Life Cycle Control of Electric Grid Equipment Based on Historical Economic Indicators

O. M. Protalinsky, A. U. Shvedov, and Anna A. Khanova

Abstract The issue of equipment lifecycle management is considered—implementation of the program of maintenance and repair, capital replacement of equipment. During the life cycle of electrical grid equipment, it is possible to identify a period in which the total cost of repairing the equipment in the future will exceed its capital replacement with new equipment with similar indicators. The materials of domestic and foreign authors were studied on the topic of the operation of the power grid equipment park, regulatory and reference information for distribution power grid companies. Calculated functions are derived based on the economic indicators of the equipment - the cost of repairs, the book value, the level of inflation, taking into account the operation of the equipment. According to the task, a decision-making agent was developed for managing the life cycle of equipment of power grid companies based on economic indicators. The implementation of this algorithm in the production asset management system of interregional distribution grid companies will optimize the life cycle costs of a piece of equipment. The calculations made based on the decision-making algorithm in managing the life cycle of the equipment of power grid companies based on economic indicators indicate a decrease in the total cost of equipment by up to 10%. Investing the freed-up capital will allow the existing high-quality characteristics of the power grid equipment fleet.

Keywords Status index · Grid equipment · Maintenance · Repair · Replacement function · Life cycle

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1 Introduction

Interregional distribution grid companies supply electricity from generation companies to consumers. They have an impressive fleet of electric grid equipment, which can reach tens of millions of units (including supports and spans). Each equipment type has its own service life and is constantly wearing out [1]. To keep it in working condition and reduce the number of accidents, which often result in having to compensate the consumers, the technical policy of Rosseti “On the Uniform Technical Policy in the Power Grid Complex” [2], which contains the basic information on equipment maintenance and repair (M&R).

The underfunding of repair and investment programs leads to the situation when cost planning for equipment repair is made only for the short term without taking into account the efficiency of complete replacement of equipment in the conditions of increased repair cost for old equipment and increased payments for compensation of damage to consumers. Modern enterprise business asset management systems (BAMS) accumulate historical data on equipment repairs during its life cycle, the analysis of which makes it possible to establish a period in which the total cost of repairing obsolete equipment in the future will exceed the cost of replacing it with new similar equipment, along with its technical support.

Alekseev et al. [3–5], and others devoted their studies to the issues of the organizational and economic efficiency increase for the maintenance and replacement of production assets and management of equipment life cycle. Despite the extensive research base, the existing models of equipment assessment, repair, and replacement planning are based on a personalized approach (requires information about each unit which is very expensive in terms of time and financial resources) and assessment of physical and chemical, and operational factors affecting the condition of the equipment [6–10]. There are no models that take into account the interrelation of economic impacts and the residual operation life of the equipment and allow using minimum initial information to assess the integral state of the enterprise equipment and the costs necessary for its repair. The results of the analysis and modelling will allow ensuring the increase of power grid company equipment life cycle management efficiency under the condition of implementing the Industry 4.0 concept [11].

2 Analysis of Interregional Power Grid Company Electrical Grid Equipment Life Cycle Management

During the life cycle of electrical grid equipment, maintenance and restoration of its performance are carried out. Following STO 34.01-24-002-2018 current, mid-life, overhaul, unscheduled and emergency types of repair are defined.

Current repairs (CR) of equipment are performed for restoration of serviceability and partial restoration of the unit life with the replacement or restoration of components of limited nomenclature and management of the unit technical condition according to the scope provided in the documentation [12].

Mid-life scheduled repairs (MLR), as opposed to current repairs, provide for the disassembly of equipment, its individual units, the measurement of defects, and drawing up an inventory of defects. Among other things, this type of repair includes inspection of drawings, sketching, and testing of individual electrical equipment assemblies.

Equipment overhaul (OH), performed to restore the serviceability and full or close to full restoration of unit life with the replacement of restoration of any of its components, may involve full unit disassembly, repair of basic and prismatic components and assemblies, replacement or restoration of all worn components and assemblies with new and more modern ones, assembly, adjustment and testing of the unit [13, 14]. When carrying out an overhaul, the equipment must not change its functional purpose. The purpose of equipment overhaul is to restore its technical and economic characteristics to values close to the design ones. The most expensive types of repairs are overhauls and emergency repairs.

A multi-year maintenance and repair (M&R) plan is compiled for scheduled works. An annual M&R plan is created every year based on the multi-year plan. The equipment is included in the multi-year plan by the frequency of repairs for each type, taking into account the priority of the most expensive (in descending order – overhaul, mid-life, current) [15–17]. With each new repair (apart from overhauls), the condition of the equipment becomes worse compared to the design parameters, and the cost of repairs is higher [21–23]. At some point, future repairs are not profitable and a complete replacement of the equipment will be an economically feasible solution [18, 19]. Figure 1 shows the life cycle of the oil circuit breaker, with its maintenance cost, and a comparison with the option of replacing it at year 22 of operation.

Electrical grid equipment is an element of the network hierarchy along the supply chain from generation facilities to consumers. According to the methodology of the Ministry of Energy No. 123 dd. 19/02/2019 it is possible to calculate the failure consequence indicator, which is measured in monetary terms [20]. Before creating a multi-year plan, it is necessary to analyze the feasibility of the complete replacement of equipment.

3 The Procedure of Life Cycle Management of Power Grid Companies' Equipment Based on Economic Indicators

The decision-making algorithm for managing the power grid companies' equipment life cycle is based on monitoring changes in the equipment condition level depending on repair maintenance costs and allows to determine the optimal replacement period for a group of homogeneous equipment of a power grid company (Fig. 2).

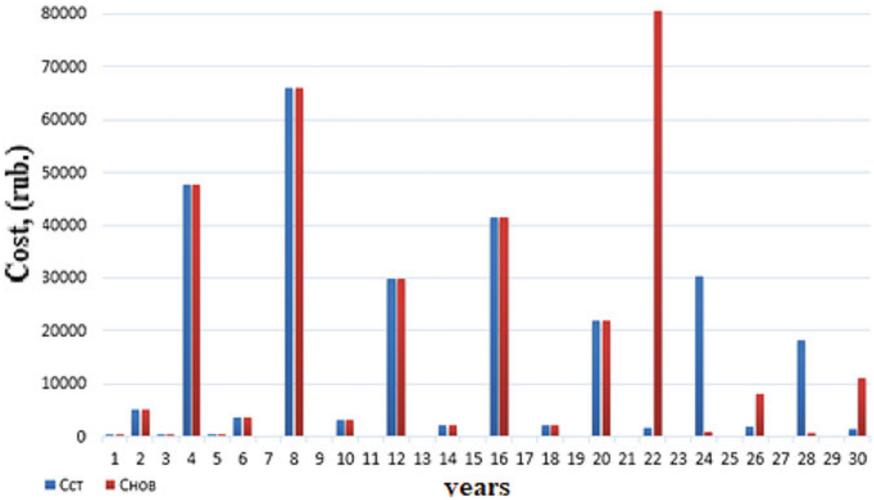

Fig. 1 Distribution of equipment repair costs over the life cycle of the oil circuit breaker VT-35-630-12,5

To prepare the equipment maintenance, forecast it is proposed to perform the following actions based on the equipment repair data for a certain brand:

1. Import historical data from external systems, including equipment repairs and failure consequence data from the BAMS and new equipment (or counterpart) cost data from the Accounting Information System (AIS).
2. Calculate the average annual cost for each type of repair (CR, MLR, OH, M&R) for a particular brand of equipment, setting the selection by equipment. for each of the periods of equipment operation, equal to the frequency of overhauls (for example, 8, 16, 24, etc. years):

$$C_{gen} = \frac{\sum_{j=1}^{t} C_{nj}}{n}, \quad (1)$$

where C_{nj} is the annual cost of maintenance of the n-th item of equipment in the j-th year, $j = \overline{1, t}$; t is the period for which the cost of equipment is recorded (number of years); n is the number of recorded pieces of equipment of a particular brand.

Calculate the cost of equipment maintenance Cold – taking into account the frequency of work for each type of repair (taking into account the priority of more time-consuming repairs) and the rated service life (for example, for oil circuit breakers 35 kW and up – CR 2 years, MLR 4 years, OH 8 years, rated service life 30 years), taking into account on each period the repair costs each period (duration and frequency of OH) C_{gen}:

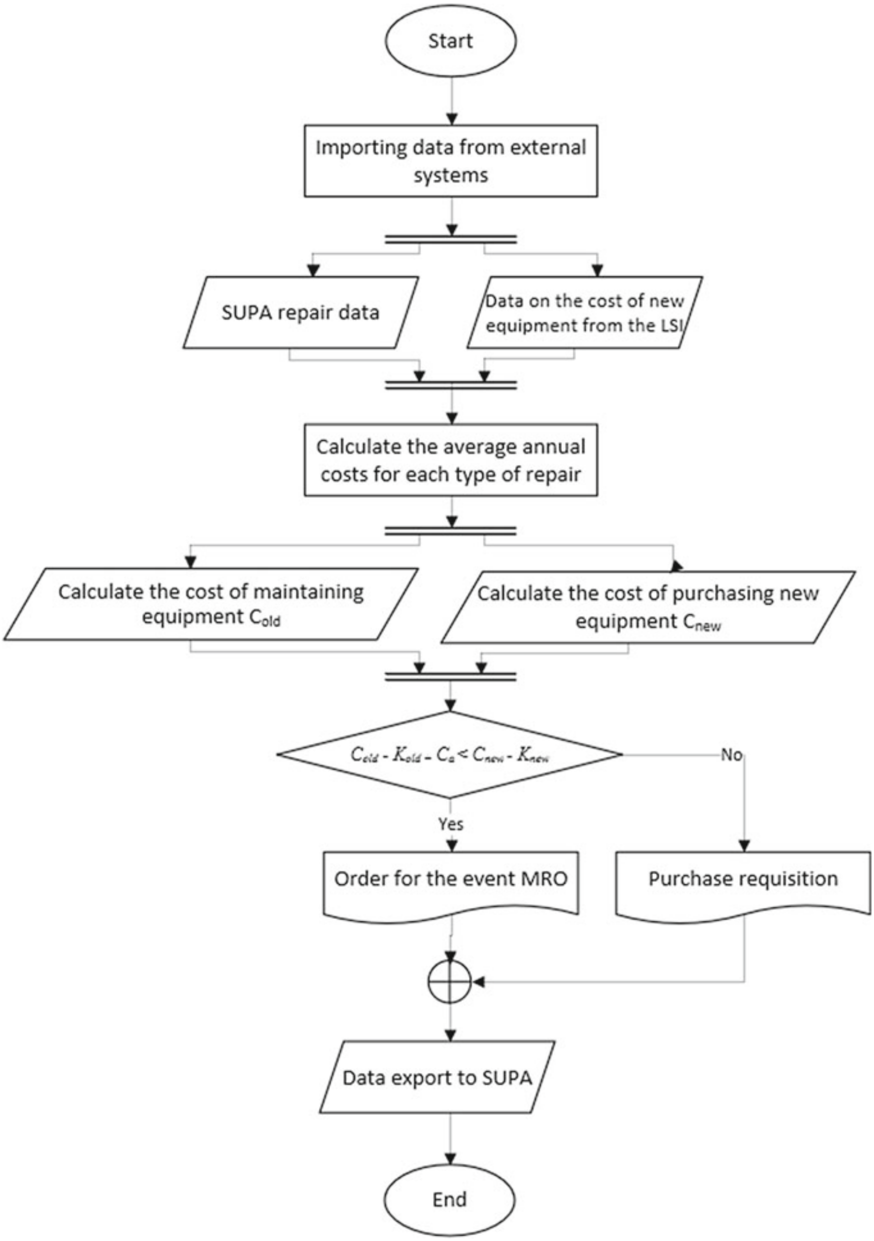

Fig. 2 The decision-making algorithm for managing the power grid companies' equipment life cycle based on economic indicators

$$C_{old} = \sum_{j=1}^{t}\left(C_{gen_j} \cdot D_j\right), \quad (2)$$

where C_{old} is the cost for the period t for the old equipment; t is the period until the end of the rated equipment service life; D_j is the discount factor in the j-th year, $j = \overline{1, t}$;

$$D_j = (1 - r)^j, \quad (3)$$

where r is the estimated rate; j is the year number, $j = \overline{1, t}$. The estimated rate is calculated using the Fisher equation:

$$r = r_0 + i + r_0 \cdot i, \quad (4)$$

where r_0 is the current key interest rate of the Central Bank of the Russian Federation; i is the projected inflation rate.

1. Calculate the costs of buying new equipment C_{new}, taking into account the cost of new equipment and its scheduled maintenance:

$$C_{new} = K_{new} + \sum_{j=1}^{t}\left(C_{plj} \cdot D_j\right), \quad (5)$$

where K_{new} is the investment into new equipment, C_{pl} is the scheduled repairs:

$$C_{pl} = \sum_{j=1}^{t}(\text{С}_{\text{об}_j} \cdot D_j), \quad (6)$$

where C_{pl} is the planned maintenance costs of equipment for the period t (from the commissioning of new equipment and the end of the standard life of the replaced equipment).

It is proposed to calculate the costs of support of the old and installation of new equipment annually when drawing up a multi-year M&R program so that the equipment can be excluded from it in the purchase acts or investment programs. A sign of exclusion from the repair program of the equipment is the following ratio:

$$(C_{old} - K_{old +} C_a) < (C_{new -} K_{new}), \quad (7)$$

where K_{old} is the residual book value of old equipment; K_{new} is the residual book value of new equipment, C_a is the cost of emergency repairs, C_a is the cost of emergency repairs:

$$C_a = (C_t + IN) \cdot u, \tag{8}$$

C_t is the costs of 1 repair, *IN* is the consumer compensation, *u* is the equipment unit failure rate;

2. Compare the cost of maintaining and repairing the old equipment C_{old} with the cost of buying new equipment C_{new} and maintaining it, taking into account the residual book value.
3. As a result, the creation of an M&R Order or a Purchase Order Request document is recommended.
4. Export data to BAMS.

4 Example of Synthesizing the Parameters of a PID Controller Model

Let us examine the described algorithm using the repair data imported from BAMS and the new equipment cost data imported from AIS. For example, the equipment is 22 years old and the issue of its replacement is on the agenda (Table 1). According to the data presented, one can see that equipment replacement including maintenance (251,670.63 rubles) is cheaper than its maintenance (279,805.24 rubles), taking into account the residual book value of the equipment Knew and the discount factor Dj. The profit amounts to (28,134.61 rub.).

5 Conclusion

The developed methodology, based on economic historical indicators, which have been maintained in AIS for more than 10 years, will optimize the life cycle costs of some equipment, free up funds for unscheduled work and investment in new equipment, which in turn will affect the fault tolerance of the entire fleet of equipment and reduce the electricity consumer compensation costs.

Table 1 Calculation of the equipment maintenance and replacement costs

Year of operation	Repair type	MRO without maintenance, rub	MRO with maintenance, rub	Replacement of equipment for 22 years without maintenance, rub	Replacement of equipment at year 22 with maintenance, rub	Discount factor (D)	C_{old}	C_{new}
1		0	495	0	495	1.00	495.00	495.00
2	CR	5059	5554	5059	5554	0.92	5122.67	5122.67
3		0	495	0	495	0.85	421.10	421.10
4	MR	60,184	60,679	60,184	60,679	0.78	47,611.32	47,611.32
5		0	495	0	495	0.72	358.23	358.23
6	CR	5059	5554	5059	5554	0.67	3707.31	3707.31
7		0	495	0	495	0.62	304.75	304.75
8	OR	115,625	116,120	115,625	116,120	0.57	65,938.83	65,938.83
…	…	…	…	…	…	…	…	…
21		0	495	0	495	0.20	98.27	98.27
22	CR	8499	8994	440,000	440,495	0.18	1646.88	80,657.27
23		0	495	0	495	0.17	83.60	83.60
24	OR	194,250	194,745	115,625	116,120	0.16	30,335.42	18,088.01
25		0	495	0	495	0.14	71.12	71.12
26	CR	13,599	14,094	5059	5554	0.13	1867.61	735.99
27		0	495	0	495	0.12	60.50	60.50
28	MR	161,775	162,270	60,184	60,679	0.11	18,292.93	6840.45

(continued)

Table 1 (continued)

Year of operation	Repair type	MRO without maintenance, rub	MRO with maintenance, rub	Replacement of equipment for 22 years without maintenance, rub	Replacement of equipment at year 22 with maintenance, rub	Discount factor (D)	C_{old}	C_{new}
29		0	495	0	495	0.10	51.47	51.47
30	CR	13,599	14,094	5059	5554	0.10	1351.60	532.64
31		0	495	0	495	0.09	43.78	43.78
32	OR	310,800	311,295	115,625	116,120	0.08	25,396.90	9473.61
Total equipment maintenance							279,805.24	310,819.30
Residual book value (K_{old})							0.00	59,148.67
Total with K_{old}							279,805.24	251,670.63

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