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An Applied Model for Identification and Evaluation of Factors Affecting Energy Losses of Electric Distribution Network Case Study: Selected Counties of Bushehr Province

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Abstract

From its generation to utilization, some of the electrical energy gets wasted in the process. This loss of energy occurs due to various reasons, one of which is energy loss in distribution networks. Considering the high cost of power generation, it is important to identify factors causing this loss. This study was carried out with the objective of identifying energy loss factors and the importance of each factor. Lack of identification for factors stealing energy, network deterioration, amount of electrical load and the impact of such factors that can have significant influence on energy loss could diverge the path of energy management. Thus, the main objective of this study was to reduce energy loss and its additional costs by developing the concept of identifying influential factors and measuring the effect of each factor especially in different regions. The statistical population of this study comprised of power and energy experts and university professors. The statistical sample included 12 energy experts and their opinions were collected using questionnaires and paired comparisons. Weights of criteria were determined using SWARA technique. COPRAS-G technique was used for measuring the importance of criteria for Bushehr province distribution networks. The importance of criteria are: energy theft, measurement error, amount of load, network deterioration, loose fittings, improper placement of equipment, the amount of voltage, conductor resistance, equipment casualty, location and size of the capacitor, geographical conditions, Size and dimensions of the conductor, leakage, and network arrangements respectively. Distribution network of Assaluyeh region had the highest energy losses.

Keywords: energy losses, COPRAS-G, electric distribution network, SWARA

1. Introduction

A significant proportion of electrical energy gets wasted throughout its generation-distribution process. According to Iranian government's balance sheetof carbohydrates, the amount of this energy loss is more than 14% in Iran's distribution networks (Department of Energy Management, Institute of International Studies, 2014). Whereas, the standard amount for this loss is 5% (Mehdi Kaboli and Ghasemlou, 2004). This energy loss could occur due to various reasons. Identification of loss factors and preventing them have an important role for reducing losses. Despite the significance of this subject and various studies that have been carried out, there has been no comprehensive study for categorizing and ranking loss factors of distribution networks in a model so that decision-makers could take necessary actions and measures for preventing energy losses. Providing an appropriate model and importance of criteria helps prioritizing criteria based on their weights and taking necessary measures for loss elimination so that losses and expenses of electricity shortages and power cuts during peak hours could be prevented.

1.1 Background of the Study

According to Iran's carbohydrate balance sheet collected in 2008, its ninth section discussed losses and optimization of all the existing energies, one of which is electrical energy and electricity. "Current and resistance of transmission lines" factor was the one recognized as the loss factor in this report (Energy Management

Department of Institute of International Studies, 2008).

Energy balance sheet is annually published for each country. Iran's balance sheet was also published in 2011 and the following factors were recognized as the ones responsible for electrical energy losses: the nature of distribution networks, its extent and vulnerability, deterioration of distribution networks, and electrical power abuse (Department of Power and Energy, 2011). Studies regarding electrical energy losses were performed in a book named "Strategic Solutions for Reducing Losses in Electrical Networks". Different casualty subjects such as loss types and factors were investigated in this book. Some of the mentioned loss factors are as follows: flow resistance, leakage, domestic consumption, measurement error and lack of measurement, network management, network capacity, equipment capacity, technical specifications of the network, and geographical conditions (Namazi, 2005). In "Restructuring Distribution Networks Using Genetic Algorithm for Reducing Energy Losses by Considering the Capacitor", Anise Rouhani et al. investigated the optimization of distribution networks using genetic algorithm. Structure of the distribution network, size and dimensions of the conductor, network deterioration, post placement, load amount of distribution transformers, and voltage levels were mentioned as factors causing energy loss in this article (Rouhani and RajabiMashhadi, 2013). In a study with the title of "Providing a Model for Reducing Electrical Energy Losses in Tehran's Electric Distribution Network", electric distribution networks were examined and a method for rearrangement of these networks were presented in which network deterioration, loading method of transmission lines, and post were recognized as loss factors (Islami Rad, 2003). Amir Kazemi performed studies on electric distribution network of South Khorasan province, in which methods of fixing voltage drops for reducing energy losses in low-voltage networks were prioritized. In addition, energy loss factors were categorized into two facility and non-facility factors as follows: Facility losses: Line losses due to the resistance of the conductors, no load losses, copper and iron losses of transformers, cable insulation losses, earthing system losses, measurement tool losses, loss fitting losses, and voltage drop losses. Non-facility losses: unauthorized branches, sub-branches, illegal demand increase, meter malfunctions, wrong issuance of electric bill, and street lighting (ShadkamAnvar, 2009). In "Reconfiguring the Arrangement of Distribution Networks for Reducing Energy Losses Using Modified Genetic Algorithm", Ali Shayanfar et al. investigated reconfiguration of network arrangements. Factors of excessive amounts of line currents, low voltage level, radial structure, and network arrangements were recognized as loss factors for electrical energy (Shayanfar et al., 2004).

According to World Bank Group Strategy reports, factors causing electrical energy loss are:

Technical factors: Factors that occur naturally such as errors in measuring systems, transformers, transmission and distribution lines, and power dissipation in the electric network.

Non-technical factors: Are losses that occur due to external elements such as energy theft, non-payment of clients, accounting and data preservation errors (Energy Strategy Group of World Bank, 2009).

In a case study performed in Michigan, the factor of energy theft was investigated for different energies such as natural gas and electricity and this factor was examined as a significant factor influencing expenses. The results showed that the impact of this factor could be reduced by installing intelligent devices but it still exists as an important factor (The International Energy Guide, 2009). In "Experiences and Experiments for Reducing losses in the Electric Distribution of Iranian Companies", Ali Arefi studied experiences of loss reduction projects in Iran. In this regard, electricity theft, measurement errors, location and size distribution of transformer, conductor size, voltage variation, street lighting, load amounts, network reconfiguration, loose fittings, and dispersed distribution were recognized as energy loss factors (Arefi et al., 2012).

In a study called "Electricity Loss and Theft in India", which was carried out in 2012, an extensive research was performed regarding electric energy theft between years 2000-2009. This factor was determined as one of the important factors responsible for energy loss (Golden and Min, 2012). In "Optimizing Location and Size of Distribution Networks for Reducing Electrical Energy Using Particle Swarm Optimization Method", Bhumkittipich made an attempt to find an optimized solution for electric distribution network location and size. Distribution network's location and size were determined as a significant and influential factor on the amount of electrical power loss (Bhumkittipich and Phuangpornpitak, 2013). In an article entitled "Employing fuzzy Systems for Reducing Energy Loss and Controlling Voltage Levels in Radial Grids", which was performed in 2010, an attempt was made for finding the appropriate location of the capacitor in radial grids. Loss factors in this study were determined as capacitor's location and size, structure of the distribution network, voltage levels (Abdolaziz et al., 2010).A summary of the collected factors are presented in the following table 1:

Table 1. A summary of factors affecting electric distribution network losses

Row	*Loss factor*	*No*
	Network arrangements	7
	Energy theft	6
	Load amounts	5
	Voltage level	5
	Equipment casualties	4
	Measurement errors	4
	Conductor resistance	4
	Network deterioration	3
	Conductor's size and dimensions	2
	Capacitor's size and location	2
	Improper placement ofequipment	2
	Loose fittings	1
	Leakage	1
	Geographical condition	1
	Network management	1
	Nature of the distribution network	1
	Power loss in electric network	1

1.2 Conceptual Model

Based on background review and experts' opinion, the following model was identified by categorizing the existing factors. Energy loss factors in electric distribution network are as follows (Fig 1):

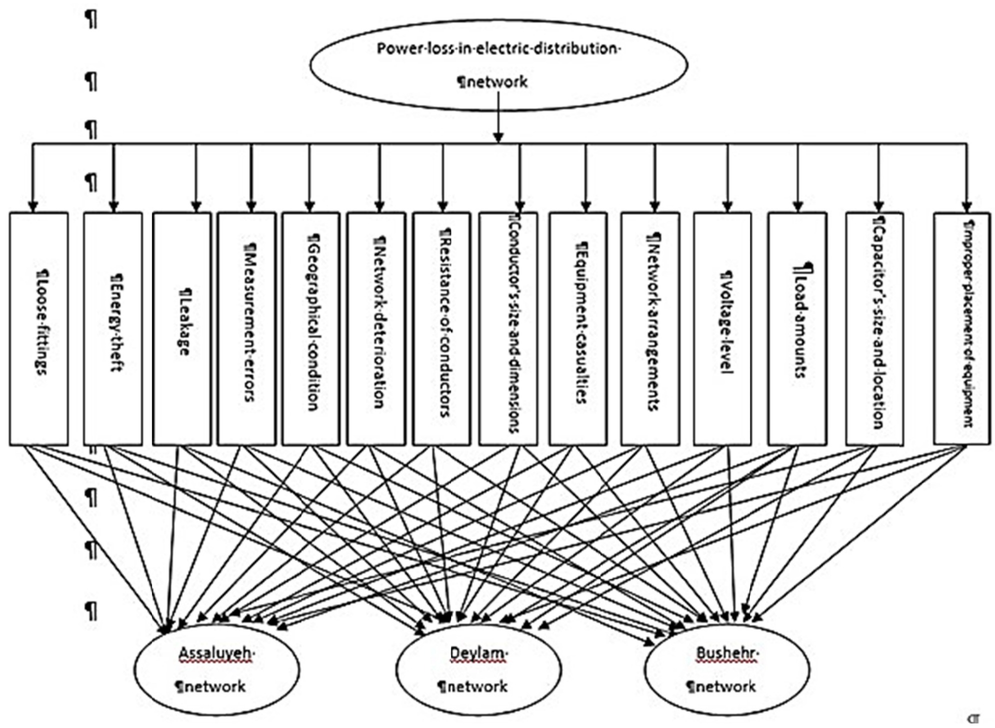

Figure 1. Conceptual model of this research in relation to electrical loss in the three selected regions of Bushehr province

1.3 Defining Indicators Affecting Electrical Loss in the Distribution Network

Energy theft: Lack of proper supervision, high electricity consumption in domestic sector, financial inability of some households in paying electricity bills, electricity theft common in some areas (Najibi, 2013).

Measurement errors: Measurement errors, proper recording of figures and statistics, numerical errors for determining the amount of consumed electrical power, and failure to install lighting meters are among loss factors (Namazi, 2005).

The amount of load: Load imbalance in distribution network is among loss factors for electrical power.

Network deterioration: Deterioration refers to the obsolescent, out of date equipment and accessories used in the network.

Loose fittings: Loose and improper fittings could also cause energy loss.

Improper placement of equipment: This factors refers to the inappropriate location of the equipment and network distribution devices.

Voltage level: Voltage drops lead to increased energy loss since loss depends on the electric current and the currents depends on the voltage $Cos\Phi$ and transmitted power. For example if the voltage is reduced by 10%, energy loss will increase by 23% (Najibi, 2013).

Conductor resistance: The resistance of electrical transmission lines and the existing equipment against the current flowing from generation up to consumption site is not identical and is subordinate to various factors such as technical specifications of the transmission lines and its equipment (Namazi, 2005)

Equipment casualties: Such as transformer, meters or post equipment related to their technical speciifications (Najibi, 2013).

Capacitor's size and location: Improper placement of fixed capacitors in primary and secondary feeders of radial networks and unsuitable capacity of the capacitor lead to increased energy loss (Hejri et al., 2004).

Geographical condition: Other important and influential factor on energy loss are ambient temperature levels and its variations, sunlight, skin effect, and climatic factors (Namazi, 2005).

Conductor's size and dimensions: The size of the conductor implemented in the conductor cable.

Leakage: Includes leakage from insulators and tree branches. When branches are closer to the conductor, there is more contact surface and the amount of energy loss will also increase (Najibi 2013).

Network arrangements: various radial shapes a network can have (Eslami Rad, 2003).

2. Methodology

This was an analytical-descriptive and a developmental study. Data were collected using three methods.Interview and library studies were used for identifying factors and indicators affecting energy loss and also for categorizing them and obtaining a conceptual model. In addition, questionnaires were used for performing paired comparisons and receiving expert opinions in order to prioritize factors. The statistical population of this study included university professors, managers, energy experts and specialists, among which the opinion of 12 experts for determining criteria weights and three Bushehr, Deylam, and Assaluyeh electric distribution networks were examined and selected. SWARA technique was used for data analysis and calculating criteria weights. COPRAS-G technique was used for prioritizing the existing options.

2.1 SWARA Method

Gradual weighting evaluation ratio is a recent analysis method for Multiple Attribute Decision-making (MADM) models which was used for the development of reasonable difference analysis method in 2010 (Hashemkhani e al., 2013). In SWARA technique, each expert prioritizes and ranks criteria at first. The most important criterion receives the number one ranking and the least important of them receives the last ranking place. Overall, criteria are prioritized based on their value (Alimardani et al., 2013). In this method, the expert plays an important role in the evaluation of the calculated weights. Also, each expert determines the significance of each criterion based on tacit knowledge and his own information and experience. Afterwards, the weight of each criterion is determined according to the mean value of group rankings (Taherkhani and Isfahani, 2012). The weight for each criterion represents its significance (Hashemkhani et al., 2013). The process of weighting criteria in SWARA technique is presented in Figure 2.

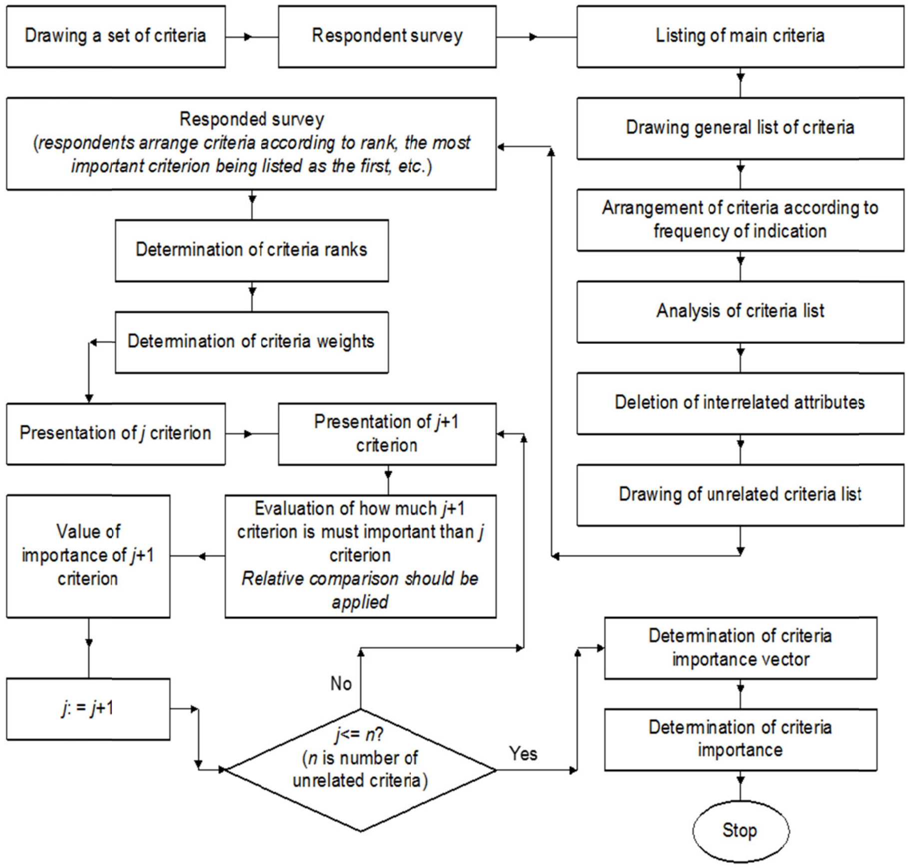

Figure 2. Determination of criteria weights according to Keršulienė and Turskis studies

Some exemplary studies of this field are presented in the following table:

Table 2. Presentation of authors and studies related to SWARA technique

#	*Article title*	*Author's name and year*
1	Investigating Regions for Implementation of Solar Projects in Iran: A New Method Derived from the Hybrid Multi-Criteria Decision Making Approach	(Vafaeipoor et al., 2014)
2	Making Decision Regarding Business Issues with the Perspective of Prediction Using New Models of Combined Decision Making for Positioning Shopping Center	(HashemkhaniZolfani et al., 2013)
3	Data Mining Efficiency and Various Properties of Decision Making	(Aghdaei et al., 2014)
4	A New Method of Multi-Criteria Decision Making Based on Vikor Method for Selection of Personnel	(Nabian, 2014)

2.2 CPRAS-G Method

COPRAS gray is a method for determining the best option among the existing ones. Therefore, this method performs the ranking (Maity et al., 2012). Option parameters are determined using the gray method. Gray system theory was first proposed by Dang in 1982. A gray system indicates that part of the system is known and another part is unknown (black, white). Since uncertainty always exits, an intermediate part called gray area is put between the two sides (Tavana et al., 2013). Steps for this method are: The first step includes selecting a set of the most important criteria and determining options. The second step is the creation of decision making matrix, which is shown by $\otimes x$. In this step, $\otimes x_{in}$ is calculated using $\underline{X}_{n1}$(Smallest value and lowest limit) and $\tilde{x}_j$ (Biggest value or highest limit).

$$\otimes X = \begin{bmatrix} [\otimes_{X_{11}}] & \cdots & \cdots & [\otimes_{X_{1m}}] \\ [\otimes_{X_{21}}] & \cdots & \cdots & [\otimes_{X_{2m}}] \\ \vdots & \cdots & \ddots & \vdots \\ [\otimes_{X_{n1}}] & \cdots & \cdots & [\otimes_{X_{nm}}] \end{bmatrix} = \begin{bmatrix} [\underline{X}_{11};\overline{X}_{11}] & [\underline{X}_{12};\overline{X}_{12}] & \cdots & [\underline{X}_{1m};\overline{X}_{1m}] \\ [\underline{X}_{21};\overline{X}_{21}] & [\underline{X}_{22};\overline{X}_{22}] & \cdots & [\underline{X}_{2m};\overline{X}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\underline{X}_{n1};\overline{X}_{n1}] & [\underline{X}_{n2};\overline{X}_{n2}] & \cdots & [\underline{X}_{nm};\overline{X}_{nm}] \end{bmatrix}; j = \overline{1,n}, i$$

The importance degree of q criterion is determined in the third step.

Normalization of the decision-making matrix is performed in the fourth step, which is done using the following formula:

(Equation 1)

$$\underline{\tilde{X}} = \frac{\underline{X}_{ji}}{\frac{1}{2}\left(\sum_{j=1}^{n}\underline{X}_{ji} + \sum_{j=1}^{n}\overline{X}_{ji}\right)} = \frac{2_{\underline{X}_{ji}}}{\left(\sum_{j=1}^{n}\underline{X}_{ji} + \sum_{j=1}^{n}\overline{X}_{ji}\right)}, \overline{\tilde{x}} = \frac{\overline{X}_{ji}}{\frac{1}{2}\left(\sum_{j=1}^{n}\underline{X}_{ji} + \sum_{j=1}^{n}\overline{X}_{ji}\right)} = \frac{2_{\overline{X}_{ji}}}{\sum_{j=1}^{n}\left(\underline{X}_{ji} + \overline{X}_{ji}\right)}; j = \overline{1,n}; i = \overline{1,m}$$

In this formula, $\underline{X}_{ji}$ means lowest value of the i(th) criterion in the j(th) option. $\overline{X}_n$is the highest value of the i(th) criterion in the j(th) option. m is the number of criteria compared to n, which is the number of options.

The fifth step is calculation of the normalized weighted decision matrix with the symbol of $\otimes\overline{X}$. Values of this matrix are calculated using the following formula:

(Equation 2)

$$\otimes_{\hat{X}_{ji}} = \otimes_{\tilde{X}_{ji}}.q \quad OR \quad \underline{\hat{X}}_{ji} = \underline{\tilde{X}}_{ji}.qi \;\; and \;\; \overline{\hat{X}}_{ji} = \overline{\tilde{X}}_{ji}.q_i$$

In this formula, q_1 value indicates the importance of the i(th) criterion. Afterwards, normalized decision making matrix is calculated as follows:

$$\otimes\hat{X} = \begin{bmatrix} [\otimes_{\hat{X}_{11}}] & [\otimes_{\hat{X}_{12}}] & \cdots & [\otimes_{\hat{X}_{1m}}] \\ [\otimes_{\hat{X}_{21}}] & [\otimes_{\hat{X}_{21}}] & \cdots & [\otimes_{\hat{X}_{2m}}] \\ \vdots & \vdots & \ddots & \vdots \\ [\otimes_{\hat{X}_{n1}}] & [\otimes_{\hat{X}_{n2}}] & \cdots & [\otimes_{\hat{X}_{nm}}] \end{bmatrix} = \begin{bmatrix} [\underline{\hat{X}}_{11};\overline{\hat{X}}_{11}] & [\underline{\hat{X}}_{12};\overline{\hat{X}}_{12}] & \cdots & [\underline{\hat{X}}_{1m};\overline{\hat{X}}_{1m}] \\ [\underline{\hat{X}}_{21};\overline{\hat{X}}_{21}] & [\underline{\hat{X}}_{22};\overline{\hat{X}}_{22}] & \cdots & [\underline{\hat{X}}_{2m};\overline{\hat{X}}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\underline{\hat{X}}_{n1};\overline{\hat{X}}_{n1}] & [\underline{\hat{X}}_{n2};\overline{\hat{X}}_{n2}] & \cdots & [\underline{\hat{X}}_{nm};\overline{\hat{X}}_{nm}] \end{bmatrix}$$

in the sixth step and after calculating total P_j of criteria values, the bigger one is preferred:

(Equation 3)

$$P_j = \frac{1}{2}\sum_{i=1}^{k}\left(\underline{\hat{X}}_{ji} + \overline{\hat{X}}_{ji}\right)$$

in the seventh step and after calculating total R_j of criteria values, the smallest one is preferred:

(Equation 4)

$$R_j = \frac{1}{2}\sum_{i=k+1}^{m}\left(\underline{\hat{X}}_{ji} + \overline{\hat{X}}_{ji}\right); i = \overline{k,m}$$

In this formula, M-K are the number of the criterion that has to be minimized.

Eighth step: Determination of the minimized criterion from R_j, the formula of which is:

(Equation 5)

$$R_{min} = \min_j R_j;^{j=\overline{1,n}}$$

Ninth step: Calculating the relative importance of each Q_j option using the following formula:

(Equation 6)

$$Q_j = P_j + \frac{\sum_{j=1}^{n} R_j}{R_j \sum_{j=1}^{n} \frac{1}{R_j}}$$

The tenth step includes determination of the optimized criterion using K formula:

(Equation 7)

$$k =_{\max j\, Qj}; ^{j=\overline{1,n}}$$

Eleventh step: finally, options are prioritized in this step.

In the twelfth step, desirability rate of each option is calculated using the following formula:

(Equation 8)

$$N_j = \frac{Q_j}{Q_{max}} \times 100\%$$

In this formula, Q_j and Q_{max} indicate the importance of the obtained options. (Zavadskas et al., 2008).Some exemplary studies performed using this method are presented in the following table:

Table 3. Presentation of authors and studies related to COPRAS-G technique

#	Article title	Author's name and year
1	A Hybrid Approach for Fuzzy Multi Criteria Decision Making in Selecting Machinery and Equipment by Considering Plate Interactions	(Tho Nguyen et al., 2013)
2	Selection of Cutting Tools Using COPRAS-G	(Maity et al., 2012).
3	Selection of Investment Projects Using COPRAS Method and Inaccurate Data	(Popović, 2012)
4	Selecting A Contractor with Multi-Criteria Decision Making Models Using COPRAS Method and Grey System of Numbers	(Zavadskas et al., 2008).

3. Result

Information related to experts and specialists who completed the questionnaires are presented in Table 12.

Table 4. Expert information

Expert	Field of Study	Educational attainment	Age	Work experience	Sex
1	Electric power	Ph.D.	32	10	Female
2	Electric power	M.S.	38	14	Male
3	Electric power	Expert	32	8	Male
4	Electric power	MS	40	17	Male
5	Physics	MS	38	15	Male
6	Management	MS	36	14	Male
7	Power electronics	Expert	30	8	Female
8	Electrical engineering	MS	38	17	Male
9	Electrical engineering	Expert	45	24	Male
10	Electric power	MS	44	22	Male
11	Electrical engineering	Expert	32	10	Male
12	Electrical engineering	MS	40	18	Male

At first, experts ranked criteria according to SWARA technique, in which mean opinions of 12 individuals were calculated. After that, criteria were ranked in ascending order (i.e. lower mean was number one and so on). Criteria are presented in Table 5 in order of priority and final weights.

Table 5. Final results of SWARA technique for weighing criteria

Criteria	Mean value of S_j	Coefficient $S_j+1 = K_j$	$W_j = \frac{K_{j-1}}{K_j}$	Weight $q_i = \frac{w_j}{\sum w_j}$
Energy theft	-------	1	1	0.2913
Measurement errors	0.45	1.45	0.6896	0.2008
Load amounts	0.275	1.275	0.5408	0.1575
Network deterioration	0.49	1.49	0.3629	0.1057
Loose fittings	0.3425	1.3425	0.2703	0.0787
Improper placement of equipment	0.523	1.523	0.1774	0.0516
Voltage level	0.41	1.41	0.1258	0.366
Resistance of conductors	0.3225	1.3225	0.0951	0.0277
Equipment casualties	0.4283	1.4283	0.0665	0.0193
Capacitor's size and location	0.6225	1.6225	0.0409	0.0119
Geographical condition	0.615	1.615	0.253	0.0073
Conductor's size and dimensions	0.335	1.335	0.0189	0.0055
Leakage	0.5841	1.5841	0.0119	0.0034
Network arrangements	0.5958	1.5958	0.0074	0.0021
Sum total			3.4328	

$=S_2\frac{0.15+0.3+0.4+0.5+0.95+0.5+0.6+0.4+0.4+0.8+0.2+0.2}{12}= 0.45$Mean value for measurement error

Measures of mean value column were obtained from the questionnaire such that the mean for 12 individuals was calculated for each row. Also, the first row is blank since paired comparisons are in a way that first criterion is calculated with the second criterion, and the second one is calculated with the third one and so on. Therefore, the number of comparisons are always one less than the number of criteria and thus the first criterion is blank.

$$K_2=0.45+1 =1.45$$

$$W_2 = \frac{1}{1.45} =0.6896$$

$$q_2=\frac{0.6896}{3.4328} = 0.2008$$

In this section and after determining all criteria weights, COPRAS-G method was used for evaluation and selection of options. The existence of two criteria with positive and negative essence is necessary for this section so that the positive criterion is in the same direction as the objective. For example, if highest energy loss is to be determined among options, positive criterion helps energy loss and negative criterion acts for reducing energy loss. Thus, six out of fourteen indicators were inversed based on their essence or in fact, their appropriate amount was considered. Which means that for instance the factor of unsuitable geographical conditions, which is a loss factor, was considered as the appropriateness level of the geographical condition that leads to loss reduction. Therefore, this was a negative criterion. The results of COPRAS-G are presented in the following table.

Table 6 is the initial decision making matrix, which was collected from expert opinions of 12 individuals and also from their mean opinions.

Table 6. Initial decision making matrix

Network arrangements	Leakage	Conductor's size and dimensions	Geographical condition	Capacitor's size and location	Equipment casualties	Conductor resistance	Voltage level	Improper placement of equipments	Loose fittings	Network deterioration	Load amounts	Measurement errors	Energy theft	
Min	Max	Min	Min	Min	Max	Max	Min	Max	Max	Max	Min	Max	Max	Type of indicator
0.0021	0.0034	0.0055	0.0073	0.0119	0.0193	0.0277	0.366	0.0516	0.0787	0.1057	0.1575	0.2008	0.2913	qi
$\underline{X}_{14};\overline{X}_{14}$	$\underline{X}_{13};\overline{X}_{13}$	$\underline{X}_{12};\overline{X}_{12}$	$\underline{X}_{11};\overline{X}_{11}$	$\underline{X}_{10};\overline{X}_{10}$	$\underline{X}_{9};\overline{X}_{9}$	$\underline{X}_{8};\overline{X}_{8}$	$\underline{X}_{7};\overline{X}_{7}$	$\underline{X}_{6};\overline{X}_{6}$	$\underline{X}_{5};\overline{X}_{5}$	$\underline{X}_{4};\overline{X}_{4}$	$\underline{X}_{3};\overline{X}_{3}$	$\underline{X}_{2};\overline{X}_{2}$	$\underline{X}_{1};\overline{X}_{1}$	Upper and lower limit / Options
3 5	1 3	1 3	1 3	3 5	3 5	1 3	1 3	1 3	1 3	1 3	0 1	3 5	1 3	Bushehr
5 8	1 3	3 5	3 5	3 5	1 3	1 3	3 5	1 3	1 3	1 3	1 3	3 5	1 3	Deylam
3 5	5 8	3 5	1 3	3 5	1 3	1 3	1 3	1 3	1 3	3 5	0 1	3 5	5 8	Assaluyeh

Table 7 was obtained by normalizing values of the previous table, which was also weighted using weights obtained from this method.

Table 7. Weighted normalized decision making matrix

Network arrangements	Leakage	Conductor's size and dimensions	Geographical condition	Capacitor's size and location	Equipment casualties	Conductor resistance	Voltage level	Improper placement of equipments	Loose fittings	Network deterioration	Load amounts	Measurement errors	Energy theft	
Min	Max	Min	Min	Min	Max	Max	Min	Max	Max	Max	Min	Max	Max	Type of indicator
0.0021	0.0034	0.0055	0.0073	0.0119	0.0193	0.0277	0.366	0.0516	0.0787	0.1057	0.1575	0.2008	0.2913	qi
$\underline{X}_{14};\overline{X}_{14}$	$\underline{X}_{13};\overline{X}_{13}$	$\underline{X}_{12};\overline{X}_{12}$	$\underline{X}_{11};\overline{X}_{11}$	$\underline{X}_{10};\overline{X}_{10}$	$\underline{X}_{9};\overline{X}_{9}$	$\underline{X}_{8};\overline{X}_{8}$	$\underline{X}_{7};\overline{X}_{7}$	$\underline{X}_{6};\overline{X}_{6}$	$\underline{X}_{5};\overline{X}_{5}$	$\underline{X}_{4};\overline{X}_{4}$	$\underline{X}_{3};\overline{X}_{3}$	$\underline{X}_{2};\overline{X}_{2}$	$\underline{X}_{1};\overline{X}_{1}$	Upper and lower limit Options
0.0004	0.0003	0.0005	0.0009	0.0029	0.0072	0.0046	0.0045	0.0086	0.0131	0.0132	0	0.0502	0.0277	Bushehr
0.0007	0.0009	0.0016	0.0027	0.0049	0.0120	0.0138	0.0137	0.0258	0.0393	0.0396	0.0525	0.0836	0.0832	
0.0007	0.0003	0.0016	0.0027	0.0029	0.0024	0.0046	0.0137	0.0086	0.0131	0.0132	0.0525	0.0502	0.0277	Deylam
0.0011	0.0009	0.0027	0.0045	0.0049	0.0072	0.0138	0.0228	0.0258	0.0393	0.0396	0.1575	0.0836	0.0832	
0.0004	0.0016	0.0016	0.0009	0.0029	0.0024	0.0046	0.0045	0.0086	0.0131	0.0396	0	0.0502	0.1387	Assaluyeh
0.0007	0.0034	0.0027	0.0027	0.0049	0.0072	0.0138	0.0137	0.0258	0.0393	0.0660	0.0525	0.0836	0.2219	

For the first option$\underline{X}_1 = \frac{1\times 2}{1+3+1+3+5+8} \times 0.2913 = 0.0277$

For the first option$\overline{X}_1 = \frac{3\times 2}{1+3+1+3+5+8} \times 0.2913 = 0.0832$

Table 8 is the final table of COPRAS-G that presents option rankings. Third option, which is the city of Assaluyeh, had the highest amount of energy loss. Priority of network losses were respectively as follows: Assaluyeh, Bushehr, Deylam

Table 8. Network rankings

N_j	Q_j	R_j	P_j	Networks
76.75	0.3075	0.0426	0.2115	**Bushehr**
59.23	0.2373	0.1338	0.20675	**Deylam**
100	0.4006	0.4375	0.3071	**Assaluyeh**

$P_{j+}$the first option

$$= \frac{0.0277+0.0832+0.0502+0.0836+0.0132+0.0396+0.0131+0.0396+0.0086+0.0258+0.0046+0.0138+0.0072+0.0120+0.0003+0.0009}{2} = 0.2115$$

$R_J$for the first option=

$$\frac{0+0.0525+0.0045+0.0137+0.0029+0.0049+0.0009+0.0027+0.0005+0.0016+0.0004+0.0007}{2} = 0.0426$$

$Q_j$for the first option=$0.2115+\frac{0.22015}{0.0426(\frac{1}{0.0426}+\frac{1}{0.1338}+\frac{1}{0.04375})} = 0.3075$

$N_J$for the first option= $\frac{0.3075}{0.4006}\times 100 = 76.75$

4. Discussion

Because of its applications, electrical power has always been important. Power outage causes many problems. This outage or shortage could happen due to various reasons, one of which is energy loss in electric distribution networks such that 16% of this energy is wasted from its generation to distribution. Reasons for energy loss in distribution networks were identified in this study. Two techniques were used for prioritizing and evaluating criteria in three networks of Bushehr province. At first, relative importance and weights for each criteria were calculated using SWARA technique. Then, COPRAS-G technique was used for ranking and evaluating options. The conceptual model was extracted by collecting expert and professor opinions and using background of the study. The results of this model was 14 criteria for energy losses. Energy theft factor led to most losses and thus it should be the first priority to be eliminated from distribution networks. In a study carried out in Michigan, energy theft was recognized as the most important loss factor (The International Energy Guide, 2009), which is consistent with our findings. Furthermore, this factors was also recognized as highly influential in a study carried out in India (Goldnomein, 2012). According to the background of the study, the factor of network arrangement and structure was one of the significant factors. Many attempts were made to optimize this arrangement using various methods. However, the impact of this factor was determined as practically very low based on expert opinions used in this study. Finally, the importance of each criteria was evaluated in the three electric distribution networks of Bushehr province, among which Assaluyeh network had the highest amount of energy loss. This is because this networks has Assaluyeh gas refineries. For some reason, these refineries do not pay their electricity cost and bills and thus the amount of the consumed energy is classified under loss and theft category. Therefore, energy decision makers should pay more attention to Assaluyeh network.

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