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Assessment of Reliability of Electrical Distribution Networks Using Fuzzy AHP

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Abstract

Reliability is one of the important factors in the electricity networks studies by which the weak points of the network are identified. Appropriate strategies can be suggested for future planning and efficient utilization of the networks by the identification of the weak points. Considering that electrical distribution networks are among the most appropriate parts in reliability measurement studies, reliability scales for Zahedan Distribution Network in 2012 were calculated in the current work. In this study, input parameters were modelled by defining appropriate membership functions with the triangular fuzzy algorithm. Then, the appropriate criterion for calculation of reliability in distribution systems was selected using Analytic Hierarchy Process (AHP), and reliability of the input parameters were calculated based on the selected criterion. The purpose of these calculations is presentation of necessary strategies for planning to decrease the number and duration of unplanned power failures, decrease the losses, and propitiate electricity consumers in Sistan and Baluchestan Province. In this paper, the case study is based on the sample network of Zahedan.

Keywords: Reliability, distribution network, evaluation indexes, fuzzy sets.

Introduction

One of the main parameters for understanding a power system is investigating the system's reliability. In order to differentiate different levels in evaluation of power systems reliability considering relationship of power system production, transfer and distribution sectors, they are classified into three levels: first level includes production equipment and facilities (HLI), second level includes transfer and production equipment (HLII), and third level include power system equipment (HLIII)[1]. Since accessibility to distribution system including production, transfer and distribution systems (due to its radial structure) is less than production and transfer systems, it is necessary to evaluate and improve reliability in this sector of the power system[1].

One essential problem in reliability studies for distribution systems is lack of access to adequate statistics and data. Lack of adequate data leads unrealistic and uncertain estimations of reliability input parameters[2].

Most part of electrical energy needed by the human is currently provided by the thermal power plants which operate with steam turbines. Gas turbines are also used in peak load as secondary producers. Electrical energy is produced by creating stem and guiding it on turbines in thermal power plants. Power plants for electrical power generation are connected to transfer systems or networks so that generated power is transferred to load consumption places[3]. Power Industry is one of the most vital industries in a country. Meanwhile, electrical distribution networks are the intersection point of power industry and the consumers and distribution system problems in this industry in the view of consumers would be viewed as the whole power industry problem. Increasing development, failure to correctly predict the trends and technological backwardness always provide problems in electrical distribution system and given 35 percent of power industry investments goes to distribution sector, and lack of proper design, unplanned system guidance and determining goals without project controls lead to loss for national asset, energy loss and dissatisfaction and pessimism in the consumers. Hence, training and transferring technical knowledge, innovation, observation of technical issues and standards, supervision, control, and evaluation in distribution systems is highly necessary[4].

Distribution networks are responsible for electrical energy transfer from generation place to consumption place and low capability networks suffer from high power failures and losses and thus undistributed or unsold energy volume is increased. In fact, measurement or investigation of reliability in these networks in the province by utilizing fuzzy systems is a guarantee for preventing from reaching to critical point and increased power failure and increases of undistributed energy and losses and expenses[1]. Thus, current work aims at providing a model for ensuring healthy and optimal distribution in distribution networks and answering the research aims.

Research Aim: Investigating the prioritization of service interruption frequency index in load points of Zahedan electrical distribution network (pilot region from Sistan and Baluchestan Province) compared to other reliability indexes of distribution networks. Investigating the prioritization of system average interruption duration index in load points of Zahedan electrical distribution network (pilot region from Sistan and Baluchestan Province) compared to other reliability indexes of distribution networks. Investigating the prioritization of consumer average interruption duration index in Zahedan electrical distribution network (pilot region from Sistan and Baluchestan Province) compared to other reliability indexes of distribution networks. Investigating is prioritization of average service availability index in Zahedan electrical distribution network (pilot region from Sistan and Baluchestan Province) compared to other reliability indexes of distribution networks? Investigating the prioritization of average energy not supplied index resulting from system fault in Zahedan electrical distribution network (pilot region from Sistan and Baluchestan Province) compared to other reliability indexes of distribution networks.

Methodology

This research study is applied in terms of purpose and it is post event survey in terms of data collection. Also, it is descriptive analytical research in terms of research method.

Statistical Population and Sample: Statistical population included all experts and managers of Zahedan Electrical Distribution Co. considering limited volume of the population, there was no sampling in this work and census method was used. That is, the questionnaire was distributed among all experts and specialists of Zahedan Electrical Distribution Co.

Data Collection Tool: In order to rate identified indexes and determine their weights, a questionnaire was developed by AHP method using Likert five-point scale[5].

Research Steps: i. Identifying evaluation indexes of distribution network reliability, ii. Weighting identified indexes using AHP, iii. Analysis of the distribution network under study and data for indexes of this network.

Steps for Index and Sub-index Extraction: Distribution system reliability was evaluated by related indexes introduced by IEEE Standard. Indexes include: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Consumer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Energy Not Supplied Index (ENS), and Average Energy Not Supplied (AENS) Index.

Data Analysis: Data were analyzed based on AHP method using Expert Choice Software and network descriptive analysis and calculating results for SAIFI, SAIDI, CAIDI, ASAI, ASUI, ENS, AENS indexes.

Results and Discussion

Aim 1: SAIF index was used to answer this question. According to the data from Zahedan Electrical Distribution Network, there is direct relationship between annual fault frequency for feeder and load factor. Fault occurrence is relatively identical for summer and it is higher than autumn. According to this index, December and January are in higher reliability level for feeder, while there is lower reliability for feeder in August.

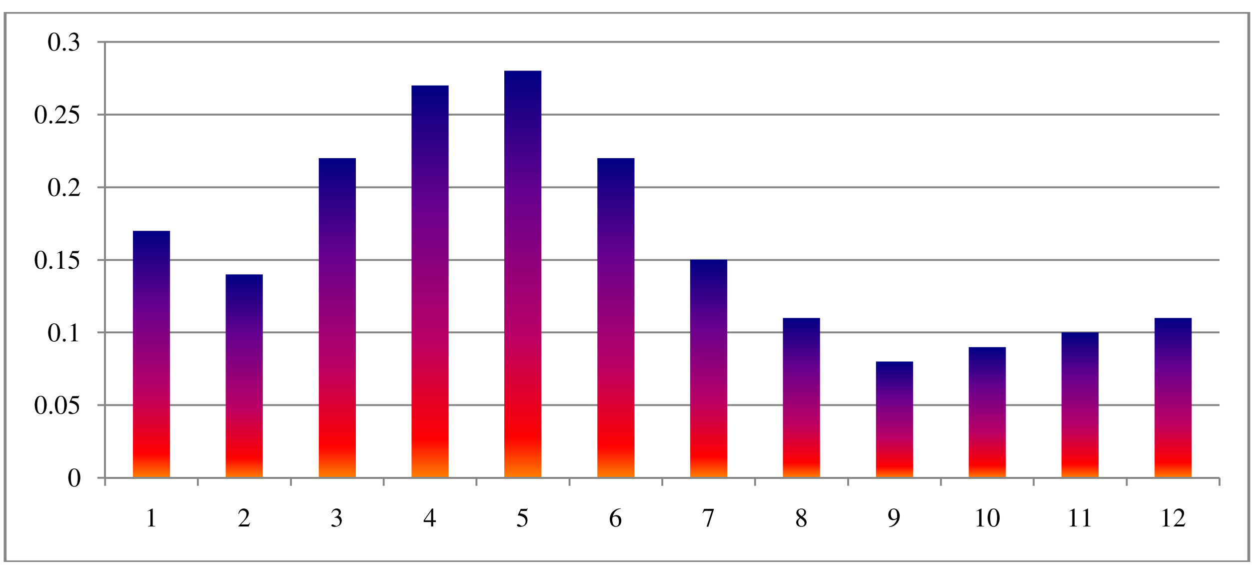

Figure-1
System Average Interruption Frequency per month in Zahedan City

If System Average Interruption Frequency is considered as a triangular fuzzy number, membership function of this index can be defined as follows:

$$\mathrm{SAIFI} = \begin{cases} 0.035x + 0.111 & \text{if } x \leq 5 \\ -0.024x + 0.250 & \text{if } x > 5 \end{cases}$$

Where, x is the year months.

Calculations are done as follows: Concepts of normalization and weighted average were used for extracting priorities from above table. To this end, the table values are normalized using the relation below:

Table-1
Initial matrix of pairwise comparison of indexes after integrating data

Index	I1 (SAIFI)	I2 (SAIDI)	I3 (CAIDI)	I4 (ASAI)	I5 (AENS)
I1	1	2.3	0.82	1.35	2.23

$$r_{ij} = \frac{\overline{a_{ij}}}{i = \sum_{i=1}^{m} \overline{a_{ij}}}$$

Table-2
Normalized matrix

Index	I1	I2	I3	I4	I5	Final weight of indexes (mean line)
I1	0.260	0.264	0.267	0.252	0.262	0.261

Hence, following table indicates index prioritization matrix based on the obtained results.

Table-3
Final prioritization matrix considering respective criteria using AHP method

Index	Weight of criteria (mean line)
SAIFI	0.261

Aim 2: To answer this question, SAIDI index was used. According to the data in Zahedan Distribution Network, the number of faults in hot months of year increases, thus duration of repair and power failure for the consumers would be longer. Because of low number of disconnect switches and the limited capacity of maneuver points, duration of power failure was increased considerably in hot months and sometimes it reached to over two times than land network's power failure. According to this index, higher reliability for feeder was observed in December, while lower reliability for feeder was observed in August.

If System Average Interruption Duration is considered as a triangular fuzzy number, membership function of this index can be defined as follows:

$$\mathrm{SAIDI} = \begin{cases} 4.84x + 1.32 & \text{if } x \leq 5 \\ -1.51x + 13.46 & \text{if } x > 5 \end{cases}$$

Where: x is the year months. Calculations are done as follows:

Table-4
Initial matrix of pairwise comparison of indexes after integrating data

Index	I1 (SAIFI)	I2 (SAIDI)	I3 (CAIDI)	I4 (ASAI)	I5 (AENS)
I2	0.43	1	0.34	0.63	1.12

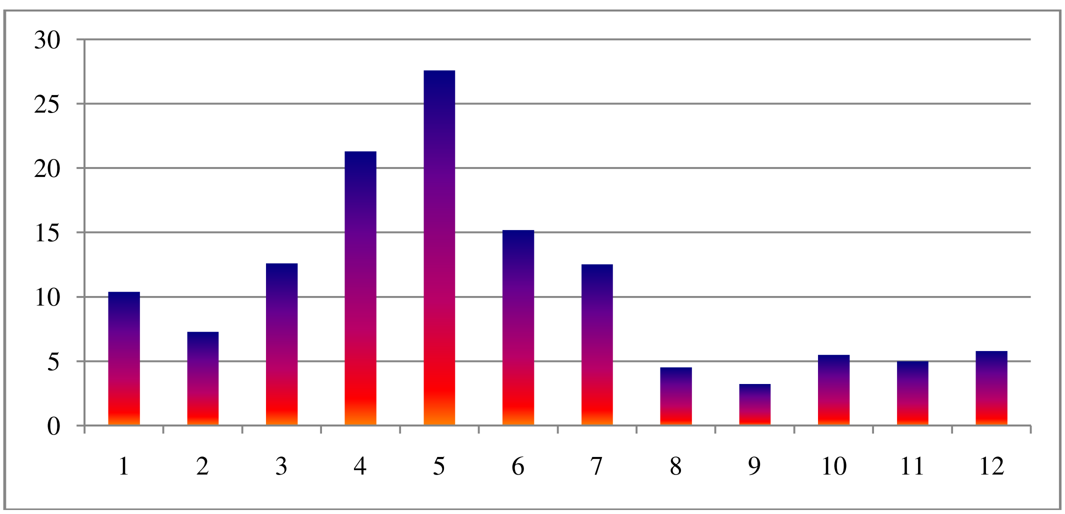

Figure-2
System Average Interruption Duration in Zahedan City

Concepts of normalization and weighted average were used for extracting priorities from table-4.

Table-5
Normalized matrix

Index	I1	I2	I3	I4	I5	Final weight of indexes (mean line)
I2	0.112	0.115	0.111	0.117	0.125	0.116

Hence, table-6 indicates index prioritization matrix based on the obtained results.

Table-6
Final prioritization matrix considering respective criteria using AHP method

Index	Weight of criteria (mean line)
SAIDI	0.116

Aim 3: To answer this question, CAIDI index was used. According to the data in Zahedan Distribution Network, frequency and duration of monthly power failure in the feeder follow an identical trend, thus CAIDI index, which represents power failure duration per fault, would follow a similar trend. Overall, there is similar behavior for feeder in the year's months and power failure duration per faultincreases in hot months. According to this index, there is higher feeder reliability in February and May, whereas there is lower reliability for feeder in September.

If Consumer Average Interruption Duration is considered as a triangular fuzzy number, membership function of this index can be defined as follows:

$$\mathrm{CAIDI} = \begin{cases} 9.89x + 44.56 & \text{if } x \leq 6 \\ -6.03x + 85.1 & \text{if} x > 6 \end{cases}$$

Where, x is the year months. Calculations are done as follows:

Table-7
Initial matrix of pairwise comparison of indexes after integrating data

Index	I1 (SAIFI)	I2 (SAIDI)	I3 (CAIDI)	I4 (ASAI)	I5 (AENS)
I3	1.22	2.9	1	1.78	2.87

Concepts of normalization and weighted average were used for extracting priorities from above table. Considering above relation, normalized values of the table-7 are shown in table-8.

Table-8
Normalized matrix

Index	I1	I2	I3	I4	I5	Final weight of indexes (mean line)
I3	0.318	0.334	0.326	0.332	0.323	0.326

Hence, following table indicates index prioritization matrix based on the obtained results.

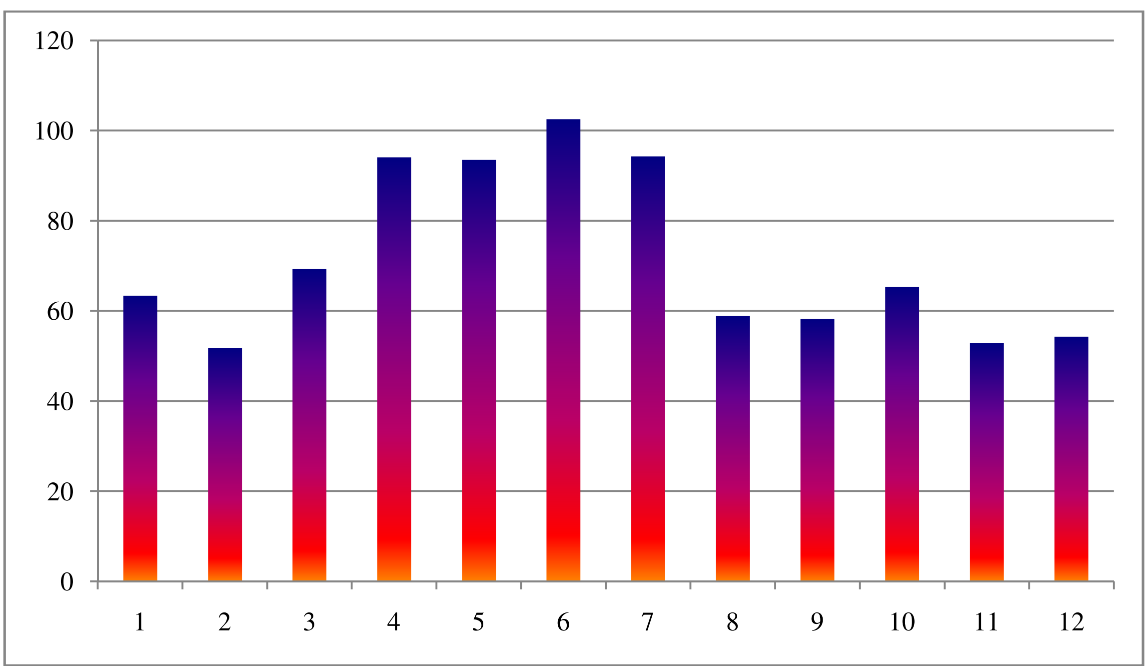

Figure-3
Consumer Average Interruption Duration in Zahedan City

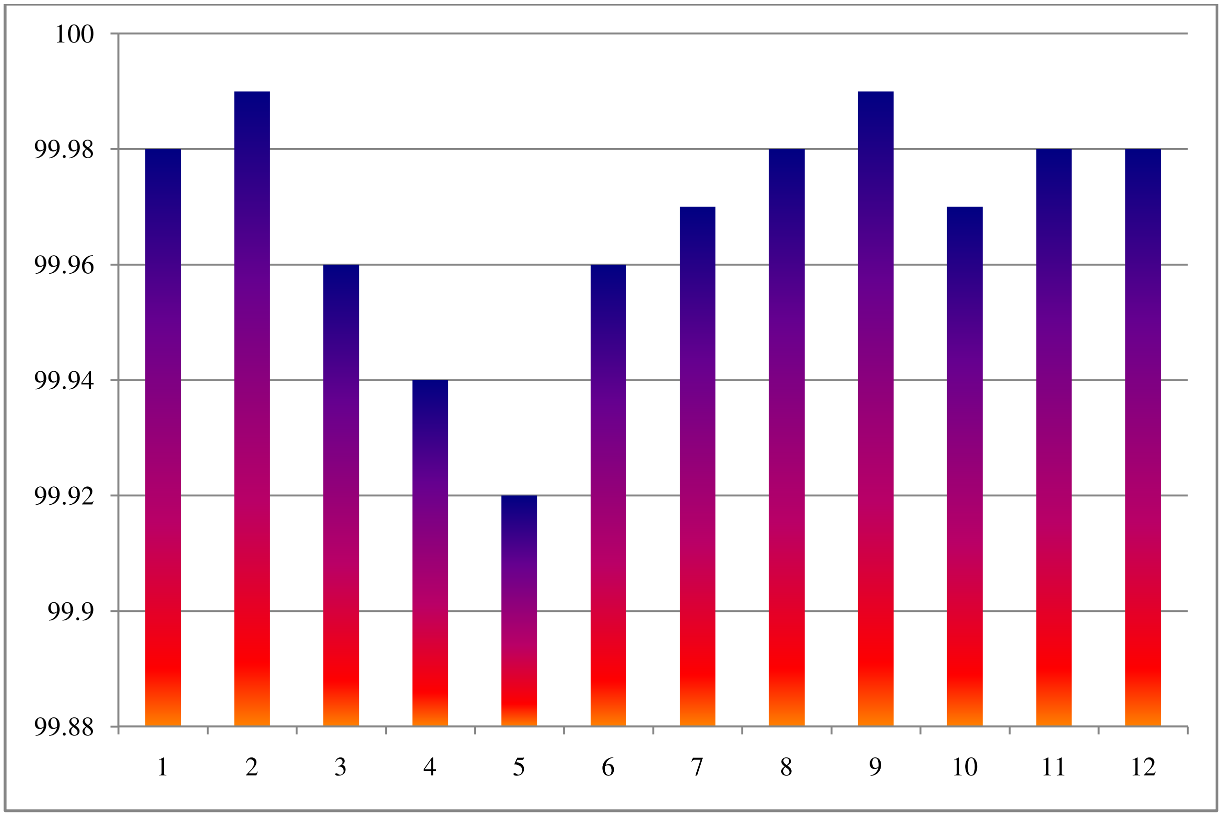

Figure-4
Average Service Availability in Zahedan City

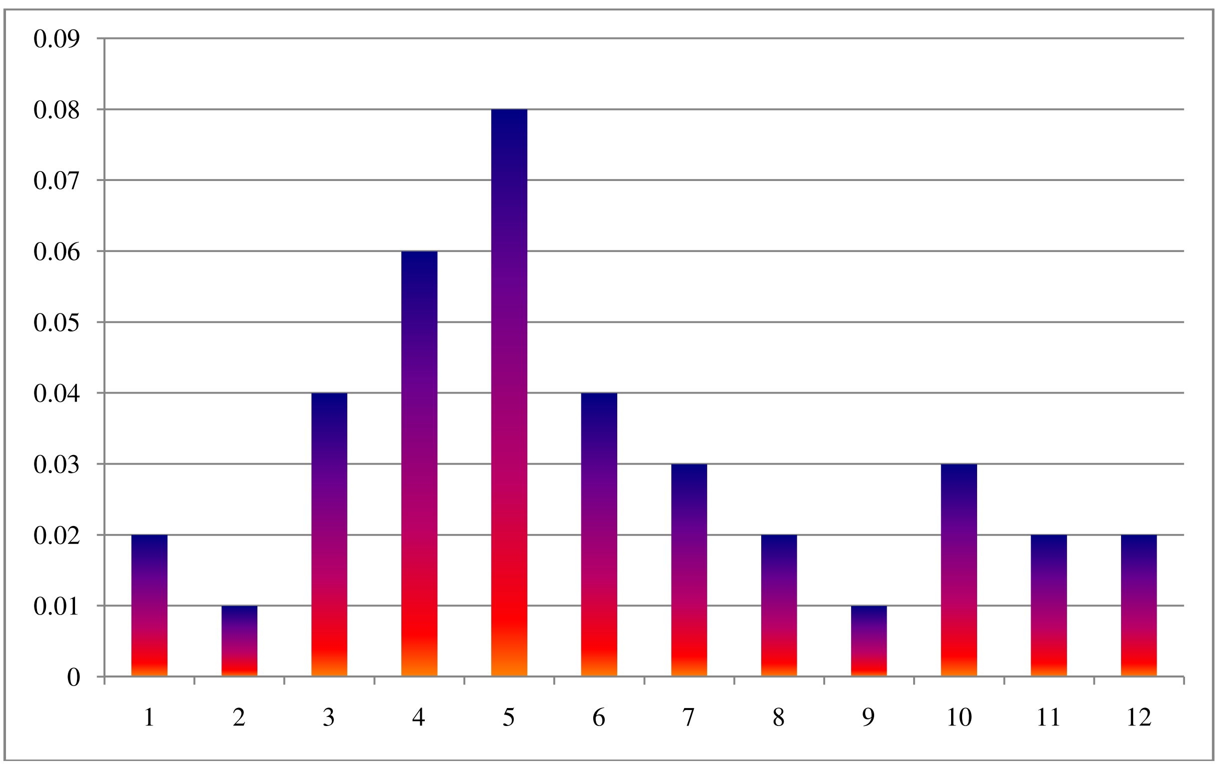

Figure-5
Average Service Unavailability in Zahedan City

Table-9
Final prioritization matrix considering respective criteria using AHP method

Index	weight of criteria (mean line)
CAIDI	0.326

Aim 4: ASAI and ASUI indexes are used to answer this question.

ASUI index presents SAIDI index data as percentage. It is clear from similar diagrams of both indexes. ASAU index presents service availability for consumers as percentage. The network consumers had better service access and reliability in cold months of the year. According to this index, there was higher feeder reliability in May and December, while lower feeder reliability was observed in August.

If Average Service Unavailability is considered as a triangular fuzzy number, membership function of this index can be defined as follows:

$$\text{ASAI} = \begin{cases} 0.017x - 0.009 & \text{if } x \leq 5 \\ -0.0025x + 0.034 & \text{if} x > 5 \end{cases}$$

Where: x is the year months. Calculations are done as follows:

Table-10
Initial matrix of pair wise comparison of indexes after integrating data

Index	I1 (SAIFI)	I2 (SAIDI)	I3 (CAIDI)	I4 (ASAI)	I5 (AENS)
I4	0.74	1.59	0.56	1	1.67

Concepts of normalization and weighted average were used for extracting priorities from above table. To this end, the table values are normalized using the relation below:

Normalized values of the table-10 are shown in table-11.

Table-11
Normalized matrix

Index	I1	I2	I3	I4	I5	Final weight of indexes (mean line)
I4	0.193	0.183	0.182	0.186	0.188	0.186

Hence, following table indicates index prioritization matrix based on the obtained results.

Table-12
Final prioritization matrix considering respective criteria using AHP method

Index	Weight of criteria (mean line)
ASAI	0.186

Aim 5: ENS and AENS indexes were used to answer this question.

ENS (energy not supplied index) index increased considerably during June to October for the network. Investigation of AENS index indicates that although unsupplied energy for the whole subscribers in the feeder is much higher especially in hot months of the year, due to higher number of feeder subscribers, amount of unsupplied energy to each subscriber of the feeder is low in all months of the year. According to this index, there is higher feeder reliability in November, while there is lower feeder reliability in July.

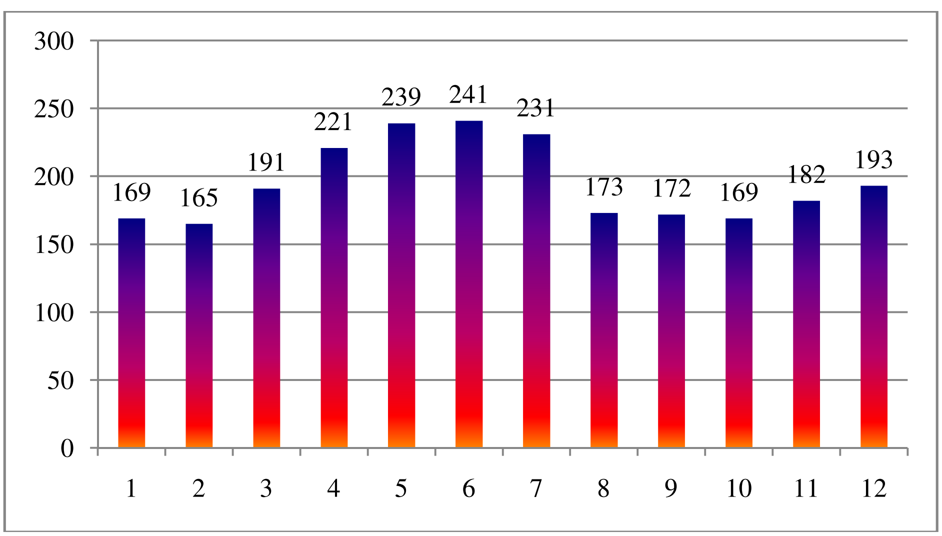

Figure-6
Monthly feeder peak load in Zahedan City

If feeder peak load is considered as a triangular fuzzy number, membership function of this index can be defined as follows:

$$\text{AENS} = \begin{cases} 17.486x + 143.13 & \text{if } x \leq 6 \\ -4.743x + 203.27 & \text{if} x > 6 \end{cases}$$

Where, x is the year months. Calculations are done as follows:

Table-13
Initial matrix of pairwise comparison of indexes after integrating data

Index	I1(SAIFI)	I2 (SAIDI)	I3 (CAIDI)	I4 (ASAI)	I5 (AENS)
I5	0.45	0.89	0.35	0.6	1

Concepts of normalization and weighted average were used for extracting priorities from above table. The normalized values of the table-12 are shown in table-14.

Table-14
Normalized matrix

Index	I1	I2	I3	I4	I5	Final weight of indexes (mean line)
I5	0.117	0.103	0.114	0.112	0.112	0.111

Hence, following table indicates index prioritization matrix based on the obtained results.

Table-15
Final prioritization matrix considering respective criteria using AHP method

Index	Weight of criteria (mean line)
AENS	0.111

Prioritizing 5 indexes for evaluating Zahedan Electrical Distribution Network reliability using AHP model: As mentioned earlier, two indexes, SAIDI and ASUI represent the same concept among 7 reliability evaluation indexes based on IEEE Standard. Also, AENS and ENS indexes represents the same concept. Thus, in fact 5 indexes were given to the experts for prioritization.

Considering there are 20 different matrix for comparison of indexes, hence AHP firstly transforms the matrixes to one single matrix. One of the best methods for combining pair wise comparison tables of all respondents is using geometric mean, because pairwise comparisons create data in the form of ratios. In addition to inverse pairwise comparisons matrix, this method is justified, since geometric mean preserves this property in pairwise comparisons matrix. If it is assumed that aij(k) component denotes the K^{th} respondents for comparing criterion I versus criterion j, then geometric mean is calculated for corresponding components using following relation:

$$\bar{a}_{ij} = \left(\prod_{k=1}^{n} a_{ij}^{k}\right)^{1/n}$$

Using above matrix, comparison of criteria would be as follows in terms of the group:

Table-16
Initial matrix of pairwise comparison of indexes after integrating data

Index	I1 (SAIFI)	I2 (SAIDI)	I3 (CAIDI)	I4 (ASAI)	I5 (AENS)
I1	1	2.3	0.82	1.35	2.23
I2	0.43	1	0.34	0.63	1.12
I3	1.22	2.9	1	1.78	2.87
I4	0.74	1.59	0.56	1	1.67
I5	0.45	0.89	0.35	0.6	1
Sum	3.84	8.68	3.07	5.36	8.89

Concepts of normalization and weighted average were used for extracting priorities from above table.

The normalized values of the table-16 are shown in table-17. Weighted average is calculated following data normalization. Values obtained from weighted average shows priority of each option.

Table-17
Normalized matrix

Index	I1	I2	I3	I4	I5	Final weight of indexes (mean line)
I1	0.260	0.264	0.267	0.252	0.262	0.261
I2	0.112	0.115	0.111	0.117	0.125	0.116
I3	0.318	0.334	0.326	0.332	0.323	0.326
I4	0.193	0.183	0.182	0.186	0.188	0.186
I5	0.117	0.103	0.114	0.112	0.112	0.111

Hence, following table indicates index prioritization matrix based on the obtained results.

Therefore, according to AHP, prioritization of the reliability evaluation indexes by this method is as follows: Consumer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), Average Service

Availability Index (ASAI), System Average Interruption Duration Index (SAIDI), Average Energy Not Supplied (AENS)

$$C.R = \frac{C.I}{R.I} = \frac{0.0025}{1.02} = 0.0024$$

Considering that calculated compatibility index is much less than 0.1, it can be said group pairwise comparisons in matrix in Table-18 has acceptable compatibility and the model is perfectly significant.

Table-18
Final prioritization matrix considering respective criteria using AHP method

Index	**weight of criteria (mean line)**
CAIDI	0.326
SAIFI	0.261
ASAI	0.186
SAIDI	0.116
AENS	0.111

Conclusion

Reviewing and monitoring factors affecting electricity customer interruption (industrial, commercial, agricultural and domestic) and fixing them as soon as possible are the most serious duty of the electric power distribution companies so that power failure is reduced. The faults occurring in distribution networks and transfer and distribution lines cause harmful events and occurrences and subsequently, severe damage and in some cases it cause irreparable damage to the network and subscriber equipment. Network reliability can be increased to global standard level by investigating factors of fault occurrence in power networks, identifying necessary measures and fixing faults in the network.

On the other hand, optimal network utilization is increased via identifying weakness points of the distribution network and improving them, and thus it helps reliability indexes improvement. In addition, equipment installation and proper performance of the preventive repair and maintenance groups can be improved by enhancing reliability indexes. Of course, regarding preventive maintenance (PM) always there is this problem that PM plan cannot be implemented effectively for some equipment.

Followings are some achievements of this plan:

Collection and analysis of outage and undistributed energy in all feeders in Zahedan City and reaching to its reduction strategies. Evaluating reliability calculating reliability indexes according to IEC international index in Zahedan City.

One of the useful findings of this activity is gaining logical and financial understanding about medium voltage network in Zahedan City, based on which it is possible to find the best combination for complement ring lines, maneuvering areas, and appropriate places for the switches so that the most effective measures are taken for reduction of power failure and outage.

Recommendations: Low reliability distribution network suffer from large number of outage and power interruption which finally results in undistributed or unsold energy. It has an ascending trend which would impose significant losses on power network and distribution companies. The other consequence is wasting human resources for fixing outages, thus less time is dedicated to customer services and there is less time left for equipment service so that this time is reduced to zero in some cities of the province.

It is suggested reliability of the posts is calculated and analyzed based on modeling all its important elements such as shin parts, switches and transformations. In addition, performance of the posts should be evaluated quantitatively for developing and designing the system. Various combinations and arrangements can be considered for the distribution networks and post and minimize the design costs (network rearrangement).

Collecting accurate data of reliability indexes can be done as follows:

Posts indexes: probability and output frequency – minimum availability - Expected output cost. System indexes: system probability and output frequency through the post output. Optional indexes: power and energy expected to interruption, output cost. Calculating average MW of interruption in the whole power network (transfer, super-distribution and distribution) of Sistan and Baluchestan Province in 2013 for optimal planning ad utilization of distribution network in the future.

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