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Analysis of synchronized asynchronous generator for a wind electric installation

***Abstract**. Objective. Analysis of the effectiveness of the use of SAG, excited according to a fundamentally new scheme, in a wind electric installation. This article analysis the application of the efficiency of a synchronized asynchronous generator in a wind electric installation. This is natural in vibration damping, which causes gusts of wind and changes in wind speed, as well as an increase in the efficiency of the device at low wind speeds. The article shows a schematic diagram of a synchronized asynchronous generator of a wind electric installation. Some properties of the synchronized asynchronous generator that drives the circuit are also explored. The article presents the advantages of using a synchronized asynchronous generator for wind turbines. The results of calculated characteristics for the given system of values are given. The possibility of operation at cosφ =1 is considered.*

***Streszczenie.** Cel. Analiza efektywności wykorzystania SAG, wzbudzonego według zasadniczo nowego schematu, w wiatrowej instalacji elektrycznej. W artykule dokonano analizy zastosowania sprawności zsynchronizowanego generatora asynchronicznego w elektrowni wiatrowej. Jest to naturalne przy tłumieniu drgań, które powoduje podmuchy wiatru i zmiany prędkości wiatru oraz wzrost wydajności urządzenia przy małych prędkościach wiatru. W artykule przedstawiono schemat ideowy zsynchronizowanego generatora asynchronicznego wiatrowej instalacji elektrycznej. Badane są również niektóre właściwości zsynchronizowanego generatora asynchronicznego, który napędza obwód. W artykule przedstawiono zalety zastosowania zsynchronizowanego generatora asynchronicznego do turbin wiatrowych. Podano wyniki obliczonych charakterystyk dla zadanego systemu wartości. Rozważana jest możliwość pracy przy cosφ =1. (**Analiza synchronizowanego generatora asynchronicznego dla wiatrowej instalacji elektrycznej**)*

Keywords: wind electric installation, efficiency, damping, excitation.
Słowa kluczowe: instalacja elektryczna wiatrowa, sprawność, tłumienie, wzbudzenie.

Introduction

Recently, in a number of countries, great work has been carried out, which are aimed at solving the problem of using wind energy. The reasons for the great interest in this problem are mainly related to the desire to expand the types of energy carriers used, which are due to a significant increase in the cost of hydrocarbon fuel and environmental pollution.

The use of wind energy through a wind power plant is associated with certain difficulties. These difficulties are determined, first of all, by the unevenness and variability of the wind flow as an energy carrier.

A very important role is also played by the fact that two machines (a wind turbine and an electric generator) are combined in a wind power plant. The properties of these machines are not fully suitable for joint work [1,2]. To date, some of these difficulties have been completely overcome, while others have been partially overcome, as a result of which a large number of wind power units of various designs and capacities have been created.

However, as the analysis of the current state of research works in this area shows, the problem under consideration requires further development. Particularly relevant is the task of improving the power generating part of the wind turbine.

Wind turbines can be divided into two large groups:

1) Wind turbines that operate at a constant speed of the wind turbine

2) Wind turbines that operate at a variable speed

In wind power installations of the first group, which is the most common, synchronous and asynchronous generators are used. The second group is a small but highly diverse group. The most typical representative of this group is a wind electric installation with a dual-feed generator [3].

Each of these groups has its own advantages and disadvantages. Let's consider these two options. The advantages of a synchronous generator are well known: it allows you to adjust the reactive power, in particular, work with cosφ = 1, which minimizes losses both in the generator and in the elements of the electrical network to which it is connected; has a higher efficiency; fits well into the power system. The disadvantages are exposure to fluctuations; the specifics of wind energy (change in its speed) the difficulty of parallel operation of the synchronous generator with the network.

Advantages of an asynchronous generator: greater dynamic stability than SG; high reliability of work; ease of input parallel operation with the network. Disadvantages: total wind energy utilization factor, including efficiency. the generator itself, lower than that of the SG, especially at low wind speeds; consumption of significant reactive power from the network.

From a comparative analysis of two options for wind power plants with AG and SG, it follows that the task of developing the power generating part of the wind turbine, which has the combination of the advantages of these options, namely:

1) good vibration damping;

2) high efficiency, especially at low wind speeds;

3) the ability to work at cosφ = 1;

4) great dynamic stability.

These properties, as will be shown below, are possessed by a synchronized asynchronous generator, which is excited along the longitudinal and transverse axes, which is achieved using a special algorithm for supplying the rotor phase windings with direct current. Let's analyze each of the above advantages in relation to the options under consideration.

Vibration damping.

When using a synchronous generator, the energy of wind gusts is completely transferred to the electrical network, mechanical loads increase significantly, and fluctuations are not smoothed out. To dampen vibrations in a wind power plant with a synchronous generator, it was proposed in [4,5] to use “pitch-regulation” both at high and low wind speeds. The use of this method at low wind speeds cannot be considered successful, since, firstly, an increase in the angle of inclination of the blades at low wind speeds leads to a decrease in efficiency. installation, and secondly, the degree of damping achieved is insufficient.

For the same purpose, in [6], it was first proposed to use a synchronous generator with longitudinal-transverse excitation in a wind turbine. In a synchronous generator of a standard design, an additional transverse excitation winding can be placed instead of a damper winding. This winding copes well with the damping of free oscillations that occur, for example, with a sharply changing load, at which it is flowed by current for a time not exceeding 10-20% of the load change period.

For a short time, such a winding is able to create an m.f. comparable to the m.f. main excitation winding. However, the long-term inclusion of this winding, according to the conditions of thermal stability, reduces the value of the m.f. up to 20% of m.f. main winding in idle mode. Approximate calculations show that the rotation of the excitation magnetic flux vector in this case is no more than 10 el. deg. To change the phase of the field along and against the rotation of the rotor, the excitation system for this winding must be reversible. The important range of phase change of the excitation field of a synchronous generator for a wind power installation is very large and amounts to approximately 30 el. deg [7,8].

Thus, the efficiency of using a synchronous generator with longitudinal-transverse excitation, made on the basis of a SG of a standard design, in a wind electric installation should be recognized as not quite sufficient, although the meaning of using such a generator, as well as approaches to solving the problem, are interesting. The use of a synchronized generator will allow solving a number of problems that are beyond the power of a synchronous generator. The ability to control the phase of the excitation field over a wide range in the SAG makes it possible to almost completely damp the oscillations that are caused by the sharply variable nature of the change in wind speed [6].

Experiment and analysis

A synchronized asynchronous machine, which has been gaining more and more interest lately, is an asynchronous machine with a phase rotor, two or three phases of which are supplied with direct current. These machines are now widely used as engines. They combine the advantages of a wound rotor induction motor (good starting properties) and a synchronous motor (high efficiency and reactive power control).

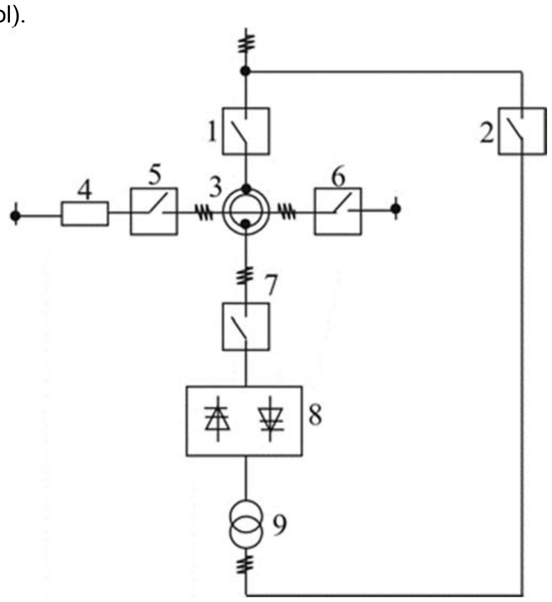

Fig.1. Schematic circuit synchronized asynchronous generator of Wind Power Facility

Synchronized induction motors of high power, due to these advantages, are used by well-known electrical engineering firms, and there is a trend towards their wider use [9,10]. They are used in drives with difficult starting conditions, as accelerating motors for large units. This concerns the damping of vibrations and increasing the stability of operation under a sharply changing load, as well as the possibility of controlling the phase of the excitation magnetic field.

These positive properties of a synchronized asynchronous generator best meet the operating conditions of a wind turbine generator, characterized by sharp and almost continuous changes in the torque on the generator shaft.

Schematic diagram of the SAG in the wind turbine is shown in Fig. 1, where 1, 2, 5, 6, 7 are switches; 3 – generator; 8, 9 – generator excitation system.

Below is an analysis of the operation of the excitation system of a synchronized asynchronous generator, which includes, according to Fig. 2, a thyristor converter 3 with separately adjustable groups of thyristors 1 and 2 and their control systems 4 and 5, respectively, a matching transformer with a secondary winding 6 and phase rotor windings A, B, C.

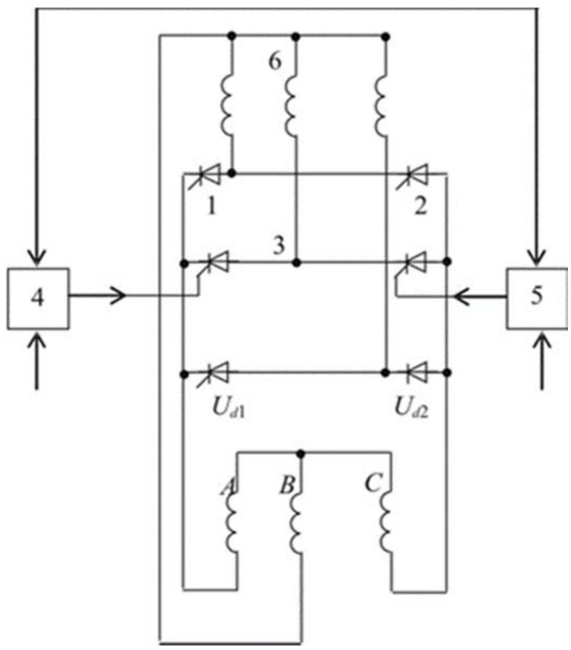

Fig. 2. Excitation system synchronized asynchronous generator

The currents in the phases are determined by the following expressions:

(1) $$I_A = \frac{2U_{d1}+U_{d2}}{3R}$$

$$I_A = \frac{U_{d1}-U_{d2}}{3R}$$

$$I_A = \frac{U_{d1}+2U_{d2}}{3R}$$

where R is the active resistance of the phase winding.

Let us direct the longitudinal axis d along the axis of phase A, and the transverse axis q - ahead of it and project the phase currents on these axes. As a result, we obtain the component currents along these axes, which we will call, respectively, the longitudinal (Ifd) and transverse (Ifq) excitation currents

(2) $I_{fq} = \frac{\sqrt{3}}{2} I_c - \frac{\sqrt{3}}{2} I_b$

Taking into account formulas (1), we obtain

$$I_{fd} = (2U_{d1} + U_{d2})/2R$$

(3) $I_{fq} = \sqrt{3}U_{d2}/2R$

This shows that the current I_{fq} depends only on U_{d2} and can be controlled completely independently by changing the control angle α_2 of thyristor group 2. However, on the other hand, this leads to a change in the current I_{fd}. There is a fairly simple method of keeping this current constant. This method consists in maintaining the current I_A constant, which becomes obvious if we compare the first equations of systems (1) and (3). In practice, this is easy to implement by stabilizing the current I_A by acting on U_{d1} [11,12,13].

The results of calculation of the values typical for this system are given in the table, where the direct current in the phase, equal to the rated current of the rotor, is taken as the basic value in relative units (r.u.). The above arguments, including the tabular data, clearly show that the proposed principle of synchronization of an asynchronous generator contributes to the production of a synchronous generator with longitudinal-transverse excitation, and the range of the phase of the excitation magnetic field is 30 el. Deg [14].

Table 1. Calculated characteristic quantities of the system

I_A	I_B	I_C	I_{fd}
r.u.			
1	0	1	1,5
1	0,25	0,75	1,5
1	0,50	0,50	1,5
1	0,75	0,25	1,5
1	1	0	1,5

Table 2. Calculated characteristic quantities of the system

I_{fq}	U_{d1}	U_{d2}	α, deg.
$\sqrt{3}/2$	1	1	30
$\sqrt{3}/4$	1,25	0,5	15
0	1,50	0	0
$-\sqrt{3}/4$	1,75	-0,5	-15
$-\sqrt{3}/2$	2	-1	-30

Efficiency increase.

Let us turn to the expression for the power at the generator terminals:

(4) $N=4{,}81 \cdot 10^{-4} D_2 \vartheta 3 \xi \eta_g \eta_r$,kW

where D is the diameter of the wind wheel, m; ϑ – wind speed, m/s; ξ– coefficient of wind energy utilization; η_g and η_r – efficiency generator and reducer. It can be assumed that the efficiency reducer η_r = const. Dependence leads to the fact that at low wind speeds, the generator power is greatly reduced. It should be noted here that the wind turbine operates in this mode for a significant part of the time of the year. It is known that asynchronous generator has an efficiency at low loads, it decreases more significantly than that of the SG, especially if the latter operates at cosφ= 1. Approximately at $N = 10\%N_{nom.}$ for AG η = 40%, and for synchronous generator η = 60% (at cosφ = 1).

Ability to work at cosφ= 1

Obviously, only a synchronous generator and, of course, synchronized asynchronous generator can have such a mode. Comparing the operation of the SG and SAG in the specified mode, preference should be given to a synchronized asynchronous generator, and here's why. To install a conventional synchronous generator in a mode with cosф = 1, it is necessary to reduce the excitation current, which entails a deterioration in stability. SAG also has two excitation windings, by adjusting the currents in which stability can be increased [15].

Compared with the synchronous generator, the SAG has great advantages in terms of increased stability. The presence of excitation windings in the longitudinal and transverse axis of a synchronized asynchronous generator allows, with appropriate regulation of the currents in them, to increase the dynamic stability. In addition to this, in the SAG circuit, by disconnecting the excitation winding (rotor) from the exciter (power system) and shorting it to resistance (or short), we can transfer the machine to the asynchronous generator mode. The latter circumstance expands the use of a synchronized asynchronous generator in a wind electric installation.

Firstly, when the wind speed exceeds the nominal value, if for one reason or another the synchronous mode of the generator cannot be maintained, the generator is quite easily transferred to the asynchronous mode. At the same time, the loss of a conventional synchronous generator from synchronism is known for big troubles - this is an emergency mode. Secondly, it is possible to start the wind electric installation from a stopped state to the required speed (by switching the asynchronous generator to the engine mode) smoothly and without jerks, without exceeding the permissible acceleration [16].

Conclusion

1. It is concluded that a synchronized asynchronous generator, which is supplied with a synchronization circuit that provides longitudinal-transverse excitation, has a number of advantages compared to an asynchronous and synchronous generator in a wind electric installation.

2. The main advantage of a new type of synchronized asynchronous generator is the damping of electromagnetic power fluctuations that are generated by the generator.

3. The presence of two excitation windings allows you to set the operation mode of a synchronized generator with cosf = 1 without compromising stability. This mode helps to minimize losses both in the generator and in the transmission line, which is especially important for remote wind drives.

4. The ability to work SAG in asynchronous mode allows you to:

a) when the wind speed exceeds the nominal one, transfer the synchronized asynchronous generator from the synchronous mode to the asynchronous generator mode without damaging the energy conversion process.

b) to carry out an electric start of a wind electric installation with the fulfillment of all requirements for mechanical strength by transferring a synchronized asynchronous generator to the mode of an asynchronous motor.

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