Analysis of the energy efficiency of 110/6 kV distribution network in an oil producing enterprise in Kazakhstan

Nassipkul Dyussembekova[1], Saulesh Minazhova[1]

[1] Satbayev University, Satbayev str. 22a, 050013, Almaty, Kazakhstan,
+7 (727) 257 71 16, info@satbayev.university, https://satbayev.university

Annotation. In connection with the adoption of the Law "On Energy Saving and Improving Energy Efficiency" [1], improving the energy efficiency of power supply systems and electrical equipment is one of the most important strategic objectives of the Republic of Kazakhstan. The largest share of irrational electricity consumption occurs precisely at industrial enterprises in Kazakhstan. This is due to the fact that a large number of electric motors, transformers and light sources continuously work at industrial enterprises of Kazakhstan. Often, underloading or overloading of electrical equipment and distribution networks is the result of inefficient operation of the power supply system and power consumption. This leads to an increase in the share of losses in transformers, electric motors, a decrease in the power factor in the power supply system, a decrease in the service life, an increase in accident rate, etc. Therefore, the introduction of energy-efficient electrical equipment is the main task of production. In this connection, optimization of equipment operation modes and reduction of losses in the system of transformation and distribution (transformers, distribution networks, electric motors) is one of the methods of saving energy consumed by an enterprise. In this article, a simulation of a 110/6 kV distribution network of an oil producing enterprise was done in order to determine the most effective mode of operation of the network.

Keywords: Power quality, energy efficiency, RES, power losses, power factor, reactive power management.

Introduction. One of the most important aspects of energy efficiency is ensuring the quality of electrical energy and assessing its impact on the technical and economic indicators of energy supplying organizations and consumers. The decrease in power quality leads to a number of negative effects such as:

- increase in active and reactive power losses;
- reduction of the electrical equipment service life;
- increase in capital investments in electrical supply systems;
- violation of normal operational conditions of power consumers;
- harming the environment and human health.

To prevent such consequences or, at least, their limitations, it is necessary to control the quality of electric power, by which we mean the implementation of methodological, organizational and technical measures aimed at providing energy efficiency in power supply systems within the established norms and rules.

Currently, Kazakhstan has a regulatory document "GOST 13109-97 - Electromagnetic compatibility of technical equipment. Power quality limits in public electrical systems" [2], in which standardized values of quality indicators are given (see Table 1).

Table 1. The main quality indicators of electrical energy according to GOST 13109-97

№	Electricity property	Power quality indicator	Standardized values of quality indicators
1	Voltage deviation	Steady voltage deviation δUy	± 5% normal acceptable value ± 10% maximum permissible value
2	Voltage fluctuations	The magnitude of the voltage change δUt	Determined by $\delta U_t = \left\| \frac{U_i - U_{i+1}}{U_r} \right\| \cdot 100$
		Dose of Flicker	Determined by $P_t = \frac{1}{T_{av}} \int \sum g_t^2 \int \delta U_t^2 dt$
3	Non-sinusoidal voltage	The distortion coefficient of the sinusoidal voltage curve K_U	Determined by $K_u = \frac{\sqrt{\sum_{n=2}^{N} U_{(n)}^2}}{U_r} \cdot 100\%$
		Coefficient of the n[th] harmonic component of the voltage, K_U (n).	Determined by $K_{u(n)} = \frac{U_{(n)}}{U_r} \cdot 100\%$
4	The asymmetry of the three-phase voltage system	Voltage unbalance factor by reverse sequence K_{2U}	2% - normally acceptable value; 4% - maximum permissible value
		Voltage unbalance factor on zero sequence K_{0U}	2% - normally acceptable value; 4% - maximum permissible value
5	Frequency deviation	Frequency deviation Δf	± 0.2 Hz - normally acceptable value; ± 0.4 Hz - maximum permissible value
6	Voltage failure	The duration of the voltage dip Δtp	Not standardized
7	Voltage impulse	Impulse voltage, U_{imp}	Not standardized
8	Short-term overvoltage	Time overvoltage coefficient, KovvU	Not standardized

Also in accordance with the Order of the Minister for Investments and Development of the Republic of Kazakhstan dated March 31, 2015 No. 393 [3], in the Republic of

Kazakhstan, the normative values of the power factor in the electrical networks of individual entrepreneurs and legal entities are valid (see Table 2).

Table 2. Standard values of power factor

Electric network voltage class	Cos φ values
Voltage 110-220 kV	≥ 0,89
Voltage 6-35 кV	≥ 0,92
Voltage 0,4 кV	≥ 0,93

According to the regulatory document, the power factor is a measure of how efficiently a consumer receives electricity from a line. For systems with a low power factor, additional power generation is required in a volume larger than it is used. This is dispersed energy, costly and undesirable for the power grid. When the power factor is less than one, the cost usually passes to the consumer in the form of a penalty for the power factor.

Given all the above, it is obvious that the analysis of energy efficiency is relevant. In this connection, this article discusses the 110/6kV power supply networks of an oil producing enterprise, where most facilities are consumers of reactive power.

Investigated object. The enterprise has its own gas-turbine power plant with a capacity of 160 MW, which supplies its facilities with electricity, and transfers part of the generated energy to the regional grid company. There are 5 main substations (SS), which consist of 26 transformers and more than 100 package transformer substation (PTS). The topology of the object is shown in the Figure 1.

The PTSs, inside the field oil product collection system and the 6 kV network to them, belong to the grid company. After the meter, installed at a voltage of 0.4 kV at the PTS, the balance responsibility of the enterprise begins, where measurements were taken. A summary table of the PTS, their number, feeding feeders and substations, according to which the work was done to study the actual parameters of power quality, is given in Table 3.

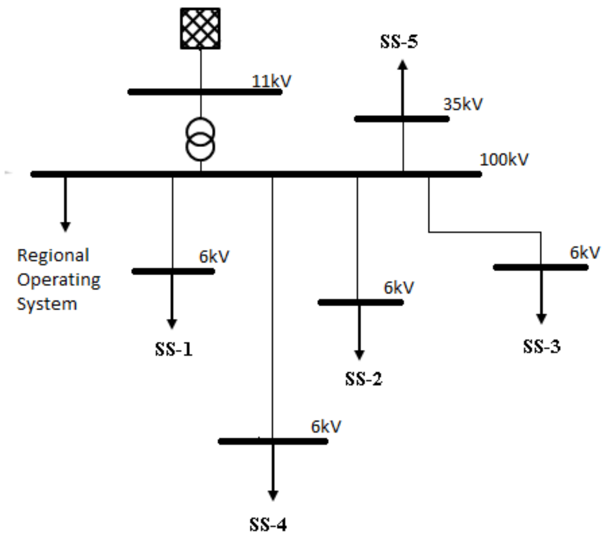

Figure 1. Topology of the invrstigsted object

Table 3. Summary table of PTS, where measurements and power quality datas were taken.

Name of the objects	Number of feeders	Number of PTS	Total power of PTS, кVA
0.4 kV voltage measurements			
SS-1	7	35	3 826
SS-2	5	28	993
SS-3	5	31	1 617
SS-4	2	15	549
Total	**19**	**109**	**6 985**

According to the results of measurements, there were revealed PTSs in which the power factor and the load factor are much lower than the required one (see Table 4), and therefore, the question of conducting an energy efficiency analysis has become acute for the investigated object. Considering the large number of PTSs at substations, it was advisable to conduct an analysis for one substation (SS-1), the methodology of which is similar for the other substations.

Table 4. The list of PTS where the power factor and load factor discrepancy was detected

№	Feeder	Name of the PTS	Str, kVA	Pinst, kV	Pcons, kV	Load factor,%
SS-1						
1	F-1	1E-9200-ET-001A	630	500	72,4	14,48
2	F-1	1E-9200-ET-006A	160	120	71,4	44,63
3	F-1	WMC-9210-ET-007	160	75	38,2	23,875
4	F-2	10-9200-ET-004	100	101,9	10,3	10,3
5	F-3	10-9200-ET-062	25	21,4	5,7	22,8
6	F-6	10-9220-ET-001	63	12,5	8,9	14,13
SS-2						
7	F-3	10-9200-ET-011	100	62,7	15,4	15,4
8	F-4	20-9400-ET-002	25	5	1,8	7,2
9	F-5	10-9200-ET-037	100	72	3,93	3,93
10	F-11	30-9400-ET-002	25	6	4,37	17,48
11	F-11	20-9400-ET-05	25	5	1,02	4,08
SS-3						
12	F-2	10-9200-ET-012	100	36,1	14,88	14,88
13	F-2	30-9400-ET-010	25	6	2,06	8,24
14	F-3	10-9200-ET-006	100	86,7	36,81	36,81
15	F-3	10-9200-ET-015	25	21,4	6,05	24,2
16	F-3	10-9200-ET-034	25	14,7	3,28	13,12
17	F-3	30-9400-ET-009	25	6	4,12	16,48
18	F-8	30-9400-ET-004	25	6	2,14	8,56
19	F-16	10-9200-ET-041	100	79,7	6,71	6,71
20	F-18	10-9200-ET-007	100	78,7	23,5	23,5
21	F-18	20-9400-ET-001	25	5	4,35	17,4

SS-4						
22	F-20	10-9200-ET-042	100	120	24,2	24,2
23	F-20	10-9200-ET-095	100	16,8	7,75	7,75
24	F-20	EMS-9200-ET-017	25	7,4	1,26	5,04
25	F-21	10-9200-ET-031	25	35,2	10,8	43,2
26	F-21	10-9200-ET-039	25	14,7	4,46	17,84
27	F-21	10-9200-ET-048	25	15,9	7,1	28,4
28	F-21	EMS-9200-ET-006	10	7,4	0,34	3,4
29	F-21	30-9400-ET-006	25	6	2,12	8,48

Methodology. The analysis was carried out using the software Power factory DigSilent. This software product is the leading integrated software for the analysis of power systems, which covers the entire spectrum of functionality from standard functions to high-tech and advanced applications [4]. With this program the SS-1 (6/0,4 kV) distribution network was modeled. The model of SS-1 distribution network is shown in the Figure 2. The following factors were taken into account in the simulation:

- Power supply source;
- Passport data of transformers and cables;
- Daily schedules of loads of the electric power consumers.

Table 5 presents the simulated options for network modes.

Table 5 – Simulated options for network modes

Options	Description
A	Initial network mode
B	Network operation mode when disconnecting an underloaded transformer

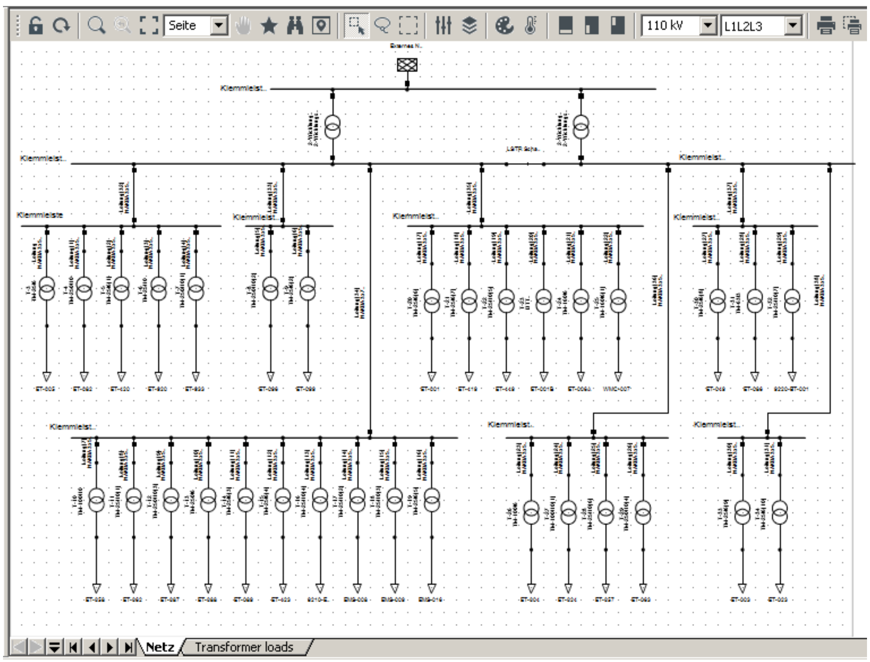

Figure 2. Model of SS-1 (6/0.4 kV) distribution network of an oil producing enterprise

Results. Due to the fact that in Kazakhstan there is no manual for energy-efficient analysis of electrical equipment, this analysis was conducted on the basis of a reference document on the best available methods for improving energy efficiency in the European Union [5].

According to the results of the analysis carried out on option A, many underused transformers were identified. It would seem that under-utilization for transformers is a positive effect, which leads to an increase in the service life of equipment, however, as shown by field tests of the European Union, under-utilization of electrical equipment is negative in terms of energy efficiency. In this case, the European Union proposes to hold a series of events to improve the energy efficiency of the mode of operation of distribution networks. One of those measures was considered in options B, the results of which lead to energy and money savings. However, it must be remembered that this method of improving the energy efficiency of transformers is valid only if the disconnecting transformer is located near the second, otherwise it will not be effective in terms of money savings.

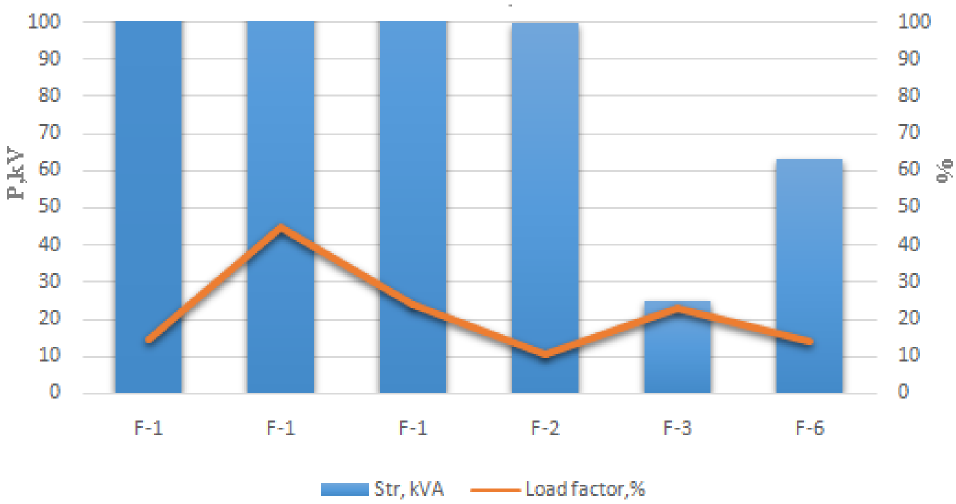

Figure 3. The result of load factor on option A

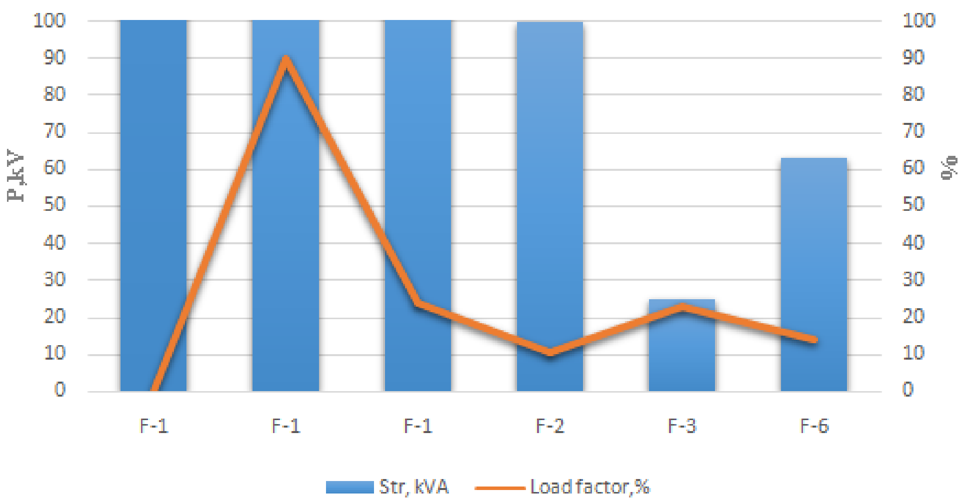

Figure 4. The result of load factor on option B

In the future, within the framework of this analysis, it is planned to model the introduction of renewable energy sources for the reactive power management in order to increase the power factor of these distribution networks.

References

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