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Influence of smart metering systems on increasing the accuracy of calculation electrical power losses in electrical networks

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Abstract. The article discusses the possibility of using data from smart electricity meters (SEM) to increase the accuracy of calculation losses in 0.4 kV low-voltage networks. An increase in accuracy can be achieved using actual data about the load graph of electricity consumers (in this case, 6(10)-0.4 kV transformer substations are meant). To date, the operating load factor is taken equal to 0.5, which does not always correspond to the actual data. Using SEM, actual load graphs can be obtained, which enable more accurate determination of the operating load factor. Consequently, the accuracy of calculation of electrical energy losses will be increased.

1 Introduction

The modern electrical power industry is transformed under the influence of advances in technology. The Smart Grid (SG) technology is the most widely developed now. This term means the concept of a fully integrated, self-regulating and self-healing electrical power system with a network topology which includes all generating sources, main and distribution networks and all types of electricity consumers controlled by a single network of information-control devices and systems in real time [1–6].

Smart electricity meters (SEM) are one of the key technological areas and an important component of the modern energy system based on the SG concept [1]. SEM performs the following functions:

- Assessing the state of equipment and the level of network integration, showing the degree of information concentration in a single center;
- Providing continuous data monitoring and minimizing errors in invoicing arrangements;
- Contributing to the optimization of network modes and reduction of pollutant emissions by providing the consumer the ability to regulate the demand;
- Supporting more complex measurements and providing continuous data monitoring;
- Facilitating direct interaction between the service provider and the consumer.

Analysis of SEM functions shows that the issues of influence of metering systems on the process of calculating the amount of electricity losses in a network are not considered yet.

It should be noted that the loss or technological consumption of electrical energy during its transmission is the most important indicator of the efficiency of electrical network, and a clear indicator of the state of electricity metering systems [7,8]. At the same time, electricity is the only type of product transmitting of which doesn't require other resources, but a part of the transmitted energy itself is consumed [9]. Therefore its technological consumption is inevitable and the task is to determine its economically justified level. An important area of activity of any electrical power system enterprise (EPSE) is the organization of work on calculating the amount of losses in the electrical network, which is on the balance sheet of the enterprise.

Thus, the relevance of the study is in assessing the impact of the development of digital energy in general, and SEM in particular, on the correctness of formation of the estimated value of electricity losses.

The novelty of the research is in the application of big data, namely information on half-hour power received from the SEM, to improve the accuracy of calculations of electricity losses.

Today the calculation of electricity losses in a 0.4 kV low-voltage network can be carried out using the method of assessing losses based on generalized information about the parameters of the network load schemes [10]:

$$\Delta W = k_{0.4} \cdot \left(\frac{W_{0.4}}{N}\right)^2 \cdot \frac{(1-d_n)^2 \cdot (1+tg^2\varphi) \cdot L_{EQ}}{F_{AV} \cdot D} \cdot \frac{1+2\cdot k_f}{3\cdot k_f} \quad (1)$$

where $k_{0.4}$ is the coefficient taking into account the load distribution along the length of the line;

$W_{0.4}$ is the electricity supply for the period, kWh;

N is the amount of electricity transmission lines, pcs;

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d_n is the share of electricity consumed at a distance of 1-2 spans from the transformer substation, with respect to the total supply to the 0.4 kV network, p.u.;

F_{AV} is the average cross-section of the head sectors;

L_{EQ} is the equivalent total length of lines, km;

k_f is the operating load factor, p.u.

Here the operating load factor is used, which determines the ratio of the average power to the maximum power for the considered period:

$$k_f = \frac{P_{AV}}{P_{MAX}} \qquad (2)$$

P_{AV} is the average power for the considered period.

P_{MAX} is the maximum power for the considered period.

According to paragraph 2 [10], in the absence of data on operating load factor, it is assumed to be 0.5. However, taking into account the technical level of development of modern EPSE and SEM, from which "big data" on power can be obtained, the coefficient can be calculated and the obtained value may differ significantly from that adopted according to [10]. This, in turn, leads to a change in the design value of electricity losses in the 0.4 kV network.

Thus, the purpose of the study is to analyze the influence of "big data" received from SEM on improving the accuracy of calculations of technological consumption of electrical energy in 0.4 kV low-voltage networks.

2 Materials and methods

In order to analyze the current state of issues on increasing the accuracy of calculations of electrical energy losses, a literary review of scientific and practical works in this area was carried out.

One of the ways to improve the accuracy of on-line calculations of electricity losses is the joint evaluation of losses in the 6(10)-0.4 kV distribution networks [11]. The informational supportability of the 6(10) kV networks allows obtaining flow distribution in the line diagram by distribution of electricity recorded by metering devices at the head section of line. The information security of low-voltage networks is worse than that of the 6(10) kV networks. Until recently, the problem of mode information in the 0.38 kV power system did not find a solution due to the absence of measuring devices in transformer substations (TS), lack of funds for their installation and human resources to carry out the necessary measurements.

At the same time, all methods for losses evaluation can be conditionally classified into deterministic, probabilistic-statistical, probabilistic-deterministic [12]. The choice of methodology for calculating electricity losses is determined by many factors: the availability of initial data and the degree of complexity of their preparation, the availability of a computer and appropriate application software, and the readiness and interest of personnel in using modern methods for calculating electricity losses.

Another way to improve the accuracy of such calculations is to study the errors of the calculated electricity losses and power using regression relationships [13]. When using the method of on-line calculations of technical losses of electricity, negative methodological errors arise that underestimate the real losses [14]. Methodological errors are explained by the difference between the average current on the interval T and the real current on the interval t_1 and t_2.

The operating load factors k_f have a significant impact on the accuracy of calculations. The reference method for determining the coefficient uses the actual thirty-minute graphs of electrical load via the formula:

$$k_f^2 = (1 + \frac{\Delta P_{CH}}{\Delta P_M}) \qquad (3)$$

Here ΔP_M is the main component of average electricity losses, which is the amount of power losses in the network, calculated at the average load in the network.

ΔP_{CH} is the changing component of losses:

$\Delta P_{CH} = \Delta P_D + \Delta P_{COR}$

ΔP_D is the component, taking into account the dispersion of the load graph shape,

ΔP_{COR} is the component that takes into account the mutual correlation of graphs.

In [15], it is concluded that in order to determine the operating load factor using the method described above, it is necessary to have information on the load graph, which in most cases excludes its application in practice. However, the development of SEM makes it possible to solve this problem.

The carried out literary analysis allows us to conclude that one of the ways to improve the accuracy of calculating electricity losses is to increase the reliability of information on operating load factor.

3 Results. Theoretical study

Increasing the reliability of information on operating load factor can be achieved by using big data obtained from intelligent electricity metering systems, in particular, half-hour power for the considered period. To obtain the adjusted coefficient, the following conditions must be met:

1. The calculation of electricity losses is carried out monthly, therefore, it is necessary to consider the integrity of half-hour power values for a month;

2. Taking into account the installation of SEM at the input of TS, the information should be collected from substations that are part of the region of electrical networks (REN), since the calculation of electricity losses is carried out separately for each REN;

Thus, the information required to calculate the operating load factor can be presented in the form of table 1.

Table 1. Half-hour power for calculating the operating load factor.

Hours	**TS No. 1**	**TS No. 2**	**TS No. 3**	**TS No. 4**	**TS No. …**
00:00	$P^1_{00:00}$	$P^2_{00:00}$	$P^3_{00:00}$	$P^4_{00:00}$	$P^n_{00:00}$
00:30	$P^1_{00:30}$	$P^2_{00:30}$	$P^3_{00:30}$	$P^4_{00:30}$	$P^n_{00:30}$
01:00	$P^1_{01:00}$	$P^2_{01:00}$	$P^3_{01:00}$	$P^4_{01:00}$	$P^n_{01:00}$
…	$P^1_{hh:mm}$	$P^2_{hh:mm}$	$P^3_{hh:mm}$	$P^4_{hh:mm}$	$P^n_{hh:mm}$
23:30	$P^1_{23:30}$	$P^2_{23:30}$	$P^3_{23:30}$	$P^4_{23:30}$	$P^n_{23:30}$

Knowing the power for the period under consideration (for example, the calculated month), it is possible to select the average value for the set of substations under consideration. However when calculating the maximum power, certain questions arise. According to (1), the maximum power should be found from Table 1 (i.e. from the set of TS), which will lead to an unreasonable underestimation of the operating load factor. However, given the availability of information for each TS, the authors propose an approach to determine the maximum power for each substation and further averaging this value:

$$P_{MAX,i} = max\{P_i\} \tag{4}$$

$$P_{MAX}^{AV} = \frac{\sum_{i=1}^{n} P_{MAX,i}}{n} \tag{5}$$

n is the number of transformer substations for which data are available.

Thus (2) will take the following form:

$$k_f = \frac{P_{AV}}{P_{MAX}^{AV}} \tag{6}$$

The algorithm for calculation the operating load factor can be presented in the following form:

1. Unloading half-hour power for the considered period;
2. Determination of average power for the entire set of TS;
3. Determination of the maximum power for each transformer substation (4);
4. Determination of the average maximum power for the set of TS (5);
5. Calculation of the adjusted value of the operating load factor (6);
6. Calculation of the adjusted value of technological consumption of electrical energy (losses) for REN.

4 Results. Practical study

In order to assess the applicability of the proposed approach to adjust the calculated electricity losses, and to assess the influence of operating load factor on electricity losses, a practical implementation of the algorithm was carried out.

To test the algorithm, 1 REN was selected, the calculations of electricity losses for 5 months of 2020 were adjusted, the electricity losses were calculated in accordance with [1]. The results of the adjusted calculation are presented in Table 2.

As it can be seen from the presented data, the adjustment of electricity losses was in average 6.43% or 10 thousand kWh.

5 Conclusions

The performed work allowed us to draw the following conclusions:

1. Increased accuracy of calculating the electricity losses can be achieved by adjustment of operating load factor;

2. Adjustment of the operating load factor is achieved by the analysis of big data received from SEM, in particular, half-hour power for the period under consideration (month);

3. The use of the adjusted operating load factor for a set of transformer substations that are part of the

Table 2. The calculated electricity losses after adjusting the operating load factor.

Month	**Operating load factor before adjustment, p.u.**	**Operating load factor after adjustment, p.u.**	**Losses before adjustment, ths. kWh**	**Losses after adjustment, ths. kWh**	**Deviation, %**
January	0.5	0.577278	208.5	194.5	7.17
February	0.5	0.572334	189.1	177.2	6.75
March	0.5	0.549563	158.6	151.5	4.72
April	0.5	0.589379	142.6	131.8	8.21
May	0.5	0.555825	124.4	118.1	5.29

considered REN made it possible to refine the amount of calculated electricity losses by an average of 6.43% or 10 thousand kWh;

Increasing the accuracy of the design value of technological consumption of electrical energy during its transportation (losses) allows one to obtain more reliable information about the structure of electricity losses. Therefore it helps to develop and apply the most effective organizational and technical measures aimed at reducing losses [16].

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