Zbigniew ŁUKASIK[1], Aldona KUŚMIŃSKA-FIJAŁKOWSKA[1], Jacek KOZYRA[1]

Uniwersytet Technologiczno-Humanistyczny w Radomiu, Wydział Transportu, Elektrotechniki i Informatyki (1)

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Automation and visualization of the process of production of biogas for the purposes of production of electric energy

Abstract*. The changes occurring on the electric energy market result also from policy towards European energy market. European countries are obliged to determine and implement uniform power industry rules. Poland is a country of high potential of development of the systems using biogas for production of electric energy. Environmentally-friendly production of energy is a goal and challenge of our times. The authors of this publication presented an example of modern automation and visualization of technology of process of production of biogas for the purposes of production of electric energy. Presented technology of automation of production of biogas confirms high level of innovativeness.*

Streszczenie. *Zachodzące zmiany na rynku energii elektrycznej wynikają z polityki ogólnoeuropejskiego rynku energii oraz wdrażania jednakowych zasad funkcjonowania względem energetyki. Polska jest krajem o dużym potencjale rozwoju instalacji wykorzystujących biogaz do produkcji energii elektrycznej. Energia wytwarzana bez zanieczyszczenia środowiska, to cel i wyzwanie współczesnych czasów. Autorzy tej publikacji przedstawili przykład nowoczesnej automatyzacji i wizualizacji technologii procesu wytwarzania biogazu na potrzeby produkcji energii elektrycznej. Zaprezentowana technologia automatyzacji wytwarzania biogazu potwierdza wysoki poziom innowacyjności.*
*(**Automatyzacja i wizualizacja procesu produkcji biogazu na potrzeby produkcji energii elektrycznej**)*

Keywords: Automation, Visualization of processes, Renewable energy, Biogas.
Słowa kluczowe: Automatyzacja, Wizualizacja procesów, Energia odnawialna, Biogaz.

Introduction

National energy balances, developed on the basis of the results of statistical studies show directions of consumption of particular carriers of renewable energy. Under national conditions, energy from renewable sources includes energy of solar radiation, water, wind, geothermal resources, energy generated from solid biofuels, biogas and liquid biofuels, as well as environment energy acquired by the heat pumps [11]. The acquisition of this form of energy in recent years was slightly increasing [25], [26]. The share of energy from renewable sources in the acquisition of primary energy increased in the years 2014–2018 from 12,12% to 14,46% [19]. The structure of acquisition of energy from renewable sources for Poland results mainly from characteristic geographical conditions and resources that can be developed [22]. Energy acquired from renewable sources in Poland in 2018 comes predominantly from solid biofuels (69,26%), wind energy (12,40%) and from liquid biofuels (10,20%). Total energy value of acquired primary energy from renewable sources in Poland in 2018 was 371 588 TJ [19].

One of the carriers of renewable energy is biogas. Biogas is combustible gas containing mainly methane and carbon dioxide, acquired in the process of anaerobic digestion of biomass. In the statistical reporting, due to method of acquisition, the following biogases are distinguished:

- landfill biogas, acquired as a result of digestion of waste on the storage yards,
- biogas from sewage sludge, produced as a result of anaerobic digestion of sewage sludge,
- remaining biogases:
  - o agricultural biogas acquired in the process of anaerobic digestion of biomass coming from energy crops, the remains from plant production and animal excrement;
  - o biogas acquired in the process of anaerobic digestion of biomass coming from waste in the slaughterhouses, breweries and remaining food industries.

According to data from November 2019, the number of biogas plants in Poland is 308 systems of total power 239 MW, including agricultural biogas plants - 96 systems of power 103 MW [20].

Low number of biogas plants results from poor financial conditions on the Polish biogas market, despite that, the development of innovative technologies and solutions in this sector is fast comparing to other countries. In the years 2014-2018, the amount of produced biogas was systematically increasing and 39,0% more biogas was produced in 2018 in comparison with 2014. It is estimated that in the next few years, up to 1000 systems can be built in Poland, and even 2500 systems before 2030 [21].

With reference to the systems using biogas, there was gradual growth of production of electric energy [23], [24]. In 2018, 38,1% more energy was produced in comparison with 2014. The growth of production of electric energy from biogas was affected by dynamic growth of use of „remaining biogases" (in 2018, the growth was 83,7% in comparison with 2014). Table 1 presents the level of production of electric energy acquired from biogas.

Table 1. Production of electric energy from biogas in the years 2014-2018

	2014	2015	2016	2017	2018
	GWh				
Biogas, including:	**816,3**	**906,4**	**1027,6**	**1096,4**	**1127,6**
biogas from waste dumps	**225,3**	**226,8**	**223,5**	**199,6**	**169,6**
biogas from sewage treatment plants	**252,5**	**275,6**	**364,4**	**340,1**	**336,5**
remaining biogas	**338,4**	**404,0**	**439,7**	**556,7**	**621,6**

Automation and visualization of the processes of production of biogas

A diagram of a biogas system was presented on Figure 1. Initially, energy resource is stored. Another step is administering biomass to the digestion chambers. Th resource in the chambers undergoes two-week process of digestion, usually methane of high electrical efficiency about 87%. Gas is transferred and combusted by the cogeneration unit. As a result, electric energy is produced and used for system internal load, and excess is sold to an energy network. The management of waste heat is currently one of the methods of improvement of economic balance of biogas investments.

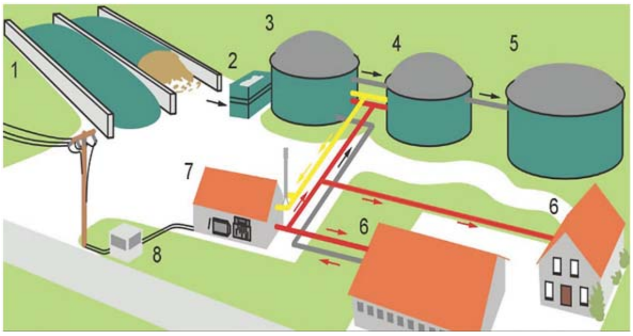

Fig.1. A diagram of a: 1 – Energy resource facility, 2 – Biomass dispenser, 3,4 - Digestion chambers, 5 – Digestate storage facility, 6 – Farm buildings heated with thermal energy, 7 – Cogeneration unit along with measurement and control equipment and boiler room, 8 – Transformer SN/nN [8]

Described technological process affects the type of implemented control system [2]. It is very important to select appropriate devices and algorithm for the type of the process of production of biogas. We should take into account especially continuous batch processes, data transmissions, controlling the drives that require appropriate selection of devices and automatic control process of biogas production technology.

In many cases, programmable logic controller is used to control the biogas plants. This controller is connected to a control panel through network that allows to exchange messages about the state and faults between controller and control panel. The values and control commands to the system are sent in the same way, which makes operation of this device much easier [4].

Thanks to applied control panel, an operator can easily enter data for modification and management of the process of production and control the state of a system. Modern control process has a very rich pallet of archiving messages and information about the state of operation of a biogas plant and can connect with a control device through GSM module [5], [6]. Control panel cooperating with programmable logic controller is perfect for visualization and operation of devices of a system by an operator, allowing also to see the current state of particular sections of a biogas plant system [3].

On the diagram presented on Figure 2, we can clearly see a diagram of logical organization of the groups of the so-called windows that makes moving between particular groups of sections intuitive and user-friendly. One group is one section or area of a system that permanent identification number was assigned to.

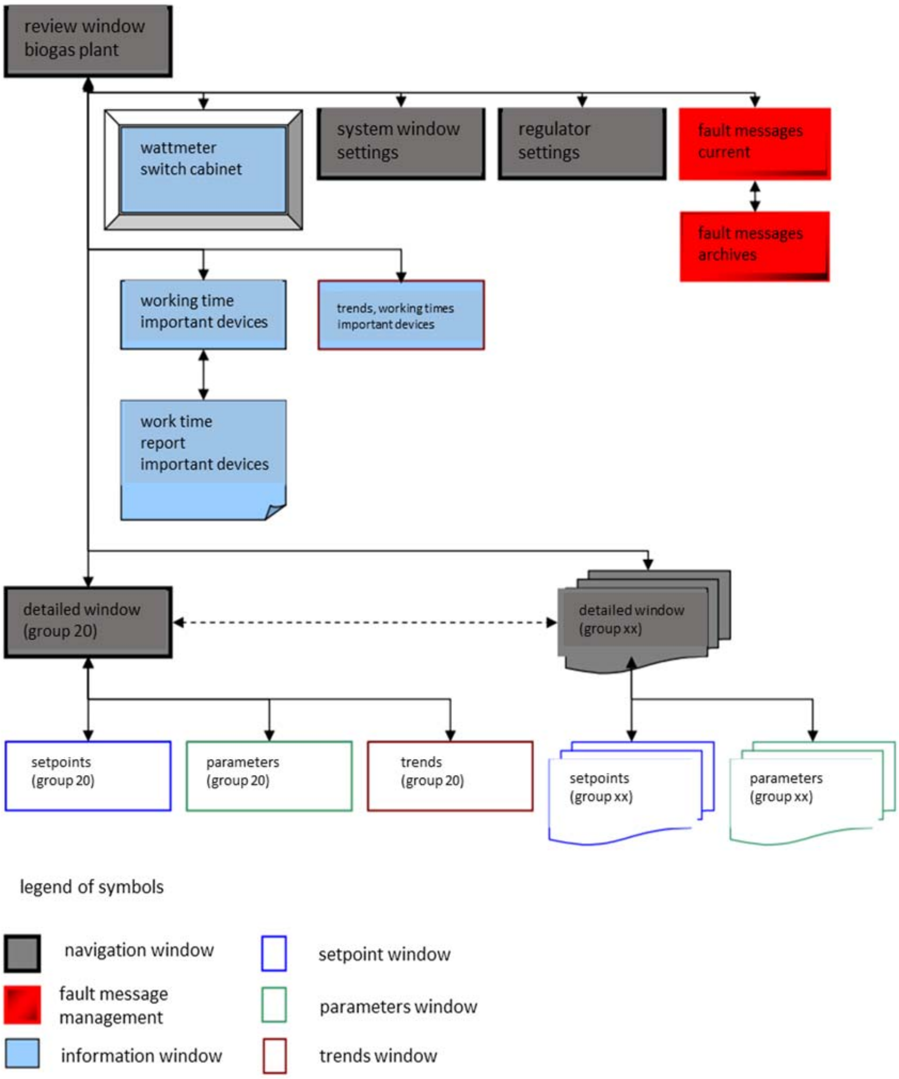

Fig.2. Organizational diagram of a control system [8]

A review windows presented on Figure 2 allow complex preview of the whole system. From there, you can go to detailed windows of particular sections of a system. In a review window, you can see only the most important parameters of the state of particular sections. Control panel allows to use detailed windows of particular sections that make all devices of this group visible. From every detailed window, you can go to subsequent windows referring only to a selected detailed window. They are usually set values, parameters, trend charts and controller settings. Figure 3 shows a main diagram of visualization of automatic control of biogas plant [6].

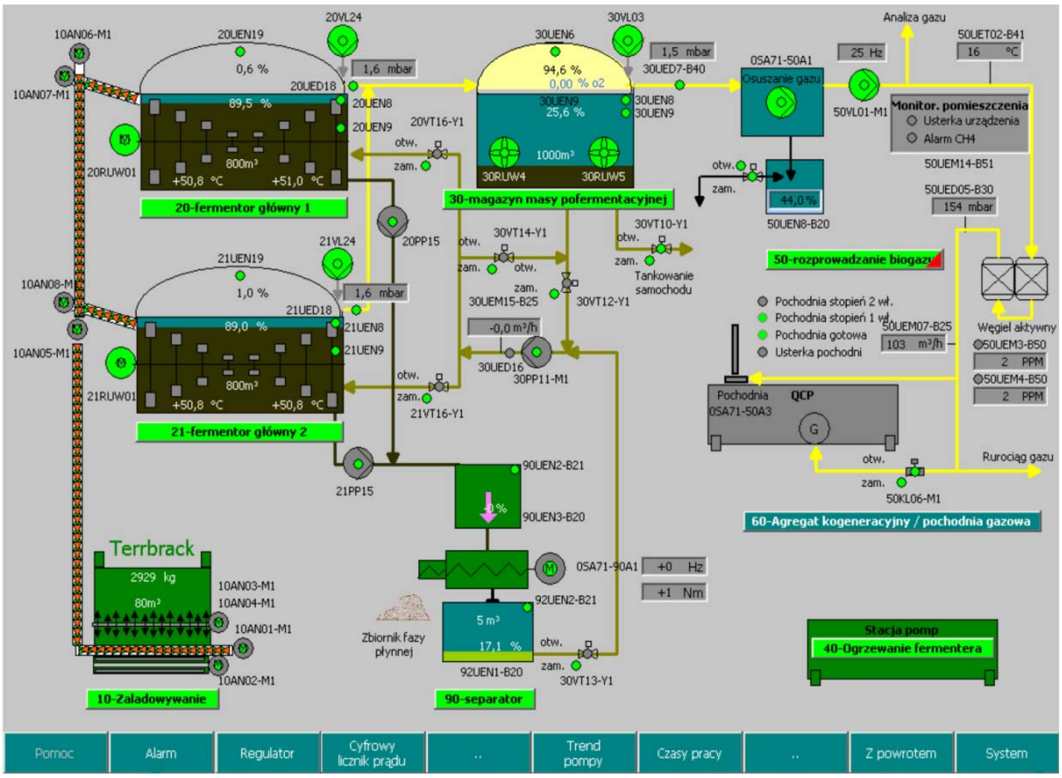

Fig.3. Main control diagram [8]

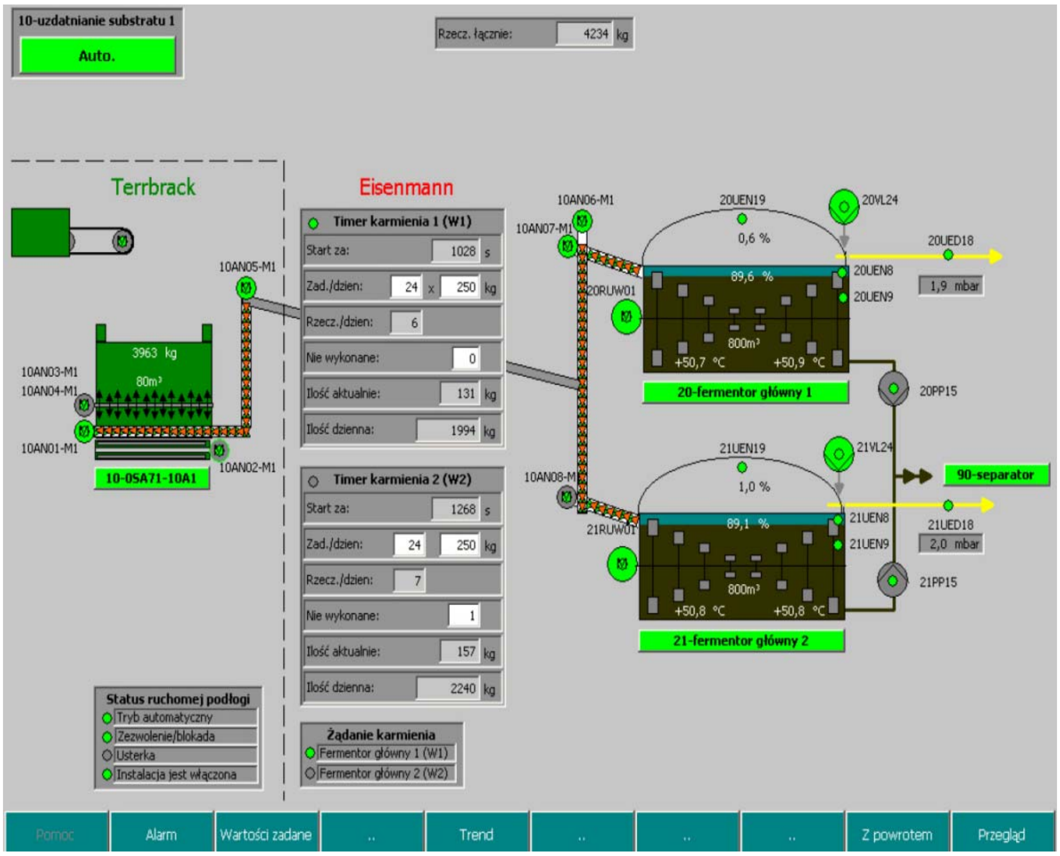

Fig.4. Visualization of automatic process of feeding substrate in a biogas plant [8]

A review window of a biogas plant of a control panel allows complex preview of the whole diagram of a system along with all technological sections. Bottom navigation bar has buttons allowing to move to various information windows [9].

Automation system includes organization of work, among others, in storage of energy resource, coordination of transport, determination of composition and maintenance of appropriate balance of feeding ram material and metering of process lines. It also controls ventilation, keeps the system clean, empties materials and storage. It control operation of a diesel engine, current generator and cooperation with a power grid [10]. Programmable logic controller is responsible for the whole automatic process of production of biogas and further conversion into electric and thermal energy. It controls operation of the machines and is adjusted to algorithm of operation. This algorithm is saved in a dedicated controller with programming language, performs operations one by one, without any additional delays [12]. An example of visualization of automatic process of feeding substrate in a biogas plant was presented on Figure 4.

Conversion of biogas into electric energy

At every biogas plant, it is necessary to use produced biogas for other required form of a product, that is, electric or thermal energy [17]. Biogas plant in the end process of production has a cogeneration unit allowing to produce electric energy or use heat for different purposes, for example, for wood drying or heating. The parameters of a cogeneration unit were presented on Figure 5.

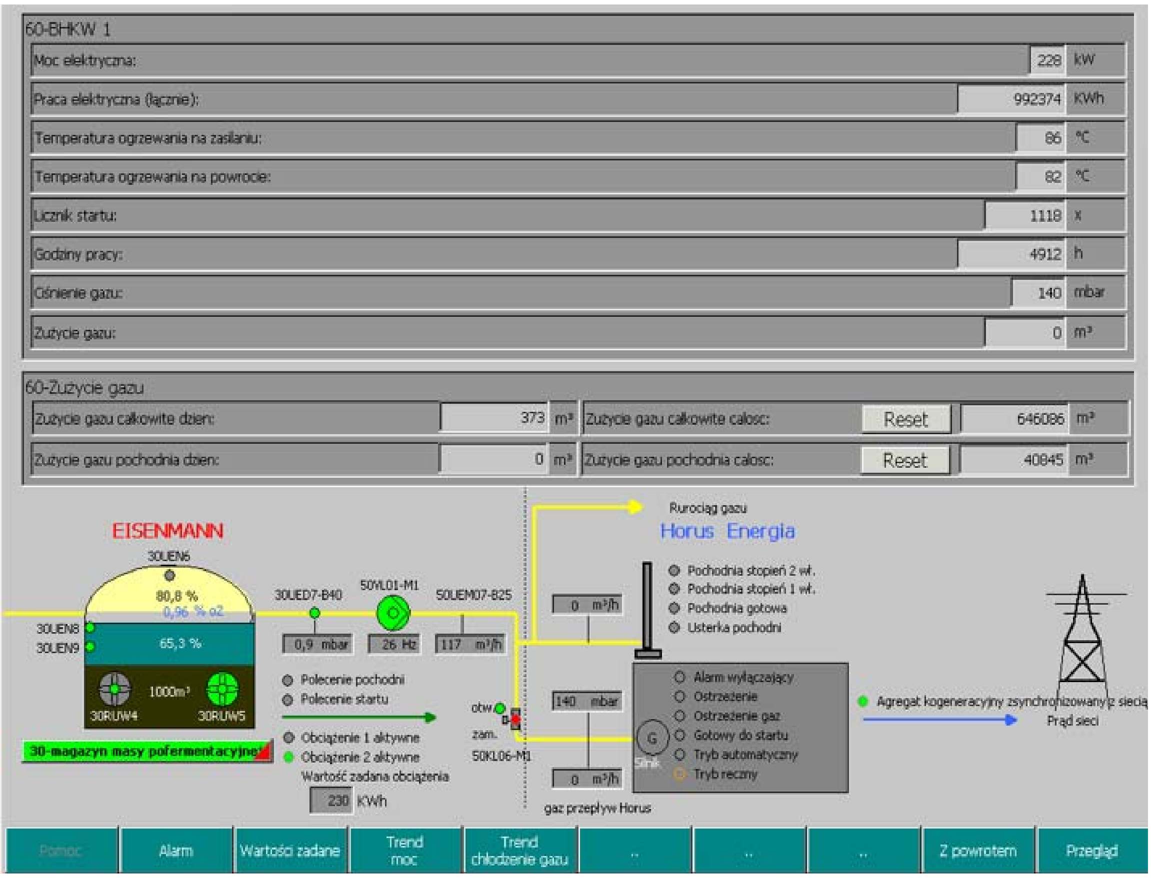

Fig.5. Visualization of parameters of a cogeneration unit [8]

A drive unit of a cogeneration unit is an industrial turbocharge, four-stroke spark ignition engine. This engine has 12 cylinders placed in V-twin system [13]. Gas is mixed with air in a mixer placed in an engine. Then, mixture of gas with air is transferred to specific cylinders. The amount of mixture is administered through throttle of a speed controller. As a result of combustion of gas-air mixture in particular cylinders, fuel energy is converted into mechanic energy (about 40%) and thermal energy (about 60%) – even if a cogeneration unit is characterized by high electrical efficiency [13].

Mechanic energy of an engine is transferred to a generator using a clutch, whereas, thermal energy can be recovered or dispersed through external radiator. Biogas is a mixture of methane about 55%, CO_2 about 45% and admixtures of carbon dioxide, trace amounts of sulphur, nitrogen and others. Gas engine with an electronic speed controller, electric starter, automatic system to control and add engine oil without interrupting operation of a unit, path to supply biogas with necessary fittings, from a device regulating the process of combustion in terms of not exceeding permissible emission of NO_x and CO_x. Data concerning power of a unit refer to operation using low-calorie gas of calorific power about 21 MJ/m^3 (60%CH_4) and methane number Mz >100. In the event of lower caloricity of gas, output power will be appropriately lower [14].

In order to select power of a unit, we must pay particular attention to the value of power demanded by the receivers. Demanded active power is determined from a relation (1):

$$P_Z = \sum_{I-1}^{n} k_Z \cdot P_i \quad (1)$$

where: P_Z - demanded active power [W], k_Z - demand factor [-], P_i - active power of a loading unit [W].

Then, it is important to calculate demand reactive power determined from a relation (2):

$$Q_2 = \sum_{I-1}^{n} k_Z \cdot tg\varphi_i \cdot P_i = \sum_{I-1}^{n} k_Z \cdot \sqrt{\frac{1}{cos^2\varphi_i} - 1} \cdot P_i \quad (2)$$

where: Q_Z - demand reactive power [var], $cos_{\varphi i}$ - power factor of a loading unit using guaranteed power supply system [-].

The values of demand active power and demand reactive power are obtained from a relation (3) demand power factor $cos_{\varphi z}$ for working unit :

$$cos_{\varphi z} = \frac{P_Z}{\sqrt{P_Z^2 + Q_Z^2}} \quad (3)$$

Another stage of selection of a unit is calculation of the lowest active power for a unit generator to meet demand of active power P_z, as well as reactive power Q_z. Determination of this power is necessary because during production of energy with power factor $cos\varphi_Z < cos\varphi_{nG}$, the ability of generating efficiency of active power decreases, which results in increase of thermal load of generator stator. A combustion device that drives the unit must be adjusted to active power of a unit, that is, with rated power factor $cos\varphi_{nG}$, therefore, during production of electric energy, having a factor $cos\varphi_Z < cos\varphi_{nG}$, efficiency of conversion of thermal energy into electric energy decreases [14]. Apparent power of a selected diesel-electric unit should meet inequality (4):

$$S_{nG} = \geq \frac{P_{Gmin}}{cos\varphi_{nG}} \quad (4)$$

where: P_{Gmin} - minimal active power of a unit [W], $cos\varphi_{nG}$ - rated power factor of a generator of a unit assumed on the basis of operation instruction recommended by the producer of a unit.

Electric energy produced in a biogas plant

Measurement and accounting system of electric energy applied in a biogas plant is compatible with applied transmission of data. It meets applicable requirements of Distribution Company defined in the Operation and Maintenance Manual of Medium Voltage Distribution Network. Accounting measurement of energy consumption by the consumer is taken in a switchgear SN 15/0,4 kV as an indirect one in a star system of current transformers. [12]. System of electric energy produced by a biogas plant is executed as a low voltage indirect system on the clamps of a generator. It is also used as a system checking the origin of energy produced from renewable sources. Both systems are synchronized in accordance with real time using GPS watch. Transmission of data to measurement system of Distribution Company takes place via communication module GSM/GPRS. Applied modem allows transmission of data from basic and reserve measurement system to the system through GSM network [16].

During operation of a biogas plant, approximate measurement of instantaneous power of a unit was taken. A chart of instantaneous power of a unit was presented on Figure 6.

A chart presented on Figure 6 shows that voltage during 15 minutes of measurement in particular phases is slightly different from remaining phase voltages. The voltage of phase L1 is different from remaining ones by 2 V. The load of particular phases is not uniform and differs maximally by 6 A. The changes in value of voltage do not exceed the level ±10% for 15 minutes of measurement in accordance with Polish Standard PN-EN 50160:1998 „The parameters of voltage in public distribution networks”, which is an implementation of European Standard EN 50160:1994. The powers returned by the unit are 76 kW for active power and about 87 VA for apparent power. For production of energy with a load of 250 kW, the unit combusts about 100m^3 of biogas. The efficiency of conversion of primary energy of biogas into electric energy is not lower than 30%.

Parametr		value	unit
tension	L1-N	236,4	V
tension	L2-N	238,9	V
tension	L3-N	238,3	V
intensity	L1	118,1	A
intensity	L2	121,8	A
intensity	L3	124,9	A
Active power		76,0	kW
Apparent power		86,7	VA
Total power consumed		776423,1	kWh

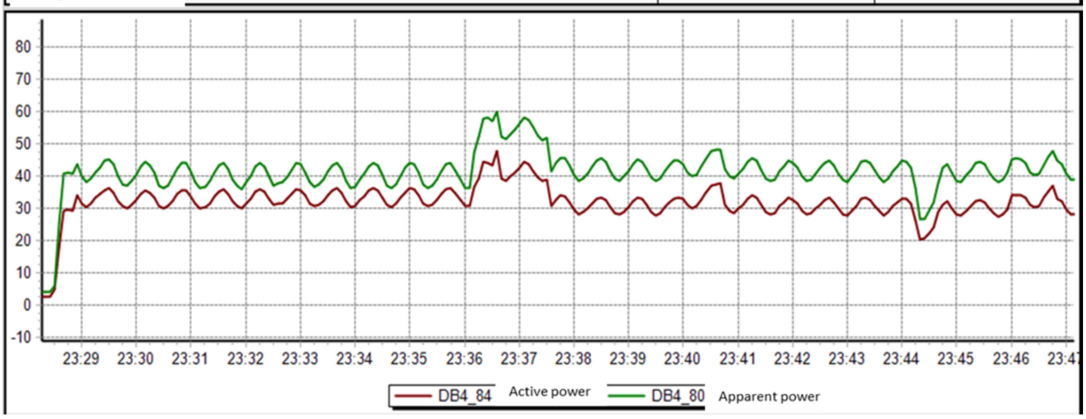

Fig.6. Instantaneous power of a unit applied in a biogas plant [8]

Conclusions

The changes occurring on the electric energy market result also from policy towards European energy market. European countries are obliged to determine and implement uniform power industry rules. Nowadays, electric energy is a significant subject on the energy market. This product is, like any other, is produced by the producers, bought be the brokers who ten sell it to individual customers, institutions and companies. Therefore, it must be transported from a place of production to an end customer.

Nowadays, the acquisition of energy from renewable sources is becoming more and more popular both in Poland and around the world. An interest in renewable sources of energy is increasing every year, also in acquisition of biogas. The development of biogas power industry is diverse both in terms of number of systems and degree of their complexity. The potential of biogas power industry in Poland is still not exploited sufficiently in comparison with other renewable sources of energy. Nowadays, along with an auction system, supporting the development of acquisition of electric energy from biogas, this area of renewable sources of energy is stable, although, we should to make development of biogas more dynamic in the context of potential of Poland, income of farmers and policies of other countries setting global trends, that is, Germany, China and the United States. We must remember that Poland possesses technology of building third-generation biogas plants, which can be applied in Poland, but can also be an interesting export goods, for example, to the Ukraine that has high potential of biogas and problems with meeting gas demand due to aggressive Russian policy.

Technology of automation of production of biogas in Poland is at high level and often more technologically advanced than similar systems in the Western countries. It can be confirmed in the examples of new investments showing current place of Poland in the group of global leaders in terms of innovations in biogas and raw materials for its production. Taking into account the amount of available biomass and bio waste, omitting target crops and municipal waste, their conversion in the biogas systems may generate more than 4000 MW of power (more than 6000 MW in a peak load), which is much higher amount than power of planned nuclear power station 3750 MW.

***Autorzy**:*
prof. dr hab. inż. Zbigniew Łukasik, UTH Rad., Wydział Transportu, Elektrotechniki i Informatyki, ul. Malczewskiego 29, 26-600 Radom, E-mail: z.lukasik@uthrad.pl; dr hab. inż. Aldona Kuśmińska-Fijałkowska, prof. UTH Rad., Wydział Transportu, Elektrotechniki i Informatyki, ul. Malczewskiego 29, 26-600 Radom, E-mail: a.kusmińska@uthrad.pl; dr hab. inż. Jacek Kozyra, prof. UTH Rad., Wydział Transportu, Elektrotechniki i Informatyki, ul. Malczewskiego 29, 26-600 Radom, E-mail: j.kozyra@uthrad.pl.

REFERENCES

[1] Bayer E., Rączka J., Baker P., Elementy nowej organizacji rynku energii w Polsce, *Forum Analiz Energetycznych*, 11, (2015)
[2] Cherubini, F., Strømman, A.H., Life cycle assessment of bioenergy systems: State of the art and future challenges. *Bioresource Technology*, 102(2), (2011), 437–451
[3] Ziółkowski T., Inwestycje w efektywność energetyczną, *Fundusze Europejskie*, (2012), No. 3 , 32-33
[4] Tylko R., *Odnawialne źródła energii*, Warszawa, (2011)
[5] Widerski R., Liberalizacja rynku energii elektrycznej szansą na rozwój usług, *Polityka Energetyczna*, 16(1), (2013)
[6] Wierzbowski M., Stankiewicz R., Współczesne problemy prawa energetycznego, *LexisNexis*, (2010)
[7] Zimny J., Rozważania na temat modelu energetycznego Polski. Czy Polska może być samowystarczalna energetycznie? Akademia Górniczo-Hutnicza. *Materiały dydaktyczne dla studiów podyplomowych Odnawialne Zasoby i Źródła Energii*, Kraków, (2010)
[8] Opracowanie Katedry Automatyzacji Procesów i Logistyki, *Automatyzacja procesów wytwarzania biogazu i przetwarzania go na energię elektryczną*, UTH Radom, (2017)
[9] https://www.aut1omatyka.siemens.pl/solutionandproducts_ia/4132.htm#moduly- [access date: 01.04.2017]
[10] Kubica W., Zamówienia sektorowe w energetyce - zagadnienia wybrane, [w:] *Regulacja innowacja w sektorze energetycznym,* W. Pyzioł (red.), Warszawa, (2013)
[11] Lindkvist, E., Karlsson, M., Ivner, J., System analysis of biogas production - Part II application in food industry systems. *Energies*, 12, (2019), 412
[12] Malko J., Ogólne uwarunkowania bezpieczeństwa energetycznego w Polsce. *Materiały konferencji naukowo-technicznej „Bezpieczeństwo energetyczne Polski”*, Warszawa, (2013), 13
[13] Głodek E., (red.), *Pozyskiwanie i energetyczne wykorzystanie biogazu rolniczego*, Warszawa, (2010)
[14] Wiatr J.: *Poradnik projektanta elektryka*, Wyd. III (rozszerzone), Warszawa, (2008), 41-50 & 326-333
[15] *Odnawialne źródła energii w Polsce*, http://spcleantech.pl [access date: 22.05.2017]
[16] Paska J., Surma T., Polityka energetyczna Polski na tle polityki energetycznej Unii Europejskiej, *Polityka Energetyczna* 16(4), (2013), 7-18
[17] Pham Minh D., Torres A.H., et al. Conversion of Biogas to Syngas via Catalytic Carbon Dioxide Reforming Reactions: An Overview of Thermodynamic Aspects, Catalytic Design, and Reaction Kinetics, S. Nanda et al. (eds.), *Biorefinery of Alternative Resources: Targeting Green Fuels and Platform Chemicals*, Springer Nature Singapore Pte Ltd. (2020), 427-456
[18] Babula M., Renewable sources of energy in Poland – biogas. Journal of Education, *Health and Sport*, eISNN 2391-8306. http://dx.doi.org/10.5281/zenodo.1419519, (2018), 8(9), 943-950
[19] Energia ze źródeł odnawialnych w 2018 r., Analizy statystyczne, *Główny Urząd Statystyczny*, Warszawa, (2019)
[20] https://wysokienapiecie.pl/23838-pomysl-na-biogazownie-pilnie-poszukiwany
[21] Dach J., Kozłowski K., Potencjał rozwoju sektora biogazu w Polsce. https://rynekbiogazu.pl
[22] Korczak, A., Olczykowski, Z., Wojciechowski, J. The smart grid technology in Poland as a part of global electric power system. *Globalization and ITS Socio-economic consequences*, 16th International Scientific Conference proceedings, PTS I-V, (2016), 945-952
[23] Lemvig Biogas, An example of successful centralized co-digestion in Denmark, Biogas in Society, IEA Bioenergy Task 37 "Energy from Biogas", (2013)
[24] Rutz, D., Sustainable use of the thermal energy of biogas, *Renewable Energies*, Munchen, Germany, (2012)
[25] Łukasik Z.,Kozyra J.,Kuśmińska-Fijałkowska A. Oddziaływanie przesyłu i rozdziału energii elektrycznej na środowisko naturalne. Autobusy: technika, eksploatacja, systemy transportowe 18, (2017)
[26] Łukasik, Z., Kozyra J., Kuśmińska-Fijałkowska A.. "An analysis of power supply reliability indexes in the selected distribution company." *Przegląd Elektrotechniczny* 96 (2020).