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ENERGY EFFICIENT SOLUTIONS FOR ELECTRIC POWER SUPPLY RURAL AND SUBURBAN CONSUMERS

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Abstract- The current stage of electric power systems development of Azerbaijan is characterized by increasing power consumption, the development of small private sites, farms, estates and increasing distance from the center of power to individual consumers 0.38/0.22 kV, which lead to a decrease in quality of electric energy and energy losses in electric networks. The necessity of modernization of power 0.38/0.22 kV and offer energy saving mixed three-phase-single-phase power distribution system. Thus losses in energy-saving power supply system is much lower than the traditional one. At asymmetrical mode technical and economic indicators of a network sharply worsen. In the paper modeling of asymmetrical modes is executed by using of Electronic Workbench computer program.

Keywords: Energy-Saving Power Supply System, Distribution System, Loss of Electrical Power, Power Quality, Transmission Line.

I. INTRODUCTION

The current stage of energy development is characterized by increasing power consumption, increasing the distance from the center of power to individual consumers which lead to a decrease in quality of electric energy and energy losses in electric networks. In this regard, at the current stage of energy development is the issue of transition to energy-saving technologies in the rural power grids, which caused a decrease in the quality of electric power and energy losses.

The main factors characterizing the power supply system are: the cost of its construction, reliability and efficiency of electricity transmission to consumers in particular, the level of energy losses. The existing in the country three-phase four-wire power supply system of rural consumers 0.38/0.22 kV characterized by a number of disadvantages: greater use of non-ferrous metals, high electricity losses (15% or more of the received electricity to the grid), poor quality of electricity associated with the excess of non-sinusoidal ratio, direct and reverse sequence 2-4 times, the high level voltage drops, causing unacceptable voltage variations in remote users.

All this leads to significant losses of electricity supplying companies, as well as bring significant harm to consumers of electric power. Today, there are many devices on the balancing of the network, but all of them because of their high cost and low reliability and inefficiencies in long lines that feed the household burden, not been widely used in networks 0.38 / 0.22 kW [1-4].

The peculiarity of the electric network for agricultural use - this is a great dispersion of electrical consumers, which leads to a considerable length of 10 and 0.4 kV, the large distance between the point of consumption, small quantities of consumption at each node and the minor density of the electric load in place of consumption.

The main factors determining the development of electric distributing networks 0.4 and 6-10 kV are voltage levels and lost. Electricity consumption by industry of the national economy of the USSR in 1985 was 61.4% in industry, in the construction 2.2%, in the transport 9.5%, in agriculture 12.2% and in domestic sector 14.7% [4, 6].

There was a continuous growth in electricity consumption until 1990. During 1990-1997 years in the level of consumption was a sharp reduction. In 1990 energy consumption amounted to 21,548 million kWh, but in 1997-13,142 million kWh. The overall reduction in 1997 was only 61% of the level 1990.

During the reduction of the total electricity consumption there was observed increase in the use of electric energy in the domestic sector (5-7% annually). This is due to the movement of commodity production from the public sphere into the private subsidiary farms, as well as construction of private and rural farms.

Electricity consumption in the Republic for 1990-1998 years in the industry fell by more than 4 times, and the consumption of the population has increased seven times compared to 1990 [4-7]. The population of Azerbaijan has increased from 7 million people in 1989 to 8.26 million people in 2003 (18%), 9.2 million people in 2015 (over 30%). However, about 52% of the population lives in cities. The total electric energy release was 22448.7 mln.kWh in 2012, of which 7600 mln.kWh industry, population and commerce 11.956 mln.kWh, i.e. 33.85% and 53.26%.

It should be noted that the rate of wear lines and substations ahead of the volume of their reconstruction, re-equipment and new construction to replace dilapidated.

The electrical load and consumption will increase energy efficiency in the use of electric energy in socially significant processes of the household, i.e., hot water supply, cooking and heating partial basic and ancillary premises. This trend will be in the near future and in the perspective different specific embodiment and it's necessary to take into account when constructing the circuit grids 6-10/0.4 kV in the villages. Overall load household and mixed species increased.

For electricity supply in rural areas of the existing structure of the network used three voltage levels: 35-110 kV, 6-10 kV and 0.4 kV. The length of 0.4-35 kV networks is more than 102.86 thousand km, of which distribution networks 6-10 kV up to 37.9 thousand km, i.e. about half which says about their importance in the overall system of power transmission and distribution for the rural region. The length of the 0.4 kV network up 60.1 thousand km.

The length of the feeders of 6-10 kW range from 15 km to 25 km. In operation there are also feeders which length of more than 30 km. Deviations voltage consumers reach values from minus (15-20%) to plus (10-15%), which is a violation of requirements of GOST 13109-97.

Losses of electric energy at power distribution network 0.4, 6-10 kV of Azerbaijan are 60% of total losses in electric, 5% of 35 kV power distribution network.

II. PRIORITY ACTIONS TO REDUCE TECHNICAL LOSSES OF ELECTRICITY IN DISTRIBUTION NETWORKS 0.4-10 KV

The priority actions to reduce technical losses of electricity in distribution networks 0.4-10 kV are:
- The use of a voltage of 10 kV voltage as the main distribution network;
- Reducing the range of construction of overhead wires 0.4 kV three-phase along the entire length;
- The use of the maximum allowable conductor section in electrical networks 0.4-10 kV in order to adapt its bandwidth to increase loads;
- The use of low power pole transformers 6-10/0.4 kV networks to reduce the length of the 0.4 kV and power losses in them;
- The increased use of devices FACTS, Smart-Grids auto-load, of the local voltage control to improve power quality and reduce its losses.

To upgrade rural power distribution networks 6-10 kV is necessary to fulfill the following main objectives: to prove the effectiveness of the signs of upgrade options of rural electric networks of 6-10 kV; identify the main technical and economic indicators of schemes of 6-10 kV networks and to develop a methodology for the selection of optimal methods of modernization; to inspect the main ways to modernize and to assess their cost-effectiveness.

III. CONVENTIONAL POWER SUPPLY SYSTEM

At present, there are power supply for agriculture, which are constructed as a central step-down transformer substation, located in the center of the electrical loads of the village, and 0.4 kV distribution networks in different directions from the substation.

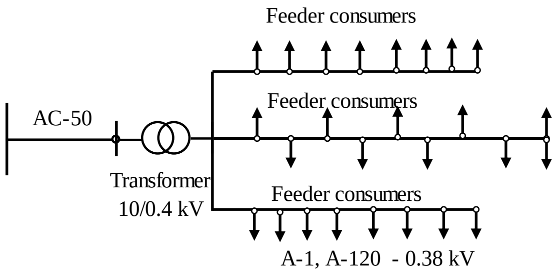

Figure 1. Centralized power supply system

Part of 0.38 kV distribution networks are in poor condition, and is a source of significant losses of electricity due to the presence of wires in the networks of different brands, oxidized twists, unbalanced loads, long distance, the lack of stability of the voltage level and etc. Losses on these networks reach to 60% of total losses.

Asymmetry of currents caused by household loading is connected by non-uniformity of distribution on phases of the single-phase consumers having, as a rule, casual character of power consumption. At an asymmetrical mode technical and economic indicators of a network sharply worsen.

For rural electric networks the asymmetrical mode is characteristic. Asymmetry of voltage is characterized by presence in a three-phase electric network of voltage of direct, return or zero sequences. As a result of displacement of a neutral of three-phase system there is an asymmetry of phase voltage. Asymmetry of voltage is caused by presence of asymmetrical loading. The asymmetrical currents of loading proceeding on elements of system of an electrical supply cause in them asymmetrical power failures. Thereof on conclusions of consumers there is an asymmetrical system of voltage. Deviations of voltage at consumers the overloaded phases can exceed admissible values while deviations of voltage at consumer other phases will be in normalized limits. In case of presence of currents of return and zero sequence total currents in separate phases of elements of a network that leads to increase in losses of active capacity increase.

Improvement of quality of electric energy is an actual problem in rural electric networks voltage 0.38/0.22 kV and inseparably linked with reduction of additional losses of the electric power caused by asymmetrical loading of phases. The analysis of operating modes of rural networks voltage 0.38/0.22 kV [1-7] has shown that asymmetry of currents is caused by household loading. The basic part of this loading is made by the single-phase consumers non-uniformly distributed on phases having, as a rule, casual character of power consumption.

Change of loading of single-phase household consumers of electric energy has casual character. Thus with certain probability to establish those limits for which it does not leave for the given moment of time. Owing to likelihood character of power consumption for any moment of time in a three-phase power line always it is necessary to expect asymmetry of phase currents, and as consequence, and voltage. At an asymmetrical mode technical and economic indicators of a network sharply worsen: losses of energy, a deviation of voltage from nominal at consumers increase, and current constantly proceeding in a zero wire causes occurrence of considerable potentials on cases of the electric equipment attached to a zero wire.

Capacity losses in a network 0.38 kV at asymmetrical loading are characterized by factor of losses of capacity

$$K_p = 1 + K_{2i}^2 + K_{0i}^2 \left(1 + \frac{3 \cdot R_N}{R_1}\right) \quad (1)$$

where K_{2i} and K_{0i} are factors of asymmetry of currents on the return and zero sequence, equal to the relation of a current of corresponding sequence to a current of direct sequence; and R_0, R_1 are active resistance of zero and direct sequence of a site of a network.

Electric power losses in a line voltage 0.38 kV taking into account asymmetry of loadings of phases (% of holiday of the electric power in a network) according to the instruction define under the formula

$$\Delta W_{load} = 0.7 K_{non} \Delta U_1 \frac{\tau}{T_{\max}} \quad (2)$$

where, ΔU_1 is the voltage loss in a maximum of loading of a network from tires $T_{\max}$ to the most remote consumer, %; and K_{non} is the factor considering non-uniformity of distribution of loadings on phases. K_{non} factor is defined from

$$K_{non} = 3\frac{I_A^2 + I_B^2 + I_C^2}{\left(I_A + I_B + I_C\right)^2}\left(1 + 1.5\frac{R_H}{R_{phase}}\right) - 1.5\frac{R_L}{R_{phase}} \quad (3)$$

where, I_A, I_B, I_C are current loadings of phases; R_L/R_{phase} is the relation of resistance of zero and phase wires [6].

In the absence of the data about current loadings it is necessary to accept: for lines with $R_L/R_{phase} = 1$; $K_{non} = 1.13$, for lines with $R_L/R_{phase} = 2$; $K_{non} = 1.2$.

Calculation of losses in a network 0.38 kV is made by a method of number of hours of the greatest losses t, using the formula

$$\Delta W_H = \Delta P_{\max} \tau \quad (4)$$

where, $\Delta P_{\max}$ is capacity losses in a mode of the maximum loading of a network.

The analysis of losses of capacity in electric networks 0.38/0.22 kV is more low considered at asymmetrical modes by means of computer program Electronic Workbench.

We take an equivalent site of a three-phase four-wire air-line 0.38/0.22 kV in the length 200 m, to each of three phases are attached on one single-phase consumer. The network eats from the transformer 25 kVA which secondary windings are connected under the scheme «a star to zero».

Calculations are spent for equivalent schemes power grid 0.4 kV with symmetric loadings of phases 5.5, 10, 20, 30 Ohm. Asymmetrical modes of different degree of asymmetry and changes of the general loading by reduction of loading of a phase by increase in active resistance within R_{LC} = 5.5-110 Ohm are generated. On the basis of computer program Electronic Workbench calculations are carried out at different degree of asymmetry depending on loading change. Results of modeling are resulted in Table 1.

Table 1. Results of calculations of power losses at asymmetrical loadings

No	Loading resistance, Ohm			Currents, A			
	A	B	C	A	B	C	0
1	20	20	20	10.78	10.78	10.78	0
2	20	20	40	10.74	10.73	5.495	5.088
3	20	20	60	10.73	10.71	3.687	6.828
4	20	20	80	10.72	10.70	2.774	7.706

No	Zero wire voltage, V	System, kW	Power losses		Increase in losses in p/u
			kW	%	
1	0	7.11	0.139	1.76	1.00
2	2.039	5.95	0.125	1.89	1.07
3	2.737	5.57	0.135	2.18	1.23
4	3.089	5.37	0.142	2.39	1.35

IV. DECENTRALIZED ENERGY-SAVING POWER SUPPLY SYSTEM

Therefore, it is expedient to replace the existing system of central power distribution system to maximum decentralization system, which will greatly reduce the losses and investment.

Scheme of decentralized energy-saving power supply system is shown in Figure 2 [1, 3].

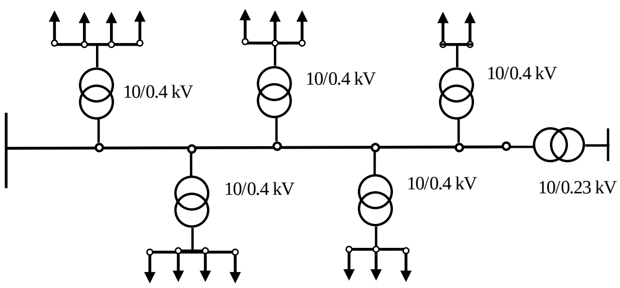

Figure 2. The scheme of decentralized power distribution

Decentralized energy-saving power supply system is a system of distribution of 10 kV with insulated wires type SIP, with the installation of a power line support as close as possible to the consumer single- or three-phase step-down transformer substation with capacity of 10, 16, 25, 40 kVA or more. This distribution network 0.38/0.22 kV small length. They are presented only in the form of bushings 0.38/0.22 kV from transformer substations to consumers.

Mixed three phase-single phase decentralized power distribution system solves the problem of providing electricity in terms of quality, reliability and efficiency. Implementation of this would eliminate the main distribution networks 0.38/0.22 kV and aerial networks of exterior lighting, passing through territory of a village.

Observations show that the deterioration of the technical condition of networks that are not compensated fairly new construction and reconstruction. These circumstances have resulted in the state of research networks, determine the extent of their adaptation to the new conditions.

Currently power for agriculture use are not adapted to changes. In recent years, there has been growth in electrical load, which causes the need to modernize electricity networks 6-10/0.4 kV.

In the next decade electric load will be determined by the development communal household of rural areas and farmers. Consumption of electric power will increase in the storage and processing of rural economic production.

These changes in the volume and nature of the electrical load necessitate the construction of new and reconstruction of existing networks 0.4 and 6-10 kV. This, together with heavy losses in electricity, - one of the main reasons for their upcoming update on towns.

Significantly changing the load impact on the distribution networks: their configuration, schematics build, design and reliability of power transmission lines. The network will have to fully meet the load growth and customer requirements on the quality of electricity, corresponding to a market economy. However, the availability of reliable electric systems will provide increased capacity and thus will increase the load of new customers.

The level of electric power loss - an important indicator of the efficiency of power grids. In the power system of Azerbaijan electric power losses are within the 9:25%. In recent years, there is a tendency to reduce them.

High losses in distribution networks caused considerable length of transmission lines, the lack of automatic voltage control in networks, as well as low-loading transformers and small sections overhead wires, built mostly in the period of electrification up to 1970.

Software quality metrics and reduce energy losses in electric systems should be one of the main criteria for selecting areas 10-0.4 kV network development and is one of the reasons why the necessary network upgrades 10-0.4 kV.

Considering these changes is necessary for the modernization of rural electric networks 6-10/0.4 kV consider systems other than the traditional three-phase four wired , which will provide greater bandwidth at a lower cost. Such a system is decentralized energy-saving power supply system is a cost-effective system as one of the areas of modernization of networks 6-10/0.4 kV. This is confirmed in the document "Concept of Technical Policy of RAO" UES of Russia, which refers to the need for a pole-mounted transformer substations.

The need for the distribution of electric power through a low voltage of 0.4 kV leads to the construction of extensive networks with substantial costs of conductive materials of non-ferrous metals, concrete poles and steel structures. As a rule, the most susceptible to damage line 0.4-0.23 kV.

In some countries, especially in the US, 0.4 kV lines have little length - within the farm or to the nearest transformer serving guide-some houses. This character of the network due to the use of a large number of transformers, especially single-phase, lowering the voltage to 0.23 kV. To provide three-phase power often sets three single-phase transformers, less often - one phase.

The extensive distribution network 0.4-0.23 kV virtually absent. Customers receive the electric power from the pole close to them or simply transformer substations.

First Decentralized energy-saving power supply system was proposed in the 1950s by I.A. Budzko. The main structural elements of Decentralized energy-saving power supply three-phase systems and single-phase pole mounted substation. On poles of overhead wires 10 kV, passing along the village in the vicinity of the consumer, are installed power transformers 10/0.4/0.23 kV with switching equipment and devices, the reception and distribution of electric power.

All distribution network is performed at a high voltage of 10 kV, and the distribution of electric power in the 0.4-0.23 kV voltage is carried out by short connections from the transformer to consumers, which allowing exclude construction of 0.4 kV overhead line (Figure 2).

Power transformers, both single-phase and three-phase, located directly on the piers. Three-phase transformer substations can be installed next to the consumers having a three-phase load. Structurally, such transformers can be performed as a single-phase transformer or as a group single-phase. Close to residential consumers set transformers 10/0.23 kV. In this case there can be one or two secondary windings with a nominal voltage of 230 V each. In the latter case electric power reach the consumer by a single-phase three-wire line. One medium wire grounded, it acts as a neutral wire, as in the three-phase four-wire network.

Compared with this one more reliable and promising a scheme in which uses three-phase group single-phase transformers. Here, the consumer receives power from three-phase symmetric system, but it simplifies the design of pole substation, aided by the possibility of a symmetrical arrangement of the single-phase transformers on the support. Furthermore, installation is simplified and power transformers in crushing the total installed power substation, and hence the weight reduction of transformers. Failure of one single-phase transformer, unlike the three-phase, does not interrupt the power supply to consumers, but merely limits the maximum load power.

As noted above, the third embodiment of decision on the substation layout is to use a three-phase transformer rod. This system compares favorably with the option of single-phase transformer when feeding three-phase motors, but the reliability is not removed. In cases where failure comes the primary winding of a phase when connecting winding triangle - star with zero, transformer can be put into operation at reducing capacity to 40% by including it in the open delta winding.

At present, Azerbaijan has established steady power supply system. For the distribution of electric power in rural areas is used three-phase four-wire system voltage of 0.4 kV. As a perspective offers Decentralized energy-saving power supply system. At the same time, the task is to determine the possibility cost-effective and technically sound option in the reconstruction of electrical networks 0.23-0.4-6-10 kV.

V. SIMULATION RESULTS

Consider the use of economic application of Decentralized energy-saving power supply system under certain conditions. Solution of the problem is based on a comparison with the classical four-wire system and Decentralized energy-saving power supply system by two parameters: power losses in the network and the cost of construction of power transmission lines.

The distances between nearby consumers have been taken the same and vary in proportion to the length of the feeder. The losses in each section of the line, W:

$$\Delta P_n = \frac{P^2 + Q^2}{U^2} R \quad (5)$$

where P and Q are active and reactive capacity, flowing through the section of the line; U is line voltage; and R is resistance of the line.

The value of the current in the main section feeder $I_{r.u}$, required for the selection of the wire section, A:

$$I_{r.u} = \frac{S}{U\sqrt{3}} \quad (6)$$

For decentralized energy-saving power supply system current value $I_{r.u}$ = 1.73 A, for the classical system $I_{r.u}$ = 45.6 A. Calculation of the voltage in the beginning of the section according to the line end

$$U_i = U_j + \Delta U \quad (7)$$

Wires size is selected by the mechanical strength according to SAE, S = 35 mm^2, for classical system by economic current density S = 50 mm^2. Resistance of each line section, in ohm:

$$R = l_{uc} r_0 \quad (8)$$

where, l_{uc} is the length of the section, km; and r_0 is resistivity of the conductor, ohm/km. The total power loss in the network for each system, in W:

$$\Delta P_\Sigma = \sum_1^n \Delta P_{ni} + \sum_1^m \Delta P_{mi} \quad (9)$$

As a result of the Equations (5)-(9), we obtain data for plotting power losses and expenses on the length of the feeder.

For example, we take the transformer substation with the capacity of 63 kVA transformers and power line of 0.38/0.22 kV. A three-phase four-wire overhead line 0.38/0.22 kV length (4×50 = 200 m, 100×4 = 400 m, 150×4 = 600 m, 200×4 = 800 m), 400 m, in each section 100 m on the support for each of the three phases are connected by one single-phase consumer. The number of consumers is 12.

The network is powered by the transformer secondary winding is connected in a "star with zero", resistance aluminum conductors overhead line sections between the points of connection of the consumers represented by a number of series-connected active resistances.

To determine the electricity losses in the network was modeled modes of consumption for both power supply systems. In the design of 0.4 kV overhead lines recommended wires A-16 ÷ A-120. Table 2 shows the results of simulation modes 0.38 kV network using a symmetric mode of calculation to determine the voltage drops and power feeder.

Load of 3-phase 4-wire system is 24.45 kW. The power loss is 1.318 kW. The total capacity of the system is 25.77 kW. Turnpike 0.4 kV overhead lines are usually performed by one section wire and only in some cases, they can be made smaller section wires

Table 2. The simulation results of 30 single-phase consumers by 2 kW

No	Wire size mm^2	Feeder length, m	Voltage drop ΔU		Power loss in the feeder ΔP	
			V	%	kW	%
1	50	200	391.78	3.10	61.23	2.04
2	35	200	396.48	4.34	61.74	2.90
3	50	500	409.33	7.72	63.01	5.02
4	35	500	420.87	10.75	64.25	7.08
5	50	750	423.85	11.54	64.45	7.42
6	35	750	440.90	16.02	66.26	10.42
7	50	1000	438.2	15.33	65.85	9.75
8	35	1000	460.7	21.22	68.20	13.64
9	120	1000	407.19	7.24	62.51	4.19
10	90	1000	414.66	9.12	63.33	5.54
11	70	1000	423.14	11.35	64.24	7.07

When the 0.4 kV overhead transmission lines with big wire size 120 mm^2 improve voltage level and reduces the loss of electric power. This requires evaluation and justification of economic efficiency.

Analysis of the electric power losses in the lines when changing the length of the feeder and the number of transformers show that the loss in transformers remains practically unchanged. In the case of Decentralized energy-saving power supply system the main component - losses in transformers, but lines losses are considerably small. In the classical system, the loss in the lines is weighty importance in the total losses. Lost in the classical system is higher than in the same index in decentralized energy-saving power supply system.

Preliminary assessment of the economic efficiency by network reconstruction 0.4 kV lines to 10% above the 0.6 km length in Azerbaijan shows that it is possible to reduce loss of electric power in the power distribution network from 15% to 4% and as a result you can save up to 77 million kWh electric powers per year.

Comparison of economic calculations of two power supply system's showed that energy-saving system that has the best technical and economic parameters in comparison with the traditional power supply system.

VI. CONCLUSION

1. At full reconstruction existing or at building of electricity transmissions 0,4 kV in rural electric networks it is necessary to pass to other systems of an electrical supply reducing influence of asymmetry, improving quality of electric energy and reducing power losses.
2. The traditional system of centralized power supply of country side consumers 10/0.4 kV, with long lines still cannot provide power quality, reliability and efficiency.
3. For the power supply of the countryside consumers are invited to move to mixed three phase-single phase decentralized system of power distribution, which allows to solve the problem of providing for power quality, reliability and efficiency.

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BIOGRAPHIES

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