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Risk assessment for electricity generation management process with swara based fuzzy TOPSIS method

SWARA temelli bulanık TOPSIS yöntemiyle elektrik üretimi yönetim sürecine ilişkin risk değerlendirmesi

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Risk Assessment for Electricity Generation Management Process with SWARA Based Fuzzy TOPSIS Method

Highlights

- *Risk analysis with SWARA Based Fuzzy TOPSIS method*
- *Analysis of Electricity Generation Management processes*
- *Comparison of the success of electricity generation plants in eliminating the risks*

Graphical Abstract

In this study, common risks in the electricity generation management process in HEPPs are analyzed using the SWARA-based fuzzy TOPSIS method.

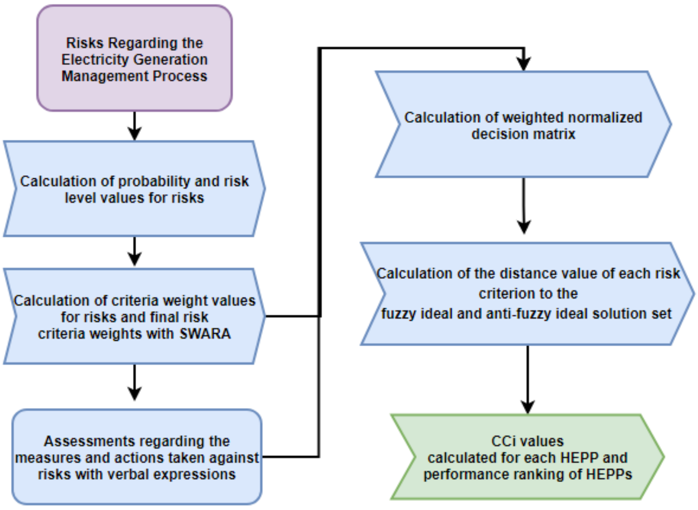

Figure. Risk assessment for electricity generation management process flowchart

Aim

In this study, it is aimed to analyze the risks related to Electricity Generation Management processes in HEPPs with the SWARA-based Fuzzy TOPSIS method.

Design & Methodology

In this study, Swara-based Fuzzy TOPSIS method is suggested to be used in risk analysis.

Originality

Performing risk analysis of Electricity Generation Management processes in HEPPs with SWARA Tabanlı Bulanik TOPSIS.

Findings

The SWARA Based Fuzzy TOPSIS method suggested in the study can be used for risk analysis of Electricity Generation Management processes in HEPPs.

Conclusion

In this study, 14 risks that may arise during the operation of the Generation Management Process in HEPPs are discussed. The performances of the related HEPPs in minimizing the risks have been evaluated with the help of SWARA and Fuzzy TOPSIS methods.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Risk Assessment for Electricity Generation Management Process with SWARA Based Fuzzy TOPSIS Method

Araştırma Makalesi / Research Article

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ABSTRACT

In the successful maintenance of electricity generation management processes in power generation plants, it is of great importance to determine the risks that may arise during the operation of the relevant processes, take measures to minimize these risks, and take the necessary actions. In this study, common risks in the electricity generation management process in HEPPs were identified and these risks were rated by experts (decision-makers) within each power plant itself. Since this rating is made by the experts of each power plant, the impact and probability values of the same risk may differ, and accordingly, different risk levels may arise for the same risk. In the study, the SWARA method was used to compare the risk levels of common risks in the electricity generation process in different power plants and calculate the final weight values of the related risks. As a result of the measures determined for each risk in the electricity generation management processes in the power plants and the actions taken for these measures, it was determined whether the relevant risks were reduced to acceptable levels by looking at the results of the internal audits. In the internal audits, the performance of HEPPs in eliminating the related risks is evaluated with fuzzy expressions separately for each risk. The risk weight values obtained by the SWARA method and the fuzzy expressions obtained as a result of the risk assessment were analyzed with the Fuzzy TOPSIS method, and the performance values of the power plants in eliminating the risks were calculated, then the performance ranking was made in the light of these values.

Keywords: SWARA, Fuzzy TOPSIS, electricity generation management process, risk analysis.

SWARA Temelli Bulanık TOPSIS Yöntemiyle Elektrik Üretimi Yönetim Sürecine İlişkin Risk Değerlendirmesi

ÖZ

Elektrik üretim santrallerinde elektrik üretimi yönetim süreçlerinin başarılı bir şekilde devam ettirilmesinde, ilgili süreçlerin işletilmesi esnasında ortaya çıkabilecek risklerin belirlenerek, bu risklerin en aza indirgenmeye çalışılması için önlem alınması ve gerekli eylemlerin hayata geçirilmesi büyük önem arz etmektedir. Bu çalışmada, HES'lerde elektrik üretimi yönetim sürecindeki ortak riskler belirlenerek bu riskler her santralin kendi içindeki uzman kişilerce (karar vericiler) derecelendirilmiştir. Bu derecelendirme her bir santralin kendi uzmanlarınca yapıldığından aynı riske ait etki ve olasılık değerleri farklılık gösterebilmekte, buna bağlı olarak da aynı risk için farklı risk dereceleri ortaya çıkabilmektedir. Çalışmada, farklı santrallerdeki elektrik üretimi sürecindeki ortak risklere ait risk derecelerinin birbirleri ile karşılaştırılması ve ilgili risklerin nihai ağırlık değerlerinin hesaplanması için SWARA yönteminden yararlanılmıştır. Santrallerdeki elektrik üretim yönetim süreçlerindeki her bir riske ilişkin alınan önlemler ve gerçekleştirilen eylemler sonucu ilgili risklerin kabul edilebilir seviyelere indirgenip indirgenmediği yapılan iç denetimlerin sonuçlarına bakılarak belirlenmiştir. Yapılan iç tetkiklerde her bir risk için ayrı ayrı değerlendirme yapılarak, santrallerin risk gidermedeki başarımları bulanık ifadeler ile değerlendirilmektedir. SWARA yöntemi ile elde edilen risk ağırlık değerleri ve risk değerlendirmesi sonucu elde edilen bulanık ifadeler Bulanık TOPSIS yöntemi ile analiz edilerek santrallerin riskleri gidermedeki performans değerleri hesaplanmış ve bu değerler ışığında başarım sıralaması yapılmıştır.

Anahtar Kelimeler: SWARA, Bulanık TOPSIS, elektrik üretimi yönetim süreci, risk analizi.

1. INTRODUCTION

Institutions and organizations applying the process management approach determine the processes related to their activities and carry out all their activities step by step through these processes. Process management is beneficial in ensuring consistency and integration in the implementation of activities and determining risks easily [1]. Determining the risks that may occur in each step of the processes established to ensure the efficient and effective sustainability of electricity generation activities in HEPPs and performing risk analysis within the scope

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of risk management are also important as they provide protection against threats and dangers.

There are two approaches, traditional and modern risk, for the concept of risk defined by the IIA (International Institute of Internal Auditors) as "the possibility of occurrence of any event that will prevent the organization from realizing its strategic, financial and operational goals". In the traditional approach, risk is defined as only negative and associated with concepts such as threat, harm, loss, and danger. In the modern approach, risk is defined as an opportunity and profit, as well as negative concepts in the traditional approach. It is also associated with positive concepts [2]. Today, institutions and organizations focus on turning risks into opportunities as well as avoiding the uncertain environment caused by risks and try to take into account and manage all kinds of risks that may arise with strategic and operational risks [3]. By effectively implementing and maintaining risk management activities in institutions and organizations, it is possible to reduce losses by providing protection against threats and dangers, as well as evaluate the opportunities that may arise and turn them into possible gains [4].

The Electricity Generation Management Process is one of the most important processes that can be used in HEPPs to ensure that electricity generation activities can be carried out in a timely, effective and efficient manner. This process can be reduced into various sub-processes, making it more understandable and easier to implement. These sub-processes can be listed as HEPP Generation Planning and Follow-up Process, HEPP Generation Works Process, HEPP Shift Management Process, HEPP Monitoring-Measurement Process, and HEPP Ancillary Services Process.

In the second part of the study, a literature review has been made on the methods used and other Fuzzy Multi Criteria Decision Making (MCDM) methods. In the third chapter, information about the SWARA method, fuzzy set theory and Fuzzy TOPSIS methods used in the study is given. In the fourth chapter, the findings obtained with the application of SWARA and Fuzzy TOPSIS methods on the risk data used in the study are shared. In the fifth chapter, an evaluation was made on the results obtained and future studies were mentioned.

2. RELATED LITERATURE

In this part, studies with Fuzzy MCDM, formed by using fuzzy set theory and MCDM methods in various fields in the literature are examined. It is seen that the studies are carried out in different fields using different types of numerical methods. The studies discussed are summarized below.

Kim et al. determined the criticality levels of the risks by analyzing 57 risks created by a team of 14 experts for international steel construction, operation, and transfer of new steel technologies with Fuzzy AHP and Fuzzy Inference System (FIS) [5]. Yavuz et al. aimed to select the manufacturing method that best suits the part planned to be processed and the production conditions. In the solution of the problem, an approach using Fuzzy AHP and Fuzzy TOPSIS methods has been introduced [6]. Gul et al. determined the safety risk levels of underground mining by proposing the VIKOR approach based on Pythagoras fuzzy numbers to establish a safety risk analysis mechanism in zinc and copper mining [7]. Rahmani et al. analyzed the security risks in electricity transmission and distribution processes using ET&BA technique and compared this technique with VIKOR and Fuzzy TOPSIS methods [8].

Wu et al. suggested a fuzzy synthetic assessment for the process of identifying prospective risk factors for China's electric vehicle supply chain and developing risk prevention measures [9]. Wu et al., within the scope of the Photovoltaic Poverty Reduction Project (PPAP) in China, with a method using project life cycle theory and Delphi method, 18 risk factors were identified. Expanded DAMATEL method was used in intuitive fuzzy environment for the determination of weights of risks and risk analysis [10]. Polishchuk et al. developed a fuzzy risk analysis model based on expert opinion by identifying 21 risk factors for environmental start-up projects in the air transportation [11]. Liang et al. used the MABAC method in their study to evaluate the risks associated with rock explosion in complex decision-making conditions (fuzzy environment) and to determine the risk levels [12]. Karasan et al. proposed a structure in which Pythagoras fuzzy clustering set is used together with Safety and Critical Impact Analysis (SCEA) to be used in risk analysis [13].

Panchal et al. conducted a risk analysis of the CHU located in a medium-sized coal-fired thermal power plant located in India [14]. Fuzzy FMEA and Gray Relationship Analysis (GRA) methods were used in this risk analysis. Adar et al. analyzed the risks that may arise during the commissioning and the operation of the laboratory-scale supercritical water evaporation system (SCWG) using the fuzzy-FMEA method. As a result of the risk assessments, it was seen that the most important risks in SCWG are explosion, injury, smell, and noise [15]. Serrano-Gomez et al. carried out the risk analysis of the construction project of a 250 MW solar power plant located in southeast Spain (Region of Murcia) using the Monte Carlo method and the Analysis Hierarchy Process with Probabilistic Fuzzy Sets (PFSAHP) [16]. Kul et al. conducted risk analysis on 23 risk factors determined with the help of Delphi method for renewable energy projects (REP) investments using AHP and FWASPAS methods [17].

When the studies in the literature are examined, it is seen that the use of Fuzzy Set Theory together with MCDM methods provides the opportunity to obtain healthier results in solving MCDM problems in fuzzy environment, making decisions about processes and evaluating processes.

3. MATERIAL AND METHODS

Regarding each step of the relevant processes in the study, 14 common risk criteria for the Electricity Generation Management Process were determined by the experts in five different HEPPs. Risk ratings related to these risks were discussed and rated separately by the experts of each power plant. Since this rating is made by the experts of each HEPP within its own structure, the impact and probability values determined for each risk may differ, and accordingly, many different risk levels may arise for the same risk.

In each HEPP, the comparison of the risk levels of the risks determined in relation to the Electricity Management Process with each other and the calculation of the final weight values of the related risks were carried out with the help of the SWARA method. Whether the risks related to the Electricity Generation Management Process in HEPPs are reduced to acceptable levels with corrective actions is determined by looking at the annual internal audit results.

With internal audits, separate assessments are made for each risk, and success levels for eliminating the risks are represented by fuzzy expressions. These fuzzy expressions are Very Bad (VB)/Very Low (VL), Bad (B)/Low (L), Medium Bad (MB)/Medium Low (ML), Medium (M), Medium Good (MG)/Medium High (MH), Good (G)/High (H) and Very Good (VG)/Very High (VH). In this study, the fuzzy expressions obtained as a result of the risk weight values and risk assessment were analyzed with the Fuzzy TOPSIS method, and the performance values of the power plants in eliminating the risks were calculated; then the performance ranking was made in the light of these values.

3.1. Fuzzy Sets

The fuzzy set theory was first presented by Lotfi A. Zadeh in 1965. Zadeh mentioned the blurring of human thought in his work and stated that the logic system expressed by 0 and 1 is not sufficient to explain the thoughts based on this fuzzy system [18-22]. The element values that make up a fuzzy set are elements with weight values expressed by fuzzy numbers between 0 and 1, unlike classical set logic. This weight value is called membership degree. Each element contained in a fuzzy set is represented by the membership function of the corresponding fuzzy set. These triangular, trapezoidal, bell curve, Z-shaped, sigmoid etc. membership functions can be expressed with membership functions [23]. The most preferred forms of membership function in the literature are triangle and trapezoid membership functions.

In this study, the SWARA method was used to calculate the final weight values of common risks in the electricity generation process at different power plants.

3.2. Step by Step Weight Assessment Ratio Analysis Method (SWARA)

SWARA is a MCDM method developed by Kersuliene et al. in 2010 and used in weighting evaluation criteria based on the opinions of expert decision makers. This method is based on the calculation of a common criterion weight value for the relevant criterion based on the degrees of importance determined by the experts for each criterion [24].

In the SWARA method, the criteria are evaluated by the decision makers and sorted in order of importance, starting from the most important. Then the importance levels of the criteria are determined by comparing them with each other. This process determines the proportional value of how important each criterion (j) is from the following criterion ($j+1$). This proportional value is called ‘the comparative importance of average values’ and represented by ‘s_j’ [25].

After obtaining the comparative significance values (s_j), the coefficient value of each criterion is calculated with Equation 1.

$$k_j = \begin{cases} 1 & ,j = 1 \\ s_j + 1 & ,j > 1 \end{cases} \tag{1}$$

Using the calculated k_j values, the importance vector value (q_j) of each criterion is obtained by using Equation 2.

$$q_j = \begin{cases} 1 & ,j = 1 \\ \frac{x_{j-1}}{k_j} & ,j > 1 \end{cases} \tag{2}$$

Finally, the calculation of the relative weight value (w_j) of each criterion is performed using Equation 3.

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{3}$$

The w_j value calculated in Equation 3 represents the weight value of j criterion, that is, its relative importance.

3.3. Fuzzy TOPSIS Method (FTOPSIS)

TOPSIS method was developed by Yoon and Hwang [26] in 1981 based on the principle of choosing the most suitable one among the alternatives. Fuzzy TOPSIS was first addressed in a study conducted by Chen in 2000 [27]. In this method, verbal expressions used in the evaluation of alternatives are represented by fuzzy triangular numbers determined in response to these statements.

Table 1. Verbal variables used for decision criteria and alternatives, and positive triangular fuzzy numbers corresponding to these expressions

Criteria		Alternatives	
Verbal Expression	**Triangular Fuzzy Number**	**Verbal Expression**	**Triangular Fuzzy Number**
VL	[0, 0, 0.1]	VB	[0, 0, 1]
L	[0, 0.1, 0.3]	B	[0, 1, 3]
ML	[0.1, 0.3, 0.5]	MB	[1, 3, 5]
M	[0.3, 0.5, 0.7]	M	[3, 5, 7]
MH	[0.5, 0.7, 0.9]	MG	[5, 7, 9]
H	[0.7, 0.9, 1]	G	[7, 9, 10]
VH	[0.9, 1, 1]	VG	[9, 10, 10]

In the Fuzzy TOPSIS method, firstly, a cluster consisting of n decision makers (*DM*) is created. After the decision makers, criteria and alternatives are determined. Decision makers are expressed by DM_i *(i = 1, 2,…,n)*, criteria by C_i *(i = 1,2,…,n)* and alternatives by A_i *(i = 1,2 ...,m)* [28]. Fuzzy verbal expressions are used by decision makers to evaluate alternatives and weigh the criteria according to their importance. These expressions are seen in Table 1.

As seen in Table 1, the fuzzy verbal expressions used in the risk assessment made by decision makers are expressed with the corresponding positive triangular fuzzy numbers to be used in the Fuzzy TOPSIS method [29,30].

After the alternatives are evaluated by n decision makers using Table 1, the values of the alternatives in the fuzzy decision matrix are represented by $\tilde{x}_{ij}$. The value of $\tilde{x}_{ij}$ consists of three components a_{ij} , b_{ij} , c_{ij}.

In the study, the weight values of the criteria ($\widetilde{w}_j$) are the weight values calculated by the SWARA method in Equation 3. Fuzzy decision matrix ($\widetilde{D}$) and fuzzy weight vector ($\widetilde{W}$) obtained in the light of these values are shown in Equation 4.

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}, \widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n] \quad (4)$$

The results of fuzzy decision matrix are subjected to the normalization process. Thanks to the normalization process, each criterion is reduced to [0,1] interval. Normalized fuzzy decision matrix ($\tilde{R}$) is represented as in Equation 5.

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn}, \ i = 1,2,3 \dots, m, \ j = 1,2,3, \dots, n. \quad (5)$$

Each element of the normalized fuzzy decision matrix is calculated by Equations 6 and Equation 7, represented by utility criterion B and cost criterion C.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c^+_j}, \frac{b_{ij}}{c^+_j}, \frac{c_{ij}}{c^+_j}\right), \ c^+_j = \max(c_{ij}), \forall_j \in B \quad (6)$$

$$\tilde{r}_{ij} = \left(\frac{a^-_j}{c_{ij}}, \frac{a^-_j}{b_{ij}}, \frac{a^-_j}{a_{ij}}\right), \ a^-_j = \min(a_{ij}), \forall_j \in C \quad (7)$$

As seen in Equation 6 and Equation 7, in cases where decision criteria are utility criteria, among the third components (c_{ij}) of the elements in each column, the largest (c^+_j) is determined. Then the components of each element in the relevant column are divided by the obtained value of c^+_j . If the decision criteria are 'cost criteria', among the first components (a_{ij}) of the elements in each column, the component value (a^-_j) with the smallest value is determined. By dividing the determined a^-_j value by the third (c_{ij}) value of each element in the related column, the new normalized value of the first component of this element is obtained. Dividing the value of a^-_j by the second (b_{ij}) value of each element in the relevant column, the new normalized value of the second component of this element is obtained. Finally, the new normalized value of the third component of this element is obtained by dividing the value of a^-_j by the first component (a_{ij}) value of each element in the respective column.

After obtaining the normalized fuzzy decision matrix, Equation 8 is used to obtain the weighted normalized decision matrix ($\widetilde{V}$)considering the importance of each criterion.

$$\widetilde{V} = [\tilde{v}_{ij}]_{mxn}, \ \tilde{v}_{ij} = \tilde{r}_{ij}.\widetilde{w}_j \quad (8)$$

As seen in Equation 8, the weighted normalized decision matrix is calculated by multiplying the fuzzy weights matrix and the normalized decision matrix. Normalized decision matrix ($\widetilde{V}$) obtained in the light of related calculations is as in Equation 9.

$$\tilde{V} = \begin{bmatrix} \widetilde{w}_1.\tilde{r}_{11} & \widetilde{w}_2.\tilde{r}_{12} & \dots & \widetilde{w}_n.\tilde{r}_{1n} \\ \widetilde{w}_1.\tilde{r}_{21} & \widetilde{w}_2.\tilde{r}_{22} & \dots & \widetilde{w}_n.\tilde{r}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \widetilde{w}_1.\tilde{r}_{m1} & \widetilde{w}_2.\tilde{r}_{m2} & \dots & \widetilde{w}_n.\tilde{r}_{mn} \end{bmatrix} \quad (9)$$

After obtaining the weighted normalized fuzzy decision matrix ($\tilde{V}$) seen in Equation 9, the fuzzy ideal solution (A^+) and fuzzy anti-ideal solution (A^-) values are calculated. These values consist of the best or worst set of values that can be obtained from all alternatives. Fuzzy ideal and fuzzy anti-ideal solutions are obtained as in Equation 10 and Equation 11.

$$A^+ = (\tilde{v}^+_1, \tilde{v}^+_2, \dots, \tilde{v}^+_n), \ \tilde{v}^+_j = max_i\{v_{ij3}\} \quad (10)$$

$$A^- = (\tilde{v}^-_1, \tilde{v}^-_2, \dots, \tilde{v}^-_n), \ \tilde{v}^-_j = min_i\{v_{ij1}\} \quad (11)$$

After obtaining fuzzy ideal and fuzzy anti-ideal solutions, the distance (d) of each alternative to these solutions is calculated. For this process, first of all, Vertex method in Equation 12 is used to determine the distances of the

Table 2. Risks regarding the electricity generation management process

Risk No	Explanation of the risks
1	The risk of not checking the availability of electricity generation units at the beginning of each day or not processing hour-based maximum, minimum and optimum generation values into the relevant system to evaluate the next day's availability.
2	The risk of not entering the electricity production values that must be entered into the system at the beginning of every hour and not recording the production imbalance situations experienced during the electricity generation within the specified period.
3	The risk of submission of the electricity production imbalances and hourly electricity production values entered into the system for the relevant day to the approval of the upper authority without checking by the persons assigned for this work or not making the approval process within the required time.
4	The risk of electricity generation imbalance due to failure of the electricity generation units to be commissioned within the required time to start the production process or the malfunctions that occur after the units are commissioned.
5	The risk of generation loss as a result of not meeting the necessary conditions to ensure that the voltage, frequency and phase angles of the units are equalized with the network during electrical energy generation.
6	The risk that the difference between the planned electricity generation amount and the actual electricity generation amount is high as a result of the electrical energy not being realized in accordance with the specified instructions.
7	The risk that the shift schedule required to maintain the necessary business cycle for safe, continuous, high quality and low-cost electricity generation within the framework of profitability and efficiency is not met or not prepared properly.
8	The risk of non-compliance with the shift schedule announced by the shift staff.
9	The risk of fatigue that may arise as a result of overtime work due to lack of personnel can reach a size that endangers job safety.
10	The risk that the staff is not competent enough to carry out the work.
11	The risk of employees not using the personal protective equipment they should use to protect themselves against health and safety risks they may encounter while working.
12	The risk of inadequate or incorrect determination of control and local measurement points within the SCADA system.
13	The risk of incorrectly entering measurement values into the system due to errors arising from the measuring device or the personnel doing the work during the recording of the measurement values obtained from the monitoring and measurement points with the SCADA recording system.
14	The risk of not recording the nonconformities determined as a result of the monitoring and measuring processes, and not notifying the relevant units about the nonconformity.

fuzzy ideal and fuzzy anti-ideal solutions to the components of each element separately.

The distance between two triangular fuzzy numbers is calculated by Equation 12 using the Vertex Method with $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$.

$$d(\tilde{m}, \tilde{n}) = \sqrt{\sum_{i=1}^{3} (m_i - n_i)^2} \tag{12}$$

Using Equation 12, the distances of each alternative to A^+ and A^- are calculated with Equation 13 and Equation 14. Here $d^+{}_i$ is the distance of the alternatives to the fuzzy ideal solution set, and $d^-{}_i$ is the distance of the alternatives to the anti-ideal fuzzy solution.

$$d^+{}_i = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}^+{}_j\right), \ \ i = 1,2, \dots, m \tag{13}$$

$$d^-{}_i = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}^-{}_j\right), \ \ i = 1,2, \dots, m \tag{14}$$

Then in order to make an evaluation among the alternatives, the proximity coefficient value for each alternative is calculated as in Equation 15 with the help of the distance values determined in Equation 13 and Equation 14.

$$CC_i = \frac{d^-{}_i}{d^-{}_i + d^+{}_i} \tag{15}$$

After calculating the proximity coefficient value of each alternative, finally, the alternative values are listed in descending order according to the CC_i values (from the value close to 1 to the value close to 0).

4. EXPERIMENTAL STUDY

In this study, the risks that may arise during the operation of the main electricity generation management process in HEPPs are discussed separately for the generation planning and follow-up, the electricity generation works, and the monitoring-measurement processes, which are the sub-parts of the electricity generation management process. The risks involved are shown in Table 2.

Among the risks listed in Table 2, risks 1, 2 and 3 are related to Electricity Generation Planning and Follow-up Process. Risks 4, 5, 6, 7, 8, 9, 10 and 11 are related to Electricity Generation Works Process, while risks 12, 13 and 14 are related to Monitoring and Measurement Process.

The impact and probability values of each risk in Table 2 and the risk levels obtained with the help of these values are determined separately at five different HEPPs, as a result of the evaluations made by the experts (decision makers) of each HEPP. The values obtained as a result of the relevant evaluations are shown in Table 3.

The risk level (R) for a risk criterion with known impact (I), probability (P) and detectability (D) values calculated with Equation 16 [31].

$$R = I * P * D \tag{16}$$

Table 3. Impact, probability, detectability and risk level values for risks

Risk No	HEPP-1				HEPP-2				HEPP-3				HEPP-4				HEPP-5			
	I	***P***	***D***	***R***	***I***	***P***	***D***	***R***	***I***	***P***	***D***	***R***	***I***	***P***	***D***	***R***	***I***	***P***	***D***	***R***
1	4	1	4	16	4	3	4	48	3	1	3	9	3	1	3	9	2	2	2	8
2	5	1	5	25	2	3	2	8	3	2	3	18	4	2	4	32	4	2	4	32
3	4	1	4	16	4	2	4	32	3	1	3	9	4	2	4	32	3	2	3	18
4	5	2	5	50	2	3	2	12	3	2	3	18	2	2	2	8	2	3	2	12
5	5	1	5	25	3	3	3	27	4	1	4	16	4	2	4	32	3	3	3	27
6	5	1	5	25	3	2	3	18	3	2	3	18	3	2	3	18	3	2	3	18
7	3	1	3	9	4	2	4	32	2	1	2	4	2	1	2	4	2	2	2	8
8	2	1	2	4	3	3	3	27	2	2	2	8	3	1	3	9	3	2	3	18
9	2	2	2	8	3	2	3	18	2	2	2	8	4	2	4	32	3	3	3	27
10	2	1	2	4	4	3	4	48	2	1	2	4	3	1	3	9	3	2	3	18
11	4	2	4	32	4	3	4	48	4	2	4	32	4	2	4	32	4	2	4	32
12	5	1	5	25	3	3	3	27	3	1	3	9	3	2	3	18	4	2	4	32
13	5	1	5	25	3	3	3	27	3	1	3	9	2	2	2	8	3	1	3	9
14	4	2	4	32	4	3	4	48	4	2	4	32	2	1	2	4	4	2	4	32

Table 4. Criteria weight values for risks and final risk criteria weights

Risk No	HEPP-1	HEPP-2	HEPP-3	HEPP-4	HEPP-5	Final Risk Criterion Weight Value
1	0.0605	0.1030	0.0561	0.0505	0.0353	0.0218
2	0.0822	0.0281	0.0896	0.1090	0.1010	0.0292
3	0.0605	0.0772	0.0561	0.1090	0.0655	0.0263
4	0.1364	0.0375	0.0896	0.0454	0.0491	0.0255
5	0.0822	0.0668	0.0806	0.1090	0.0873	0.0304
6	0.0822	0.0501	0.0896	0.0758	0.0655	0.0259
7	0.0420	0.0772	0.0336	0.0303	0.0353	**0.0156**
8	0.0252	0.0668	0.0505	0.0505	0.0655	0.0184
9	0.0378	0.0501	0.0505	0.1090	0.0873	0.0239
10	0.0252	0.1030	0.0336	0.0505	0.0655	0.0198
11	0.1002	0.1030	0.1288	0.1090	0.1010	**0.0387**
12	0.0822	0.0668	0.0561	0.0758	0.1010	0.0272
13	0.0822	0.0668	0.0561	0.0454	0.0393	0.0207
14	0.1002	0.1030	0.1288	0.0303	0.1010	0.0331

Table 5. Assessments regarding the measures and actions taken against risks

Risk No	HEPP-1		HEPP-2		HEPP-3		HEPP-4		HEPP-5	
	VE	TFN	VE	TFN	VE	TFN	VE	TFN	VE	TFN
1	G	[9,10,10]	VG	[9,10,10]	G	[7,9,10]	B	[0,1,3]	B	[0,1,3]
2	G	[7,9,10]	G	[7,9,10]	G	[7,9,10]	B	[0,1,3]	VG	[9,10,10]
3	B	[0,1,3]	B	[0,1,3]	VG	[9,10,10]	MG	[5,7,9]	VG	[9,10,10]
4	B	[0,1,3]	VG	[9,10,10]	B	[0,1,3]	MG	[5,7,9]	B	[0,1,3]
5	MG	[5,7,9]	VG	[9,10,10]	G	[7,9,10]	VG	[9,10,10]	B	[0,1,3]
6	MG	[5,7,9]	B	[0,1,3]	MB	[1,3,5]	G	[7,9,10]	VG	[9,10,10]
7	VG	[9,10,10]	B	[0,1,3]	MB	[1,3,5]	G	[7,9,10]	MG	[5,7,9]
8	G	[7,9,10]	G	[7,9,10]	MB	[1,3,5]	G	[7,9,10]	MB	[1,3,5]
9	B	[0,1,3]	MG	[5,7,9]	B	[0,1,3]	VG	[9,10,10]	B	[0,1,3]
10	G	[7,9,10]	MB	[1,3,5]	G	[7,9,10]	MG	[5,7,9]	MB	[1,3,5]
11	VB	[0,0,1]	B	[0,1,3]	B	[0,1,3]	MG	[5,7,9]	G	[7,9,10]
12	MG	[5,7,9]	MB	[1,3,5]	G	[7,9,10]	B	[0,1,3]	VG	[9,10,10]
13	G	[7,9,10]	G	[7,9,10]	VG	[9,10,10]	VG	[9,10,10]	G	[7,9,10]
14	B	[0,1,3]	VG	[9,10,10]	G	[7,9,10]	G	[7,9,10]	G	[7,9,10]

Table 6. Weighted normalized decision matrix $(\tilde{V})$

Risk No	HEPP-1	HEPP-2	HEPP-3	HEPP-4	HEPP-5
1	[0.0196,0.0218,0.0218]	[0.0237,0.0263,0.0263]	[0.0182,0.0234,0.026]	[0,0.0024,0.0072]	[0,0.0027,0.0082]
2	[0.0153,0.0196,0.0218]	[0.0179,0.023,0.0256]	[0.0182,0.0234,0.026]	[0,0.0024,0.0072]	[0.0246,0.0273,0.0273]
3	[0,0.0022,0.0065]	[0,0.0026,0.0077]	[0.0141,0.0156,0.0156]	[0.012,0.0167,0.0215]	[0.0246,0.0273,0.0273]
4	[0,0.0022,0.0065]	[0.023,0.0256,0.0256]	[0,0.0016,0.0047]	[0.0099,0.0139,0.0179]	[0,0.0027,0.0082]
5	[0.0109,0.0153,0.0196]	[0.023,0.0256,0.0256]	[0.0109,0.0141,0.0156]	[0.0179,0.0199,0.0199]	[0,0.0021,0.0062]
6	[0.0146,0.0205,0.0264]	[0,0.0026,0.0077]	[0.0016,0.0047,0.0078]	[0.0139,0.0179,0.0199]	[0.0186,0.0207,0.0207]
7	[0.0264,0.0293,0.0293]	[0,0.003,0.0091]	[0.0016,0.0047,0.0078]	[0.0139,0.0179,0.0199]	[0.0104,0.0145,0.0186]
8	[0.0205,0.0264,0.0293]	[0.0213,0.0274,0.0304]	[0.0018,0.0055,0.0092]	[0.0139,0.0179,0.0199]	[0.0021,0.0062,0.0104]
9	[0,0.0029,0.0088]	[0.0152,0.0213,0.0274]	[0,0.0018,0.0055]	[0.0349,0.0387,0.0387]	[0,0.0021,0.0062]
10	[0.0205,0.0264,0.0293]	[0.003,0.0091,0.0152]	[0.0129,0.0166,0.0185]	[0.0194,0.0271,0.0349]	[0.0033,0.0099,0.0166]
11	[0,0,0.0026]	[0,0.003,0.0091]	[0,0.0018,0.0055]	[0.0194,0.0271,0.0349]	[0.0232,0.0298,0.0331]
12	[0.0132,0.0184,0.0237]	[0.0026,0.0078,0.013]	[0.0129,0.0166,0.0185]	[0,0.0039,0.0116]	[0.0298,0.0331,0.0331]
13	[0.0184,0.0237,0.0263]	[0.0182,0.0234,0.026]	[0.0215,0.0239,0.0239]	[0.0349,0.0387,0.0387]	[0.0232,0.0298,0.0331]
14	[0,0.0026,0.0079]	[0.0234,0.026,0.026]	[0.0167,0.0215,0.0239]	[0.0191,0.0246,0.0273]	[0.0232,0.0298,0.0331]

In Equation 16, Impact (I) value is the measure of the damage that a risk may cause or the impact of a risk on goals and activities. Probability (P) value is the probability of a risk occurring within a specified time frame and Detectability (D) value is the possibility of detecting and eliminating a fault before it occurs.

The impact, probability and detectability values determined for five different HEPPs (by the experts of each HEPP within their body) regarding the 14 risks included in Table 2 and the risk level values calculated in the light of these values are shown in Table 3.

In the light of the data in Table 3, the weight values of the risk criteria and the weight values of the final risk criteria obtained as a result of the calculations made using the SWARA method in Equation 1, Equation 2 and Equation 3 are shown in Table 4.

The final risk criterion weights in Table 4 are calculated by taking the average of the risk criteria weight values obtained for each HEPP related to a risk. As a result of the measures taken in the electricity generation management processes in HEPPs and the actions taken regarding each risk, the success rates in reducing the relevant risk levels to an acceptable level, are evaluated with fuzzy verbal expressions, considering the results of the internal audits performed within this scope. These evaluations and corresponding triangular fuzzy number values are shown in Table 5.

In the study, the analysis process was carried out with the Fuzzy TOPSIS method by using the evaluations made with verbal expressions (VE) and their corresponding triangle fuzzy numbers (TFN) in Table 5 and the weight values of the final risk criteria shown in Table 4. The weighted normalized decision matrix $(\tilde{V})$ obtained with the help of Equation 6, Equation 7 and Equation 8 is shown in Table 6.

After obtaining the weighted normalized decision matrix $(\tilde{V})$ in Table 6, the distances of each risk criterion value to the ideal solution set (d^{+}_{i}) and the anti-ideal solution set (d^{-}_{i}) are calculated with the help of Equation 13 and Equation 14. The values obtained as a result of the related calculations appear in Figure 1 and Figure 2.

In the light of the fuzzy ideal and anti-ideal values obtained in Figure 1 and Figure 2, performance comparisons between HEPPs can be made by looking at the values of risk criteria for the electricity generation management process and the success rates in minimizing the risk. The proximity coefficient values (CC_i) calculated with Equation 15 can be used for performance comparisons. CC_i value calculated for each HEPP is shown in Figure 3.

As seen in Figure 3, the proximity coefficient value calculated for each HEPP is ranked from a value close to 1 and to a value close to 0. As a result, the success of each HEPP in minimizing the risk levels of risks arising in the electricity generation management process has been compared.

5. CONCLUSION AND EVALUATION

In order for the electricity generation management processes to continue in an effective, timely and efficient manner in electricity generation facilities, the risks that may arise during the operation of the electricity generation management processes should be identified and recorded in detail.

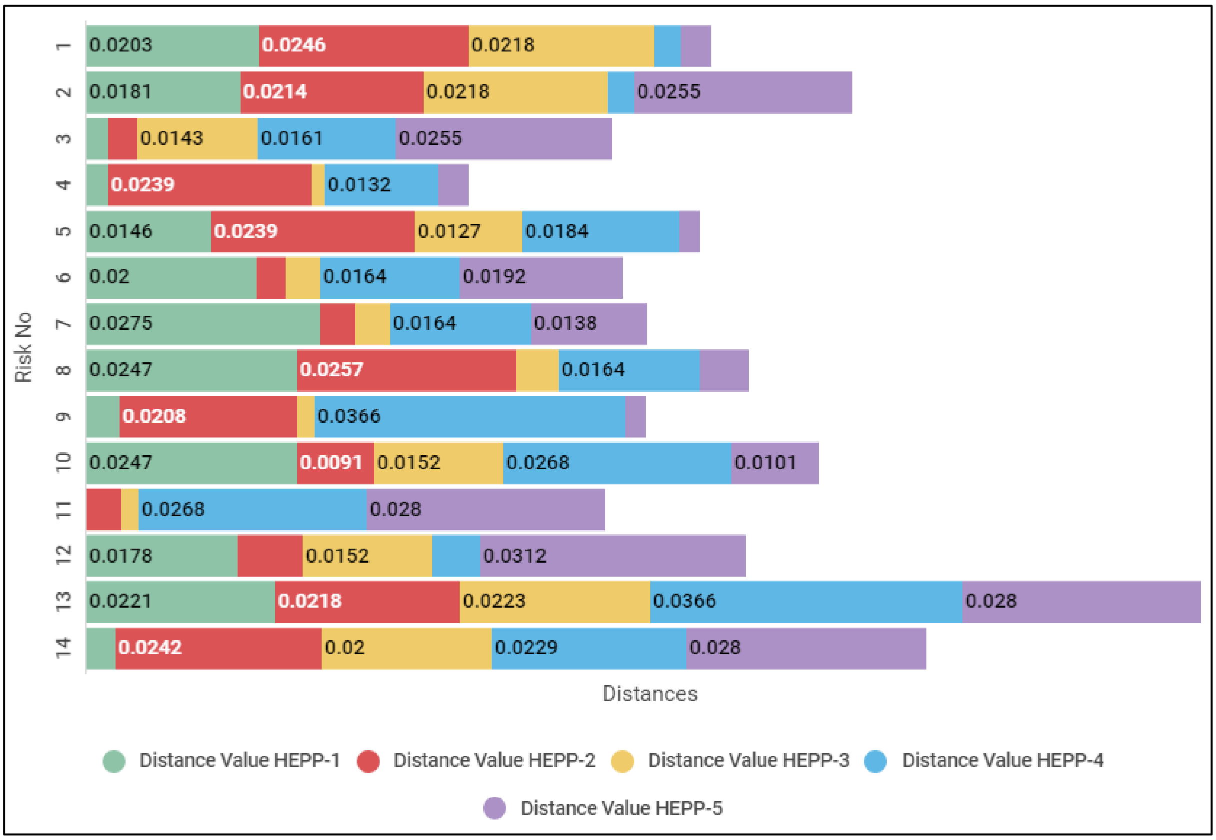

Figure 1. The distance value of each risk criterion to the fuzzy ideal solution set (d^{+}_{i})

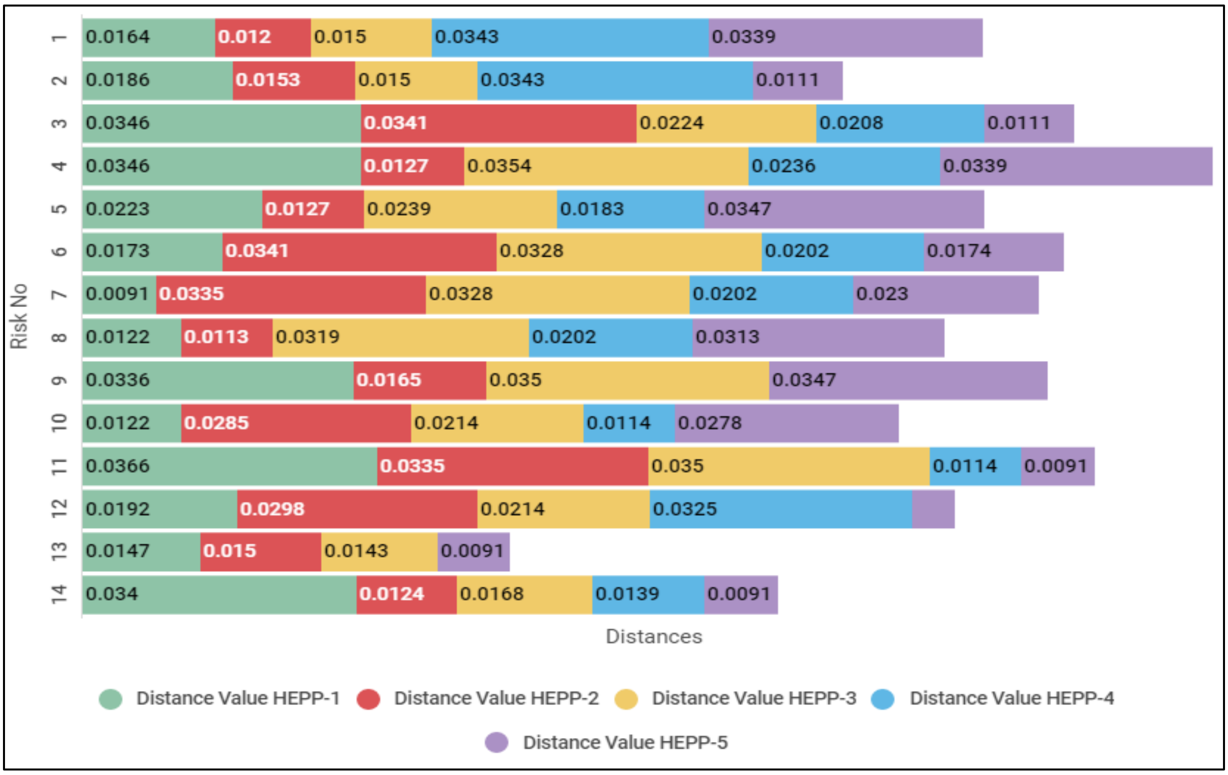

Figure 2. The distance value of each risk criterion to the fuzzy anti-ideal solution set ($d^{-}{}_{i}$)

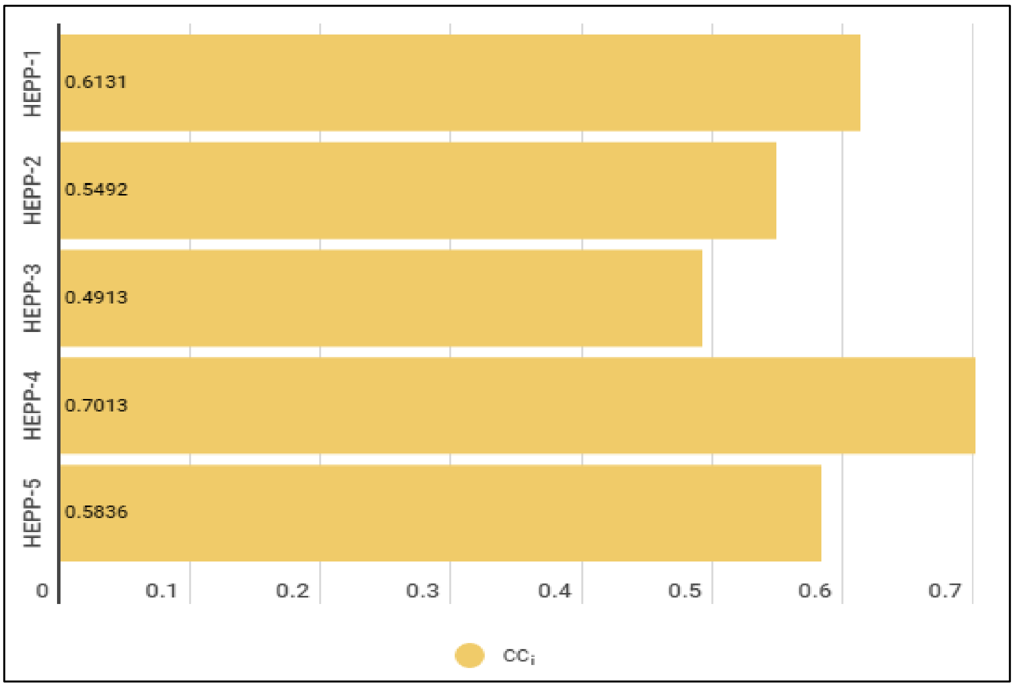

Figure 3. CC_i values calculated for each HEPP and performance ranking of HEPPs

In order to eliminate these risks or reduce them to acceptable levels, appropriate teams must be formed, and protection must be provided against threats and dangers that may be caused by the risks with corrective/ preventive and appropriate actions. In addition, if there are opportunities that arise in this process, it is important to evaluate them and convert them into profit for a healhy operation of electricity generation management processes.

In this study, 14 risks that may arise during the operation of the Generation Management Process in HEPPs are discussed. The performances of the five HEPPs subject to the study in minimizing the risk levels of the related risks have been determined in the light of the data obtained as a result of the internal audits.

The performances of the related HEPPs in minimizing the risks have been evaluated with the help of SWARA and Fuzzy TOPSIS methods. In the light of the evaluations made, it is seen that the most successful power plant in minimizing the risks is HEPP-4, and the most unsuccessful plant is HEPP-3.

It is important to perform risk analysis in order to maintain the electricity generation activities effectively and efficiently. Within the scope of risk management, it is necessary to determine the strategic and operational risks that may arise in any activity carried out by institutions and organizations and take appropriate corrective actions and actions to eliminate or minimize these risks. In addition, it should be ensured that the situation monitoring plans for the risks are prepared, the risk levels related to the risks are monitored periodically, and new measures are taken if necessary.

In the future study, it is aimed to use different MCDM methods to determine the weights of the risks related to the electricity generation process and to compare the risk analysis results obtained using these methods with the Fuzzy TOPSIS method.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Hamdullah KARAMOLLAOĞLU: Designing, Validation, Writing - Review & Editing, Supervision

İbrahim YÜCEDAĞ: Conceptualization, Validation, Review & Editing, Analysing results

İbrahim Alper DOĞRU: Conceptualization, Validation, Review & Editing

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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