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Autonomous constant voltage generator

ABSTRACT: The relevance of this research work is due to the fact that farms and other farms are located at a considerable distance from sources of centralized power supply. Therefore, it is necessary to introduce autonomous generators as the main units that ensure the uninterrupted functioning of energy systems. The purpose of this research work is to analyze the features of the functioning of an autonomous constant voltage generator, as well as to determine the basic physical laws that are of fundamental importance in its operation. The basis of the methodological approach in this scientific study is a combination of methods of system analysis with an analytical study of the general principles of operation of such devices, which are of fundamental importance from the point of view of ensuring the proper level of operational reliability. The main results obtained in this research work should be considered the definition of equations for calculating the instantaneous values of the three-phase excitation current, as well as the peak value of the three-phase excitation current of an autonomous constant voltage generator. The results obtained in the course of this scientific research and the conclusions formulated on their basis are of fundamental importance for developers of modern technological systems, including autonomous constant voltage generators, as well as for employees of technological services of modern industrial enterprises, whose professional responsibility includes the practical operation of such devices to solve a complex of technical tasks facing these enterprises.

KEYWORDS: electric power, rotor, asynchronous motor, stator, magnetic flux

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Introduction

To date, in the Republic of Kazakhstan, a significant number of farms and manufacturing enterprises located in remote areas do not have a centralized power supply due to their geographical remoteness and relatively low electricity demand. The introduction of micro hydropower plants (HPPs) and wind turbines in such farms is difficult, primarily because of their significant cost (Cazaurang et al. 2020; Fialko et al. 1994). At the same time, the bulk of the cost relates directly to their electrical equipment, especially autonomous synchronous generators, which are usually used in such units. It should be taken into account that the generator is not able to produce the required amount of electricity with characteristic changes in the rotational speed of the turbine shaft of a micro hydroelectric power plant or a wind wheel for units of this kind. For this reason, the development of cheap, relatively easy-to-operate autonomous generators that can produce electrical energy in sufficient volumes should be considered as a difficult scientific and practical task. One of the solutions to this problem is the use of generators based on mass-produced asynchronous motors with stabilized voltage parameters (Dimitrakopoulos et al. 2021).

The experience of the practical application of the considered sources of electrical energy, as well as the scientific developments of a number of researchers, are clear evidence of the fact that the prospects for the subsequent improvement and expansion of the operating efficiency of the bulk of the currently existing stand-alone power generating sets, both special and general purpose, are closely related to the practical resolution of issues. Such issues are related to increasing the reliability and cost efficiency of the power-generation process. The quality of the implementation of this kind of task is determined by the generator excitation system and the features of its functioning. Automatic excitation regulators of such devices adjust the priority magnetic flux of the generator, ensuring that the requirements for the volume of electricity produced and the dynamic stability of the autonomous system during transitions of different workloads are met. To fully ensure the automatic maintenance of the generator output voltage by the excitation system, it is required to determine the patterns of change in the excitation current at various values and power factors of the load and the rotor speed (Coppola and Esztergar-Kiss 2019).

The establishment of the regularities of changing the parameter of the excitation current of an experimental autonomous generator based on an asynchronous motor should be carried out by means of the impromptu removal of the adjustment parameter of the generator at different rpm values. The large territory of the Republic of Kazakhstan and its low population density lead to the fact that, from an economic and technical point of view, it is inexpedient to meet the energy needs of thousands of farms located far from centralized power supply sources at the expense of large industrial enterprises. In South and South-East Kazakhstan, the presence of a large number of small mountain rivers with the necessary water supply makes it possible to solve the problem of power supply to low-power consumers. The advantage of hydropower in comparison with other options is often a relatively small change in water discharge during the year and the absence of periods of calm (Li et al. 2020).

The production of electricity at micro hydroelectric power plants has the lowest cost. Damage to the environment during installation is excluded. In this context, the practical use of autonomous constant voltage generators is the optimal solution from the point of view of ensuring the necessary volumes of electricity generation are sufficient to meet the needs of both farms in Kazakhstan and individual industrial facilities (Walsh and Strano 2018; Peleshenko et al. 2017). The final consumers of this kind of system will be farms and other farm units located at a considerable distance from the electricity supply centers. Their practical implementation will contribute to improving the overall culture of production and the quality of life of the employees.

Cheban and Tolkatsky (2011) considered the excitation system of an automatic asynchronous generator in their work, namely the excitation system with a static type inverter, an asynchronous valve generator. Vanashi et al. (2021) consider that the most promising direction to date is the development and creation of autonomous diesel generators with variable speed parameters. However, autonomous generators with stabilized voltage parameters are widely used in engineering. This determines the need for the qualitative scientific study of various aspects of regulating the voltage parameters of autonomous generators.

The purpose of this research work is to study the features of the practical use of an autonomous constant voltage generator for the needs of industrial enterprises and residential facilities of the Republic of Kazakhstan in order to form objective ideas about the possibilities of such devices, which are of practical importance from the point of view of meeting the real needs of electricity consumers.

1. Materials and methods

The basis of the methodological approach in this scientific study is a combination of methods of system analysis of the main aspects of the functioning of an autonomous constant voltage generator, with an analytical study of the general principles of operation of such devices, which are of fundamental importance from the point of view of ensuring the proper level of operational reliability. The methods of scientific research involve the use of the capabilities of the algebraic apparatus with the calculation of the parameters of the currents in the phases of the generator rotor winding at a constant load, corresponding to the graph of the linear change in the rotor speed and the timing diagram of the currents in the phases of the generator rotor winding. The picture of scientific research is supplemented by the construction of graphs of the functional dependence of the linear change in the rotational speed of the generator rotor at a constant load and at the corresponding excitation current of a three-phase generator. The preparation of a high-quality theoretical basis for this research work involves conducting systemic studies of the publications on issues related to the practical use of autonomous constant voltage generators. It is necessary to solve problematic issues of ensuring an adequate level of power supply for geographically remote industrial facilities and residential areas.

First of all, a systemic study of the main aspects of the functioning of an autonomous constant voltage generator, which is important from the point of view of its practical application in autonomous power supply systems, was conducted. This stage was preceded by the preparation of a high-quality theoretical base necessary for the consistent implementation of a full range of scientific research. An analytical study of the general principles of operation of such devices was then performed, which is of fundamental importance from the point of view of ensuring the proper level of reliability of their operation. It is envisaged to conduct practical research on the features of changing the control characteristics of an autonomous constant voltage generator using an experimental stand in laboratory conditions. In general, the results obtained in the course of this research work and the conclusions formulated on their basis can subsequently serve as a qualitative methodological basis for subsequent scientific research on a wide range of issues related to the use of autonomous constant voltage generators in modern autonomous power supply systems.

2. Results

A scientific study of the main aspects of the development and subsequent use of autonomous constant voltage generators has produced the following results. By supplying a three-phase rotor winding using modern microprocessor systems regulated by size, frequency, and the phase sequence of the three-phase current, it is possible to adjust the stator windings of the electromotive force (EMF) of the generator, both the rotation frequency of the main magnetic flux and its magnitude, thus stabilizing the output voltage of the generator with variable turbine speed and generator load (Sguarezi 2021). The developed excitation system meets certain conditions:

1. The excitation current generates the main magnetic flux with a fixed frequency of rotation towards the stator winding when the rotor rotates with a non-constant frequency.

2. The parameter of the excitation current is in strict accordance with the parameter of the magnetic flux at the specified parameters of rotor speed and generator load.

In particular, the equations for the values of the currents in the phases of the rotor winding of the generator at a constant load are in accordance with the graph of the change in the rotor speed and the graph of the time change in the currents in the phases of the rotor winding of the generator shown in Figure 1, will look like this:

$$
(t) = \begin{cases}
I_m\left(\Delta\omega_r\right)\sin\left[\int_{t_1}^{t_2} \Delta\omega_{r1}\left(1-\dfrac{t}{t_2}\right)dt\right] & if\ t_1 \leq t \leq t_2; \\
i_a\left(t_2\right) = const\ if\ t_2 < t < t_3; \\
I_m\left(\Delta\omega_r\right)\sin\left[\int_{t_3}^{t_4}\left(\Delta\omega_{r4}\dfrac{t-t_3}{t_4-t_3}\right)dt\right] & if\ t_3 \leq t \leq t_4,
\end{cases}
\tag{1}
$$

$$i_b(t) = \begin{cases} I_m(\Delta\omega_r)\sin\left[\int_{t_1}^{t_2}\Delta\omega_{r1}\left(1-\dfrac{t}{t_2}\right)dt - \dfrac{2\pi}{3}\right] & if\ t_1 \le t \le t_2; \\[2mm] i_b(t_2) = const\ if\ t_2 < t < t_3; \\[2mm] I_m(\Delta\omega_r)\sin\left[\int_{t_3}^{t_4}\left(\Delta\omega_{r4}\dfrac{t-t_3}{t_4-t_3}\right)dt - \dfrac{2\pi}{3}\right] & if\ t_3 \le t \le t_4, \end{cases}$$ (2)

$$i_c(t) = \begin{cases} I_m(\Delta\omega_r)\sin\left[\int_{t_1}^{t_2}\Delta\omega_{r1}\left(1-\dfrac{t}{t_2}\right)dt + \dfrac{2\pi}{3}\right] & if\ t_1 \le t \le t_2; \\[2mm] i_c(t_2) = const\ if\ t_2 < t < t_3; \\[2mm] I_m(\Delta\omega_r)\sin\left[\int_{t_3}^{t_4}\left(\Delta\omega_{r4}\dfrac{t-t_3}{t_4-t_3}\right)dt + \dfrac{2\pi}{3}\right] & if\ t_3 \le t \le t_4 \end{cases}$$ (3)

where:

$i_a(t)$, $i_b(t)$, $i_c(t)$ – instantaneous parameters of three-phase excitation current,

$I_m(\Delta\omega_r)$ – its peak value,

$\Delta\omega_r = \omega_n - \omega_r$ – the difference between the rated and the real rotor speed,

ω_n – nominal rotor speed,

ω_r – current rotor speed.

Figure 1 shows time diagrams of linear changes of the rotor speed parameter at a stable load and the corresponding three-phase excitation current.

To carry out initial experiments and register the main parameters of the generator, an experimental stand was created, the laboratory scheme of which is shown in Figure 2.

In order to establish the basic regularities of correcting the magnitude of the excitation current when the load changes, under conditions of a stabilized voltage at the terminals of the generator, which corresponds to the nominal parameter, it is necessary to apply the regulating characteristic of the generator $I_f = f(I)$ at $\underline{U} = $ const, $\omega_r = $ const. As shown in Figure 3, at constant load (R, $\cos\varphi = 1$) due to the response of the cross section of the demagnetizing armature, as the load current increases, the excitation current strength must be increased to 20–27% of the nominal excitation current for each of the selected speeds. With an active-inductive (RL) and inductive (L) load, the armature response in the longitudinal direction will be more pronounced and to replenish the parameter of its magnetic flux, it is necessary to increase the excitation current. For a capacitive load (C, $\cos\varphi < 1$, the current increases in the EMF phase), the typical armature response contributes to the increase in the values of the magnetic flux and voltage. To maintain stable voltage with a capacitive load, the excitation current should be reduced to 13–18% of the set value for each of the speeds. Of significant practical interest is the control characteristic recorded with changes in the rotor speed. During the fixation of these characteristics by correc-
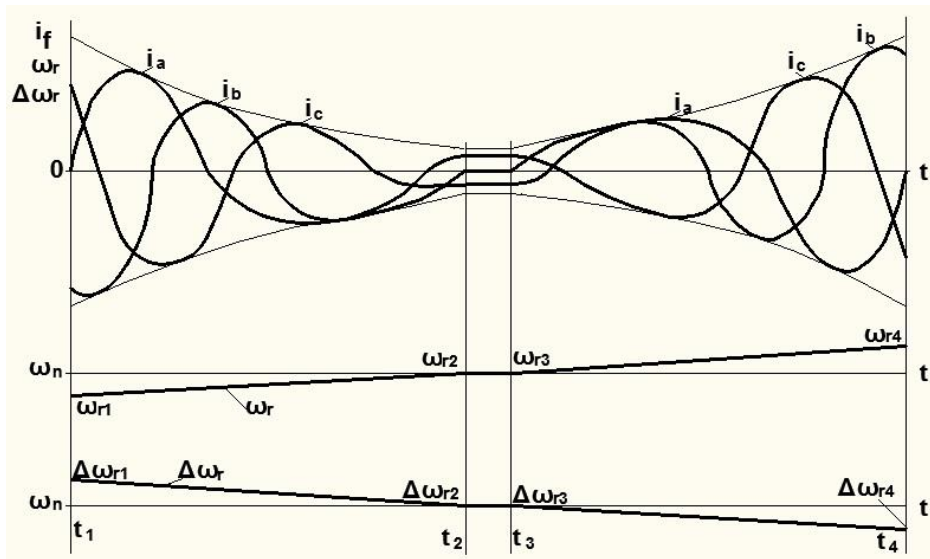
Fig. 1. Diagrams of the time of changes in the rotor speed at constant load and the corresponding three-phase excitation current of the generator

Rys. 1. Wykresy czasu zmian prędkości wirnika przy stałym obciążeniu i odpowiadającego mu trójfazowego prądu wzbudzenia generatora
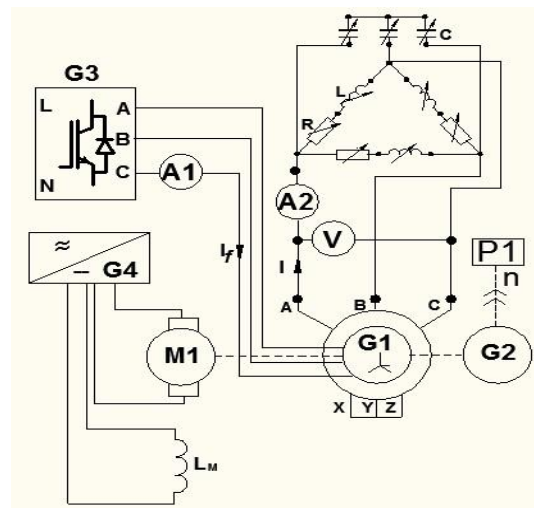

Fig. 2. Schematic diagram of the laboratory bench
G1 – generator, G2 – tachometer, G3 – excitation correction system, G4 – DC motor power supply, P1 – speed index, M1 – armature of the DC motor with unregulated excitation, L_M – excitation winding of the DC motor

Rys. 2. Schemat ideowy stołu laboratoryjnego

ting the frequency and the value of the three-phase excitation current, the output voltage of the generator was unchanged in frequency f and the value of U in the parameters of the rotor speeds = 188.4 ... 126.0 rad/s, at rated rotation speed = 157.0 rad/s. The adjustment characteristic of the generator is shown in Figure 3.
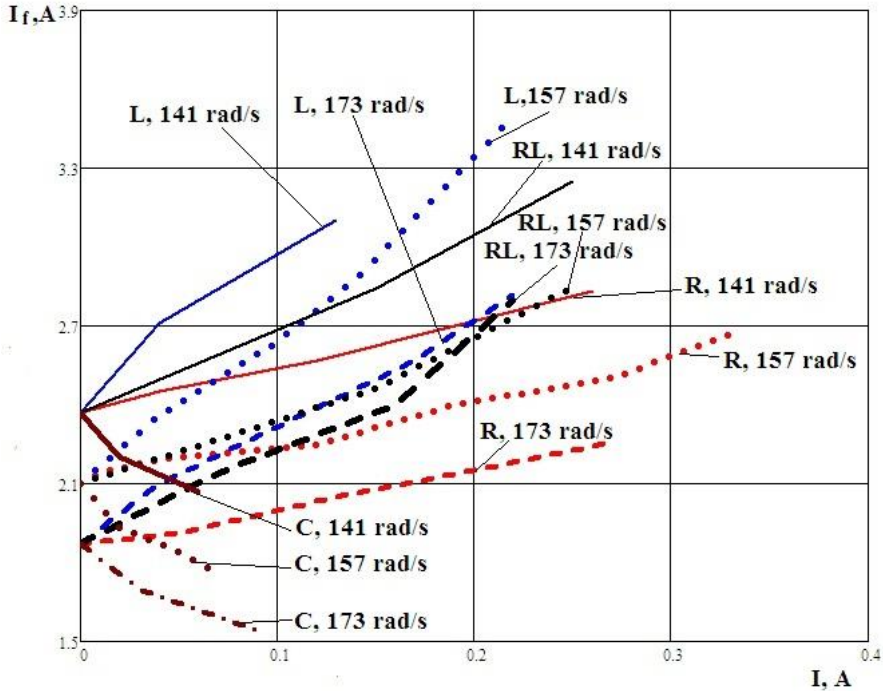

Fig. 3. Dependence of the adjustment characteristics of the generator $I_f = f(I)$ at U = const, ω_r = const
Note: I_f – the current strength at different generator excitation phases

Rys. 3. Zależność charakterystyk regulacyjnych generatora dla $I_f = f(I)$ przy U = const, ω_r = const
Uwaga: natężenie prądu w różnych fazach wzbudzenia generatora

The experiment carried out in this scientific study has clearly demonstrated that for the specified range of rotor speed variation, in the idle mode, the excitation current should be adjusted non-linearly within 0.10–0.65 A, both when the speed increases and when it decreases from the synchronous value (Xhafa 2021). Figure 4 shows the dependence of the adjustment characteristics of the generator $I_f = f(I, \omega_r)$ at f = const, U = const, I = 0.

Figure 5 shows the examples of the experimental generator adjustment characteristics for various types of loads $I_f = f(I, \omega_r)$ at f = const, U = const.

The planes $I_f = f(I, \omega_r)$ of the adjustment characteristic are symmetrical concerning the plane of synchronous speed corresponding to the cases of increasing and decreasing the rotor speed from the nominal value. A practical task was also set to conduct an experimental study of the characteristics of idle operation and short circuit, and external characteristics at various rotor
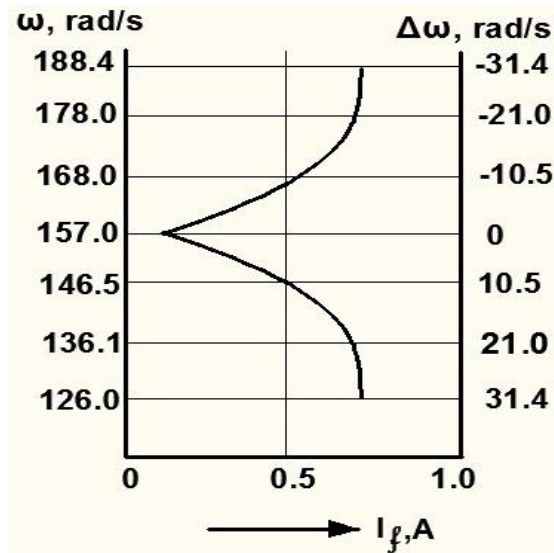
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Fig. 4. The adjustment characteristic of the generator $I_f = f(I, \omega_r)$ at f = const, U = const, $I = 0$
Note: I_f – the current strength at different generator excitation phases

Rys. 4. Charakterystyka regulacji generatora dla $I_f = f(I, \omega_r)$ przy f = const, U = const, $I = 0$
Uwaga: natężenie prądu w różnych fazach wzbudzenia generatora

rotation speed constants when the characteristic is removed (Shankar and Mukherjee 2016). The description of the change in the parameters of the idle operation of the generator has the form of a graph of the dependence of the voltage at the output of the generator on the excitation current $U_0 = E_0 = f(I_{f0})$ when the external circuit of the generator $I = (0)$ is disconnected and ω_r = const. The tests in the idle mode were performed with a stabilized thermal regime of the generator and the results of the tests performed are shown in Figure 6. The study of the revealed parameters indicates that at a typical value of rotor speed, the excitation current is in direct proportion to the EMF induced in the stator up to $I_{f0} = 1.5$ A. The sequential discrepancy between the idle mode parameter and linear dependence, with a subsequent increase in the current, is directly related to the saturation of the magnetic circuit.

In the case under consideration, to maintain the nominal voltage $U_0 = 220V$ in the idle mode and with a mismatch in the rpm values, the excitation current was characterized by the following changes: $I_{f0} = 2.1A$, at $\omega_r = 157$ rad/s; $I_{f0} = 2.37A$, at $\omega_r = 141$ rad/s; $I_{f0} = 1.87A$, at $\omega_r = 173$ rad/s. This indicates that with a decrease in the rotor speed of the generator by 10% of the rated value, the excitation current increases by 12.9%, and with an increase of 10%, it decreases by 11%. In this case, an increase in speed becomes the cause of an increase in the EMF of the generator windings at a fixed value of the excitation current. With a decrease in speed, the picture is exactly the opposite. The external characteristic of an autonomous generator is the dependence of the voltage at the terminals of the stator winding on the load current $U = f(I)$ at I_f = const, ω_r = const. With an active load (R) and a sharp increase in the stator current to the rated value,
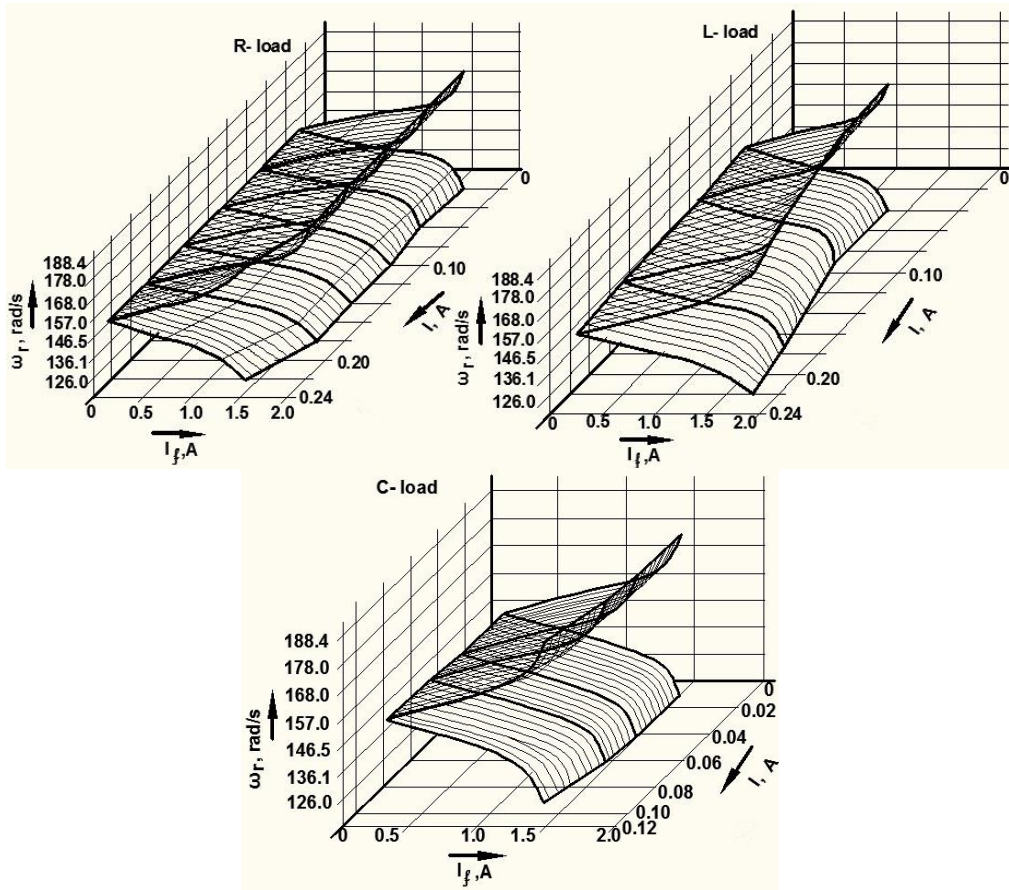
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Fig. 5. The adjustment characteristics of the generator $I_f = f(I, \omega_r)$ at f = const, U = const
Note: I_f – the current strength at different generator excitation phases

Rys. 5. Charakterystyki regulacyjne generatora dla $I_f = f(I, \omega_r)$ przy f = const, U = const
Uwaga: natężenie prądu w różnych fazach wzbudzenia generatora

there is a decrease in the generator voltage by 31–34% of the rated voltage, which is determined by the rotation speed. Mixed active-inductive (*RL*) and inductive (*L*) loads lead to a decrease in the voltage value, mainly due to armature demagnetization. At the same time, a systematic increase in the load leads to an increase in the voltage on the generator due to the magnetizing action of the armature to 8–17% of the rated value.
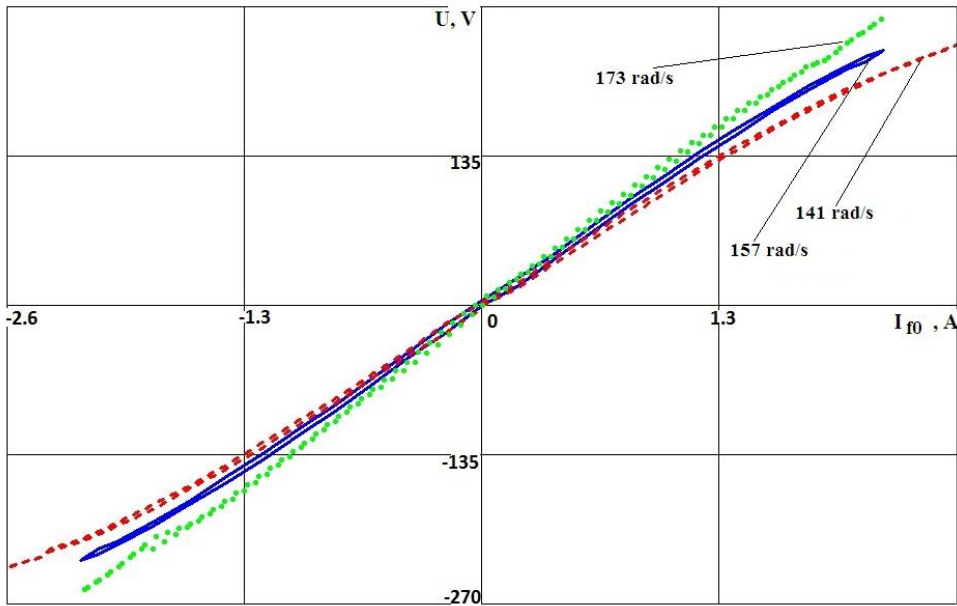
Fig. 6. Parameters of the idle operation of the generator $U_0 = f(I_{f0})$ at $I = 0$, $\omega_r = $ const

Rys. 6. Parametry pracy jałowej generatora dla $U_0 = f(I_{f0})$ przy $I = 0$, $\omega_r = $ const

3. Discussion

The idea of a practical asynchronous generator with a phase rotor for autonomous systems is by no means new. The accumulated experience is clear evidence of the fact that this is primarily due to cheapness, the simplicity of design and reliability of operation under normal conditions, the resistance to external influences, the low probability of accidents, and most importantly, the prudent use of resources. Of all the previously created excitation systems for asynchronous generators with a phase rotor, one can distinguish an excitation system with a static type inverter, an asynchronous valve generator, which is controlled by introducing an EMF into the phase rotor circuit while adjusting the amplitude and frequency of the output voltage. However, the excitation systems proposed in these works are energy intensive and cumbersome (Cheban and Tolkatsky 2011). Autonomous asynchronous motors with a short-circuited rotor, due to their structural simplicity, the absence of sliding contacts, the presence of advantages in terms of mass parameters, their overall characteristics and rotor rotation speed compared to classical synchronous generators and DC generators, do not cease to be widely used as generating devices in miniature power complexes.

As readers will know, an autonomous asynchronous generator requires a reactive magnetizing current to create a magnetic flux. As a result, an asynchronous generator can successfully

operate in a generator mode or parallel with the main grid, with a rotor speed higher than synchronous, as well as in a completely autonomous mode with self-excitation, receiving a reactive excitation current from an external source, in particular from capacitors connected to the terminals (Konstantinova et. al. 2021). The algorithm for constructing the characteristics of an asynchronous generator with a rotating stator is based on the practical application of the algorithm for a situation with a stationary stator when stable operation and a balance of active and reactive power parameters are observed at any design point of the mode, but the angular field rotation speed and frequency differ from synchronous ones. If we proceed from the physical relations and experiments conducted on physical models, then the rotation of the stator restores the frequency value to the set nominal value. This gives grounds for calculating the parameters of an autonomous asynchronous generator with a rotating stator (Castillo-Garcia et al. 2016).

The conditions for self-excitation of autonomous DC and asynchronous generators are presented in various scientific studies, textbooks and scientific monographs on electrical machines, but their conclusions are similar to each other and are formed simplified based on heuristic methods. At the same time, electromechanical systems prone to self-excitation are characterized by the same principles of stability (the balance of phases and amplitudes, the presence of positive feedback and corresponding loop amplification, stability criteria) as systems of any other physical nature (Ordatayev and Keshuov 2013; Szederkenyi et al. 2018). At the same time, the process of the development and subsequent limitation of automatic oscillations in the generator can be analyzed using structural schemes that are operator forms of a system of differential equations of an electric machine, in the presence of a nonlinear link – a magnetic circuit with saturation. One of the most significant characteristics of an autonomous generator should be considered as a set of short-circuit parameters – the relationship between the values of the stator current and the excitation current $I_k = f(I_{v0})$ in the presence of a short-circuit dependence on the stator terminals at the set rated rotor speed.

The dependence of the parameter of the short-circuit current in the stator winding on the magnitude of the excitation current is fixed under conditions of a stable increase in the excitation current. The short-circuit parameters are characterized by a pronounced dependence, which is due to the presence of the stator winding resistance, which is insignificant in comparison with the inductive one. The current lags behind the EMF by 90° and is a longitudinal current, while the armature reaction becomes demagnetizing, for this reason, there is no saturation of the magnetic circuit of the machine (Babayomi et al. 2021). DC and AC electric machines are widely used in modern electric-power-generation systems. The choice of specific types of electric machines is dictated by a combination of various factors from cost to weight and size indicators, reliability, environmental conditions, as well as the ability of these machines to perform specific operations. Self-excitation generators are a separate class of electrical machine since they create conditions for generating electricity without the additional creation of magnetic excitation fields. The operation of the generator in the stand-alone mode implies the possibility of observing two fundamentally different options of the generator's operation – with a constant speed and with a variable speed.

In the first case, the problem of the entire electrical complex with constant values of the consumed electricity is solved on the side of the primary engine. In the second case, a similar problem can be solved by transferring directly to the electricity side. At the same time, the electrical converter becomes significantly more complex and includes an electrical generator capable of producing electricity with variable voltage and frequency values, as well as a static converter that outputs standard electricity values. An autonomous generator is one of the key elements of modern micro-hydroelectric power plants. Today, micro HPPs are mainly equipped with synchronous generators. Among their main disadvantages, as a rule, there is a high price, which is approximately half of the total cost of micro-hydroelectric power plants, as well as difficulties in maintaining the stability of the frequency and the voltage parameter when the speed of the hydraulic turbine changes. The latter drawback negatively affects the operation of the electric drive of mini-equipment, which is quite widely introduced in farms, because, as tests carried out at the Kazakh Research Institute of Mechanization and Electrification of Agriculture have shown, the voltage frequency of a synchronous generator of a micro HPP can vary from – 10 to + 10% of the nominal values (Achkar et al. 2021).

The operation of an electric generator in autonomous mode involves the regulation of the load and generator capacities. When switching consumers on and off, there is a significant change in the parameters of the local electrical system, which has a significant impact on the operation of the generator itself. During the performance of a complex of scientific studies aimed at setting up experiments with the outline of active loads commensurate with the parameters of the active power of the autonomous generator itself, there was a significant decrease in the operating voltage, as well as the rotational speed of the primary engine. With a sequential increase in the rotational speed of the primary engine of the autonomous generator, there was a gradual transition to the nominal parameters of the rotational speed and voltage, with a gradual set of active load (Zhou et al. 2018). This indicates that, according to the results of the experiments carried out, it is necessary to accurately calculate the load surge, while the primary engine should be equipped with a fast-acting regulating device capable of responding to changes in the voltage parameters and the generator rotor speed, as well as the EMF frequency, taking into account the real capabilities of the generator itself when it is overloaded.

A relatively new technological direction in the electric power industry is the development and subsequent implementation of autonomous diesel generator sets. Such power plants are intended for the cyclical supply of electricity to consumers in geographically remote areas that are not connected to the general power grid. To date, the total energy capacity of such power plants has reached several tens of millions of kilowatts. Autonomous diesel generator sets are widely used in railway transport; in particular, in diesel-electric locomotives operating on non-electrified sections of railways, DC and AC installations are used with a capacity of 2,000 kW or more. Diesel generator sets are also actively used in modern heavy automotive equipment. Modern haulage trucks operating in the mine have power plants in their composition which feed traction electric motors, transmission and control elements. Generators with a capacity from 350 to 2,600 kW are installed on such trucks. Today, a mobile power plants on special vehicles are actively used to supply electricity during construction, repair, geological exploration, and in a number of other cases (Chuang et al. 2016).

Ship power plants are actively used on water transport facilities, while these power plants provide power to general ship power consumers, propeller electric motors, floating cranes, and other powerful technological equipment. Internal combustion engines are used as the primary electric motors at these stations, among which, diesel engines are widely used. Most of these diesel generators operate at a constant, rated speed over a wide range of operating load changes. At the same time, fuel consumption is far from optimal, the efficiency is lowered. The most promising direction today is the development and creation of autonomous diesel generators with a variable speed parameter (Vanashi et al. 2021). In the past few decades, much attention has been paid in shipbuilding to the development and implementation of autonomous electrical installations, which have a number of indisputable advantages over installations that employ direct transfer of power from heat engines to the ship's propeller. Aside from this, due to the practical application of such installations, the ship acquires increased maneuverability, its survivability and reliability increase and it becomes possible to select a certain amount of power for auxiliary needs.

The development and implementation of unified ship power plants on an industrial scale, based on the use of autonomous constant voltage generators, presupposes the presence of a single DC link and a diesel generator with variable rotor speed. When operating a diesel generator set with nominal speed parameters but under conditions of variable loads, there is an increased fuel consumption (Zhao et al. 2018). At the same time, the control of the rotational speed of the shaft of an internal combustion engine by compulsory methods makes it possible to achieve a highly efficient mode of generating electrical energy. One of the most relevant options for increasing the energy performance of a generalship power plant can be the transfer of one of the parallel operating diesel generators to the variable speed mode. At the same time, the load between diesel generators operating in parallel is distributed at full proportion to their rotational frequencies, regardless of the individual loading of the propeller motors.

A power semiconductor converter is used to stabilize the voltage of a diesel generator operating in variable speed mode. Self-excited electromechanical systems are characterized by the same stability principles as systems with a different physical nature. These include the presence of constant positive feedback and loop gain, the preservation of the ratio of amplitudes and phases, as well as the balance of stability criteria (Serban and Ion 2017). In this context, the process of the appearance of synchronous oscillations in an autonomous generator and their limitation can be qualitatively analyzed by creating circuits of a certain structure, which should be considered, in essence, as the operator form of the complex differential equations of an electric machine, created based on the practical application of a nonlinear magnetic circuit.

The principle of operation of an autonomous electricity generator is based on the occurrence of a residual magnetic flux, which is the reason for starting the rotor rotation and the appearance of an electromotive force (Vienovic et al. 2021). In the stator winding with a given number of turns due to the capacitors at the output, a capacitive excitation current appears, which forms the EMF and the corresponding magnetic flux. Thus, a positive magnetic flux feedback loop is formed, which contributes to the start of the self-excitation process. The amplitude of the flux and EMF is limited due to the nonlinearity of the magnetization characteristic of the autonomous

generator. It is advisable to study any transients in the electric drive system of an autonomous generator by conducting numerical experiments using a specific mathematical model. As a result, it is possible to obtain graphs of changes in the parameters of current and voltage, as well as torque, and the speed of the motor in time, based on which, it is advisable to analyze all the processes occurring in the system.

Summary

The practical application of an automated constant voltage generator in modern power systems is associated with the need to calculate the parameters of instantaneous values of the three-phase excitation current, peak values of the three-phase excitation current, as well as the difference between the nominal and current rotor speed, the nominal rotor speed and the parameter of the current rotor speed. In addition, it is mandatory to develop a mathematical model, which should allow the calculation of transient processes in a generator based on an asynchronous motor with a phase rotor installed on it. During the creation of such a model, it is mandatory to take into account the design features of the electric machine, as well as the voltage drop in the cable line and the electromagnetic inertia of inductors in the electrical circuit. Using modeling, the prospect of forming a stable state of the frequency parameter of the output voltage of the generator by a three-phase excitation current, which is fed to the rotor and adjusted according to the parameters of magnitude, frequency, and phase change, is demonstrated.

In general, it is necessary to determine the principle of varying the value of the excitation current in the specified ranges of load current and rotational speed with different types of load to ensure the stabilization of the output voltage parameters of the autonomous generator studied in this scientific work. This means that the excitation system must provide a change in the excitation current of the generator in accordance with certain patterns under a given operating mode. The final consumers of these kinds of systems will be farms and other farm units located at a considerable distance from the electricity supply centers. The introduction of autonomous generators as the main nodes that ensure the smooth functioning of such systems will increase the overall production culture and improve the living conditions of employees of organizations in which such systems are used. The excitation system of these generators, when changing the parameters of the incoming load and the rotor rotation speed, must ensure the creation of a rotating magnetic field, with a constant rotation frequency relative to the stator winding as well as a constant value of the main magnetic flux of the generator.

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Orken ORDATAYEV

Autonomiczny generator stałego napięcia

Streszczenie

Ważność niniejszej pracy badawczej wynika z faktu, że gospodarstwa rolne i inne gospodarstwa położone są w znacznej odległości od źródeł scentralizowanego zasilania. Dlatego konieczne jest wprowadzenie autonomicznych generatorów jako głównych jednostek zapewniających nieprzerwane funkcjonowanie systemów energetycznych. Celem niniejszego artykułu jest analiza cech funkcjonowania autonomicznego generatora napięcia stałego, a także określenie podstawowych praw fizycznych mających fundamentalne znaczenie w jego działaniu. Podstawą podejścia metodologicznego jest połączenie metod analizy systemu z opracowaniem analitycznym ogólnych zasad działania tego typu urządzeń, które mają fundamentalne znaczenie z punktu widzenia zapewnienia odpowiedniego poziomu niezawodności działania. Za główne wyniki uzyskane należy uznać określenie równań do obliczania wartości chwilowych prądu wzbudzenia trójfazowego, a także wartości szczytowej prądu wzbudzenia trójfazowego autonomicznego generatora napięcia stałego. Uzyskane w toku badań naukowych wyniki i sformułowane na ich podstawie wnioski są bardzo ważne dla twórców nowoczesnych systemów technologicznych, w tym autonomicznych generatorów stałego napięcia, a także dla pracowników służb technologicznych nowoczesnych przedsiębiorstw przemysłowych, których odpowiedzialność zawodowa obejmuje praktyczną obsługę takich urządzeń w celu rozwiązania kompleksu zadań technicznych stojących przed przedsiębiorstwami.

SŁOWA KLUCZOWE: energia elektryczna, wirnik, silnik asynchroniczny, stojan, strumień magnetyczny