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ANALYSIS OF THE RELIABILITY OF AUTOMATED ELECTRIC MOTOR DRIVES OF CABLE CARS AT SKI FIELDS

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Abstract:
The basic questions that arise when maintaining an automated electric drive relate to the safety and reliability of the elements in operation. The maintenance strategy of these elements is planned to start from the basic facts related to the plant's importance, type and purpose. The main purpose of maintenance is the timely detection of a fault and its elimination, i.e. ensuring continuous operation of the plant. In this work, the operation of the cable car was analyzed by monitoring the reliability of the electric drive. An analysis of the significance of reliability coefficients is a potentially new method for maintenance planning. The aim of the research was to define a new strategy for the maintenance of the facility and ensure the maximum safety of skiers through the analysis of previous events. Research is based on coefficients that indicate the reliability, frequency of failures, availability and unavailability of the elements that make up a drive. The essence of the conducted research is based on a new strategy for planning and maintaining such a facility, aiming to ensure skiers' safety and protection.

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1. INTRODUCTION

Cable cars as a means of public transport are used today on ski slopes for transporting skiers, in tourism [1], for panoramic views of the landscape [2], in cities (for crossing landscape barriers or steep hills, for avoiding traffic bottlenecks [3] and narrow streets and informal settlements [4,5]), etc. In recent years, cable cars have represented a severe alternative to mass transport for the mobility of the local population [6,7]. Unlike other means of public transport (cars, railways, buses), cable cars are less harmful to the environment because they do not emit harmful gases like CO_2 [8], which makes them the most promising type of surface transport [9].

The main advantages of cable cars are the following: easy assembly and disassembly [10], safe transportation [11], cheap means of transportation [12], a good movement speed of about 15 m/s [13], resistance to all weather conditions (even at wind speeds of 70-100 km/h [14]), etc.

The fact is that every element of the cable car can break down and thus cause a stoppage in operation. The causes of failures are different: from aging equipment and increased stress to unprofessional handling, etc. Some defects can be repaired, and some cannot, so the complete element must be replaced. Any disruption or stoppage in the system's operation causes unplanned costs due to failure to perform its function, as well as the purchase of a new and replacement of a defective element.

The probability of failure is higher in more complex systems (systems with more elements) [15]. It is approximately equal to the sum of the failure probabilities of its parts. If the probability of

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the occurrence of an event is multiplied by the measure of possible consequences, in that case, we talk about risk. There is always a risk. It should be made as small as possible or at least acceptable whenever possible. The failure of an element can adversely affect the operation of neighbouring elements, the object in which the element is located, or the entire system, depending on the position or importance of the defective element in the system [16]. This means that the system should be built and maintained to break down as little as possible. If an element in the system fails, its consequences should be as minimal as possible, and the failure should last as short as possible. In order to achieve those mentioned above, it is necessary to: acquire appropriate; quality and reliable elements (equipment), manage the maintenance process and ensure the appropriate configuration of elements in the system so that if one element fails, another one takes over the function without interruption (for example, double-sided power supply). The cable car itself is a single unit that certainly consists of several subsystems. Each subsystem can be viewed as a unique independent entity, but for the reliable operation of the cable car, compliance with all subsystems is necessary.

2. RELIABILITY OF THE CABLE CAR

For cable cars to be reliable, cable car operators must maintain the quality and safety of the complete equipment [17,18]. All control work should be based on a proactive prediction of critical failures, using appropriate reliability models such as, for example, failure trees [19] or simulation models [20].

Reliability is the ability of an element, object or technical system to successfully perform a given function under defined conditions during its working life. The reliability of an element depends on the quality of its production, the conditions of exploitation and the quality of maintenance during its operation. Every serious company monitors reliability coefficients and forms a maintenance strategy according to them.

Maintenance of the cable car is a complex process carried out through diagnostics and specific work. Mandatory activity is maintenance planning and diagnostics. Diagnostics means determining the state of an element or equipment and is performed periodically or to assess reliability in further work. The operator must organize the operation, maintenance and control of the cable car to ensure the conditions for the cable car to operate safely. Operation, maintenance and control of the cable car must be adapted to the technical conditions, as well as the risks of the location where the cable car is located [21,22].

In practice, reliability coefficients are obtained by monitoring the operation of many elements over time and statistical processing of the obtained data [23]. It can be expected that the elements in the next period will behave similarly to the previous one. This means there are precise data on the element's behavior for the previous period. For the next period, there is only an expectation (probability) that does not necessarily come true [24].

3. MATERIALS AND METHODS

Complete research into the availability of electric drive elements was conducted at the Kopaonik ski resort in the Republic of Serbia. It is the most extended ski center, with ski tracks 64 km long. All slopes are very well connected with cable cars and lifts, with over 34,000 skiers per hour capacity. The ski resort is automated and covered by SCADA systems for remote management and data acquisition. The ability to generate and save data provides researchers with great opportunities for comprehensive analysis of the state of drive elements.

This paper analyzes the behavior of electric motors over ten years. The aim of the research was to define a new strategy for the maintenance of the facility and ensure the maximum safety of skiers through the analysis of previous events. The complete work methodology used in the research is presented below.

The reliability coefficient and frequency of failures (λ) in the research are presented as the probability of failure (failure) for the number of elements in failure (n) concerning the total number of elements (N) for a particular time (t). In addition to this name for (λ), failure intensity is also often used.

The frequency of failures (λ) that was observed in the research is expressed through Eq. 1:

$$\lambda = \frac{n}{Nt} \tag{1}$$

The higher the values of n, N and t, the more reliable values of failure frequency (λ) can be obtained by statistical processing.

The reciprocal value of the failure frequency can be expressed through the average time between two failures (*PVIK*) on the observed element in the system. The average time between two failures can be expressed by Eq. 2:

$$PVIK = \frac{1}{\lambda} \tag{2}$$

When an element breaks down in the technical system, its operation stops. The duration of the downtime depends on the time required to eliminate the fault (repair time). During this time, the element is unavailable. The availability (*r*) can be expressed through Eq. 3 as the ratio of the working time (t_r) of the element to the working time (t_r) increased by the downtime (t_z).

$$r = \frac{t_r}{t_r + t_z} \tag{3}$$

Unavailability (*p*) represents (addition to 100%) availability and can be expressed via Eq. 4:

$$p = 1 - r = \frac{t_z}{t_r + t_z} \tag{4}$$

The unavailability of the element (*p*) can be expressed as the number of hours of downtime of the element reduced to the annual level (*t'*) in relation to the number of hours in a year (*8760* hours), Eq. 5:

$$p = \frac{t_z'}{8760} \tag{5}$$

Apart from failure, the element can be unavailable due to regular inspection, overhaul, etc. The element is available for the rest of the time ($8760 - t'_z$).

Unavailability due to failure (p_k) in order to be complete must also take into consideration the probability of failure, which depends on the frequency of failures on an annual basis (λ_{god}), downtime (t_r) and the number of hours, so it is:

$$p_k = \lambda_{god} \frac{t_r}{8760} \tag{6}$$

The above Eqs. 1-6 refers to malfunctions of the active part. A similar mathematical analogy could be made for the accompanying auxiliary elements. These failures are common, but their elimination is also much simpler and faster. In any case, the analysis would be more credible if all elements were included in the consideration.

4. RESULTS AND DISCUSSION

4.1. The results of research on the reliability of electric motors

A total of 25 electric motors (*N=25*) were in operation at the observed ski resort that powered the cable cars. If it is known that for a period of ten years (*t=10*) there were three failures on electric motors (*n=3*), the frequency of failures (*λ*) according to Eq. 1 is:

- ✓ annual level was λ=0.012 failures/day or
- ✓ expressed in hours $\lambda = 1.36 \cdot 10^{-6}$ failures/hour.

The calculations used accurate data from the field for the observed period, and for the next period, only expectations that this trend will continue. The average time between two failures of the observed element is the reciprocal value of the failure frequency (*PVIK*) and according to Eq. 2, it was 83.33 years.

The average value between two failures of the observed element (electric motor) is 83 years or expressed in 0.72·106 hours. This means that the probability of one engine breaking down is very low. One breakdown at 83 years old. However, in a transmission system in which there are 25 engines, one failure can be expected approximately every three years, which can be represented by the frequency of failures (f_f), Eq. 7:

$$f_f = \frac{PVIK}{N} = \frac{83}{25} \approx 3 \tag{7}$$

Individual elements can be very reliable, but the probability of failure increases with an increase in the number of elements in the system. An electric motor cannot work for 83 years because its working life is about 30 to 40 years, depending on the type of motor. This frequency of failures (one failure every 83 years) implies regular maintenance of the electric motor and its replacement due to age. In addition, there is always the possibility that a failure will occur during its working life, which is discussed here.

With the previously mentioned reliability indicators, the failure (Of) can be represented via Eq. 8, from which it can be seen that it depends on the total number of analyzed electric motors *N*=25, the adopted working life T_l=40 years and the frequency of failures f_f=3. Based on the presented calculation from Eq. 8, it can be concluded that failure can be expected on approximately every other electric motor during its working life.

$$O_f = \frac{N}{T_l / f_f} \approx 2 \tag{8}$$

As seen from Eq. 8, the value of this indicator is directly influenced by the type of electric motor. Each engine has its characteristics that are prescribed and correct. One of those characteristics is the shelf life. This research analyzed motors in operation with the following characteristics (asynchronous motor 2.2 kW, working life 30-40 years), which is only sometimes the situation in practice. Further research on this topic would be of great importance for improving the reliability indicators of electric drive elements.

Taking into account the precise and accurate data on the behavior of various elements of the cable car drive in the previous period, an analysis of the frequency of breakdowns was made. From Eq. 1, the values found in Table 1 were obtained.

Table 1. Frequency of failure of elements in operation

Frequency of failure	N	t	n	λ
Drive electric motor	25	10	3	0.0120
Microswitch	100	10	10	0.0100
Force reading probe	130	10	12	0.0092
Tachometer generator	50	10	5	0.0100
Hydraulic brake	75	10	5	0.0067
Sensor for measuring wind strength and direction	50	10	2	0.0040

Based on the data listed in Table 1, it is easy to reach the parameters that indicate the availability and unavailability of elements in the plant, which is graphically represented in Fig. 1.

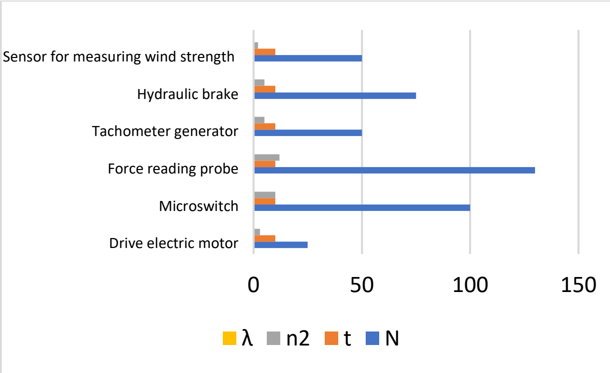

Fig.1. Failure frequency analysis

Table 2 shows an overview analysis of the situation for all observed elements of the electric motor drive with the probability of occurrence of that event.

Table 2. Availability and unavailability of elements in the plant

Availability/ Unavailability	t_1	t_2	*r*	*p*
Drive electric motor	8760	100	0.98871	0.0136
Microswitch	8760	250	0.97225	0.0285
Force reading probe	8760	350	0.96158	0.0368
Tachometer generator	8760	400	0.95633	0.0456
Hydraulic brake	8760	350	0.96158	0.0266
Sensor for measuring wind strength and direction	8760	250	0.97225	0.0114

Based on Eqs. 3 and 4, the data in Table 2 were obtained. The overview analysis of the data in this Table 2 indicates that in the previous period, the most work stoppages were with tachometer generators and the least with electric motors. This is also a realistic picture from the previous period with a tendency to repeat itself in the future.

Fig. 2 shows a graphical overview of the analysis of availability (*r*) and unavailability (*p*).

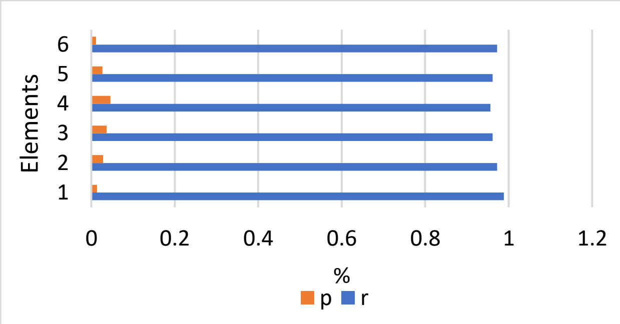

Fig. 2. Graphic representation of the availability and unavailability of elements in the plant

Fig. 2 shows that the probability of failure of electric motors, tachometers and microswitches is significantly higher, while it is significantly lower with sensor probes and brakes.

4.2. Analysis of results and proposal for future research

The elements individually can be very reliable. However, with the increase in the number of elements in the system, the probability of failure also increases - in proportion to the number of elements (*N*). The indicators will give more accurate results with a more significant number of samples. The author proposes to analyze a more significant number of different types in further research of electric motors, where each electric motor's working life would be considered.

The probability of failure also depends on the type of element being observed. It is necessary to analyze several elements and compare the results. The author suggests that the obtained results are analyzed using a mathematical method, such as the non-parametric Chi-square test.

Significant knowledge would be gained by applying mathematical statistics to a larger number of samples. The non-parametric test would determine the distribution of parameters and the distribution coefficient, which carries information about the state of the observed element.

4.3. A proposal for reliable operation

From the aspect of the economy, it would be ideal for predicting the moment of failure (failure) of an element in order to eliminate the cause of its occurrence in time. In general, this is not feasible, so it is possible to intervene too early or too late when the dismissal has already occurred. Through this analysis, that is, by calculating the coefficients, we get the risk time, which helps us a lot in planning the plant maintenance itself. When a malfunction has already occurred, it must be eliminated and then the element is repaired or replaced. Instead of not waiting for a layoff, it is possible to intervene earlier so that it does not occur, and therefore two types of maintenance are recommended: corrective and preventive.

Corrective maintenance is when an element is intervened only after its failure (failure). This can be part of a maintenance strategy for processes where downtime costs are low. This is the most affordable maintenance method that can be recommended from a maintenance cost perspective.

Preventive maintenance implies that elements are maintained before their failure occurs. Here we work on the correct elements and this type of maintenance is applied to important elements that are expected to be highly reliable in operation. There may still be a failure, but to a much lesser extent than when there is no maintenance.

5. CONCLUSION

In today's time, supervisory control systems have become integral to almost every technical-technological process. They are realized in computer network framework and enable monitoring, management and data acquisition. The data generated in these systems offer much information about the sample being examined. Various methods carry out the analysis of these samples. One of those methods presented in this paper refers to calculating the reliability coefficient and the probability of the father of the system. Specifically, in this work, the method of defining reliability through preventive maintenance has been applied to the ski lift maintenance strategy. Application of the presented method in research is prevalent.

This paper shows the method of calculating the reliability coefficient, frequency of failures, availability and unavailability of elements. Based on these coefficients, the main goal of the research was to obtain a new preventive response strategy for the maintenance of such a system. The research's essence was to indicate that the number of samples should be as large as possible so that the conclusions would be as accurate as possible. Continuing research on this topic in the future is crucial in order to develop new strategies (methods) in maintenance to ensure the safety and protection of human lives. Timely planning of future maintenance activities or even replacing an element or equipment is of great importance for ensuring the safety and protection of human lives.

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