Analysis of Measures to Reduce the Energy Facilities Impact on the Environment on the Example of the Crimean Energy System

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Abstract. The world community is seriously concerned about the harmful effects of human activity on the environment. Reducing this influence is on the agenda for most countries. Energy facilities play the greatest role in environmental pollution with harmful emissions. Reducing the generated electricity will positively contribute to an improvement of the environmental situation. This can be achieved by decreasing electric energy losses during its transmission. The paper considers losses at various stages of electric energy transmission, presents the components of actual losses, as well as measures to reduce them. The effectiveness of two methods is analyzed on the example of the Crimean energy system: the method of interrupting the low voltage network and the method of disconnecting part of the transformers in the low loads mode. Conclusions about the need for operational regulation of the considered energy system in order to reduce electric energy losses are made.

1. Introduction

Environmental preservation issues come to the fore during the energy projects implementation. After all, the main environmental pollution source remains the objects used for the needs of heat supply, electricity production and transport. They account for about 64% of all greenhouse gas emissions, including 84% of all carbon dioxide emissions into the atmosphere as of 2005. In addition, these facilities are responsible for methane, nitrogen oxide, sulfur dioxide and carbon monoxide emissions. This leads to the emergence of processes that are detrimental to the environment, leading to climate change and, as a result, affect human health [1, 2].

One of the ways to reduce environmental pollution by energy facilities is to decrease the produced electricity amount. However, this will inevitably lead to a decrease in the intensity of growth in the industry development and scientific and technological progress. An effective solution to this problem can be control and reduction of electricity losses during its transmission to consumers [3-8].

2. Materials and methods

There are three time levels at which the values of technical electric energy losses are determined. The first one is conceptual. It defines the principles for the development of the country's energy system: focus on powerful energy sources and long lines, or use of small power plants, which are located in
close proximity to consumers. The second level is operational and reconstructive. At this level, the network modes and parameters are adapted to existing loads; it is possible to use more modern equipment. These measures can reduce electric energy losses by up to 1.5% of the amount of its supply to the grid. The third level is operational. Reducing losses to 0.2% of the amount of electric energy supply to the network is possible due to network modes direct monitoring [9].

Average losses values at various stages of electric energy transmission under normal conditions are estimated by the following values, which are calculated relative to the supplied electricity amount [10]:
- losses on the transformer installed between the energy source and the network - 1-2%;
- losses in transit networks - 2-4%;
- losses on a transformer installed between transit and distribution networks - 1-2%;
- losses in distribution networks and transformers - 4-6%.

There are also data on the electric energy losses assessment during transmission in relative units of the energy sold amount [11]:
- transit networks - 0.1% for urban networks and 0.7% for rural networks;
- power transformers - 0.1% for urban networks and 0.7% for rural networks;
- distribution lines - 0.9% for urban networks and 2.5% for rural networks;
- no-load distribution transformers - 1.2% for urban networks and 1.7% for rural networks;
- distribution transformers under load - 0.8% for urban networks and 0.8% for rural networks;
- other lines - 0.5% for urban networks and 0.9% for rural networks.

Long-term experience in the electrical networks operation shows that electric energy losses during transmission and distribution are considered satisfactory if they do not exceed 4-5% of the amount of electricity supplied to these networks. Considering from the physics of electric energy transmission through networks point of view, losses of 10% are believed the maximum permissible [12]. In the Russian Federation, electricity losses are quite high, although their amount was reduced from 13% in 2008 to 10.6% in 2020. In the country's energy strategy, a course is taken to achieve the losses amount of 7.3% by 2035 [13].

The electric energy rate in the retail market is regulated by the executive authority of the constituent entity of the Russian Federation in the state regulation field. It already includes the price of services for the electric energy transmission and takes into account the cost of standard technological losses in electrical networks [14]. Therefore, losses due to idle running and auxiliary needs of the substation are borne by the consumer as necessary costs to maintain the network operability. However, the losses associated with the electric energy transmission, which subsequently, among other things, will be spent on the mentioned losses, are borne by the grid organization and are not included in the tariff. Therefore, the network organization is primarily interested in the development of the network and network equipment in order to reduce losses.

According to Federal Law No. 35-FZ "On Electric Power Industry", the Government of the Russian Federation or federal executive authorities authorized by it are responsible for approving the methodology for determining and the procedure for compensating for losses of electric energy in electrical networks, as well as the standards for such losses when setting the amount of payment for the corresponding services for the transmission of electric energy [15].

There are four components of the electric energy actual losses [16, 17]:
- technical losses - associated with the losses of part of the transmitted electricity for heating network elements;
- losses for auxiliary needs of substations - associated with costs to ensure the correct operation of substation equipment;
- losses due to errors in the electric energy measurement;
- commercial losses - associated with problems arising in the field of control over electricity consumption.

There are two types of electric energy technical losses in electrical networks that arise during its transmission - conditionally constant losses (do not depend on the amount of transmitted power (load)
and load (variable) losses (depend on the amount of transmitted power (load) [18]. Conditionally constant losses are estimated at 25-30% of the total electricity losses during transmission [11].

Active power load losses in a three-phase network element with phase resistance $R$ and current in phase $I$ are expressed by the following well-known formula [9]:

$$ \Delta P = 3I^2R = \frac{P^2 + Q^2}{U^2}R, $$

where $P$ and $Q$ are active and reactive power transmitted through the element; $U$ is the network line voltage.

There are techniques that allow to change each parameter included in the right side of the equation: the values of power and resistance can be varied by changing the network topology; the voltage can be changed due to different modes operation of static reactive power compensators and power plants. However, well known that all the parameters of the power grid are interconnected. Therefore, for example, with an increase in voltage, electricity consumption also increases due to the presence of a static load characteristic, and when the network topology changes, the flow distribution will change.

Loss reduction measures can be divided into four groups [9, 19, 20]:
- measures to improve the electrical networks operating modes;
- measures for the electrical networks reconstruction;
- measures to improve the electricity metering system;
- measures to reduce the theft of electricity.

3. Results and discussion

Active power losses are minimal if the power is distributed along the network branches in proportion to their active resistances. This is only possible if the network is uniform. In reality, this is quite rare. However, such a flux distribution can be achieved, for example, by opening the low voltage network [9]. The paper discusses the effectiveness of this method used to reduce losses on the example of the Crimean power system.

The calculation was carried out for power region, which has one of the highest load - the southern coast of Crimea. The mode of the highest and lowest loads for 07.07.2020 was selected for analysis. The loads are distributed evenly over both high voltage sections to simplify calculations and eliminate the influence of repair and operating schemes on the substation low side. The equivalent circuit for this power region is shown in Fig. 1.

The minimum loads mode is considered for 07.07.2020 at 4:00 (Fig. 2, a).

The losses are $\Delta P = 15.266$ MW for a closed circuit.

It can be seen from the calculation results (Fig. 2, a) that the most optimal from the losses point of view is to open the sectional switch at SS 110 kV G. In this case, the losses are slightly lower than with a normally closed network. This suggests that the southern coast of Crimea region is well optimized and does not require additional operational measures to reduce losses.

For the same power region, the highest loads mode for 07.07.2020 at 13-00 is considered (Fig. 2, b).

The losses are $\Delta P = 33.646$ MW for a closed circuit.

For the highest loads mode, some dividing points of the power region are unacceptable: in this case, the permissible continuous current in the normal circuit or the emergency permissible current in the post-emergency modes of network elements is exceeded.

As can be seen from the calculations results (Fig. 2, b), the most optimal mode is realized in the case of dividing the circuit at SS 110 kV H. However, it differs slightly from the mode when dividing the circuit at SS 110 kV G, SS 110 kV I. This can be explained by insufficient mobility of available reactive power reserves at substations on the South Coast of Crimea, which can lead to such a flow distribution at some points in time. As practice shows, the most optimal dividing point is SS 110 kV G.
The following substations with power transformers of 220-330 kV voltage class are considered:
- Substation 330 kV A: AT-1 220/110/10 (ATDTsTN-125000/220/110-68); AT-2 220/110/10 (ATDTsTNG-125000/220); AT-3 330/220/35 (ATDTsTN-250000/330/220-U1); AT-4 330/220/35 (ATDTsTG-240000/330);
- Substation 330 kV B: AT-1 220/110/35 (ATDTN-125000/220/110-U1); AT-2 330/110/35 (ATDTN-200000/330/110-U1); AT-3 330/110/35 (ATDTN-200000/330/110-U1);
- Substation 330 kV C: AT-1 330/220/10 (ATDTsT-240000/330/220-72 U1); AT-2 330/220/10 (ATDTsTG-240000/330); AT-3 330/220/10 (ATDTsTG-240000/330);
- Substation 330 kV D: AT-1 330/110/35 (ATDTsTN-125000/330/110-77 U1); AT-2 330/110/35 (ATDTsTN-125000/330/110-U1).

All transformers are operated in parallel via a busbar switch in the normal mode.

Figure 1. Equivalent circuit of southern coast of Crimea power region.

Figure 2. Losses in the southern coast of Crimea power region in the minimum (a) and maximum (b) loads mode.

Another method to reduce losses is to disconnect some of the transformers at low loads. This measure is advisable to carry out when the subsequent decrease in no-load losses turns out to be greater than the increase in load losses due to a change in the distribution of the total load between a smaller number of transformers [9]. The paper analyzes this method using the example of the Crimean power system.
The minimum loads mode for 2020 (06/15/2020 5:00) was taken to assess the effectiveness of the method. Initial loss calculations show that:
\[ \Delta P_{\text{load SS}} = 1,139 \text{ MW}, \quad \Delta P_{\text{idling SS}} = 5.31 \text{ MW}, \quad \Delta P_{\Sigma} = 15.548 \text{ MW}. \]

On bus-connection switches 110 and 220 kV the disconnections have been made. Calculations show that:
\[ \Delta P_{\text{load SS}} = 1.093 \text{ MW}, \quad \Delta P_{\text{idling SS}} = 5.31 \text{ MW}, \quad \Delta P_{\Sigma} = 16.011 \text{ MW}. \]

The losses on the autotransformers decreased, but the total losses in the power system increased due to the redistribution of power flows. Taking into account the fact that the circuit with separate operation of bus systems is unreliable both from the point of view of power supply to consumers and ensuring the power grid functioning, this method for the analyzed substations is considered inappropriate.

The Crimean energy system is special in that it has one point of synchronization with the unified energy system of Russia via the energy bridge. This leads to a pronounced relationship between the loading of power plants and losses in the Crimean power system.

The work calculates losses at 50 different flows along the Crimean energy bridge at different times of the day for June 2020. The calculation results are shown in Fig. 3.

As can be seen from Fig. 3, the minimum losses are achieved when the power transmitted to the Crimean power system is approximately 100-200 MW. The most frequently observed modes correspond to losses of 20-35 MWh and 35-50 MWh.

It is optimal to maintain a mode corresponding to a minimum of losses. However, there are currently no mechanisms that allow grid organizations to influence the load schedule of power plants in their operating area. In addition, emergency situations arise in the unified energy system of Russia, requiring the implementation of even the most remote power reserves, and the elimination of which is a priority in relation to the creation of the most optimal operating mode of the network.

The calculated data were approximated by the least squares method for a quadratic function to determine the dependence:
\[ \Delta P(P_{PB}) = 0.000154508264999P_{PB}^2 - 0.042038592157678P_{PB} + 26.9936394207082, \]
where \( P_{PB} \) is the active power flow through the power bridge.

Comparison of the actually calculated losses and the losses obtained using the approximation is shown in Fig. 3.
4. Conclusions
Electrical energy loss control during its transmission will have a positive effect not only for the grid company and its consumers, but also for the environment. The energy supply company and its customers first of all will be able to reduce their costs. At the same time, the amount of generated electricity will decrease, which will lead to a reduction of pollutants emissions into the atmosphere.

The types of losses and measures to reduce them are considered. The method of interrupting the low voltage network and the method of disconnecting part of the transformers in the low loads mode are analyzed using the example of the power region of the Crimean power system. The results show that the considered power region of the Crimean power system is well optimized and does not require additional regulation.

Active power losses are calculated depending on the amount of electrical energy transmitted through the Crimean energy bridge at different times of the day for June 2020. An analytical function of this dependence is found. The analysis showed that this dependence has a minimum when power, transmitted to the Crimean energy system, is equal to 100-200 MW. However, the grid company currently does not have the ability to maintain the amount of transmitted electricity within these limits.

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