11. Powers in the case of parallel-connected piezo-plates.

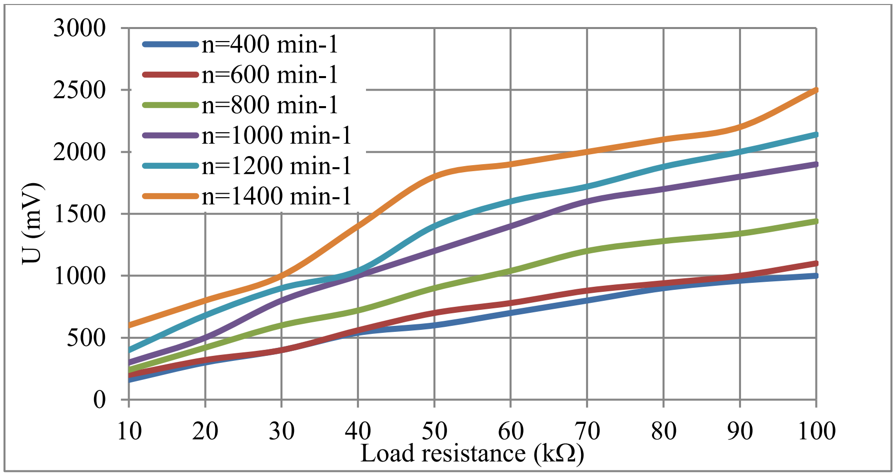

FIGURE 12. Voltages in the case of series-connected piezo-plates.

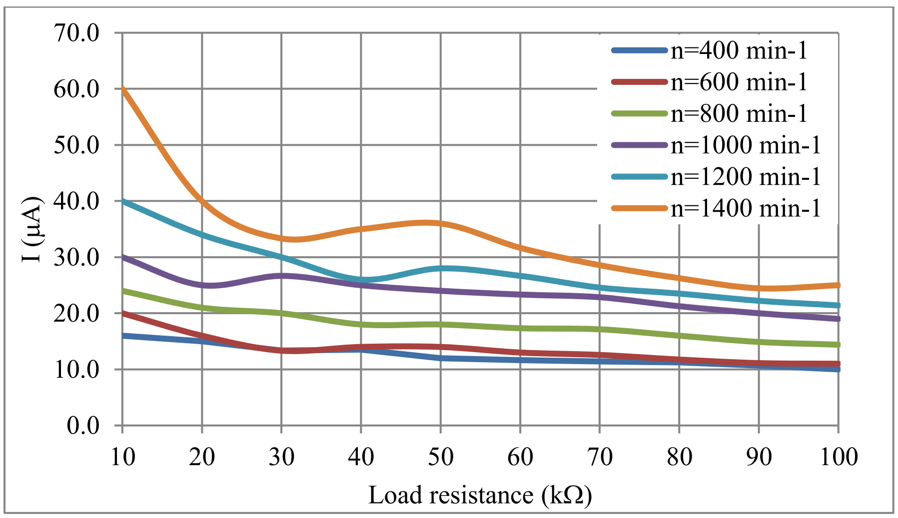

FIGURE 13. Currents in the case of series-connected piezo-plates.

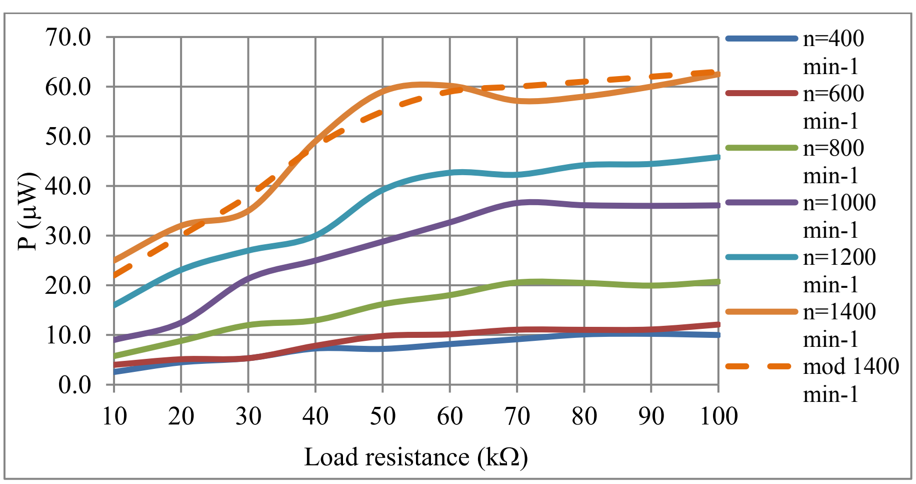

FIGURE 14. Powers in the case of series-connected piezo-plates.

The graphs show that with the increase in the number of revolutions, the voltages, currents and powers of the generator increase linearly in the circuits with both parallel and series-connected piezoelectric plates. The voltages and currents in the cases of series connection are twice as high as those, in the cases of the parallel connection, and the powers are 4 times higher. The increase in the load resistance leads to an increase in the measured voltages and powers, and decrease in the currents for both connection schemes of the piezoelectric plates. The presented model simulates the operation of the piezoelectric wind generator with sufficient accuracy. The maximum relative error between the experimentally measured and the obtained from modeling maximum powers for n=1400 min^{-1} in case of series connection is δ_{max}=10,7%, and for the case of parallel connection of the piezo-plates it is δ_{max}=7,6%.

Table 1 presents the maximum measured voltages, currents, and powers, as well as the maximum relative errors for the two types of connection of the piezoelectric plates in the wind generator.

TABLE 1. Maximum, voltages, currents and powers and relative errors at 1400 min^{-1}.

Type of connection of the piezoelectric plates	Maximum measured voltages (V)	Maximum measured currents (μA)	Maximum measured powers (μW)	δ_{max} (%)
Parallel	1.25	30.2	15.7	7.6
Series	2.51	60.5	62.3	10.7

CONCLUSIONS

From the conducted experimental studies and on the basis of the simulations with ANSYS R19.1 and MATLAB, it has been established that with the increase of the revolutions per minute, the voltages, currents and powers of the generator increase linearly for the schemes with both parallel- and series-connected piezo-plates. The voltages and currents in the cases of series connection are twice as high as those, in the cases of parallel connection, and the powers are 4 times higher. The presented model accurately simulates the operation of the piezoelectric wind generator, as the maximum relative error between the measured and the obtained from the simulation powers for n=1400 min^{-1} for the case of series connection is 10.7%. With this type of piezoelectric generators, relatively high voltages and small currents are obtained at high-resistance loads. When the piezo-plates are series-connected after the voltage doublers, and at the highest number of revolutions per minute n=1400 min^{-1}, the best output electrical parameters are obtained. The proposed series connection scheme is more suitable to be used for practical implementation of the considered piezoelectric wind generator with a vertical axis.

An additional increase in the electrical parameters can be achieved by adding 3 or 6 more piezoelectric springs in both schemes of connection.

ACKNOWLEDGMENTS

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

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