To evaluate the operational status of the transformer load using a feed-forward neural network for analysis

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Abstract. The results of the first transformer load obtained using the FNN neural network in Fig. 5 determined on the basis of the algorithm described in Fig. 4 show that if the dynamics of transformer loads continue at this rate, after 8 years the minimum loads will increase from 0.8 and after 12 years begins to work in the danger zone completely. Taking into account that the coefficient of wear of transformers and the occurrence of minimum loads is equal to 20% according to Fig. 1, it can be said that this situation is in a very serious situation. And the maximum value of the load has already reached its maximum point. In this case, it is suggested that the issue of load redistribution in this Kibray 35/6 substation and its distribution networks should be seriously considered or a new transformer should be installed and appropriate switching devices should be selected.

1 Introduction

Today, substations are equipped with modern accounting, relay protection, and automatic control systems. The integration of modern accounting, relay protection, and automatic control systems in substations represents a significant advancement in the power distribution and management sector. This integration provides several crucial benefits that enhance the efficiency, reliability, and safety of the energy grid [1,2,3,6]. Modern accounting systems integrated into substations provide real-time and accurate data on energy consumption [4,5,7]. This detailed information allows for better analysis of usage patterns, helps in identifying peak usage times, and facilitates more efficient load distribution planning [8]. Automatic control systems within substations enable intelligent and automated management of energy distribution. This ensures that power is supplied to different areas based on real-time demand, optimizing the load and reducing wastage [9]. However, these systems are not able to predict the expected future loads.

It is known, the normal load factor of a power transformer refers to the average percentage of the transformer's rated capacity that is being utilized over a specific period of time. It is important to operate a transformer within its normal load factor to ensure efficient and reliable operation [10,11]. The normal load factor is typically expressed as a percentage of the transformer's rated capacity. A common practice in power systems is to operate transformers at a normal load factor between 70% and 80% of their rated capacity to ensure optimal performance, efficiency, and longevity [12]. Operating a transformer below 30% of its rated capacity or above 90% can lead to inefficiencies and may impact the transformer's lifespan and reliability [13]. It's important for power system operators and engineers to carefully monitor the load on transformers and manage the distribution of loads to maintain a suitable normal load factor, balancing efficiency and cost-effectiveness with the transformer's design and capabilities [16-23].

2 Experimental research

In the case of an incident that occurred during the expedition, investigations were carried out on the load variations of a 35/6 kV two 4000 kVA transformers at the Kibray substation (the subsequent research object). Initially, the process of changing the total power of the auxiliary transformers on the researched object was analyzed.

Fig.1. The three-day load variations (in kVA) of the first transformer at the research object (obtained from the radiometer system).

The load graphs of the transformers at the research object have been quite similar. As seen in Figure 1, the transformer operates with a load exceeding 70% of its capacity for the majority of the observed times. Additionally, the maximum and minimum load values vary from day to day. Therefore, continuous monitoring of the loadings of these transformers to analyze their
operations and determine these values, namely the maximum and minimum loading limits, is necessary to align with the intended purpose [24-29].

In the subsequent phase, predictions of the expected future loads of the transformers at the Kibray substation were conducted using artificial intelligence, specifically the Feed forward neural network (FNN) approach. It should be noted that the initial step in identifying the anticipated future loads of the transformers involves gathering data and their primary reprocessing [15]. The data for the research were obtained from the radiometer system, which records the following parameters for each feeder (see Figure 2):
1. Three-phase currents (A) on all phases.
2. Voltages (kV) on all phases.
3. Active power (kW).
4. Reactive power (kVAr).
5. Power factor angle (degrees).

As primary data, the monthly average maximum and minimum load factors of two 35/6 transformers for all months in 2021, 2022 and from January to April in 2023 were calculated using the following formula:

\[ k = \frac{S_f}{S_0} \] (1)

where, \( S_f \) is the actual value of total power, \( S_0 \) is the amount of nominal power [30-36].

The average minimum (k\(_{\text{min}}\)) and maximum (k\(_{\text{max}}\)) values of loading calculated based on formula (1) were taken as primary factors below (Table 1).

Table 1.

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In Table 1, in addition to the \( k_{\text{min}} \) and \( k_{\text{max}} \) values, the difference between them \( \Delta k \) is presented, and from the decrease of this value, we should say that as the loads have increased over the years, the difference between the maximum and minimum loads is also decreasing. At the same time, if we take into account that the transformers begin to work inefficiently when the load exceeds 90%, the load transition limit can be set at 85%. If we analyze the maximum values presented in Table 1, it can be seen that they have already exceeded 85%. This situation occurred 18 times in the T1 transformer and 23 times in the T2 transformer among the 28 time series data. This shows that they worked at an average load of 80%, and the time of occurrence of these loads can be seen from Figure 1 that in more than 70% of the 3-day period, the load of the transformers is greater than 85%. Given that this situation is already in an abnormal state, it is enough to perform the forecasting problem only through the minimum values of loading. At first, the adequacy of \( k_{\text{min}} \) given for each transformer in Table 1 was determined in IBM SPSS using the Gaussian distribution law of the received data (Fig. 2, 3).
Fig. 2. Checking the first data for the Gaussian normal distribution law

The values in Figure 2 and Figure 3 show that the received primary data can be used in the next step. This situation indicates that there is no need to build a Fit model in this case.

For forecasting, it is appropriate to divide the primary data into 80% train set, 15% validation set and 5% test set according to the quantity.

Feed Forward Neural Network (FNN) was used to calculate loading coefficients. It has 2 layers, one hidden layer and one output layer. 100 epochs and 16 batch sizes were taken as FNN parameters. The hidden layer has 10 neurons and one hidden layer with ReLU (Rectified Linear Unit) activation function. The output layer has one output layer with 1 neuron (unit) and no activation function is specified.

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Forecasting is carried out based on the algorithm shown in Figure 4. In this algorithm, a model is first prepared by train and gets results corresponding to train. The obtained results are assessed for compatibility with the entered values using Pearson's correlation. If the Pearson correlation is less than 0.7, the algorithm is sent back for relearning. Otherwise, the next 3 load factors are projected. At this point, it should be noted that it is not the state of the following values that is important to us, but when the load of the transformer exceeds 0.85. Because one of the main goals was to implement planning by calculating how long the load of the transformer will increase. In this case, the next 3 values are predicted and their average values are calculated. If the average value is below 0.85, the predicted values are added back to the initial data list and the next 3 values are predicted. In this order, the period of acceptance of loadings higher than 0.85 is calculated [37-41].

3 Research results

The results of the first transformer load obtained using the FNN neural network in Fig. 5 determined on the basis of the algorithm described in Fig. 4 show that if the dynamics of transformer loads continue at this rate, after 8 years the minimum loads will increase from 0.8 and after 12 years begins to work in the danger zone completely. Taking into account that the coefficient of wear of transformers and the occurrence of minimum loads is equal to 20% according to Figure 1, it can be said that this situation is in a very serious situation. And the maximum value of the load has already reached its maximum point. In this case, it is suggested that the issue of load redistribution in this Kibray 35/6 substation
and its distribution networks should be seriously considered or a new transformer should be installed and appropriate switching devices should be selected.

![Graph](image.png)

**Fig.5.** Prediction results of the first transformer load obtained using the FNN neural network (since the loads of both transformers are almost the same, only the results of the first transformer are presented)

### 4 Conclusion

1. The in-depth assessment of the transformers at the Kibray substation paints a concerning picture of their operational conditions. The frequent breaching of the optimal load factor underlines an emerging inefficiency, coupled with potential threats to the longevity and dependability of these transformers.

2. Leveraging the Feed forward neural network (FNN) approach yielded invaluable insights into the future load expectations on the transformers. The projection indicates that, without intervention, the transformers at the Kibray substation are poised to consistently operate in high-risk zones within the next 8-12 years.

3. Such a trajectory of increasing load factors not only jeopardizes the operational efficiency of the transformers but also signals potential disruptions in power distribution. Moreover, continuous operation at these levels could accelerate wear and tear, ultimately leading to frequent maintenance needs or potential system failures.

4. Given the aforementioned challenges, it becomes imperative for stakeholders to act promptly. Immediate considerations should encompass strategies for load redistribution to evenly distribute the operational pressure among transformers. Additionally, expanding the infrastructure of the Kibray 35/6 substation, such as introducing new transformers or implementing state-of-the-art switching devices, could effectively mitigate the impending risks and ensure a consistent and reliable power supply.

### References

12. A common practice in power systems is to operate transformers at a normal load factor between 70% and 80% of their rated capacity to ensure optimal performance, efficiency, and longevity.