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Investment technique for ensuring energy supply continuity in ring grids

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Abstract

The importance of energy supply for both end-users and electricity distribution entities, as well as the need for reliable energy quality parameters, is significant. This study delves into scenarios where these parameters cannot be met, outlining formulas for calculating compensation and other financial obligations that distribution companies may incur. The study highlights various types of interruptions that disrupt energy supply continuity within electricity distribution networks and elucidates their impacts on the network infrastructure. The establishment of alternative energy sources and the enhancement of the network infrastructure through coupling are recommended to mitigate the consequences of these interruptions. Investments in alternative energy sources and network improvements are compared to penalty amounts incurred when the quality parameters for energy supply continuity cannot be met. The F13/F14 Ring Network, a proposed coupling approach that can improve energy supply, is identified and its installation costs are compared with the existing conditions. Additionally, the magnitude of fines that distribution companies may potentially face is estimated. As a result, a comprehensive cost-benefit analysis is conducted, integrating these comparisons to evaluate the economic sustainability and advantages associated with the proposed F13/F14 Ring Network coupling method.

1. Introduction

Voltage quality (also referred to as "power quality") encompasses topics related to the ideal voltage level and deviations in waveform. Voltage quality covers a wide range of issues including harmonics, voltage level fluctuations, voltage drops, and more. A comprehensive study has been conducted on regulations regarding voltage quality [1]. The fundamental purpose of electric power system design and operation is to provide all network users (consumers, producers, and both) with an acceptable level of energy supply continuity and voltage quality. In this context, the term "acceptable" can be assessed through various approaches. Traditionally, such decisions were often made by local energy providers, and customers were required to accept the outcome without question. However, this approach has been replaced by international standards or general requirements set at the national level. For instance, limitations for continuous events such as voltage level fluctuations and harmonics in Europe are defined in the EN 50160 standard [2, 3]. Limitations on interruption events such as the number and duration of outages are determined by regulatory bodies in some countries. Nevertheless, the ultimate decision on what is considered acceptable always rests with the customers, and in this context, requirements are becoming increasingly stringent. This is especially true for cases where prolonged outages take on political dimensions in certain situations. Similarly, a tightening of regulations is observed for issues affecting industrial customers, such as significant voltage drops [4, 5].

Electric distribution companies conduct grid improvement projects to enhance energy continuity and quality. The importance of these initiatives in ensuring supply continuity is emphasized. Through operational enhancements or additional investments within the existing grid, efforts are made to achieve customer satisfaction with energy supply. In this paper, a cost-benefit analysis of a method aimed at improving energy supply continuity in a city grid is conducted using the F13/F14 Ring Grid model. Compensation penalties to be levied on distribution companies for prolonged or frequent outages exceeding a certain threshold value are calculated within the electric distribution network. The study examines the costs incurred by the distribution company due to outages in the absence of the F13/F14 ring grid and compares these with the situation after implementing the ring grid, taking compensation penalties into account. The paper compares the establishment cost of the ring grid with the benefits through cost-benefit analysis. In the ring network model proposed in this study, estimating the quality of supply continuity allows taking into account all potential factors, both interconnected and independent, including not only reliability factors but also investment costs. Thus, this study presents a new approach that proposes to use the benefit-cost analysis model to calculate the continuity quality of the power supply [6]. This method allows estimating continuity of supply by taking into account various factors, including investment costs.

The methodology used involves conducting a cost-benefit analysis of a method aimed at improving energy supply continuity using the F13/F14 Ring Grid model. This analysis is used to calculate the compensation penalties to be imposed on distribution companies and to compare the costs incurred due to outages in the absence of the F13/F14 ring network with the post-implementation situation. Additionally, the cost of establishing the ring network is compared with the benefits achieved through cost-benefit analysis.

This analysis proposes to use different feeders to calculate compensation penalties imposed on distribution companies and compare them with the situation after the implementation of the costs incurred due to interruptions in the absence of the F13/F14 Ring Grid. In addition, the installation cost of the ring grid is compared with the benefits obtained through cost-benefit analysis, presenting a new approach for connection between two feeders. The coupling system used in the methodology aims to improve energy supply continuity by integrating the F13/F14 Ring Grid model and performing cost-benefit analysis.

2. Reliability and supply continuity in power systems

Electrical energy service quality is basically; It consists of three main components: supply continuity, voltage quality and commercial quality. Supply continuity defines interruptions in energy supply by analyzing the number and duration of disruptions, assessing the reliability of the electrical system. Voltage quality focuses on specific characteristics of voltage waveform, including frequency, RMS value, fluctuations, flicker, imbalance, and harmonic distortion. Commercial quality evaluates the relationship between electric companies and customers. The main aim of this study is to contribute to a better understanding of the concept of supply continuity.

Outages can be classified based on their nature or duration. According to their nature, outages are defined as follows [7]:

- Planned Outages: In most cases, these outges occur as a result of deliberate circuit breaker opening by the system operator to de-energize a portion of the network, affecting one or more customers. Customers are informed in advance. Such measures are usually used for maintenance operations or construction of new parts of the network. Generally, these types of outages lead to an improvement in network reliability.
- Unplanned Outages: These outages occur due to unforeseen events, such as component failures, lightning strikes, excavation activities, or incorrect switching operations.
- Extraordinary Events: Events associated with natural disasters.

According to their duration, outages are defined as follows:

- Long-Term Outages: Lasting more than three minutes.
- Short-Term Outages: (In most European countries) lasting three minutes or less.

2.1. Reliability in power systems

The primary objective of an electrical energy system is to provide consumers with economical, high-quality, acceptable, reliable, and uninterrupted energy supply. The ability of the system to fulfill this inherent expectation throughout its operational period is referred to as reliability. Electrical energy system reliability analysis is conducted at three levels. The reliability analysis performed at the production zone level determines whether the generated energy can meet the total system load [8]. Enhancing the reliability of electrical distribution systems is currently of increasing interest and importance because power outages caused by any errors affect both energy providers and end-users. Closed-ring operation mode ensures high reliability by reducing the duration and frequency of faults [9].

To date, reliability indicators used in the design of power systems have limitations as they do not consider all possible factors influencing the continuity of power supply [10-12]. These reliability indicators often only account for the reliability of devices and components in the system [13, 14]. As an alternative, the Dempster-Shafer (DS) mathematical evidence theory-based method derived from Dempster and Shafer's names may include series modeling to predict signals from sequentially connected sensors [15-17]. Other uncertainty prediction methods are available for modeling dependent and independent elements (both series and parallel). The CF-based method is sometimes used to model system quality to predict uncertainty. This method has been successfully applied to estimate information quality [18-20] and also in the authors' publications [21]. In summary, the method presented in this paper for determining the continuity quality of power supply represents an approach based on cost-benefit analysis, distinct from the multi-layer prediction method described in [22, 23] for uncertainty prediction.

In a modern electrical distribution network, providing uninterrupted energy supply is technically and economically challenging. However, as consumers' dependence on electrical energy grows, better performance in energy supply continuity is expected [24].

Some indicators exist that measure and evaluate the costs or losses incurred in the service schedule and on the consumer side as a result of power interruptions, and these should be considered in planning and operations. Network reliability analysis produces load point and system indicators. These indicators are divided into energy indicators and frequency/expectancy indicators. In this study, Load point indicators [25];

- System Average Interruption Duration Index (SAIDI)
- System Average Interruption Frequency Index (SAIFI)
- Average Service Availability Index (ASAI)
- Customer Average Interruption Duration Index (CAIDI)
- Customer Interruption Index per Interrupt (CIII),

These indices have been evaluated as for a part of a Distribution Company's network. All service providers need to have the necessary data to calculate all reliability indicators.

2.2. Continuity quality

The quality of energy supply continuity refers to the capacity of an electrical distribution network system to provide the electricity service that consumers should receive, at an acceptable cost and without disrupting vital activities, with the least possible frequency and duration of interruptions.

The Energy Market Regulatory Authority (EPDK) obliges energy distribution companies to record short, temporary, and long electrical outages occurring within the energy distribution network for supervision purposes. This requirement aims to maintain transparency and ensure that this information is always presented in an open manner. Detailed data about long-term outages that need to be preserved are explained as:

- The voltage level and location of the origin of the outage,
- Date and start time of the outage,
- Source of the outage,
- Depending on the infrastructure status, the number of distribution and main users affected by the outage,
- Depending on the infrastructure status, outage duration for distribution and main users,
- Depending on the infrastructure status, separate outage durations and corresponding customer numbers for distribution and main users supplied with energy gradually,
- Time when the outage ended for all affected users.

Extended-only outages fall into two categories: outages with notice and outages without notice. Records of unnotified outages specified in the second paragraph are kept only at the distribution level for short and temporary outages.

The electrical distribution company evaluates energy supply continuity quality parameters for each year based on Low Voltage (LV) or Medium Voltage (MV) levels and zoning conditions. The assessments encompass:

- System-wide average interruption duration and frequency indices for both notified and non-notified long outages,
- System-wide average interruption frequency index for short and temporary outages,
- Equivalent interruption duration and frequency indices for both notified and non-notified long outages,
- At the LV level, on a user basis, calculations of equivalent interruption duration and frequency indices for both notified and non-notified long outages.

These evaluations are conducted to assess the quality of energy supply continuity for different categories of outages, considering LV or MV levels and zoning conditions.

SAIDI is calculated for each of the "n" total interruptions occurring throughout a calendar year, as well as for each of the "m" user groups that experience these interruptions and subsequently have their energy supply restored step by step. The mathematical expression for calculating SAIDI is shown in Equation 1.

$$\text{SAIDI} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(U_{i,j} * t_{i,j})}{U_{total}} \quad (1)$$

In Equation 1:

- $U_{i,j}$: Represents the number of users in group j who are affected simultaneously by the *ith* interruption.
- $t_{i,j}$: Represents the duration of the interruption for user group j.
- U_{total}: Represents the total number of users served by the distribution company at the beginning of each calendar year.

SAIFI is calculated considering the total "n" interruptions that occur within a calendar year and is based on the Equation 2:

$$\text{SAIFI} = \frac{\sum_{i=1}^{n} U_{\text{i}}}{U_{total}} \quad (2)$$

In Equation 2:

- U_{i}, Represents the number of users affected by the ith interruption.

The CAIDI is calculated for each feeder by summing up the durations of all "n" interruptions occurring within a calendar year (Equation 3):

$$\text{CAIFI} = \sum_{i=1}^{n} t_i \quad (3)$$

In Equation 3, $t_i$represents the duration of the *ith* interruption for each feeder.

CAIFI term refers to the evaluation of the total "n" interruptions that occur within a calendar year. It is calculated separately for each feeder, indicating the number of interruptions.

If the CAIDI and CAIFI calculated for each feeder exceed the acceptable threshold values proposed, the distribution company is obligated to compensate users based on the principles determined below. The authority to review and adjust these values remains with the regulatory authority.

For CAIDI and CAIFI calculations, the proposed threshold values are as follows:

For CAIDI:
- Within Zoning Area: 72 hours
- Outside Zoning Area: 96 hours

For CAIFI,
- Within Zoning Area: 56 times
- Outside Zoning Area: 72 times

The compensation amount to be paid to the user for CAIDI is calculated using the Equation 4:

$$PUFO_f = [\text{CAIFI}f - \text{TVCAIFI}f] * ENS * AD_f \quad (4)$$

In Equation 4:
- $PUFO_f$: Represents the compensation amount to be paid to the user for unmet targets due to "f" feeder.
- CAIFIf: Represents the equivalent interruption duration index calculated for "f" feeder in the previous calendar year.
- TVCAIFIf: Represents the acceptable threshold value for equivalent interruption duration index.
- ENS: Represents the cost of the unit of energy not supplied (approved by the Authority upon the distribution company's proposal within the framework of procedures and principles determined by the Authority).
- AD_f: Represents the average demand in kW for "f" feeder in the previous calendar year.

Compensation amounts at the feeder level are allocated based on the connection capacities of consumers connected to the relevant feeder and are offset in a lump sum or in equal installments from the distribution service fees of the following year. Compensation payments are made without the need for individual applications. According to the Regulation on the Continuity of Electricity Supply, Commercial and Technical Quality of Electricity Delivered in the Distribution System of the Electricity Market, compensation to consumers does not eliminate the right to claim damages for damage to their own equipment, provided that the consumer is not at fault.

3. Energy supply continuity in ring grids

As a method for ensuring energy supply continuity, an example of an electrical distribution network's ring line will be discussed. The Ring Network; To minimize the impact of power outages in the supply areas of F-13 and F-14, which originate from the District Transformer Station (TM), a ring network has been established at the TR113 main building shown as Figure 1.

F-14, with a characteristic of 477 MCM, is supplied by a total of 4142 subscribers, including 4142 Low Voltage (LV) subscribers and 8 Medium Voltage (MV) subscribers, and is fed by a total of 43 transformers. On the other hand, F-13, with a characteristic of 3/0 Pigeon, is supplied by 110 LV subscribers, 8 MV subscribers, and a total of 10 transformers. In the event of an MV fault on the feeders, since there is no alternative supply point, a significant number of subscribers remain without power for an extended period. During the time it takes to rectify the fault and restore power to the line, subscribers are left without electricity. Furthermore, this situation results in the distribution company having to pay compensation fines due to the inability to ensure supply continuity.

The Geographic Information System (GIS) used by the Distribution Company, shown in Figure 1, integrates the distribution network onto the zoning layout. The yellow-marked area represents the region where the F-14 feeder is energized, while the blue area represents the region where the F-13 feeder is energized. It can be observed from the image that both feeders, indicated by the two colors, merge in the same root building. In the case of a fault or outage, the region left without power can be supplied from the other feeder. Thus, faults can be rectified without leaving subscribers without power, ensuring supply continuity. Additionally, the coupling cell within the ring network, depicted in the image, is a cell with inputs from two separate sources and possesses an automatic switching feature. This prevents any delays during switching operations, ensuring efficient maneuvering.

The Distribution Company obtained data from the Inavitas system, where analyzers installed on feeders in the District TM measure and report quality parameters such as power, current, voltage, etc. The Inavitas system serves as a program for analyzing feeders and is commonly used by Distribution Companies. The graph depicting the apparent power (S) values during fault conditions for the F-13 and F-14 feeders, which are utilized as the ring network, is presented based on data from the Inavitas system. In Figure 2, the F-13 feeder is indicated by the blue color, and the F-14 feeder is represented by the black color. Upon observing the graph, it becomes evident that the load of F-14, indicated in black, is transferred to F-13, depicted in blue, at the point where F-14 is disconnected.

In Figure 3, it is observed that there is a fault in the square area corresponding to F-14, resulting in the feeder losing power. By activating F-13, which serves as an alternative power source for F-14, the creation of a powerless area is prevented. Both feeders receive power from the F-13 F-14 ring network, as indicated by their supply areas.

Based on the data obtained from Inavitas for a 10-minute interval, an outage occurred in the F-14 feeder on July 25, 2023, at 23:00, and power was restored around 10:50 on July 29, 2023. A total of 4142 subscribers fed from the F-14 feeder were affected by the outage. The process of transferring the load from F-14 to F-13 took 50 minutes, and the restoration of F-14 to its normal state took an additional 30 minutes. There are reasons behind the extended time taken for the activation and deactivation of the ring network. One possible reason is the failure to report the outage as an alert. If outage information is not provided to the 186 electrical fault alert line, the teams unaware of the outage cannot take action. Another reason for the extended process of activating and deactivating the ring network is the mandatory implementation of occupational health and safety conditions by the electricity distribution companies. During the electrical operation in the

Distribution Company, a "Visual Confirmation" is conducted. Operators monitor and guide the stages of the maneuver using tablets called "press-talk," ensuring that occupational safety measures are taken at maneuver points, the correct safety equipment is used, proper grounding is established, correct isolation is achieved, and energy control is verified. Therefore, maneuvers that are expected to be shorter in duration can take longer due to these occupational health and safety considerations. However, the automatic activation and deactivation of alternative power sources can be achieved by incorporating the ring network's root building or distribution centers into the SCADA system.

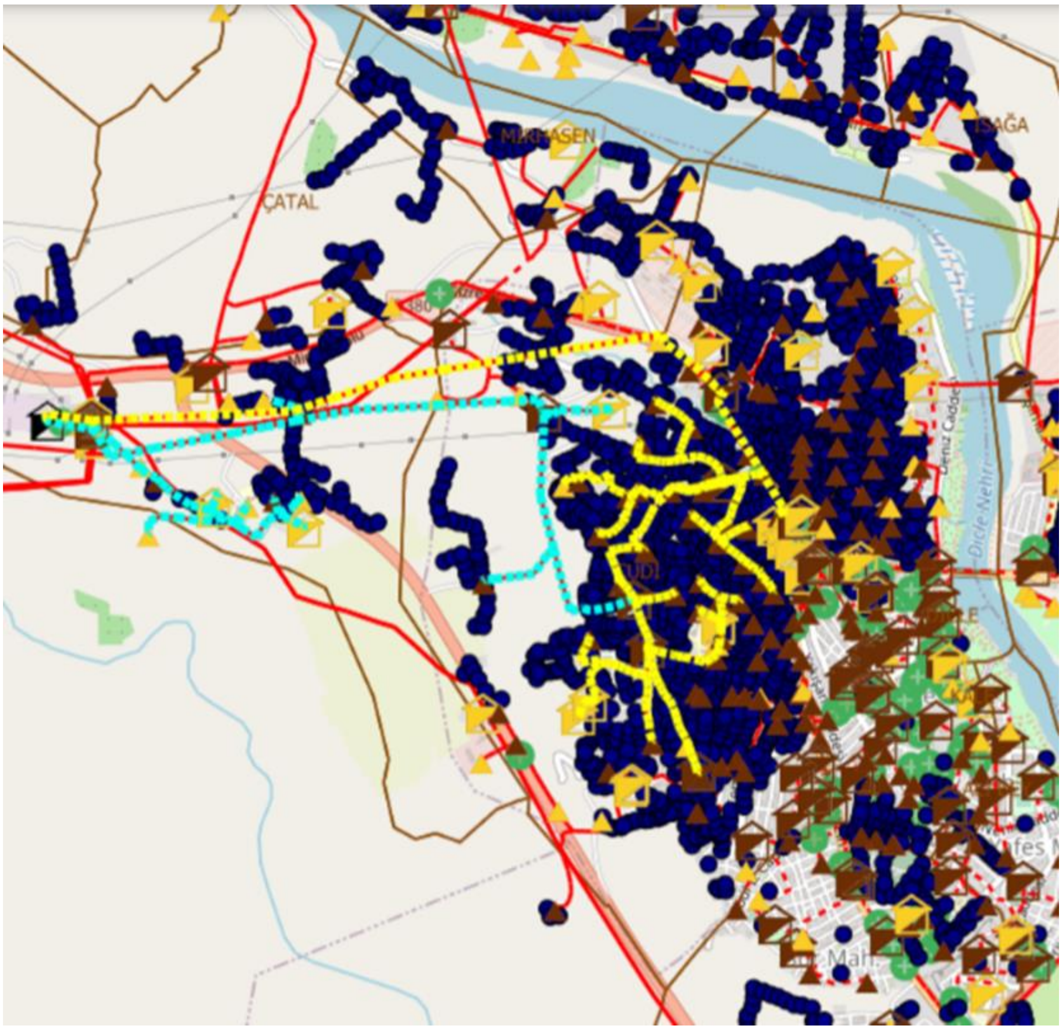

Figure 1. Model of F13-F14 Ring Network.

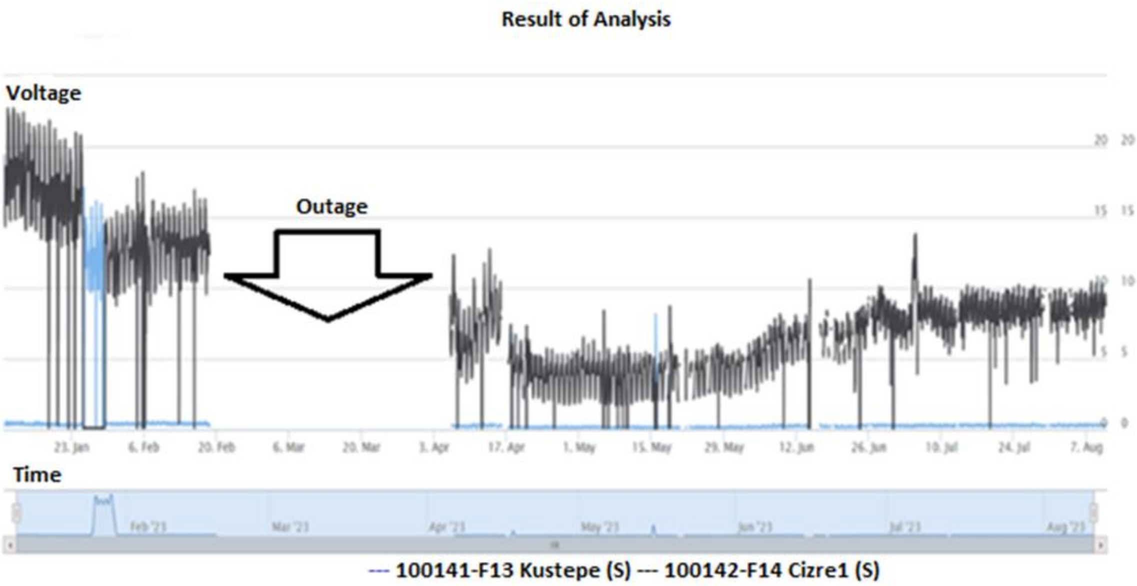

Figure 2. Outage of F-13 F14 ring grid model.

Figure 3. Support of F-13 ring grid model.

F13 and F14 information showing the number of customers, load points, amount of energy, number of faults and the duration of these faults are shown in Table 1.

In Table 2, the calculation of compensation penalties that distribution companies are responsible for in the event of long-duration outages is provided. If the alternative power supply is not activated, distribution companies incur significant penalties for each long-duration outage. However, when there are alternative power sources for the feeders in case of a fault, the occurrence of long-duration outages is prevented, and no penalties are imposed.

Table 1. F13 and F14 Feeders data.

Period of 2023	F13	F14
Number of Subscribers	118	4150
OG Number of Failures	18	168
Failure Time (Hours)	31	297,3
P (Kw)	0,4	15,5
Conductor Characteristics	3/0 PIGEON	477 HAWK

Table 2. F-14/F-13 Ring Status Interruption.

F-14/F-13 Ring Status Interruption	No	Yes
Starting Interruption	25.07.2023 23:00	25.07.2023 23:00
End Interruption	29.07.2023 10:50	29.07.2023 10:50
End Interruption (Min)	83,833	1,33
Number of Affected Subscribers (Urban AG)	4.142	4.142
Number of Affected Subscribers (Urban OG)	8	8
Total Number of Affected Subscribers District	4.150	4.150
If the Leakage Rate was below 40%, how much compensation would be paid (TL)	457.414	-

Considering the situation where the ring network is not activated on July 25, 2023, at 23:00, an outage occurred in the F-14/F-13 feeder, and power was restored around 10:50 on July 29, 2023, affecting 4142 subscribers fed from the F-14 feeder. The F-14 feeder remained without power for approximately 84 hours. According to the "Electricity Market Regulation": "Under this Regulation, the compensation amounts to be paid to users by the distribution company have been determined for the year 2021. Compensation amounts are updated using the revaluation rate published every year, and the updated compensation amounts are used for payments starting from the following year." In this context, the compensation amounts to be paid to users for the year 2022 are as follows: For long-duration outage compensation, residential subscribers with a contract capacity of 160 kVA or less will receive 108.96 TL, while other subscribers will receive 217.92 TL. Users with a contract capacity between 160 kVA and 630 kVA (inclusive) will receive 653.76 TL, and users with a contract capacity above 630 kVA will receive 1307.52 TL. For annual outage compensation calculations, CAIFI is set at 54.48 TL, and CAIDI is set at 27.24 TL. Users with a contract capacity between 160 kVA and 630 kVA (inclusive) will receive 480 TL, while users with a contract capacity above 630 kVA will receive 960 TL." Based on this information, the total compensation amount to be paid to subscribers affected by long outages is calculated. All AG subscribers are considered to have a contract capacity of less than 160 kVA, while OG subscribers are considered to have a contract capacity between 160 kVA and 630 kVA.

The Long Duration Outage Compensation has been calculated as 457,414 TL. In the event of a long-duration outage, the distribution company is responsible for paying the compensation penalty. If the alternative power source is not activated, distribution companies incur significant penalties for each long outage. When there are alternative feeders available for the feeders in case of a fault, long-duration outages are prevented, and no penalties are incurred.

In Figure 4, Inavitas data for June 2021 is presented where the F-13/F-14 ring network was not established. Upon examining this data, it can be observed that during the month, in cases of outages in F-14, where there is no alternative power source, feeder users experienced prolonged periods without electricity. The highlighted red square indicates instances where the load in F-14 has dropped to zero, while the load in F-13 remains unchanged.

In the absence of the F-13/F-14 ring investment, let's analyze the situation for a fault that occurred. According to the 10-minute data obtained from Inavitas as shown in Figure 5, a fault occurred in F-14 at around 15:20, and power was restored at around 20:20. Since there is no alternative power source, all subscribers within the supply area of the F-14 feeder experienced a total of 5 hours without electricity.

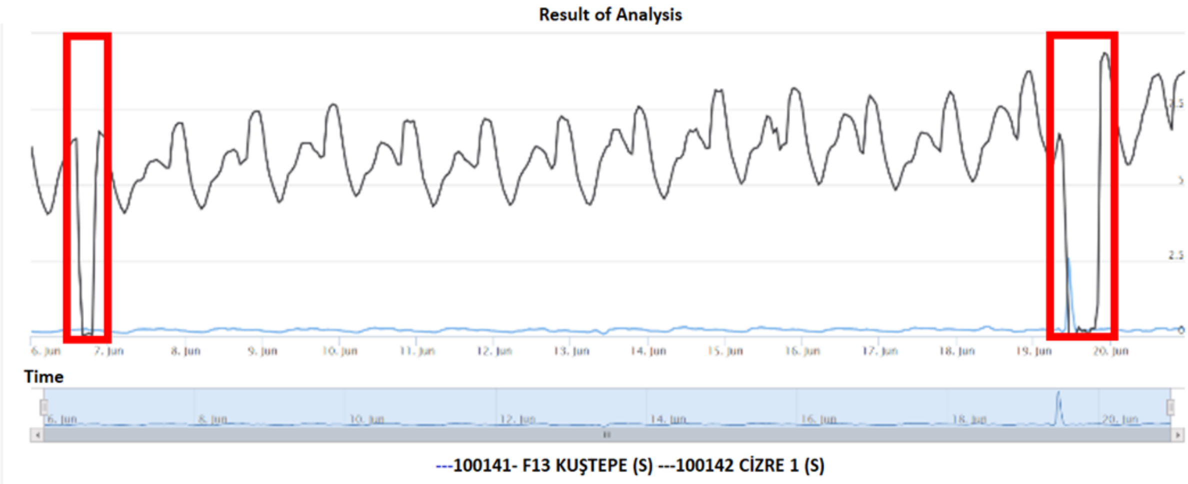

Figure 4. Without electricity for a long time June 2021.

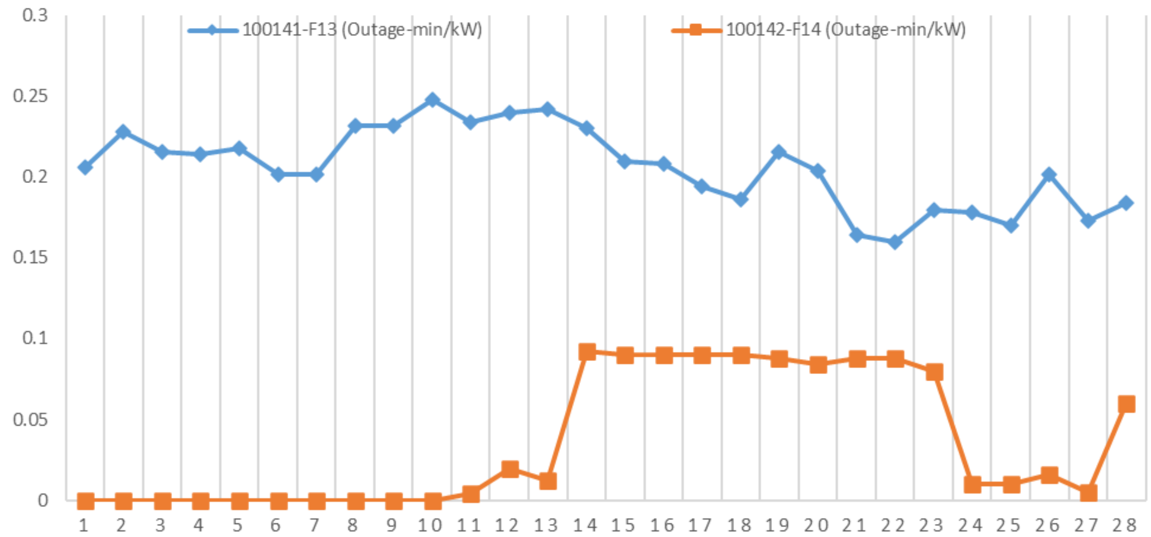

Figure 5. Numerical data for F13 and F14 for the year 2021.

Considering the energy consumption in 2021, assuming the current situation is half as much, the number of subscribers is assumed to be 2500. In order to perform feeder-based compensation calculation.

Assuming that there were 20 occurrences of the existing fault, and all subscribers are in the same tariff and have the same characteristics (Equation 5-6):

$$\text{CAIFI} = \sum_{i=1}^{n} t_i \quad (\text{CAIDI}) = 100 \tag{5}$$

$$PUFO_f = [\text{CAIFI}f - \text{TVCAIFI}f] * ENS * AD_f = [100 - 72] * 6 * 60 * 100 * 0.8 = 806{,}400.00 \text{ TL} \tag{6}$$

The 2021 residential unit price is 0.8 TL, and the average power of the feeder is chosen as 6 kW.

In the case of a long-duration outage that occurred on June 19, 2021, in F-14, lasting for approximately 11 hours, when the compensation calculation is made, it was determined that for long-duration outages in 2021, compensation of 80 TL per subscriber with a power capacity of less than 160 kVA should be paid. With a hypothetical example of 2021 subscriber numbers, it is evident that solutions need to be implemented due to the impact of prolonged outages on users' quality of life, as well as the responsibility of distribution companies for not providing continuous and quality electrical energy, which can result in penalty conditions. Network investments should aim to provide alternative power sources and ensure high-quality and continuous electrical energy.

Figure 6 displays a GIS view of the cell layout of the F-13/F-14 ring installation. According to the network, there is an input cell (F-14), two output cells supplying separate transformers, one backup cell, and one transformer protection cell within the root building due to the presence of an internal transformer. Additionally, there is an F-13 ring cell along with a coupling cell to enable ring operation with F-13. The coupling cell is where two separate energy sources enter. In the event of a fault, it automatically switches to the energy source that is operational. The cost of the installed facility is calculated, and the investment amount to be incurred is determined.

The installation cost of medium voltage metal-clad modular cells and a monoblock concrete transformer building for the recommended ring system has been investigated. This cost, based on the 2023 TEDAŞ unit price, results in an estimated cost of 534,095.06 TL for the installed F-13/F14 ring investment network.

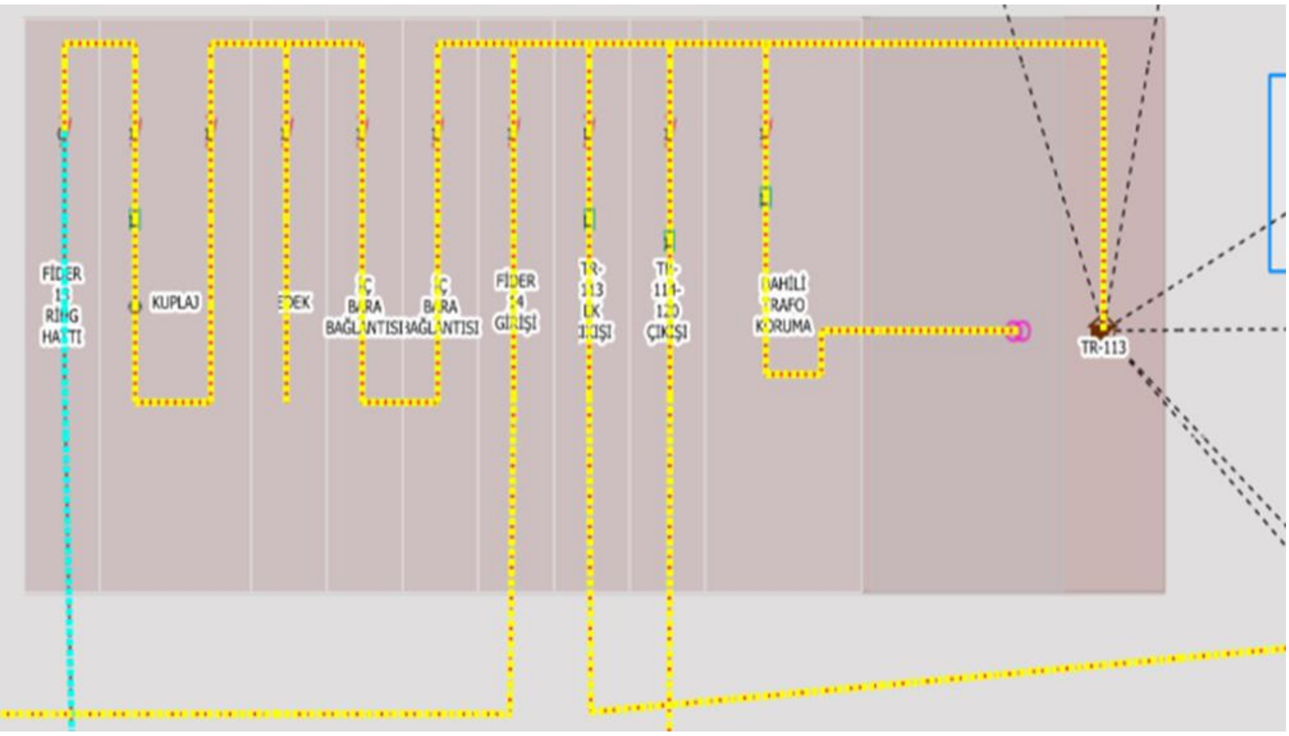

Figure 6. System of Model TR113 Cell Layout.

4. Conclusion

The proposed methodology focuses on evaluating the effectiveness of a specific method to increase the continuity of energy supply in ring networks. The F13/F14 Ring Grid model was used as a framework to analyze the impact of this method, thus adopting the cost-benefit approach to begin the analysis. This involves evaluating the costs associated with implementing the method, such as the costs associated with upgrading or replacing existing grid infrastructure to accommodate the ring grid configuration. On the other hand, the benefits of the method are evaluated by taking into account the improvements in energy supply continuity with the implementation of the ring network. One of the main issues examined in the methodology is the calculation of compensation penalties. These penalties are determined according to predetermined criteria and aim to encourage distribution companies to maintain service quality at a certain level. By quantifying the penalties that will be imposed on distribution companies for prolonged or frequent outages that exceed a certain threshold, the analysis provides a means to measure the potential financial impact of the method on these companies. Additionally, the methodology includes a comparison between costs and benefits associated with the method. While the costs include those incurred in installing the ring grid, the benefits include improvements in energy supply continuity and a corresponding reduction in outage-related costs.

The study aims to determine whether the advantages gained from applying the method outweigh the associated costs by conducting a comprehensive cost-benefit analysis. It is worth noting that the methodology takes into account a variety of factors beyond just reliability considerations. For example, they include investment costs, regulatory requirements and customer preferences regarding acceptable levels of energy supply continuity. By considering these factors collectively, a more holistic assessment of the feasibility and effectiveness of the method can be obtained. Overall, the coupling methodology used in this study offers a structured approach to evaluate the potential benefits, costs and feasibility of implementing a method aimed at increasing the continuity of energy supply in ring networks. This method uses the F13/F14 Ring Grid model, where one line is fed from the other in case of fault on a feeder. Conducting a comprehensive cost-benefit analysis, the study aims to provide insight into the economic and operational consequences of adopting this method. As a result, ensuring the continuity of electricity supply is vital for the needs and functioning of modern society. Strategies such as the use of alternative energy sources, installation of backup energy lines, infrastructure investments and technological innovations play an important role in minimizing the negative effects of power outages and meeting the energy needs of society. These steps not only increase the continuity of energy supply, but also contribute to the establishment of a sustainable and reliable energy infrastructure. In this study, the most important process to ensure the continuity of energy supply in network enterprises is the provision of an alternative power source. The alternative power source, which prevents users from being without electricity due to any potential interruption in the grid, is advantageous for both users and distribution companies.

Looking at the cost calculation, although it might seem like an initial expensive investment, comparing the potential costs of compensation fines for single long outages or total possible outages on the feeder, as shown in Figure 6.5, reveals that the investment cost of the ring network would be much more beneficial. Furthermore, like any investment, long-term returns of alternative energy investments should be taken into account. In the model, two output cells feed separate transformers for the F-14 feeder, and there is one spare cell. Additionally, a transformer protection cell exists within the main building. For achieving a ring connection with F-13, there is a coupling cell along with an F-13 ring cell. The investment made in the coupling cell is used as a cell where two different energy sources can enter. In the case of an unexpected fault, it provides uninterrupted energy supply by automatically switching to the source with energy. The investment cost for the established coupling cell is calculated as 535,095.06 TL. On the other hand, the compensation costs attributed to distribution company due to outages, for example, in the year 2021, an outage of 5 hours resulted in a fine of 806,400.00 TL. The designed ring investment would be lower than this amount, which is 271,304.94 TL, thus preventing such an outage. Similarly, in 2021, a penalty of 200,000.00 TL was issued due to an outage lasting 11 hours. Another analyzed outage occurred in 2023, lasting for 11.5 hours, which resulted in a calculated fine of 457,414.00 TL.

The method employed in the study compared the outcomes and penalty processes between the presence and absence of the F-13/F-14 ring network. It was determined that the investment cost, which is approximately equal to the estimated compensation amount for a long outage in F-14, is more profitable in the long run. To ensure that electricity distribution companies prioritize the continuity of energy supply, a comparison between such penalty situations and investments that would improve the grid needs to be made. These investments will not only enhance the grid in the long term but also ensure user satisfaction while avoiding the occurrence of penalty situations.

Author contributions

Rojin Temiz: Conceptualization, Methodology, Software, Writing-Original draft preparation. **Mehmet Rida Tur:** Data curation, Software, Validation, Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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