The significance of the operation of a short-circuited rotor asynchronous machine in generator mode and the experimentally determined features of the dependence of the output voltage on the load

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ABSTRACT: Based on the results of recent studies to improve the efficiency and reliability of electric power systems, it has been established that an asynchronous generator with a short circuited traditional rotor has high technical and economic indicators compared to a direct current generator and a synchronous generator with the same power, with autonomous operation of wind power plants, as well as a wide range of static and dynamic stability. This article outlines the reasons for changes in the output voltage of the AG depending on the load value and the unit rated power of the AG, based on the resistance of the elements of its equivalent circuit.

KEYWORDS: AG with a traditional squirrel-cage rotor, AG with self-excitation, frequency characteristics.

1. INTRODUCTION

The growing demand for electricity in recent years indicates that finding stable and efficient energy sources is more relevant than ever. The growing energy needs of the world are now not met by the use of traditional energy sources, which do not even meet modern environmental requirements, based on the consumption of natural energy resources, the reserves of which are increasingly limited, and the application of innovative technologies aimed at the widespread introduction of renewable energy sources and increasing their efficiency has been raised to the level of state policy [1].
One such technology is the implementation of traditional short-circuited asynchronous generators (AG) that allow for ensuring power supply stability at wind power plants (WPS) operating in autonomous mode.

II. EXPERIMENTAL PART

The results of research on the efficiency and reliability of electric power systems show that short-circuited rotor AGs have smaller structural dimensions and weight compared to similar high-power SGs, high energy performance and reliability, simplicity of construction, low cost, as well as the advantage of the AG rotor in electrical and magnetic symmetry, which determines the reliable occurrence of transient processes, as well as their ease of operation mainly in autonomous mode, making the use of AG as a component of renewable energy sources important [1,2].
In addition, the fact that the short-circuited AG rotor consists of cast aluminum windings, a significantly smaller air gap between the stator and rotor - allows for a reduction in losses along the path of the main magnetic flux. Such a characteristic indicates that the rotor has low active resistance, and AG has a high efficiency coefficient,

which ultimately indicates high efficiency of AG, as well as higher static and dynamic resistance compared to SG to any external influences [3].

Due to the fact that the rotor winding consists of cast aluminum, the rotor's ability to operate at high operating temperatures and the possibility of increasing its maximum speed expands the operating range of the AG.

The absence of brush or contact rings in short-circuited rotary AGs, as in SGs, creates convenience during their maintenance and requires less cost, as well as ensures stable power supply by reducing generator downtime, especially the use of AGs in WPSs is of great importance [4].

In recent years, the production of small-sized, inexpensive capacitor banks of various capacities and voltages has been widely established - the possibility of widespread use of traditional asynchronous machines of any power with short-circuited rotors as generators and obtaining the necessary amounts of reactive power for their excitation has been created.

The autonomous operation of AG is especially important for the power supply of consumers located in remote areas where power outages occur, as well as those without a main power transmission line [5].

When the load of an autonomously operating AG changes, the unchanging output voltage is ensured by regulating the capacitance of the capacitors [6,7].

The research was conducted in the following sequence:

- the possibility of starting a low-voltage AG with a traditional short-circuited rotor with a nominal power of 4 kW at a direct nominal voltage (380 V) during self-excitation;

- What amount of active power can be applied to a self-excited AG without allowing its output voltage and frequency to change during idle operation?

- the influence of increased active load on changes in voltage and generator frequency under conditions of automatic output voltage regulation;

Initially, when the 4 kW AG rotor is driven by a primary motor at nominal speed, the magnitude of the linear voltage arising in the generator-stator winding due to the residual magnetic field in the rotor is 5÷6 V [8].

When a capacitor battery was connected parallel to the stator winding of the AG and the capacitor's phase capacitance, which provides its excitation at a nominal voltage of 380 V, was calculated, it turned out that Cexc =17 μF.

As a result, the output frequency of an AG excited at nominal voltage during autonomous operation was f = 50 Hz.

After excitation AG, the following experiment was conducted to determine what value of the active load the output voltage and frequency of the AG remained unchanged (Figure 1).
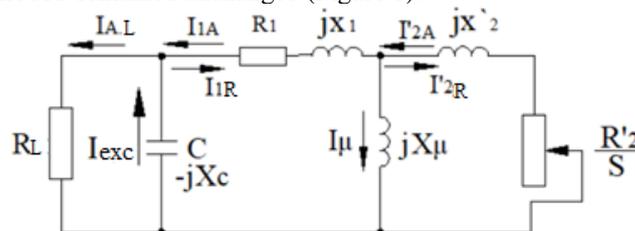

Fig. 1. T-shaped replacement circuit of an AG excited at nominal voltage

Here: I1A – is the active component of the AG current.

I1R – is the reactive component of the AG current.

I'2A – is the reduced active component of the AG rotor current.

I'2R – is the reduced reactive component of the AG rotor current.

IA.L – AG load active current.

Iexc – current that excites the capacitor.

Iμ – is the reactive current of the magnetizing AG.

Based on the results of the experiment, it was established that the output voltage and frequency of the AG at Cexc=17μF=const depend on the active load as follows (Fig. 2):
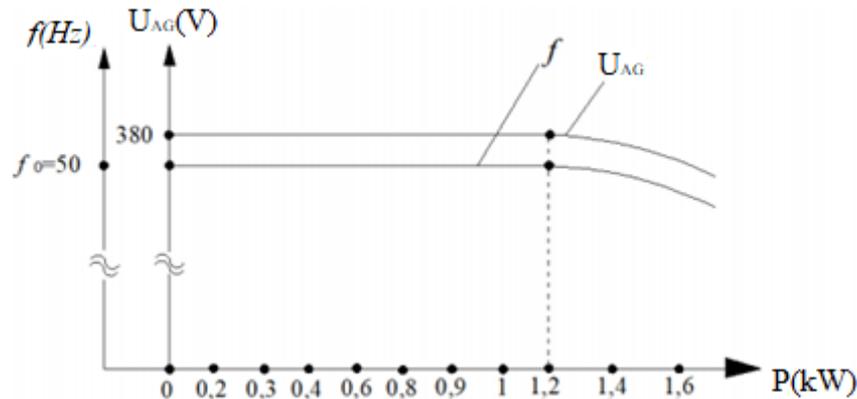
Fig. 2. Graph of the dependence of the output voltage and the frequency of the excited AG at the nominal voltage on the active load

From these graphs, at Сехс=17мкФ=const, when analyzing the dependence of the output voltage and frequency of the AG on the active load, it was established that before the load P=1.2 kW, the voltage and frequency remain unchanged at the nominal values, and with subsequent loads, these parameters decrease.

Considering that the nominal power of the asynchronous machine selected as an AG and the mechanical power on its shaft is 4 kW, it becomes clear that the electrical power of the AG is PAG=Pmex·η=4 kW·0.86=3.44 kW. From the given graph, it can be seen that the AG load up to 30% (1.2 kW) of the nominal load, the output voltage and frequency values remain unchanged, i.e., equal to the nominal voltage and nominal frequency values [9].

Maintaining the output voltage at the nominal voltage level at various AG loads is ensured by automatically changing the capacitance of the capacitor panel using an "Automatic Control Device consisting of contactors and a microprocessor", creating capacitances equal to the reactive power consumed by the AG.

The next experiment, related to the fact that when an automatic regulating device is connected to the output of an AG excited at nominal voltage, increasing the active load ensures the unchanging output voltage and frequency of the AG, was carried out according to the following replacement scheme (Fig. 3).
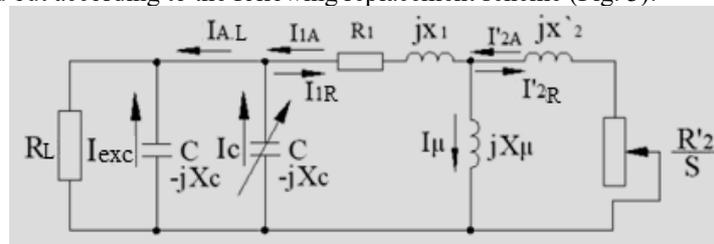

Figure 3. T-shaped substituting circuit for AG with automatic voltage regulation device

Here: IC is the current of an automatically changing capacitor.

Based on the experimental results, it was established that the output voltage and frequency of the automatic regulator AG depend on the active load as follows (Fig. 4):
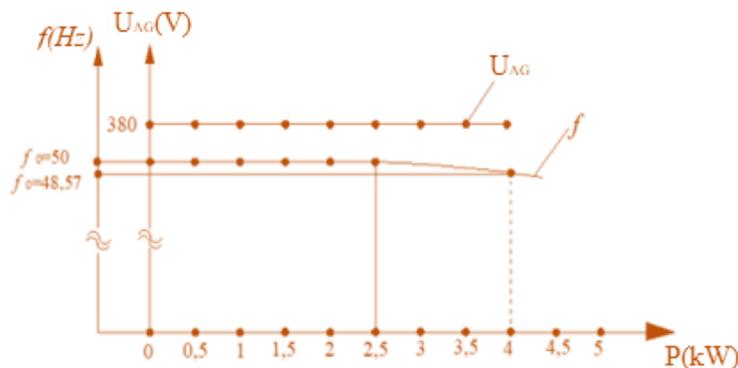

Figure 4. Graph of the dependence of voltage and frequency of an AG with a device for automatic voltage regulation on the active load

From the graph, it can be seen that when connected to the output of an AG with an automatically regulating device for increasing active load up to 4 kW, the output voltage remains unchanged, equal to the nominal 380V, and the output frequency is maintained at f = 50 Hz until a load of 2.5 kW. Thus, it has been established that the control device also positively affects frequency stability, in particular, the AG load remains unchanged up to 70% of the nominal load (2.5 kW/3.44 kW) at a frequency of f = 50 Hz, and at a load of 4 kW f = 48.57 Hz [10].

From the above, it can be seen that the changes in the output voltage and frequency of the AG depend on the change in the main magnetic flux of the generator Φ and were analyzed based on the replacement circuit, up to what load the output voltage and frequency of the AG without a regulating device remain unchanged at their nominal values.

The T-shaped replacement circuit consists of three branches: the stator winding branch, the rotor branch, and the magnetizing branch, the inductive reactances in the circuit, and Kirchhoff's law for the stator circuit is expressed as follows:

$$X_S = 2\pi f L_S; \; X_\mu = 2\pi f L_\mu; \; X_\sigma = 2\pi f L_\sigma$$

Magnetizing network voltage:

$$U = L_\mu \cdot \frac{dI_\mu}{dt}$$

when changing this formula and replacing with $\frac{d}{dt} \to p$

$$U = p \cdot L_\mu \cdot I_\mu$$

turns out.

By introducing the transformation p → jω we obtain the frequency response.

$$U = J \cdot \omega \cdot L_\mu \cdot I_\mu = J \cdot \omega \cdot W_S \cdot \Phi_\mu$$

Therefore, the main magnetic flux:

$$\Phi\mu = \frac{U}{J \cdot \omega \cdot W_S} = -J \cdot \frac{U}{2 \cdot \pi \cdot f \cdot W_S} = \frac{1}{\sqrt{2} \cdot \pi \cdot W_S} \cdot \left(\frac{U}{f}\right)$$

W_S – number of stator winding turns;

From this expression, it can be seen that to ensure the constancy of the main magnetic flux of an AG without a regulating device, the condition $\left(\frac{U}{f}\right) = const$ is required. Analysis of the situation where the output voltage and frequency of a 4 kW generator remain unchanged up to 30% of the nominal load shows that the generator itself compensates for the decrease in the main magnetic flux by increasing the stator current, i.e., strives to ensure the unchanging nature of the main magnetic flux - synchronous generators without a regulating device can be compared to the ability to maintain them in synchronization due to their synchronizing power [11].

Table1
Values of the resistances of AG substituting circuits of different power in nominal and relative units

Nominal AG power [kW]	Unit of measurement	Active and inductive resistances			
		R_1	R'_2	X_1	$X\mu$
22	Ohm	0,285	0,152	12,896	34,667
	p.u	0,03091	0,0165	1,399	3,760
17	Ohm	0,384	0,205	14,723	38,849
	p.u	0,03294	0,0176	1,263	3,333
10	Ohm	0,636	0,339	20,976	53,24
	p.u	0,03297	0,0175	1,087	2,760
4	Ohm	1,831	0,977	44,241	109,238
	p.u	0,04	0,022	0,966	2,385

From the T-shaped replacement circuit of the AG, increasing the active load leads to an increase in slip S, resulting in a decrease in the active resistance of the rotor R_2, an increase in the active current of the rotor I'_{2A}, resulting in an increase in the active current of the stator I_{1A}. Increasing I_{1A} leads to a decrease in capacitor current I_C ($I_C = \frac{U}{X_C}$) due to an increase in voltage drop across the active and inductive resistances of the stator winding, which leads to a decrease in the active load and voltage U at the ends of the capacitor. From this, it follows that in generators with high nominal power, the output voltage and frequency remain unchanged at loads exceeding 30% of the nominal power of the AG due to small values of voltage drop in the stator winding [12].

III. CONCLUSION

Based on the research carried out, the following can be established:
- AG with a massive rotor with squirrel-cage copper cages as a natural damper provides better damping of electromechanical oscillations of regime parameters caused by external periodic disturbances and shocks.
- Comparison of the frequency characteristics of model AGs with various designs of massive rotors shows that AG with a massive rotor with squirrel-cage copper cells is characterized by high energy performance compared to others.

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