Efficiency of the generating set with synchronous generator supplied with single-phase electricity receivers

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Summary. The paper presents the analysis of efficiency changes of synchronous generating set supplying the single-phase receiver sets. The laboratory stand was described as well as the methodology of investigations. On the basis of investigation results, the influence was evaluated of size and character of electricity receiver on the efficiency of generating set.

Key words: synchronous generating set, efficiency of generating set.

INTRODUCTION

Electrical equipment applied on the farm is used continuously, cyclically, or incidentally. An example of continuous operation is to maintain a specific climate in livestock buildings (ventilation, heating, humidification, etc.). Cycler work concerns the room operations, preparation of feed or handling animals (milking cows, feeding the feed, milk cooling, etc.). In these cases, the correct work requires continuity of electricity supply. Its primary source is a professional power network. In the case of individual consumers, it does not have the possibility of bilateral supplying. This forces the use of the reserve source of electrical energy. The source of the reserve in relation to controls, which is unacceptable for even a momentary loss of power are usually UPS. On the other hand, a typical device requires sources with higher power and a sufficiently long time of power reserve, such as generating sets.

Typical electrical appliances on the farm are refrigerators, motors, 1-phase heaters and lighting. In this case allowable power interruption time varies from several minutes to about 1 hour. Thus, a sufficient source of backup in a typical farm may be one-phase generating set with manual start-up [6].

SYNCHRONOUS GENERATING SET

The generating set consists of two main components: the drive and generator (Fig. 1). Propelling device is usually an internal combustion engine with spark ignition. The power is transferred to an electric generator synchronous or asynchronous. Here, mechanical energy is converted into electrical energy.
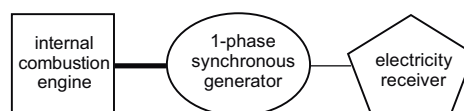

Fig. 1. Layout of generating set

The quality of parameters of energy (230V and 50 Hz) is achieved by maintaining the speed and the selection of the magnetizing current. So, the device additionally includes the system of speed control and field current regulator.

A typical synchronous generator consists of two main parts [5, 9, 15]: the stator (armature) and rotor, which is the magnetizer (Fig. 2).
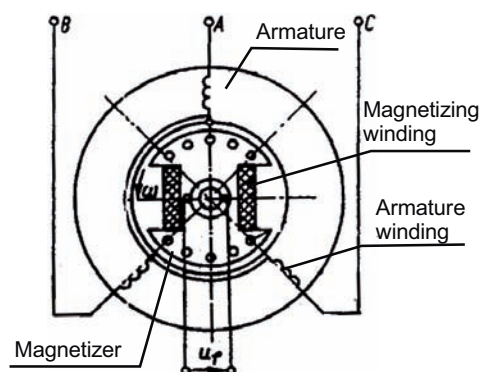

Fig. 2. The schematic diagram of the synchronous machine [15]

The flow of direct current through the magnetizing winding wound on the rotor of the generator produces a magnetic flux. The stream is rotated with the rotor windings, at the same speed relative to the stator induces in its winding an AC voltage. The value of this voltage affects magnetizing current. The frequency of the generating voltage is directly proportional to the rotor speed.

The conversion of mechanical energy to electrical energy occurs with certain efficiency. It shall be changed with the changes of power and the type of connected electricity receivers. Hence the aim of the described study was to determine the efficiency of energy conversion depending on the generator load.

LABORATORY STAND

Measurements were conducted on the laboratory stand (Fig. 3) made in the Department of Technology Fundamentals at the University of Life Sciences in Lublin. The investigations were carried out on the single-phase synchronous generator (1) the type EA 2000 about the nominal power $P_n = 1,7$ kW, the indicative power $S_n = 2$ kVA, the nominal voltage $U_n = 230$ V and the nominal intensity of current $I_n = 8,7$ A.
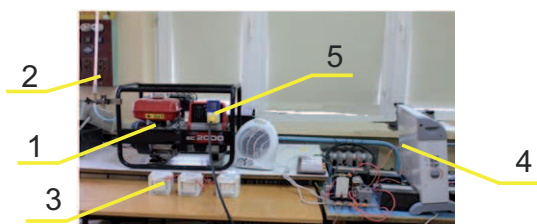

Fig. 3. The laboratory stand to measure the efficiency of power generating set: 1. power generating set, 2. fuel measurement system, 3. inductive load, 4. resistive load, 5. energy power meter

The engine of generating set (1) has a modified fuel system. The carburetor unit is supplied via calibrated burette (2). This allows for measuring doses of burned fuel. The time to obtain a specified portion of the burned fuel was measured using a stopwatch. The inductive elements (3) and a resistance (4) were used to load the generator. Measurement of the load power was provided by multi-parameter energy power meter (5).

METHODOLOGY

The generator is followed by conversion of mechanical energy into electrical energy. The mechanical energy produced in the combustion engine is the result of thermal energy Q_p generating from the combustion of fuel. The end result is generating electricity (W_p).

To determine the efficiency of processing, a specified amount of thermal energy (Q_p) was obtained after combustion of fuel metered dose (V) and the amount of power (W_p) produced by the generator.

Thermal energy is based on the volume of spent fuel and its calorific value (c_p):

$$Q_p = V * c_p, \text{ [J]}. \tag{1}$$

The amount of electricity (W_p) is based on the measured electrical power (P) received from the generator and the combustion time (t_s) at a certain amount of fuel (V):

$$W_p = P * t_s, \text{ [J]}. \tag{2}$$

The energy conversion efficiency is based on the formula:

$$\eta = W_p / Q_p. \tag{3}$$

THE RESULTS OF INVESTIGATION

During the study unleaded petrol Pb95 was used. The calorific value is dependent on the manufacturer and distributor of fuel and is between 29-38 MJ/ m³ [11, 12, 13, 14]. For the calculation purposes the calorific value was equal to 32 MJ/m³. During each measurement 5 cm³ of fuel was consumed.

In the first part of the study the generator was debited by resistance. The load varied from no load to 1,07 of generator rated power. The results are summarized in Table 1.

Table 1. The investigation results of the synchronous generating set load resistance

P, W	t_s, s	W_p, J	Q_p, J	η, -
0	32,6	0	160000	0,000
208	30,1	6268	160000	0,039
423	28,1	11877	160000	0,074
605	26,4	15992	160000	0,100
878	22,5	19792	160000	0,124
1120	19,7	22027	160000	0,138
1418	17,6	24957	160000	0,156
1668	15,6	26021	160000	0,163
1760	14,6	25701	160000	0,161

Then, resistive-inductive load was attached to the generator. Constant active power was kept of about 1 kW and 0,5 kW and varied inductive load. The measurement results are shown in Table 2 and Table 3.

Table 2. The investigation results of the synchronous generator with resistive-inductive load for P ≈ 1kW

$\cos\phi$, -	t_s, s	W_p, J	Q_p, J	η, -
0,59	21,0	12629	190000	0,066
0,80	17,0	17114	190000	0,090
1,00	20,4	21711	190000	0,114

T a b l e 3. The investigation results of the synchronous generator with resistive-inductive load for P ≈ 0,5kW

$\cos\phi$, -	t_s, s	W_p, J	Q_p, J	η, -
0,50	22,2	11645	190000	0,061
0,55	25,7	13604	190000	0,072
0,65	26,2	14358	190000	0,076
0,85	28,7	15737	190000	0,083
1,00	27,9	14814	190000	0,078

Fig. 5. The graph of changes of the efficiency of the generating set when changing the power factor for load $P \approx 1$ kW

THE ANALYSIS OF INVESTIGATION RESULTS

The analysis results are presented as graphs of changes efficiency η as a function of load power changes *P* or changes of the power factor cosϕ.
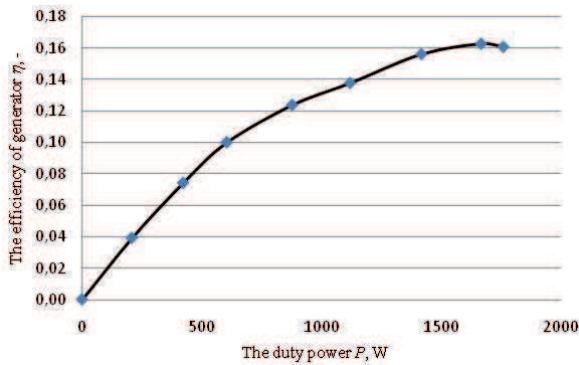

Fig. 4. The graph of changes of the efficiency of the generating set when changing the load power

Figure 4 shows the change in the efficiency of the generating set as a function of power factor, for constant loading generator active power equal to 1 kW. Increasing the generator load increases the efficiency of energy conversion. The maximum efficiency of 16,3% was achieved for the power of 1,67 kW load. The energy conversion efficiency increases linearly from 0 to 10% power in range from 0 to about 0,6 kW. Further increase in power up to 1,67 kW is an approximately linear increase in efficiency to 16,3%. In this range, efficiency gains are smaller than before. Exceeding the rated power causes a decrease in efficiency. At 1,76 kW load power efficiency is 16,1%.

The course of changes in the efficiency of the generating set as a function of load power is of a different nature than changes of the electrical efficiency of the generator itself. In a typical generator, the efficiency initially increases rapidly, and in a wide range of loadings it remains practically constant [2, 4]. The efficiency of the generator is dominated here by the internal combustion engine efficiency as a function of load torque. Changes of the internal combustion engine efficiency initially increases slightly as a function of load torque and then, after reaching the maximum, it slightly decreases [1, 7].
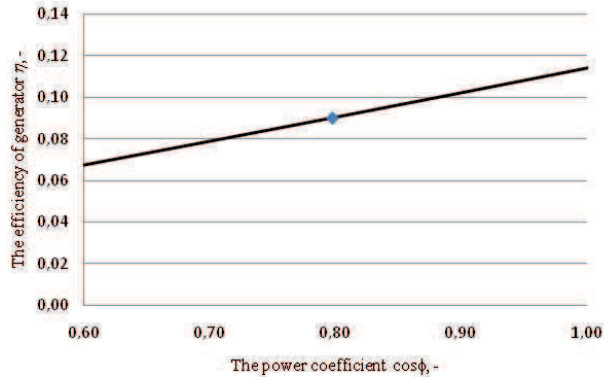
Figure 5 shows the change in the efficiency of the generating set as a function of power factor for the constant active power loading generator equal to 1 kW.

In this case, the efficiency increases with increasing generator power factor. When the active power load is 1kW, the increase of power factor *cos*ϕ from 0,6 to 1,0 increases the efficiency of the generator from 6,6% to 11,4%.

Changes in the efficiency of the generator as a function of the power factor for a constant active power loading generator of 0,5 kW are shown in Figure 6.
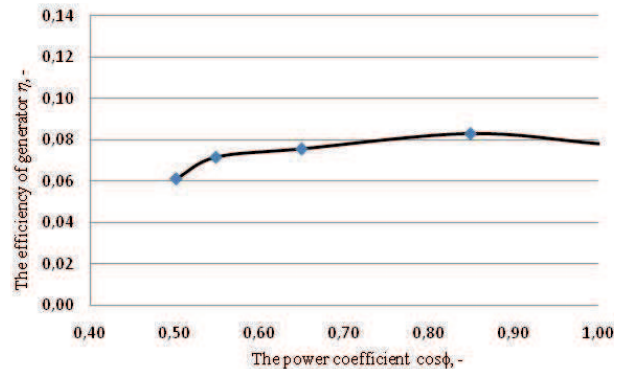

Fig. 6. The graph of changes of the efficiency of the generating set when changing the power factor for load $P \approx 0,5$ kW

When the active power load is 0,5 kW, the increase of power factor *cos*ϕ from 0,5 to 1,0 increases the efficiency of the generator from 6,1% to 8,3%.

Increase of the power factor is associated with the reduction in the reactive current of supply receiver. This reduces energy loss and thus increases efficiency.

CONCLUSIONS

The study showed that the efficiency of single-phase synchronous generating set of low power is small. The maximum one was 16.1%. The highest value of efficiency is achieved at the load with an output power close to the rated power of generator.

So, from the economic point of view, the power of the generator must be matched to the power supplied by loads, so that it worked with the power unit similar to

the plate. However, this implies an increased emission of pollutants into the environment [3, 8, 10].

The most efficient use of energy contained in the fuel is possible with supplying resistive loads, such as incandescent lighting or convection heating.

The supply of resistive-inductive (RL) devices causes a decrease in the efficiency of the electric generating set. Thus, it may be expedient to use systems for reactive power compensation.

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SPRAWNOŚĆ ZESPOŁU PRĄDOTWÓRCZEGO Z SYNCHRONICZNYM GENERATOREM WYPOSAŻONYM W JEDNOFAZOWE Z ODBIORNIKI ELEKTRYCZNE

Streszczenie. W artykule przedstawiono analizę zmian sprawności zespołu prądotwórczego z generatorem synchronicznym zasilającego odbiorniki jednofazowe. Opisano stanowisko badawcze i metodykę badań. Na podstawie przeprowadzonych pomiarów dokonano oceny wpływu wielkości i charakteru obciążenia na sprawność pracy zespołu prądotwórczego.

Słowa kluczowe: zespół prądotwórczy, sprawność zespołu prądotwórczego.