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Short circuit and load flow analysis of the central feeder of Rize province in DIgSILENT software Rize province

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ABSTRACT

In today's energy systems, load flow and short circuit analysis are critical for grid security and performance. In particular, understanding the effects of new structures and equipment on existing infrastructure is a vital requirement for preventing power quality problems and sustainable energy management. In this study, load flow and short circuit analysis of a feeder in the center of Rize is investigated using DIgSILENT software. The analysis reveals that a new building added to the feeder increases the loading by 14.8%, which is due to reactive power loading. Moreover, adding a charging station and a movie theatre increased the line loading by 27.2% and nearly doubled the overall grid loading. Short circuit analysis showed that the new building increased the short circuit loading by 10.9%, while the loading of the special provincial disaster directorate line was 17.4%. The results reveal that the maximum loading at the Rize transformer substation is 21.74% and 1.005 pu at Akarsu cabin, providing a detailed assessment of the impact of new buildings and equipment on grid performance. These findings provide important insights for the future development of the region's power infrastructure.

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1. INTRODUCTION

Today, the stability and reliability of electric power systems are paramount with the continuous increase in energy demands. The increasing integration of renewable energy sources and the growing complexity of power distribution systems require extensive short circuit and load flow analysis to ensure efficient and reliable operation of these systems. Short circuit analysis helps to determine the effects of faults on the system. In contrast, load flow analysis is a critical tool for assessing power flow and voltage stability in the grid [1]. These analyses are vital to ensure efficient and reliable operation of distribution feeders. Short circuit analysis helps in the design of protection devices and ensures system reliability by identifying fault currents that can occur in electrical systems. DIgSILENT software is capable of detailed modelling of various power system components such as transformers, generators and transmission lines [2]. The algorithms for optimizing reactive power allocation offered by the software are important for maintaining voltage stability [3]. Furthermore, the ability to simulate various failure scenarios allows engineers to assess the effects of failures on system performance and develop appropriate measures [4]. Load flow analysis is necessary to understand the operating state of the power system under normal conditions. This analysis provides information on voltage profiles, power losses, and overall efficiency of the system [5, 6]. Advanced computational tools, such as DIgSILENT's Python interfaces, improve the accuracy and efficiency of load flow analyses by increasing the ability to manage large data sets and automate repetitive tasks [7]. The results of these analyses inform decisions such as system upgrades and the integration of renewable energy sources, which are becoming increasingly important in today's power systems [8]. Accurate estimation of feeder parameters is a critical requirement for performing an effective load flow analysis. Advanced techniques such as radial basis function neural networks and multi-run optimization methods increase the accuracy of these parameter estimates and improve computational processes [9]. Moreover, developments such as the integration of distributed generation units and energy storage systems further emphasize the need for accurate load flow analysis [10]. Voltage regulation on distribution feeders plays a critical role in maintaining system stability and ensuring optimal performance. Various methods have been proposed for the effective management of voltage levels, such as inter-line voltage controllers and coordinated controls between energy storage systems and voltage regulators [11, 12]. Furthermore, feeder reconfiguration techniques have been developed to optimize system performance [13, 14].

DIgSILENT is a powerful software capable of performing these analyses comprehensively. Through detailed modelling and simulation techniques, the software precisely evaluates short circuit events and load flow. This improves grid security and helps us to understand the long-term impact of system design

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changes. A study conducted on the Araklı-II feeder in Trabzon province examined the impacts of distributed generation (DG) sources on the power grid. The effects of DG sources on voltage profiles and busbar short-circuit currents were modelled and simulated using DIgSILENT software with real parameters. The analysis revealed that DG sources improved the voltage levels of the busbars; however, elevated levels of single-phase and three-phase short-circuit currents were observed [15]. Power Factory's comprehensive analysis capabilities provide decision-makers with key insights to optimize system performance and ensure reliability. A recent study addressed the impact of electric vehicle charging stations (EVCSs) on power grids by strategically deploying Distributed Generators (DGs) at weak nodes identified through a weak bus placement approach [16]. In this study, the integration of 13 EVCSs increased demand and system losses but adding three DGs reduced losses close to the baseline level. Using the Newton-Raphson load flow and contingency analysis, the study demonstrated an effective strategy to mitigate power losses and voltage fluctuations caused by EVCSs. Similarly, Yang et al. used radial basis function neural networks and multi-run optimization methods to improve the accuracy of parameter estimates in distribution systems [17]. Ruiz analyzed the effects of renewable energy integration on the power grid by combining Python and DIgSILENT software [18]. These studies in the literature demonstrate the importance of innovative techniques in evaluating grid performance in both short circuit and load flow analysis.

This study provides a unique contribution to the literature by comprehensively analyzing the impact of new constructions and loads on the performance of the power grid in the central feeder of Rize province, focusing on both load flow and short circuit analyses. While numerous studies in the literature address the integration of renewable energy sources and new loads into distribution systems, detailed analyses conducted under local conditions using real parameters remain limited. The methods employed and the results obtained in this study offer practical findings that can guide regional energy planning and future system designs. The data derived from the study provide actionable strategic solutions to enhance grid security and ensure the long-term reliability of the system.

2. SIMULATION METHODOLOGY AND ANALYSIS SETUP

The analyses were performed using DIgSILENT software. This software supports many functions such as power flow analysis, short circuit analysis, reliability analysis, generation adequacy analysis, optimal power flow analysis, and low voltage network analysis. The user-friendly graphical interface is designed to facilitate data entry and visualization of analysis results. Flexibility is provided in the project creation process depending on the complexity of the system. Users can define system components under the existing network structure or by creating new groups. The load flow and short circuit analyses conducted using DIgSILENT software were based on specific assumptions and settings. For load flow analysis, loads were primarily modelled using constant power (P-Q) representation, with the main transformer station (slack bus) designated as the reference point. Voltage limits were assumed to be within ±5% of the nominal values, and the Newton-Raphson method was employed for solution accuracy. Short circuit analyses were performed in compliance with the IEC 60909 standard, addressing both single-phase and three-phase fault scenarios [19]. Fault impedance was assumed to be zero or negligible, and the time-domain behaviour of short circuit currents was analyzed using symmetrical and asymmetrical components. Additionally, the resistance (R) and reactance (X) values of the lines were meticulously defined to ensure solution accuracy. DIgSILENT software, with these assumptions and settings, was effectively utilized to evaluate the performance of the network. As illustrated in Figure 1, the data entry window facilitates the definition of system components and the organization of data.

Load flow analysis allows power systems to be analyzed under steady-state conditions. During this analysis, active and reactive power values, current and voltage values are calculated. In the programmed, load flow analysis is performed using P-Q, P-V and oscillation busbars. The identification of these busbars is critical to ensure the power balance of the system. Active power control is used to ensure the power balance in the system. In the DIgSILENT program, two basic methods can be applied with the load flow calculation tool: slack generator utilization and system balancing through loads or generators. These methods make it possible to balance the active power in the system. Secondary control reestablishes the low-cost generation of each generator to achieve frequency stabilization, while primary control aims to maintain the frequency of the system at the nominal level by increasing or decreasing the active power of the generators. These two types of control are necessary to ensure system stability and are calculated by various equations. If the active power control by primary control option is selected in the load flow order of the power factor, the power balance is determined by all generators (synchronous generators, static generators and external networks) with a primary control gain value different from zero. The modified active power of each generator is recalculated according to Equation (1):

$$P_i = P_{i-dispact} + \Delta P_i \tag{1}$$

Where P_i is the modified active power of the generator, $P_{i-impact}$ is the initial active power transfer of generator i and ΔP is the active power change at generator i. The active power change (ΔP_i) at each generator is determined by the primary control gain value corresponding to (K_{pf-i}) and the total frequency change as in Equation (2).

$$\Delta P_i = K_{pf-i} * + \Delta f \tag{2}$$

Here, K_{pf-i} is the primary control gain parameter of generator i and Δf is the total frequency variation. The total frequency variation (Δf) is obtained as in Equation (3):

$$\Delta f = \frac{\Delta P_{Tot}}{\sum K_{pf}} \tag{3}$$

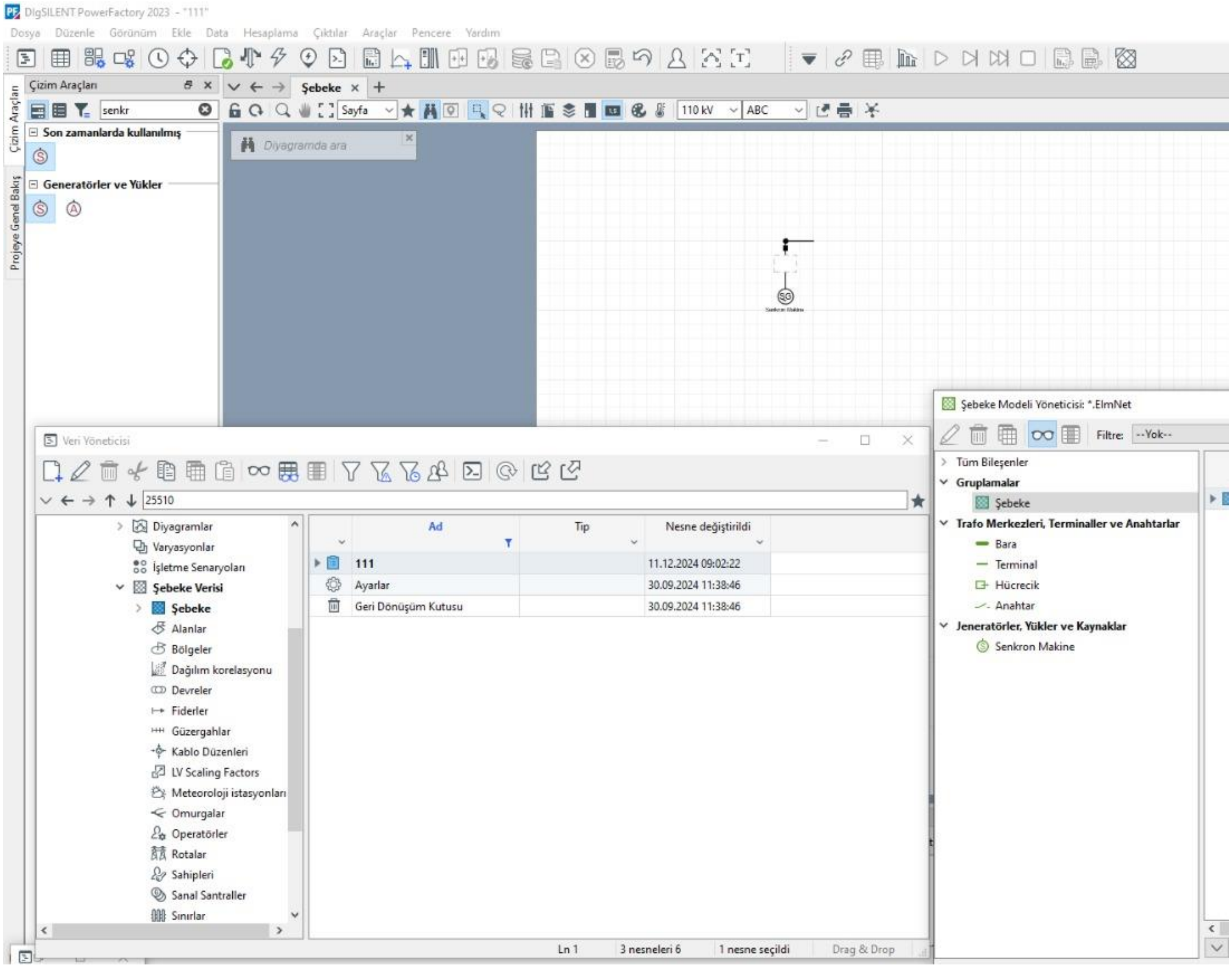

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Fig. 1. The main window of the DIgSILENT software.

ΔP_{Tot} corresponds to the sum of the active power variables of each generator and is calculated as in Equation (4).

$$\Delta \mathbf{P}_{Tot} = \sum_{i=1} \Delta \boldsymbol{P}_j$$
(4)

Reactive power control is used to regulate voltages in transmission networks and to optimize interactions with neighbouring networks. In DIgSILENT software, voltage regulators of generators can be adjusted manually or automatically.

Short circuit analysis is critical to ensure that faults in the system do not damage the equipment. Short circuit currents are calculated using the short circuit time-function plot in Figure 2.

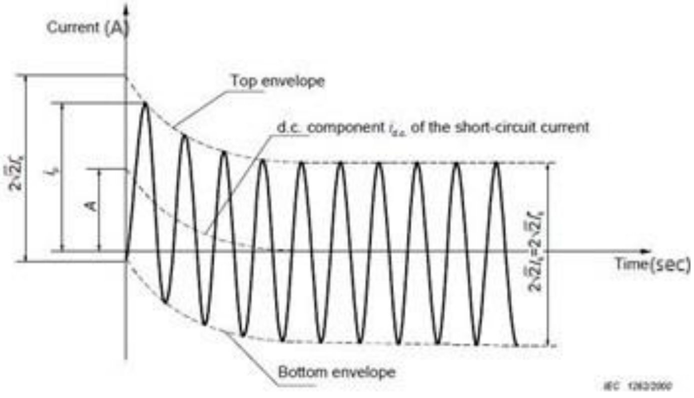


Fig. 2. Short circuit current-time graph [20].

In this way, the short-circuit current-time function is an important set of parameters that help us to understand how the current in the short-circuit state changes with time. In this function, I_k represents the initial symmetrical short-circuit current (RMS), while I_p is the instantaneous value of the maximum short-circuit current. I_b represents the symmetrical short-circuit breaking current (RMS), while I_{DC} indicates the DC component. Also, k is a factor used in the calculation of the maximum short-circuit current and A is the factor used in the calculation of the symmetrical short-circuit breaking current.

In DIgSILENT, this analysis is performed by the IEC 60909/VDE 0102 method and short circuit powers and currents are calculated using the equivalent voltage source method [21]. Harmonic and flicker analyses are performed to evaluate the harmonic and flicker values of lines, transformers and other elements in the system. These analyses are performed using the data of the system components. Finally, the results of the analyses are displayed under each system element and include information such as active and reactive power values, load capacity and voltage. These analyses provide a comprehensive approach to evaluate and optimize the performance of power systems, and the tools and methodologies DIgSILENT offers help to improve the reliability and efficiency of systems.

3. RESULTS

In this study, load flow and short circuit analyses of a feeder in the center of Rize were performed using DIgSILENT PowerFactory software. DIgSILENT PowerFactory, as a tool that allows comprehensive modelling and analysis of electricity transmission and distribution systems, was the base material for these analyses. Load flow analysis was performed using the Newton-Raphson method to evaluate the voltage profiles, current distributions and power losses of the system. The analyses were carried out to examine the existing load profiles as well as the effects of newly added structures. Short circuit analyses were performed with scenarios under IEC and ANSI standards to determine the performance and durability of the system under short circuit conditions. These analyses were used to evaluate the performance of the feeder in detail and to identify potential power quality problems by revealing the factors affecting the power quality and reliability of the system. Figure 3 shows the analyzed center feeder.

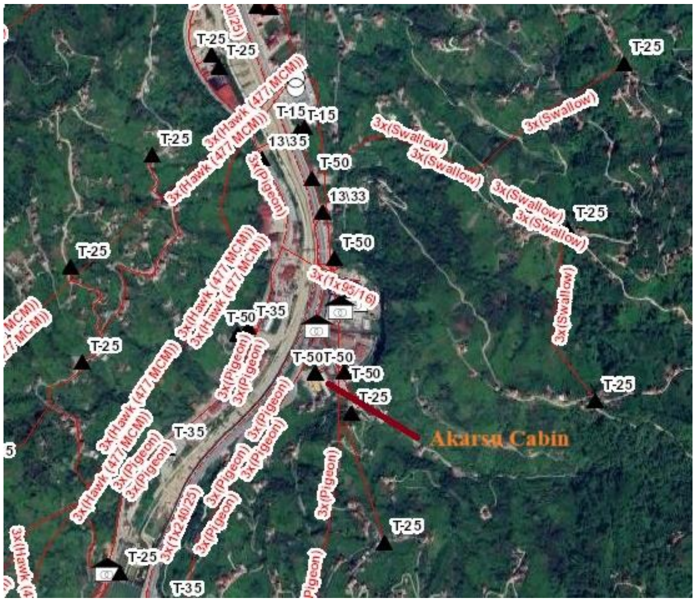


Fig. 3. Map representation of the analyzed Akarsu cabin feeder.

3.1. Load Flow Analysis of Feeder

In this section, the effects of newly added buildings and other loads on a feeder in the Rize central region are investigated by load flow analysis. Load flow analysis is used to understand power flows, loads and voltages, and because of this analysis, factors such as voltage spikes on busbars, loads on cables and transformers, changes in the direction of power flow and reactive power capacity of the generation facility are evaluated. In this study, when a new building (5 MW) is added to a feeder in the Rize centre, the load analyses of the cabinets are given in Figure 4.

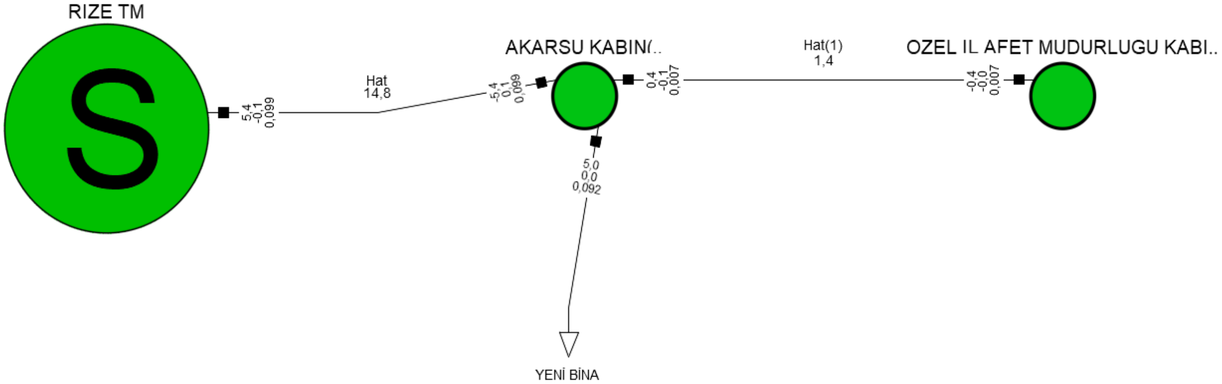


Fig. 4. Load flow analysis of the feeder in Akarsu cabin.

The power in power lines consists of two components: active power (P) and reactive power (Q). The total power (S) is expressed in its complex form as $S = p + jQ$, where P represents the real (active) power, Q represents the imaginary (reactive) power, and j denotes the imaginary unit commonly used in electrical engineering to indicate the imaginary component.

The study particularly emphasizes the role of active power. Based on this analysis, the addition of a new building with a capacity of 5 MW to the feeder located in the center of Rize results in specific current and power values measured on various lines.

In the section from Rize Substation to Akarsu Cabin, 5.4 MW power is initially carried, and 5 MW active power is drawn at Akarsu Cabin. As a result of this withdrawal, the remaining active power on the line after the Flow Cabin was measured as 0.4 MW. This causes power loss and a decrease in current values. While the initial current was 0.099 MA, the current drawn for the new building fed from the Stream Cabin was measured as 0.092 MA and 0.007 MA at the outlet. The loss of power along the line causes the current to decrease due to the resistance and reactance of the line. In the section from Rize substation to Akarsu cabin, there is a significant power loss due to high current (14.8 MA) and these losses cause a decrease in the remaining current (1.4 MA) in the line after Akarsu cabin. In the first analysis, 5.4 MW power and 0.099 MA current are carried from the Rize transformer substation to Akarsu cabin, while the remaining power after Akarsu Cabin is 0.4 MW and the output current is 0.007 MA. These power losses are related to the resistance and reactance of the line and the loading rate is analyzed as 14.8%. To present the calculated results in a more structured and understandable way, the main findings are summarized in Table 1. This table provides a clear comparison of the performance of the system under existing conditions and after the addition of new loads.

These results highlight the significant impact of additional loads on current levels and loading percentages, underscoring the need for further evaluation of power quality and grid reliability.

In the second analysis shown in Figure 5, the initial power of the line from the Rize transformer substation (TM) to the Akarsu cabin was determined as 9.9 MW.

Table 1. Power flow analysis of Rize TM and Akarsu cabin.

Analysis Case	*Power at Rize TM (MW)*	*Power at Akarsu Cabin (MW)*	*Output Power from Akarsu Cabin (MW)*	*Current (MA)*	*Loading (%)*
Existing conditions	5.4	5.0	0.4	0.099	14.8
With new loads (building, cinema, charging station)	9.9	9.5	0.4	0.182	27.2

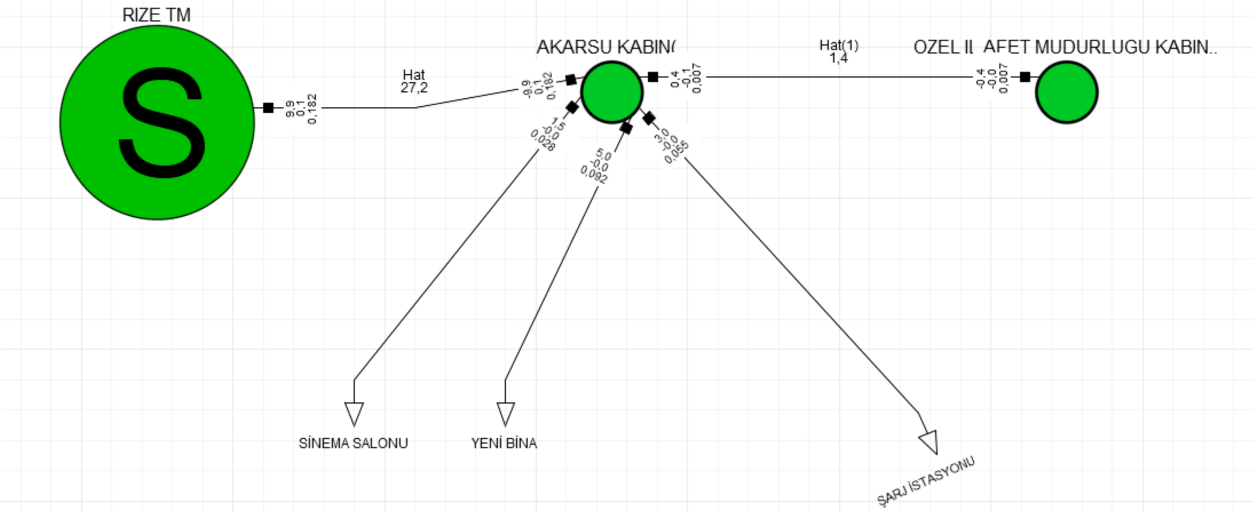


Fig. 5. Load flow analysis of structures attached to the feeder.

In this case, a total of 9.5 MW power is drawn because of additional loads (new building, cinema and charging station), which reduces the power value on the line after the Akarsu cabin by 0.4 MW and the current by 0.007 MA. The current values are measured as 0.182 MA at Rize TM, the total current drawn from the Stream Cabin is 0.175 MA and the current at the outlet is 0.007 MA. In this analysis, line loading was calculated as 27.2%. The differences between the two analyses are as follows:

- In the first analysis, the current line between the Rize substation and Akarsu cabin was 14.8 MA, while in the second analysis, this value increased to 27.2 MA. This increase reflects the effect of additional loads.
- While the power transported from Rize TM was 5.4 MW in the first analysis, this value increased to 9,9 MW in the second analysis. The power withdrawn from the Stream cabin, which was 5 MW in the first analysis, increased to 9.5 MW in the second analysis.
- The current Rize substation is 0.099 MA in the first analysis and 0,182 MA in the second analysis. The current drawn from the Stream cabin is 0.092 MA in the first analysis and 0.175 MA in the second analysis.
- Similar power loss and current reduction were observed in both analyses. These losses occur due to the resistance and reactance of the line.

This study highlights the importance of regular analysis to assess the capacity and performance of the distribution network. The impact of additional loads on the system significantly increases the values of power and current carried along the line, so continuous monitoring is required to minimize power losses and improve system efficiency.

In the analysis, the constant power (P-Q) model is preferred to represent the loads. This model assumes that the active (P) and reactive (Q) power demands remain constant regardless of voltage fluctuations and is highly suitable for steady-state load flow analysis. The relatively constant operational power demands of the loads analyzed in this study, which include facilities such as a movie theatre and a charging station, justify the choice of the constant power model.

The impact of this model on system performance is evaluated in terms of voltage profiles, power losses and line loading. The results show that the model represents the load behaviour accurately enough and provides reliable results in different loading scenarios. Alternative models, although able to capture dynamic elements, were not deemed necessary for the objectives of this study.

3.2. Feeder Short Circuit Analysis

Short circuits are transient phenomena characterized by a rapid rise in fault current due to the introduction of a low-impedance path in the circuit. In this study, the short circuit parameters calculated using the IEC 60909 method form the basis for understanding the behaviour of fault currents during transient conditions lasting 100-200 milliseconds. The symmetrical short circuit current (I_k) can be expressed in Equation (5).

$$I_k = \frac{U_N}{Z_k} \tag{5}$$

Where U_N is the nominal system voltage, and Z_k represents the short circuit impedance, which is calculated as Equation (6).

$$Z_k = \sqrt{R_k^2 + X_k^2} \tag{6}$$

Here, R_k and X_k are the resistance and reactance components of the equivalent impedance at the fault location. The peak short circuit current (I_{peak}) is determined using the following Equation (7).

$$I_{peak} = \mathrm{k}.I_k \tag{7}$$

Where k is the peak factor, dependent on the network's X/R ratio. For typical distribution networks, k ranges between 1 and 1.8 reflecting the ratio of reactance to resistance in the system.

The transient DC component of the short circuit current (I_{DC}) decays exponentially over time and is described by Equation (8):

$$I_{DC}(t) = I_{DC0} e^{\frac{-t}{T}} \tag{8}$$

Where $T = L/R$ is the time constant, derived from the system's inductance (L) and resistance (R). Finally, the total asymmetrical short circuit current I_{asym} is the sum of the symmetrical AC component and the transient DC offset:

$$I_{asym} = I_{DC}(t) = I_{DC0} + I_k \tag{9}$$

These equations provide a comprehensive framework for understanding how fault currents evolve during the initial 100-200 milliseconds of a short circuit event. This transient period is particularly critical as it occurs before protective devices, such as circuit breakers, can isolate the fault. The behaviour of these currents highlights the stress imposed on system components and underlines the importance of designing equipment to withstand these transient conditions.

This study was carried out to perform a short circuit analysis at Rize Central Fiduciary and to evaluate the effects of new loads on the system. The analysis was performed using various parameters and scenarios to understand the effects of short circuit currents and power values on the system.

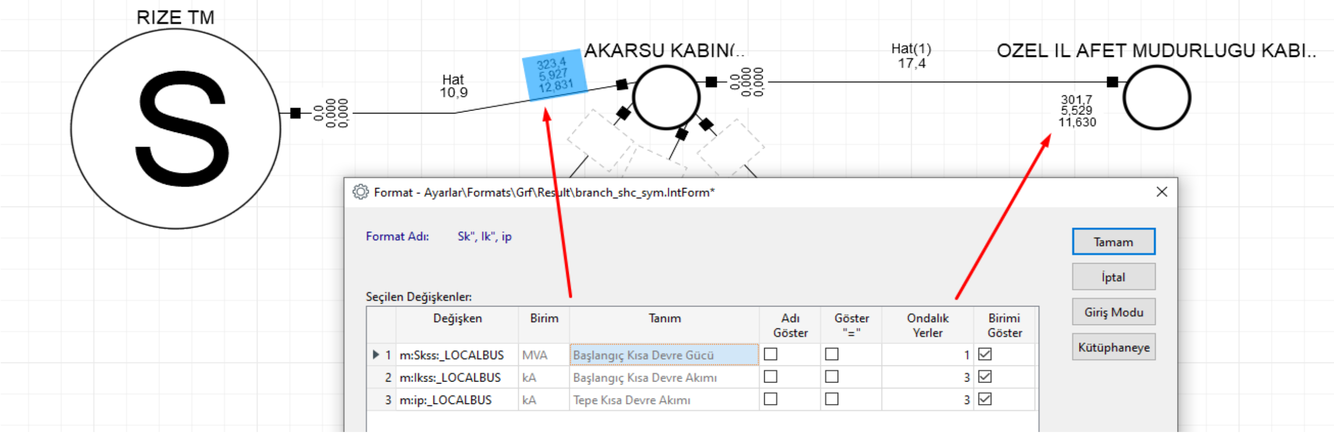
Firstly, the short circuit analysis of the Rize Central Fiduciary was performed and the initial short circuit power, short circuit current and peak short circuit currents were calculated for each element in the system. As shown in Figure 6, the short circuit parameters of each element were determined and analyzed in detail.

The current values on the line between the Akarsu Cabin and the Special Provincial Disaster Directorate Cabin were also analyzed. The current value on the line between Rize TM and Akarsu Cabin was determined as 10.9 MA and the current value on the line between Akarsu Cabin and Special Provincial Disaster Directorate Cabin was determined as 17.4 MA.

Short circuit power and current values were also calculated. Initial short circuit power was determined as 323.4 MW and short circuit current as 5.927 kA at the entrance of the Stream Cabin. When a new building was added, these values decreased to 301.7 MW and 5.529 kA, respectively. The peak short circuit current was 12.831 kA at the beginning and decreased to 11.630 kA when a new building was added. These results show that the new loads affect the short-circuit power and current in the system. To present the calculated results in a more structured and understandable way, the main findings are summarized in Table 2. This table provides a clear comparison of the performance of the system under existing conditions and after the addition of new loads.

The decrease in short circuit parameters due to additional loads indicates potential implications for the operation of protection devices. Further detailed analysis is recommended to assess the broader impacts on grid stability and reliability.

In order to evaluate the effects of the new loads, the short circuit analysis of when a building, a cinema hall and a charging station were added to the Rize central feeder was detailed. As shown in Figure 7, changes in short circuit power and current values were observed with the addition of these new loads to the system.



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2	m:Ikss:_LOCALBUS	kA	Başlangıç Kısa Devre Akımı	☐	☐	3	☑
3	m:ip:_LOCALBUS	kA	Tepe Kısa Devre Akımı	☐	☐	3	☑

Fig. 6. Short circuit analysis and parameters of the feeder.

Table 2. Impact of new loads on short circuit parameters.

Component	*Initial Short Circuit Power (MW)*	*Short Circuit Power with New Loads (MW)*	*Initial Short Circuit Current (kA)*	*Short Circuit Current with New Loads (kA)*
Rize TM	323.4	301.7	5.927	5.529
Akarsu Cabin	10.9 MA	10.630 MA	-	-
Akarsu Cabin (special directorate line)	17.4 MA	-	-	-

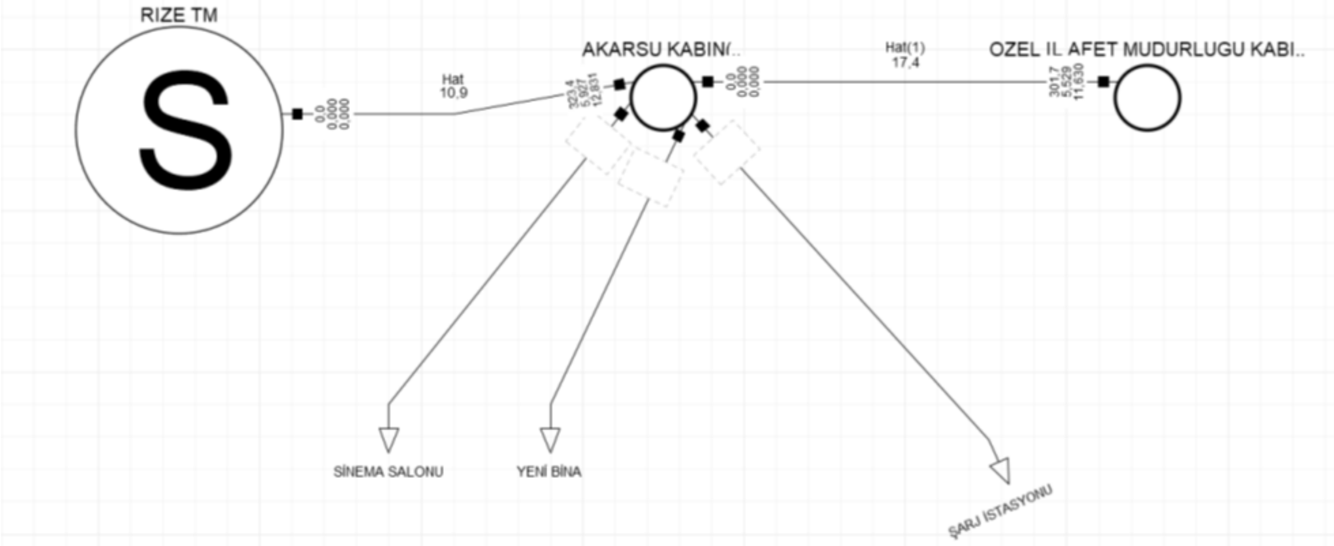

Fig. 7. Short circuit analysis of structures attached to the feeder.

With the addition of the new loads to the River Cabinet, the short circuit power decreased to 301.7 MW and the short circuit current decreased to 5.529 kA. In addition, the peak short circuit current was measured as 10.630 kA with the addition of new loads.

The studies present the results of the short circuit analyses and the changes in the short circuit capacity of the system in detail and provide the necessary data to understand the effects of the new loads on the network. These analyses reveal important parameters that network operators should consider when evaluating system performance and stability in case of new loads.

Finally, the voltage and load utilisation fluctuations of Rize TM and Akarsu Cabin over a period of one month are analysed. The graphs presented in Figure 8 and Figure 9 show the changes in load and voltage fluctuations over time in light of the data obtained during the January 2024 period.

Fluctuations in load utilisation and the analysis of maximum, minimum and average values provide important information about the performance and efficiency of the system. Voltage fluctuations are used to identify factors affecting the performance of the system and to develop energy management strategies.

These comprehensive analyses provide important findings for energy management and grid design and help grid operators monitor and manage system performance more effectively.

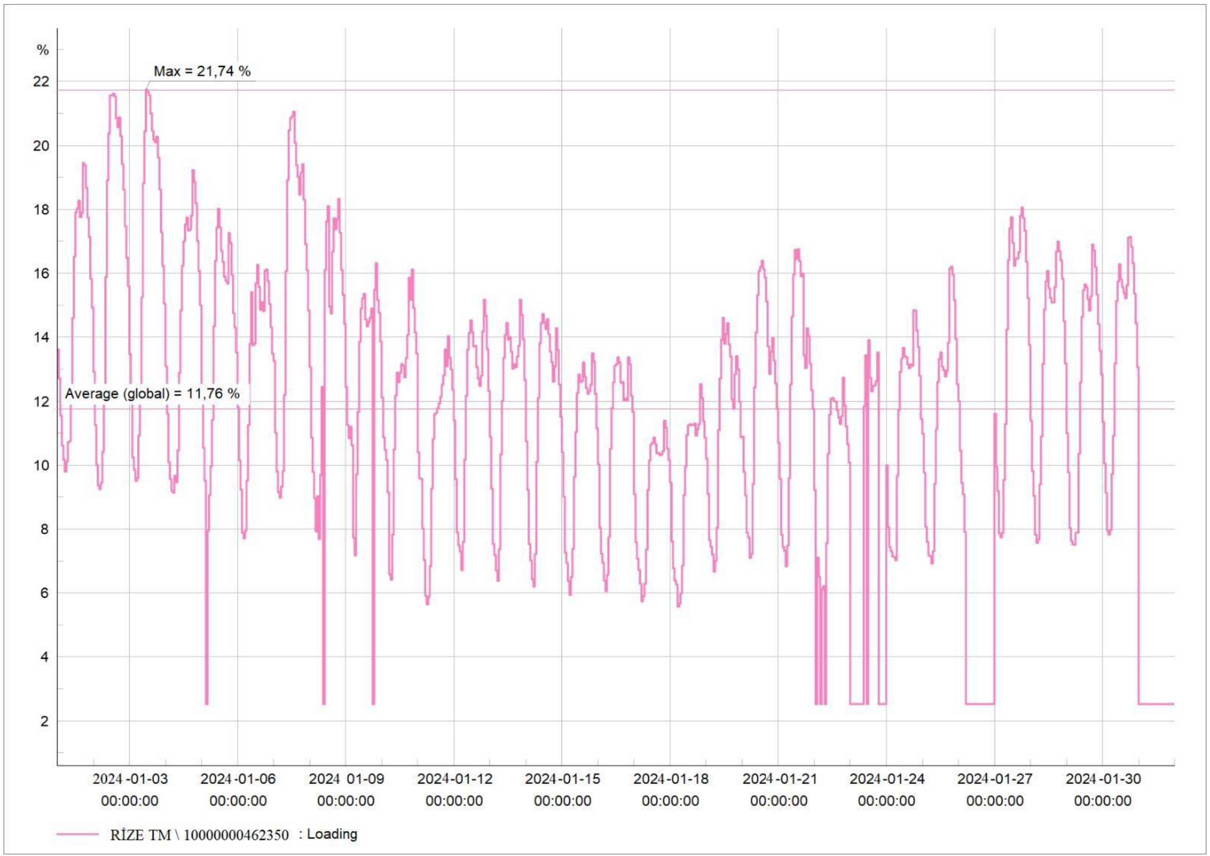

Fig. 8. Short circuit analysis of RİZE TM during January 2024.

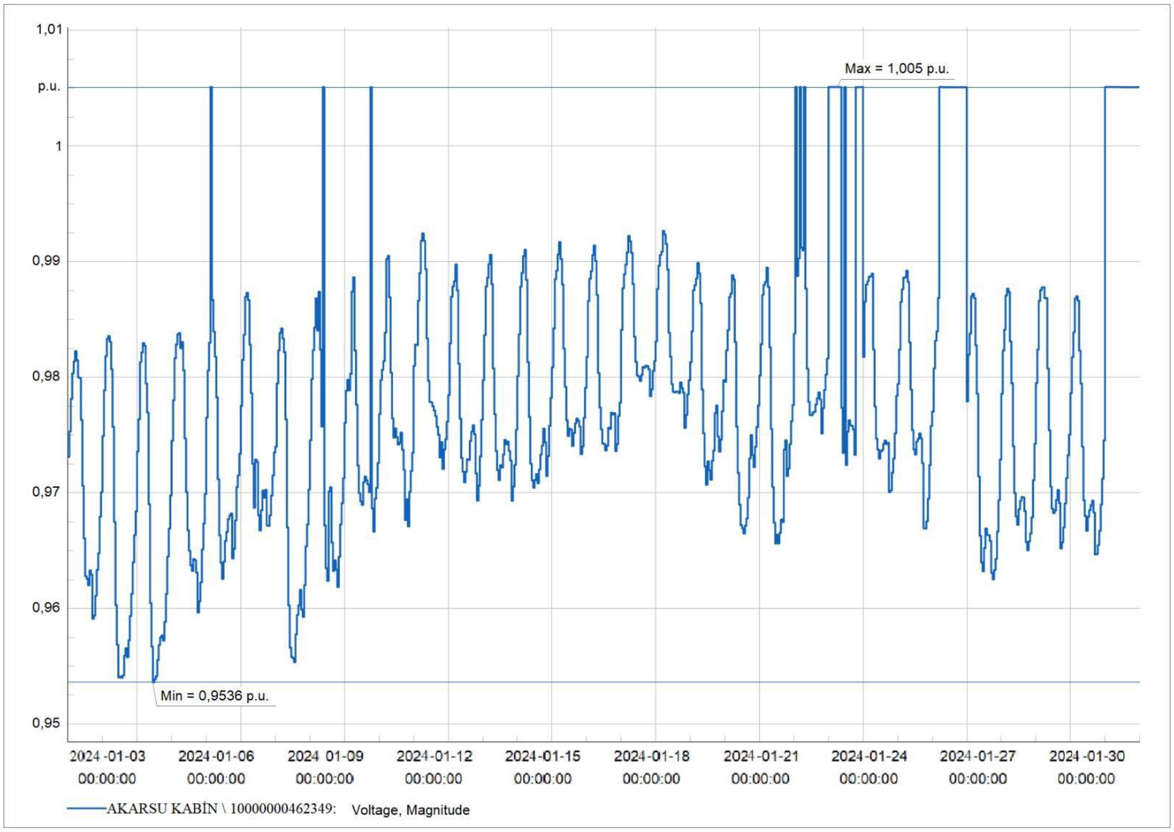

Fig. 9. Short circuit analysis of the Stream Cabin during January 2024.

3.3. Voltage Regulation Under Open-Circuits Conditions

Open-circuit conditions at the load bus have significant implications for voltage regulation within the feeder system. When a load bus transitions to an open-circuit state, the absence of load alters the reactive power balance and system impedance, leading to notable voltage deviations. These deviations can be analyzed theoretically using the following Equation (10).

$$V_r = \frac{\Delta V}{V_{Nominal}} x100 \qquad (10)$$

Where V_r represents the percentage of voltage regulation, ΔV is the voltage change, and $V_{Nominal}$ is the nominal system voltage. For a feeder under open-circuit conditions, the voltage deviation depends on the line resistance (R), reactance (X), and the pre-fault reactive power flow (Q), as described by Equation (11).

$$\Delta V = \frac{Q.X - P.R}{V_{Nominal}} \qquad (11)$$

In such cases, both active and reactive power drop to zero at the affected bus, leading to reduced current flow and potential overvoltage conditions due to the dominance of reactance in the voltage profile.

To demonstrate the theoretical implications, a simulation was conducted using DIgSILENT PowerFactory software. The feeder system was modelled under two scenarios: normal operating conditions with full load and an open-circuit condition at the farthest load bus. The key parameters included a 5 km feeder length, 10 kV nominal voltage, line impedance values of R=0.12 Ω/km and X=0.38 Ω/km, and a load at the bus defined by P=500 kW and Q=250 kVAR. The results showed that the voltage at the load bus increased by approximately 8.25% under open-circuit conditions due to the absence of load-induced reactive power consumption. Under normal operating conditions, the voltage at the load bus was 0.97 pu, while in open-circuit conditions, it increased to 1.05 pu, resulting in a significant deviation.

The accompanying graph (Figure 10) illustrates the voltage profiles along the feeder under both scenarios.

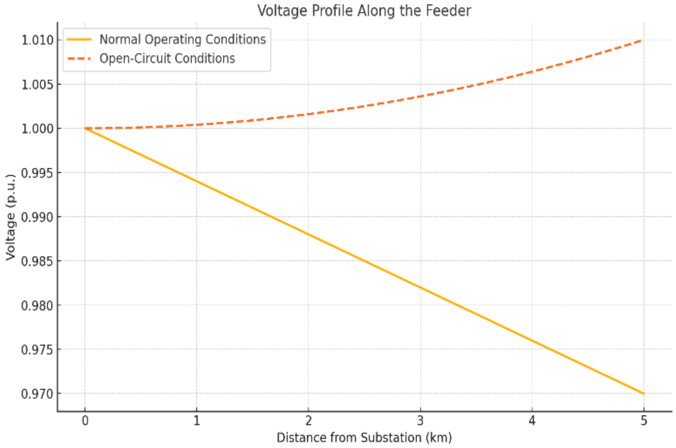

Figure 10. Voltage profile along the feeder under normal operating conditions and open-circuit conditions.

Under normal operating conditions, the voltage gradually decreases along the feeder due to active and reactive power losses. However, in open-circuit conditions, a voltage spike is observed at the farthest load bus, attributed to reduced current flow and the reactive impedance's dominance. These findings emphasize the importance of voltage regulation mechanisms, such as capacitor banks and voltage regulators, to mitigate overvoltage issues during open-circuit scenarios. Proper feeder design and reactive power management are critical to maintaining grid stability and ensuring reliable operation under various conditions. This analysis provides a comprehensive understanding of the impact of open-circuit conditions on voltage regulation and highlights strategies to address potential challenges.

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