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LOSSES OF ELECTRICAL ENERGY IN POWER GRID OF AZERBAIJAN

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Abstract- This paper summarizes the results of the analyses of energy losses in the power grids of Azerbaijan power system. At the same time the dynamics, structure of the energy losses in the power grids was examined and held comparative analyses with foreign countries. Evaluation of the reserve of decrease in the energy losses was conducted. It is found out that, technical power consumption in the electric networks lies at 7% from the supply point of energy to the grid. Due to organizational and technical measures to improve the electricity metering system, to reduce commercial losses in distribution electric grids, EE quality indicators and technical and economic indicators of the power system have improved. This is also the result of research conducted by Azerbaijan Research Institute of Energetics and Energy Design, Baku, Azerbaijan to develop software, consistently carry out calculations for the normalization of losses and measures to reduce EE losses. The overall economic effect is estimated from the reduction of relative EE losses from 21.7% in 2009 to 11.6% in 2015 at 150 million $.

Keywords: Power System, Grid, Electricity Losses, Comparative Analyses of Electricity Losses.

I. INTRODUCTION

Energy transmission in the grid system is conducted by measuring the amount wasted of certain part of the product, which is called technical consumption. In the technical literature it is mainly used "energy loss" term.
Energy losses in the power grid are one of the main indicators characterizing economic efficiency of the power system. This indicator also shows how efficiently the metering system measures the usage of power, and how is economically viable the sale of electrical energy of the power supply organizations.

Energy losses has a major impact on solving development problems: development problems, reconstruction and re-equipment of the electrical networks, improvement of operational methods and administration, improving accuracy of the energy metering system. As known that, the energy losses can be computed as the difference between the supplied and the billed energy.

The task of the maintenance team is to determine the optimal level and maintain the actual losses at the same level. One of actions of decrease in losses EE is perfection of the organization of works by calculations of technical losses of electrical energy (EE) [1-4].

Methods are developed for calculation of losses EE on the basis of known laws electrical engineers with use of circuit and regime parameters of networks.
1. Schematic methods based on calculations of technical losses of power and energy in electrical networks for specified values of the parameters of the circuit and loads.
2. Statistical methods use regression dependences of electric power losses on generalized characteristics of circuits and modes of electrical networks.
3. The estimation methods are based on specific indicators and generalized data, such as the total length of power lines, power and number of transformers.

For calculation of load losses, the following methods can be used [1-3]:
1. The elements-wise calculation methods based on the formula

$$\Delta W_{н} = 3\Delta t \cdot \sum_{i=1}^{k} R_i \cdot \sum_{j=1}^{T/\Delta t} I_{ij}^2 \quad (1)$$

where, k is the number of network elements; I_{ij} is the current of the ith element by the resistance R_i at time j and Δt is periodicity of the sensors fixing the current loads of the elements.
2. The methods of characteristic regimes use the formula

$$\Delta W = \sum_{i=1}^{n} \Delta P_i t_i \quad (2)$$

where, ΔP_i is loading losses in network in ith regime and n is number of regimes.
3. Methods of characteristic days using formula

$$\Delta W = \sum_{i=1}^{m} \Delta W_i^c D_{eqvi} \quad (3)$$

where, m is the number of characteristic days, ΔW_i^c is calculated loss of electricity by load graphs and D_{eqvi} is equivalent duration of the ith characteristic chart in a year.

4. Losses in conductors are proportional to their resistance and increase according to the square of current in transmission line. One of the methods is based on the use of the time of maximum power losses, τ [1-2]. According to method maximum power losses, energy losses can be calculated from the expression presented

$$\Delta W = \frac{S_{\max}^2}{U_{nom}^2} R \cdot \tau \quad (4)$$

where, τ is called as time of maximum power losses and $S_{\max}$ is maximum load over time T.

5. For calculation of loading losses in the distributive network the method of average loadings is used:

$$\Delta W_{\ell} = \Delta P_{av} k_f^2 T \quad (5)$$

where, ΔP_{av} is capacity losses in a network at average loadings of nodes during T and k_f is load loss factor. At representation of a current by continuous function of loss of the electric power it is possible to present

$$\Delta W_f = R \int_0^T I^2(t)\,dt = R I_{ms}^2 T \quad (6)$$

where, I_{ms} is mean-square value of a current.

Temperature of airlines wires is defined by loading current. In [4] Influence of wire temperature on an error of electric power losses calculation is estimated. Objective of the work is to explore dynamics of the energy loss structure in the grid, and to make a comparative analysis between Azerbaijan and other countries. at the same time assessment of the loss reserve in the electricity networks will be done.

Several factors affect the level of technical energy loss is for configuration of network scheme and parameters of the unit; transmission in the grid lines and characteristics of the connection load; network mode options, interactions between different energy streams; the degree of reactive power compensation; the quality of the electricity transmitted; actual status of grid system.

EE loss reduction in the grid is a complex problem, which needs significant capital investment (1)-(6), that is necessary for optimization development of electrical networks, at the same time for the upgrading energy metering systems, adaptation new information technologies in energy distribution activities and in the administration of the network modes, also for the training of personal and to equip them with electricity measurement tools.

One of the main measurement indexes in the energy system is the productive supply of EE to consumers. According to this index is determined maximum energy output of the power plant, working modes of the plants. It is required to determine correct consumption of EE by consumers in order to determining energy balance in grid.

II. ANALYSES OF ENERGY LOSSES IN THE POWER SYSTEMS

The measures taken by the State such as single price for all the consumers and installation of electric counters resulted in the reduction of the EE loss output in the republic and significant change in the consumption structure of EE. For example, EE supply to population dropped from 7443.7 mln kWh to 6501.0 mln kWh.

It is instructive to compare the data shown in Figure 1 to data about energy loss level in industrialized countries. According to the graph, at the Western European countries and Japan energy loss is in the range of 4.0-8.9% from the total energy transmitted. Energy loss in the following countries is more than 9.8-11%: Canada, New Zealand.

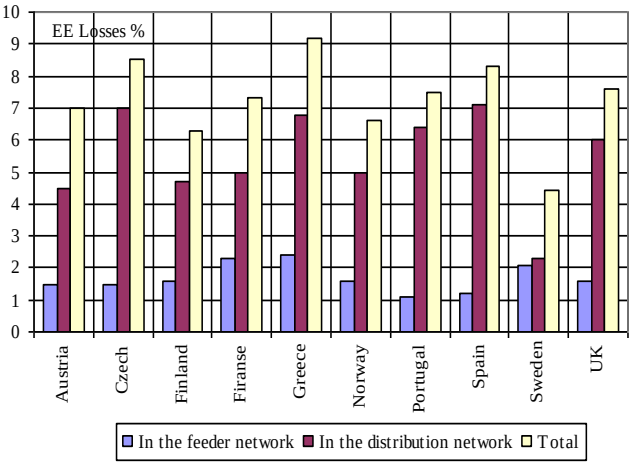

Figure 1. Energy loss in the grid system of EE countries

The total relative loss in EES of European countries is in the range of 4.4% to 8.5% (average 7.3%). Of this the total amount of technical losses for the supply of electrical networks is 14-26% (mid value of 23%) accounted and the total percentage of the losses in distribution networks are 52-85% (mid value 77%).

Figure 2 indicates statistical data of electricity production and consumption between 2010 and 2016 in Azerbaijan. Comparing the levels of energy loss between different countries shows that, almost the same level of economic development there is remarkable variation. The level of energy loss level is determined first off all according to the power generation and distribution conditions of the country [5].

The relative loss level in the grid system of Ministry of Energy USSR (1960) was around 8%, in 1970 which it increased till 9% and till 1990 the level was constant. Energy loss dynamics in Russian federation between 1994 and 2008 are shown [6].

Relative EE loss in the EPS of Belarus and Georgia is around 10%. According to international experts, in most countries of the world, relative energy losses created during the transmission and distribution process are satisfactory if they do not exceed 4-5%.

Over the past six years, production has been 24952.9-18709.5 = 6243.4 mln kWh or increased by 33.37%.

To solve the question on the technical - economical energy loss reduction problem and its reduction level it is important to focus on the energy production and distribution established in this region. The analysis of such parameters shows that the EE loss level of EPS in Azerbaijan is higher than optimal, so there is potential and exist reserves to reduce them.

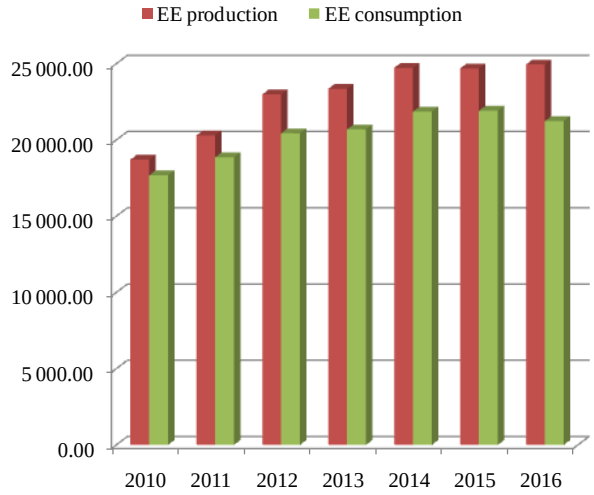

Figure 2. Statistical data of EE production and consumption in Azerbaijan

Total technical energy losses from the EPS in the grid lines of Azerbaijan were 1908.36 mln kWh. At the same time energy losses in the supply network were 685 mln kWh. In 2012, commercial losses of the energy were around 584.4 at Azerenerji JSC, Baku, Azerbaijan, for "Baku Electric Network" was 182.7 mln kWh and total 766.5 mln kWh. This total amount around 79.9% was in the 110 mln kW distribution grid system and around 20.34% in the 110 kV transmission lines.

Commercial losses mainly occurred in the 0.4-10 kV grids, total loss for the country from those lines was around 22.76%.

III. POWER AND ENERGY LOSSES SOFTWARE

Software named "Power and energy losses" was developed in Azerbaijan Research Institute of Energetics and Energy Design, Baku, Azerbaijan (Figure 3). This software is being used for calculation of technical energy losses in Azerbaijan Power System. "Power and Energy Losses" software consists of 9 programs for different purposes, such as power losses in high and low voltage power lines, corona losses, losses in transformers, distribution systems etc.

"Power and Energy Losses" is aimed to calculate electricity in the grid system and all the components of technological power loss, regulatory power consumption for needs of substations, actual and allowable imbalances at the power and normative characteristics of power and electricity losses. "Power and energy losses" is used in research and development organizations, distribution, sales and metrological service centers of Azerenerji JSC, Baku, Azerbaijan, and distribution networks.

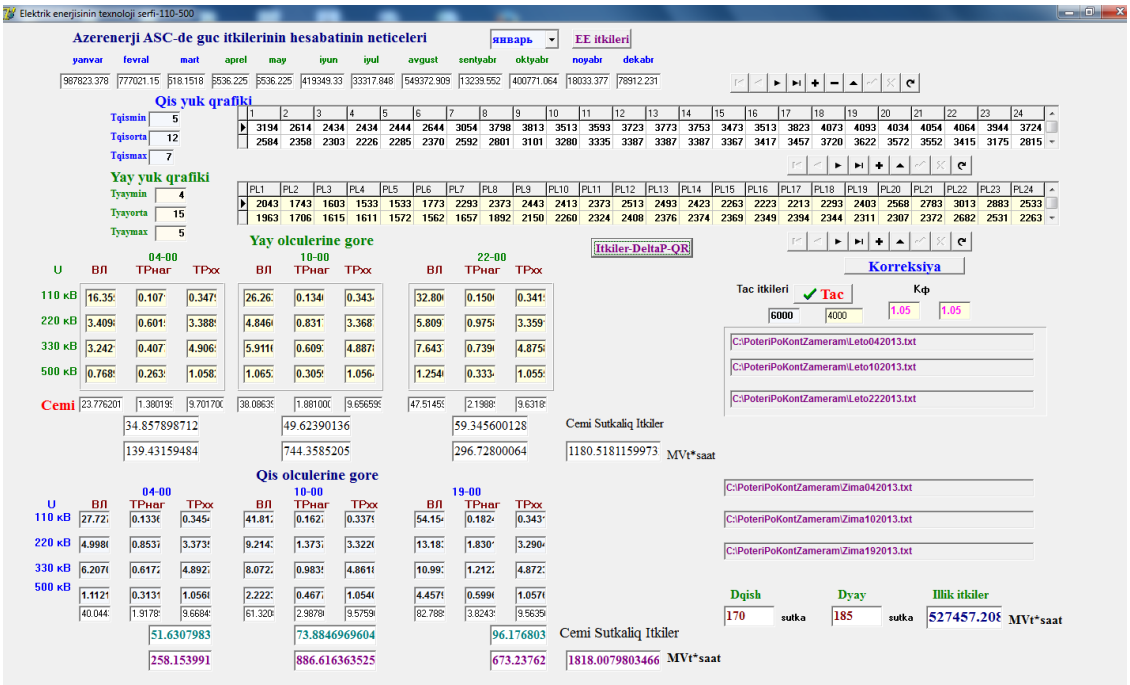

Figure 3. "Power and Energy Losses" software

At the same time with the help of "Power and Energy Losses" has been made long term measurement, analyze and summing up the total losses of electricity in the grid. Result of these calculations show that energy loss was around 7%. The loss of electrical energy in the supply field lines stands at around 2.5% for the 110-220-500 kW lines, in 4-5% for 35 kW, 6-10 kW and 0.4 kW is 10-15% from the EE release point through these lines.

After the adaptation of necessary measures to reduce losses in the EE, the total energy loss could be reduced to 7% which is the level of European countries. According to the calculation 23% of the total loss happens in the feeding grid lines and 77% in the distribution grid lines. Reserve of electricity loss reduction in Azerbaijan energy system was calculated around 2 bln kWh, 50% of which is in the total electricity loss limit. This is equal to energy production of a power plant with a capacity of 400 MW.

Priority in loss reduction must be given to the measures in the 0.4-10 kV distribution lines. Commercial losses: In 2013 the volume of the losses dropped from 766.5 mln kWh (2012) to 613.5 mln kWh which is almost 20% lower than a year before. Reduction gives possibility to preserve almost 46×10^3 $ per year.

Effects of an economic analysis of the reduction of EE losses in Azerbaijan: Starting in 2009 a reduction in the amount of EE lost in Azerbaijan has been observed. This can be attributed to government measures such as: grid network development, construction of modular power plants in the regions.

IV. IMPACT OF DISTRIBUTED GENERATION ON ENERGY LOSSES

The government has introduced new modular power plants "Wartsila" in different regions of the country. Table 1 shows modular power plants with gas engines with an efficiency in the range of 46%.

Total value of DG is around 916 MW, 147 MW is in Nakhchivan and 769 MW in Azerenerji JSC. The program of the government for the development of fuel and energy complexes includes introduction/construction of the renewable energy sector as well.

Azerbaijan Renewable Energy government comity was established on 16 July 2009. According to the government decision, 10% of the total energy production of Azerbaijan must come from renewable.

Table 1. Modular power plants of Azerbaijan EPS

No	Name	Installed capacity [MW]	Stations [Number×MW]
1	Astara	87	5×(2×8.7)
2	Sheki	87	5× (2×8.7)
3	Xacmaz	87	5× (2×8.7)
4	Naxchivan	87	5× (2×8.7)
5	Baku	104	4× (3×8.7)
6	Sanqacal	300	6× (3×16.62)
7	Shaghdag	104	12×8.7
8	Nakhchivan	60	4×15

It is important to mention government decrees and programs passed last years:

- Government program on Poverty reduction and Economic development (2003),
- Government program in Socio-economic development of the regions of Azerbaijan (2004),
- Government program on the use of renewable energy sources in the country (2004),
- Plan of complex measures to improve the environmental situation from 2006-1010 (2006),
- Government program on sustainable economic development and poverty reduction in Azerbaijan between 2008-2015 (2008),
- Presidential Decree on the establishment of the State Agency for Alternative and Renewable Energy under the Ministry of Industry and Energy (2009),
- Recently ABEMDA, launched "Gobustan Test and Training Center" in the Gobustan region and in the magnitude of 5.5 MV wind and solar power plants and biogas unit was established.

Figure 4 shows share of electricity generated from renewable sources in total production of electricity, in percent [5]. The relatively small impact of TCS Shahdagh, Sheki, Khachmaz and Astara are due to the fact that most of the power produced by the TPP is for local consumption and there is a transfer of power to the weak-coupling power transmission lines to neighboring consumers.

Official figures show that the power system with distributed generation has improved voltage levels depending on the operating mode of power plants and their unction the effect of reducing losses varies greatly. The optimal placement of distributed generation in Azerbaijan EES in comparison with existing arrangement of DG significantly reduces electricity losses and improves the reliability and quality of electricity supply.

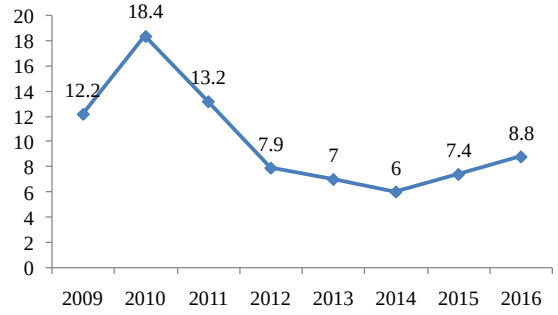

Figure 4. Share of electricity generated from renewable sources

V. ECONOMIC ASSESSMENT EFFECT OF LOSSES

Due to measures to normalize EE losses and reduce commercial losses in distribution electric grids, the technical and economic indicators of the Azerbaijan Power System have been significantly improved.

This is the result of attention to the energy sector, the construction of new and modern thermal power plants (distributed generation), high-voltage transmission lines, the good work of Azerbaijan Research Institute of Energetics and Energy Design for a long time. Change of actual EE losses in the power system networks for 2009-2016 are shown in Figures 5 and 6.

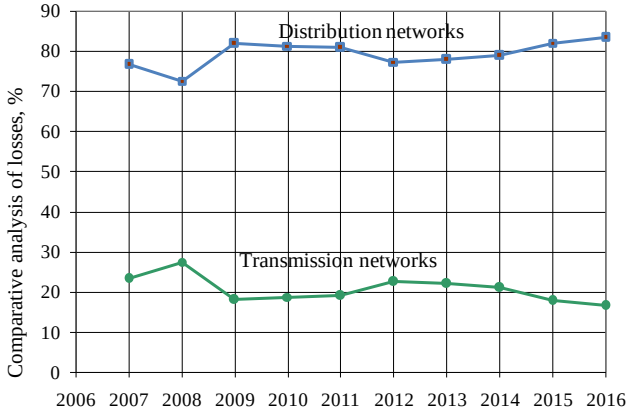

Figure 5. Dynamics of actual losses in Azerbaijan electric system

Table 2 shows economic effect from reducing electricity losses in 2009-2016 years. Figure 6 shows the real losses of EE in the power system between 2009-2016 (information from the Government Statistical Committee) Due to Table 2 the overall economic benefits within 6 years from reducing losses is $416.3 \times 0.06 \times 10^6 = 24.9 \times 10^6$ $/year. The total economic effect within 6 years is 150 million $. Azerbaijan Research Institute of Energetics and Energy Design for EE starting in 1980, developed methods, algorithms and software for EE losses calculation [7].

Note that cost of project development is within 10% of total cost. In this case, share of Azerbaijan Research Institute of Energetics and Energy Design in reducing the power losses equal to 15 million $.

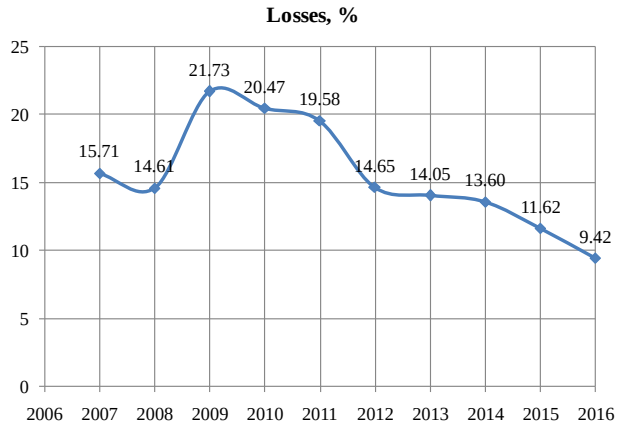

Figure 5. Losses of EE in the power system

Table 2. The economic effect of reducing electricity losses

Year	Production [10^6×kWh]	Losses [10^6×kWh]		Saving [10^6×$]
		Actual	Change	
2009	18599.5	4 100.3	0	0
2010	18346.9	3 830.1	-224.2	-13.45
2011	19617.0	3 973.4	-201.5	-12.09
2012	22448.7	3 367.6	-1212.0	-72.72
2013	22986.1	3 280.6	-166.7	-10.00
2014	24362.5	3 362.5	-198.3	-11.90
2015	24530.9	2 868.6	-495.0	-29.70
2016	24952.9	2350.2	-2497.7	-184.57

VI. DISCUSSION AND CONCLUSION

According to the calculations of Azerbaijan Research Institute of Energetics and Energy Design the estimated power losses in the EES Azerbaijan should be at the level of 7% of the grid supply. Total reserve of the energy loss reduction in the grid system is around 1.7 bln kWh or 50% of the total energy loss.

The loss of energy in the feeding grid lines of 110-220-500 kV was 2.5% of the ES in the 35 kV lines this figure stood at 4-5% of the ES, in ES 6-10 kV and 0.4 kV 10-15% from the feeding point EE through these lines. It is estimated that if the losses in the EPS, evaluated at an average of 204 mln kWh for the year 2009-2015 about 12 million AZN can be saved per year.

The total loss that can be attributed to the EPS Azerbaijan for example, in 2012 is estimated at 3367 mln KWh. At the same time, the losses in the main electric networks are 685 mln kWh. Losses in distribution networks amounted 1836 mln kWh, commercial energy losses are around 766 mln kWh. From the total loss value about 79.66% can be attributed to distribution in the ES 110 kV and below, 20.34% in the transmitting ES 110 kV and above lines.

Commercial losses of electricity for the year 2012 amounted, in Azerenerji JSC was 584.8, "Baku Electric Network" was 182.7 and total loss value was 967.5 total mln kWh. Commercial losses are mainly concentrated in the networks 0.4-10 kV. It is estimated that, total share of losses from these for the whole country is 22.76%.

These analyses have made a comparison of losses of EE in EPS energy system of Azerbaijan and had investigated the dynamics and structure of the energy losses in power grids of Azerbaijan, made comparative analysis of energy losses in the Azerbaijan EPS with other countries. Electricity losses in the ES of the developed countries are in the range between 4-9%. 14-16% of the total technical energy loss was accounted in the supply networks, where the overall proportion of the total loss in distribution networks is 52-85%

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BIOGRAPHIES

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