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IDENTIFICATION AND ASSESSMENT OF INDICATORS AFFECTING ENERGY LOSS IN THE ELECTRIC DISTRIBUTION NETWORKS CASE STUDY: ASSALUYEH, BUSHEHR AND DEYLAM

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Abstract. Due to its widespread applications, electrical energy has always been of great importance so that a power outage even for a moment may cause many irreparable problems. Power outage or shortage may occur for different reasons including the loss of energy in the electric distribution network. Loss of energy will impose enormous costs to the government. In this regard, the aim of this study is to identify the factors causing the loss of energy in the electricity distribution networks. By further understanding of these factors, their impact on the distribution networks can be largely reduced. The lack of knowledge on the regions with high loss of energy and the importance of each indicator in a particular area will result in more energy loss by diverting the decisions of managers and decision-makers from the main goal. Twelve experts from the electricity industry participated in this study. The comments by the experts were collected using a questionnaire. Using the theoretical background and the Likert scale, the parameters affecting the energy loss in the distribution networks were identification. These indicators include energy theft, measurement errors, load, network aging, loose connections, improper placement of equipment, voltage, resistance of the conductor, losses from equipment, the location and size of capacitors, geographical conditions, size and dimensions of the conductor, current leakage and network configuration. Using the Cardinal weights, the indicators were weighted and ranked in Assaluyeh, Bushehr and Deylam in Bushehr province. The most important factors affecting energy loss in Assaluyeh, Bushehr and Deylam include energy theft, the location and size of the capacitors and network configuration, respectively.

Keywords: loss of energy, Cardinal weights, electricity distribution network.

Introduction. In the today's world, the need for various forms of energy is felt more than ever. People use different energy sources to advance their goals. Renewable and nonrenewable energies are the most important categories of energy. Electrical energy is one of the cleanest energies. Thus, the use of this energy is quite common in the present century. Like other forms of energy, part of electrical energy is lost while transferring from power plants to consumers [1].

Electrical energy is produced in power plants and passes through the transmission grid to the distribution network to reach the end consumer. During the production process to consumption, a significant part of the electrical energy is lost. According to the hydrocarbon balance sheet released by the Iranian government, energy loss in the distribution network is more than 16 percent [2] while the standard rate of energy loss in the standard networks is only 5% [3]. Actually, about 75 percent of energy loss is related to the distribution network [4]. The lack of follow-up and poor information management in this area can impose significant costs on the huge power distribution network. Hence it is important to identify factors affecting energy loss in the distribution networks to provide the management with a way to monitor and control energy losses by identifying the influential factors. Management should also be aware of the ranking of the factors affecting energy loss in each city. In the case of lack of funds and time, the management should just pay attention to the most important indicator in each city to fix it. Consequently, the main objective of this study is to reduce energy loss and associated costs by identifying the factors affecting energy loss and their impact in different regions.

Literature Review. During the process of production and distribution of electric energy, a significant portion of this energy is lost. According to the hydrocarbon balance sheet released by the Iranian government, the amount of the losses in the distribution network is more than 16 percent [2].

In an article by Kamel *et al.* (2009) entitled "Optimal size and location of distributed generations for minimizing power losses in a primary distribution network", an algorithm was presented to optimize the energy. The results showed that the size and location of the network have an important role in energy losses [5].

The Section 9 of the hydrocarbon balance sheet collected in 2008 concerns energy loss and optimization of the total energy including electric power. According to the report, the current and resistance of the transmission and distribution lines are the main factors causing power losses [2].

Energy Balance Sheet is published annually in every country. Iran's balance sheet was released in 2011. According to this report, the nature of the distribution networks and its extent and vulnerability, distribution network aging and misuse of power were the main factors causing power loss [6].

I his book entitled "The loss of electric energy in the distribution network", Heidari discusses the losses in the electricity networks. The book outlines the types and models of energy loss. According to Heidari, the factors causing energy loss in the distribution networks include power loss, energy loss and corona loss in power lines, losses due to current leakage, losses caused by unbalanced load and losses in transformers [7].

Gholami Ghasri *et al.* conducted a study entitled "Optimal reconfiguration of distribution networks to reduce power loss by using modified genetic algorithm". They introduced a modified genetic algorithm to solve reconfiguration problem as the most cost effective way to prevent energy loss. The results showed that improper placement of capacitors, voltage, load, network aging and improperly configured network are the main causes of energy loss [8].

In an article entitled "Factors affecting production, design, installation and operation of aerial distribution networks and silicone rubber insulators in coastal areas (Hormozgan province)", Nemati studied the effect of geographical conditions such as humidity, pollution, heat and wet equipment in the distribution network on the energy loss [9].

In a book entitled "Strategic approaches to reduce energy loss in electrical networks", power loss was investigated. The book covers various topics including the factors causing energy loss. Some of these factors include current resistance, current leakage, domestic consumption, measurement errors and lack of error, network management, network capacity, equipment capacity, technical specifications of networks and geographical conditions [10].

Rohani and Rajabi Mashhadi conducted a study entitled "Structural changes in distribution networks by genetic algorithms to reduce energy loss using capacitors" to optimize the distribution networks using the genetic algorithm. In this article, the distribution network structure, the size and type of conductor, network aging, placement of posts, the load on distribution transformers and voltage were identified as energy loss factors [11].

In an article entitled "Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks ", Gopiya Naik *et al.* studied loss factors and advantages of loss reduction. According to the authors, the size and location of the distribution network and suitable capacitors play an important role in energy loss. In this regard, they proposed a method to reduce losses [12]. An article entitled "A model to reduce electrical energy losses in electricity distribution network in Tehran" studied the electric energy distribution networks and proposed a way for reconfiguration of the distribution networks. According to the results, network aging and loading of lines and substations were the main factors affecting power loss in the distribution network [13]. Loose connection is one of the factors causing energy losses in the distribution network. In a study entitled "Profits caused by elimination of loose connections in Jolfa power distribution management", Asadzadeh investigated energy loss in Jolfa, East Azerbaijan. The results showed that profits may be returned to the organization by elimination of loose connections. Energy will be lost if the loose connections are not eliminated and the electricity distribution companies cannot sell this energy [14].

Shadkami divided the energy loss factors into two categories of facility and non-facility fatcors as below: Facility loss: line losses due to the resistance of conductors, no-load loss, brass and iron losses in transformers, dielectric losses in cables, losses related to the earthing system, losses related to measuring devices, losses related to loose connections and losses related to voltage drop. Non-facility losses, unauthorized connections, lateral connections, illegal increased demand, malfunction of meters, wrong electric bills and lighting [15]. Shayanfar *et al.* studied network reconfiguration in an article entitled "reconfiguration of distribution networks to reduce energy loss by using modified genetic algorithm". High electrical current in the lines, low voltage level, radial structure and network configuration were mentioned as the sources of power loss [16]. According to the World Bank strategy group, factors causing the loss of electrical power include: Technical factors such as errors in measurement systems, transformers, transmission and distribution lines and loss of power in the grid. Non-technical factors due to external factors such as energy theft, nonpayment by customers, accounting error and data maintenance [17].

Seddiqizadeh *et al.* (2014) optimized the location of capacitors in the distribution network. Using particle swarm algorithm, they minimized the energy losses in the distribution network. The location of capacitors was a very important factor in their article entitled "Network reconfiguration and optimal location of capacitors to minimize losses by using particle swarm algorithm" [18].

In a case study in Michigan, theft of different energies such as natural gas and electricity was investigated as an important factor influencing the cost of energy. According to the results, the impact of this factor can be reduced with the installation of smart devices, but energy theft still remains an important factor.

Winther (2012) studied energy theft in India, Tanzania and Zanzibar. According to the results, energy theft especially in India is the most important factor in the power loss in the distribution network. The cost of energy theft is more than one percent of GDP. Electricity theft or robbery includes illegal connections, meter tampering, theft of cables and equipment and nonpayment of the bills [20].

In an article entitled "Experiencing a decline in the losses in the electric power distribution in Iranian companies ", Arefi studied energy loss reduction projects in Iran. According to the results of this study, the main factors influencing energy loss in Iran include theft of electricity, measurement errors, location distribution and size of transformers, conductor size, voltage, and street lighting, load, network reconfiguration, loose connections and scattered distribution [21].

An article entitled "Theft and loss of power in India" was published in 2012. This paper is an extensive study on the theft of electricity from 2000 to 2009. The article shows the importance of this factor in energy loss [22].

In an article entitled "Energy theft prevention strategies", Arabeglou *et al.* (2009) studied the importance of energy theft. They investigated the ways for energy theft and the methods to prevent theft of electricity [23].

In the article entitled "optimal placement and sizing of distributed generation for power loss reduction using particle swarm optimization", Bhumkittipich found an optimal solution for the location and size of the electricity distribution network. This article introduces the location and size of the distribution network as one of the most important and influential factors in power loss [24].

In an article entitled "Electricity theft: a comparative analysis", Smith studied energy theft and its impact on energy loss in the distribution network in 102 countries from 1980 to 2000. In the meantime, energy theft includes meter tampering, theft of cables and equipment and errors in electricity bill [25].

In an article entitled "Optimal reconfiguration and capacitor allocation in radial distribution systems for energy losses minimization", Oliveira *et al.* (2010) proposed an algorithm for finding the optimal location and size of the capacitors to reduce the loss of energy in radial distribution networks. The operating voltage and the load were effective in energy loss [26]. In an article entitled "Use of fuzzy systems to reduce energy loss and voltage control in radial networks", the author aimed at finding the proper location of capacitors in a radial network. According to the results of this study, the loss factors include the location and size of capacitors and the structure of the distribution network and the voltage [27].

Power theft or illegal connections is a factor with a significant impact on the losses in the distribution network. Taghizadeh and Ghanbari studied the effect of this factor in an article entitled "Factors increasing unauthorized power connections and prevention methods". While presenting the high prevalence of illegal connections, they proposed strategies to reduce energy theft [28]. Junjie *et al.* introduced the location and size of the network as an important factor in energy losses. Using immune algorithm, they investigated the optimal location of the network to reduce the loss of energy and associated costs. The article was published with the title "Size and location of distributed generation in distribution system based on immune algorithm" [29].

According to Karimi, energy theft includes meter tampering, unauthorized connections and theft of cables and equipment. Generally, this factor plays a significant role in energy loss and imposes heavy costs on the power generation. On the other hand, this factor reduces the quality of energy delivery and causes power outage in the grid [30].

According to literature, a total of twenty-two indicators were identified as shown in Table 1.

Table 1: Factors identified in the literature

	Loss factor
1	Network configuration
2	Energy theft
3	Load
4	Losses caused by equipment
5	Network aging
6	Voltage
7	The location and size of the capacitors
8	Current leakage
9	Measurement error
10	Size and type of conductor
11	Loose connections
12	Inappropriate placement of equipment
13	Resistance of the conductor
14	Geographical conditions

15	Network management
16	The nature of the distribution network
17	Power loss in the grid
18	Current
19	Power loss
20	Corona losses
21	Network capacity
22	Dielectric loss

Methodology. This is a descriptive study in which the required data were collected by desk and field studies. Desk study was used to identify effective indicators. Field studies were used to categorize and rank the indicators in each city. In this step, the final indicators were identified among 22 indicators using a Likert scale. At the next step, the importance of each indicator in Assaluyeh, Bushehr and Deylam was determined using Cardinal weights and linear programming. Experts participating in the study were 12 experts in the power industry. Demographic characteristics of the experts are shown in Table 2.

Table 2: Demographic characteristics of the experts participating in the study

Expert	Field of Study	Degree	Age	Work experience	Gender
1	Power engineering	PhD	32	10	Female
2	Power engineering	MSc	38	14	Male
3	Power engineering	BSc	32	8	Male
4	Power engineering	MSc	40	17	Male
5	Physics	MSc	38	15	Male
6	Management	MSc	36	14	Male
7	Electronics	BSc	30	8	Female
8	Electrical engineering	MSc	38	17	Male
9	Electrical engineering	BSc	45	24	Male
10	Power engineering	MSc	44	22	Male
11	Electrical engineering	BSc	32	10	Male
12	Electrical engineering	MSc	40	18	Male

Likert scale. After identifying the basic indicators, they were examined by referring to the 12 experts in the electricity office. To select the most important indicators, the basic indicators were returned to the experts. For this purpose, the experts were provided with a questionnaire entitled the impacts of the indicators on energy losses in the distribution network. The experts answered questions using the five-point Likert scale with "very high, high, medium, low and very low" items. For example, "very high" was used for indicators with a significant impact on the energy loss. In contrast, "very low" was used for factors with a little impact on energy loss. According to the category, the items were converted into scores so that a score of 5 and 1 was given to "very high" and "very low" statements, respectively. Using the averages, the indicators with a score of above 3 were selected as final indicators.

Cardinal weights method. Most existing group algorithms give a "ranking" of priorities for m options (for a candidate or m indicators) without taking account the intensity of preference. Some algorithms in this field have been provided for group decision-making such as collective selection functions of "Breda", "Coke and Seifert", "Bernardo" and so on. It should be noted that the ranking algorithms require fewer assumptions than Cardinal algorithms. The algorithm described below achieves the Cardinal weights for the options by prioritizing m options using a linear programming model. To use this model, the priority of the m options is assumed to be as follows:

$$A^{(i)}_{1} > A^{(i)'}_{2} > \cdots > A^{(t)}_{j} > A^{I}_{j+1} > \cdots > A^{(i^n)}_{m+1} > A^{(i^m)}_{m}$$

So that the options $A^{(i)}$ and $A^{(i'')}$ are in the first and last places, respectively. On the other hand, the only correct understanding of the relationship $A_j^{(t)} > A_{j+1}^{(l)}$ (the superiority of the option t to the option I) is this fact that $W_j > W_{j+1}$.

Therefore, for prioritization, we should have:

$W_1 > W_2 > \cdots > W_j > W_{j+1} > \cdots W_{m-1} > W_m$

In other words:

$(W_1 - W_2) > 0, (W_2 - W_3) > 0, \ldots, (W_J - W_{J+1}) > 0, \ldots, (W_{m-1} - W_m) > 0$

However, in order to consider the intensity of the experts' comments, the parameter J is used:

$J_1(W_1 - W_2) > 0, J_2(W_2 - W_3) > 0, \ldots, J_n(W_n - W_{n+1}) > 0, \ldots, J_{m-1}(W_{m-1} - W_m) > 0, J_m(W_m) > 0$

The parameter J is a factor to consider the intensity of preference in the above-mentioned inequalities. So, in order to access the appropriate values from the existing w:

$Max: \{J_1(W_1 - W_2), J_2(W_2 - W_3), \ldots, J_n(W_n - W_{n+1}), \ldots, J_{m-1}(W_{m-1} - W_m), J_m(W_m)\}$

$St:$

$\sum_{j=1}^{m} W_n = 1$

$W_n \geq 0$

To maximize the above multi-objective decision model (MODM), the minimum objectives should be maximized (Z is an arbitrary value).

$Max\, Z$

$:St$

$Z \leq J(W_j^{(t)} - W_{j+1}^{(l)}) \quad j = \{1,2,3,\ldots,m\} \quad t = \{1,2,3,\ldots,m\} \quad t = \{1,2,3,\ldots,m\}$

$Z \leq m w_m^{(i)} \quad i = \{1,2,3,\ldots,m\}$

$\sum_{j=1}^{m} w_j^{(i)} = 1$

$w_j^{(i)} \geq 0$

By solving this model, Cardinal weights (relative weights) of the indicators are obtained where $W_j^{(i)}$ represents the Cardinal weight of the option i [31]. The advantages of this method are as follows:

- There are no reliable methods to obtain the Cardinal weights directly.
- Group ranking techniques have less and easier assumptions than Cardinal group techniques.
- There is no proven technique to convert results of any method to Cardinal weights (except this method).
- There are no exceptions to the proposed method so that it is applicable for all rankings.

According to Asgharpour, j is considered as a uniform ascending sequence of numbers (example: 1, 2, 3, etc.). But it seems that the use of a uniform sequence of numbers for problems with the same number of indicators leads to consistent weights by ignoring the impact of experts' comments on weighting. So instead of uniform numbers for j, an ascending sequence of numbers can be achieved in accordance with the experts' comments using the advantages of linear allocation and dividing the scores by the score of the top index. In this way, the intensity of experts' comments is considered in prioritizing the indicators [32].

Results. According to literature, factors affecting energy loss in electricity distribution network were identified. Then, the collected indicators were refined by referring the experts in power industry. This means that some indicators were combined. For this purpose, the impact of indicators on the energy loss was determined using a Likert scale. The results of the questionnaires and calculations are shown in Table 3.

Table 3: Questionnaire calculations using the Likert scale

Average weight	**Total weight**	**Frequency**					**Number of participants**	**Indicator**
		1	**2**	**3**	**4**	**5**		
12=3.5÷42	2×5+5×4+3×3+1×2+1×1=42	1	1	3	5	2	12	Network configuration
12=4.16÷50	4 × 5 + 6 × 4 + 2 × 3 + 0 × 2 + 0 × 1=50	0	0	2	6	4	12	Energy theft
12=3.08÷37	1 × 5 + 3 × 4 + 5 × 3 + 2 × 2 + 1 × 1=37	1	2	5	3	1	12	Load
12=3.5÷42	1 × 5 + 6 × 4 + 3 × 3 + 2 × 2 + 0 × 1=42	0	2	3	6	1	12	Voltage
12=4÷48	3 × 5 + 4 × 4 + 3 × 3 + 2 × 2 + 0 × 1=48	0	2	3	4	3	12	Losses caused by equipment

12=3÷36	0 × 5 + 3 × 4 + 6 × 3 + 3 × 2 + 0 × 1=36	0	3	6	3	0	12	Measurement error
12=3.58÷43	1 × 5 + 6 × 4 + 4 × 3 + 1 × 2 + 0 × 1=43	0	1	4	6	1	12	Resistance of the conductor
12=4.17÷50	3 × 5 + 8 × 4 + 1 × 3 + 0 × 2 + 0 × 1=50	0	0	1	8	3	12	Network aging
12=3.25÷39	0 × 5 + 4 × 4 + 7 × 3 + 1 × 2 + 0 × 1=39	0	1	7	4	0	12	Size and type of conductor
12=3.16÷38	0 × 5 + 5 × 4 + 4 × 3 + 3 × 2 + 0 × 1=38	0	3	4	5	0	12	The location and size of the capacitors
12=3.75÷45	2 × 5 + 6 × 4 + 3 × 3 + 1 × 2 + 0 × 1=45	0	1	3	6	2	12	Inappropriate placement equipment
12=3.83÷46	2 × 5 + 6 × 4 + 4 × 3 + 0 × 2 + 0 × 1=46	0	0	4	6	2	12	Loose connections
12=3.58÷43	0 × 5 + 8 × 4 + 4 × 3 + 0 × 2 + 0 × 1=43	0	0	4	8	0	12	Current leakage
12=3.75÷45	3 × 5 + 5 × 4 + 2 × 3 + 2 × 2 + 0 × 1=45	0	2	2	5	3	12	Geographical conditions
12=2.33÷28	0 × 5 + 2 × 4 + 3 × 3 + 4 × 2 + 3 × 1=28	3	4	3	2	0	12	Network management
12=1.83÷22	0 × 5 + 1 × 4 + 1 × 3 + 5 × 2 + 5 × 1=22	5	5	1	1	0	12	The nature of the distribution network
Average weight	**Total weight**	**Frequency**					**Number of participant**	**Indicator**
		1	**2**	**3**	**4**	**5**		
12=2.08÷25	0 × 5 + 1 × 4 + 3 × 3 + 4 × 2 + 4 × 1=25	4	4	3	1	0	12	Power loss in the grid
12=2÷24	0 × 5 + 1 × 4 + 4 × 3 + 1 × 2 + 6 × 1=24	6	1	4	2	0	12	Current
12=2.08÷25	0 × 5 + 1 × 4 + 3 × 3 + 4 × 2 + 4 × 1=25	4	4	3	1	0	12	Power loss
12=1.16÷25	0 × 5 + 0 × 4 + 0 × 3 + 2 × 2 + 10 × 1=14	10	2	0	0	0	12	Corona loss
12=1.83÷22	0 × 5 + 0 × 4 + 2 × 3 + 6 × 2 + 4 × 1=22	4	6	2	0	0	12	Network capacity
12=1.75÷21	0 × 5 + 0 × 4 + 1 × 3 + 7 × 2 + 4 × 1=21	4	7	1	0	0	12	Dielectric loss

Eventually, indicators with an average of three or above were selected and the experts' comments were finalized. In the meantime, eight indicators were combined with other indicators. The final indicators are shown in Table 4.

Table 4: Refined indicators

	Loss factor
1	Network configuration
2	Energy theft
3	Load
4	Voltage
5	Losses from equipment
6	Measurement error
7	Resistance of the conductor
8	Network aging
9	Size and type of

	conductor
10	The location and size of the capacitors
11	Inappropriate placement of equipment
12	Loose connections
13	Current leakage
14	Geographical conditions

The Cardinal weights of the indicators in each city using Asgharpour's method

After determining the indicators using experts' opinions, the Cardinal weights of the indicators in each city were determined using Asgharpour's method. To this end, the rank and importance of each indicator in Assaluyeh, Bushehr and Deylam were determined.

The Cardinal weights of the Bushehr network are as follows:

$Max\ Z$

$:St$

$Z \leq 1(W_1^{(1)} - W_2^{(2)})$
$Z \leq 1 \div 23(W_2^{(2)} - W_3^{3})$
$Z \leq 1 \div 25(W_3^{(3)} - W_4^{(4)})$
$Z \leq 1 \div 27(W_4^{(4)} - W_5^{(5)})$
$Z \leq 1 \div 31(W_5^{(5)} - W_6^{(6)})$
$Z \leq 1 \div 33(W_6^{(6)} - W_7^{(7)})$
$Z \leq 1 \div 84(W_7^{(7)} - W_8^{(8)})$
$Z \leq 1 \div 92(W_8^{(8)} - W_9^{(9)})$
$Z \leq 1 \div 96(W_9^{(9)} - W_{10}^{(10)})$
$Z \leq 1 \div 98(W_{10}^{(10)} - W_{11}^{(11)})$
$Z \leq 2 \div 27(W_{11}^{(11)} - W_{12}^{(12)})$
$Z \leq 2 \div 33(W_{12}^{(12)} - W_{13}^{(13)})$
$Z \leq 2 \div 56(W_{13}^{(13)} - W_{14}^{(14)})$
$Z \leq 2 \div 58(W_{14}^{(14)})$
$W_1^{(1)} + W_2^{(2)} + W_3^{(3)} + W_4^{(4)} + W_5^{(5)} + W_6^{(6)} + W_7^{(7)} + W_8^{(8)} + W_9^{(9)} + W_{10}^{(10)} + W_{11}^{(11)} + W_{12}^{(12)} + W_{13}^{(13)} + W_{14}^{(14)} = 1$

$W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{11}, W_{12}, W_{13}, W_{14} \geq 0$

The Cardinal weights of the Deylam network are as follows:

$Max\ Z$

$:St$

$Z \leq 1(W_1^{(1)} - W_2^{(2)})$
$Z \leq 1 \div 12(W_2^{(2)} - W_3^{3})$
$Z \leq 1 \div 22(W_3^{(3)} - W_4^{(4)})$
$Z \leq 1 \div 25(W_4^{(4)} - W_5^{(5)})$
$Z \leq 1 \div 86(W_5^{(5)} - W_6^{(6)})$
$Z \leq 2 \div 15(W_6^{(6)} - W_7^{(7)})$
$Z \leq 2 \div 2(W_7^{(7)} - W_8^{(8)})$
$Z \leq 2 \div 35(W_8^{(8)} - W_9^{(9)})$
$Z \leq 2 \div 65(W_9^{(9)} - W_{10}^{(10)})$
$Z \leq 2 \div 8(W_{10}^{(10)} - W_{11}^{(11)})$
$Z \leq 2 \div 82(W_{11}^{(11)} - W_{12}^{(12)})$
$Z \leq 3 \div 05(W_{12}^{(12)} - W_{13}^{(13)})$
$Z \leq 3 \div 37(W_{13}^{(13)} - W_{14}^{(14)})$
$Z \leq 3 \div 67(W_{14}^{(14)})$
$W_1^{(1)} + W_2^{(2)} + W_3^{(3)} + W_4^{(4)} + W_5^{(5)} + W_6^{(6)} + W_7^{(7)} + W_8^{(8)} + W_9^{(9)} + W_{10}^{(10)} + W_{11}^{(11)} + W_{12}^{(12)} + W_{13}^{(13)} + W_{14}^{(14)} = 1$

$W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{11}, W_{12}, W_{13}, W_{14} \geq 0$

The Cardinal weights of the Assaluyeh network are as follows:

$Max\ Z$

$:St$

$Z \leq 1(W_1^{(1)} - W_2^{(2)})$
$Z \leq 1 \div 12(W_2^{(2)} - W_3^{3})$
$Z \leq 1 \div 18(W_3^{(3)} - W_4^{(4)})$
$Z \leq 1 \div 22(W_4^{(4)} - W_5^{(5)})$
$Z \leq 1 \div 32(W_5^{(5)} - W_6^{(6)})$
$Z \leq 1 \div 33(W_6^{(6)} - W_7^{(7)})$
$Z \leq 1 \div 48(W_7^{(7)} - W_8^{(8)})$
$Z \leq 1 \div 58(W_8^{(8)} - W_9^{(9)})$
$Z \leq 1 \div 70(W_9^{(9)} - W_{10}^{(10)})$
$Z \leq 1 \div 72(W_{10}^{(10)} - W_{11}^{(11)})$
$Z \leq 1 \div 82(W_{11}^{(11)} - W_{12}^{(12)})$
$Z \leq 1 \div 84(W_{12}^{(12)} - W_{13}^{(13)})$
$Z \leq 1 \div 87(W_{13}^{(13)} - W_{14}^{(14)})$
$Z \leq 2 \div 24(W_{14}^{(14)})$
$W_1^{(1)} + W_2^{(2)} + W_3^{(3)} + W_4^{(4)} + W_5^{(5)} + W_6^{(6)} + W_7^{(7)} + W_8^{(8)} + W_9^{(9)} + W_{10}^{(10)} + W_{11}^{(11)} + W_{12}^{(12)} + W_{13}^{(13)} + W_{14}^{(14)} = 1$

$W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, W_{10}, W_{11}, W_{12}, W_{13}, W_{14} \geq 0$

Table 5 shows the parameter j used in the Cardinal weights of the distribution network of Bushehr.

Table 5: The parameter j used in the Cardinal weights of the distribution network of Bushehr

	Indicators	Total rank	J
1	The location and size of the capacitors	51	51÷51=1
2	Network aging	63	63÷51=1.23
3	Measurement error	64	64÷51=1.25
4	Loose connections	65	65÷51=1.27
5	Losses from equipment	67	67÷51=1.31
6	Load	68	68÷51=1.33
7	Resistance of the conductor	94	94÷51=1.84
8	Voltage	98	98÷51=1.92
9	Inappropriate placement equipment	100	100÷51=1.96
10	Network configuration	101	101÷51=1.98
11	Geographical conditions	116	116÷51=2.27
12	Energy theft	119	119÷51=2.33
13	Size and type of conductor	131	131÷51=2.56
14	Current leakage	132	132÷51=2.58

Table 6 shows the parameter j used in the Cardinal weights of the distribution network of Deylam.

Table 6: The parameter j used in the Cardinal weights of the distribution network of Deylam

	Indicators	Total rank	J
1	Network configuration	40	40÷40=1
2	The location and size of the capacitors	45	45÷40=1.12
3	Voltage	49	49÷40=1.22

4	Load	50	50÷40=1.25
5	Network aging	75	75÷40=1.86
6	Geographical conditions	86	86÷40=2.15
7	Measurement error	88	88÷40=2.2
8	Loose connections	94	94÷40=2.35
9	Size and type of conductor	106	106÷40=2.65
10	Losses from equipment	112	112÷40=2.8
11	Energy theft	113	113÷40=2.82
12	Resistance of the conductor	122	122÷40=3.05
13	Current leakage	135	135÷40=3.37
14	Inappropriate placement of equipment	147	147÷40=3.67

Table 7 shows the parameter j used in the Cardinal weights of the distribution network of Assaluyeh.

Table 7: The parameter j used in the Cardinal weights of the distribution network of Assaluyeh

	Indicators	Total rank	J
1	The location and size of the capacitors	58	58÷58=1
2	Size and type of conductor	65	65÷58=1.12
3	Energy theft	69	69÷58=1.18
4	Network aging	71	71÷58=1.22
5	Measurement error	77	77÷58=1.32
6	Losses from equipment	86	86÷58=1.33
7	Network configuration	91	91÷58=1.48
8	Voltage	92	92÷58=1.58
9	Loose connections	99	99÷58=1.70
10	Inappropriate placement of equipment	100	100÷58=1.72
11	Geographical conditions	106	106÷58=1.82
12	Resistance of the conductors	107	107÷58=1.84
13	Currant Leakage	109	109÷58=1.87
14	Load	130	130÷58= 2.24

By solving the model in Lingo 12, the weight of indicators in the selected distribution networks in Bushehr province is obtained as shown in the following tables.

Table 8 shows the Cardinal weights of the loss indicators in Bushehr network

Table 8: The Cardinal weights of loss indicators in Bushehr Network

Indicator	Weight
The location and size of the capacitors	0.1582
Network aging	0.1399
Measurement error	0.1250
Loose connections	0.1104
Losses from equipment	0.0959
Load	0.0820
Resistance of the conductor	0.0682
The voltage	0.0582
Inappropriate placement	0.0487
Network configuration	0.0394
Geographical conditions	0.0301
Energy theft	0.0221
Size and type of conductor	0.0142
Current leakage	0.0070

Table 9 shows the Cardinal weights of the loss indicators in Deylam network

Table 9: The Cardinal weights of loss indicators in Deylam Network

Indicator	Weight
Network	0.1717
The location and size	0.1484
The voltage	0.1276
The load	0.1086
Network aging	0.0900
Geographical conditions	0.0775
Measurement error	0.0666
Loose connections	0.0561
Size and type of conductor	0.0562
Losses from equipment	0.0374
Energy theft	0.0291
Resistance of the conductor	0.0208
Current leakage	0.0132
Inappropriate placement	0.0063

Table 10 shows the Cardinal weights of the loss indicators in Assaluyeh network

Table 10: The Cardinal weights of loss indicators in Assaluyeh Network

Indicator	Weight
The location and size of the capacitors	0.1513
Size and type of conductor	0.1356
Energy theft	0.1215
Network aging	0.1082
Measurement error	0.0953
Losses from equipment	0.0834
Network configuration	0.0716
The voltage	0.0609
Loose connections	0.0510
Inappropriate placement	0.0417
Geographical	0.0326
Resistance of the conductor	0.0239
Current leakage	0.0154
The load	0.0070

Conclusion. In this research work, the factors affecting energy loss in the distribution networks were identified. To this end, 22 loss factors were first identified by reviewing literature and referring experts in the power industry. After refining, 14 factors were identified as final indicators. The factors include energy theft, measurement errors, load, network aging, loose connections, improper placement of equipment, voltage, resistance of the conductor, losses from equipment, location and size of the capacitors, geographical conditions, size and type of conductors, current leakage and network configuration. The weight of indicators in Assaluyeh, Bushehr and Deylam was calculated by using Cardinal weights method. According to the pie chart 1, more than half of the circle is allocated to the location and size of the capacitors, conductor size and type, energy theft and network aging. This reflects the importance of these indicators in energy loss in Assaluyeh distribution network.

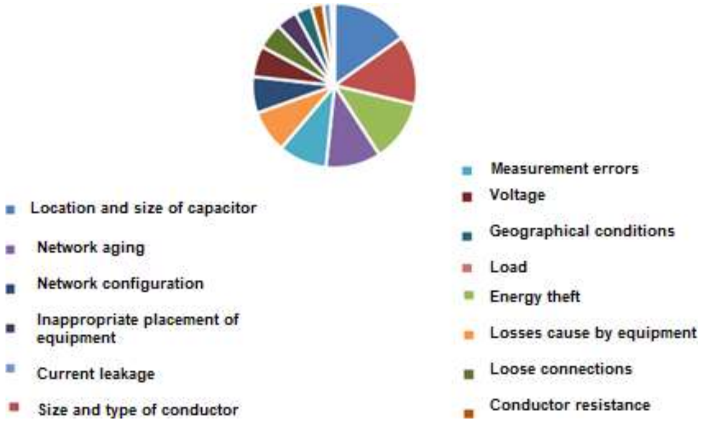

Chart 1: The importance of energy loss indicators in Assaluyeh distribution network

As can be seen in the pie chart 2, the location and size of the capacitor, network aging, measurement errors and loose connections are the most important factors influencing energy loss in Bushehr distribution network. In fact, these factors cause energy loss in the distribution network.

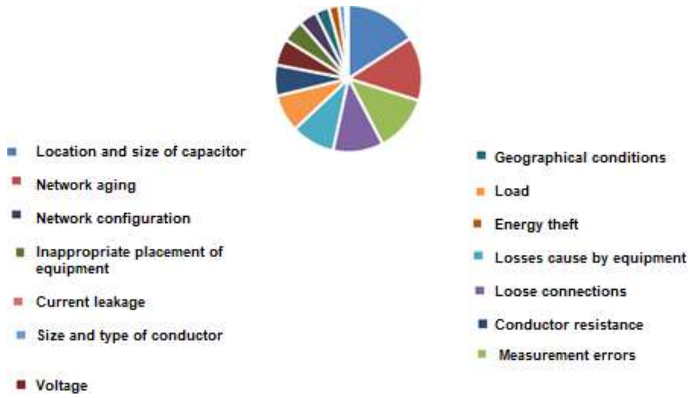

Chart 2: The importance of energy loss indicators in Bushehr distribution network

According to the pie chart 3, more than fifty percent of the chart is allocated to network configuration, location and size of the capacitors, voltage and load in the Deylam distribution network.

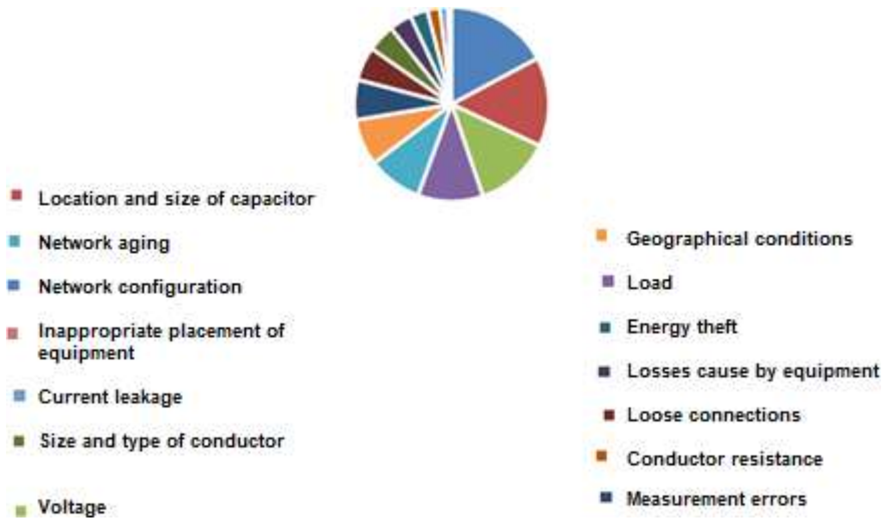

Chart 3: The importance of energy loss indicators in Deylam distribution network

In all three networks, the weight of the location and size of the capacitors is higher than 10%. As a result, this factor is of great importance in all three distribution networks. Therefore, managers should pay particular attention to this factor, because it plays a significant role in all three selected networks with high energy loss.

The weight and importance of each indicator were mentioned in the previous section. The important factors in each city with a weight higher than 10% are discussed in the conclusion section. In this regard, the following strategies are proposed to reduce the energy loss in each city according to the literature and experts' comments.

The highest energy loss is observed in Assaluyeh distribution network. In this network, four factors are of greater importance. The first factor is the location and size of the capacitors. Dig SILENT and GIS were used to identify the appropriate location of capacitors in the Assaluyeh network. Given the energy loss in the distribution network, mathematical models are proposed to be used in operation and location considering other conditions of the network to reduce energy loss. The next factor is the type and size of conductors. According to geographical conditions of Assaluyeh, it is recommended to pay more attention to this issue, because experts have ignored this factor. In fact, conductors must be installed very carefully.

The next factor is energy theft in the Bushehr distribution network. As mentioned, about 96% of the Assaluyeh distribution network is composed of aerial lines leading to easier theft of cables and equipment and unauthorized electrical connections. It is suggested to use underground cables to prevent theft. However, due to the high cost of this change, smart networks are recommended to be used to report any theft or unauthorized use to the power center upon the occurrence. The fundamental problem in Assaluyeh is the presence of refineries so that very high consumption of electricity and nonpayment of costs impose significant losses to the electricity office. Solving this issue is only possible by consultations between the electricity office and government institutions.

The last important factor is network aging. One way to avoid network aging is preventive maintenance and repair. Due to insufficient labor in Bushehr province, priority is given to larger networks so that Assaluyeh is often placed in last priority for maintenance. But given the importance of the Assaluyeh network in terms of energy loss, it is recommended to hire specialists to work exclusively on the repair and maintenance of the Assaluyeh network. In the case of sufficient budget, old equipment should be replaced and new equipment must be purchased. Since the funding has always been difficult, the cost of equipment can be provided with consultations between the refinery and power management, because this leads to high quality power supply to the refineries. By reducing the losses caused by network aging, investment returns to the electricity office may even be more than electricity bills of refineries. Of course, more research is needed in this regard.

Like the Assaluyeh network, the location and size of the capacitors are not suitable in the Bushehr network. Therefore, same solutions are recommended for the Bushehr network. The next factor is network aging. Referring to the experts, it was found that the main priority is given to repair in the Bushehr network and maintenance in the second place. But experts must prevent energy loss by hiring more maintenance workers and paying more attention to maintenance. Since replacing the old equipment is very costly, the energy loss can be largely reduced by increasing the number of maintenance workers and periodical inspections of equipment, because if energy is not lost, it can be sold to the consumers leading to a high return on investment for the organization. By using a smart network, this type of loss not only can be reduced but other loss factors can also be significantly reduced. The next factor is measurement errors. As mentioned in the conclusions, most instructions have been designed for experts. Therefore, it is suggested that the instructions are first reviewed by an expert to teach them to the technicians in a training session. More accurate and more advanced equipment should be used to measure technical issues. In general, human intervention should be reduced to reduce measurement errors. Loose connections also cause energy loss in Bushehr network due to incomplete repairs. Therefore, the maintenance workers must receive the necessary training to learn instructions and do repairs more carefully.

Deylam distribution network also suffers from improper network configuration. Because of the long and voluminous nature of the network, the entire network configuration cannot be changed using mathematical models. But it is recommended to identify regions of high energy loss to reconfigure the network at the same regions. Mathematical models can be used in these regions. The location and size of the capacitors are not suitable like in the other networks. A same strategy is recommended for Deyalm distribution network. Generally, all suggestions are fundamental but due to the high costs, maintenance and correction of energy losses is often recommended as they arise. The voltage on the network is inappropriate. In other words, the voltage on the Deylam distribution network is higher than other cities. As a result, a lower energy loss is expected but this voltage level is not consistent with other network elements. As a result, the voltage, load, repair and inspections should be consistent. There is a charge imbalance in the network. It is recommended that design engineers revise some parts of the network to apply the necessary modifications.

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