IMPROVING THE EFFICIENCY OF DISTRIBUTIVE NETWORKS WITH THE APPLICATION OF GREEN TECHNOLOGIES

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Abstract

Based on an analysis of the capabilities of various software systems for analyzing the modes of distribution power networks using simulation models, it was determined that the most effective module that allows for visual and operational research is the use of the DIgSILENT PowerFactory program. Using this complex, a study of the load conditions of the Sarygaya distribution network of Azerishik OJSC was carried out. The results obtained showed that the loads of most 6 kV feeders exceed the permissible values, the voltage drops are high, and these conditions confirm the high probability of emergency outages in the network. Accordingly, proposals were made to redesign and design the network topology. The calculated experiments conducted with the application of the software complex require the implementation of the necessary scheme-mode measures for the improvement of the reliability of the distribution network and the implementation of uninterrupted electric power supply. As one of such measures, it was proposed to connect green energy sources to two points of the studied distribution network. Studies have confirmed that the obtained new circuit topology is convenient and effective.

Keywords: distribution network, DIgSILENT PowerFactory complex, line overloads, voltage drop, voltage profile

I. Introduction

The application of green energy technologies through renewable sources is a priority for modern energy systems. These sources are primarily integrated into distributive electric systems (DES) at lower voltage levels [1-4]. However, addressing the challenges of modern demands involves improving or reconstructing existing distributive networks and employing various approaches to solve emerging issues. Primarily, adopting effective decisions among existing and proposed alternatives requires rigorous regime investigations. Conducting regime investigations through simulation models is advantageous [5]. These models simulate the processes of electricity generation, transmission, and distribution in the power system, enabling the analysis of system performance mechanisms. Such analyses typically aim to identify important regime parameters such as voltage drops, active and reactive power losses, non-sinusoidal and non-symmetrical regimes, and power distribution to assess the overall state of the energy system.

One of the main issues addressed by DES is assisting in optimizing system design. Simulations are conducted to improve the system's performance mechanism and increase efficiency by altering different components and parameters. This is crucial for reducing investment costs, minimizing power losses, and ensuring security. Furthermore, simulation models in DES allow for the optimization of exploitation processes, such as energy production and transmission, in the most effective and secure manner, empowering system and network operators to manage them in real time through simulations.

Moreover, in complexly configured DES, simulations can be used to determine the type of fault and implement necessary corrections, analyze and resolve issues such as energy imbalance, regime oscillations, non-sinusoidal voltage problems, voltage drops, and other problems. Simulations can also be employed for the analysis and resolution of these issues[6,7]. The article focuses on the analysis of regimes and the enhancement of efficiency based on real DES using DIgSILENT PowerFactory complex models, in conjunction with the application of green energy technologies.

II. Mathematical Model for the Regime Calculation of the Distributive Network

Generally, the following non-linear equations system is used in the investigation of regimes in electric power systems: [8]:

$$\left.\begin{aligned} \Delta P\left(\delta,\ P_s,\left|U_{наг}\right|,\ Q_g\right) &= P_i^{sp} - \left|U_i\right| \cdot \sum_{j=1}^{N} \left|U_j\right| \cdot \left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) = 0,\ \ \forall i \in N \\ \Delta Q\left(\delta,\ P_s,\left|U_{наг}\right|,\ Q_g\right) &= Q_i^{sp} - \left|U_i\right| \cdot \sum_{j=1}^{N} \left|U_j\right| \cdot \left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) = 0,\ \forall i \in n_{pa} \end{aligned}\right\} \tag{1}$$

in here $\Delta P, \Delta Q$ - the non-linear difference functions of active and reactive power injections in the $i -$ node; P_i^{sp}, Q_i^{sp} the given values of active and reactive power injections at the $i -$ node; $\delta -$ the angle of the voltage vector at the node; $P_s -$ the generation active power of the base node; $Q_g - PU$ the generation reactive power; $|U_{наг}| - PQ$ the voltage at the nodes; $|U_i| -$ the voltage at the
$i -$ node; $\delta_{ij} -$ The angle between the voltage vectors of busbars i and j ; $G_{ij}, B_{ij} -$ the real and imaginary parts of the admittance matrix elements; $N -$ the number of nodes.

Equations (1) and (2) can be written in vector form as follows:

$$f(x) = \begin{bmatrix} \Delta P\left(\delta, P_s U_{PQ}, Q_g\right) \\ \Delta Q\left(\delta, P_s, U_{PQ}, Q_g\right) \end{bmatrix} = 0 \tag{2}$$

Since it is directly impossible to obtain several solutions simultaneously based on equation (3), the problem is solved iteratively with the help of known methods. For example, by using the Newton-Raphson method, the problem posed by the linearization of equations (1) and (2) can be solved:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = [J] \begin{bmatrix} \Delta\delta \\ \Delta P_s \\ \Delta U_{PQ} \\ \Delta Q_g \end{bmatrix} \tag{3}$$

here $[J]-$ As known, the Jacobian matrix is written as follows [10,11]:

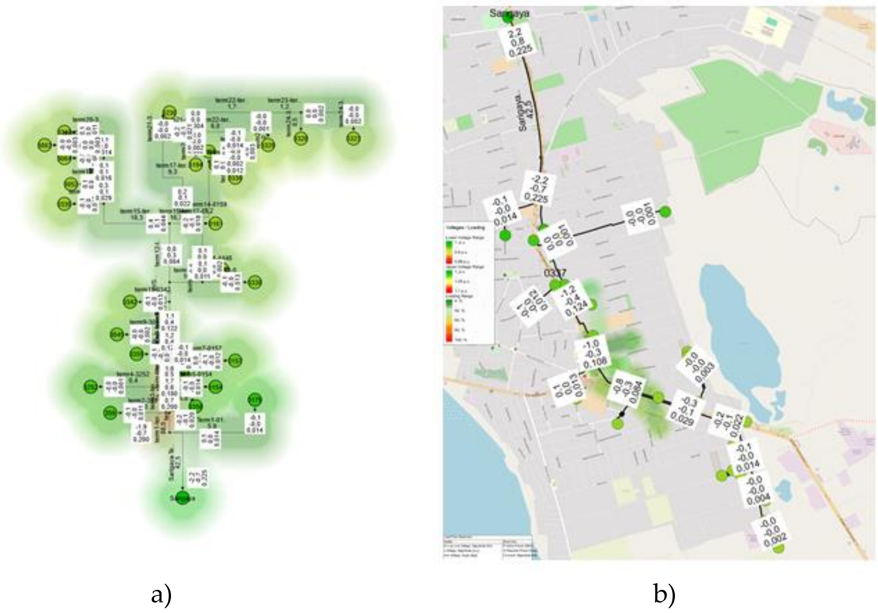
$$[J] = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial P_s} & \frac{\partial P}{\partial U_{PQ}} & \frac{\partial P}{\partial Q_g} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial P_s} & \frac{\partial Q}{\partial U_{PQ}} & \frac{\partial Q}{\partial Q_g} \end{bmatrix} \tag{4}$$

III. Investigation of the Determined Regimes of the Distributive Network

III.1. Research on the current determined regime of the power grid

Currently, the problems identified in the network of the transmission system operator of the electricity system in Azerbaijan have not yet been fully resolved. These problems include inadequate planning for the construction of new substations and half-stations, excessive voltage drop, continued use of outdated electrical equipment, etc. To address these issues, it is crucial to simulate replacement equipment and establish a mathematical model during the refurbishment process. For instance, analyses of load and voltage profiles have been conducted using the "DIgSILENT Powerfactory" program for the 6 kV feeder "Novxanı - 1 H/X," which is 11.2 km long and supplied from the 35/6 kV "Sarıqaya" substation. Active and reactive power losses have been calculated, and simulations have been performed for refurbishment works on the feeder. Several loading regimes have been examined in the simulation program: normal regime, 50%, and 70% overload regimes.

In Figure 1, the simulation model (a) of the load analysis of the Novxanı-1 6 kV feeder and the integration scheme (b) of the feeder into the GIS are presented. As shown in Figure 1a, there are several branches along the length of the distribution network, and the 6/0.4 kV voltage transformer stations are capable of handling underloading conditions (up to 10%). Even in normal loading conditions, some elements may experience overload (Figure 1b), highlighting the necessity of appropriate exploitation, refurbishment, and improvement measures to enhance the efficiency of the network operation. Research investigations on the aforementioned issues were conducted based on the simulation model of the Distribution Management System (DMS). Initially, the loading of the 17-branch 6 kV feeder was examined under the current normal operating conditions. Table 1 illustrates the voltage profile on the "Novxanı-1 6 kV feeder line" within the network area connected to "Sarıqaya" in the normal regime.



a) b)

Figure 1: *Simulation model of the 6 kV "Novxanı-1" feeder: a - model of the load analysis in the determined regime of the feeder; b - integration of the load analysis mathematical model into the Geographic Information System (GIS) in the determined regime of the feeder.*

. In the current determined operating regime, there has been a voltage drop of ΔU=7% at the final transformer station of the feeder.

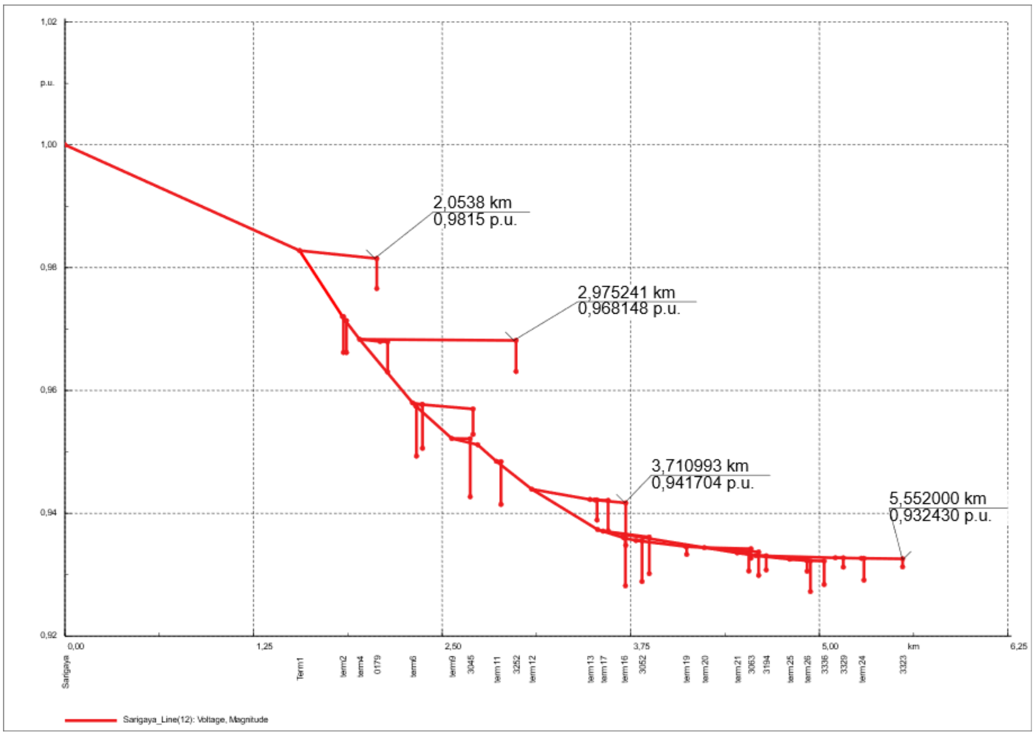


Figure 2: *Voltage profile along the Novxanı-1 feeder line in the current determined operating regime*

Let's examine the loadings on the 6 kV feeder lines (Table 1). As shown, the loadings of individual branches vary within the 23-88% interval. For instance, the load on the term9-term10 branch is minimal at 23%, while the term1-term2 branch is at 88%. In other words, the loadings vary along the length of the feeder, resulting in a wide range of voltage drops. As a result, voltage levels at demand nodes fluctuate between (0.932-0.942)·U_nom, which is below the nominal level.

Table 1: *Loading Degrees of Sarıqaya Distribution Network Feeder Lines*

Name	Network	Loading, %	Current value, kA
term1-term2	Sariqaya	88,0	0,211
term2-term3	Sariqaya	83,4	0,200
term3-term4	Sariqaya	75,1	0,180
Bəzi term4-term6	Sariqaya	68,7	0,165
term6-term8	Sariqaya	58,1	0,139
term8-term9	Sariqaya	51,5	0,124
term10-term11	Sariqaya	50,8	0,122
term11-term12	Sariqaya	45,2	0,108
Sarigaya-Term1	Sariqaya	42,5	0,225
term12-term15	Sariqaya	35,0	0,084
term9-term10	Sariqaya	23,0	0,122

Looking at the current loading regime of the feeder, we see that between two branches, the AS-50 line is loaded up to 88% of its nominal capacity in the determined regime. It has been determined that in some nodes, the reactive/active ratios (reactive power factor) fall within the interval of 0.35 – 0.365. The high demand for reactive power leads to significant power and voltage losses, rendering the regime inefficient. Specifically, an active power loss of 106 kW and a reactive power loss of 259 kVAr are considered.

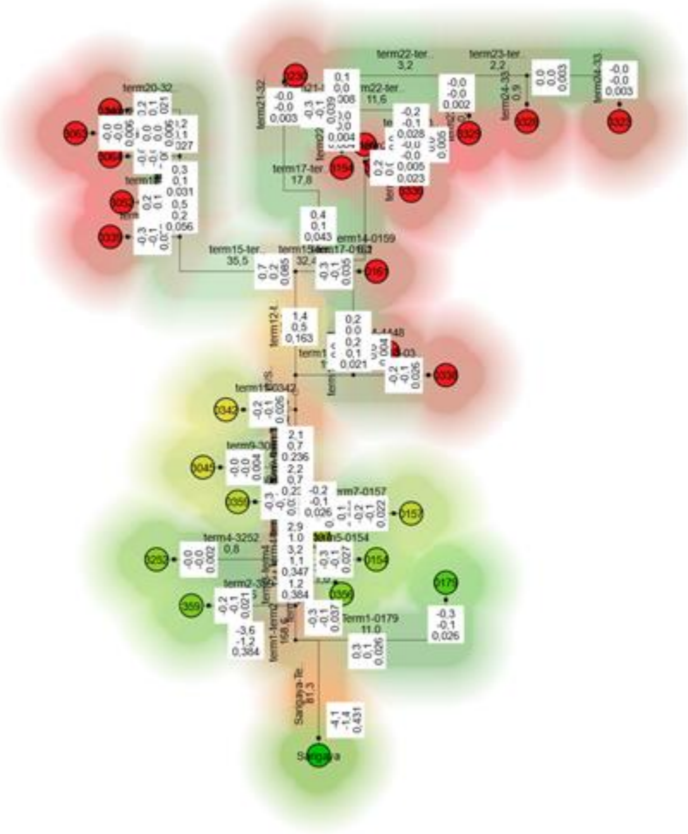
III.2. Simulation Study of Overloading Regime

If we consider a democratic increment, it is anticipated that the loading of the Distribution Management System (DMS) will increase by 50% compared to the current situation. Therefore, a simulation of the feeder's 50% overload regime has been conducted (Figure 3). It is evident from Figure 3 that the probabilities of overload for the branches of the 6 kV feeder line in the distribution network are significantly high (Figure 3a), and the values of voltage drops exceed the permissible limit at 17 nodes (Figure 3b), in other words, they are greater than 11%. In this regime, we can observe an increase in voltage drop at the final node supplied by the feeder by up to 13%.

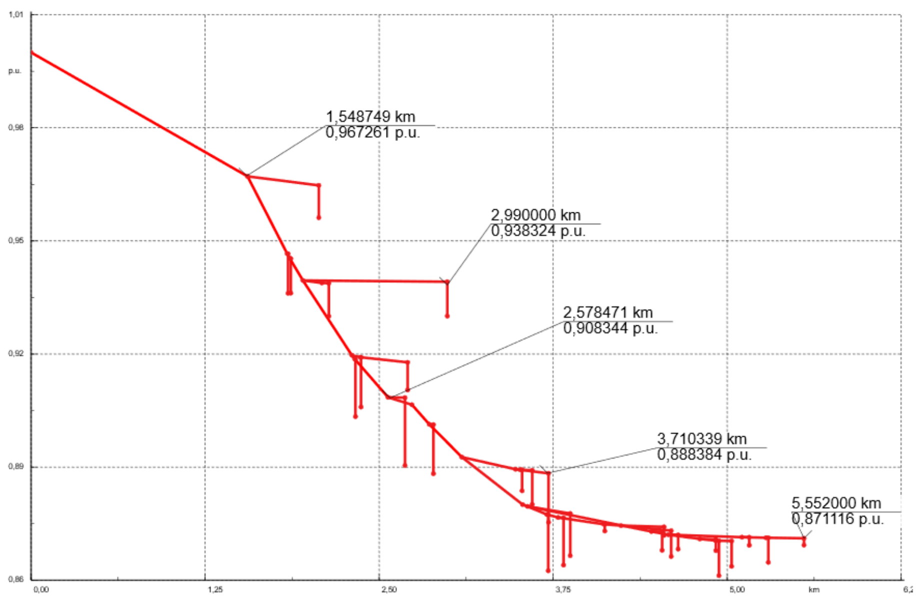
An air line with a nominal value of 240 A being overloaded by more than 68.6% above its nominal value would not only affect the quality of electrical energy but also lead to interruptions and accidents in electricity supply. This is primarily related to the inadequate width and length of the feeders, necessitating appropriate measures to modernize the network.

As shown in Table 2, some branch lines are exposed to overloading beyond their nominal capacity (12.3-68.6%). For instance, an air line with a nominal value of 240 A being overloaded by more than 68.6% above its nominal value could lead to both a decrease in the quality of electrical energy and interruptions or accidents in electricity supply. In Figure 4, the active and reactive demands of consumer nodes are depicted under a 50% overload condition.

As observed, during a 50% overload, the reactive/active ratios (reactive power factor) of the consumer nodes in the distribution network fall within the range of 0.35 – 0.365. In this scenario, the demand for reactive power is high, resulting in significant power (active power loss of 366 kW, reactive power loss of 550 kVAr) and voltage losses (13.4%) in the network, rendering the regime inefficient.



a)



b)

Figure 3. *Overloads of distribution network feeder lines*
a – Loads of feeder lines; b - distance dependence profile of feeder voltages

As seen, the voltage values fluctuate within the range of (0,876-0,915)U_{nom} , and they are significantly below the nominal level.

Table 2: *The loading of the feeder and its branches*

Name	Network	Real Loading, %	Real Loading, kA
term1-term2	Sariqaya	168,6	0,405
term2-term3	Sariqaya	160,0	0,384
term3-term4	Sariqaya	144,5	0,347
term4-term6	Sariqaya	132,5	0,318
term6-term8	Sariqaya	112,3	0,269
term8-term9	Sariqaya	99,7	0,239
term10-term11	Sariqaya	98,2	0,236
term11-term12	Sariqaya	87,5	0,210
Sarigaya-Term1	Sariqaya	81,3	0,431
term12-term15	Sariqaya	67,8	0,163
term9-term10	Sariqaya	44,5	0,236
term15-term16	Sariqaya	35,5	0,085

III.3. Efficiency of the distribution network with the application of green energy technologies promotion

Another method of increasing the operational efficiency of the viewed grid is the application of green energy technologies based on wind and solar energy sources. Since the Absheron region is rich in wind and solar reserves, the connection and integration of these sources should be considered in the modernization of the grid. For instance, given that the average wind speed on the Absheron Peninsula is 9.1 m/s and the solar irradiance density per square meter is 3.7 kWh/m^2, the advantage of utilizing green technologies according to the existing scheme is already known. However, it is necessary to conduct regime investigations and confirm the profitability of the measures taken. For this purpose, research was conducted using the DIgSILENT PowerFactory complex and the simulation model established by PEŞ.

Figure 4 illustrates the simulation model of integrating green technologies (one solar and one wind power station) into the distribution grid. As shown in the figure, a solar station with a capacity of 2 MW is connected to the 6 kV section of the Sarıqaya node, while a wind station consisting of 2 Furhlender FL 2500 wind turbines with a total capacity of 5 MW is connected to the 35 kV node. The “TM 0342” branching from “TM 0338” is divided into two sections via the circuit-breaker.

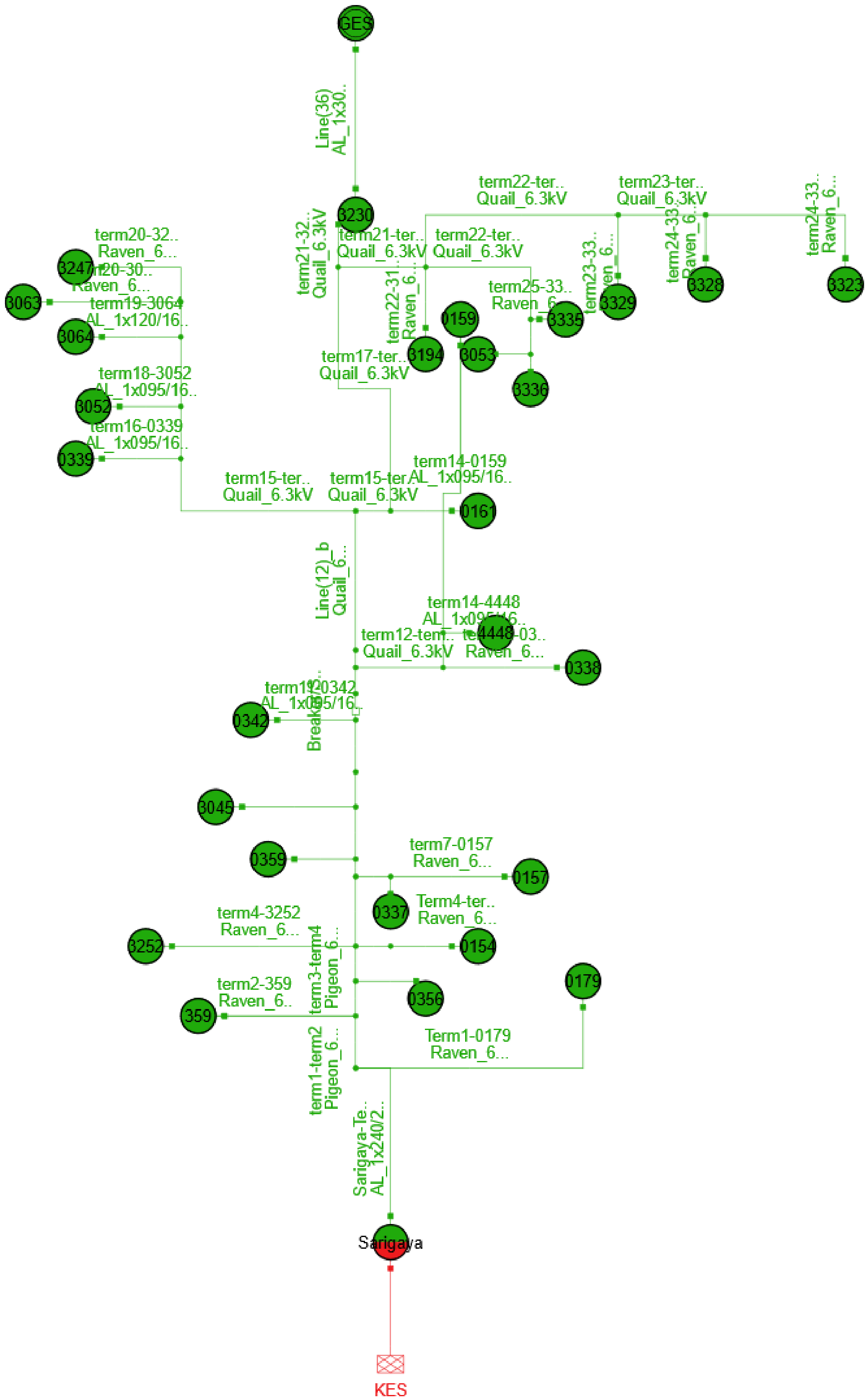


Figure 4: *The model of a distribution network for the current determined regime, integrating green energy sources (wind, solar)*

In Fig.5, the voltage values and profiles of the branches of the 6/0.4 kV distribution network, considering the integration of green energy sources, are provided. As seen from Figure 5, the voltage values on the branches (0,969-1,0)U_{nom} are within the acceptable normal release limits, with a maximum loading of 37%. With the presence of green sources, the analysis of the active and reactive power demands on consumer branches of the distribution network has revealed that the reactive power ratio in the considered regime ranges from 0,112 to 0,465, necessitating appropriate measures for reactive power compensation.

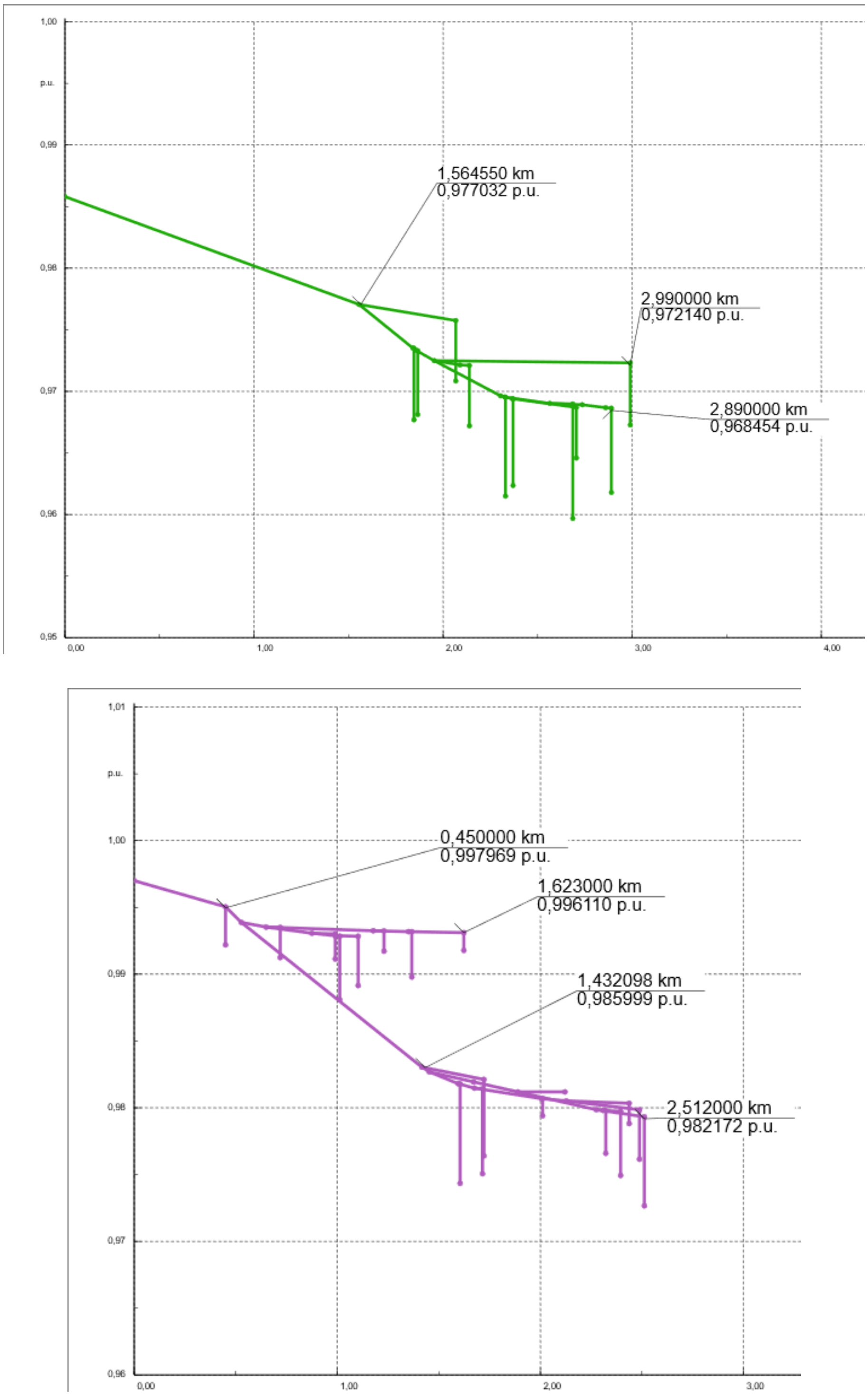


Figure 5: *Voltage profile with the integration of green energy sources*

In Fig. 6, the voltage values and profile for consumer branches are provided for the regime of 50% excess loading with the integration of wind and solar energy sources into the distribution network. As evident from the voltage profile and values, the voltages are within the range of (0,941-1,0)U_{nom} and are considered acceptable. Accordingly, the loading on feeder lines ranges from 13.1% to 67.8% in the considered scenario.

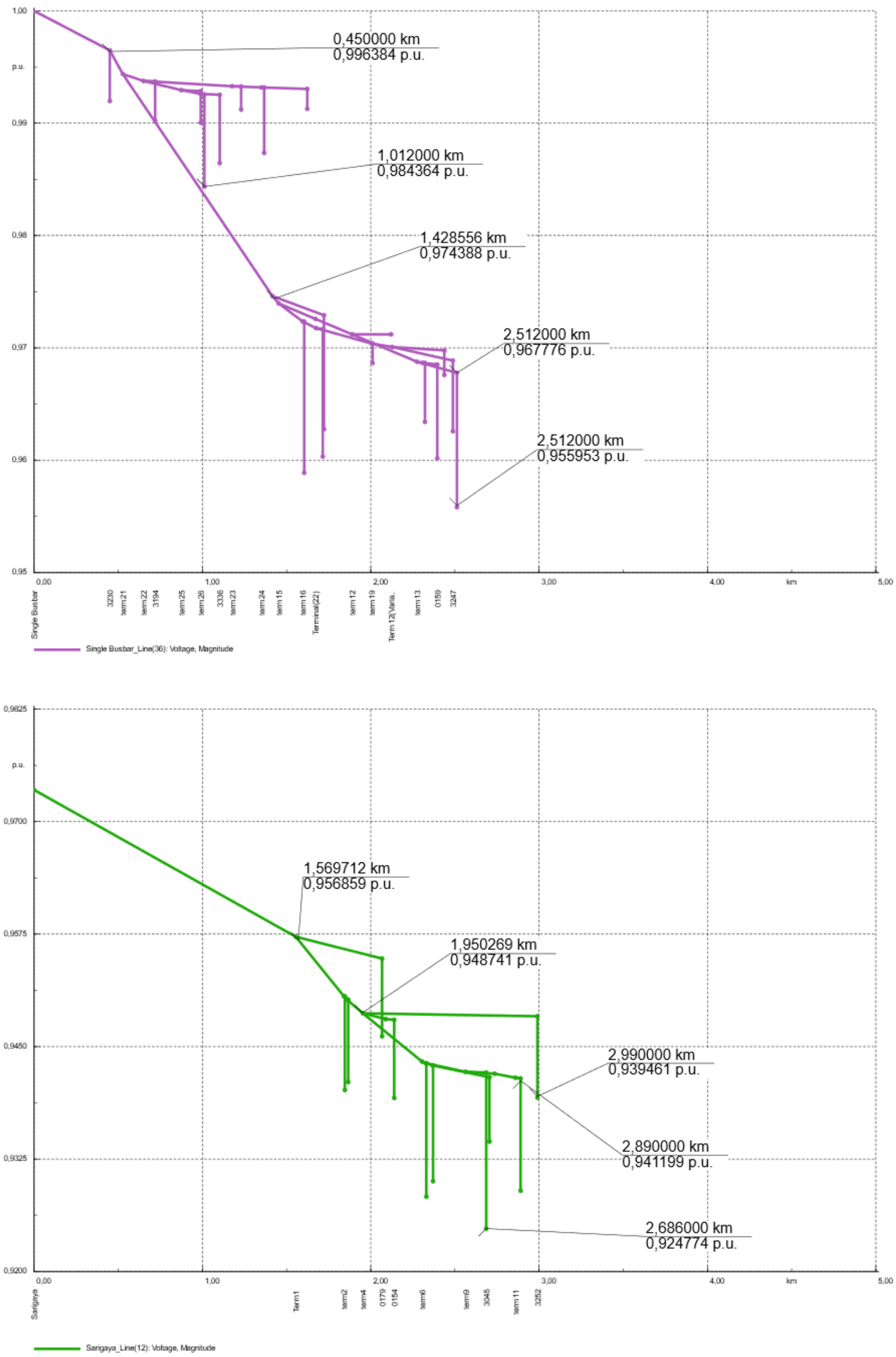


Figure 6: *Voltage profile with the application of green sources*

As shown in Fig. 6, during the integration of green energy sources into the distribution network with a 50% excess loading, the ratio of reactive power ranges from 0,127 to 0,403. In this case, it is necessary to implement appropriate measures for reactive power compensation in some branches.

IV. Comparative analysis of modeling calculation results

The comparative analysis of the modeling calculation results for the alternative regime-scheme solutions of the distribution electrical network is presented in Table 3. The comparative analysis results between the existing and proposed schemes indicate that the proposed variant appears to be more effective in addressing the issues arising in the existing scheme, namely, voltage drop, excessive loading of elements, and ensuring the reactive power ratio falls within acceptable intervals. Specifically, the comparative regime calculations between the existing and proposed schemes, considering the current and green energy technologies, have shown that transitioning from the existing scheme to the proposed variant reduces the voltage drop from 6.7% to 3.3%, decreases the loading percentage on lines from 168% to 67.8%, and significantly improves the shedding capability in critical load regimes. Power loss decreases from 106.73 kW to 48.82 kW, representing a reduction of up to 54.2%. Similar analyses have been conducted for network regimes with 50% and 80% excess loading, yielding comparable results. Thus, the results of the analysis of the modes of the distribution network make the issues of its improvement or reconstruction relevant and necessary. Therefore, it is necessary to perform appropriate works for the improvement and implementation of the network with the application of green energy technologies in order to ensure that consumers are supplied with excellent, reliable and necessary quality electricity.

Table 3: *The comparative calculation results of the variants*

Parameter	Determined regime	50% excess loading	80% excess loading
Excisting scheme			
ΔU, %	0 ÷ 6,7	1,7 ÷ 13,3	5,0 ÷ 16,7
ΔP, kW	106,73	366,67	637,27
$tg\phi$	0,185 ÷ 0,684	0,105 ÷ 0,407	0,082 ÷ 0,415
Implementation of green energy technologies			
ΔU, %	0 ÷ 3,3	1,7 ÷ 6,7	2,0 ÷ 5,7
ΔP, kW	48,82	133,63	637,27
$tg\varphi$	0,14 ÷ 0,413	0,12 ÷ 0,388	0,105 ÷ 0,402

VI. Conclusions

1. Research based on the mathematical model and software module of the actual distribution electrical network's load regimes has shown that the majority of the 6 kV feeder lines are overloaded, leading to excessive voltage drops and increased power losses. Accordingly, it is necessary to improve the existing network or reconsider its topology.

2. A mathematical model based on the maximum voltage drop of the guiding line has been developed for the analysis of distribution electrical network regimes. This model allows for the consideration of active and reactive injections based on green technologies in the network. The application of green energy (wind and solar) sources has been proposed to address the problems arising during loading in the examined distribution network and to increase the efficiency of the regime. In these cases, the effectiveness of the distribution network's operation is improved.

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