UDC 620.9:658
DOI: 10.15587/2706-5448.2023.289928

Stefan Zaichenko,
Denys Derevianko,
Roman Kulish

DETERMINATION OF ENERGY EFFICIENCY OF AUTONOMOUS GENERATING EQUIPMENT OF INDUSTRIAL PARKS IN CONDITIONS OF MILITARY AGGRESSION

The work considers the problem of determining the factors of energy efficiency of industrial parks in the conditions of military aggression in the conditions of the introduction of the National Economic Strategy and regulatory influence on Industrial Parks in Ukraine. The energy efficiency of industrial parks primarily depends on the main parameters of the selected technological processes that are embedded in the basis of enterprises and their productivity. A significant factor affecting the environmental friendliness and energy efficiency of industrial parks is the method of energy generation. On the basis of the analysis of the work of enterprises operating in conditions of military aggression, the main factors determining the energy efficiency of electricity production have been determined. Such factors are the overall efficiency of the power generating unit, which is determined by monitoring and diagnosing the power unit. Analyzing changes in energy efficiency, the characteristics of the power part of one of the most powerful diesel engines were selected. It is obvious that the diesel locomotive will consume more fuel to generate energy with a decrease in efficiency. The main diagnostic factors of generating equipment that affect the energy efficiency of industrial parks in conditions of military aggression are: the ratio of currents in compressor and depressurized modes, the real degree of compression, and as a result, the efficiency of the power plant. On the basis of the determined factors, the effectiveness of the implementation of the system of monitoring and diagnosing the power units of energy-generating equipment of enterprises in the conditions of military aggression was determined. Recommendations have been established to minimize fuel consumption and reduce emissions to ensure the main principles of industrial parks, environmental friendliness and energy efficiency.

Keywords: *industrial parks, energy efficiency, electric generator, internal combustion engine, energy indicators, diagnostic parameter.*

Received date: 19.08.2023
Accepted date: 23.10.2023
Published date: 28.10.2023

How to cite
Zaichenko, S., Derevianko, D., Kulish, R. (2023). Determination of energy efficiency of autonomous generating equipment of industrial parks in conditions of military aggression. Technology Audit and Production Reserves, 5 (1 (73)), 28–31. doi: https://doi.org/10.15587/2706-5448.2023.289928

1. Introduction

Analysis of regulatory impact on industrial parks in Ukraine is possible provided that a comprehensive determination of criteria involving the assessment of costs, benefits, and consequences of new or existing regulations is carried out to provide information to individuals making important policy decisions. The evaluation of regulatory impact should be based on the principles of energy resource efficiency, balance, predictability, transparency, feasibility, and take into account public opinion [1–4]. Predictability and energy resource efficiency in production can be achieved by identifying the main factors determining the state of energy-generating capacities. Furthermore, the National Economic Strategy for the period up to 2030 sets out the guidelines, principles, and values in economic policy. Among them are European integration (the implementation of the state's strategic course towards full membership of Ukraine in the EU) and economic climate change mitigation (increasing energy efficiency, developing renewable energy sources, promoting the circular economy, and synchronizing with the «European Green Deal» initiative).

The energy efficiency of industrial parks primarily depends on the fundamental parameters of the chosen technological processes that form the basis of enterprises and their productivity. However, a significant factor influencing the environmental and energy efficiency of industrial parks is the method of energy generation. Under normal economic conditions, the undisputed leaders in terms of energy efficiency and environmental friendliness are nuclear and renewable energy. In the conditions of military aggression, when the adversary damages the main generating and distribution facilities, leaving only 40 % of the total system, backup and emergency power sources become the main one.

In the first nine months of 2022, Ukraine imported generators worth 202 million USD, which is 196 million USD more than the previous year [5]. Taking into account the cost of one kilowatt of capacity at 274.26 USD, this new capacity amounts to approximately 1 GW. Most of the generators purchased by Ukrainian enterprises use internal combustion engines as the driving device for the alternator, which significantly altered the distribution of losses in production in terms of the cost of the generated electrical energy. Among the generators introduced into production, 37 % are powerful stations (over 110 kVA) used by small and medium-sized industrial businesses.

In the scientific literature, there are works dedicated to various aspects of industrial park development and the determination of factors influencing their energy efficiency. Among the researchers working on the topic of industrial parks, notable works include [6–8]. The United Nations Industrial Development Organization (UNIDO) also conducts research in this area [9], etc.

The *aim* of research is to identify the factors affecting the energy efficiency of industrial parks in the context of military aggression, taking into account the transition of enterprises to self-generation of electrical energy using internal combustion engine-based generators.

To achieve this objective, the following tasks were addressed in the work:

– Identifying the key factors that shape the energy efficiency of electricity production and, consequently, the efficiency of enterprises within industrial parks.
– Evaluating the effectiveness of implementing a monitoring and diagnostic system for power units of energy-generating equipment at enterprises in the conditions of military aggression based on the identified factors.
– Providing recommendations for minimizing fuel costs and reducing emissions to ensure adherence to the core principles of industrial parks, including environmental sustainability and energy efficiency.

2. Materials and Methods

The following methods were employed in the research:
– Analytical method for the analysis of parameters of generator units based on internal combustion engines.
– Graph-analytical method for studying the change in the efficiency of the power part of the generator based on the current ratio in compressor and leaky modes.

3. Results and Discussion

The primary means for determining the main energy parameters and the condition of energy equipment remain technical diagnostic systems, which have become an integral component of modern technical facilities. Modern power generation units based on internal combustion engines have a range of parameters, mostly focused on monitoring the quality of the generated electrical energy. To establish diagnostic parameters that could predict and determine energy efficiency in production, it is necessary to create a diagnostic testing system.

One of the primary factors used to assess the energy efficiency of a diesel engine is indicated thermal efficiency. Indicated thermal efficiency is the ratio of the heat that has been converted into mechanical work during the working cycle to the total heat input from fuel into the engine. The value of indicated thermal efficiency depends on parameters such as compression ratio, air-fuel ratio, and crankshaft speed.

Indicated thermal efficiency can be calculated using the following formula:

$$\eta_i = \frac{p_i l_0 \alpha}{H_u \rho_k \eta_v}, \quad (1)$$

where p_i – mean indicated pressure; ρ_k – density of the fuel; H_u – lower heating value of the fuel; η_v – volumetric efficiency; l_0 – specific air consumption necessary for fuel combustion; α – air-fuel ratio.

Using this formula is complicated due to the large number of components and the complexity of their determination.

However, indicated thermal efficiency can be theoretically determined, assuming that the working fluid is pure air and that only CO_2 and H_2O are formed during the combustion of hydrocarbon fuel in pure air. Another assumption is the absence of heat exchange with the cylinder walls throughout the entire cycle. Under these assumptions, the efficiency of such a theoretical cycle is:

$$\eta = 1 - \left(\frac{1}{\varepsilon}\right)^{k-1}, \quad (2)$$

where ε – compression ratio; k – adiabatic index (the ratio of specific heat at constant pressure to specific heat at constant volume), which equals 1.4 for air.

Considering the high informativeness of the actual compression ratio of the engine and the strong dependency of power unit performance, the compression ratio is selected as the primary diagnostic indicator. However, the method of its determination requires improvement and modernization. Given the possibility of using starter motor starting currents for analyzing the operation of piston engines [10, 11], it is proposed to use electrical characteristics, the current and voltage supplied to the starter during the crankshaft rotation, as auxiliary parameters to determine the necessary diagnostic object parameters.

The obvious economic benefit of implementing a power plant's power unit diagnostic system lies in fuel savings during electricity generation for the facility and cost savings from unplanned diesel generator repairs.

Reducing specific fuel consumption during electricity generation will also lead to a decrease in harmful emissions, which is an integral concept of eco-industrial parks [1].

It is also important to note that the implementation of a power unit diagnostic system will enhance the overall generator reliability by predicting the resource based on the actual compression ratio of the diesel or individual cylinders.

As mentioned earlier, by experimentally determining the actual compression ratio based on established currents and its impact on the overall generator efficiency after diagnostics using the developed method, it is possible to calculate the cost savings using a developed mathematical computer model [10–15] of the power equipment diagnostics process for diesel engine-based generators.

When analyzing the change in energy efficiency, characteristics of the power unit of one of the most powerful diesel engines, the 16CHN26/26(5D49) with a power output of 3000 hp (2200 kW), were selected. To establish the relationship between the change in efficiency and the diagnostic parameter, the ratio of currents K_I in the compressor and depressurized modes was used to create a diagram (Fig. 1).

The diagram of changes in the efficiency of the generator's power unit as a function of the current ratio K_I in the compressor and depressurized modes shows the difference between the efficiency in the case of a working engine (0.337) and working conditions. It is evident that when efficiency decreases, the generator will consume more fuel. The fuel consumption increase factor is:

$$K_n = \frac{\eta_0}{\eta_s}, \quad (3)$$

where η_0 – efficiency in a healthy state; η_S – efficiency in a working state.

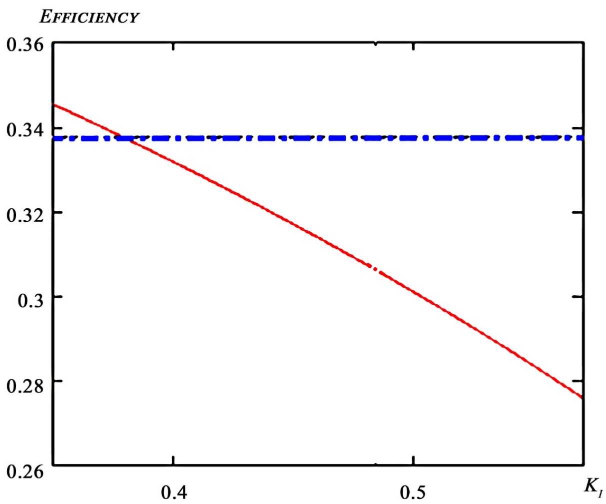

Fig. 1. Diagram of changes in the efficiency of the generator's power unit as a function of the current ratio K_I in the compressor and depressurized modes

Excess fuel consumption in a faulty state:

$$\Delta Q = Q(K_n - 1), \quad (4)$$

where Q – fuel consumption in a healthy state:

$$Q = N \cdot BSFC = 2200 \cdot 211 = 464 \text{ kg/h}, \quad (5)$$

where N – engine power (2200 kW); $BSFC$ – specific fuel consumption (0.211 kg/(kW·h)).

So, for the case of a working state in the selected example:

$$\Delta Q = 464\left(\frac{0.337}{0.328} - 1\right) = \frac{12.73 \text{ kg}}{\text{kW} \cdot \text{h}}. \quad (6)$$

Assuming a power usage of 50 % and usage time of 50 % over 12 months of operation, the annual excess fuel consumption will be:

$$\Delta Q_a = 12.73 \cdot 24 \cdot 12 \cdot 365 \cdot 0.5 \cdot 0.5 = 334500 \text{ kg}. \quad (7)$$

By multiplying it by the fuel cost C_f (as of November 2022, 1.78 USD), let's obtain the annual economic benefit in monetary terms when eliminating the defect related to the deterioration of the cylinder-piston group:

$$E_a = \Delta Q_a \cdot C_f = 334500 \cdot 1.78 = 595410 \text{ USD}. \quad (8)$$

The cost of diesel cylinder repair in the scope of an overhaul is $C_r = 29823.35$ USD. The estimated cost of purchasing diagnostic equipment is $C_{eq} = 1095.23$ USD.

The total cost of diagnostic measures is C_{total}:

$$C_{total} = C_r + C_{eq} = 29823.35 + 1095.23 = 30918.58 \text{ USD}.$$

The payback period for the proposed measure:

$$T = \frac{C_{total}}{E_a} = \frac{30918.58}{595410} \approx 0.052 \text{ year} \approx 19 \text{ days}. \quad (9)$$

In this way, the implementation of the proposed measures is economically justified.

Taking into account the above, it is evident that for the implementation of the National Economic Strategy and regulatory influence on Industrial Parks in Ukraine, under the conditions of military aggression, a comprehensive assessment of the factors affecting energy efficiency, predictability, and environmental performance of enterprises is possible. The key factors that fundamentally affect the operation of enterprises are the condition of power-generating equipment based on internal combustion engines, which are determined by monitoring and technical diagnostics systems. Using factors such as the K_I current ratio in compressor and depressurized modes, the actual compression ratio, and, as a result, the efficiency of the power installation will significantly increase energy efficiency and reduce harmful emissions.

The research was conducted based on assumptions regarding the intensity and duration of the diesel generator's use with deviations from its normal operating condition.

Prospects for further research may include the development of an automated diagnostic and predictive system for the state of diesel generator sets.

4. Conclusions

Based on the analysis of enterprises operating under the conditions of military aggression, the main factors determining the energy efficiency of electricity production have been identified. These factors include the overall efficiency of the power generation installation, which is determined through monitoring and diagnostics of the power unit. The main diagnostic factors of the power generation equipment that affect the energy efficiency of industrial parks in the conditions of military aggression are the K_I current ratio in compressor and depressurized modes, the actual compression ratio, and consequently, the efficiency of the power installation. Based on these factors, the effectiveness of implementing a monitoring and diagnostics system for power units of power generation equipment at enterprises in conditions of military aggression has been determined. For one of the most powerful diesel engines, the 16CHN26/26(5D49), with a power of 3000 hp (2200 kW) used for electricity generation, the annual economic benefit in monetary terms amounted to 595,410 USD. Recommendations have been established to minimize fuel costs and reduce emissions to ensure the core principles of industrial parks: environmental friendliness and energy efficiency.

Conflict of interest

The authors declare that they have no conflicts of interest related to this research, including financial, personal, authorship, or any other interests that could influence the research and its results presented in this article.

Financing

The research was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the work presented.

References

1. Shevchuk, N. A., Tulchynska, S. O., Pohrebniak, A. Yu. (2021). Directions of changes in regulatory acts on the development of industrial parks in Ukraine. *Ekonomichnyi visnyk Natsionalnoho tekhnichnoho universytetu Ukrainy «Kyivskyi politekhnichnyi instytut», 20*. doi: https://doi.org/10.20535/2307-5651.20.2021.252588
2. *Natsionalna ekonomichna stratehiia 2030*. Kabinet Ministriv Ukrainy. Available at: https://nes2030.org.ua Last accessed: 12.12.2022
3. *Pro Industrialni parky* (2012). Zakon Ukrainy No. 5018-VI. 21.06.2012. Available at: https://zakon.rada.gov.ua/laws/show/5018-17#Text Last accessed: 12.12.2022
4. Tulchynska, S., Shevchuk, N., Popelo, O., Pohrebniak, A., Kravchyk, Y. (2021). Operation of industrial parks in the conditions of sustainable development and the paradigm of circular economy. *Laplage Em Revista, 7 (3C),* 238–247. doi: https://doi.org/10.24115/s2446-6220202173c1602p.238-247
5. Skilky heneratoriv zavezly do Ukrainy u 2022 rotsi (2022). *Slovo i Dilo*. Available at: https://www.slovoidilo.ua/2022/12/22/infografika/ekonomika/skilky-heneratoriv-zavezly-ukrayiny-2022-roc-zi Last accessed: 20.10.2023
6. Bellantuono, N., Carbonara, N., Pontrandolfo, P. (2017). The organization of eco-industrial parks and their sustainable practices. *Journal of Cleaner Production, 161,* 362–375. doi: https://doi.org/10.1016/j.jclepro.2017.05.082
7. Yehorov, I. Yu., Boiko, O. M., Hryha, V. Yu. (2015). *Industrialni parky v Ukraini: problemy stanovlennia ta perspektyvy rozvytku*. Kyiv, 139.
8. Solihah, N., Nashiruddin, M. I., Sugesti, E. S. (2021). Regulatory Impact Analysis for XGS-PON Standardization Development in Indonesia. *2021 13th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT),* 246–252. doi: https://doi.org/10.1109/icumt54235.2021.9631660
9. *International recommendations for Industrial Parks* (2019). UNIDO. Vienna. Available at: https://www.unido.org/sites/default/files/files/2019-11/International_Guidelines_for_Industrial_Parks.pdf Last accessed: 02.01.2023
10. Zaichenko, S., Shevchuk, S., Opryshko, V., Pryadko, S., Halem, A., Adjebi, A. (2020). Determination of autonomous electrical energy source technical condition based on an internal combustion engine. *2020 IEEE KhPI Week on Advanced Technology (KhPIWeek),* 305–308. doi: https://doi.org/10.1109/khpiweek51551.2020.9250074
11. Denysiuk, S., Zaichenko, S., Opryshko, V., Derevianko, D. (2021). Assessment of consumers power consumption optimization based on demand side management. *EUREKA: Physics and Engineering, 2,* 19–31. doi: https://doi.org/10.21303/2461-4262.2021.001689
12. Shakhmeister, L. G., Dmitriev, V. G. (1987). *Teoriia i raschet lentochnykh konveierov.* Moscow: Mashinostroenie, 336.
13. Zaichenko, S., Denysiuk, S., Pobihailo, V., Dubovyk, V., Derevianko, D., Jukova, N. (2022). Comparison of energy efficiency of a synchronous electric generator with a spark ignition engine using gasoline and gasoline blended with ethanol. *2022 IEEE 3rd KhPI Week on Advanced Technology (KhPIWeek)*. doi: https://doi.org/10.1109/khpiweek57572.2022.9916431
14. Cai, B., Sun, X., Wang, J., Yang, C., Wang, Z., Kong, X. et al. (2020). Fault detection and diagnostic method of diesel engine by combining rule-based algorithm and BNs/BPNNs. *Journal of Manufacturing Systems, 57,* 148–157. doi: https://doi.org/10.1016/j.jmsy.2020.09.001
15. Zaichenko, S., Erçetin, Ü., Kulish, R., Derevyanko, D., Shalenko, V. (2021). Determination of Diagnostic Parameters of Power Plants Based on Internal Combustion Engines. *Mining Revue, 27 (3),* 86–92. doi: https://doi.org/10.2478/minrv-2021-0028

✉***Roman Kulish,*** *Postgraduate Student, Department of Automation of Electrical and Mechatronic Complexes, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, e-mail: venenationhesperus@gmail.com, ORCID: https://orcid.org/0000-0003-0647-1578*

Stefan Zaichenko, *Doctor of Technical Sciences, Professor, Department of Automation of Electrical and Mechatronic Complexes, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-8446-5408*

Denys Derevianko, *PhD, Associate Professor, Acting Head of Department of Power Supply, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-4877-5601*

✉*Corresponding author*