EFFICIENCY ASSESSMENT OF THE MAIN EQUIPMENT OF ELECTRIC POWER SYSTEMS

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Abstract

The paper deals with the issues related to efficiency of the main equipment of electric power systems (EPS). An efficiency indicator has been selected that takes into account relationships between efficiency, economic component, technological advance and reliability. We show the possibility for pilot test (or validation) of the efficiency indicator, and for comparison of the main EPS equipment with account of its efficiency.

Key words: efficiency, reliability, availability factor, failure-free operation, maintainability, durability, durability factor, electric power systems.

Efficiency is a complex property that includes degree of technological advance of the object, its reliability, and its economic characteristics. It is obvious that the higher the technological advance and reliability, and the lower the costs, the higher the object's efficiency. Efficiency can be evaluated using integrated indicators that take into account economic efficiency, technological advance and reliability, or a system of indicators each characterizing the corresponding efficiency component. Selection of the efficiency indicator is influenced by certain requirements that, with account of recommendations (1,2), can be worded as follows:

- common physical sense;
- minimum scope of indicators (if they are more than one);
- possibility for pilot tests or for validation;
- sufficient sensitivity of indicators towards impact of different factors on the efficiency.

Recommendations given in (3) propose two indicators for the efficiency evaluation. The first one is total costs for the considered time period (C), and the second one is technological efficiency factor (Э) that is a product of the performance factor (η), availability factor (K_{Γ}), and the service life factor ($K_{Д}$):

$$Э = \eta \times K_{\Gamma} \times K_{Д}.$$

The present paper considers the option of using one complex indicator for the efficiency evaluation that takes into account economic characteristics, technological advance and reliability taken together. The ratio between the total costs for the considered period and the amount of useful energy (Wr) output by the facility with account of its technological advance and reliability at the same time period is offered to be used as such an indicator.

$$E = C/Wr\ . \tag{1}$$

Ability to test (or validate) the selected efficiency indicator can be ensured by availability of data on the useful power supplied to consumers for the considered time period and actual total costs for the same period.

Efficiency of new equipment should be assessed using calculations based on the available data on the technological advance and reliability of the facilities, rather than on the results of pilot tests (that are, as a rule, time-consuming). Economic component of the efficiency should comply with the recommendations given in (4).

Evaluation of the equipment efficiency for the forthcoming period of its operation

Performance factor is an indicator of technological advance of the facility (3). Capacity is the energy transfer rate (energy/time ratio), therefore, the performance factor equals to the ratio between the useful energy output and total energy input.

$$\eta = W/Wo\ ,$$

where W = useful energy output, provided that the object is absolutely reliable (Fig. 1); Wo = the amount of energy that can be supplied for the considered time period, i.e., marginal output of the facility.

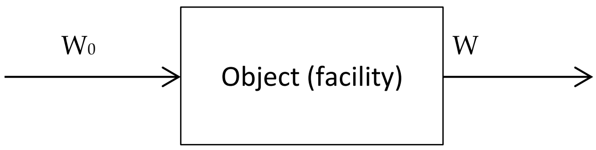

Figure 1. An absolutely reliable facility

Main EPS equipment is not an absolutely reliable object (Fig.2, where Wr = the amount of energy supplied by the facility with account of technological advance, failure-free operation and maintainability) whose behavior is described by a random process where periods of appropriate operation (when the object is fully operable) and periods of recovery (when the object is under overhaul), alternate (5). The object's operation process is shown in Fig. 3, where *To1* = time to the first failure, *Tв1* = period of the first emergency repair.

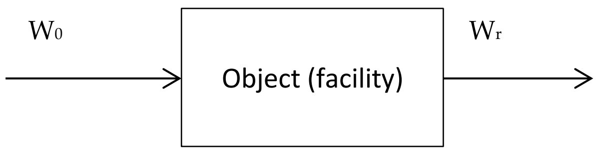

Figure 2. An object whose efficiency is dependent on its technological advance, failure-free operation and maintainability

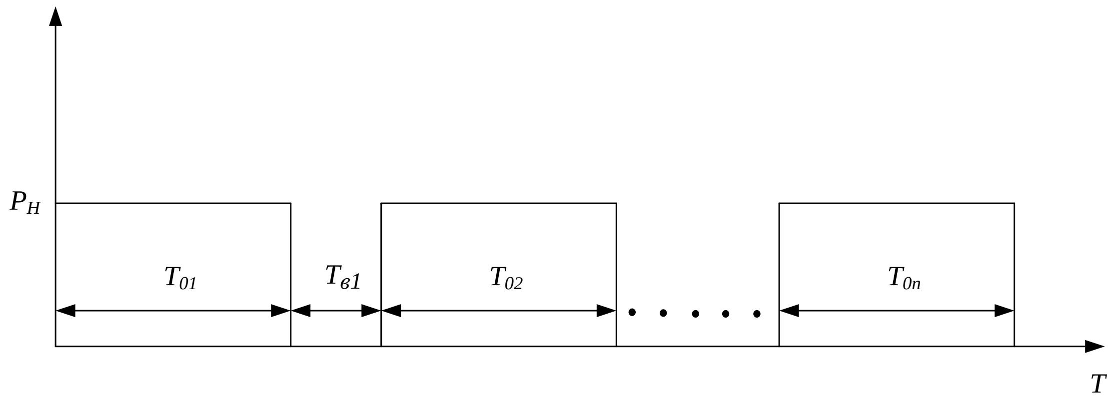

Figure 3. Object operation during considered time period

In formula (1) let us multiply and divide the denominator by W and then by Wo

$E = C/Wr = C/(Wr \times (Wo/Wo) \times (W/W)) = C/(Wo \times (W/Wo) \times (Wr/W))$.

Then

$$E = C/(Wo \times \eta \times (Wr/W)). \quad (2)$$

At a sufficiently large number of failures (n) during the considered time period

$$Wr = P_H \times \sum_{i=1}^{n} To_i\,; \quad (3)$$

$$W = P_H \times (\sum_{i=1}^{n} To_i + \sum_{i=1}^{n} Тв_i). \quad (4)$$

If we substitute the right-hand parts of equations (3) and (4) into formula (2), and divide the nominator and denominator by *n*, then an expression for the efficiency factor (*E)* will take the form:

$$E = C/(Wo \times \eta \times (K_{\Gamma}/)). \quad (5)$$

And

$$K_{\Gamma} = To/(To + Тв) = Wr/W\,,$$

where To = mean time of operation between failures.

$$To = (1/n) \times \sum_{i=1}^{n} To_i\,;$$

$Тв$ = mean time of recovery

$$T_{в} = (1/n) \times \sum_{i=1}^{n} T_{вi} ;$$

Amount of power supplied to consumers in the forthcoming period of operation:

$$Wr = Wo \times \eta \times K_{\Gamma}.$$

Comparison of objects in terms of their efficiency

Compared options must have similar energy effect (4).

Let us first consider the case when similar equipment is compared under similar operating conditions (objects are operated for the same time period (7); load during the period under study is assumed to be equal to the rated load (Pr); the amount of power the object can produce during the considered period is the same for all the objects).

In this case comparison of objects in terms of efficiency is reduced to computing the efficiency factors using formula (5) and to comparison of the values obtained. For example, for two objects:

$$E_1 = C_1/(Wo \times \eta_1 \times K_{\Gamma 1}) \quad \text{и} \; E_2 = C_2/(Wo \times \eta_2 \times K_{\Gamma 2}),$$

where E_1 and E_2, η_1 and η_2, $K_{\Gamma 1}$ and $K_{\Gamma 2}$ = efficiency factors, efficiency performances and availability factors for the first and second objects, respectively. As we have already mentioned, the objects under consideration differ in cost, technological advance and reliability. The amount of energy produced by each of them is the same.

Let us now consider the case when objects receive different amount of energy (Wo_1 and Wo_2 , respectively). The efficiency factor for the first object is:

$$E_1 = C_1/(Wo_1 \times \eta_1 \times K_{\Gamma 1}), \tag{6}$$

The efficiency factor for the second object is:

$$E_2 = C_2/ (Wo_2 \times \eta_2 \times K_{\Gamma 2}). \tag{7}$$

Different objects can be compared if they are reduced to identical energy output. Let us introduce the factor

$$L = Wo_1 / Wo_2 .$$

Now, let us multiply the nominator and denominator of expression (7) by the L factor. Then:

$$E_2 = (C_2 \times L)/((Wo_2 \times \eta_2 \times K_{\Gamma 2}) \times L) = (C_2 \times L)/(Wo_1 \times \eta_2 \times K_{\Gamma 2}). \tag{8}$$

Comparison of equations (6) and (8) shows that objects were reduced to the required terms of comparison. They receive similar amount of energy. Efficiency of the considered objects can be compared by comparing the efficiency factors computed using equations (6) and (8).

Thus, to be able to assess the object efficiency (for the forthcoming period of its operation) and to compare it to other objects, we need information about total costs and amount of energy the object can obtain in the considered time period, as well as the performance factor, and availability factor.

Comparison of objects one of which has been in operation over a long time period

Equations (6) and (8) can be used for evaluating the efficiency and comparing the new equipment to the equipment that has been in operation over a long time period. It should be kept in mind that the considered time period for equipment that has been in operation over a long time period equals the remaining service life. The amount of energy obtained will correspond to this period. The major share of the main EPS equipment (generating and network equipment) has exceeded the rated service life (due to high wear some equipment cannot be repaired). New equipment will get energy for the period of time that equals the average service life. Results of comparison may be used for justifying the equipment substitution by the new one.

Determination of reliability indicators for equipment that has been in operation over a long time period.

These indicators are usually determined by generalizing the initial statistical data on similar equipment for a certain time period. Time period selected for determining the reliability indicators must be, on the one hand, sufficiently long to ensure more accurate values of the equipment reliability indicators that are based on a large amount of statistical data, and, on the other hand, it must be sufficiently short, as an extended period is inclined to obscure the results of any tendency towards the equipment reliability increase or decline, and, hence, is not desirable.

This period is usually taken equal to 2-5 years. This approach towards determination of the equipment reliability indicators on the base of retrospective data has some drawbacks. It is obvious that reliability of some units can differ considerably due to equipment aging and different operating conditions, as it varies for each piece of equipment as they are impacted by different factors.

Therefore, it is advisable to have data on reliability of individual units that correspond to the forthcoming period of operation (the more so because the decision on their efficiency is made for these particular units).

Accurate determination of the equipment reliability indicators can be made based on the analysis of reliability change for certain units only. This approach to reliability indicators determination was first offered in 80s of the last century when operating conditions of thermal power plants of the Irkutsk Electric Energy System changed. Due water shortage in the reservoirs (the forecast on water inflow into the HPP reservoirs was erroneous) the equipment of thermal power plants was operated at full capacity over a year, scheduled maintenances were not carried out, and accident rate at EPS increased. Adequacy of statistical data used for determination of reliability indicators could not be ensured. For forecasting the reliability indicators it was offered to use the methods of exponential smoothing or a multi-factor model, i.e. availability of data on factors affecting the equipment reliability. Assessed was the validity of relations between equipment reliability in the year under consideration and scope of scheduled maintenances performed in the current year and in the preceding years. Calculations have shown that the scope of scheduled maintenances performed in the current year and in the preceding years has a considerable impact on the accidents rate of generating equipment in the year under consideration. In 90s the equipment reliability was offered to be assessed on the base of the analysis of statistical data represented as time series (7-9).

Identified was the availability of annual cycles of emergencies in EPS depend on the degree of the equipment wear and on a number of other factors. Particularly, existence of multi-year emergency cycles was proven experimentally in electric networks, that are caused by heavy wind and ice loads followed by large-scale failures and damages of supports, and breaks of wires on the transmission lines.

SUMMARY

1. A technique for assessing the efficiency of the main EPS equipment with account of its economic characteristics, technological advance, and reliability has been proposed.

2. For assessing the efficiency of the main EPS equipment, an efficiency factor is proposed that equals the ratio between total costs for the considered time period and amount of useful power supplied to consumers.

3. The amount of useful power supplied to consumers in the forthcoming period is determined as a product of the input energy (the amount of energy the object can receive in the considered time period), performance factor, and availability factor.

4. Ability to check (or validate) the selected efficiency indicator can be ensured by availability of data on the useful power supplied to consumers over the considered time period, and actual total costs for the same period.

5. A technique for assessing the efficiency of the main EPS equipment can be used for evaluating the efficiency and for comparing new equipment with equipment that has been in operation over a long time period. Results of comparison may be used for justifying the equipment substitution by the new one.

6. Equipment aging usually results in higher EPS emergency rate. Equipment reliability for the forthcoming period of operation should be evaluated based on the analysis of its reliability change using appropriate statistical data.

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