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# Evaluation of Operational Risk in Power Substations and Its Rational Reduction on the Basis of Multicriteria Allocating Resources

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**ABSTRACT** The present work aimed at improving the quality of operational risk estimation for power substations and increasing the efficiency in its reduction using models and methods of multicriteria decision-making. The application of the proposed methodology allows one to assess, compare, prioritize, and/or order power substations from the point of view of operational risks and to rationally allocate available resources to reduce operational risks. It is presented a method of Systemic Risk Assessment (SRA) that integrates concepts of risk assessment and multicriteria decision-making techniques. The use of SRA permits one to take into account expert opinions to obtain the operational risk estimates. These estimates serve for allocating resources between substations within the framework of multicriteria models. The analysis is based on applying the Bellman-Zadeh approach to decision-making in a fuzzy environment to solve multicriteria problems and provide their harmonious solutions. The risk assessment results of the three power substations show that the power substation (PS)2 has the highest risk level (0.314), followed by PS1 (0.267), and PS3 (0.199), and the allocation of financial resources between the substations is the following: PS1: *R$* 465,000.00, PS2: *R$* 1,714,339.00 and PS3: *R$* 820,661.00. The Case Study, demonstrates the possibility of reducing the subjectivity of the risk evaluation and the improvement of the quality of the decisions made in resource allocation.

**INDEX TERMS** Accident prevention, allocation of resources, AHP, Bellman-Zadeh approach, decision making, Electrical safety, substations, risk analysis, risk assessment, risk matrix.

## I. INTRODUCTION

Electricity is an indispensable form of energy for functioning different segments of the industry and also for human life. However, the improper use of electricity can result in injury to workers, including fatalities, and damage to electrical equipment, which causes production losses [1]–[6]. In addition, expenses with lawsuits and fines imposed by inspection agencies can be generated [7]. The decrease in the frequency of accidents of electrical origin compared to other types of risks may lead to a misconception that the electrical hazard management of electrical risks is under control [6]–[8]. Although these accidents are rare when they do occur, they are usually serious and, can lead to fatal outcomes [3]. Considering this, the implementation of qualified management to reduce the risks involved in the process of operating power substations has become necessary in the activities of companies, which realize the corresponding management [6], [7]. The complexity of carrying out a risk assessment is a major challenge for these companies [9]. The determination of the most critical substations in terms of operational safety is necessary, for the rational use of limited financial resources.

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However, decisions on allocating available resources between the substations are usually made empirically, without using convincing methods [7].

Taking into account the results of [10], it is possible to develop methods that allow the rational allocation of resources between power substations, analyzing models of multicriteria decision-making integrated with the risk concepts. Generally, multiobjective decision making is known as the continuous type of multicriteria decision making and its main characteristics are that the decision-maker (DM) needs to achieve multiple objectives while these objectives are non-commensurable and conflict with each other [11], [12]. A multiobjective decision-making model includes a vector of decision variables, objective functions that reflect the objectives, and constraints [11], [12]. The DM attempts to maximize or minimize the objective functions [11], [12].

The risks are often evaluated by a group of experts and these evaluations are based on their knowledge, experience, intuition, and also on individual choices [11], [12].

In this context, the present research aims at developing a methodology based on decision-making techniques to reduce subjectivity in the process of assessing operational risks of power substations. The evaluation results serve as a basis for the allocation of available financial resources in the maintenance management process. The Case Study is also an original aspect of this work and provides useful results for engineers, managers, and mining companies and power distribution companies.

The main contribution of this research is the development of a method that considers technical and safety information for resource allocation in solving operational risk problems.

The main innovative factor is the improvement and reduction of the subjectivity of the traditional risk matrix models (for instance, [13]–[20]) that allows obtaining risk estimates to the preparation of information for the allocation of resource.

The application of methodological foundations for construction and analysis of the $\langle X, F\rangle$ models (as multiobjective models) to rationally allocate available resources to reduce operational risks is another innovative factor of this work. This approach has already been widely used to resolve various power engineering problems [10], [21], and is utilized in this research, for the first time, to resource allocation in solving operational risk problems.

One of the most important results of the paper is the proposed method called SRA. Its use permits one to realize an easy-to-apply approach at the engineering level, which includes:

- Definition of criteria related to evaluating risks in operating power substations;
- Standardization of criteria and evaluation modes;
- Use of the knowledge of experienced professionals in weighting the criteria.

The most significant functions of SRA are the following:

- Generation of solutions based on integrating the concepts of risks and existing techniques for multicriteria decision making;
- Integration of criteria and sub-criteria for constructing so-called risk matrices;
- Reduction of subjectivity in the process of the risk assessment;
- Preparation of information for resource allocation;
- Reduction of inadequacy or lack of statistical data.

The paper results are of a general character and have the potential to be applied to other types of problems, once the concepts of risk assessment and decision making are properly integrated.

## II. RISK ASSESSMENT

### A. RISK CONCEPT

Risk can be defined as a measure of the extent of the hazard, evaluated by correlating the probability or frequency of undesirable events to their consequences or effects [19], [22]. Its representation is defined by the following expression:

$$R_i = P_i C_i, \quad i = 1, 2, \ldots, n, \tag{1}$$

where $R_i$ corresponds to the risk value of the ith event, $P_i$ corresponds to the probability of the occurrence of the ith event, $C_i$ is the consequence of the ith event [8], [23]. The probability can be described as a number between 0 and 1 that represents the degree of belief that the event will occur and its consequence is the estimated value or score for a given result [19]. Risk assessment is an analytical process that consists of many steps designed to ensure that risks are correctly identified and analyzed concerning to their consequences and the probability of their occurrence [19].

The related literature presents methods traditionally used in the risk assessment process, such as Hierarchy Risk Control, HIRARC, Bowtie, JSA, FMEA, FTA, LOPA, and HAZOP [8], [24]–[34]. These methods, despite their relevance in the context of risk assessment, do not permit one to provide information, necessary to construct the so-called risk matrices and, to rationally allocate resources.

Several works are dedicated to solving power substations risk assessment problems. The authors of [35] have applied a tool to evaluate the risk conditions of power substation transformers. In the work [22], the authors utilize a probabilistic methodology to evaluate the risks of major accidents on power substations. In [36], an approach to probabilistic risk assessment of power substation grounding systems is proposed. The authors of [37] propose a methodology for the cybersecurity risk assessment of the substation automation system applying the Analytic Hierarchy Process (AHP) method. In [38], [39], the authors propose a seismic risk assessment for power substation components. In the work [40], an approach to risk assessment of power substation is proposed to solve the relationship of secondary devices, and risk analysis of its impact on primary devices.

In [41], a risk assessment method is introduced to solve power substation problems applying the AHP method, and triangular fuzzy numbers. In [42], a model is applied to evaluate the financial risk of a power substation project. The author of [43] presents a method introduced to conduct an information security risk assessment for a power substation communication system using the AHP and Delphi method with a combination of the Gray theory. In [44], the authors propose an intelligent substation information security assessment tool to prevent cyber-attacks.

The most cited works use data analysis to solve risk assessment problems. In some circumstances, there is no historical data available. For this reason, expert's opinions are considered to obtain the operational risk estimates and reduce the inadequacy or lack of statistical data. In all the cited works, questions related to the systematic power substation risk assessment are not considered. These works are dedicated to solving specific problems, such as power transformer risk assessment, automation systems risks, cyber-attacks, project investment decisions, and damage caused by earthquakes. Besides, none of the works consider aspects related to the operation, maintenance, and safety simultaneously for the preparation of information for resource allocation. The purpose of this study is to develop the method to estimate and reduce the operational risk through the allocation of financial resources between power substations, applying multicriteria decision making techniques. To achieve this goal, the study proposes a method that reduces the subjectivity within the risk assessment and prepares the information for resource allocation.

### B. RISK MATRIX

The risk can be represented graphically through its components (probability and consequence), applying the risk matrix [16].

The risk matrix is usually used to prioritize and order risk reduction control measures in the decision-making processes [15]–[20]. It is considered easy to apply and interpret. It is used by people with no experience in risk management [17]–[20]. The traditional risk matrix model allows a quantitative, semi-qualitative, or qualitative assessment to be carried out, generally, inaccurate results due to the high degree of uncertainty provided by the probability and consequence quantification process [13]–[20].

A risk matrix is a tool used for allocating resources to reduce risks [16]. Due to its technical limitations, the quality of resource allocation is usually compromised. We highlight the high degree of uncertainty provided by traditional risk matrix models, inadequate risk assessment by participants (human cognitive bias), and inadequate integration of collective opinions during the risk assessment process [13]–[15]. The typical risk management error is to spend all financial resources on highly unlikely events while less severe events can manifest, if more likely [16].

Few works are dedicated to design risk matrices, for instance, [13]–[20]. Their results provide recommendations for the design and use of risk matrices. In [14], [47], linguistic scales are used to reduce uncertainties in the risk matrix design. The authors of [48] construct a risk matrix based on the AHP method. The work [49], describes how cognitive biases affect the placement of risk points within a risk matrix when experts subjectively judge the likelihood of the risk, and, separately, the consequence of a risk. The related literature demonstrates the use of the decision-making method (AHP) to solve risk assessment problems to minimize the corresponding uncertainties. In addition, works do not apply multicriteria models to allocate available resources integrated with the risk matrix concepts.

Therefore, it is not possible to define a global value of operational risk applying the discussed methods and correlated works for the construction of objective functions for resource allocation in power substations.

## III. DECISION MAKING MODELS

There are two wide classes of models applied in the multicriteria analysis: multiobjective decision-making models (in [11], [21], they are called $\langle X, F \rangle$ models) and multi-attribute decision-making methods (e.g. AHP, MAUT, and $\langle X, R \rangle$ models) [11], [21].

Several works are dedicated to solving decision making problems in a fuzzy environment, for instance, [21], [49]–[54].

Multi-attribute decision-making is characterized by allowing to identify, evaluate, compare, order, prioritize, and make the most rational choice of alternatives in decision-making problems [11], [21].

The AHP method is used in decision-making processes considered in [11], [55]–[57]. AHP is a combination of qualitative and quantitative, systematic, and hierarchical analysis methods [55].

The combination of these methods is used in a variety of decision situations, from the areas of government, business, industry, and education [11]. The method consists of performing structural modeling that in addition to qualitative structuring, incorporates structure in the form of weights [55]–[57]. AHP can also be used with many types of data, including judgments based on experiences and values [11]. In addition, the AHP method provides a performance evaluation of the result of [55]–[57]. Besides, the AHP method allows assessing the consistency of judgments [55]–[57]. The AHP method allows representing the preferences of DMs, especially in situations where the decision group is composed of individuals with divergent interests and views [11].

In [11], [21], multiobjective decision-making is defined as the continuous type of multicriteria decision-making. The principal characteristics are that the decision maker (DM) needs to achieve multiple objectives while these objectives conflict with each other and are non-commensurable [11], [21]. The DM attempts to maximize or minimize the objective functions [11], [21]. The results of the [11]–[59] show that the analysis of $\langle X, F \rangle$ models can be based on the Bellman-Zadeh approach to decision making in a fuzzy

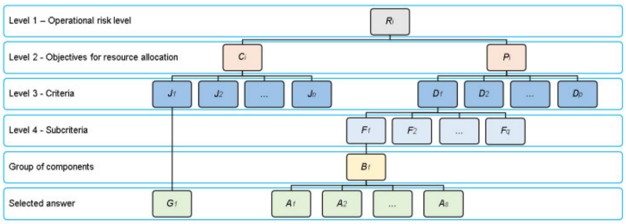


**FIGURE 1.** Mental model of mathematical hierarchy.

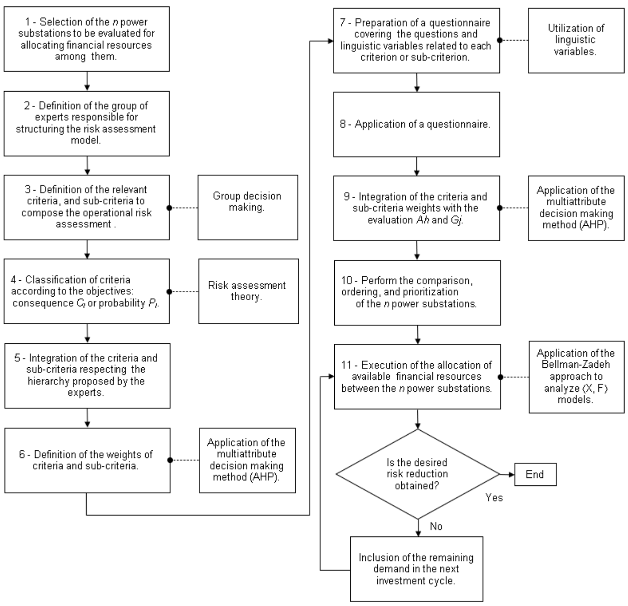


**FIGURE 2.** SRA method flowchart.

**TABLE 1.** Technical specification of power substations.

| ID | *kV* | *MVA* |
|---|---|---|
| PS1 | 34.5 | 15 |
| PS2 | 138 | 43 |
| PS3 | 69 | 43 |

**TABLE 2.** Result of the operational risk assessment.

| Power Substation | Probability | Consequence | Risk Level |
|---|---|---|---|
| PS1 | 0.418 | 0.638 | 0.267 |
| PS2 | 0.381 | 0.825 | 0.314 |
| PS3 | 0.498 | 0.400 | 0.199 |

environment. Its adaptation and application provide a constructive and computationally effective way to generate harmonious solutions in the analysis of $\langle X, F \rangle$ models.

Expert's opinion can be used in the risk assessment process. Linguistic variables are used to better represent human thinking and thus reduce the subjectivity of responses [50].

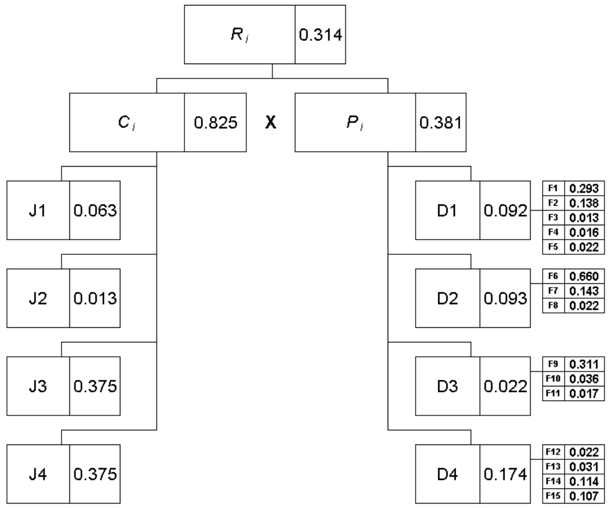


**FIGURE 3.** Mathematic hierarchy PS2.

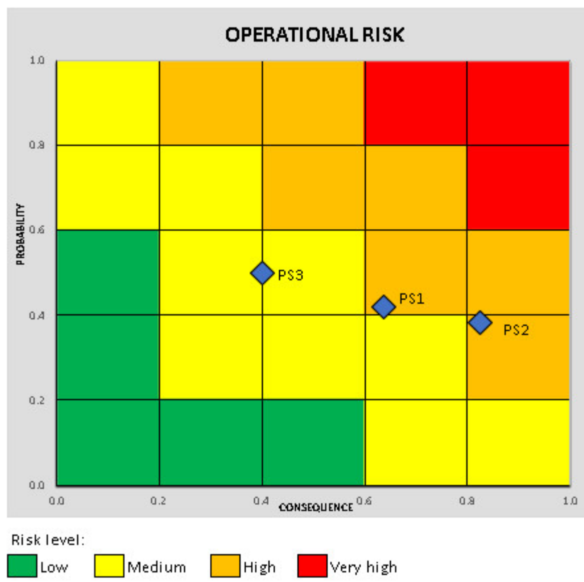


**FIGURE 4.** Risk assessment result.

**TABLE 3.** Result of the allocation of financial resources.

| $x_1[R\$]$ | $x_2\ [R\$]$ | $x_3\ [R\$]$ |
|---|---|---|
| 465,000.00 | 1,714,339.00 | 820,661.00 |

In this context, AHP was selected as the basis for the SRA method. Similarly, an expert's opinions are used to determine the weights of the evaluated criteria to improve the risk assessment results. Finally, the Bellman-Zadeh approach is applied to generate solutions in the analysis of $\langle X, F \rangle$ models.

## IV. ALLOCATION OF RESOURCES - $\langle X, F \rangle$ MODEL

Existing methods of resource allocation, based on fundamental allocation principles (proportional allocation,

**TABLE 4.** Criteria applied to $C_i$.

| ID | Criterion | Definition | Scale | Definition |
|---|---|---|---|---|
| J1 | Environmental impact | Assessment of environmental impact due to interrupting electricity. | Low | Failure in the electricity supply does not compromise the functioning of environmental control and monitoring systems and equipment. |
| | | | Medium | Failure in the supply of electricity compromises the operation of noncritical environmental control and monitoring systems and equipment. |
| | | | High | Failure in the electricity supply compromises the operation of critical environmental monitoring and control systems and equipment. |
| J2 | Reputational impact | Evaluation of reputational impact due to interrupting electricity. | Low | Failure in the electricity supply does not compromise the company's image. |
| | | | Medium | Failure in the electricity supply compromises the company's image (local impact). |
| | | | High | Failure in the electricity supply significantly compromises the company's image (regional or national impact). |
| J3 | Productive impact | Productive impact assessment due to failure in the electricity supply. | Low | Failure in the electricity supply does not compromise the critical part of the production process. |
| | | | Medium | Failure in the electricity supply jeopardizes the critical part of the production process. |
| | | | High | Failure in the electricity supply compromises the overall production process of one or more operating units. |
| J4 | Financial impact *R$* | Estimated value of the construction of a new power substation. | Low | $x < 1M$ |
| | | | Medium | $1M \leq x \leq 20M$ |
| | | | High | $x < 20\text{M}$ |

optimal allocation, and inverse priority principle [60]) have significant limitations [11] that can be eliminated by applying a multicriteria approach, which allows one to consider and maximize positive consequences or minimize negative consequences of allocating resources or their shortages. For instance, the first results in this area are related to the resolution of the set of problems of allocating power and energy shortages at different levels of territorial, temporal, and situational hierarchies of load management, generated by the impacts of the Chernobyl disaster [61].

The satisfaction of objectives related to the multiobjective allocation of resources is associated with the maximization or minimization of linear objective functions [10]:

$$F_p(X) = \sum_{i=1}^{n} c_{pi} x_i, \quad p = 1, 2, \ldots, q, \tag{2}$$

where $x_i, i = 1, 2, \ldots, n$ are the variables, which correspond to the volume of resources sought for the $i$th consumer $c_{pi}, p = 1, 2, \ldots, n, i = 1, 2, \ldots, n$ are specific indicators, corresponding to the $p$th specific objective, for the $i$th consumer. At the same time, the satisfaction of objectives in the case of multiobjective allocation of shortages of resources is associated with the maximization or minimization of linear objective functions [10]:

$$F_p(\Delta X) = \sum_{i=1}^{n} c_{pi} \Delta x_i, \quad p = 1, 2, \ldots, q, \tag{3}$$

where $\Delta x_{i,} i = 1, 2, \ldots, n$ are the variables, which correspond to the volume of resource limitations sought for the ith consumer. The objective functions Equation (2) and Equation (3) are not the only types of objective functions, which can be used in the multiobjective allocation of resources or their shortages. Other types of objective functions (linear, fractional, quadratic, etc.) are considered in [61]; sometimes they can better reflect the essence of specific objectives.

Three models of the allocation of resources or their shortages are considered in [10]:

### A. ALLOCATION OF AVAILABLE RESOURCES

Consumer demands $D_i, i = 1, 2, \ldots, n$ are given, and a total available resource is $R < \sum_{i=1}^{n} D_i$.

Then, the problem exhibits the following structure:

$$F_p(X) \Rightarrow \max_{X \in L} \text{ or } \min_{X \in L}, \quad p = 1, 2, \ldots, q \tag{4}$$

**TABLE 5.** D1 - sub-criteria applied to $P_i$.

| ID | Sub-criterion | Definition | Scale | Definition |
|---|---|---|---|---|
| F1 | Redundancy | Analysis of the existence of redundant equipment that can be used when failures occur. | Active redundancy | Existence of redundant equipment available immediately. |
| | | | Inactive redundancy | Existence of redundant equipment available without the possibility of immediate operation. |
| | | | There is no | There is no redundant equipment. |
| F2 | Technology | Verification if the technology used is lagging from the safety and operational point of view. | State of the art | The most modern equipment is applied. |
| | | | Intermediate technology | Equipment that meets basic technical and safety requirements. |
| | | | Outdated technology/ Equipment unavailable | Outdated equipment is used or equipment is unavailable. |
| F3 | Technical assistance | Establish the availability of specialized labor to carry out maintenance at the substation location. | Regional | Professional, residing in the region is available. |
| | | | Nacional | Professional from another state is available. |
| | | | There is no | There is no qualified labor to perform the maintenance. |
| F4 | Backup equipment availability | Analysis of the existence and complexity of replacing a certain equipment due to the failures. | Exists | Equipment is available in stock or for rent. |
| | | | Depends on acquisition | There is no equipment and its use is dependent on delivery. |
| | | | There is no | Equipment cannot be replaced. |
| F5 | Spare parts | Analysis of the difficulty of replacing spare parts. | Immediate | Spare parts available from stock. |
| | | | Acquisition | Spare part is unavailable and its use is dependent on delivery. |
| | | | There is no | Spare part is discontinued. |

subject to the constraints

$$0 \leq x_i \leq D_i, \quad i = 1, 2, \ldots, n \tag{5}$$

and

$$\sum_{i=1}^{n} x_i = R. \tag{6}$$

### B. ALLOCATION OF RESOURCE SHORTAGES WITH UNLIMITED CUTS

The consumer demands $D_i, i = 1, 2, \ldots, n$ are given and a total available resource is $R < \sum_{i=1}^{n} D_i$. So, the resource shortage is $A = \sum_{i=1}^{n} D_i - R$,and the problem has the following structure:

$$F_p(\Delta X) \Rightarrow \max_{X \in L} \text{ or } \min_{X \in L}, \quad p = 1, 2, \ldots, q \tag{7}$$

subject to the constraints

$$\Delta x_i \geq 0, \quad i = 1, 2, \ldots, n \tag{8}$$

and

$$\sum_{i=1}^{n} \Delta x_i = A. \tag{9}$$

### C. ALLOCATION OF RESOURCE SHORTAGES WITH LIMITED CUTS

Demands $D_i$, $i = 1, 2, \ldots, n$, as well as minimally acceptable consumer demands $D_m$, $i = 1, 2, \ldots, n$. The problem is to achieve Equation (7), taking into account the constraints:

$$0 \leq \Delta x_i \leq A_i = D_i - D_i^m, \quad i = 1, 2, \ldots, n \tag{10}$$

and Equation (9).

## V. SYSTEMIC RISK ASSESSMENT

This section presents the proposed methodology based on applying risk concepts and decision-making techniques. Its

**TABLE 6.** D2 - sub-criteria applied to $P_i$.

| ID | Sub-criterion | Definition | Scale | Definition |
|---|---|---|---|---|
| F6 | Maintenance procedure | Evaluates the quality of the maintenance procedure designed for use by professionals who work in the substation. | Adequate | Adequate procedure for use by professionals. |
| | | | Requires improvements | The procedure requires improvements for use by professionals. |
| | | | There is no | There is no intervention procedure. |
| F7 | Operation procedure | Evaluates the quality of the operational procedure designed for use by professionals who work at the substation. | Adequate | Adequate procedure for use by professionals. |
| | | | Requires improvements | The procedure requires improvements for use by professionals. |
| | | | There is no | There is no intervention procedure. |
| F8 | Operation type | Defines the level of protection offered by the equipment during its operation. | Remote operation or N/A | Equipment operation performed remotely or the concept does not apply. |
| | | | Partially remote operation | Remote operation equipment operation in some circumstances. |
| | | | There is no remote operation | Local operation using PPE. |

**TABLE 7.** D3 - sub-criteria applied to $P_i$.

| ID | Sub-criterion | Definition | Scale | Definition |
|---|---|---|---|---|
| F9 | Labor | Type of labor required to perform maintenance on the component group. | Basic | Interventions usually require basic labor. |
| | | | Expert | Interventions usually require expert labor. |
| | | | There is no | There is no qualified labor to perform the maintenance. |
| F10 | Average daily exposure | Defines the average intervention time in the component group. | $x < 2$ | Interventions with an average time of maximum 2 hours. |
| | | | $2 \leq x \leq 4$ | Interventions with an average time between 2 to 4 hours. |
| | | | $x < 4$ | Interventions with an average time of more than 4 hours. |
| F11 | Intervention frequency | Defines the average intervening time period in the component group. | Annually | Annual intervention. |
| | | | Semi-annually | Semiannual intervention. |
| | | | Monthly | Monthly intervention |
| | | | Weekly | Weekly intervention. |
| | | | Daily | Daily intervention. |

application reduces the subjectivity of risk assessment and raises the quality of decisions related to allocating resources between power substations. The methodology proposes to construct a risk matrix integrating this process with applying the AHP method to determine the risk levels of power substations under study, to define the amounts of financial resources to be allocated according to objectives linked to the risk assessment.

The SRA method has the following steps:

Step (1) Selection of the n power substations to be evaluated for allocating financial resources among them.

Step (2) Definition of the group of experts responsible for structuring the risk assessment model.

Step (3) Definition of the relevant criteria, and sub-criteria to compose the operational risk assessment of the power substations.

Step (4) Classification of criteria according to the objectives: consequence $C_i$ or probability $P_i$. From this classification, it is possible to construct the hierarchy for each axis of the risk matrix.

Step (5) Integration of the criteria and sub-criteria respecting the hierarchy proposed by the experts.

**TABLE 8. D4 - sub-criteria applied to $P_i$.**

| ID | Sub-criterion | Definition | Scale | Definition |
|---|---|---|---|---|
| F12 | History of operational incidents or failures | Defines the average time of occurrence of incidents or operational failures in the equipment. | > Annually | Occurrence of an incident or failure with a time greater than 1 year. |
| | | | Semi-annually | Incident or failure occurring more than one month and less than one year. |
| | | | Monthly | Incident or failure occurring within less than one month. |
| F13 | Maintenance Type | Classification of the type of maintenance adopted on the equipment. | State of the art | Maintenance model based on techniques recognized as the most moderate and effective. |
| | | | Preventive and Predictive | Adoption of preventive and predictive techniques. |
| | | | Corrective | Performance by breaking or paralyzing the equipment. |
| F14 | Critical operational condition identified | Identification of conditions that can promote personal accidents, operational losses or outages of the electrical system. | Not critical | Critical conditions were not identified in the group under analysis. |
| | | | Partially adherent | One critical condition was identified in the group under analysis. |
| | | | Multiple critical situations | Two or more critical conditions were identified in the group under analysis. |
| F15 | Adequacy and adherence to the maintenance plan (Backlog) | Analyse the existence, consistency and execution of the maintenance plan proposed to the equipment. | Adherent | Maintenance plan prepared with engineering validation, registered in a computerized system and with adherent inspections. |
| | | | Partially adherent | Maintenance plan prepared with engineering validation, registered in a computerized system and with nonadherent inspections. |
| | | | Non-adherent | There is no maintenance plan or plan validated by engineering. |

This research defines an integration model between the risk matrix, criteria, sub-criteria, and their respective weights. An example of a mental model of this hierarchy is illustrated in Figure 1. For its construction, it is recommended to be limited to five sub-criteria per criterion, given the complexity involved in making the comparisons and obtaining a coherent judgment using the AHP method [55]–[57].

Step (6) Definition of the weights of criteria and sub-criteria. At this stage, experts compare the groups of criteria or sub-criteria at the same level and define a collective opinion. The studies (for instance, [10], [52]), used the collective opinion to solve decision-making problems. The determination of the weight values of each criterion of the consequence ($\omega_j$) and probability ($\omega_k$) or sub-criterion of the probability ($\omega_f^k$) are obtained by applying the concepts recommended by the AHP method [55]–[57]. The recent works demonstrate that the AHP method is adequate to determine of the weight values (for instance, [10], [63]).

Step (7) Preparation of a questionnaire covering the questions and a linguistic scale related to each criterion or sub-criterion. This questionnaire also considers the insertion of the s groups of components defined by the experts. According to the selected answer from linguistic scale, a score of $A_h$ (linguistic scale level) was obtained for assessments related to probability $P_i$ and $G_j$ (linguistic scale level) for assessments related to the consequence $C_i$. For questions with three or five answer options, a linguistic scale is applied (0.1, 0.5, or 1.0) or (0.1, 0.2, 0.4, 0.6, or 1.0), respectively. Several works use linguistic scales in decision-making processes (for instance, [10], [21]). All answer options are previously conceptualized by experts to reduce subjectivity in

**TABLE 9. Matrix of pairwise comparisons 1.**

| Criterion | J1 | J2 | J3 | J4 |
|---|---|---|---|---|
| J1 - Environment impact | 1.00 | 1.00 | 0.33 | 0.33 |
| J2 - Reputational impact | 1.00 | 1.00 | 0.33 | 0.33 |
| J3 - Operational impact | 3.00 | 3.00 | 1.00 | 1.00 |
| J4 - Financial impact | 3.00 | 3.00 | 1.00 | 1.00 |
| Sum | 8.00 | 8.00 | 2.67 | 2.67 |

**TABLE 10.** Eigenvector and eigenvalue 1.

| Criterion | J1 | J2 | J3 | J4 | Sum | $\omega_j$ | Vector | $\lambda_{Max}$ |
|---|---|---|---|---|---|---|---|---|
| J1 - Environment impact | 0.13 | 0.13 | 0.13 | 0.13 | 0.50 | 0.13 | 4.00 | 4.00 |
| J2 - Reputational impact | 0.13 | 0.13 | 0.13 | 0.13 | 0.50 | 0.13 | 4.00 | |
| J3 - Operational impact | 0.38 | 0.38 | 0.38 | 0.38 | 1.50 | 0.38 | 4.00 | |
| J4 - Financial impact | 0.38 | 0.38 | 0.38 | 0.38 | 1.50 | 0.38 | 4.00 | |
| Sum | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 1.00 | | |

$a = 4,\ CI = 0.00,\ RI = 0.90,\ CR = 0.00.$

the operational risk assessment process [11], [12]. The linguistic scales defined in the questionnaire represent the level of probability and operational impact by criterion or sub-criterion. The higher scale value, the greater the contribution to operational risk. For each group of criteria ($\omega_j$ and $\omega_k$) or sub-criterion ($\omega_f^k$), the sum of the weights is limited according to the following expressions:

$$\sum_{j=1}^{m} \omega_j = 1, \tag{11}$$

$$\omega_j \geq 0, \tag{12}$$

where $\omega_j$ correspond to the weight value of the $j$th criterion,

$$\sum_{k=1}^{p} \omega_k = 1, \tag{13}$$

$$\omega_k \geq 0, \tag{14}$$

where $\omega_k$ correspond to the weight value of the $k$th criterion.

$$\sum_{f=1}^{q} \omega_f^k = 1, \quad \forall k = 1, 2, \ldots, n, \tag{15}$$

$$\omega_f^k \geq 0, \tag{16}$$

where $\omega_f^k$ correspond to the weight value of the $f^k$th sub-criterion of the $k$th criterion.

Step (8) Application of a questionnaire through interviews and field evaluation of the n power substations. Conducting interviews with using questionnaires is a practice applied to obtain the desired information in a more organized and objective way [64]–[67].

Step (9) Integration of the criteria and sub-criteria weights with the evaluations $A_h$ and $G_j$ (answers to the questions related to the probability and consequence, respectively) performed in the previous step. Their calculation makes it possible to obtain the value of the operational risk $R_i$. At this step, it is calculated

$$B_f = \sum_{h=1}^{s} A_h, \quad f = 1, 2, \ldots, q, \tag{17}$$

which represents the sum of the values obtained in answering each question $A_h$ of the hth group of components, of the fth sub-criterion. It is also calculated

$$F_f = \frac{\omega_f^k B_f}{s}, \quad f = 1, 2, \ldots, q, \quad k = 1, 2, \ldots, p \tag{18}$$

representing the result of the evaluation of the $f$th subcriterion multiplied by the weight $\omega_k$ of the $f$th sub-criterion referring to the $k$th criterion and divided by the amount of s groups of components.

It is possible to calculate the sum of the $F_f$ indicators of the $q$th sub-criterion belonging to the level 3 as follows:

$$K_k = \sum_{f=1}^{q} F_f, \quad k = 1, 2, \ldots, p. \tag{19}$$

Calculating

$$D_k = \omega_k K_k, \quad k = 1, 2, \ldots, p, \tag{20}$$

for the $k$th criterion belonging to the level 2, it is possible to obtain

$$P_i = \sum_{k=1}^{p} D_k, \quad i = 1, 2, \ldots, n \tag{21}$$

**TABLE 11.** Matrix of pairwise comparisons 2.

| Criterion | D1 | D2 | D3 | D4 |
|---|---|---|---|---|
| D1 - Equipment | 1.00 | 3.00 | 3.00 | 0.20 |
| D2 - Procedure | 0.33 | 1.00 | 3.00 | 0.14 |
| D3 - Manpower | 0.33 | 0.33 | 1.00 | 0.14 |
| D4 - Maintenance | 5.00 | 7.00 | 7.00 | 1.00 |
| Sum | 6.67 | 11.33 | 14.00 | 1.49 |

**TABLE 12.** Eigenvector and eigenvalue 2.

| Criterion | J1 | J2 | J3 | J4 | Sum | $\omega_k$ | Vector | $\lambda_{Max}$ |
|---|---|---|---|---|---|---|---|---|
| D1 - Equipment | 0.15 | 0.26 | 0.21 | 0.13 | 0.76 | 0.19 | 4.40 | 4.24 |
| D2 - Procedure | 0.05 | 0.09 | 0.21 | 0.10 | 0.45 | 0.11 | 4.03 | |
| D3 - Manpower | 0.05 | 0.03 | 0.07 | 0.10 | 0.25 | 0.06 | 4.11 | |
| D4 - Maintenance | 0.75 | 0.62 | 0.50 | 0.67 | 2.54 | 0.64 | 4.42 | |
| Sum | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 1.00 | | |

$a = 4,\ CI = 0.08,\ RI = 0.90,\ CR = 0.09.$

**TABLE 13.** Matrix of pairwise comparisons 3.

| Sub-criterion | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| F1 - Redundancy | 1.00 | 7.00 | 7.00 | 7.00 | 9.00 |
| F2 - Technology | 0.14 | 1.00 | 5.00 | 5.00 | 5.00 |
| F3 - Technical assistance | 0.14 | 0.20 | 1.00 | 1.00 | 1.00 |
| F4 - Spare equipment availability | 0.14 | 0.20 | 1.00 | 1.00 | 1.00 |
| F5 - Spare parts | 0.11 | 0.20 | 1.00 | 1.00 | 1.00 |
| Sum | 1.54 | 8.60 | 15.00 | 15.00 | 17.00 |

**TABLE 14.** Eigenvector and eigenvalue 3.

| Sub-criterion | F5 | F6 | F7 | F8 | F9 | Sum | $\omega_f^1$ | Vector | $\lambda_{Max}$ |
|---|---|---|---|---|---|---|---|---|---|
| F1 - Redundancy | 0.65 | 0.81 | 0.47 | 0.47 | 0.53 | 2.93 | 0.59 | 6.16 | 5.31 |
| F2 - Technology | 0.09 | 0.12 | 0.33 | 0.33 | 0.29 | 1.17 | 0.23 | 5.22 | |
| F3 - Technical assistance | 0.09 | 0.02 | 0.07 | 0.07 | 0.06 | 0.31 | 0.06 | 5.05 | |
| F4 - Spare equipment availability | 0.09 | 0.02 | 0.07 | 0.07 | 0.06 | 0.31 | 0.06 | 5.05 | |
| F5 - Spare parts | 0.07 | 0.02 | 0.07 | 0.07 | 0.06 | 0.29 | 0.06 | 5.09 | |
| Sum | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 5.00 | 1.00 | | |

*a = 5, CI = 0.08, RI = 1.12, CR = 0.07.*

of Equation (1), which is to be used in allocating resources between substations.

The use of $J_j$ calculated as

$$J_j = \omega_j G_j, \quad j = 1, 2, \ldots, m \tag{22}$$

permits one to obtain $C_i$ as follows:

$$C_i = \sum_{j=1}^{n} J_j, \quad i = 1, 2, \ldots, n. \tag{23}$$

Step (10) Perform the comparison, ordering, and/or prioritization of the n power substations, by analyzing the values of $R_i$. The risk matrix is used to represent the result.

Step (11) Execution of the allocation of available financial resources between the n power substations, applying the model 1 of [10].

The procedures of resource allocation based on risk assessment applying the SRA method given in Figure 2.

## VI. CASE STUDY

This section presents a Case Study illustrating the application of the SRA method to assess the operational risk of three power substations.

The methodological tools and their combinations, proposed in the present work, are applied to a Case Study related to mining company in Minas Gerais state, Brazil.

The results of this research can provide important indicators to manage the operational risk of the power substations.

Under step (1) of the method, the power substations were selected. Their characteristics are presented in Table 1.

Applying step (2), the group of experts is defined on the basis of their competence in working with power substations.

**TABLE 15.** Matrix of pairwise comparisons 4.

| Sub-criterion | F6 | F7 | F8 |
|---|---|---|---|
| F6 - Maintenance procedure | 1.00 | 1.00 | 0.14 |
| F7 - Operation procedure | 1.00 | 1.00 | 0.14 |
| F8 - Operation type | 7.00 | 7.00 | 1.00 |
| Sum | 9.00 | 9.00 | 1.29 |

Applying step (3), Tables [4]–[8] (APPENDIX) are constructed. The selection of criteria, sub-criteria, scales, definitions, and groups of components is based on a review of literature on risk assessment [8], [28], power substation concepts [68]–[70], and interviews with a very experienced seniors engineers in power substations. Besides, the company-specific business strategy, environmental strategy, and maintenance strategy are considered.

The 12 groups of components defined by the experts are listed below:

1) Lightning protection systems;
2) Disconnect switch systems;
3) Circuit breaker switching systems;
4) Auxiliary power systems;
5) Cabling and buses systems;
6) Protection, measurement, and control system;
7) Power transformers and associated systems;
8) Switchgear and controlgear systems;
9) Bank of capacitors and reactors;
10) Grounding system;
11) Fire protection system;
12) Civil infrastructure and general aspects.

**TABLE 16.** Eigenvector and eigenvalue 4.

| Sub-criterion | C10 | C11 | C12 | Sum | $\omega_f^2$ | Vector | $\lambda_{Max}$ |
|---|---|---|---|---|---|---|---|
| F6 - Maintenance procedure | 0.11 | 0.11 | 0.11 | 0.33 | 0.11 | 3.00 | 3.00 |
| F7 - Operation procedure | 0.11 | 0.11 | 0.11 | 0.33 | 0.11 | 3.00 | |
| F8 - Operation type | 0.78 | 0.78 | 0.78 | 2.33 | 0.78 | 3.00 | |
| Sum | 1.00 | 1.00 | 1.00 | 3.00 | 1.00 | | |

$a = 3$, $CI = 0.00$, $RI = 0.58$, $CR = 0.00$.

Applying steps (4) and (5), the hierarchy for structuring the risk assessment is constructed. Figure 3 presents the proposal defined by the experts. The values presented in this figure exemplify the evaluation of the PS2 power substation. The corresponding values are calculated applying step (9).

The execution of step (6) permits one to obtain the vector of priorities that represent the weights of the criteria ($\omega_j$ and $\omega_k$) or sub-criteria ($\omega_f^k$) [55]–[57]. The Tables 10, 12, 14, 16, 18, and 20 (APPENDIX) represent the pairwise comparison matrices of criteria, and sub-criteria analyzed by the experts. The consistency of judgments was checked applying the following expressions of [55]–[57]:

$$CR = \frac{CI}{RI} \tag{24}$$

and

$$CI = \frac{\lambda_{Max} - a}{a - 1}, \tag{25}$$

where $CI$ is the Consistency Index, $\lambda_{Max}$ corresponds to the maximum eigenvalue of the matrix $A$, $a$ corresponds to the matrix dimensions dim(A) $=$ *(axa)*, $CR$ is the Consistency Ratio, and $RI$ corresponds to the random consistency index matrices. The results of calculations of $CR$ show that the comparisons presented by the experts are satisfactory ($CR \leq 0.10$) [55]–[57]. The vectors of priorities of each criterion and sub-criterion, $\lambda_{Max}$, a, RI, and CR are represented by the Tables 9, 11, 13, 15, 17, and 19 (APPENDIX), respectively.

Under step (7), the questionnaire is prepared, considering the linguistic scale for each criterion or sub-criterion, defined by the experts. The use of the questionnaire, by step (8), permits one to evaluate the operational risks. The data collected is based on interviews and the field analysis carried out in conjunction with the technicians responsible for the power substations. Tables 21 and 22 (APPENDIX) represent, for example, the result of the evaluation of the PS2 power substation.

Applying step (9), the values of $P_i$, $C_i$, and $R_i$ of each power substation are calculated, using Equations (17)–(23), and (1), respectively. The corresponding results are presented in Table 2 and allow the construction of the risk matrix represented in Figure 4.

The execution of step (10) permits one to compare, order, and/or prioritize the power substations, taking into account the values of $P_i$, $C_i$, and $R_i$. These values are given in Table 2 and are reflected in Figure 4. It is possible to observe that the power substations PS1 and PS2 are located in the high-risk cell and the power substation PS3 in the medium-risk cell.

**TABLE 17.** Matrix of pairwise comparisons 5.

| Sub-criterion | F9 | F10 | F11 |
|---|---|---|---|
| F9 - Manpower | 1.00 | 7.00 | 9.00 |
| F10 - Daily average exposure | 0.14 | 1.00 | 3.00 |
| F11 - Intervention frequency | 0.11 | 0.33 | 1.00 |
| Sum | 1.25 | 8.33 | 13.00 |

The total resource available for the three power substations is $R = 3{,}000{,}000.00$ *R\$*. Thus, the following constraints are to be taken into account:

$$x_1 + x_2 + x_3 = 3,000,000.00. \tag{26}$$

Besides, the following constraints, related to the demand of the substations, are to be considered:

$$0 \leq x_1 \leq 465,000.00, \tag{27}$$
$$0 \leq x_2 \leq 1,866,000.00, \tag{28}$$

and

$$0 \leq x_3 \leq 1,116,000.00, \tag{29}$$

where $x_1, x_2$, and $x_3$ are the variables, which correspond to the volume of sought resources, and the corresponding demands (*R\$* 465,000.00, *R\$* 1,866,000.00, and *R\$* 1,116,000.00) refer to the investment needed for solving the operational risk problem of the three power substations, respectively.

The objectives are the following:

1) Predominant provision of resources for power substations with higher probability of operational occurrence;
2) Predominant provision of resources for power substations with higher potential environmental impact, reputational impact, productive impact, and financial impact.

The variables $P_i$ and $C_i$ from the Table 2 are used to construct the following objective functions:

$$F_1(X) = 0.418x_1 + 0.381x_2 + 0.498x_3 \rightarrow \max, \tag{30}$$
$$F_2(X) = 0.638x_1 + 0.825x_2 + 0.400x_3 \rightarrow \max. \tag{31}$$

**TABLE 18.** Eigenvector and eigenvalue 5.

| Sub-criterion | F9 | F10 | F11 | Sum | $\omega_f^3$ | Vector | $\lambda_{Max}$ |
|---|---|---|---|---|---|---|---|
| F9 - Manpower | 0.80 | 0.84 | 0.69 | 2.33 | 0.78 | 3.19 | 3.08 |
| F10 - Daily average exposure | 0.11 | 0.12 | 0.23 | 0.46 | 0.15 | 3.04 | |
| F11 - Intervention frequency | 0.09 | 0.04 | 0.08 | 0.21 | 0.07 | 3.01 | |
| Sum | 1.00 | 1.00 | 1.00 | 3.00 | 1.00 | | |

$a = 3$, $CI = 0.04$, $RI = 0.58$, $CR = 0.07$.

**TABLE 19.** Matrix of pairwise comparisons 6.

| Sub-criterion | F12 | F13 | F14 | F15 |
|---|---|---|---|---|
| F12 - History of operational failures or incidents | 1.00 | 3.00 | 0.11 | 0.33 |
| F13 - Maintenance type | 0.33 | 1.00 | 0.11 | 0.20 |
| F14 - Operational critical condition | 9.00 | 9.00 | 1.00 | 7.00 |
| F15 - Maintenance plan | 3.00 | 5.00 | 0.14 | 1.00 |
| Sum | 13.33 | 18.00 | 1.37 | 8.53 |

**TABLE 20.** Eigenvector and eigenvalue 6.

| Sub-criterion | F12 | F13 | F14 | F15 | Sum | $\omega_f^4$ | Vector | $\lambda_{Max}$ |
|---|---|---|---|---|---|---|---|---|
| F12 - History of op. failures or incidents | 0.08 | 0.17 | 0.08 | 0.04 | 0.36 | 0.09 | 4.04 | 4.27 |
| F13 - Maintenance type | 0.03 | 0.06 | 0.08 | 0.02 | 0.19 | 0.05 | 4.07 | |
| F14 - Operational critical condition | 0.68 | 0.50 | 0.73 | 0.82 | 2.73 | 0.68 | 4.67 | |
| F15 - Maintenance plan | 0.23 | 0.28 | 0.10 | 0.12 | 0.72 | 0.18 | 4.32 | |
| Sum | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 1.00 | | |

$a = 4$, $CI = 0.09$, $RI = 0.90$, $CR = 0.10$.

**TABLE 21.** PS2 - criteria applied to $C_i$ [J1, J4] - evaluation result - $G_j$.

| *G1* | *G2* | *G3* | *G4* |
|---|---|---|---|
| 0.5 | 0.1 | 1.0 | 1.0 |

The solution was found using the application entitled Adaptive Interactive Decision Making System (AIDMS2). It implements the fuzzy set based multiobjective allocation of resources (or their shortages) as described in [71]. The solution to the problem of allocation financial resources is represented in Table 3. The result is considered harmonious [10]–[12], [71] and the levels of satisfying the objective functions $F_1(X)$ and $F_2(X)$ are 0.6607 and 0.6607, respectively.

## VII. DISCUSSIONS

In this research, methodological tools for considering the information of qualitative character have been proposed and applied to assess, compare, prioritize, and/or order power substations from the point of view of operational risks and to rationally allocate available resources to reduce operational risks.

The proposed methodology allows the experts to express their opinions to define criteria and sub-criteria and their weights applying multiattribute decision-making methods. The weight vectors are obtained through the AHP method. Its application, using expert's opinions, provides the reduction of uncertainties. The power substation risk assessment results are generated through applying questionnaires that permits the consideration of linguistic scales. Besides, the integration of criteria and sub-criteria for constructing a so-called risk matrix allows the preparation of information for resource allocation. In particular, for the three power substations, their demands and constraints are defined. In addition, the objectives are defined to solve the resource allocation problem. The $\langle X, F \rangle$ models are utilized in this work, for the first time, for power substation resource allocation. Likewise, the modification of the Bellman-Zadeh approach is applied to generate harmonious solutions in the analysis of $\langle X, F \rangle$ models.

In the Case Study, Table 2 permits one to observe the power substations risk levels. The analysis of the results shows that PS2 has the highest risk level (Table 2 - 0.314), followed by PS1 (Table 2 - 0.267), and PS3 (Table 2 - 0.199). The results of allocating financial resources (Table 3) indicate that the power substations received: PS1: *R$* 465,000.00, PS2: *R$* 1,714,339.00, and PS3: *R$* 820,661.00. This allocation provides the harmonious solution [10]–[12], [71].

**TABLE 22.** PS2 - sub-criteria applied to $P_i$ [F1, F15] - evaluation result - $A_h$.

| s | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ | $A_{11}$ | $A_{12}$ | $A_{13}$ | $A_{14}$ | $A_{15}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.10 | 0.50 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.40 | 0.10 | 0.50 | 0.50 | 0.50 |
| 2 | 1.00 | 0.50 | 0.10 | 0.10 | 0.50 | 1.00 | 1.00 | 0.10 | 0.50 | 0.50 | 0.40 | 0.50 | 0.50 | 0.10 | 0.50 |
| 3 | 0.10 | 0.10 | 0.10 | 0.10 | 1.00 | 0.10 | 1.00 | 0.10 | 0.50 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 4 | 0.10 | 0.50 | 0.10 | 0.50 | 0.50 | 1.00 | 1.00 | 1.00 | 0.50 | 0.10 | 0.20 | 0.10 | 0.50 | 0.50 | 0.50 |
| 5 | 0.50 | 0.50 | 0.10 | 0.10 | 0.10 | 1.00 | 1.00 | 0.10 | 0.50 | 0.10 | 0.10 | 0.50 | 1.00 | 0.10 | 1.00 |
| 6 | 1.00 | 1.00 | 0.10 | 0.10 | 0.10 | 1.00 | 1.00 | 0.10 | 0.50 | 0.50 | 0.20 | 0.10 | 0.50 | 0.10 | 0.50 |
| 7 | 0.50 | 0.50 | 1.00 | 0.50 | 0.50 | 1.00 | 1.00 | 0.10 | 0.50 | 0.50 | 0.20 | 0.10 | 0.50 | 0.10 | 0.50 |
| 8 | 1.00 | 1.00 | 0.50 | 0.50 | 0.50 | 1.00 | 1.00 | 1.00 | 0.50 | 0.50 | 0.60 | 0.10 | 1.00 | 0.10 | 1.00 |
| 9 | 0.50 | 1.00 | 0.10 | 0.50 | 0.50 | 1.00 | 1.00 | 1.00 | 0.50 | 0.10 | 0.20 | 0.10 | 0.50 | 0.10 | 0.50 |
| 10 | 0.10 | 0.50 | 0.10 | 0.10 | 0.10 | 1.00 | 1.00 | 0.10 | 0.10 | 0.10 | 0.40 | 0.10 | 1.00 | 0.10 | 0.50 |
| 11 | 1.00 | 0.50 | 0.10 | 0.50 | 0.50 | 1.00 | 1.00 | 0.10 | 0.50 | 0.10 | 0.10 | 1.00 | 1.00 | 0.10 | 0.50 |
| 12 | 0.10 | 0.50 | 0.10 | 0.10 | 0.10 | 1.00 | 1.00 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 1.00 | 0.10 | 1.00 |

Based on the risk matrix analysis it is easy to see that power substation PS2 has higher risk and requires more consideration than substations PS3 and PS1. In contrast, PS3 has the highest probability value than PS1 and PS2. The matrix analysis without considering the multiobjective optimization can lead to spending all resources in power substations PS1 and PS2. In this situation, the power substation PS3 can be not maintained and its operational conditions can be compromised.

One of the important results of this work is the allocation of available resources based on risk assessment, considering simultaneously the following objectives: probability and consequence. The ARS method minimizes errors avoiding spending all financial resources on highly unlikely failures while less severe failures can manifest, if more likely.

## VIII. CONCLUSION

The main contribution of this research is the development of the method for considering qualitative information in allocating resources to reduce of the operational risk on power substations. Besides, the AHP and $\langle X, F\rangle$ models are utilized here for the first time, to allocate available resources integrated with risk matrix concepts. The Bellman-Zadeh approach is applied to generate harmonious solutions in the analysis of $\langle X, F\rangle$ models.

The proposed method adequately generates such objectives that guide the distribution of financial resources between the power substations, which are usually limited. The rational use of financial resources contributes to the prevention of personal and material accidents and reducing production losses due to failures in the management process.

The results of the research are illustrated by applying the methodology in a Case Study of allocating financial resources aimed at reducing the risks of three power substations. The differential of this method lies in the possibility of reducing the subjectivity of power substation risk assessment and raising the quality of the decisions made for the allocation of resources. In addition, the SRA method provides the reduction of the uncertainties in constructing the risk matrices. The existing results related to risk matrices are concentrated on their construction and applications, and does not simultaneously consider the total resource available, demands, and constraints to resource allocation to reduce of the operational risk.

The Case Study results provide important information to resource allocation based on risk assessment on power substations. The SRA method performs the integration of safety, technical, management, and financial aspects of power substations of different technologies, sizes, and ages.

The methodology has universal characteristics and can be used in other contexts, where it is necessary to allocate financial resources to reduce risks of any nature.

## APPENDIX

See Tables 4–22.

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