Robotic power line maintenance systems

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Abstract. When transmitting electricity over long distances, overhead power lines are used. When servicing the lines, brigades of workers performing manual inspection are used. This collection of information is not efficient and time-consuming, since it is possible to identify only those problems that a person can see. Problems such as the destruction of insulators, the slope of the poles of power lines, a small layer of icing will remain unnoticed and will lead to serious consequences, such as a break in power lines and falling poles. If the lines are broken and the supports fall, the repair team will have to drive the entire section of the power transmission line from start to break, if the terrain allows you to use ground transportation. Provided that some lines can stretch for hundreds of kilometers - troubleshooting can stretch for several hours or even days. The use of robotic systems will prevent such accidents, and in case of their occurrence due to force majeure circumstances, speed up the search and repair. The likelihood of electric shock will also be reduced.

1. Introduction
According to the official data of the Ministry of Energy of Russia, in 15157 accidents occurred in electric networks of voltage 110 kV and higher. Figure 1 presents a graph of the distribution of accidents by month of the year. The statistics also show that 53% of all accidents for this year occurred due to damage to power lines (PL). Due to damage to overhead line insulators (OL) and poor technical condition, 12% of the total number of accidents occurred, that is, about 1800. The accumulation of snow, ice and extraneous debris triggered 3% of all accidents. Also 5% of accidents are caused by mechanical damage to poles and lightning cables of overhead lines. The main number of accidents (about 72%) occurs in the warm season from April to September.

The commissioning of robotic systems will reduce the number of accidents associated with such factors, as well as prevent long-term power outages to consumers of reliability categories I and II.

It will not be possible to completely exclude the human factor, since human-electrical interaction remains, but in the long-term development of such complexes it will be possible to transfer them to a fully autonomous mode of operation. Information on the state of electrical equipment will be obtained in unified centers where it will be processed and decisions will be made on the need for repairs or a complete replacement of equipment [1].
2. Researches
Calculation and design of a robotic system began with the construction of a concept. This robot must move along power lines, not fall from a crosswind, vibrations and other mechanical disturbances. The robot must be quick-detachable for easy operation. It is intended to use the robot without disconnecting the electrical equipment from the power source, therefore, the materials of the robot must be non-conductive and have electronic protection against electromagnetic radiation. Also, the robot must have a set of sensors and devices for collecting information and maintaining power lines [2].

At the beginning of work, the worker must connect the charged battery to the robot power circuit, turn it on and establish a communication channel. In the first version of the robot, this is a bluetooth channel. The range of the robot in open space will not exceed 30 meters. After turning on the remote control and the robot, the device is automatically searched for and connected. Its operability is checked and installed at the beginning of the power line. The robot moves at a speed of 3-5 meters per minute.

An infrared temperature sensor directed directly to the power line cable takes temperature data. This information, obtained in degrees, is analyzed by a computer and information is provided on the presence of an overload in the current-carrying part, which negatively affects the stability of the electric power system, the degree of aging of electrical equipment and leads to an increase in electricity losses during transmission.

A camera mounted on board the robot transmits the image to the operator. Using this information, the operator can see those cracks, chips and other defects that are not visible from the ground. These defects can lead to the complete destruction of the insulators or cable, which leads to power outages. When identifying small cracks, additional studies need to be carried out using an ultraviolet camera, which allows you to see all the microcracks and their depth [3]. Next, a decision is made to send a repair team to replace equipment.

On board the robotic system there is an accelerometer that allows you to determine the degree of inclination of electrical equipment from the normal. A significant slope can occur due to heaving of the earth and frequent cycles of freezing and thawing in the northern regions. This leads to the tearing out of the ground of the foundation and piles from the ground and, as a result, the fall of supports with a further breakdown of power lines. Upon receipt of information about a significant slope, a repair team is sent that will either restore the foundation and stability of the equipment, or will dismantle it with the subsequent preparation of soil for a new installation.
All sensors are connected to a microcontroller that polls the sensors several times per second, which transfers all the information to the operator. The figure 2 presents a block diagram of the Executive bodies of the robot.

![Block Diagram](image)

**Figure 2.** The block diagram of the Executive bodies of the robot.

The data of the accelerometer, temperature sensor and image from the video camera are transmitted directly to the operator’s control device.

The first robot model was designed using SolidWorks software [4]. The shape of the wheels was selected for a cable with a diameter of 2.5 cm. PLA plastic was used as the available material. The created geometry of the wheel was designed for safety margin, deformation and stress. The calculation results are presented in figure 3.
Figure 3. The result of studies of deformation (1) and stresses (2).

The body is made in such a form that allows you to start the robot from the right side and land on the cable. The assembled model does not provide protection against electromagnetic effects, since tests of the test sample were carried out on 220/380 V. lines. When using the robotic system on high and ultra-high voltage lines, it is necessary to protect the microcontroller and motor driver from exposure to electromagnetic fields. For this, you can use the Faraday cage. This protection is in the form of a blank metal box or duct, the inner walls of which are insulated with non-conductive material. All electronics are placed inside the cell.

Figure 4 presents a General view of the robot.

Cleaning the electrical cable is carried out with brushes made of hard plastic, in order to avoid shorting the cleaning system to the engine. The brushes rotate in a circle and are pressed to the cable from several sides. Since wear of the brushes is inevitable - such a consumable item can be made from recycled plastic bottles [5].

The text of the program is presented below:

```c
#include <BTCA2A.h>
```
btca2a; int Forward = 5; int back = 6; int up = 7; int down = 8;
void setup() { btca2a.SetupHardwareSerial(0, 9600); pinMode(Forward, OUTPUT);
pinMode(back, OUTPUT); }
void loop() { btca2a.ReadCommand(); if (btca2a.ButtonPressed(KEYCODE_BUTTON_A)) {
analogWrite(Forward, 255); analogWrite(back, 0); } else if (btca2a.ButtonPressed(KEYCODE_BUTTON_B)) {
analogWrite(Forward, 0); analogWrite(back, 255); } else if (btca2a.ButtonPressed(KEYCODE_BUTTON_C)) {
analogWrite(down, 255); analogWrite(up, 0); } else { analogWrite(Forward, 0);
analogWrite(back, 0); analogWrite(down, 0); analogWrite(up, 255); } }

3. Prospect of development
At the next stage of development, it is planned to make changes to the geometry of the robot. Its main building is planned to be executed in the form of "π". This will further accelerate the installation time of the robot, and shifting the center of gravity to the very bottom of the body will allow the robot not to fall, even when the robot rotates around the cable by 70-80 degrees.

The next step is to replace the bluetooth module with Wi-Fi. This will increase the range of the robot, speed up the transfer of information [6].

To ensure complete autonomy, it is planned to install engines with blades for installing the robot on the overhead power lines (OPL) without human participation: unmanned take-off and landing on the cable. This will allow only one person to install the robot at the beginning of the power line and diagnose it, without interrupting the manual movement of the robot between supports and insulators. This modernization will add designs up to 2 kg of weight, but it will significantly reduce the time to commission the robot. The battery capacity does not need to be significantly increased, since the take-off and bypass times take 15 to 40 seconds. Provided that the supports of power lines are installed at a distance of 300 - 400 meters. In the study of 5 km of power lines, the flight time will be 5 minutes [7].

The creation of a wireless charging of robot batteries powered by the electromagnetic field of power lines is considered. However, the efficiency of such charging will be low, and the weight of the secondary windings will significantly complicate the flight and adversely affect the autonomy of the robot.

4. Conclusions
In the process of working on robotic systems, statistics on accident rates on power lines in Russia were collected. The main reasons are weather conditions and conditions that are not dependent on human activities. However, about 20% of accidents can be prevented by commissioning such robotic systems. With the massive use of robots, there will be a need to create common centers for the collection and analysis of information. To eliminate subsequent accidents due to the human factor, it is proposed to introduce artificial intelligence systems that have a significant sample with images of insulators of varying degrees of deterioration, various angles of support of the supports and cable temperatures under various weather conditions [8]. Such a system will allow you to process large flows of information and send recommendations on how to eliminate them to working teams that are closest to the place of the problem.

The electric injuries of working teams during repair work will also decrease. According to the official data of Roskomndzor, in 2017 there were 54 fatal accidents, 23 of them on electric networks. The main reasons are violations of labor protection rules when working with electrical installations. Therefore, if we reduce the frequency of human interaction with electrical equipment directly, the number of violations of safety rules and accidents will decrease.

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