Akaki Tsereteli State University

Faculty of Technical Engineering

Copyrighted manuscript

Petre Kachkachishvili

Determination of power and energy losses and technical and organizational measures to reduce them on the example of Kutaisi distribution network

The Author's Abstract

of the Doctoral Thesis Nominated for Academic Degree

of the Doctor of Engineering (0719)

Kutaisi

2022

Dissertation has been performed at the Department of Energy and Telecommunications of the Faculty of Technical Engineering at Akaki Tsereteli State UIniversity

Dissertation advisor: Professor Omar Zivzivadze

Reviewers:

Marlen Shalamberidze - Akaki Tsereteli State UIniversity; Professor - Emeritus.

Zaza Papidze - Akaki Tsereteli State UIniversity; Associate Professor.

The Dissertation defense is held on _________________22.12.22___________________

at the meeting of the Dissertation Commission established by the Dissertation Council of the Faculty of Technical Engineering. Address: Georgia,Kutaisi,Tamar Mepe N59. I Building, Room No. №1114.

The Author’s abstract was sent out on “ ____ ” ________________

Secretary of Dissertation Council __________________ /N. Sakhanberidze/

General description of paper

Topicality of research

Many researchers have worked on solving the problem of reactive load compensation and they have proposed different methods of solving this problem. The most accurate method among these methods is a system approach, which involves considering all the elements and all the consumer nodes of all the voltage step grids of the power grid. This method is essentially the universal one, but on the one hand is characterized by a large dimension (a large number of elements of the power grid and consumer nodes) and, besides, the input data are of relatively low quality.

One of the indicators of the quality of input data is their veracity or accuracy. Since the distribution networks (medium and low voltage networks) of the power grid are set up around the country, it is difficult to obtain accurate information for subjective or objective reasons, and the data obtained are undetermined and contain errors.

In a modern market economy, by form of power supply and distribution networks ownership, the power grid is divided into many private companies. It is even more difficult and sometimes even impossible to obtain from these companies the data (especially accurate data) on the operating modes of their distribution networks and their characteristic parameters. Given the above, the solution of the equation system given below is likely to contain errors and fail to meet the optimization requirements. Moreover, due to the differences in the goals, objectives and financial capacity of individual companies, it is not possible to realize reactive load compensation across the entire system in a short period of time (at least in a few years). Therefore, the method of the systematic approach to the optimal compensation of the reactive load should be replaced by a method for which it will be sufficient to use only easily obtainable data on a given distribution network and its supply network. However, the level of reactive load compensation established by this method in the distribution network will adequately respond to the task at hand. That is, the global problem of optimal reactive load compensation (the system approach problem) should be reduced to local tasks of a separate distribution network.

The purpose of the work is to present the reactive load compensation in the dose that minimizes the active power (energy) losses in the Kutaisi distribution network at minimal capital costs. Reactive Power Compensation is the targeted generation or consumption of reactive power by the compensating device. The problem of optimal reactive load compensation in the distribution networks is systemic problem and its solution is performed by the system approach method, the criterion of which is to minimize the total costs in the electricity transmission grid.

Research subject and methods

The problem of reactive load compensation in the power grid is solved in two stages. In particular: first, the level of reactive load compensation in the consumer nodes of the supply network, which will be optimal for this supply network, will be determined using the system approach method; second, the problem of optimal reactive load compensation in a given distribution network will be solved based only on data on this network, and the results obtained at the first stage will be taken into account when making the final decision.

Due to the different interests of the supply and distribution networks of Kutaisi, the amount of reactive load compensation is also different, and it is necessary to develop such a methodology for solving the reactive load compensation problem, which will harmonize these different interests and will give us the maximum benefit on a global scale.

The results of solving the problem set when using the simplified mathematical model obtained as a result of theoretical research, with a view to checking their accuracy, were compared with the results of the solutions obtained in the full-scale consideration of the principle of a systemic approach. The results of the comparison confirmed the completeness of the mathematical model adopted in the thesis and the feasibility of its implementation in practice.

Main research findings and novelty of research.

The resulting expression represents a simplified mathematical model for solving the problem of optimal reactive load compensation in the considered regional power grid.

$$\sum_{j=1}^{k} R_{ij} Q_{j\text{з}} = -\sum_{j=1}^{k} R_{ij} Q_j + [(1-\beta)\sigma'_k - \mathrm{a}]\frac{U_{б}^2}{2}.$$

The numerical value of the β coefficient for the regional networks with different characteristic parameters can generally be determined with different accuracy according to data presented in Table 1.

By means of the parameter of the high-voltage supply network, we determine the internal resistance $R_{k,k}$ for the considered regional network and, accordingly, σ'

$$\sigma' = \frac{2R_{K,K} Q_{K\sum}}{U_{б}^2},$$

where $Q_{K\sum}$ - is a total reactive load for the considered regional network.

According to the data of the same high voltage supply network, we will determine σ_K and will consequently establish

$$\sigma'_K = \sigma_K - \sigma$$

The internal and interaction resistances $R_{i,j}$ included in the system of equations should be calculated with respect to the balancing node taken in the high voltage supply network.

$$R_{i,j} = R_{K,K} + R'_{i,j} \qquad\qquad i,j = 1,2 \ldots K\ .$$

where $R'_{i,j}$- the internal and interaction resistances of the nodes of the low-voltage regional network nodes, calculated with respect to node K.

The simplified mathematical model allows us to solve the problem of optimal reactive load compensation in the regional network with sufficient accuracy for engineering calculations, even in the conditions of the initial non-deterministic data required for the solution.

Practical value

Calculation and study of the modes of the 110 kilovolt supply network of Kutaisi using the PSS/E (Power System Simulator for Engineering) program showed that:

At the possible allowed value of the load characteristic, the magnitude of the voltage in the nodes of the network does not deviate from the permissible limits.

At the possible allowed value of the load characteristic, losses in the network do not deviate from the permissible limits.

Overloading of lines in the network does not occur at the possible allowed value of the load characteristic.

All calculation expressions, at various initial conditions, are recorded in a form that is convenient for practical use.

As the field of application of the results can be considered the 110 kV supply networks where the distribution networks are the 10, 6 kV level networks.

The structure and volume of dissertation work. The dissertation consists of an introduction, four chapters, conclusions and, references. The dissertation is made up of computer-printed 134 pages.

The main results of dissertation by chapters and general conclusions

In the **introduction**, attention is focused on what reactive load compensation is in such a way as to minimize active power (energy) losses in the network at minimum capital costs. It is also about the relevance of mutually independent solutions of technical problems in separate distribution networks of the power grid in modern conditions of the development of the market economy.

The first chapter analyzes the energy processes occurring in the alternating current circuit and the features of reactive power in the power grid as a concomitant event of active power transfer. Reactive power is practically a convenient form for analyzing transient processes in the alternating current circuit.

Reactive power compensation is an effective means of regulating voltage and active power losses in the network. From this point of view, the adjustable compensating devices, synchronous compensators, condenser batteries and shunt reactors are more convenient.

In terms of reactive load compensation, compensators are characterized by a positive regulatory effect when the voltage changes in the network, while non-adjustable condenser batteries have a negative regulatory effect, although the installation and operation of the latter is relatively simpler and also requires relatively less active power from the network.

Despite some disadvantages, condenser batteries are more widely used in the distribution network than synchronous compensators, because they can be installed:

- directly close to consumer at 0.38 kV voltage (individual compensation);
- in the distribution networks (group compensation);
- on the low voltage (0.38, 6, 10kV) busbars of substations (centralized compensation).

The current state of reactive load compensation solution is also discussed. The essence of the problem is discussed here from the viewpoint of a systemic approach. This problem has attracted lot of research both in the former Soviet Union and outside it. This is due to the fact that in the conditions of a rational solution to the problem, great technical and economic benefit can be easily achieved.

Rational reactive load compensation is an integral part of the scientific-technical complex of power industry, because according to the reactive power balance in the power grid, almost one third of it needs to be generated by compensating devices installed close to consumers. Many years of research in the mentioned field were aimed at reducing the dimension of problem and breaking down the silos of information of individual subsystems, which is due to the departmental subordination of these subsystems and different possibilities of collecting initial reporting information depending on the mode of operation of the network.

All currently available results of research in the mentioned direction, as it is emphasized in the work of Kovalyov I.N. (Choosing compensating devices when designing electrical networks, - M.,: ENERGOATOMIZDAT, 1990) can be conditionally divided into two groups, the first of which includes the methods of the reduction of individual subsystems, and the second includes the so-called partial calculation method, which is another approach.

Yu.S. Zhelezko in his work (Reactive power compensation- M.,: ENERGOATOMIZDAT, 1985), recommends that the PP(t)+jQ(t) schedule, which will be determined by an independent calculation, be considered given in the connection nodes of the high-voltage lines of the power grid’s generating network with the main network. With this method, it is possible to determine the total input reactive power $Q Э$ after optimizing the reactive load of each distribution network included in the 110-500kV power grid, after which an independent task of optimal distribution of $Q Э$ power between nodes of the given distribution network is performed.

A number of authors recommend in their works to replace the distribution network with an equivalent active resistance, which is calculated according to the known power losses. According to other researchers, easier reduction is possible in the 6-35 kV networks. In particular, the equivalent resistance of the mentioned voltage network can be obtained by sequential and parallel addition of the resistances of the branches of the diagram tree. The authors call their method partial, which applies to relatively short radial and trunk lines of 6-10kV voltage, which are more typical for industrial networks. [Basic construction of industrial networks/ Г.M. Kayalov, E.A. Kadzhan, I.N. Kovalyov, E.G. Kyreniy. M.: ENERGIA, 1978]. This method involves localization of the reactive load compensation problem. In the existing scientific and technical literature, in the most common version of reactive load compensation, the objective function is formulated in the form of reduced costs, and the issue of minimizing this function is considered. In the another version of problem, the total power of the compensating devices is taken as a specified one, and in this case the problem considers the issue of optimal distribution of this power among the nodes of the network.

The authors (Arzamastsev D.A., Sklyarov Yu.S.) propose to consider the problem on the assumption that, on the basis of technical or other engineering considerations, the installation locations of compensating devices are specified. In this case, the solution of the problem is considered by the coordinate descent method.

Some authors (Kayalov G.M., Molodtsov V.S.) based on the mathematical problem of quadratic programming, propose a matrix-calculation method to change the procedure of solving a complex system of equations representing the mode of the power grid with compensating devices by calculating the optimal values of the output power of these devices using the matrix formulas.

A relatively successful special method is the method of cost potentials, which is discussed in the works of a number of authors (Mearovich M., Mako D., Takahara I., Kholmskiy V.G., Shcherbina Yu.V. and others). Here, when solving the problem, the conditional scheme of the power system network is considered, which contains only the active resistances of the network elements and the calculated reactive loads of the nodes.

Authors Pospelov G.E., Sych N.M. and Fedin V.T. propose to use the so-called criteria method that will allow us to determine not only the capacity and installation locations of compensating devices, but also the rational sequence of their installation.

During the exchange of reactive power between inductive, capacitive elements and power sources, there are additional losses of active power in the network.

$$\Delta P_Q = \frac{Q^2}{U^2} R.$$

Individual components of the relative incremental losses of active power with respect to the considered node of the power grid, caused by the loads of the given node and the rest of the network nodes, respectively:

$$\sigma_i = \sigma_i^1 + \sigma_i^{ii},$$

where:

$$\sigma_i^1 = \frac{2}{U_n^2} R_{ii} Q_i \quad and \;\; \sigma_i^{ii} = \frac{2}{U_n^2} \sum_{\substack{j=1 \\ j\neq 1}}^{n} R_{ij} Q_j$$

The calculation expression of active power losses according to nodal loads in the electric network has the form as follows

$$\Delta P = \frac{1}{U_n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} R_{ij} (P_i P_j + Q_i Q_j)$$

In this expression, node generation is taken with a "plus" sign, and load with a "minus" sign.

According to this agreement, the functional dependence ΔP(Qi) has a form that shows the nature of the reduction of active power losses in the network during the reactive load compensation in the *i*-th node.

At this time, the component σiii of the relative incremental losses remains unchanged, while the absolute value of the component σ_i^1 decreases proportionally to the compensation and becomes zero in case of complete compensation of the reactive load in the node. The reduction of the σ_i^1 component is proportional to the self-resistance of the node. The expediency of reactive load compensation should be sought for those nodes where the absolute value of the relative incremental losses of active power is the greatest and at the same time the internal resistance of this node is high.

If we do not take into account the costs of purchase, installation and operation of the compensating device, then in terms of reducing active power losses, full compensation of the reactive load in all nodes of the network is cost-effective. Since each technical device, including the compensating one, requires significant capital and operating costs, in the case of a given specific network, there will be a uniquely determined threshold value of relative incremental loss, after which further compensation of the load is not cost-effective.

The hierarchy of the power grid and the peculiarity of an approach to solving the problem of optimal reactive load compensation are also discussed. Here, taking into account the unified equivalent electrical circuit, according to the vertical hierarchical structure of the power grid, the global problem of optimal reactive load compensation is set and the possibility of decomposition of this problem is investigated, which allows us to consider the problem in the form of separate, relatively simple, local problems.

The power grid is divided into four hierarchical vertical levels according to network voltages (Fig. 1).

This division implies that the network of level *k* has an electrical connection with only one node of the network of k+1 level. Level IV of the hierarchy contains the main sources, any of which can be considered to be a balancing node.

In such an approach to the problem, the reactive load compensation in the distribution autonomous network of the III and lower level affects to a certain degree the power distribution in the supply network, and therefore, in terms of loss estimation, this influence must be evaluated and taken into account when solving the global problem. In particular, in the autonomous networks of levels III, II and I located in the vertical structure, in order to obtain a more accurate solution of the problem, the degree of reactive load compensation in autonomous networks connected to other nodes of the supply network should be further taken into account.

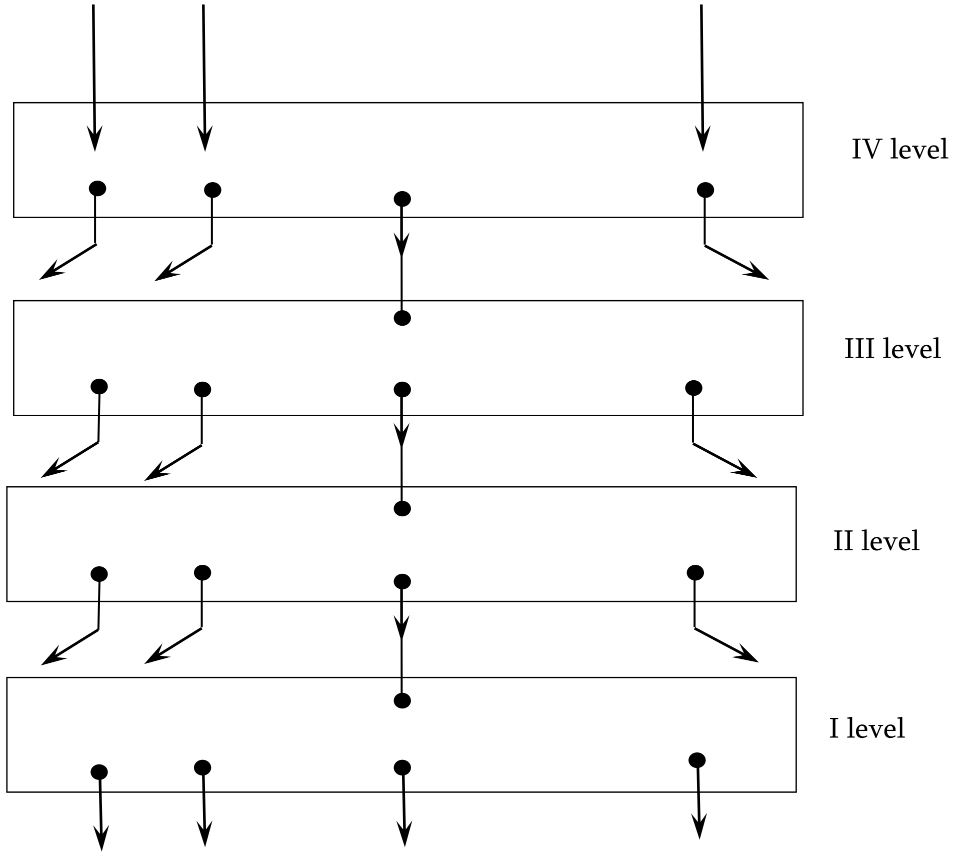

Fig. 1

I level – 0.38 kV voltage distribution network
II level – 6-10 kV voltage distribution network
III level – 35-110 kV voltage distribution network
IV level – 220-500 kV voltage supply network

Taking into account the hierarchical structure, the problem of optimal reactive load compensation can be set in different ways, depending on which nodes of the network level we want to install the compensating device and if reactive generation of power sources is given or to be found. The number of these problems is equal to eight, of which the IA problem is considered to be the most global, because at this time, at all levels along the vertical hierarchy, the optimal power values of the compensating devices will be determined, and the optimal reactive loads of the generation sources will be determined.

All proposed methods and approaches to the problem of optimal reactive load compensation are characterized by both advantages and disadvantages and are more or less successfully used in the electric networks of various purposes and configurations.

Hierarchy level	Nodes where installation of compensating devices is envisaged	Reactive generation of power sources	Task index
I	A_I, B_I……..M_I	Searchable	IA
		Available	IB
II	A_{II}, B_{II}……..M_{II}	Searchable	IIA
		Available	IIB
III	A_{III}, B_{III}……..M_{III}	Searchable	IIIA
		Available	IIIB
IV	A_{IV}, B_{IV}……..M_{IV}	Searchable	IVA
		Available	IVB

The basics of simplifying the global problem of reactive load compensation have been established:

1. Based on the hierarchical structure of the network, it is shown that the lower we go along one vertical of the hierarchy, the less significant is the influence of the loads and compensation of the nodes of the second vertical hierarchy on the value of the optimal load compensation in the nodes of the vertical being under consideration;

2. At level IV of the hierarchy, where the power transmission lines are practically always loaded with a load less than the natural capacity, the generation of reactive power by the lines almost always exceeds the reactive power losses in the same lines, and as a result, at this level of the hierarchy, we have excess reactive power, which in some cases must be compensated by shunt reactors, therefore, we have reason enough to conditionally choose the node connecting the vertical structure to level IV as the balancing node when setting the mentioned problem;

3. Level I of the vertical hierarchy is an independent open network of 0.38 kV voltage, from which the 6-10/0.38 kV voltage transformer boxes feed single-phase consumers of 0.38 kV voltage, while from the high voltage (6-10) kV bus-bars substations, as the analysis of the report showed, by installing the single-phase compensating device near the single-phase 0,38 kV consumers, economic benefit is so insignificant that its omission practically cannot affect the results of solving the problem. Thus, the bus-bars of the 6-10/0.38 kV voltage transformer boxes

of the 6-10 kV distribution network we consider to be the space for installation of the compensating device;

4. As we know, the relative incremental losses of active power with respect to the balancing node are equal to zero, due to which, in our case, level IV and the rest of the vertical hierarchical levels connected to it will be out of consideration. That is, the principle of a systemic approach to the problem will not be implemented. In order to avoid this, the connection node of the considered vertical structure to level IV is considered to be a conditional balancing node, for which the existence of the network of level IV of the power grid will be considered through its internal resistance R_{KK} and the relative incremental losses σ_K, which is calculated with respect to the balancing node obtained in the supply network.

The second chapter discusses the 110 kV network of Kutaisi, in the cases of existing mode load, when the power factor is 0.95, the result of the calculation shows that there are no overloads in the network. The magnitude of the voltage and losses do not deviate from the allowed limits. The reactive energy generated by the lines is negligible. The network replacement scheme is presented in the power grid modeling program - PSS/s (Power System Simulator for Engineering), as well as the calculation results, or the parameters of the network's operation mode, namely the voltage in all nodes of the network, as well as the values of active and reactive energy in all nodes and at the beginning and the end of all the lines.

The scheme showing the mode in the power grid modeling program - PSS/s (Power System Simulator for Engineering), and it illustrates the load of the lines as a percentage and the flow distribution.

There are no overloads in the network:

The connecting line Bakisubani between Kutaisi 3 and Kutaisi 6 substations is loaded to 13%.

The connecting line Kvitiri between Kutaisi 3 and Kutaisi 6 substatins is loaded to 4%.

The connecting line Kvitiri 1 between Avangardi and Auto Factory substatins is loaded to 11%.

The connecting line Sakarkhno between the Auto Factory and the Auto Factory 2 substations is loaded to 0%

The connecting line Gora between the Auto Factory 2 and Sataflia substations is loaded to 18%

The connecting line Banoja between the Sataflia and Kutaisi 4 substations is loaded to 29%.

The connecting line Choma between the Kutaisi 4 substation and Gumati HPP is loaded to 38%.

The connecting lines Motsameta 1 and Motsameta 2 between Gumati HPP and Rioni HPP are loaded to a maximum of 7%.

The connecting lines Motsameta 1 and Motsameta 2 with Kutaisi 5 substation are loaded to a maximum of 10%.

The connecting line of Mukhiani between Rioni HPP and the Bakisubani substation is loaded to 34%.

The connecting line Sarbevi between Rion HPP and the Didi Kutaisi substation is loaded to 0%.

The connecting line Geguti between the Didi Kutaisi and the Kutaisi 6 substation is loaded to 34%.

In the case of 80% load of power transformers when the power factor is 0.95 and the load according to the instructions is distributed as follows:

Active and reactive load components whose value does not depend on the voltage $P = const, Q = const$, are 50%.

Active and reactive load components whose value is directly proportional to the voltage value P=K_1 U and Q=K_1 U are 30%.

Active and reactive load components whose value is directly proportional to the voltage value $P = K_1 U$ and $Q = K_1 U$ are 20%.

The scheme illustrating the mode in the power grid modeling program - PSS/s (Power System Simulator for Engineering), and it shows the load of the lines at a percentage and the flow distribution. There are no overloads in the network

The Bakisubani line connecting the Kutaisi 3 and Kutaisi 6 substations is loaded to 22%. The Kvitiri line connecting the Kutaisi 3 and Avangardi substations is loaded to 24%. The line Kvitiri 1connecting the Avangardi and Auto factory substations is loaded to 42%.

The line Sakarkhno connecting the Auto Factory and the Auto Factory 2 substations is loaded to 13%. The Gora line connecting the Auto Factory 2 and the Sataflia substations is loaded to 32%. The Banoja line connecting the Sataplia and Kutaisi substations 4 is loaded to 61%.

The connecting line Choma between the Kutaisi 4 and Gumati HPP is loaded to 79%. The connecting lines Motsameta 1 and Motsameta 2 between Gumati HPP and Rioni HPP are loaded to a maximum of 18%. The connecting lines between the Motsameta 1 and Motsameta 2 with the Kutaisi 5 substation will be loaded to a maximum of 27%. The connecting line Mukhiani between Roin HPP and Bakisubani substation will be loaded to 88%.

The connecting line Sarbevi between Rioni HPP and the Didi Kutaisi substation will be loaded to 0%. The Geguti line connecting the Didi Kutaisi and Kutaisi 6 substations will be loaded to 77%.

In the case of 100% load of power transformers when the power factor is 0.95 and the load according to the instructions is distributed as follows:

Active and reactive load components whose value does not depend on the voltage ძაბვაზე $P = const, Q = const.$ are 50%.

Active and reactive load components whose value is directly proportional to the voltage value $P = K_1 U$ და $Q = K_1 U$, are 30%.

Active and reactive load components whose value is directly proportional to the square of the voltage $P = gU^2$and $Q = bU^2$,are 20%.

The scheme illustrating the mode in the power grid modeling program - PSS/s (Power System Simulator for Engineering), and it shows the load of the lines at a percentage and the flow distribution. There are no overloads in the network

The Bakisubani line connecting the Kutaisi 3 and Kutaisi 6 substations is loaded to 25%. The receipt line of Kutaisi 3 and Avangard St. is loaded by 27%. The Kvitiri line connecting the Kutaisi 3 and Avangardi substations is loaded to 24%. The line Kvitiri 1 connecting the Avangardi and Auto factory substations is loaded to 49%.

The line Sakarkhno connecting the Auto Factory and the Auto Factory 2 substations is loaded to 16%. The Gora line connecting the Auto Factory 2 and the Sataflia substations is loaded to 38%. The Banoja line connecting the Sataflia and Kutaisi substations 4 is loaded to 71%.

The connecting line Choma between the Kutaisi 4 and Gumati HPP is loaded to 93%. The connecting lines Motsameta 1 and Motsameta 2 between Gumati HPP and Rioni HPP are loaded to a maximum of 21%. The connecting lines between the Motsameta 1 and Motsameta 2 with the Kutaisi 5 substation will be loaded to a maximum of 32%. The connecting line Mukhiani between Roin HPP and Bakisubani substation will be loaded to 103%.

The calculation and study of the modes of the 110 kilovolt supply network of Kutaisi using the PSS/E (Power System Simulator for Engineering) program showed that:

At any of the possible permissible values of the load characteristic, even when the power transformers are loaded to 80%, the magnitude of the voltage in the nodes of the network does not deviate from the allowed limits.

At any of the possible allowed values of the load characteristic, even when the power transformers are loaded to 80%, losses in the network do not deviate from the allowed limits.

At any of the possible allowed values of the load characteristic, even when the power transformers are loaded to 80%, there are no line overloads in the network.

In case of 100% load of power transformers, transmission line Mukhiani will be overloaded.

Based on the analysis of the data on the particular substations and feeders discussed in the **third chapter**, the feeders have been identified where it is necessary to install compensating devices, in particular, these are the 6 kV feeders, such as: "Rubbers" and "Kvitiri". In such a case, we use the partial reactive power compensation method. The partial method involves the localization of the reactive load compensation problem. In particular, high 6.10 kV ВБК and low 0.38 kV НБК compensating devices are considered. In addition, the specific value of low voltage compensating devices is higher than that of high voltage. Accordingly, compensating devices, particularly synchronous compensator, are placed on the 6 kV bus-bar.

The data obtained after compensation show that the voltages at the nodes have increased, for example, the voltage at node "c" increased from 5.4 kV to 5.96 kV, and at node "Z" - from 0.3 kV to 0.4. After reactive power compensation, the load on the transmission lines has reduced accordingly.

After reactive power compensation, the voltage at the 6 kV node "X" increased from 5.3 kV to 5.8 kV, and the voltage at the 0.4 kV node "C" increased from 0.2 kV to 0.4 kV. After installing the reactive power compensating device, the load on the power transmission lines was reduced accordingly.

The supply network for the Kutaisi electric circuit is a complex connected network with a voltage of 110 kV. The main sources of generation are located in individual nodes of this network and therefore belong to level IV of the hierarchy. Any of these sources, depending on its installed capacity, can be considered to be a balancer. When considering the problem of optimal reactive load compensation in the distribution network of level III or even lower, it is recommended and appropriate to fulfill the principle of regional balance of reactive load. Nevertheless, the reactive load compensation in the distribution autonomous network of level III (or even lower) has a certain degree of influence on the power distribution in the supply network, and therefore, in terms of evaluating the change in losses, when solving the global problem, it is necessary to evaluate and take into account the mentioned influence.

Accordingly, in the second stage of this research, a common scheme is presented, which contains both the supply (level III of the hierarchical structure) network and the distribution network (i.e., the level II of the vertical hierarchical structure), where the substations are connected to each other, which will allow us to be aware of, first of all, the flow distribution between the substations. as well as the interaction of reactive power compensation at different levels of the hierarchical structure.

The results of calculations showed us that the voltages in the nodes do not correspond to the standards established by the technical-operational rules. In particular, in the case of "Auto factory substation", the voltage on the 110 kV bus-bar is 108kV, the same situation is in the case of the "Bakisubani" substation.

In this case, the substations that receive power from the power plants were chosen as the space for installing the compensating devices, because they are the direct source of reactive power generation. Accordingly, the compensating devices were installed in the "Kutaisi 4", "Kutaisi 5" and "Bakisubani" substations.

According to the calculation results, in those substations where the voltage was low before the compensation, it increased after the compensation. In particular: in "Bakisuna" and "Auto factory" substations, the voltage on the 110 kV bus-bar is 111 kV and 109.2 kV, respectively. Also, the load on power transmission lines was reduced.

Based on the conducted research and the analysis of the obtained results, we can make the following conclusion:

1. In terms of reducing active power losses and optimal reactive power compensation, it is recommended to install the compensating device in the 6-10 kV voltage substation.
2. Based on the analysis of a hierarchical structure of the network, the paper presents, in the considered distribution network, the optimal reactive load compensation in the form that implies the interconnection of the given network and the rest of the system;
3.. Installing the compensating device at the end of the 0.4 kV voltage line, in terms of reducing active power losses, has a much higher effect in a high-voltage (35-110kV) network than in a 10/0.4 kV network itself.
4. Calculation images of the optimal value of active power losses caused by reactive loads of nodes have been obtained, which allows us to pre-estimate the priority of compensation according to nodes.
5. The technical effect obtained by reducing losses in the high-voltage network is shown, distributed according to the capacities of reactive power compensating devices installed in each low-voltage network.

The fourth chapter. The distribution network of Kutaisi includes 13 substations and feeders. The nominal voltages of these feeders are 6 and 10 kV. Reduction in power and energy losses is a necessary condition for the economical operation of the power system. Power and energy losses in the electrical networks can be divided according to nominal voltage levels. A proper analysis shows the greater share of losses - 65% comes from 0.1-10 kV networks, 10% - from 35 kV networks, and 25% - from 110-220 kV networks.

From the above, it can be seen that the most effective measure is the one that reduces energy losses first in the 0.1-10 kV voltage networks, and then in 35-110 kV voltage networks.

In order to identify loss reduction measures, first of all, it is necessary to study the network where these measures are needed. In our case, the distribution network of Kutaisi. The study means to calculate the parameters of the mode, which will give us a certain idea about the state of the network. In this regard, one important fact is worth noting here. The calculation of the mode parameters can be performed during operation with different modes of the network (established mode at maximum load, established mode at minimum load). There are also other modes of operation of the electrical network, which we will not consider. When working with these modes of the electrical network (established mode at maximum load, established mode at minimum load) it is clear that the parameters of the mode will be different.

The distribution network of Kutaisi is currently operating mostly in the minimum load mode, so it would be wrong to assess the network's stability and then make any conclusions on this basis. The resiliency of the electrical network can be assessed during the peak load mode, which is actually only expected for a short period of time.

It therefore follows that complete information about the state of the electrical network can be obtained in such a mode of operation, the duration of which is longer than the duration of operation in other modes.

Thus, the operating mode of Kutaisi distribution network with 80% load is the most suitable for what we want, and we decided to calculate the parameters of the mode in such a case.

Thus, with the combination of the theoretical materials discussed above and the PSSE program, let us reduce capacity and energy losses in the distribution network of Kutaisi by three methods: 1) replacing the cross-section of the wires in the areas of the feeder main; 2) improvement of the active power coefficient of the network through reactive power compensation; 3) Increasing the nominal voltage level of the network. First, we reduce energy losses by method 1.

Immediately before starting the calculation, using the PSSE program, let us find out what are the parameters of the mode on the feeders during its maximum load. With this, we will evaluate the electrical stability of the feeder with respect to expected maximum loads.

In the distribution network of Kutaisi, at maximum load, a group of feeders was identified, whose wires on the main sections were loaded more than to 100% of the permissible current, which was reflected by an unacceptable deviation of the voltage in the nodes of the network. This fact indicates a critical mismatch of F and S_{max} parameters of this part of the network. That is, the load capacity of this part of the network does not correspond to the expected maximum load.

A part of the feeders was also identified, the wires of the main areas of which were loaded within 80-90% of the permissible current when working in the maximum mode. That is, the load capacity of this part of the network corresponds to the expected maximum load.

At maximum load, in order to ensure the required voltage value at the consumption nodes and at the same time, to minimize energy losses, some feeders require an increase in the cross-section of the wires or the installation of a compensating device.

We also found that in order to meet the requirements of the network, some feeders need to increase the cross-section of the wires and install a compensating device.

In addition, the group of consumers whose nominal voltage was 6 kV was almost removed from operation. The low nominal voltage of one of the substations – Bakisubani - calculated above is 10 kV. Despite the fact that we have reduced energy losses on the feeder “Khaoiani" of this substation, this does not mean that the voltage of 10 kV of the distribution network of Kutaisi is not enough to meet the requirements that will be imposed on the power grid. Our goal was to show how much the losses would be reduced in the case of a 10 kV feeder and thus understand the effectiveness of the measure we have shown above.

If we assume that $E_6 = 1$, then the reactive power compensating device should not be installed on some feeders under conditions of the existing wiring. This measure will be considered effective if the wires of the trunk areas on the same feeders are replaced by the $V \Longrightarrow \min$ condition.

In a certain group of feeders, assuming $E_6 = 1$, the technical-economic calculation proved the effectiveness of reactive load compensation under conditions of the existing wires.

General conclusions

In a market economy, the power transmission network is divided according to nominal voltage and purpose and is owned by different companies. The subject of interest of each company is the high efficiency of its transmission network. To achieve this goal, in many cases, it will be economically feasible to compensate the reactive load in the network. Determining the optimal capacity of the compensating device and its location in the network, as we mentioned, is a systemic problem and therefore it goes beyond the scope of a specific company.

The calculation and study of the modes of the 110 kilovolt supply network of Kutaisi using the PSS/E (Power System Simulator for Engineering) program showed that:

1. At any of the possible permissible values of the load characteristic, even when the power transformers are loaded to 80%, the magnitude of the voltage in the nodes of the network does not deviate from the allowed limits.
2. At any of the possible allowed values of the load characteristic, even when the power transformers are loaded to 80%, losses in the network do not deviate from the allowed limits.
3. At any of the possible allowed values of the load characteristic, even when the power transformers are loaded to 80%, there are no line overloads in the network.
4. In case of 100% load of power transformers, transmission line Mukhiani will be overloaded.
5. Based on the conducted research and the analysis of the obtained results, we can make the following conclusion:
6. In terms of reducing active power losses and optimal reactive power compensation, it is recommended to install the compensating device in the 6-10 kV voltage substation.
7. Based on the analysis of a hierarchical structure of the network, the paper presents, in the considered distribution network, the optimal reactive load compensation in the form that implies the interconnection of the given network and the rest of the system;
8. Installing the compensating device at the end of the 0.4 kV voltage line, in terms of reducing active power losses, has a much higher effect in a high-voltage (35-110kV) network than in a 10/0.4 kV network itself.
9. Calculation images of the optimal value of active power losses caused by reactive loads of nodes have been obtained, which allows us to pre-estimate the priority of compensation according to nodes.

10. The technical effect obtained by reducing losses in the high-voltage network is shown, distributed according to the capacities of reactive power compensating devices installed in each low-voltage network.
11. In the distribution network of Kutaisi, at maximum load, a group of feeders was identified, whose wires on the main sections were loaded more than to 100% of the permissible current, which was reflected by an unacceptable deviation of the voltage in the nodes of the network. This fact indicates a critical mismatch of F and S_{max} parameters of this part of the network. That is, the load capacity of this part of the network does not correspond to the expected maximum load.
12. A part of the feeders was also identified, the wires of the main areas of which were loaded within 80-90% of the permissible current when working in the maximum mode. That is, the load capacity of this part of the network corresponds to the expected maximum load.
13. At maximum load, in order to ensure the required voltage value at the consumption nodes and at the same time, to minimize energy losses, some feeders require an increase in the cross-section of the wires or the installation of a compensating device.
14. We also found that in order to meet the requirements of the network, some feeders need to increase the cross-section of the wires and install a compensating device.
15. If we assume that $E_{б} = 1$, then the reactive power compensating device should not be installed on some feeders under conditions of the existing wiring. This measure will be considered effective if the wires of the trunk areas on the same feeders are replaced by the $V \Longrightarrow$ min condition.
16. In a certain group of feeders, assuming $E_{б} = 1$, the technical-economic calculation proved the effectiveness of reactive load compensation under conditions of the existing wires.
17. Replacing the wires is ineffective and the wires on the trunk sections must be replaced on demand $\Delta P \Longrightarrow$min.
18. The optimal value of the relative incremental loss of active power in the network was determined, which allows us to pre-estimate the priority of compensation according to nodes.
19. In the low-voltage distribution network, the capital costs (investments) required for installing the power compensating device, the annual costs required for the payment of investments, the annual operational costs of the equipment service, and the annual savings obtained by reducing active power losses in the compensating device have been calculated.
20. The economic effect obtained by reducing losses in the high-voltage network is shown, distributed in proportion to the capacities of compensating devices installed in each low-voltage network.

Approbation of dissertation work.

A number of issues of the dissertation topic were reported at the V International Scientific Conference of Akaki Tsereteli State University "Energy: Regional Problems and Development

Opportunities" held in Kutaisi 2018. F. Akhaladze, P. Kachkachishvili, A measure to reduce electrical power and energy losses by means of a static controlled compensating device.

Published papers on the dissertation topic

1. Demuri Chomakhidze1*, Omari Zivzivadze2, Petre Kachkachishvili2, Akaki Kiladze2 .The Role and Importance of the Energy Saving in Georgia. Theoretical Economics Letters, 2018, 8, 1740-1745

2. Petre Kachkachishvili, Optimal relative incremental losses of electrical power. Georgian Scientists. 4(02), 2022, pp. 141-144
3. Phridon Akhaladze, Petre Kachkachishvili. Projection of technical economic figures, Georgian Scientists, 4(02), 2022 pp. 150-154