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Design of Multi-Level Mathematical Model for Radial Supply Networks in Power Systems

Abstract: - Today, the rapid advancement in technology and the expansion and development of human needs for sustainable technologies have placed greater emphasis on electrical energy. Consequently, enhancing reliability in electrical systems within the power industry has become highly significant. The objective of this research is to present a mathematical model to calculate and improve reliability, taking into account economic constraints in the power distribution network. This research is practical in terms of its objectives and outcomes, and it is operational in nature, based on operations research. It employs mathematical modeling and Python software, using data from the period between 2019 to 2023. Utilizing expert opinions and the Analytical Hierarchy Process (AHP) method, the findings indicate that parameters such as disconnectors, high and low voltage busbars, power transformers ranging from 20 kV to 400 V, communication cables, capacitors, generators, and UPS systems are crucial in assessing the reliability of this network. Accordingly, a suitable mathematical model has been developed considering the objective and constraints associated with each parameter. The designed model was then implemented in Python software to obtain the reliability at each stage based on the software's output. To verify the performance of the calculated power system, it was also implemented and analyzed in ETAP software, which is specialized for electrical systems. Given that increasing reliability also raises costs, and these two objectives are contradictory, this study aims to increase reliability and reduce costs in each of the power lines under study. Throughout all these stages, cost constraints will be considered based on the cost list for electrical installations, buildings, and equipment, determining the optimal state that maximizes reliability in each power line while minimizing costs imposed on the system. Using expert opinions and decision-making techniques, the findings indicate that parameters such as circuit breakers, high and low voltage busbars, 20 kV to 400 V power transformers, communication cables, capacitors, generators, and UPS are of greater importance in calculating the reliability of this network. The results show that after 50 iterations and simulations, the ultra-emergency line has a higher importance and ranking in reliability among the four output feeders. In all stages, the reliability of all lines has been calculated considering economic constraints. Considering the comprehensiveness of this study, the results can serve as a suitable basis for implementing research and operational projects in extensive radial networks in the power industry. Before execution, all stages of simulation, implementation, and reliability calculation of the lines can be computed and compared.

Keywords: Electrical Systems, Power Network, Reliability

I. INTRODUCTION

The reliability of a system indicates the degree of confidence in its proper and optimal performance under normal and abnormal conditions, which is related to the quality of a product over time [1]. The most common definition of reliability is the probability that a system will perform its assigned task correctly under specified environmental conditions. The quality and stability of electricity supply is one of the most important indicators for both large and small consumers (households) [2]. The reliability of power systems is assessed both online (for current operational conditions) and offline (for potential expansion) [3]

The first concept refers to the reliability of the system in a static state and depends on the availability of sufficient resources within the system to meet the demand load of customers or to achieve the system's operational goals. These resources include the necessary equipment for generating sufficient electrical energy, as well as appropriate and adequate equipment in the transmission and distribution sectors to transfer electrical energy from the

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generation site to the load points connected to the system. In other words, the system's competency is evaluated under static conditions, which do not encompass system disturbances. The second concept, system dependability, relates to the system's ability to respond to disturbances that affect it. Thus, system dependability is assessed by the system's response to any incident or disturbance it encounters. For instance, the use of a device known as a UPS (Uninterruptible Power Supply) in some sensitive applications illustrates this concept. The UPS operates in such a way that the loads it supplies receive a completely sinusoidal voltage without any distortion or frequency changes. Even in the event of a power outage caused by an incident or accident, the UPS can continuously supply power to the consumer without interruption [4]. The incidents and disturbances that occur include conditions caused by random disruptions at any point in the system, which may result in the loss of the costs incurred for energy generation and transmission for a long or short duration [5].

Given that there has been no previous study identifying the influential parameters on reliability in a continuous and chain-like power system, similar to a supply chain, and in a multi-level manner, and considering the importance of the reliability of the power supply system, we aimed to identify and prioritize several interconnected parameters related to the reliability of the power system. Following this, we intend to measure the reliability of each piece of equipment and each line, taking into account economic constraints, which are critical in decision-making [6]. In this study, we seek to answer the question of whether it is possible to design a model for the radial and multi-level power distribution network, which is currently serving customers, that optimizes reliability while also considering economic constraints.

This research aims, in the first stage, to identify the parameters and indices influencing the reliability of the power network. In the second stage, it seeks to present objectives and constraints in the form of a linear programming model based on these indices and parameters, allowing for the measurement and attainment of the highest reliability in a multi-level and radial power transmission network. In the third stage, considering the significance of costs in projects, cost is included as the second objective function. This ensures that while aiming for the desired reliability level for each line, we also achieve the minimum possible cost.

Research Background

A power network can be broadly divided into three major sections: generation, transmission, and distribution. Each of these sections contains various types of equipment, whose performance can significantly impact the supply to consumers [7]. The first step in evaluating and improving system reliability is to establish criteria for design objectives. These criteria are estimated based on consumer needs. Figure 1 shows a schematic of a power system. Various elements such as high and low voltage busbars, disconnectors, transformers, low voltage transmission lines, and capacitor banks can be observed. The presence or absence of each element in any line significantly affects the final system output, which is the consumer load. As a result, some lines that are more critical use parallel elements to enhance reliability. In Figure 1, four feeders are shown, each employing specific elements based on the importance of the load they supply in each line.

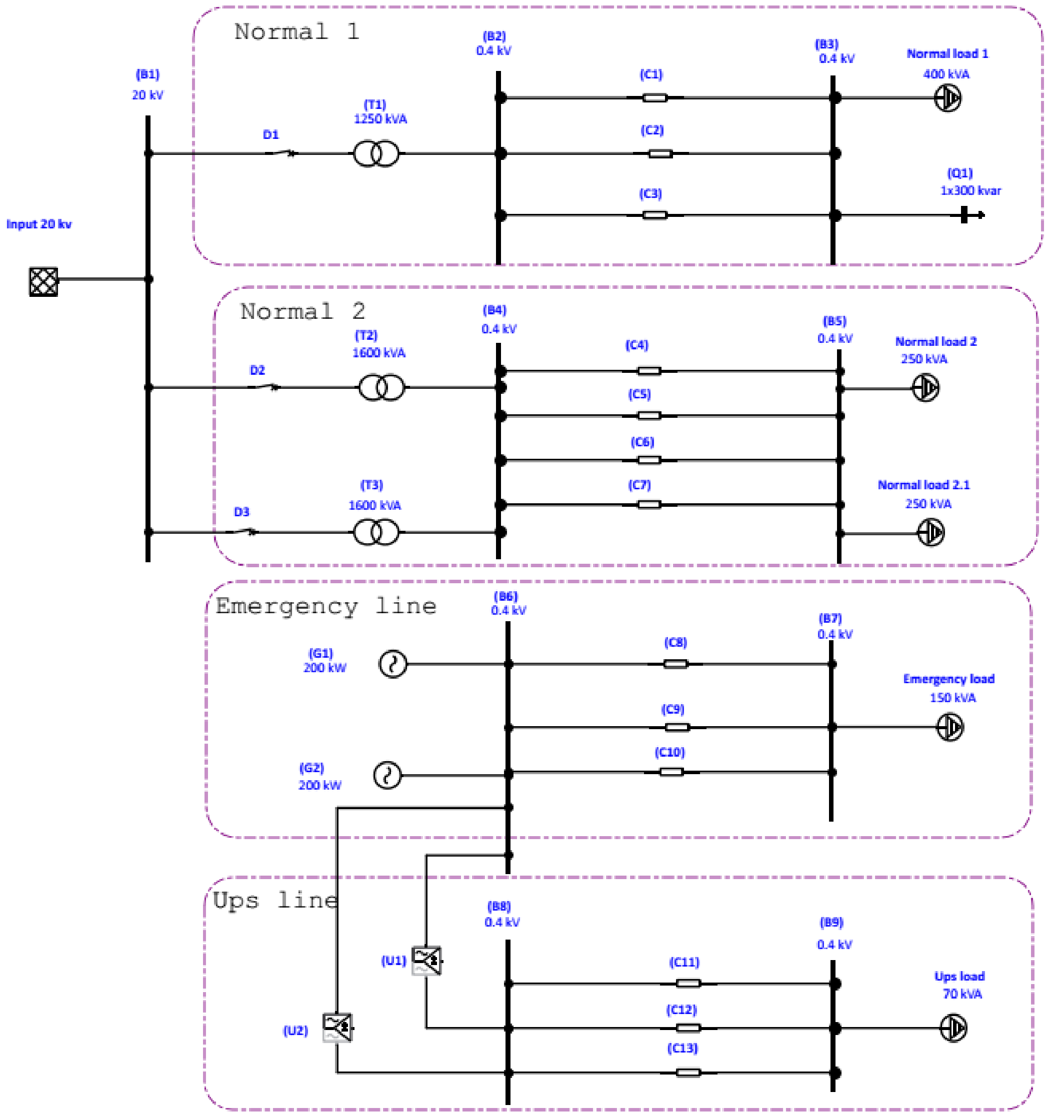

Figure 1. General schematic of the studied power system with 4 consumers (Researcher's findings)

Given the equipment used and the figure above, brief descriptions of each element are provided for better identification:

D - High-Voltage Disconnectors:

High-voltage disconnectors serve as switches to interrupt or establish connections under specific conditions in power systems. The reliability of these devices depends on factors such as lifespan, operating temperature, capacity, pollution resistance, humidity, panel stress, operating voltage, maintenance procedures, current capacity, etc. [8]. Disconnectors, also known as high-voltage switches, are designed for use in high-voltage environments and have a specialized structure different from standard electrical switches found elsewhere. Their purpose is primarily for circuit disconnection and connection during maintenance tasks or system protection [8]. The proper functioning of these devices is crucial; malfunctioning under normal or critical conditions can significantly impact the overall reliability of the system. Internal systems of these switches must be designed to suppress intense sparks resulting from their operation and prevent them from transferring outside environments [9]. Various studies have explored the role of reliability in different types of switches, including very high-voltage disconnectors [10].

T - Transformer:

Transformers are devices that convert high-voltage (20 kV, high-pressure) into low-voltage (400 V, low-pressure) suitable for consumption purposes. Power transformers are equipment used for voltage transformation from high to low and vice versa. When dealing with long-distance power transmission, higher voltages are used to minimize losses, while voltages are reduced to 230 volts (single-phase) or 400 volts (three-phase) closer to consumers to accommodate household and other usage requirements. Naturally, the correct or incorrect operation of these devices also affects the system's reliability [4].

B - High-Voltage Busbars:

High-voltage busbars are made of copper strips and can branch off a 20 kV line. The diagram above shows three branches taken from it. Low-voltage busbars, similar to high-voltage ones, are made of copper and used to branch off low-pressure consumption points.

Transmission Cables:

For transferring energy over long distances, transmission cables are necessary. In this study, low-voltage cables are used to transmit voltage over a distance of one kilometer (based on the system's design). Like busbars, cables are made of copper and are available in various sizes; in this design, sizes 240 and 300 are used.

According to a study by the Edison Institute (2016), 70% of power outages in the United States are due to natural events such as lightning, rain, and snow, while 11% are caused by animals and birds [11]. Hence, the reliability of underground power lines is significantly higher compared to overhead lines due to these factors [12].

Capacitor Bank:

In one of the distribution lines or feeders, a capacitor bank has been utilized. This equipment significantly aids in improving the power factor, preventing energy loss, and stabilizing the voltage at the end busbar [4].

Generator:

Generators supply emergency loads in the system, providing power to essential functions approximately 15 seconds after power outage, once the generator starts and is under load. These include lighting for certain parts of buildings or HVAC systems in broadcast studios.

UPS:

UPS stands for Uninterruptible Power Supply and is used in critical locations where continuous voltage supply is paramount. This equipment supplies emergency loads, including both city power and backup scenarios, ensuring uninterrupted power delivery to critical systems. The reliability of a UPS depends on numerous factors. This complex and expensive equipment's reliability is influenced by the manufacturer brand, batteries, and the number of battery strings used. Although initially the comparison of these parameters is not considered due to the use of the same brand and number of battery strings in this system, the role of the number of battery strings in reliability calculations will be demonstrated in subsequent stages. The layout of the UPS is also crucial in the aforementioned matter. Figure 2 illustrates two parallel UPS units along with their respective components, enhancing reliability.

In this configuration, the load is divided between two devices. If an incident occurs with either device, the other device will fully supply the load, ensuring that no power outage is displayed at the output despite the changes.

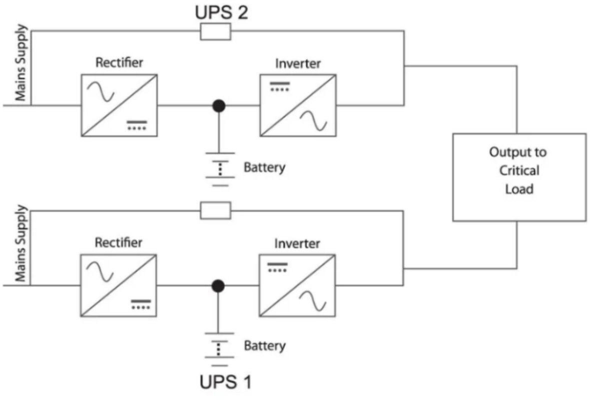

Figure 2. internal diagram of 2 parallel ups

Some researchers,[13] compared the reliability of a UPS with a single control system to a device with multiple control systems, analyzing and examining failure rate changes due to temperature increases using the Weibull probability density function. This device, like other equipment, follows the bathtub curve, where the left side represents the burn-in and initial testing phase, the middle section encompasses the useful and normal operating life, and the right side indicates the failure due to wear-out.

All UPS units must be equipped with batteries to supply power to consumers when there is an outage. Therefore, batteries are a fundamental component of this equipment. The brand, type of battery, ampere-hour rating, number of parallel battery strings for each device, battery lifetime, and the environmental temperature where the batteries are stored all significantly impact the reliability of both the batteries and the UPS units.

Consumer loads:

Based on the needs of consumers, this study considers buildings of varying importance—less important, important, and very critical. Each section will have its specific load requirements [4].

Increasing reliability in systems leads to higher costs. The costs associated with enhancing reliability vary depending on the system's design and structure and can encompass numerous factors. For instance, adding an additional transformer to the existing set to improve line reliability incurs significant costs not only in terms of equipment but also in operation, maintenance, and servicing. On the other hand, reducing reliability imposes substantial costs on the operator. Beyond repair costs, component replacement, or ultimately, system replacement, it is essential to calculate the costs associated with downtime and outages due to failures.

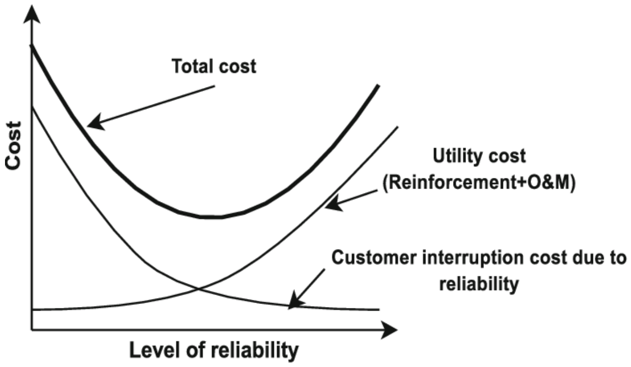

Figure 3. Total reliability cost curve

If the reliability percentage is plotted on the horizontal axis of a graph and costs on the vertical axis, one curve will represent the costs associated with low reliability and another curve will represent the costs of ensuring reliability. As observed, an economic balance typically emerges at a point on the graph, indicating the optimal level of reliability [14].

A review of theoretical literature and previous research highlights the critical importance of calculating and measuring reliability in complex, multi-tiered power grid systems. Most past studies have focused on analyzing and optimizing the reliability and lifespan of internal components of power transmission lines, transformers, UPS systems, and so on, individually. Even in studies where parameters have been considered integrally, they have only been examined within a simple electrical system. Therefore, the gap addressed in this article involves presenting a mathematical model to measure reliability in a complex, radial power distribution network while simultaneously examining cost implications concerning the significance of reliability across different lines Based on the review of previous studies and related literature, a few examples are noted:

Table 1. Research Conducted on Parameters and Their Effects on Reliability

Results and method	The title of the research	year	researcher
Different types of circuit breakers have been examined, along with their applications and reliability	type of circuite breaker	2023	Khosropanah & Davoovi [10]

Reduction in reliability and lifespan of transformers in harmonic environments.	Harmonic effect on transformer lifetime	2022	Ahmadi
Calculating the reliability under internal generator stresses and the role of generator protections in this context.	Reliability analysis and optimal generator allocation and protection strategy of a non-repairable power grid system	2022	Minhao Cao & Jianjun Guo [12]
The role of heat and temperature on the reliability of batteries in renewable energy systems has been examined.	Reliability Assessment of Renewable Power Systems Considering Thermally-Induced Incidents of Large-Scale Battery Energy Storage.	2022	Siying Li & Chengjin Ye [15]
Using the Markov Chain model to evaluate the reliability of generators	Dynamic Reliability Evaluation of Diesel Generator System of One Chinese 1000MWe NPP Considering Temporal Failure Effects	2021	Dingqing Guo & Manjiang Yang [16]
Using the Monte Carlo technique, a method has been developed to calculate efficiency to enhance reliability in power systems.	Improving Computational Efficiency Techniques for Reliability Assessment of Electric Power Systems	2020	Dmitry Krupenev & Denis Boyarkin [3]
Examining the Role of Battery Maintenance and Repair in UPS Reliability	Predictive Maintenance of VRLA Batteries in UPS towards Reliable Data Centers	2020	Jing-Xian Tang & Jin-Hong Du [17]
Comparison of the Reliability Impact on Repairable and Non-Repairable Cables	Reliability Evaluation of Underground Power Cables with Probabilistic	2019	H. Nemati & A. Sant'Anna [18]
Methods to Increase the Reliability of Semiconductors in Electronics	Design for Reliability of Power Electronic Systems	2018	Huai Wang & Frede Blaabjerg [8]
Investigation and analysis of various power switch configurations to enhance reliability.	Reliability analysis of regular redundancy arrangements for power switches and presenting a new surplus structure	2018	Rahimi & Hoseini [19]
Examining the effects of cost on increasing or decreasing reliability.	Cost of reliability	2017	Nathan Taylor1, & Andrew Western [20]
Using an enhanced Crow Search Algorithm, an optimal method for the maintenance and repair of power transformers has been proposed.	Preventive and corrective maintenance and repairs in order toincrease the efficiency of the life of the power transformer	2017	Afzali. P & Key nia [21]
comparison of different control boards in enhancing the reliability of UPS systems	Distributed UPS control systems reliability analysis	2017	Tommaso Addabbo & Ada Fort [13]
The performance of repairable components in series and parallel systems has been compared.	Reliability analysis of random fuzzy repairable parallel and series system	2016	Amiri, Maghsod & Amir Reza Ayatollahi [22]
Temperature plays a critical role, as higher temperatures can significantly reduce the lifespan and reliability of transformers.	The influence of modeling transformer age related failures on system reliability	2015	S. K. E. Awadallah, J. V. Milanovic [23]

The role of UPS reliability in medical systems	Reliability Assessment of Uninterruptible Power Supply (UPS) System for Medical Operations in Zaria Kaduna State	2015	Olaitan Akinsanmi & Adedayo Kayode Babarinde [24]
Comparison of Different UPS Deployment Configurations and Their Roles in Enhancing Reliability	Reliability Comparison of Uninterruptible Power Supply (UPS) System Configurations	2013	Slobodan Jovanovic & Khairil Rahmat [25]
The Impact of Pollution on Transformer Lifespan in a City in the Netherlands: A Model for Reducing Lifespan from 60 to 30 Years	Modeling of Replacement Alternatives for Power Transformer Populations	2012	Arjan van Schijndel & Peter A. A. F. Wouters [26]

II.RESEARCH METHODOLOGY

This research is applied in terms of its objective and operational research-based in nature. It is a cross-sectional study with combined variables. The study environment consists of 20 kV and 400 V power lines of the Islamic Republic of Iran Broadcasting (IRIB), where reliability is of utmost importance. To identify high-importance indices and parameters affecting the reliability of multi-tier and parallel power systems, expert opinions were sought. These experts, numbering 15, have over 20 years of work experience and hold university degrees in Electrical Power Engineering and Master's degrees, and are key decision-makers in their workplaces.

The process of this research is as follows:

Initially, a review of previous studies revealed that no single study has comprehensively examined all significant and impactful parameters mentioned in the literature. Many factors, such as temperature or lifespan, can affect both themselves and other elements that influence reliability. Using the outcomes of reviewed articles and technical books, about 20 significant factors were identified for expert evaluation. After screening, these parameters were reduced to approximately 13. To prioritize the influential indices and parameters for formulating the mathematical model, the fuzzy Delphi technique was employed. Furthermore, due to the independence of the four lines in this network and their independent electric load consumption, the Analytic Hierarchy Process (AHP) technique was used to determine the weights of the lines.

The reliability of each component varies based on its technical specifications. For instance, the reliability of a distribution transformer can be influenced by factors such as lifespan, operating temperature, capacity, pollution, humidity, and more. However, certain factors may have a greater impact or weight compared to others. Considering the identified parameters and indices used in the proposed mathematical model, we define these parameters as follows:

Table 2. Definition of Modeling Parameters

W_i i=1,2,3,4	The weights of Normal Line 1, Normal Line 2, Emergency Line, and Ultra-Emergency Line.
RV_{Bi} i=1,2…,9	The reliability of busbar voltage (number of instances where voltage dropped to zero) over the period 1398-1402.
RL_{Bi} i=1,2,…..9 RL_{Di} i=1,2,3 RL_{Ti} i=1,2,3 RL_{Ci} i=1,2,3 RL_{Q} RL_{Gi} i=1,2	The reliability of the lifespan of busbars, circuit breakers, cables, transformers, capacitors, UPS systems, and generators is calculated using the Weibull distribution $R(t)=\exp\left[-(\frac{t}{\theta})^{\beta}\right]$

RL_{Di} i=1,2,3 RL_{ui} i=1,2	
RSD_i i=1,2,3 RST_i i=1,2,3 RSC_i i=1,2,3 SQ RS_{Gi} i=1,2 RS_{ui} i=1,2	The current capacity of the circuit breaker, transformer, and cable is calculated using the equation $S=\sqrt{3}*V*I$ and the triangular fuzzy function
RT_{ti} i=1,2,3 Rt_{Ci} i=1,2…,13 Rt_Q Rt_{bui} i=1,2 Rt_{bGi} i=1,2	Reliability and the impact of temperature are represented as trapezoidal or triangular fuzzy numbers.
n_T	number of transformers.
K_{Ci}	Cable length in meters
C_B	Cost of Purchasing Various Items
C_{PM}	Cost of Performing Preventive Maintenance and System Upkeep
C_D	Design and Implementation Costs
C_Z	Costs and Losses Due to Power Outages

According to Figure 1, there are several lines for different consumers, and the overall reliability of the lines, which is derived from the output and reliability of the 4 lines, can be obtained from the following formula:

$$Z=\left(1-(1-W_1R_{N1})*(1-W_2R_{N2})*(1-W_3R_E)*(1-W_4R_U)\right) \qquad (1)$$

In the above equation, (w) represents the weight of each line. Additionally,

R_{N1} , denotes the reliability of the normal line number one, which includes typical and less critical loads such as street lighting or regular office rooms that will be turned off when the main power supply is interrupted. Supplies loads such as street lighting or typical office rooms that can be temporarily shut down during power outages.

R_{N2} , represents the reliability of normal line number two, which handles loads that are slightly more critical than those on normal line number one. These include lighting inside more important buildings and the ventilation systems of office rooms. Similar to line number one, these loads will also be turned off when the main power supply is interrupted.

R_E , represents the reliability of the emergency line, which handles emergency loads. When there is a power outage, these loads will be re-energized after approximately 15 seconds, the time it takes for the generator to start. This ensures that the downtime is minimal. Examples of such loads include studio lighting and cooling systems.

R_u , The critical loads are referred to as "critical loads" and must never be shut down under any circumstances. Continuous and uninterrupted power supply is essential for these loads, such as sound and video consoles in broadcast studios, lighting for live broadcasting studios, and signal transmission and reception systems.

To determine the importance of each line based on the types of loads they supply, the Analytic Hierarchy Process (AHP) will be used. The weights or coefficients for each line will be determined as follows, based on the opinions of 15 technical experts:

$$Max\ \mathrm{Z} = (1 - (1 - 0.039\mathrm{R_{N1}}) * (1 - 0.083\mathrm{R_{N2}}) * (1 - 0.246\mathrm{R_E}) * (1 - 0.633\mathrm{R_U})) \tag{2}$$

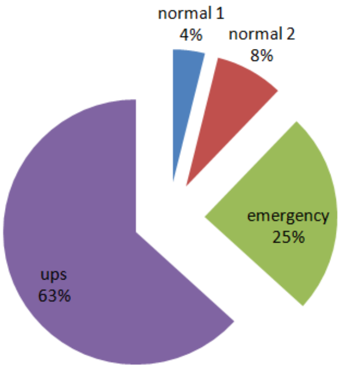

Figure 4. Graphical Model of the Importance of Each Line in the Power Grid Network Under Study

As expected, loads associated with UPS systems should have higher importance and naturally must also have the highest reliability to achieve this goal. To achieve the desired reliability, higher costs will naturally need to be incurred (which will be discussed in later stages).

Obtaining parameters that collectively impact the overall reliability of the system is a crucial aspect in the stages of reliability assessment. General conclusions regarding components such as transformers, busbars, high-pressure disconnectors, cables, generators, and UPS systems were examined using fuzzy Delphi technique and weighted via AHP based on the opinions of 15 technical experts. After posing questions and conducting surveys using Super Decisions software, parameters such as lifespan, temperature, capacity, number of elements, and voltage were found to be of greater importance. Regarding factors that may have higher importance and impact on reliability compared to others, temperature is notable. Temperature, utilized across all power system equipment shown in Figure 1, holds significant importance and ranks first. Elevated temperatures significantly affect equipment lifespan and consequently impact power system reliability. Lifespan ranks second, with a slightly lower weight compared to temperature, followed by voltage in third place.

The reliability equations for each line, considering series and parallel equipment, as illustrated in Figure 1, are obtained using the following formula:

$$\mathrm{Max\ Z}=(1\text{-}(1\text{-}\mathrm{W_1R_{N1}}).(1\text{-}\mathrm{W_2R_{N2}}).(1\text{-}\mathrm{W_3R_E}).(1\text{-}\mathrm{W_4R_U})) \tag{3}$$

$$\mathrm{R_{N1}}=\mathrm{R_{B1}}.\mathrm{R_{D1}}.\mathrm{R_{T1}}.\mathrm{R_{B2}}.(1\text{-}(1\text{-}\mathrm{R_{C1}})(1\text{-}\mathrm{R_{C2}})(1\text{-}\mathrm{R_{C3}})).\mathrm{R_{B3}}.\mathrm{R_Q} \tag{4}$$

$$\mathrm{R_{N2}}=\big(1\text{-}(1\text{-}\mathrm{R_{D2}})(1\text{-}\mathrm{R_{D3}})\big).\big(1\text{-}(1\text{-}\mathrm{R_{T2}})(1\text{-}\mathrm{R_{T3}})\big).\mathrm{R_{B4}}.\big(1\text{-}(1\text{-}\mathrm{R_{C4}})(1\text{-}\mathrm{R_{C5}})(1\text{-}\mathrm{R_{C6}})(1\text{-}\mathrm{R_{C7}})\big).\mathrm{R_{B5}} \tag{5}$$

$$\mathrm{R_E}=(1\text{-}(1\text{-}\mathrm{R_{G1}})(1\text{-}\mathrm{R_{G2}})).\mathrm{R_{B6}}.(1\text{-}(1\text{-}\mathrm{R_{C8}})(1\text{-}\mathrm{R_{C9}})(1\text{-}\mathrm{R_{C10}})).\mathrm{R_{B7}} \tag{6}$$

$$\mathrm{R_U}=(1\text{-}(1\text{-}\mathrm{R_{U1}})(1\text{-}\mathrm{R_{U2}})).\mathrm{R_{B8}}.(1\text{-}(1\text{-}\mathrm{R_{C11}})(1\text{-}\mathrm{R_{C12}})(1\text{-}\mathrm{R_{C13}})).\mathrm{R_{B9}} \tag{7}$$

The equations above pertain to the reliability of each of the lines depicted in Figure 1. In each line, each parameter is derived from calculating other parameters while considering constraints associated with each parameter.

The lifetime factor has been calculated and evaluated using the Weibull distribution. The reliability of capacitors' voltage has been determined based on statistics of voltage interruptions during the period from 2019 to 2023. Other parameters such as size denoted by S in cables, transformers, rectifiers, generators, and UPSs have been obtained from electrical calculations performed during project design and initial stages. The temperature factor, denoted by t, in some equipment like batteries, transformers, and cables significantly impacts reliability, considering the environment and expert opinions and technical catalogs impose constraints.

In the following equations, each parameter and its constraints are highlighted. Some constraints relate to the technical specifications of each equipment, while others pertain to its design. Some variables, such as the statistics-based voltage interruption of capacitor number one over the years 2019 to 2023, have been quantified numerically. Some variables have also been calculated using fuzzy logic methods.

$$R_{Bi}= RL_{Bi}.RV_{Bi} \quad , \quad i=1,2,\dots,9 \tag{8}$$

$RV_{B1}=0/989$, $RV_{B2}=0/987$, $RV_{B3}=0/986$, $RV_{B4}=0/991$, $RV_{B5}=0/991$

$RV_{B6}=0/993$, $RV_{B7}=0/993$, $RV_{B8}=0/999$, $RV_{B9}=0/99$

Based on Equation 8, the reliability of various busbars can be calculated. In these equations, the reliability of the voltage of different busbars has been calculated and obtained over a 5-year period.

$$R_{D1}=RL_{D1}.RS_{D1} \tag{9}$$

$$36\ A\le S_{D1}\le 40\ A \tag{10}$$

$$R_{Ti}=RL_{Ti}.RS_{Ti}.Rt_{Ti}.Rn_{Ti} \quad i=1,2,3 \tag{11}$$

$$1250\le S_{T1}\le 2000 \tag{12}$$

$$R_{Ci}=RL_{Ci}.RS_{Ci}.Rt_{Ci}.Rn_{Ci}.RK_{ci} \quad i=1,2,\dots 13 \tag{13}$$

$$240\le S_{Ci}\le 400 \quad i=1,2,3 \tag{14}$$

$$0^o\le t_{C_i}\le 70^o \quad i=1,2,\dots 13 \tag{15}$$

$$1000\ \le K_{ci}\le 1500\ m \quad i=1,2,3 \tag{16}$$

$$1000\ \le K_{ci}\le 1200\ m \quad i=4,5,\dots 10 \tag{17}$$

$$R_Q=RL_Q.RS_Q.Rt_Q \tag{18}$$

$$300\ kvar\le s_Q\le 400\ kvar \tag{19}$$

$$0^O\le t_Q\le 45^o \tag{20}$$

$$Q_c=P(\tan\theta_1-\tan\theta_2) \tag{21}$$

$$R_{Di}:L_{Di}.S_{Di} \quad i=2,3 \tag{22}$$

$$35\ A\le S_{Di}\le 55\ A \quad i=2,3 \tag{23}$$

$$1600\ \le S_{Ti}\le 2000 \quad i=2,3 \tag{24}$$

$$5^o\le t_{T_i}\le \mathbf{75}^o \quad i=1,2,3 \tag{25}$$

$$300\le S_{Ci}\le 400 \quad i=4,5,6,7,\dots,13 \tag{26}$$

$$380\ v\le V_Q\le 400 \tag{27}$$

$$R_{Gi}=L_{Gi}.t_{bGi}.S_{Gi} \quad i=1,2 \tag{28}$$

$$10^o\le t_{bGi}\le 40^o \quad i=1,2 \tag{29}$$

$$200\le S_{G\ i}\le 400\ kw \quad i=1,2 \tag{30}$$

$$R_{ui}=L_{ui}.L_{bui}.S_{ui}.t_{bui} \quad i=1,2 \tag{31}$$

$$15^o\le t_{bui}\le 35^o \quad i=1,2 \tag{32}$$

$$0\le L_{bui}\le 43800\ h \quad i=1,2 \tag{33}$$

$85 \leq S_{ui} \leq 120$ kw	i=1,2	(34)
$1000 \leq K_{ci} \leq 1100$ m	i=11,12,13	(35)

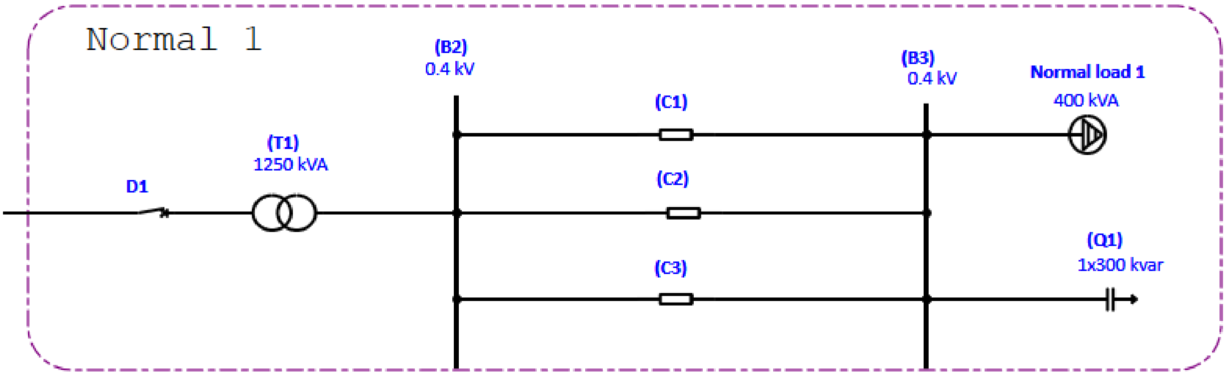

Figure 5. schematic of Normal line1 (N1)

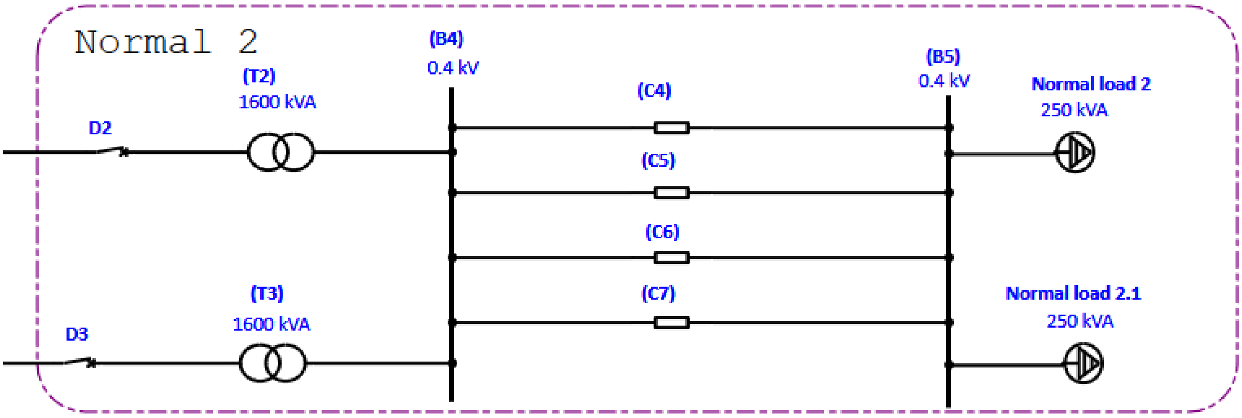

Figure 6. schematic of Normal line2 (N2)

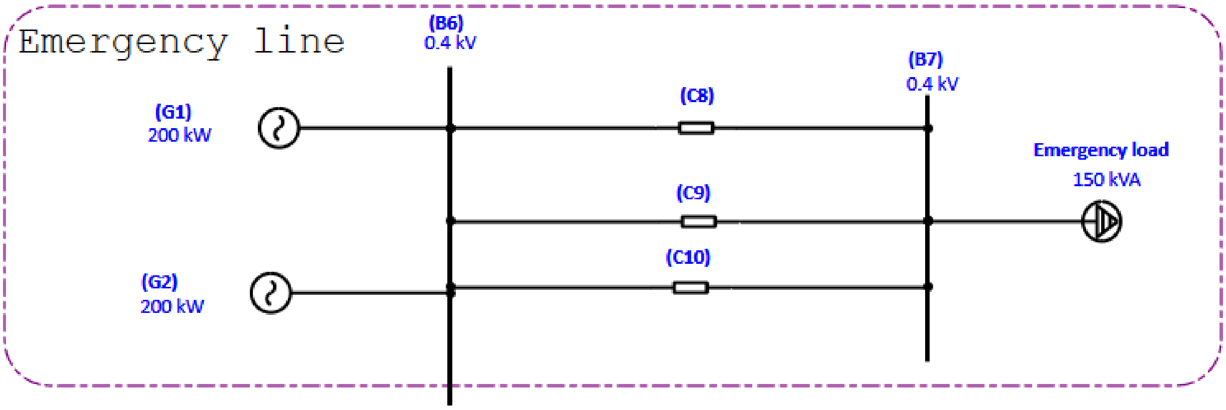

Figure 7. schematic of Emergency line (E)

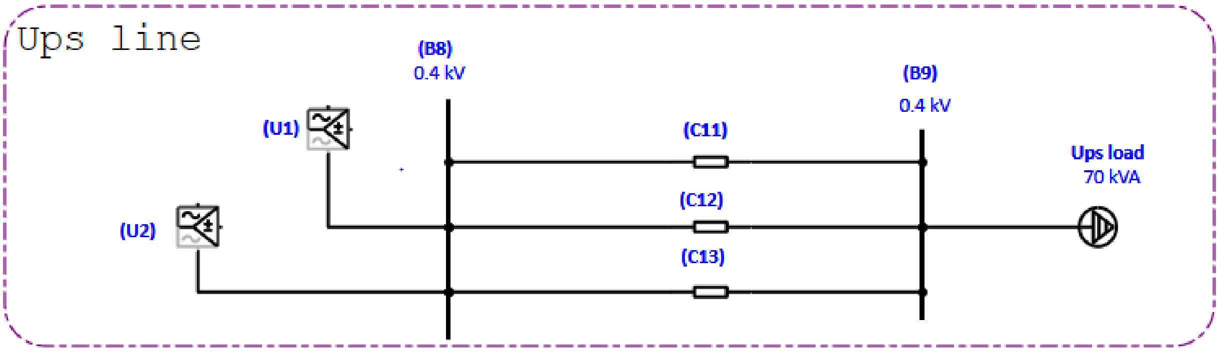

Figure 8. schematic of ups line (U)

Cost Reduction as the Second Objective

In the power system, all equipment is designed and purchased based on the load requirements of the consumer. The electrical demand, determined by the load purchased from the power company, dictates the specifications for high voltage switches, transformers of various capacities, and cables of different sizes, each with varying costs. Additionally, the maintenance costs of these components, generators of various capacities, and UPS systems with different capacities are crucial factors.

The purchase prices of various items can be calculated from the 2024 Electrical Engineering Price List [27]. The following outlines the key cost components:

1. High Voltage Switches: These switches are crucial for managing the electrical flow and ensuring safety and efficiency in the system. Their cost varies based on their capacity and specifications.
2. Transformers: Depending on the required capacity, transformers are chosen to match the load requirements. Costs vary significantly with different power ratings.
3. Cables: The size and type of cables used in the power system are determined by the load requirements and environmental conditions. The price of cables varies based on their size and material.
4. Maintenance Costs: Regular servicing and maintenance of high voltage switches, transformers, and cables are essential for ensuring reliability and longevity. These costs need to be factored into the overall budget.
5. Generators: The capacity of generators must align with the power demand of the system. Different capacities come with different price tags, impacting the overall cost structure.
6. UPS Systems: Uninterruptible Power Supplies with varying capacities are crucial for ensuring continuous power supply, especially for critical loads. Their costs are a significant part of the budget.

The purchase prices and maintenance costs for these items can be referenced from the 2024 Electrical Engineering Price List. These elements collectively contribute to the total cost, and efficient management and procurement strategies can lead to significant cost savings. The following section will discuss cost-related indicators:

Cost of Purchasing Various Items

The purchase of all the equipment mentioned above will incur costs, which are determined according to the following equation:

$$C_B = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{Bij} . X_{Bij} \quad (36)$$

Costs for performing preventive operations and system maintenance:

All electrical equipment examined in this study requires preventive operations and proper maintenance to ensure that the equipment and system function effectively. These activities involve costs such as labor, spare parts, and equipment replacement.

$$C_{PM} = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{PMij} . X_{PMij} \quad (37)$$

The maintenance and repair costs vary depending on the assets and capital of each business. However, as mentioned, the maintenance budget can account for up to half of the operational costs. Some examples of these costs are provided in the table below:

Table 3 - Maintenance and Repair Cost Ratio to Total Operating Cost

percentage	Industry
20% - 50%	mine
15% - 25%	Metal production
15% - 25%	Appliances
3% - 15%	productive
3% - 5%	Assembly

Design and Implementation Costs

At the beginning of the project, based on customer requirements, costs must be incurred to engage expert designers and engineers for the design and execution of the work. These costs are calculated according to the following formula

$$C_D=\sum_{i=1}^{n}\sum_{j=1}^{n} C_{Dij}.X_{Dij} \qquad (38)$$

Cost and Loss Due to Power Outages

In all aspects of the supply chain, if the system fails to perform its tasks properly, it will incur costs. In this study, these costs are incurred when a power outage occurs and are calculated according to the equation below:

$$C_Z=\sum_{i=1}^{n}\sum_{j=1}^{n} Cz_{ij}.Xz_{ij} \qquad (39)$$

Based on the above-mentioned content, the overall cost function will be as follows:

$$\text{Min } C=C_B+C_{PM}+C_D+C_L+C_Z \qquad (40)$$

$$\text{Min } C=\sum_{i=1}^{n}\sum_{j=1}^{n} C_{Bij}.X_{Bij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{PMij}.X_{PMij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{Dij}.X_{Dij}+\sum_{i=1}^{n}\sum_{j=1}^{n} Cz_{ij}.Xz_{ij}$$

$$C_{N1}=C_{N1B}+C_{N1PM}+C_{N1D}+C_{N1Z} \qquad (41)$$

$$CN_1=\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N1Bij}.X_{N1Bij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N1PMij}.X_{N1PMij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N1Dij}.X_{N1Dij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N1Zij}.X_{N1Zij}$$

$$C_{N2}=C_{N2B}+C_{N2PM}+C_{N2D}+C_{N2Z} \qquad (42)$$

$$CN_2=\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N2Bij}.X_{N2Bij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N2PMij}.X_{N2PMij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N2Dij}.X_{N2Dij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{N2Zij}.X_{N2Zij}$$

$$C_E=C_{EB}+C_{EPM}+C_{ED}+C_{EZ} \qquad (43)$$

$$CE=\sum_{i=1}^{n}\sum_{j=1}^{n} C_{EBij}.X_{EBij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{EPMij}.X_{EPMij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{EDij}.X_{EDij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{EZij}.X_{EZij}$$

$$C_U=C_{UB}+C_{UPM}+C_{UD}+C_{UZ} \qquad (44)$$

$$CU=\sum_{i=1}^{n}\sum_{j=1}^{n} C_{UBij}.X_{UBij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{UPMij}.X_{UPMij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{UDij}.X_{UDij}+\sum_{i=1}^{n}\sum_{j=1}^{n} C_{UZij}.X_{UZij}$$

$$
\begin{gathered}
C_{total}=\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N1Bij}.X_{N1Bij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N1PMij}.X_{N1PMij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N1Dij}.X_{N1Dij}\\
+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N1Zij}.X_{N1Zij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N2Bij}.X_{N2Bij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N2PMij}.X_{N2PMij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N2Dij}.X_{N2Dij}\\
+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{N2Zij}.X_{N2Zij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{EBij}.X_{EBij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{EPMij}.X_{EPMij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{EDij}.X_{EDij}\\
+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{EZij}.X_{EZij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{UBij}.X_{UBij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{UPMij}.X_{UPMij}+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{UDij}.X_{UDij}\\
+\sum_{i=1}^{n}\sum_{j=1}^{n}C_{UZij}.X_{UZij}
\end{gathered}
$$

The costs mentioned above represent a portion of the project expenses. According to the work performed by the relevant contractors, in addition to the purchase costs listed in the checklists provided in the cost catalog, typically 20% of the price of each item is allocated for maintenance and repair costs, 10% for design and implementation costs, and a fixed amount for damage and loss costs. In examining all the scenarios discussed, the fixed damage and loss cost will not be considered in the comparisons between different scenarios since it remains constant and does not affect the outcomes.

III.RESEARCH FINDINGS

The research findings were based on real data from the power network of the Islamic Republic of Iran Broadcasting (IRIB). Mathematical modeling was conducted and implemented using Python software, utilizing the information mentioned above. Through 50 iterations and simulations, the reliability of each of the 4 hierarchical levels in the network was separately calculated. Ultimately, the total reliability of the entire network was also assessed by aggregating the reliabilities of these levels.

As in real-world implementation of this power system, each line's reliability should correspond to its importance. Therefore, the highest reliability measure naturally goes to the emergency line, followed by the backup line, and then normal lines 2 and 1 in decreasing priority. In real-world scenarios, the most critical loads, such as audio and video transmission consoles, are associated with emergency loads, which have the highest reliability. Following the previously mentioned explanations, lower importance loads are assigned to emergency, normal feeder 2, and normal feeder 1.

Next, we examine the software's output, with results as presented in Table 2:

Table 4. Model Output Based on Python Software

Z total	**RU**	**RE**	**RN2**	**RN1**	**Number of out put**	**Z total**	**RU**	**RE**	**RN2**	**RN1**	**Number of out put**
0/64	0/82	0/85	0/72	0/55	26	0/73	0/99	0/96	0/96	0/76	1
0/73	0/98	0/97	0/14	0/34	27	0/73	0/98	0/78	0/65	0/32	2
0/65	0/87	0/86	0/12	0/17	28	0/54	0/56	0/97	0/9	0/7	3
0/5	0/52	0/97	0/29	0/4	29	0/54	0/55	0/89	0/87	0/47	4
0/72	0/99	0/96	0/15	0/39	30	0/74	0/98	0/98	0/51	0/44	5
0/36	0/41	0/98	0/4	0/15	31	0/36	0/41	0/87	0/96	0/39	6
0/41	0/31	0/97	0/52	0/59	32	0/49	0/56	0/48	0/8	0/12	7

0/71	0/99	0/7	0/65	0/15	33	0/45	0/58	0/27	0/53	0/56	8
0/66	0/85	0/86	0/92	0/47	34	0/67	0/99	0/27	0/26	0/64	9
0/74	0/98	0/97	0/95	0/76	35	0/54	0/67	0/7	0/89	0/21	10
0/68	0/99	0/24	0/65	0/26	36	0/54	0/58	0/84	0/4	0/26	11
0/61	0/77	0/79	0/33	0/77	37	0/59	0/74	0/79	0/47	0/48	12
0/73	0/98	0/96	0/16	0/22	38	0/71	0/99	0/73	0/34	0/18	13
0/68	0/9	0/97	0/6	0/38	39	0/44	0/39	0/96	0/63	0/4	14
0/7	0/99	0/62	0/56	0/41	40	0/52	0/51	0/98	0/96	0/28	15
0/44	0/44	0/71	0/96	0/53	41	0/5	0/44	0/98	0/67	0/26	16
0/69	0/99	0/35	0/95	0/58	42	0/42	0/58	0/47	0/81	0/46	17
0/68	0/99	0/17	0/96	0/33	43	0/4	0/32	0/7	0/97	0/41	18
0/71	0/99	0/65	0/5	0/34	44	0/65	0/27	0/98	0/49	0/31	19
0/72	0/99	0/89	0/84	0/46	45	0/7	0/93	0/88	0/96	0/39	20
0/68	0/99	0/32	0/95	0/58	46	0/71	0/99	0/65	0/44	0/75	21
0/7	0/99	0/42	0/97	0/39	47	0/73	0/99	0/97	0/48	0/26	22
0/67	0/99	0/63	0/95	0/62	48	0/5	0/67	0/38	0/62	0/43	23
0/68	0/99	0/19	0/26	0/32	49	0/68	0/91	0/83	0/48	0/21	24
0/61	0/92	0/17	0/65	0/5	50	0/69	0/98	0/51	0/49	0/36	25
Z total		RU			RE		RN2		RN1		average
0/6134		0/7818			0/712		0/6316		0/4144		

In Table 3, the software output provides the calculated reliability measures for each line over 50 iterations. This allows for a detailed examination of the reliability of each line individually, based on the computed reliability curves. Next, each line will be analyzed and scrutinized based on these curves to gain insights into their performance and reliability characteristics. This analysis will likely involve assessing factors such as the stability of reliability measures across iterations, identifying any trends or patterns in reliability, and understanding how each line contributes to the overall reliability of the network.

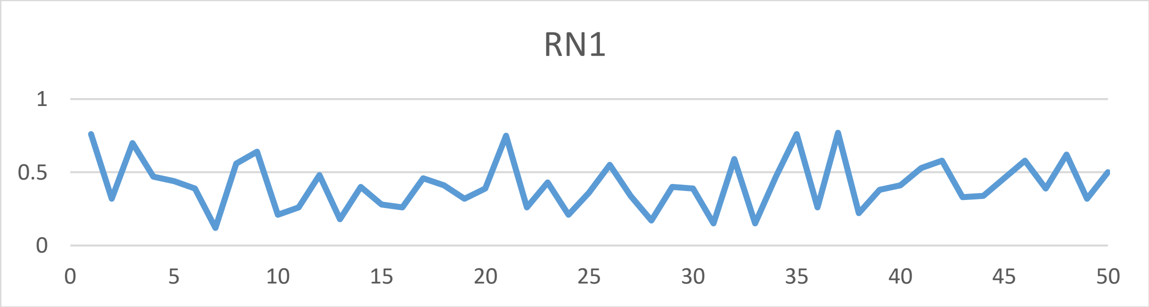

Figure 9. Reliability Curve of the normal 1 feeder

According to the explanation provided, line RN1, as shown in Figure 5, includes loads of very low importance. If the power is cut off in the entire city, these loads would go without power. Additionally, if any equipment on this line is in a position with low reliability, it could affect the entire line, resulting in its low reliability after 50 iterations, as observed in Figure 9. This line has lower reliability compared to other lines, with an average reliability after 50 iterations reaching 0.41, indicating its lower reliability capability.

Further analysis and examination of this line may require investigating various factors, such as the impact of power outages on low importance loads or specific conditions that could affect the reliability of this line.

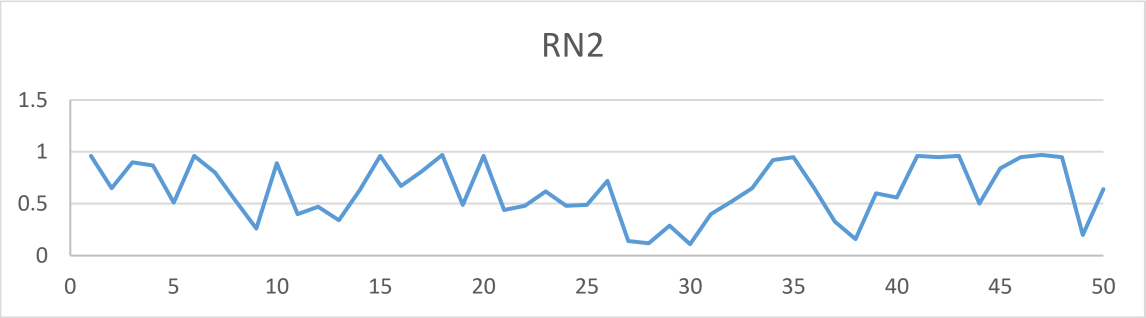

Figure 10. Reliability Curve of the normal 2 feeder

Line RN2, as depicted in Figure 6, is expected to show higher output results compared to RN1 due to its utilization of stronger equipment and parallel elements to enhance reliability. In practice, this line may connect to loads that are of higher importance compared to those connected to RN1.

This expectation arises because RN2 benefits from more robust equipment and parallel configurations, which are designed to increase reliability. In contrast, RN1, as previously discussed, tends to serve loads of very low importance, impacting its overall reliability measure negatively.

It is observed that after 50 iterations, the average reliability of this line (RN2) measures 0.63. (The curve of the obtained reliability values can be observed in Figure 10).

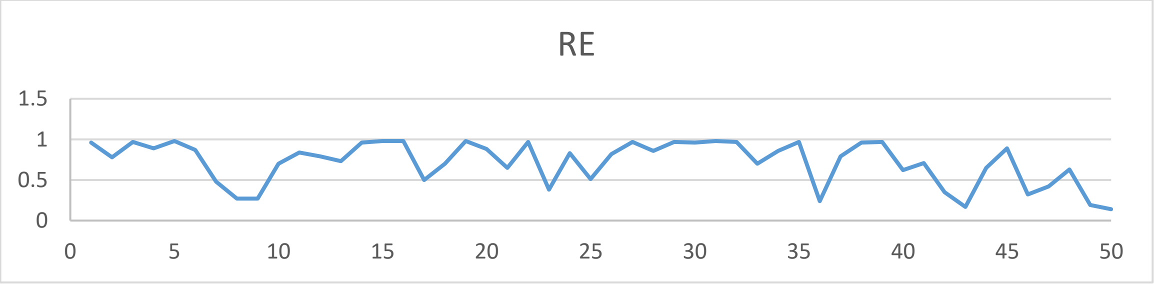

Figure 11. Reliability Curve of the Emergency feeder

The emergency line (RE), as shown in Figure 7, includes loads that remain without power during city-wide outages until a generator comes online (approximately 15 seconds), after which these loads are powered by the generator. The loads connected to this line are of higher importance compared to the previous two scenarios, and it is expected that parallel elements with higher reliability are utilized in this line.

After calculating and measuring the reliability, it has been determined that this line has a higher reliability coefficient compared to the previous two scenarios. The average reliability measure for this line is recorded at 0.71. (The curve of the obtained reliability values can be observed in Figure 11)

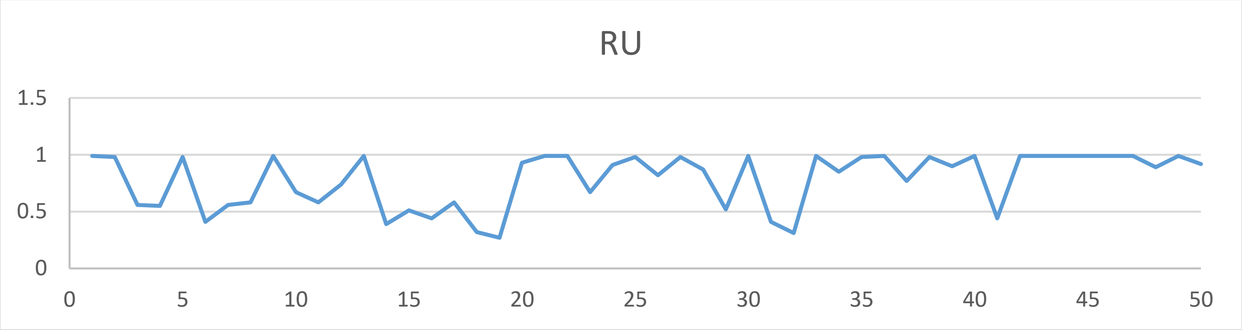

Figure 12. Reliability Curve of the Critical Emergency Line

This higher reliability measure is attributed to the use of parallel elements and enhanced reliability features designed to ensure uninterrupted power supply to critical loads during emergency situations.

The terminal consumption line (shown in Figure 9) includes emergency loads that must never experience a voltage outage under any circumstances, requiring the highest level of reliability among all lines. After obtaining outputs from the software, it is observed that the reliability measures 0.78.

One crucial element contributing significantly to enhancing reliability in this line is the UPS (Uninterruptible Power Supply) batteries. It's noted that if one battery in a battery chain fails to operate correctly, the entire set will lose power [25]. Therefore, in some software outputs, the reliability of this line may show slightly lower figures, which is natural. This variability can be influenced by battery conditions and ambient temperature, affecting the UPS's reliability and consequently the entire line [15].

The design of this battery chain is tailored to variable temperatures, as depicted in Figure 12. Observing most software outputs even reaching reliability figures as high as 99.0 demonstrates that under favorable conditions as described, a reliability of 99.0 can indeed be achieved, ensuring maximum reliability is realistically achievable.

According to experts' opinions and standards such as TIER [28], the reliability measures for emergency lines should fall within specified ranges. The TIER standard is generally used for measuring the reliability of IT systems and data centers, establishing specific ranges for reliability at different levels. For instance:

-TIER I: Requires a minimum reliability of 99.671%.

- TIER II: Requires a minimum reliability of 99.741%.

- TIER III: Requires a minimum reliability of 99.982%.

- TIER IV: Requires a minimum reliability of 99.995%.

These ranges indicate the system's reliability against power outages and disruptions. For emergency lines, the TIER standard dictates that these lines should have higher reliability, typically falling within TIER III and TIER IV ranges, meaning they should achieve at least 99.982% and 99.995% reliability, respectively.

$$0/55 \leq R_{N1} \leq 0/75 \quad , \quad 0/75 \leq R_{N2} \leq 0/85 \tag{46}$$

$$0/85 \leq R_E \leq 0/95 \quad , \quad 0/95 \leq R_U \leq 0/99 \tag{47}$$

Given that Line 1 includes entirely normal consumption and is not highly critical, the desired reliability for this line would be acceptable between 55.0% and 75.0%.

IV.ANALYSIS ON NORMAL FEEDER ONE:

Initially, using assumptions and preliminary calculations performed by Python software over 50 iterations, the average reliability of this line was found to be 43.0%. Therefore, efforts are being made to increase reliability to the desired range.After consulting with industry experts and feasibility studies to explore conditions under which higher reliability can be achieved, the following scenarios can be considered:

Scenario 1:

In this scenario, by adding one transmission line to three other lines, the average output from Python over 50 iterations reaches 46.0. This addition was also implemented simultaneously in ETAP 19 software to calculate load distribution practically and simulate it in a real environment. The performance accuracy was also verified in this environment.

It is noted that adding the fourth cable divides the current between Busbar 2 and Busbar 3. In the fourth cable, the voltage at Busbar 3, which is the closest busbar to the consumer load, measures 394 volts. This is an increase of only 2 volts compared to the three-cable configuration, where the voltage was 392 volts. However, in both configurations, the voltage remains within the desired range.

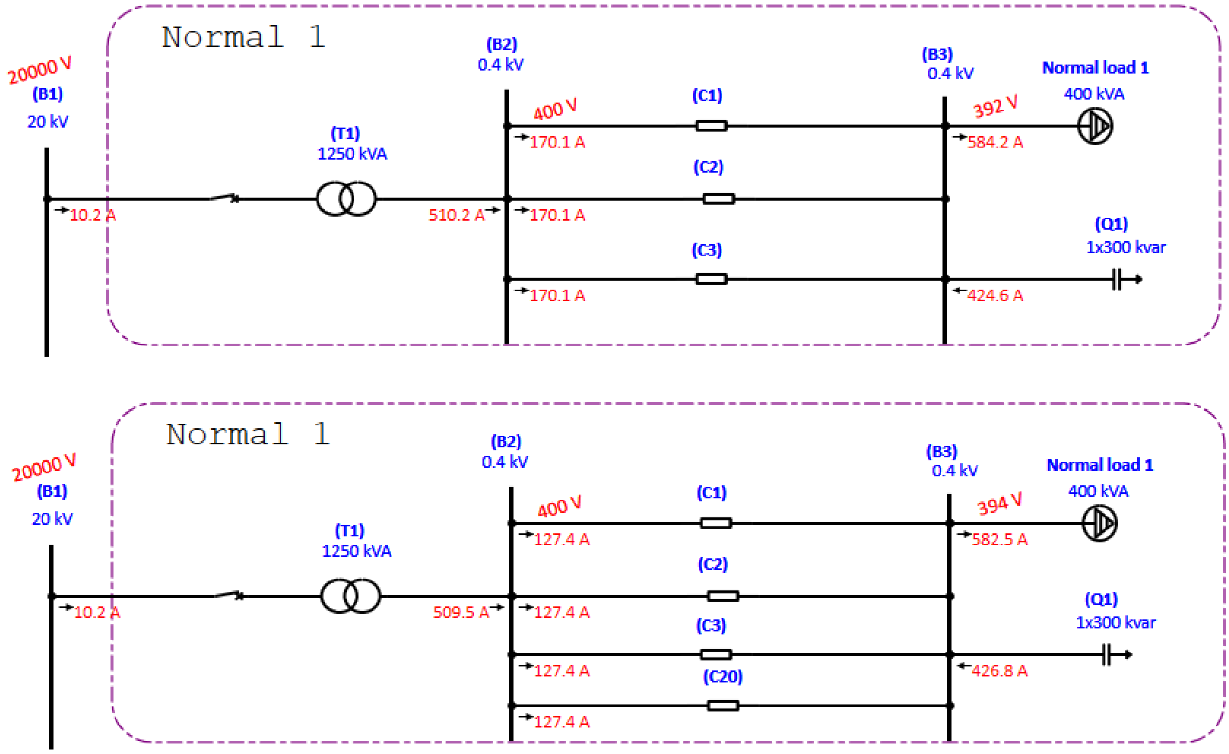

Figure 13. Comparison of load flow output in ETAP 19 software in the scenarios of three cables versus four cables

Scenario 2:

In this scenario, by improving the ambient temperature around the transformer location using ventilation and heaters to achieve a more desirable operational range, the average output from Python over 50 iterations will reach 0/47 Achieving this figure will not incur significant costs.

Improving the ambient temperature conditions around the transformer can lead to enhanced performance and reliability, ensuring that operational parameters remain within optimal ranges. This approach is cost-effective relative to the benefits gained in terms of reliability and performance stability.

Scenario 3:

In this scenario, we are considering paralleling another capacitor bank at the output busbar to potentially raise the busbar voltage to a permissible limit with greater confidence. After analyzing and calculating the reliability output in Python software, a reliability figure of 0/47 was achieved. Introducing another capacitor bank at the output busbar aims to stabilize and enhance voltage levels, ensuring they remain within acceptable operational limits. The investment required reflects the significant improvement in reliability and operational efficiency expected from this enhancement.

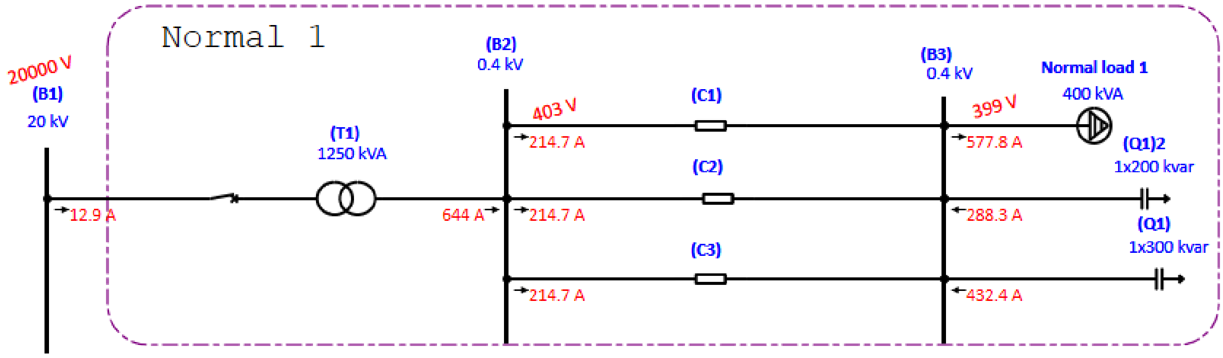

Figure 14. Load Flow Output in ETAP 19 Software with the Addition of the Second Capacitor Bank

Implementing this scenario in ETAP19 software demonstrates that adding another capacitor bank will indeed bring the busbar voltage at the consumer end to a more desirable level. However, it's crucial that the size of the second bank is carefully calculated to prevent overcompensation, which could potentially push the voltage above 400 volts and lead to equipment damage.

Scenario 4:

In this scenario, we are examining the option of paralleling another transformer and reactor with the existing ones to achieve higher reliability. After 50 iterations, the output indicates a reliability figure of 0/71 which is very desirable. However, this option comes with a significantly high cost. While this scenario offers substantial reliability benefits, the decision to proceed would also consider cost-effectiveness and budget constraints.

Scenario 5:

In the fifth scenario, we increase the rated capacity of the transformer from 1250 kVA to 1600 kVA to supply a higher current to the load. However, practically, this change hasn't proven useful since the previous transformer could also supply the consumer load with a similar current, and the load current remains constant without any change.

Nevertheless, we have evaluated the reliability of this scenario, and after 50 stages, the average reliability capability has reached 0/54. Although none of the above five scenarios individually met the desired reliability level, it is necessary to examine combinations of these scenarios to achieve both lower costs and the desired reliability level. As a result, according to Table 4 and the calculations in Python software, we will have the following numbers:

Table 5. Calculating the Reliability of the normal 1 Line in Various Scenarios

Condition	**Reliability of feeder 1**
Initial state	0.43
Adding transmission line C20 (1)	0.46
Improving temperature of transformers (2)	0.47
Adding capacitor bank (Q2) (3)	0.47
Adding circuit breaker and transformer (4)	0.71
Increasing the capacity of transformers (5)	0.54
Combination (1) & (2)	0.46
Combination (1) & (3)	0.47
Combination (2) & (3)	0.49
Combination (1) & (2) & (3)	0.55

Combination (1) & (2) & (3) & (4)	0.79
Combination (1) & (2) & (3) & (5)	0.54
Combination (1) & (2) & (3) & (4) & (5)	0.81

Similar to the other line, it will arrive according to the following table:

Table 6. Calculating the Reliability of the normal 2 Line in Various Scenarios

Condition	**Reliability of feeder 2**
Initial state	0.73
Adding transmission line C30 (1)	0.74
Improving temperature of transformers two and three (2)	0.79
Increasing the capacity of transformers and circuit breakers (3)	0.91
Combination (1) & (2)	0.78
Combination (2) & (3)	0.94
Combination (1) & (3)	0.9
Combination (1) & (2) & (3)	0.94

Table 7. Calculating the Reliability of Emergency Line in Various Scenarios

Condition	**Reliability of Emergency feeder**
Initial state	0.76
Adding transmission line C40 (1)	0.79
Improving temperature of battery (2)	0.9
Increasing the capacity of Generator (3)	0.89
Combination (1) & (2)	0.9
Combination (2) & (3)	0.95
Combination (1) & (3)	0.84
Combination (1) & (2) & (3)	0.96

Table 8. Calculating the Reliability of the Ultra-Emergency (ups) Line in Various Scenarios

Condition	**Reliability of Ups feeder**
Initial state	0.87
Increasing the capacity of ups (1)	0.91
Adding battery chain UPS 1 (2)	0.91
Adding two battery chains to each UPS (3)	0.91
Improving temperature of battery (4)	0.89
Combination (1) & (2)	0.95

Combination (1) & (3)	0.97
Combination (2) & (4)	0.95
Combination (3) & (4)	0.95
Combination (1) & (2) & (4)	0.97
Combination (1) & (3) & (4)	0.99

As mentioned earlier, among the 4 power lines under investigation, each has its own priority and importance based on power consumption. Accordingly, the normal line has the least importance, while the emergency line holds the highest priority. This means that if higher expenditure is justified, priority is given to the line with greater importance to ensure higher reliability. In the tables below, you can observe the comparison of reliability achieved from different scenarios along with the associated costs in each case. In these tables, column charts in green indicate compliance within the required reliability range.

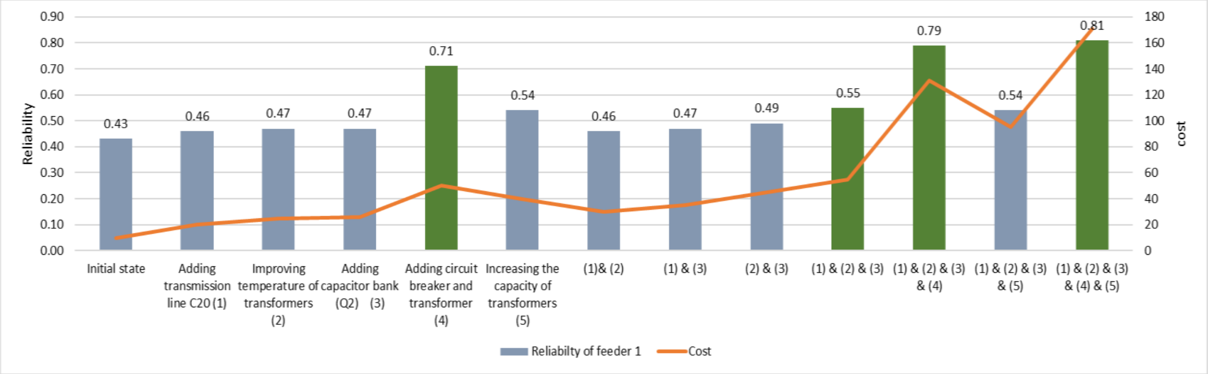

Figure 15. comparative reliability and cost tables for different operational states related to a normal feeder1

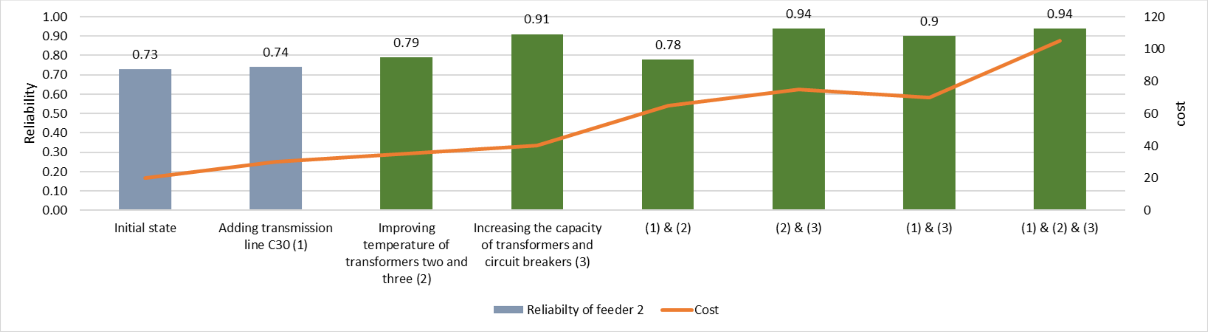

Figure 16. comparative reliability and cost tables for different operational states related to a normal feeder2

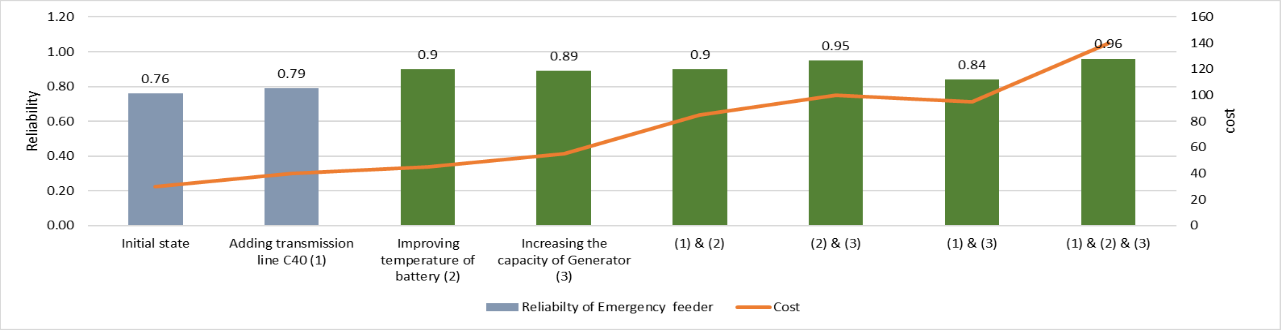

Figure 17. comparative reliability and cost tables for different operational states related to a Emergency feeder

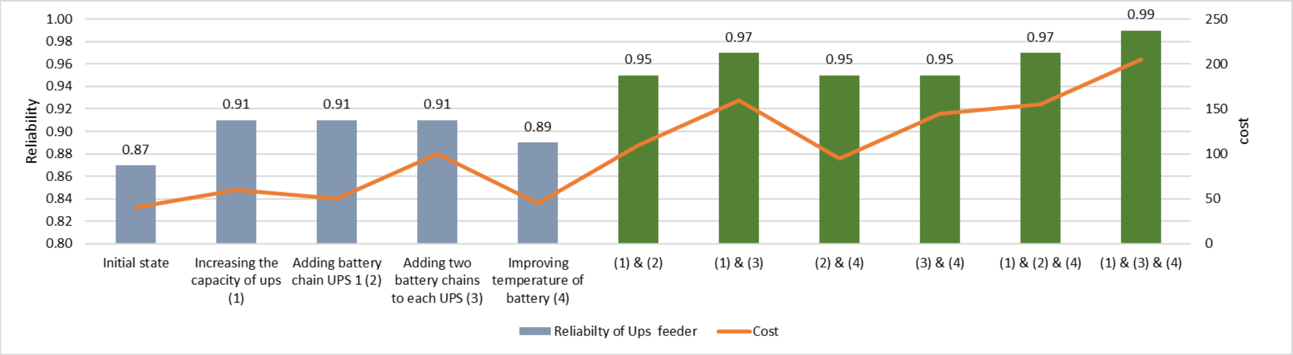

Figure 18. comparative reliability and cost tables for different operational states related to a ups feeder

Upon reviewing and comparing the tables above, it can be concluded that for Normal Line 1, the optimal scenario is a combination of scenarios 1, 2, and 3. In this case, a reliability of 0/55 has been achieved, which falls within an acceptable range. For Normal Line 2, modifying scenario 2 alone results in a reliability of 0/79, which is within the permissible range. The Emergency Line, with an optimal combination of scenarios 2 and 3, achieves the optimal reliability and cost ratio with a value of 0/95.

Finally, for the ups Line, considering its highest importance coefficient among all lines, a combination of scenarios 1, 3, and 4 achieves the highest reliability of 0/99. Given the importance of the consumption on this line, it justifies higher costs to ensure the highest reliability.

V.CONCLUSION AND RECOMMENDATIONS

Reliability assessment is a critical aspect in any system, influencing confidence in its operational performance within supply chains, manufacturing plants, or production facilities. Cost considerations also play a significant role in this relationship. In this study, the power lines, which are a form of supply chain, were examined. Each component within this chain could positively or negatively impact the output of its subsequent section, with each piece having various parameters that could either increase or decrease reliability. All parameters of each component were analyzed using fuzzy Delphi technique and weighted using Analytic Hierarchy Process (AHP).

After implementation in Python software and conducting 50 iterations of output analysis, higher reliability was achieved in lines deemed more critical. This demonstrates the value of each line and how its reliability is calculated and assessed. Based on these findings, prioritizing higher expenditures can also be determined accordingly.

In this research, the reliability of the power system, which includes transformers, cables, busbars, UPS, generators, and capacitor banks, was evaluated based on indicators such as temperature, lifespan, capacity, number of parallel elements, and voltage. Studies such as [29], [23], and [26] focused on the effects on transformer lifetime, the role of harmonic loads, and environmental pollution on transformer performance. Studies by [24], [13], [17] examined the effects on control systems and maintenance in UPS reliability. [19] and [16] explored the impact of fault currents and their configurations on reliability. Additionally, [12] investigated the effects of mechanical and internal stresses on diesel generator reliability.

In future studies, a combination of detailed examination of individual equipment parameters, as considered in this study, along with more specific information regarding transformers, such as the type of transformer and insulation, as well as the role of service and maintenance in reliability [30], will be important. Additionally, for UPS systems (including internal circuit types, transformer base or transformer-less configurations, and the impact of load types on reliability), batteries (examining the effects of temperature on their condition, [15], and the type of battery testing services are crucial. Furthermore, the significant impact of increasing battery chains [17] on reliability should be considered.

Regarding cables, comparing cable materials and their installation methods alongside switches (comparing insulation types among switches) and a comprehensive review of these components in small local distribution lines and in a broader context within the city and national power distribution networks are essential. Moreover, detailing the cost functions associated with each component segment is critical.

This approach will ensure a relatively confident assessment of the designed power system's performance before equipment implementation. Furthermore, the inclusion of more influential parameters will enhance the accuracy of reliability calculations and consequently bring the reliability degree closer to reality

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