Gearbox Development for an Emergency Brake System of the Wind Turbine

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Abstract. The article justifies the need to use independent power supply sources in the Arctic regions. It gives arguments in favour of using wind-driven power plants as autonomous power sources. It describes the problems of operating wind energy equipment in the arctic climate. As a solution of the above operational problems, it is proposed to use an emergency brake system in wind power plants. We proposed a design of an emergency brake system exemplified by a 3 kW vertical-axial wind turbine. We calculated the gearbox parameters for the proposed design and created a computer model of the gearbox based on the obtained parameters. We also analysed the advantages of the developed gearbox and the design of the emergency brake system in general.

1. Introduction

Currently, humanity has been actively developed the northern regions of the planet. This is primarily due to the fact that the northern parts of the world are rich in minerals [1,2]. A full development of the northern lands will significantly delay the advent of the hydrocarbon energy crisis [3]. Furthermore, the development of the Arctic territories is a favorable location of transport routes. The development of shipping traffic along the northern routes will allow one to significantly reduce transport costs, as well as to increase the speed of delivery of goods [4,5].

However, before starting the global development of the Arctic, it is necessary to solve the problem of the global energy supply of those regions. To allocate mining stations, significant energy capacities will be needed for their continuous operation. It is also necessary to maintain livable conditions for the personnel, first of all – to provide them with heat. In addition, the specificity of oil companies implies mobility [6,7]; i.e., oil stations may be temporarily located for the period of exploring the area for the presence of minerals. In the absence of an oil field in the selected location, the station will be moved to another location. Accordingly, power supply sources should be moved together with the station. Reliable navigation is paramount for transport sailors in arctic weather conditions [8]. A regular and stable power supply, albeit of low power, is needed for navigation beacons.

It will be extremely expensive to conduct power lines in those regions [9]. The costs of electrical wiring will be paying off for a very long time. Therefore, at the moment, the main source of electricity in the north of the planet is diesel generators [10]. However, this option for generating electrical energy cannot be permanent. Firstly, the costs of fuel delivery to the Arctic facilities are also rather
high [11]. In addition, a difficult transport accessibility of those regions jeopardizes the energy supply of the facilities [12]. Secondly, diesel generators affect the environment of those regions [13]. The lack of the necessary infrastructure makes it impossible to competently recycle the waste accumulated from the electricity generation using diesel engines [14].

Thus, a reliable autonomous energy source is needed for a full development of the north. At the same time, it should be environmentally-friendly. Wind-driven power plants can be one of such options. In the Arctic, it is more efficient to use small wind turbines. Such wind turbines can operate completely autonomously [15]. As compared to medium and large wind turbines, they are cheaper and easier to deliver to the north [16]. Besides, small dimensions will allow one to dismantle the wind turbine and relocate it, if necessary.

2. Operations features of wind turbines in the Arctic region
For stable and safe operation of a wind turbine in the Arctic region, it is necessary to adapt its configuration to the climatic conditions of those places. The Arctic has a favourable wind potential to use wind power plants [17]. But at the same time, wind loads may be excessively high and destroy wind turbines. Despite the fact that wind turbines have basic (standard) control systems, they need to be upgraded with additional brake systems to be operated in the Arctic. The main control system generally uses an electric generator in its operation. Consequently, an additional (redundant) brake system must operate using a different mechanism. To this end, it is proposed to use a mechanical system for emergency brake. The emergency brake system is designed to prevent any excessive wind wheel speed, excessive temperature of the generator winding, as well as to slow down the wind turbine in case of excessive vibrations of the structure. The wind wheel is braked by a frictional engagement of the brake elements of the mechanical control system and the brake drum on the wind turbine rotor.

In most cases, medium-sized wind turbines are equipped with conventional disc brake mechanisms [19, 20]. However, these brake system designs are located in the gondola of horizontal-axial wind turbines and occupy an additional space inside [21]. Besides, this type of brake systems has a limited efficiency and, as a rule, is not equipped with a smart control algorithm [22].

3. Brake system for the wind turbine
This paper proposes to consider a mechanical system for emergency brake exemplified by a 3 kW vertical-axial wind power plant (Fig. 1). The hub of a wind wheel is installed on the wind turbine mast by means of a flange connection. An electric generator is located inside the hub (in the upper part), and the blades are structurally attached to the external elements of the hub. This wind turbine design does not allow us to place the disc brake system inside the hub of the wind wheel, since there is no free space in it. In this regard, the authors proposed a different version of the mechanical brake system.

![Figure 1. 3 kW vertical-axial wind power plant in South Ural State University.](image_url)
A three-jaw braking unit is installed between the coupling flanges of the mast and hub (Fig. 2). Brake elements are moved in the direction from the center to the brake drum mounted on the hub of the wind wheel. When the brake elements press the wall of the brake drum, friction braking begins. The motion to the brake elements of the three-jaw unit is transmitted by the rotation of the standard spiral disc, which is widely used in three-jaw lathe chucks.

Figure 2. General view of the emergency brake system for the wind turbine.

However, a very powerful drive is needed to transfer enough torque to the spiral disc. The size of the drive is limited by the internal diameter of the mast, where it is expected to be placed. Thus, it was proposed to choose a standard HarmonicDrive electric motor with a gearbox installed on it. The type and characteristics of the electric drive are shown in Fig. 3 [23]. The gearbox must transfer power with a torque increase factor of at least 562. In addition, the gearbox, like the electric motor, must be structurally placed inside the mast.

Figure 3. General view and characteristics of the motor.

For the specified parameters, we proposed to choose a planetary type of the gearbox, since this type has a relatively compact size and a high gear ratio [24]. Figure 4 shows a kinematic diagram of the gearbox installed between the electric motor and the three-jaw braking unit. As a result of the calculation (table 1), it is obtained that the gearbox will have a total gear ratio of 625 and consist of 4 stages (the gear ratio of each stage is 5). The maximum outer diameter of the gearbox (the outer diameter of the epicycle) is 165 mm, and the diameter of the internal through hole in the gearbox is 25 mm. The efficiency of each stage of this type is 0.98 [25], thus the total efficiency will be equal to 0.92. Given the gear ratio of the gearbox and its efficiency, the torque transmitted to the three-jaw unit will be 2070 N·m, which meets the requirements posed to the driving part of the braking system.

Figure 4 shows a computer model of a planetary gearbox placed in an adjustable housing. To easily install the gearbox, we provided a housing with a flange mount to the mast of wind turbine and a flange connection with an electric motor. Thus, the electric motor and the gearbox can be mounted in the wind turbine mast as a single unit (Fig. 6).
Figure 4. Gear kinematic diagram for the mechanical brake system of the wind turbine: 1 – small gear (sun), 2 – large gear (planet), 3 – carrier, 4 – epicycle.

Table 1. Calculation of the gearbox parameters.

| Solve for: | Planet | Number of planets: | 4 |
|------------|--------|--------------------|---|
| **Given:** | Speed (RPM) | Torque (N·m) | |
| Input      | 2000   | 3.6               | |
| Output     | 400    | 18                | |
| Gear ratio | 5      |                   | |
| **Min. # teeth** | | | |
| Ns         | 14     | Adjust Ns by:     | 1 |
| Np         | 20     | Adjust Np by:     | 1 |
| Nr         | 54     | Adjust Nr by:     | 1 |
| **Pitch**  |         | **Module**       | |
| Pn (teeth/in.) | 10   | m                | 2.63 |
| Pt (teeth/in.) | 9.66 |                   | |
| ds (in.)   | 1.45   | ds (mm)          | 36.81 |
| dp (in.)   | 2.07   | dp (mm)          | 52.59 |
| dr (in.)   | 5.59   | dr (mm)          | 142  |
| **Pitch-line velocity** | | | |
| V (ft/min) | 758.9  | V (m/s)          | 3.86 |
| H (hp)     | 1.011  | H (kW)           | 0.754 |
| **Factor of safety from fatigue** | | | |
| nfs        | 96.14  |                   | |
| nfp        | 67.84  |                   | |
| nfr        | 137    |                   | |
| **Factor of safety from yielding** | | | |
| nys        | 193.42 |                   | |
| nyp        | 215.99 |                   | |
| nyr        | 275.63 |                   | |
| **Elastic coefficient** | | | |
| Cp (sqrt(psi)) | 2291 | Ze (sqrt(Mpa)) | 190 |
Figure 5. Computer model of the planetary gearbox assembly (offset section): 1 – flange for mounting to the mast, 2 – gearing grooves with a flange of the spiral disc of the three-jaw unit, 3 – through hole, 4 – small gear (sun), 5 – carrier, 6 – large gear-planet (satellite), 7 – epicycle, 8 – gearbox housing, 9 – motor flange mount.

Figure 6. Mechanical system for emergency brake of the 3 kW wind turbine mounted on the mast (the mast is transparently displayed).

4. Conclusion
The developed design of the emergency brake system has several significant advantages:
1. All the elements of the brake system are located inside the wind turbine mast; thus, they do not create shading of the disc area of the wind wheel. This allows us to avoid losses of the wind turbine energy efficiency.
2. The design of the gearbox provides a high gear ratio. This value of the reduction factor allows us to use a small-sized electric motor. Besides, the control system in the activated state (when the jaws are pressed against the brake drum) does not require electric power to maintain the position. The jaws remain motionless due to the presence of internal friction forces in the gearbox.
3. We do not need to rework the existing design of wind turbines, since the brake system is located in the unused cavities of the wind power plant.

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