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ENERGY EFFICIENCY IMPROVING OF A WIND ELECTRIC INSTALLATION USING A THYRISTOR SWITCHING SYSTEM FOR THE STATOR WINDING OF A TWO-SPEED ASYNCHRONOUS GENERATOR

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Abstract- A calculation method has been developed and the choice of the stator winding of a two-speed asynchronous generator of a wind electric installation has been carried out. The connection diagrams of the stator winding are considered when switching the number of poles in a ratio of 2:1. A thyristor system for switching the stator winding of a two-speed asynchronous generator of a wind turbine has been developed. The use of a three-phase thyristor commutator for switching the stator winding of a two-speed asynchronous generator for starting a wind generator in a motor mode, which becomes necessary at low wind speeds (2.5-3.5 m/s), is proposed. The mechanical characteristics of a two-speed machine with a 2:1 switching of the number of poles at a constant torque and at a constant power are obtained.

Keywords: WEI, TSAG, Thyristor, Switching, Commutation, Starting Moment, Modeling, Speed.

1. INTRODUCTION

The use of wind energy in recent years is the most widespread. Local placement of wind turbines, ease of installation of the mechanism and application are clear advantages over conventional energy sources. A wind electric installation (WEI) or a wind generator is installation that converts the kinetic energy of the wind flow into the mechanical energy of the rotor rotation with further conversion into electrical energy. Wind turbines (or wind power plants - wind turbines) are classified as renewable energy sources. They are distinguished from traditional sources that generate electrical energy by the absence of raw materials and waste, they can operate in a wide range of environmental conditions: 100% humidity and temperatures from -40 to +85 °C. The only requirement is a high level of wind [1, 2, 3].

Wind electric installation have number of advantages, which leads to their widespread use. These advantages are:

1. Full renewable energy is used. When the sun influences, there is a constant movement of air flow in the atmosphere, the creation of which does not require extraction, transportation, or combustion of fuel. The source is fundamentally inexhaustible.
2. Under the action of wind turbines, harmful emissions are completely absent. Therefore, this installation is considered environmentally friendly.
3. The use of wind turbines is mainly justified for isolated places.
4. When a WPP is put into operation, the price of a kilowatt-hour of generated electrical energy is significantly reduced.
5. Variable speed wind turbines able to tune into the wind. At the same time, the regulation of the rotation frequency relative to the wind speed is carried out in such a way as to achieve maximum power generation, etc.

To increase the efficiency of wind application, stepwise speed control began to be used. To do this, two windings with a different number of pole pairs are placed in the generator stator. At the lowest wind speed, in order maintain optimal speed, a low speed of rotation of the wind wheel is used and the winding with the largest number of pole pairs is included in the generator. When the wind speed rises above a certain limit, it switches to the smallest value of the number of pole pairs and an increase in rotation speed is allowed [4, 5].

Two-speed wind electric installations are widely used, so their circuit is quite simpler than circuits with converters. A two-speed asynchronous generator is an asynchronous generator that operates in two speed modes. Step adjustment is provided by series-parallel switching of the stator windings. Unlike standard asynchronous machines, these machines have additional rotational speed designations. For example, 4/2 (1500/3000 rpm), 6/4 (1000/1500 rpm), 8/4 (750/1500 rpm), 8/6 (750/1000 rpm), 12/6 (500/1000 rpm). With this design of a two-speed generator, the overall and connecting dimensions are identical to standard electric motors. These generators are used to drive gearboxes, geared motors, fans and other applications that require a change in speed. The main of these installations is the wind power plant [6, 7, 8].

According to the device and purpose, two-speed machines are divided according to:

1) The number of phases - single-phase, three-phase
2) Applications - general industrial, crane, explosion-proof

3) Body design - foot-mounted, combined, with one or two shafts.

Structurally, two-speed machines differ from standard ones in that they have a special stator design, while the rotor is usually squirrel-cage. The most common types of construction of two-winding machines are types with two dependent windings and with two independent windings. The device of two-speed machines with two dependent windings can differ due to the ratio of the number of poles - 1:2, 3:2, 4:3. When there is a speed ratio of 1:2, a single pole-switched Dahlander stator winding is used. At ratios of 3:2, 4:3, one pole-switched winding is used according to the method of amplitude-phase modulation. When using dependent windings, two-speed machines are available in standard sizes, independent ones are slightly larger. The principle of operation of these machines is to switch the connection diagrams of the stator winding, as a result of which the number of poles changes.

The use of TSAG makes it possible to increase the generation of electrical energy at low wind speeds from 3.5 to 5 m/s. Consider the advantages of a two-speed generator used for wind turbines. Advantages:

1) Low noise level
2) Minimal vibration
3) High performance
4) High starting torque
5) Simplicity and reliability of design
6) Ability to work at two speeds

Since the rotation speed depends on the wind, it must be regulated. Step speed control is important for wind turbines. Therefore, at present, two-speed asynchronous generators are widely used in wind electric installations.

2. SELECTION OF THE STATOR WINDING OF A TWO-SPEED ASYNCHRONOUS GENERATOR

The case is considered when the number of poles of the stator winding changes in the ratio $2p_1/2p_2 = 8/4 = 2:1$. In this case, each phase of the stator winding consists of two parts, each of which has an equal number of coil groups. When both parts are flowed around by currents in the same direction, a magnetic field arises with large number of poles; when changing the direction of the current in one of the parts, the number of poles is reduced by half.

Such switching of the current direction should be carried out in all phases at the same time, and the switched parts of the winding can be connected in series or in parallel. The winding pitch in the tooth division for both numbers of poles, and the width of the phase zone, which occupies the sides of each coil group, are the same. But since the pole division τ changes twice when the number of poles is switched, the phase zone in electric degrees and the relative pitch of the winding also change. With a small number of poles, the phase zone is α=60°, and with a double number α=120° [9, 10].

The most widely used 2:1 connection scheme (Dahlander's scheme) are shown in Figure 1. Star - double star circuits (Figure 1a, 1b) provide switching at a constant torque, and triangle - double star circuits, which are shown in Figure 1c and 1d at approximately constant power. As can be seen from the diagrams that are shown in Figure 1, when moving from a low speed to a high speed, the direction of the current changes in half of the half-windings of the stator phases. In order for the direction of the field growth to remain unchanged in this case, it is also important to switch the ends of the 2 phases of the winding [11].

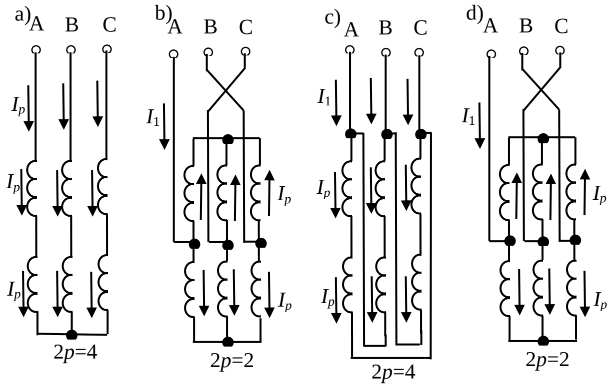

Figure 1. Fundamental schemes of the connection of the stator winding when switching the number of poles in a ratio of 2:1

For these circuits, we can consider the ratios of powers P_2 and moments M in a simplified form (1, 2). Linear voltage U_1, current I_p in each half-winding of the stator phase, efficiency η and cosφ remain constant (3, 4). In this case, for circuits shown in Figures 1a and 1b:

$$\frac{P_{12}}{P_{11}} = \frac{\sqrt{3}U_l I_{l2}\cos\varphi}{\sqrt{3}U_l I_{l1}\cos\varphi} = \frac{\sqrt{3}U_l 2I_p\cos\varphi}{\sqrt{3}U_l I_p\cos\varphi} = 2 \quad (1)$$

$$\frac{M_2}{M_1} = \frac{P_{22}}{Q_{22}} = \frac{Q_{21}}{P_{21}} = \frac{P_{12}}{Q_{22\eta}} = \frac{Q_{21\eta}}{P_{11}} = 1 \quad (2)$$

For the schemes shown in Figure 1c, 1d, we have:

$$\frac{P_{12}}{P_{11}} = \frac{\sqrt{3}U_l I_{l2}\cos\varphi}{\sqrt{3}U_l I_{l1}\cos\varphi} = \frac{\sqrt{3}U_l 2I_p\cos\varphi}{\sqrt{3}U_l \sqrt{3}I_p\cos\varphi} = 1.15 \approx 1 \quad (3)$$

$$\frac{M_2}{M_1} = \frac{P_{22}}{Q_{22}} = \frac{Q_{21}}{P_{21}} = \frac{P_{12}}{Q_{22\eta}} = \frac{Q_{21\eta}}{P_{11}} = 0.575 \approx 0.5 \quad (4)$$

In these equations index 1 means lower frequency rotation and index 2 higher frequency rotation. When applying the schemes that are shown in Figure 1c, 1d, as a rule, the same power is indicated for both speeds, i.e., accepted that $P_{12} = P_{11}$ and $M_2 = 0.5M_1$. A variant of a two-speed asynchronous generator is calculated, in which the power ratio is 13/18 kW, as you can see, $\frac{P_{12}}{P_{11}} = 1.385 > 1$, therefore, the stator winding circuit is chosen according to Figure 1a, 1b. Rated linear voltage U_n=380V

3. CONTACTOR SYSTEM OF SWITCHING IN STATOR WINDING OF A TWO-SPEED ASYNCHRONOUS GENERATOR OF A WIND ELECTRIC INSTALLATION

A contactor is an indispensable device in situations where it is necessary to frequently switch electric current. It allows you to close and open the circuit up to several thousand times per hour. At the same time, the contactor has both electrical and mechanical wear resistance. To perform its function, the contactor must have a simple and reliable design. Of course, some items may differ from model to model. This mainly concerns the number and appearance of contacts and coils. But in general, the internal structure of the contactor has a standard design. So, the main elements of the contactor include: 1) Electromagnetic system; 2) Main contact system; 3) Auxiliary contact system (block contacts); 4) Extinguishing system.

The first circuit is implemented on contactors and is shown in Figure 2. It works in the following way. At the first stage (at wind speeds $5.0 \leq v \leq 5.5$ m/s), contactors K2 and K3 are off, and contactor K1 is on. In this case, as can be seen from the figure, two equal parts of the stator winding are connected in series, and terminals A, B, C are connected to the electrical network through the closed contacts of contactor K1. Thus, the asynchronous generator of a wind electric installation generates electrical energy and delivers it to the electrical network to consumers [12, 13]. At the second stage (at wind speeds $v > 5.5$ m/s), the contactor K1 is turned off, its contacts open and the stator winding is disconnected from the electrical network. Following this, commands are given, which are generated by the microprocessor control system of the wind turbine, to turn on the contactor K2, and then the contactor K3. In this case, the conclusions A, B, C are closed to each other. The stator winding circuit of an asynchronous generator takes the form shown in Figure 1b.

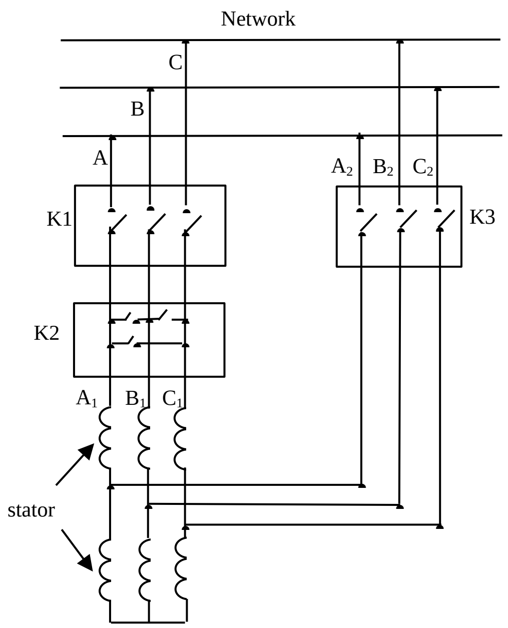

Figure 2. Contactor scheme of switching the stator winding of a two-speed asynchronous generator of a wind electric installation

As a result, the number of stator winding poles is halved. In this case, the rotational speed of the shaft of the asynchronous generator was increased by the wind turbine to the appropriate value, that is, more than 1500 rpm by the amount of slip. It should be noted here that the commands for switching the stator winding of the asynchronous generator and its connection to the electrical network are issued after the generator shaft speed is brought by the wind turbine to the appropriate value (in the first stage, more than 750 rpm, and in the second stage, more than 1500 rpm). Once again, we note that the control commands for switching the stator winding of an asynchronous generator are generated by the wind turbine control system.

4. THYRISTOR SYSTEM OF SWITCHING THE STATOR WINDING OF A TWO-SPEED ASYNCHRONOUS GENERATOR OF A WIND ELECTRIC INSTALLATION

The above contactor scheme for switching the stator winding of an asynchronous generator has a number of disadvantages:
– High cost;
– Large dimensions and weight;
– High power of control signals;
– Poor compatibility with the microprocessor control system.

The thyristor circuit for switching the stator winding, shown in Figure 3, does not have these disadvantages. In addition to the functions of switching the stator winding, it can perform a number of new functions. The most important of them is the ability to regulate the voltage in the electrical network. This function can be very useful when the wind turbine is running in motor mode, more specifically when starting the input of the wind turbine. This will be discussed in the following.

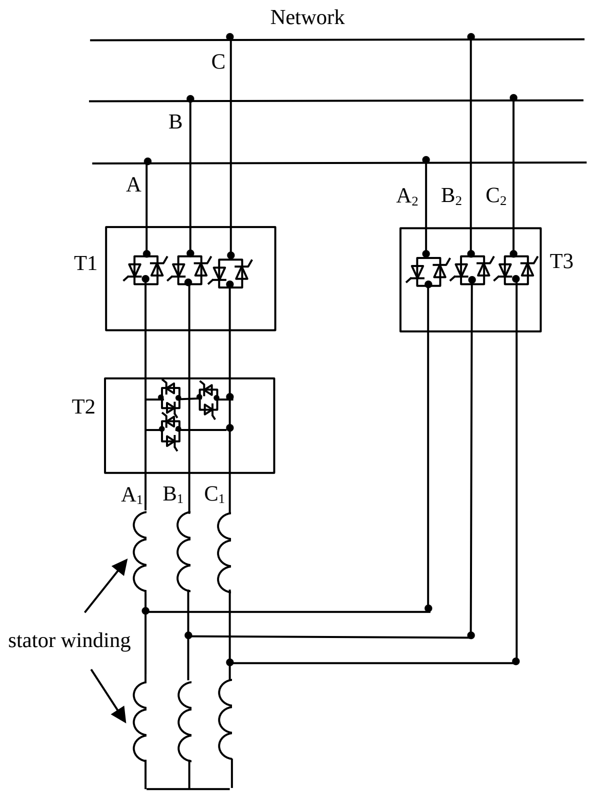

Figure 3. Thyristor scheme of switching the stator winding of a two-speed asynchronous generator of a wind electric installation

The principle of operation of a thyristor pair in phase is known. Each thyristor passes the corresponding half-wave of the AC voltage when the following conditions are met:

– The presence of a positive potential at the anode;

– Supply of a pulse with the appropriate parameters to the control electrode.

By placing two back-to-back thyristors in each phase, we will switch a three-phase AC circuit. In addition to switching the stator winding to change the number of poles, the thyristor system according to Figure 3 (we are talking about blocks T1 and T3) can also perform much more effective protection of the stator winding in the event of a short circuit or other damage than the contactor scheme.

5. APPLICATION OF A THYRISTOR SYSTEM FOR SWITCHING THE STATOR WINDING FOR START-UP OF A WIND ELECTRIC INSTALLATION

In practice, at wind speeds of 2.5-3.5 m/s, the wind turbine does not come into rotation. The reason for this is that the torque generated by the wind turbine is not sufficient to overcome the so-called starting torque of the wind turbine. The wind speed range of 2.5-3.5 m/s is observed very often (according to some sources, approximately 30-35% of the annual duration). The generation of electrical energy at these speeds would be very important. This paper proposes to overcome this shortcoming. It is a so-called motor start-up of a wind turbine. We are talking about the fact that the wind generator is transferred to the motor mode of operation for a very short period of time. When starting off after a certain number of revolutions, the moment of resistance of the wind turbine abruptly decreases. Thus, as soon as the wind turbine shaft starts to move, the wind turbine picks up the rotation and then starts to work independently in the normal mode.

It is recommended to use the motor mode of operation of the wind generator at a low synchronous frequency of rotation of the generator (in our case, 750 rpm, $2p$ = 8). To do this, in the developed system for switching the number of poles of the stator winding according to Figure 3 thyristor switches T2 and T3 are opened, and T1 is closed. In this case, the mains voltage is applied to the stator winding of the asynchronous generator and the machine starts to rotate [14, 15].

As you know, the initial starting current of an asynchronous motor reaches a value of 5 - 7 rated current. To eliminate the negative value of such a large current surge, it is proposed to reduce the voltage supplied to the stator winding using the T1 thyristor unit, switching it to the voltage regulator mode. To do this, the thyristor unit is equipped with a pulse-phase control system (PPCS). With the help of PPCS, the thyristor control angle is changed, by selecting the value of which it is possible to limit the starting current to an acceptable value. At the same time, in blocks T2 and T3, the use of such a system is not required [16, 17].

6. SIMULATION RESULTS

Using the program and according to the calculation, Figure 4 shows the mechanical characteristics were.

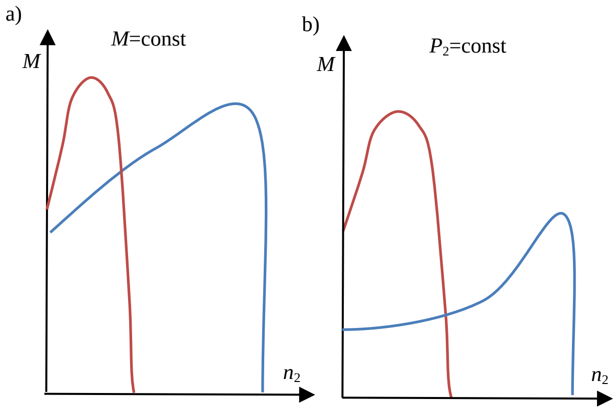

Figure 4. Mechanical characteristics of a two-speed machine with a ratio of 2:1 switching of the number of poles (a) at a constant torque, (b) at a constant power

7. CONCLUSIONS

The use of a two-speed asynchronous generator in a wind electric installation can significantly increase the wind utilization factor (ultimately, the plant efficiency), which is especially important at low wind speeds. This allows you to significantly increase the annual production of electrical energy. Thanks to the thyristor switching circuit of the stator winding, more effective protection of the stator winding from short circuit is provided. The development of a thyristor system for switching the stator winding of a two-speed asynchronous generator for starting a wind generator in a motor mode improves the operation of a wind turbine at low wind speeds (2.5-3.5 m/s).

APPENDICES

The dependences of current, efficiency and slip on P_2 are called operating characteristics. These quantities can be calculated analytically or found from a pie chart. For analytical calculation, we will use the formulas that are used in determining the nominal values of r_1, I_1, S, cosφ using these formulas, we calculate the values for 0.25P_2; 0.5P_2; 0.75P_2; 1.25P_2, which we are interested in. It is necessary to take into account the fact that when calculating additional losses, efficiency values are conditionally taken. The result of the calculation is entered in Tables 1 and 2.

Table 1. Calculation result for $2p$=8 characteristics

Conventions	Output power in fractions of the nominal				
	0.25 P_2	0.5 P_2	0.75 P_2	1.0 P_2	1.25 P_2
P_2, kW	3.25	6.5	9.75	13	16.25
I_1, A	7.9	10	12.9	16.1	20.5
cosφ	0.44	0.65	0.75	0.82	0.81
η, p.u.	0.809	0.864	0.870	0.862	0.840

Table 2. Calculation result for 2*p*=4 characteristics

Conventions	Output power in fractions of the nominal				
	0.25 P_2	0.5 P_2	0.75 P_2	1.0 P_2	1.25 P_2
P_2, kW	4.5	9	13.5	18	22.5
I_1, A	9.7	16.6	24.4	33.2	43.4
cos φ	0.81	0.90	0.93	0.94	0.92
η, p.u.	0.858	0.894	0.893	0.879	0.855

NOMENCLATURES

1. Acronyms

WEI Wind Electric Installation
TSAG Two-Speed Asynchronous Generator
PPCS Pulse-Phase Control System

2. Symbols / Parameters

I_l: The line current value
I_p: The phase current value
M: The moment
P_1: The value of the power supplied to the machine
P_2: The value of useful power
S: The full power
n_2: The rotation frequency
cosφ: The power coefficient
η: The efficiency
I_1: The stator current
U_l: The line voltage
I_{l1}: The line current value of lower rotation frequency
I_{l2}: The line current value of higher rotation frequency
U_n: The nominal voltage
Q: The reactive power

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