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Factor Modeling Based on the Power Distribution Transformers Load Factor Using Least Square Error Method: A Case Study of Ilam

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Abstract

Electrical energy is one of the most important resources of human society. Each year, a considerable amount of the produced electrical energygoes to waste during transportation from power plants to the customers. Losses, are defined as a portion of the electric energywhich does not have the ability to perform beneficial work. Numerous factors contribute to losses in distribution networks which are generally divided into two categories: losses due to technical factors and losses resulting from the non-technical and management factors. In this paper, through collecting and analyzing the necessary data from registers installed in distribution transformers of city of Chardavol, and also using the existing standard relationships between Loss Factors, a suitable model is presented in order to estimate the losses in terms of load factor for the distribution transformers of the abovementioned city.

Keywords

energy losses; Load factor; Loss Factor.

1. Introduction

In this paper, using the collected data from registers installed on four sample transformers, which include low-load, medium load, and high load transformers, first we calculated no-load energy losses and load energy losses, and then load factor and Loss Factor of the mentioned transformers. Using provided standard models of Loss Factor, we then obtained the optimal model for the sampletransformers which is generalizable to all transformers in the city of Chardavol.

2. Generalities Regarding the Load Factor and Loss Factor

Load Factor is defined as the ratio of average load in a time period to the peak load in the same period. The load factor can be simply defined by the following formula:

$$LF = \frac{P_{ave}}{P_{max}} \quad (1)$$

Another indicator which is used in studies is Loss Factor which is calculated by the ratio of average energy loss in the study period, to the maximum energy loss. This definition can be demonstrated as follows:

$$Loss\ Factor = \frac{Eloss_{Avg}}{Eloss_{Max}} \quad (2)$$

3. The Energy Losses in Distribution Transformers

As we know, energy losses in transformers are composed of two components; namely no-load energy losses and load energy losses.

No-load energy losses depend on voltage, frequency, and temperature changes. Giventhe efforts of the power companies' officialsto stabilize the abovementioned factors, long-term no-load energy lossis obtained using the following equation [1-2]:

$$E_{Lfe} = T \times of \times P_{fe} \quad (3)$$

Where:

- E_{Lfe} : No-load energy losses in the T period,
- of: Utilization factor,
- P_{fe}: Nominal no-load losses,
- T: Period of utilization.

Load energy loss is a function of load changes. In order to calculate energy losses, we have to use power loss values at load peak times and loss factor. As a result, the amount of energy loss in this case is calculated as follows [1-5]:

$$E_{Lcu} = T \times of \times LSF \times P_{cu} \quad (4)$$

Where:

- E_{Lcu} : Load energy loss,
- T: Period of utilization,
- of: Factor of utilization,
- P_{cu}: Nominal load loss,
- LSF: Loss factor.

Now, total energy loss is no-load energy losses plus load energy losses, the amount of which is generally equal to:

$$E_{LC} = E_{Lfe} + E_{Lcu} \quad (5)$$

4. Calculation of energy losses in sample distribution substations

4.1. Equipment needed for data collection

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In this section, registers installed in sample distribution substations are used to measure various parameters (voltage, current, power factor, energy, etc.)

4.2. The method of calculating the energy losses from sampled substations

In order to determine energy losses it is necessary to use data from registers and the following formula which has been mentioned before [1-5]:

$$E_{LL} = T \times of \times k^2 \times P_{cu} + T \times of \times P_{fe} \qquad (6)$$

$$k = \sum_{i=1}^{n} \left(\frac{S_i}{S_n}\right)^2 \qquad n = 1,2,\ldots,24 \qquad (7)$$

Where:

- T: Period of utilization,
- P_{cu}: Nominal Load Losses,
- P_{fe}: Nominal No-load Losses,
- of: Factor of utilization,
- S_i : The momentary power measured by the registers,

S_n: Distribution transformer nominal power.

4.3. Calculating energy losses, load factor, and loss

Table 1 shows load and no-load energy losses in a period of 24 hours which have been calculated using the previously mentioned formulas for the sample distribution substations.

Table I. Load and no-load energy losses in a period of 24 hours.

Sample substations	No-load energy losses	Load energy losses	Total energy losses
Next to the governorate building	17.28	0.6844	17.964
Next to the Radiology	17.28	13.991	31.271
Mushkan	8.16	0.0349	8.1949
Cham Qule	5.04	0286	5.326

For example, the following shows energy loss for the distribution substation next to the governorate building in the city of Sarableh.

E_{lfe}: No-load energy loss,

T: Period of utilization, which in the case of no-load, is 24 hours,

of: Factor of utilization, since the Trans is loaded during the year, is equal to one year,

P_{fe} : Which is equal to the 0.75 KWfor the315 KVAsubstation next to the Radiology Building in the city of Sarableh,

E_{Lcu}: Load energy loss,

T: Period of utilization is 60.15 hours for the load mode (measurements were taken every 15 minutes),

P_{cu}: Which is equal to the 5.4 KW for the 315 KVA substation next to the Radiology Building in the city of Sarableh,

S_i: The momentary power measured by the registers,

S_n : Nominal capacity of the substation next to the Radiology Building in the city of Sarableh is equal to 315 KVA. Therefore, k^2 is equal to:

$$k = \sum_{i=1}^{n} \left(\frac{S_i}{S_n}\right)^2 = 0.507$$

Now we calculate load energy loss:

$$E_{Lcu} = 0.6844$$

Finally, total amount of losses for no-load and load scenarios is equal to:

$$E_{LC} = 17.964$$

Table 2 shows load factor and loss factor of sample distribution substations, using the formulas discussed above.

For example, the calculations of factor loss for the substation next to the governorate buildingis given below. In order to calculate average energy losses, we divide the total amount of load and no-load energy losses from table 1, which we calculated earlier, to the number of records which in this case is 96, and we have:

$$\text{Average amount of load and no} - \text{load energy losses} = \frac{17.964}{96} = 0.1871$$

Maximum amount of lost energy, which is composed of no-load and load energy losses, is calculated as follows:

$$\textit{The average maximum amount of load energy losses in } 15\ \textit{min} = T.\left(\frac{S_{max}}{S_n}\right)^2.P_{cu} = \frac{15}{60} \times 5.4 \times \left(\frac{36}{315}\right)^2 = 0.0176$$

$$\textit{The average maximum amount of no} - \textit{load energy losses in } 15\ \textit{minutes} = 15.60 \times 0.72 = 0.18$$

Then, calculate the loss factor for the distribution substation next to the governorate building in the city of Sarableh:

$$\textit{Loss factor for the substation next to the governorate building} = \frac{0.1871}{0.1976} = 0.946$$

Table II. Load and loss factor for the sample substation.

Sample substation	Maximum load (KW)	Load factor	Loss Factor
Next to the governorate building	11.2	0.605	0.946
Next to the Radiology	62.3	0.753	0.818
Mushkan	3.7	0.777	0.991
Cham Qule	25.8	0.655	0.871

5. Modeling of Loss Factor

In order to calculate energy losses in every power grid, while it’s necessary to have the power loss in the peak load, loss factor should also be known. This factor depends on several parameters, including load and load curve shape. Therefore, it’s a function of type of consumption. Previous studies show that, ina certain consumer, whether transmission or distribution network, if parameters of peak load and transmitted energy are known, loss factor will remain restricted to an amount between maximum (LF) and minimum (LF2), regardless of the shape of the curve.

So far, several models have been proposed for calculating the loss factor, the majority of which have definedthis factor as a function of load factor. Although they appear to be different, most of them lead to similar results in

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networks with high load factor. However, a tangible difference can be noted in networks with low load factor. One of the important reasons which contribute to differences between models, are networks under study. In other words one of the most important agents which affect the loss factor, is the shape of the load curve. Common loss factor models are as follows:

1. Simple quadratic model; a is constant
   $LSF = a.LF^2$
2. Quadratic model
   $LSF = a.LF^2 + (1-a)LF$
3. Quadratic model
   $LSF = a.LF^2 + b.LF + c$

5.1. Investigating existing models in order to determine the optimal factors for sample substation

Models that have been mentioned thus far, only are about modeling of line losses, because only losses in load mode have been considered. As we know, load loss depends on the load factor and no-load loss does not depend on the load factor. Here, we have ignored no-load loss, but when modeling losses in land distribution transformers which have high load, no-load losses cannot be ignored. Therefore, in order to calculate the related parameter for land distribution transformers, the following model is used. This model consists of two sections; the first part is the load factor function and the second part doesn't depend on load. In this paper, due to the unavailability of the necessary information, we ignore this matter.

In order to model line losses, standard models mentioned earlier are used. In this investigation, four sample distribution substations have been used as the input data, and the fourth sample was used to test the model. Also, the higher the number of distribution substations is, the higher the accuracy of the model will be. In this article model's optimal factors are determined by minimizing the least square error.The results are presented in Table 3.Models tested include:

1. $LSF = a.LF^2$
2. $LSF = a.LF^2 + (1-a)LF$
3. $LSF = a.LF^2 + b.LF + c$

Where:

- $LSF1$: Loss factor of the sample substation using the corresponding model.
- LSF= The actual loss factor of the sample substation
- $E = (LSF - LSF1)^2$

In order to familiarize ourselves with method of minimizing the least squares in the substation model, a brief description is given. Here, we consider $LSF = Y$ and $LF = X$, for convenience.

Using load factor and loss factor of the distribution transformers, we calculate coefficients of the target function in order to minimize square error.

$$E = \sum_{i=1}^{4} \left(Y_i - (ax_i^2 + bx_i + c)\right)^2$$

Thus, the above equation must be solved and in order to obtain coefficientsof a,b, and c, we have to minimize this equation.

$$\frac{\partial E}{\partial c} = 0 \qquad \frac{\partial E}{\partial b} = 0 \qquad \frac{\partial E}{\partial a} = 0$$

Table III. The results of optimization of loss model factors.

Sample	LF	LSF	LSF_1	Mathematical model	The optimal factors	Sum of squared errors
First	0.605	0.946	0.316	$LSF = a.LF^2$	$a = 0.865$	0.9763
Second	0.753	0.818	0.490			
Third	0.777	0.991	0.522			
Fourth	0.655	0.871	0.371			
First	0.605	0.946	0.876	$LSF = a.LF^2 + (1-a).LF$	$a = -0.764$	0.0395
Second	0.753	0.818	0.895			
Third	0.777	0.991	0.909			
Fourth	0.655	0.871	0.827			
First	0.605	0.946	0.914	$LSF = a.LF^2 + b.LF + c$	$a = -0.3169$	0.0182
Second	0.753	0.818	0.902		$b = 0.3448$	
Third	0.777	0.991	0.929		$c = 0.8222$	
Fourth	0.655	0.871	0.912			

After solving the equation (some of them are solved in the form of matrix and the other are simply solved) a,b, and c are obtained:

$$c = 0.8222 \qquad b = 0.3448 \qquad a = -0.3169$$

Then, these values are compared with the previously mentioned models. Based on the available errors, it can be seen that the third model, which has the lower error, is the most appropriate one for air distribution substations in the city Chardavol. After replacing the a,b, and c coefficients, we have:

$$LSF = -0.3169.LF^2 + 0.3448.LF + 0.8222$$

5.2. Testing the model

The method for testing the mentioned models is as follows: we chose one of the sample substations and insert it into the provided test model. Here, we test the fourth sample, namelythe air distribution substation of Cham Qule.

The values of actual loss factor (LSF) and the obtained loss factor which were obtained using the provided models ($LSF1$), are presented in table 4 for comparison.

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Table VI. Comparing the factors of loss models.

Mathematical model	LSF	$LSF1$	$\|\Delta LSF\|$
$LSF = 0.865LF^2$	0.871	0.371	0.5
$LSF = 0.764LF^2 + 1.764LF$	0.871	0.827	0.044
$LSF = -0.3169F^2 + 0.3448LF + 0.822$	0.871	0.912	0.041

6. Conclusion

Considering that the loss factor indicator plays an important role in determining the annual energy lossesand it can help power companies in their planning in order to reduce losses, and given the fact that loss factor is a function of load factor, which can vary in different areas depending on the type of consumption, therefore the appropriate loss factor model for each area changes with the amount of consumption in that region. As have been mentioned in the article, the third model is the most appropriate one for the air distribution substations in the city of Chardavol. Appropriate models for the rest of the distribution substations can be obtained using the presented method and the data provided by registers.

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