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Analysis of systems and methods of emergency braking of wind turbines

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Abstract: Increased wind loads in the world and the lack of human control over the operation of wind turbines create high risks of their operation. The most common accidents in the operation of wind turbines are: the destruction of the blades due to the excess of the rotor speed, overheating of the generator windings, the destruction of the structure due to increased vibrational vibrations. As a rule, braking systems are used in wind turbines to prevent the listed negative factors. This article discusses wind turbine power control systems, control systems and braking systems, since each type of these systems has its own specific and narrowly focused task. The article also presents the results of the search and analysis of existing systems and methods of emergency braking of WEI.

Keywords: WEI, emergency breaking, vibrations, frequency, generator.

1. Introduction

The regional distribution of wind turbines, simple installation of the mechanism and applications are the main advantages relative to conventional energy sources. Wind electric installation (WEI) is equipment that converts the kinetic energy of the wind flow into the mechanical energy of the rotation of the rotor with further conversion into electrical energy. Like any other installation, a wind turbine also has a number of disadvantages: the inconstancy of energy access, the high cost of the device, the noise that occurs during the action of electric drives, the freezing of the blades that create fragments. It must be borne in mind that the wind power plant works when there is wind. In this case, any emergency situations can occur [1,2].

Wind electric installations are optimized in such a way that they generate the most energy at the most probable wind speeds (known to be 11 m/s). And it would be economically inefficient to design a wind turbine for higher wind speeds, since high wind speeds are quite rare. But, despite this, there is a need to regulate all wind turbines with fast winds. Otherwise, the installation rotor may be destroyed or the power transmissions may be overloaded. All this will lead to the almost complete destruction of the wind turbine, as well as the danger to nearby objects and possible human injury. Such emergency factors could be avoided by increasing the structural strength of the moving elements of the wind power plant, but then the weight and size characteristics will also increase, which in turn will lead to a decrease in efficiency (due to the bulky design) and an increase in the cost of the product [3,4].

In addition, during the operation of the wind turbine, energy losses occur in the generator, as a result of which heat is released. Although the efficiency of modern generators is very high, the absolute losses are quite large, which leads to a significant increase in the temperature of the active steel, copper and insulation. An increase in the temperature of structural elements, in turn, leads to their gradual destruction and a decrease in the service life of the generator, in extreme cases, this can lead to the ignition of some elements of the generator. In addition, the magnetic components of the generator begin to lose their magnetic properties at high temperatures (over 150 ºC). Usually, in industry and mechanical engineering, various cooling systems are used to prevent the occurrence of this negative factor. But since the installation of a cooling system on a wind turbine is economically and practically impractical, it will be more acceptable if the wind wheel speed control systems adapt to the temperature of the generator and prevent it from overheating. The practice of operating wind turbines has shown that at a certain speed, resonant vibrations of the mast and rotor can occur. In this case, the resonant rotation frequency can be significantly less than the limiting rotation frequency. For example, for a vertical-axis installation with a power of 3 kW "WEI -3", the resonant frequency occurs during rotation at 67 rpm and 120 rpm. Although the maximum rotation speed is 180 ... 200 rpm [5,6].The wind flow by its nature has a wave-like characteristic, therefore, the wind power plant will either accelerate or decelerate (amplitude jumps in acceleration and deceleration will be smoother than that of the wind flow due to the inertia of the structure). As a result of constant acceleration and deceleration, the wind turbine passes through the resonant frequency of rotation from time to time. If the process of acceleration or deceleration of the rotor occurs relatively quickly, then the duration of stay in the resonant state will be short. However, if for some reason the change in the rotor speed occurs at a low speed, then the time spent by the installation in a state of resonance increases. Continuous loads of resonant vibrations will lead to the destruction of the structure. As a rule, the vibration effect leads to an increased decrease in the durability of the unit, the destruction of bearings, cracking of the foundation, radial runout occurs - these negative effects lead to the destruction of the wind turbine and create a danger during its operation [7,8].

Thus, for the safe and stable operation of wind turbines, it is necessary to equip them with control and emergency braking systems to prevent the occurrence of the negative factors listed above. The wind turbine emergency braking system is a safety system designed to automatically brake the wind turbine in the event of an emergency. It works by monitoring the operation of the wind turbine and detecting any unusual or dangerous situations such as wind gusts, cable breaks, fires, loss of control over the wind turbine, etc. When the system detects such a situation, it immediately automatically and safely brakes the wind turbine. This prevents potential equipment failure and reduces the chance of a serious accident. The emergency braking system of a wind turbine usually consists of several components, including sensors, controllers, and braking systems. It must meet strict international safety standards to ensure its reliability and efficiency.

2. Object and subject of research

The purpose of the study is the impact of the emergency braking system on the safety of operation of a wind electric installation. To develop an emergency braking system for a wind turbine, it was decided to choose a mechanical braking system, because mechanical structures are able to withstand significant dynamic and thermal loads. At the same time, an electric drive is selected for the system as the most reliable drive mechanism and the most suitable for the conditions in which wind turbines are operated.

The figure shows a block diagram of the braking system. The controller receives data from the following sensors: generator temperature, rotor speed and vibration velocity on the design of the wind turbine. If at least one of the measured values reaches the limit value, the controller will send an activation signal to the drive. The braking torque is transmitted from the electric drive through the mechanical braking unit to the rotor of the wind turbine, thereby braking it.

Obviously, if at least one of the measured values tends to exceed its nominal values, then the following facts are likely: the steady wind load exceeds normal values (above 11 m/s); there is a failure or malfunction in the main power control system of the wind turbine; there are other technical malfunctions in the energy complex [9,10].

In order to create sufficient torque for wind turbine braking, it is necessary to use a reduction gear in addition to the electric drive - a gearbox. In addition, this will allow the use of an electric drive of small dimensions. Even small wind turbines have relatively large values of rotor torque at wind speeds above 11 m/s in relation to the torque of common electric drives.

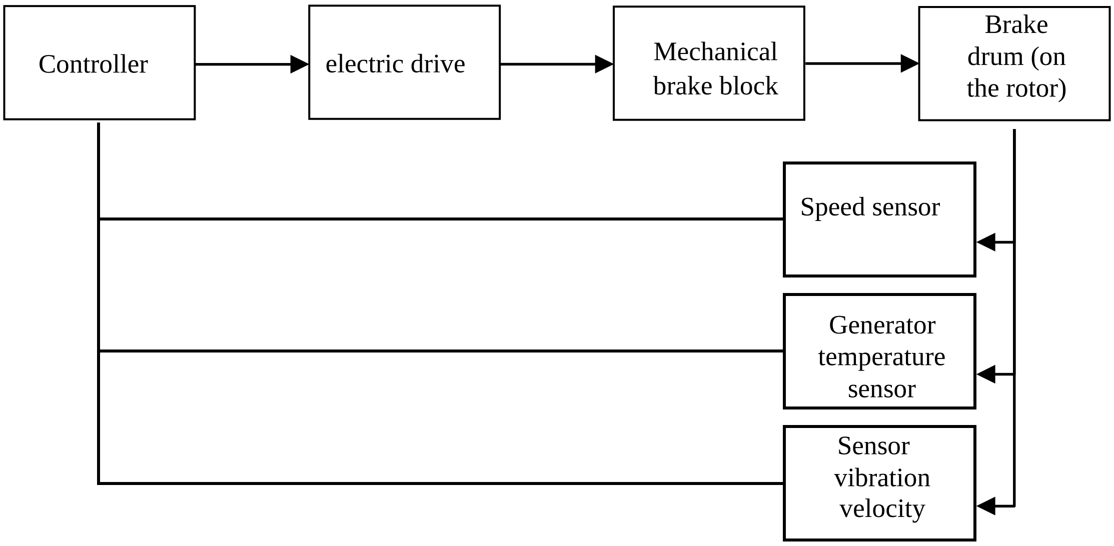

Figure 1. Structural diagram of the emergency braking system of a wind electric installation

Two methods can be used to hold the wind wheel in the inhibited state: activation of the electric drive in the shaft holding mode, or the use of self-jamming elements in the mechanical unit. For the energy security of the entire wind energy complex, the option with self-jamming mechanical elements is more preferable, because in this case, there are no costs for the power supply of the electric drive. In this case, the rotor of the wind power plant can be in the inhibited state for a long time without a significant discharge of the batteries of the energy complex. However, it must be borne in mind that in order to deactivate the system (disengage the rotor), it is also necessary to spend electricity to start the electric drive in the reverse direction. Thus, the system must take into account the charge level of the batteries so that there is always enough energy left for at least one activation of the system (one braking).

The purpose of the study is the impact of the emergency braking system on the safety of operation of a wind electric installation [11].

3. Research methods

The wind energy industry has a very wide range of different systems responsible for the stability of wind turbines and the prevention of accidents. However, one should distinguish between power control systems for wind turbines, control systems and braking systems.

Power control systems include, as a rule, systems that allow monitoring, analyzing the current state of the wind turbine, and, depending on the given program, influence the operation of the wind turbine, including slowing it down. But an important nuance here is that the wind turbine power control systems are not designed for emergency situations when any elements of the control system itself and the wind turbine as a whole fail. Thus, such systems are not installed on wind turbines as the only ones, but are supplemented by devices or other systems that partly duplicate the functionality of the main system.

Control systems for wind turbines advantageously include systems that keep or limit the basic performance of a wind turbine within acceptable ranges. As a rule, in such systems, the adjustable parameter is the speed of rotation of the wind turbine rotor.

Emergency braking systems are mostly installed on wind turbines in addition to the main wind turbine control or regulation system. The main task of the braking system in this case will be to prevent uncontrolled operation of the wind turbine and to prevent possible emergency consequences in the event of failure of the main control system or any other components of the wind turbine.

Below are the results of the search and analysis of existing systems and methods of emergency braking:

Shoe brakes.

This type of emergency braking system is the most common among the rest. In terms of their design, this type of brake is very similar to automobile disc brakes. A brake disc is installed on the wind wheel shaft, and brake pads are located on the sides of the disc. When braking is required, the pads compress the brake disc and the braking process begins. Shoe brake systems can have two types of drives: electric and hydraulic.

Electrically driven systems may have a gearbox or other mechanical transmissions that convert rotational motion into translational [12,13].

Advantages:

– this type of braking devices is highly reliable, since the design is largely borrowed from the automotive industry, where it has been tested for many years;

– also, shoe brake systems of wind turbines make it possible to provide high braking torques due to the fact that the brake discs can be scaled to the required size, thereby creating a larger arm for applying the braking torque;

- in addition, shoe brakes are able to work even at high temperatures - this allows them to absorb a large amount of excess power on the wind turbine without compromising the structure.

Flaws:

- a very important drawback of this type of brakes is their significant overall dimensions and the impossibility of a compact location inside the wind turbine structure, which makes them applicable only to large wind turbines that have capacious nacelles;

- also, the disadvantages include the high energy consumption of the brake system, because during the entire braking time, the system spends electricity to keep the pads in a compressed state;

- if the drive for this type of brake is hydraulic, then the design becomes much more complicated due to the addition of a hydraulic station to its composition.

3.1 Closing the windings of the wind turbine electric generator

Emergency braking of the wind wheel is possible in some cases by closing the windings of the electric generator of the wind turbine. Moreover, both the control system and the operator of the wind turbine can close the windings of the generator. But this method of emergency braking of a wind wheel should not be confused with the method of controlling the rotor speed by closing the generator windings using pulse-width modulation [14,15]. In the latter case, the wind wheel is braked, and the process of full braking may take a long time (depending on the wind conditions in which the wind turbine operates).

Advantages:

- when the windings of the generator are shorted, the wind wheel brakes very quickly, after which it remains in the inhibited state;

- in addition, to close the generator windings, a small amount of electricity is sufficient to switch the relay contacts if this operation is performed by automation. To perform this operation, a person only needs to switch the toggle switch, which also requires a small amount of time and effort.

Flaws:

– abrupt braking of the rotor at a high rotation speed can lead to deformation or destruction of its mechanical structure;

- in the process of braking, a large amount of heat is released on the generator windings in a short period of time, which can lead to melting or ignition of the windings;

- it is impossible to slow down the wind wheel in this way if the electric generator is overheated, or if there is a violation of the integrity of the cable of the electric generator going to the control system.

3.2 Combined shutdown of the wind turbine

The combined method of stopping a wind turbine may include several procedures: aerodynamic braking, mechanical braking, and generator braking. This method is usually used on large wind turbines when it is necessary to stop the wind wheel as quickly as possible without causing damage to the structure.

Advantages:

– the wind wheel braking process can take a short time compared to other methods due to the use of two or more braking mechanisms.

Flaws:

– low reliability of this method, because during braking, standard elements and components of the wind turbine are used, which in an emergency may not work correctly or be disabled.

4. Conclusions

After analyzing the data, it can be argued that the modern wind energy industry still needs reliable braking systems that can prevent accidents at wind turbines. From the analysis of statistical data on accidents at installations, it follows that the most important characteristics by which the technical condition of the facility should be monitored are the rotor speed and generator temperature. Also, monitoring of vibration oscillations of the structure should be ensured.

In addition, an important requirement for the wind turbine braking system is complete autonomy from the main control system. And also, the braking system must contain mechanical elements that can withstand increased loads.

In general, the system must provide safe operating conditions for wind turbines even with individual wind speeds corresponding to 10 points on the Beaufort scale. Thus, it is necessary to develop a braking system that will meet the above requirements.

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