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IMPROVEMENT OF THE POWER SUPPLY SYSTEM RELIABILITY BY MEANS OF UNMANNED AERIAL VEHICLES

Energy system of Ukraine comprises the distributed electric grids of complex configuration, the generating facilities and consumers of electric energy are located at large distances.Numerous objects of energy branch require constant monitoring.However, the upgrading of theequipment takes place at a slow rate that leads to the increase of the wear. Depreciation of equipment in the power supply system of Ukraine affects the reliability of power supply and quality indicators.Ageing and wear of the equipment results in the increase of accidents and emergencies.As it is impossible to completely replace the outdated equipment simultaneously, the concept of gradual replacement is adopted. In such conditions, maintaining of the operating condition of the equipment is ensured by the routine maintenance, performed by the operating crew. But the quantity of the staff constantly decreases, that is why, to maintain the operating conditions of the system new technologies should be developed and introduced which enable to detect the exact location of the fault and its character. The dependence of the system reliability on the frequency of riding inspections is shown. To achieve standard reliability values, the frequency of inspections should be a function of the wear of the equipment, and not a constant. Calculations are presented, showing the need to increase inspections to maintain the reliability of the system at the proper level. The increase in the frequency of inspections leads to the increase in the cost of servicing the power system, and as a result, the increase in the cost of electric energy. The authors suggest using unmanned aerial vehicles for the inspections, determination of the location of the accident. It is shown that the use of unmanned aerial vehicles will increase the number and quality of inspections, thereby increasing the reliability of the electric power system and, accordingly, reducing the cost of electric energy transportation.

Key words: *power supply system, reliability, quality of electric energy, unmanned aerial vehicles, monitoring, cost of electric energy transportation.*

Introduction

A great amount of power engineering facilities operating in Ukraine, require constant control. This task is performed by the telemetric systems and linemen teams. In recent years the upgrading of the engineering systems is carried out at a slow rate, that is why, the wear level of the equipment grows [1, 4, 5, 8].High wear levels leads to the increase of the faulty states probability and as a results, to the systems disconnections. The situation worsens as a staff of the linemen team must be increased to maintain the wornout systems but the energy companies do not increase the staff but even reduce it. That is why, to maintain the system in operation state, new technologies must be developed,[2, 3], their introduction enables to increase the probability of the faulty place detection and the character of the fault without increasing the staff.

Aim of the researchis the development of the measures, aimed at the maintenance of the electric grids and energy systems by means of the unmanned aerial vehicles and demonstrations of the economic advantage of the suggested technology over the conventional one.

Results of the research

The following electric engineering facilities of Ukraine are considered:

– generation facilities (hydropower stations, thermal power stations and nuclear power plants);

– energy conversion stations;

– electric grids.

The following energy facilities have considerable wear level (Table 1, Table 2).

Table 1

State of hydroelectricstations of the power of more than 10 MW

№	HPS designation	Installedpower MW	Annual generation mln. kW/hr	Year of putting into operation of the last unit
1	Dniprovska	1 548	4 008	2008
2	Dnistrovska-1	702,0	865	1983
3	Kremenchytska	682,8	1 516	1960
4	Kanivska	444,0	972	1975
5	Kyivska	408,5	790	1968
6	Seredniodniprovska	352,0	1 328	2008
7	Kahovska	351,0	1 489	1956
8	Dnistrovska-2	40,8	?	2000
9	Tereblia-River	27,0	123	1956
10	Alexandrivska	11,5	30	1999
	Total	4 491,4	>11 111	

On the example of one energy company we will show the state of the equipment wear.Situation concerning the state of the energy supply equipment is similar at other energy distribution companies [7].

Table 2

Number of the substations elements and their wear state

№	Designation	Number, units	Wear, %
1	110 kVpowertransformers	173	88
2	35 kVpowertransformers	332	93
3	6-10 kVpowertransformers	12947	64
4	Switches 6-110 kV	7435	22
5	Packages of BS and SC110 kV	84	100
6	Packaes of BS and SC 35 kV	63	100
7	DS 6-10 kV	272	82

Dependence of the faults frequency on the equipment wear level

Residual resource: total operation of the facility from the moment of its technical state control to the transition to the boundary state, residual resource (residual operation to the failure, residual term of service) are individual reliability indexes (life cycle, failure-free) that present the actual duration of the facility operation to the moment when the facility reachesthe boundary state or further operation of the facility is not expedient. The expediency rules are constructed according to economic criteria and security criteria.

Boundary state of the facility can be characterized:

– transition of the non-restorated into non-operational state;

– reduction of the efficiency of the facility usage as a result of the reliability worsening;

– economicinexpediency of further operation;

– moral ageing and the installations and equipment.

According to the normative standard(GOST 27.502-83) there must be certain number of inspections and repairs of the equipment. Normalized number of the inspections is based on the reliability requirements.

From these normalized labour expenditures the needed quantity of the service staff for certain system or equipment is calculated. Calculation of the number of the inspections is carried out according to the notmative documents (for instance, state standard GOST 27.502-83)

In the process of the calculation the minimal volume of the statistical information needed to obtainthe necessary reliability indices of the elements of the energy supply system, is determined.According to State Standard GOST 27.502-83 methods for the determination of the minimal number of the observation objects can be parametric (in case of the known type of the law of the distribution of the studied random value) and non-parametric (type of the distribution law is unknown).

Probability of failure-free operation – it is a probability that the element will not fail during certain period of time *t* in the presetoperation conditions.

Probability of the failure-free operation is expressed by the density of the probability *f(t)* in such a way

$$\text{Над}(t) = \int_{e}^{\infty} f(t)dt$$

The event, opposite to the probability of the failure-free operation is called the probability of the failure during the preset time interval *t* in the preset operation conditions

$$\text{Авар}(t) = \int_{-\infty}^{t} f(t)dt$$

Complete group of events represents

Над(t)+Авар(t)=1.

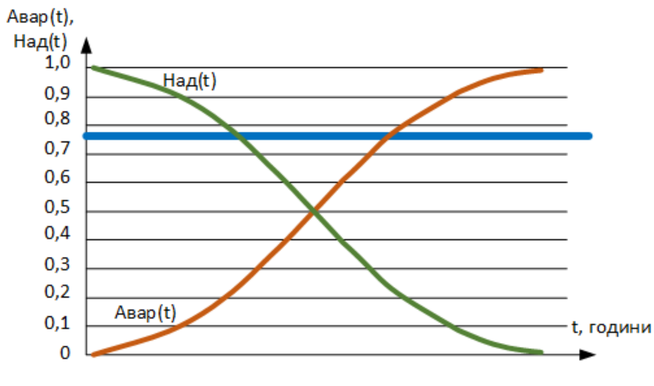

Fig. 1. Graph of the probability change of the faultless operation

The graph (Fig.1)shows the change of the faultless operation of the system depending to the time of the operation.It is seen from the graph that the probability of a failures grows gradually. Technical indices of the failures probability increase is gradual worsening of the system elements reliability. In case of loading, that exceeds the possibilities of the worn out element the failure of the element occurs and as a result, worsening of the whole system operation or the failure of thewhole system takes place.

For the variants, when the equipment did not reach the state of the group 3 (Fig. 1) and if the inspection is carried out once a year, then it is possible to evaluate the state of the system and envisage the slowly running processes of the equipment wear. But more often in such a way normal operation state of the equipment is determined.

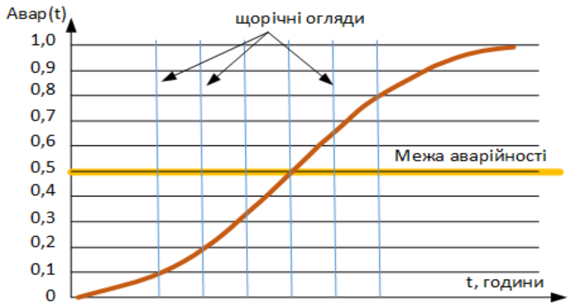

Fig. 2. Graph of the equipment failures and periodic inspections

It is obvious that the inspections are intended to detect rapid growth of ΔАвар(t)or detect the Авар(t) level that may correspond to the failure level values. Thus, it is necessary to increase the frequency of the annual inspections to reach the needed values of ΔАвар(t). The greater is the wear level of the equipment the more frequent inspections are needed.

N = f(Авар(t))

We determine the needed number of the inspections to provide the reliability regarding failures prevention.

The time interval between the inspections (frequency of inspections) must be provided the increment of the failure function by certain value ΔQ(t) ≤const

The increment of the failure function for the initial time *to* will be written:

$$\Delta\text{Авар}(t_0) = \text{Авар}(t_0 + \Delta t) - \text{Авар}(t_0)$$

But this increment must occur during certain time interval Δt

$$\frac{\Delta\text{Авар}(t_0)}{\Delta t} = \frac{\text{Авар}(t_0+\Delta t) - \text{Авар}(t_0)}{\Delta t}$$

and the derivative from the function Авар(t) will be obtained

If $\Delta t$is directed to zero, then we obtain

$$\lim_{\Delta t \to 0}\left(\frac{\Delta\text{Авар}(t_0)}{\Delta t}\right) = \lim_{\Delta t \to 0}\left(\frac{\text{Авар}(t_0+\Delta t) - \text{Авар}(t_0)}{\Delta t}\right)$$

Thus, the number of the inspections must be dependent on the derivative of the failure function:

$$N = \lim_{\Delta t \to 0}\left(\frac{\text{Авар}(t_0+\Delta t) - \text{Авар}(t_0)}{\Delta t}\right) = \text{Авар}'(t)$$

In graphic form

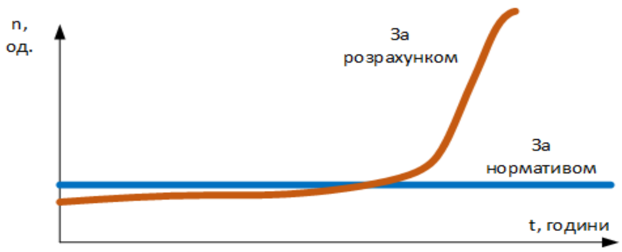

Fig. 3 Graphic of the inspections according to the norm and according to calculations

It is obvious that the number of the inspections to maintain (prevent) the number of failures at the preset level must increase in accordance with the increase of the failures function. And the number of the inspections must exceed the normative values for the worn out equipment.

Energy system of Ukraine is characterized by the considerable level of the equipment wear [1,4, 6, 7]. That is, the system of the inspections nowadays can not provide the necessary level of the fault-free operation.

As the issue from this situation, the monitoring of the state of the over-head transmission line by means of the unmanned aerial vehicles is suggested. The frequency of the flight inspection can be more frequent than the inspections, performed by the operating staff crews, as a resultΔАвар(t) decreases and the necessary level of the system reliability is achieved.

The suggested solution

In accordance with planned scheduleof the over-head transmission lines maintenance one complex of the unmanned aerial vehicleper 150 km. of the transmission levels is needed.

The cost of one UAV complex consists of the cost of quadcopter and cost of the equipment. QuadcopterDJI Matrice 210 RTK V2 Combo is, according to [9] 326,4 thousand Hrs.

Fig. 4 Quadcopter DJIMatrice 210 RTKV2 Combo

To realize the work by means of UAV it is necessary to hire (train) the specialist who can operate and maintain such equipment. Salary fund of UAV engineer-operator is (taking into an account taxes) 16,78thous.hrs per month.

Salary fund per year, is, accordimhly, 16,78 * 12 = 201,36 thous. hrs.

According to technical specifications the resource of UAV operation is 10000 hours. This corresponds to five years of operation.

The expenditures for the UAV complexes for the period of five years will be

B5 = Byear*5 + UAV

B5 = 326,4+201,36*5 = 1333,2thous. hrs. = 1,33mil. hrs.

Profit part of UAV operation comprises the share of the prevented failures (cost of their consequences for the consumers). In our opinion, the share of the failures, avoided due to the inspections, performed by UAV is 42% of the total number of the failures.On the example of one region the calculated loses in the operation area of one UAV can reach 1.3 mil. hrs. per year.

Then the sum of the losses, prevented due to UAV operation will be:

P = 1,3 * 0,42 = 0,55mil. hrs.

Profit share during five years of UAV operation will be:

P5 = P *5years = 0,55*5 = 2,73mil. hrs.

The pay-back term of one UAV complex will be:

E5/P5 = 1,33/2,73 = 0,4872 of the year

Conclusion

To maintain the normal reliability level of energy system it is necessary to apply changeable frequency of the inspections, which is the function of the equipment wear. The surface inspections of the equipment are suggested to perform by means of the unmanned aerial vehicles. It is shown that such complexes enable not only to maintain the reliability level but also to decrease the expenditures for the maintenance of the system and as a result decrease the cost of electric energy transportation. The authors consider the direction of the research, carried out, perspective and will continue the work over the development of the similar systems.

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Recommended by the Department of Automation and Cybersecurity of energy systems of National Technical University “Kharkiv Polytechnic Institute”.

Editorial office received the paper 19.03.2020.
The paper was reviewed 28.03.2020.

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