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Introduction of Configurational Indicators for Distribution Network Optimality Based on a Zoning Methodology

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ABSTRACT: The configuration of electrical distribution network may alter upon the changes in the load density and the load distribution in the region. Regional climatic conditions affect the rating of the components in the distribution network. Therefore, they have some influences on the network configuration as well. These two affecting factors (electrical load and climate) are not directed by the system operator or designer. Hence, it is pleasurable to find an appropriate network plan to satisfy the load requirements as well as the climate undesirable influences in real operating conditions. This paper is aimed to find some quantitative relevancies between the network configuration and the affecting parameters (i.e. climatic conditions, load density, load profile and loss factor) to achieve this goal. It has tried to define some factors to quantify the network configuration in order to simplify judgement about the design quality of the network. This means that these factors can be used as quantitative benchmarks that help network planner to understand which parts of the existing network are not in accordance with the optimal configuration. This study is conducted through statistical analysis on real data attained from several networks in different climatic conditions and different load situations. The idea is examined via performing the network design optimizations on 35 scenarios for the networks located in 5 different areas. Results are presented in tables and figures that are informative and practical for the network engineers to design and operate the distribution system in different loading conditions and climatic situations.

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1- INTRODUCTION

The problem of finding a proper configuration for a specific distribution system is a combinatorial problem due to the time-variant parameters. Characteristics of electrical load across the network area such as load density, load growth, daily load profile and power factor are important parameters that perform the best possible way for serving the network connected consumers. Adding other factors like climatic condition, network type (underground or overhead), price of energy and equipment, operational cost (due to repair and maintenance process), power/energy loss, and reliability make the problem more complicated.

There are lots of great works in literature offering solutions to access the network optimum configuration being capable to meet one or more goal(s) to overcome this complexity. Goals are achieved by compromising the cost with one or more aforementioned parameter(s). These solutions were attained through different optimization techniques in different problem solving conditions. Generally, the problem of finding the network optimum configuration is raised in two levels. The first is at the distribution network design, which is called 'optimum planning problem'. The second is at the network operation, which is called 'optimum reconfiguration problem'. The way of entering the problem to find the best configuration in these two levels is largely the same. However, there are some differences in problem solving conditions as well as optimization objectives. Nevertheless, the final result of both is quite similar (i.e. the best arrangement of distribution network nodes and branches to serve the electrical customers under the prescribed conditions). The previous works in design level can be categorized in two parts. In the past years, the problem of finding the optimum configuration mainly focused on finding the most economical solution (single objective function), with the optimal location and size (capacity) of future substations and/or feeders to meet the future demand. This part of studies can be called the planning of traditional distribution network. For example, optimization of the cost during the optimal feeder routing and branch conductor sizing is carried out in [1] by using of a dynamic programming algorithm. Another example is [2], in which the authors tried to propose a planning method based on the branch exchange technique. The technique included operational risks for the events with low-probability and high consequences to find an optimum configuration for distribution network. In [3], the topic of environmental effects on distribution network planning is deeply investigated by formulating a multi-dimensional spatial distribution network planning problem based on the raster map in geographic information system.

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Table 1. The arrangement of channels

No. of customer	Total load [MW]	MV line length [km]	LV line length [km]	No. of transformers	Power loss [%]
13768	14.0	15.1	81.0	56	8.6

Simultaneous determination of optimal service areas and capacities of distribution substations was carried out in [4] by introducing a hybrid heuristic and learning automata-based algorithm. In another paper, an exhaustive review of distribution planning works has been provided that presents an interesting classification for different applied methods [5].

In the recent years, finding the optimum distribution network configuration is further complicated due to the high penetration of distributed generation (DG) technologies, storages, and the participation of the consumers in the form of active demand. Majority of works are devoted to these topics, suggesting different solutions to handle the related new issues. This part of the literature can be categorized as planning of active distribution network. In [6], a multistage network expansion planning problem considering DG was solved in a tri-level programming. In the upper level, the DISCO identifies the optimal investment plan in network assets and the best potential locations for DG. In the middle level, the DGENCO determines the best location, sizing, and timing for DG installation, so that the corresponding profit is maximized. Finally, in the lower level, the IDSO is responsible for the optimal operation of the expanded distribution system. In [7], the idea of dynamic network reconfiguration is exploited to affect the integration of DGs. This paper uses the remote-controlled switches as a tool for optimum reconfiguration with the aim of maximum DG accommodation. Another active network planning study was reported in [8]. In this paper, the impact of multiple DG configurations on the potential of active network management (ANM) schemes was investigated. In [9], authors carried out studies that are required for upgrading the radial systems to radial-loop configuration. In this regard, the reliability of the system was the main criterion and two operational parameters, including power loss and voltage profile, were analyzed to achieve the best configuration.

Apart from the literature that exists in the field of distribution network design (optimum plan), there are lots of papers paid attention to finding the best configuration in operation level (optimum reconfiguration). Similar to the first level, the researches in this level can also be categorized in traditional and active network studies as well. They attempted to find the best configuration to achieve different targets in operation. In [10- 12], reconfiguration carried out with two targets of power loss and reliability. In [13], reliability was replaced by voltage profile in objective function and was applied with power loss. Operational cost was added to the two above targets in [14], and conformed a three-objective function for optimal reconfiguration in an active distribution network. In active distribution networks, optimum reconfiguration was also investigated using the same objective function as mentioned for traditional networks [15, 16]. In [17], 4 potential alternatives namely, DG installation, network reconfiguration, distribution feeders' reinforcement, and installation of capacitor banks were employed for power loss reduction goal. In the proposed model, a budget constrain was added to the problem. Some other objectives like distributed generation hosting capacity was also used in other researches [18].

Literature review in the field of distribution network optimum configuration reveals a huge part of efforts accomplished by authors to obtain the exact mathematical-analytical solutions to achieve optimum (re)configuration. However, few attention was paid to introduce essential quantitative indicators that could be accounted as bench marks for network optimum configuration. Authors of this paper tried to study this topic based on the results of an optimization technique that had been reported in [19- 23]. This technique had been frequently used in several real cases and was patented in national intellectual property center [24]. This paper aims to define some quantitative indicators that can be used as analytical criteria for recognition of the parts of the network which are not in an optimum configuration. The task is carried out by solving the optimization problem for 35 scenarios on the networks located in 5 different climatic zones. Results give an overall view of how the affecting parameters (i.e. load and climate condition) can influence the optimum configuration of a distribution network in real situations.

2- PROBLEM STATEMENT

The network depicted in Fig. 1 is a real urban distribution network of a small city named Orzuyeh, located in the southern half of Iran. A brief description of this network is shown in Table 1.

As can be seen in Fig. 1, this network is a large-scale distribution system which extends across the city streets and alleys. This network was designed in the far past, and has expanded during the years.

There are large number of such networks that belong to the past. Hence, their utility owners normally want to know about their cost-effectiveness. New optimization techniques which were suggested in literature, can be used as solutions for this request. Using these methods, it would be possible to optimize the network configuration and its structure according to network-owners' objectives. As mentioned in the introduction, a regular part of the objective function is total cost (TC), which is the sum of the system installation

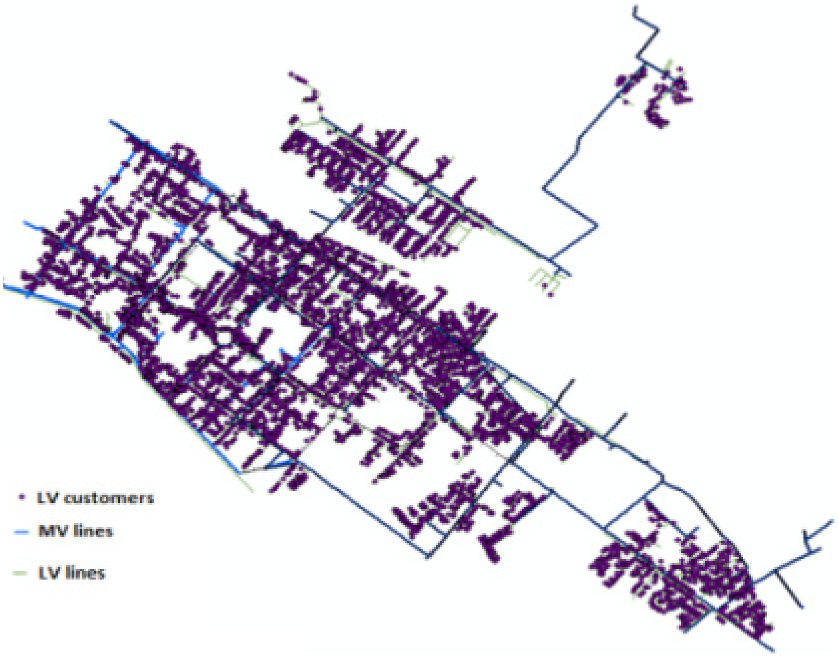

Fig. 1. Overview of Orzuyeh distribution network

(FC) and operational cost (OC).

$$TC = FC + OC \tag{1}$$

System installation (fixed) cost comprises the below items:

$$FC = \sum_{p=1}^{P} SC_p + \sum_{m=1}^{M} MVC_m + \sum_{l=1}^{L} LVC_l \tag{2}$$

Where:
FC: installation cost
SC: cost of substation development
MVC: cost of MV feeder expansion
LVC: cost of LV feeder expansion

System operation cost mainly contains energy loss cost plus the repair and maintenance cost. The repair and maintenance cost is normally a small ratio of the system installation cost (e.g. 1- 2%). Energy loss cost (LC) is formulated as follows:

$$LC = \left(\sum_{j=1}^{J} LL_j + OL \times \sum_{i=1}^{I} \left(NL_i + \alpha_i \times FL_i \right) \right) \times PP \tag{3}$$

Where:
LL: cost of losses in MV and LV feeders
OL: operational lifetime of the network
FL & NL: transformer full load and no-load losses
α_i: loading factor of transformer
PP: price of unit of electrical energy

If the applied optimization technique gives practical responses, the network can be operated in a well-designed state. However, in most cases the optimization algorithms give suggestions that are very difficult to implement in practice; since they usually offer considerable changes, including uninstalling the existing networks that are not admitted by the network customers. Furthermore, there are some other problems in using these algorithms. For example, providing detailed electrical and economic data for these optimization algorithms is a time consuming and costly task. Another problem is the suggested methods in literature that do not usually work effectively for the large-scale networks. Owing to this fact, this paper tries to generate some quantitative indicators which can practically explain the status of the network configuration. In other words, these indicators can declare the deviation of the network parts from their optimum configuration. In the next section, the indicators are described, and the methodology for calculating their values is explained in the following sections.

3- INDICATORS FOR NETWORK STRUCTURE

Optimum configuration of a distribution network should comprise several properties. Some main items are as follows:

- Best route for medium voltage (MV) and low voltage (LV) feeders, while satisfying the technical constrains like voltage drop, conductor ampacity, etc.
- Best location for distribution transformers with the highest utilization factor, while complying the allowed capacity limit.
- Least value for the cost function of the network, including capital expenditure and operational costs.
- Lowest/Highest values for some technical parameters like power loss, reliability indices, etc. (optional).

It is possible to define some indicators that represent the main properties of the optimum configuration. The indicators should include the technical and economical features of the plan. In this study, a large number of indicators were defined at the first step. They were calculated for many scenarios (the details of scenarios are described in the following sections). However, Comparative analysis between the indicators in different scenarios show that it is possible to decrease the number of indicators. In this case, it is possible to summarize all features to some principal indicators:

- LV feeder length per customer (Indicator Number 1): ratio of the total length of the LV feeders to the number of customers.
- LV feeder length to MV feeder length (Ind. No. 2): ratio of total length of LV feeders to total length of MV feeders
- Transformer capacity per customer (Ind. No. 3): ratio of the total capacity of transformers to the number of customers.
- Two most prevalent capacities for transformers (Ind. No. 4): two rated capacities of the transformers that are mostly used in the network.
- Average utilization factor of transformers (Ind. No. 5): ratio of the total electrical load to the total capacity of the transformers.
- Average efficiency of transformers (Ind. No. 6): ratio of the total electrical load (except loss) to the total power served to transformers (load plus loss).
- Average number of LV feeders per transformer (Ind. No. 7): ratio of the total number of LV feeders to the number of transformers.
- Average length of LV feeders for two most prevalent capacities of transformers (Ind. No. 8): ratio of the total length of the LV feeders which are connected to a set of two-prevalent capacities of transformers to the number of members of that set.
- Power loss in network components (Ind. No. 9): ratio of the power loss value in each part (transformers, LV feeders, MV feeders) of the network to the total load (in percent).
- Cost of energizing per customer (Ind. No. 10): ratio of the total distribution network costs including capital expenditures and operational costs, to the total number of customers.

These 10 indicators can provide a quantitative vision from a distribution network. It is more informative when compared with a set of predefined reference values. The reference values are obtained from optimum plans which are prepared for the same network or similar ones. Similar networks are the networks located in the similar environmental conditions with similar loading characteristics. To find similar networks at the first step, it is possible to find zones with a similar climatic condition. Afterwards, the electrical load characteristics are checked in each zone, and if the load characteristics were not similar, further modification should be applied to uniform the loading conditions in every zone. The next section describes the zoning methodology, from the viewpoint of the distribution network, applied for the entire map of Iran.

4- ZONING METHODOLOGY FOR DISTRIBUTION NETWORK

Climatic conditions such as ambient temperature, amount of precipitations, height above sea level, humidity, pollution, wind speed, amount of sunlight, etc. can highly affect the performance of the distribution network equipment. The weather conditions mainly influence transformers, cables/ conductors and switchgears. National and international standards define some classifications for climate conditions that occur in the power systems. For example, climate map of Iran is shown in Fig. 2 [25].

As mentioned before, the climatic condition is not the only influential factor for zoning the distribution networks. It is also affected by another important factor which is the electrical load. Distribution network is the only part of the power system which extends across the city streets and alleys. Therefore, its configuration depends on the load distribution along the network area. Hence, it is possible to say that the network configuration depends not only on the quality of planning, but also on the electrical load characteristic. In order to relate the economic-technical indicators to the quality of the network planning, the indicators are calculated inside the zones with almost the same load and climatic conditions. Two load-related parameters which denote the load compression within the area and its time-related pattern, are calculated in Table 2 for different climate classifications of Iran. In table 2, μ and σ are the average value and standard deviation of the load densities for the provinces belong to a specific class of the climate map. As can be found from Table 2, load density has wide range values related to climate condition. However, the load factor diversity is not as high as the load density. In order to homogenize the load densities more within a certain climate class, it is required to replace some provinces between the adjacent similar climate classes.

The following interval is considered as confidence interval (equivalent to confidential probability of about 70%) for the load density values in each climate class:

$$\mu-\sigma < density < \mu+\sigma \qquad (1)$$

Based on (1), the climate affiliation of each province is double checked through its load density value. The resultant changes in the climate classifications are brought at the last column of Table 2. According to these changes, the modified map of climate/load classifications in Iran is shown in Fig. 3. As can be seen in Fig. 3, there are 5 climate/load classes. Studying the quality of distribution network configuration using economic-technical indicators is more meaningful at any individual zone.

5- SCENARIOS FOR PLANNING PARAMETERS

Electrical load, as the most important affecting parameter, is normally presented by three features: peak magnitude, daily variation profile and power factor. In general, the peak

Table 2. Electrical load parameters in residential areas of Iran

Province	Load density (*den*) [W/m^2]	Load factor	Climate classification (Fig. 2)	Revised class
Boushehr	2.16	0.66	Hot & humid (load density: μ=2.59, σ=1.59)	-
Khouzestan	4.35	0.45		-
Hormozgan	1.26	0.52		-
Guilan	1.72	0.50	Mild & humid (load density: μ=1.87, σ=0.36)	-
Mazandaran	2.28	0.41		-
Golestan	1.61	0.49		-
Kerman	0.59	0.72	Hot & dry (load density: μ=1.14, σ=0.56)	-
Semnan	1.60	0.82		-
Yazd	0.56	0.71		-
Isfahan	0.99	0.76		-
Qom	1.55	0.67		-
Fars	0.71	0.78		-
Sistan	1.95	0.62		Hot & humid
Eastern- Azarbayjan	0.32	0.63	Cold (load density: μ=0.60, σ=0.44)	-
Western-Azarbayjan	0.7	0.72		-
Ardabil	0.31	0.63		-
Zanjan	0.34	0.58		-
Qazvin	1.33	0.69		Mild & dry
Southern- Khorasan	0.35	0.80	Mild & dry (load density: μ=0.81, σ=0.38)	Hot & dry
Lorestan	0.36	0.59		-
Khorasan-Razavi	1.43	0.71		Hot & dry
Tehran	5.67	0.66		-
Markazi	0.85	0.75		-
Hamedan	0.61	0.72		-
Kermanshah	1.05	0.60		-
Kordestan	0.71	0.69		-
Ilam	1.11	0.52		-

magnitude of the loads inside a certain area corresponds to its density in that area. In addition, daily load profiles are also represented by their load factor. The range of changes in these two quantities and their dependence on the climatic conditions was illustrated in the previous section. The third feature, namely power factor, has an almost simple behavior. It mainly depends on the type of the load and does not have crucial dependency on the climate/load –related map. Table 3 shows the range of the power factor changes for three major categories of the loads. The climate condition has two main effects as another affecting parameter. The first is embedded in the load features, as was discussed in the previous sections.

The second affecting property appears in the loading level of the equipment. The equipment located in different climatic zones can be utilized to certain levels of loading, depending on the climatic conditions. Thus, derating factors of the equipment vary from point to point according to the climatic situation. These factors are calculated for each climatic zone and are considered in planning.

At the final step, all possible values across a certain zone (Table 2) should be considered in planning calculations. In this way, lots of load density and load factor permutations exist, which each pair needs an individual planning calculation. It is obvious that performing the planning tasks for the entire state space is not reasonable due to the time-consuming and big-data processes. To avoid this, scenario-based analysis is an efficient tool to provide a judgement about the structural changes in the network configuration. In this approach, the parameters change in their possible intervals and in definite steps. Thus, each scenario is a representative of a most practical state in which some of the parameters are in their extremes and some others take their averages. In this case, Table 4 is arranged to cover the practical variations in the load parameters across a certain zone (climate class).

There are some notes that should be revealed about Table 4:

- This set of scenarios (7 numbers) devote only to one climate class. In other words, the total number of scenarios is

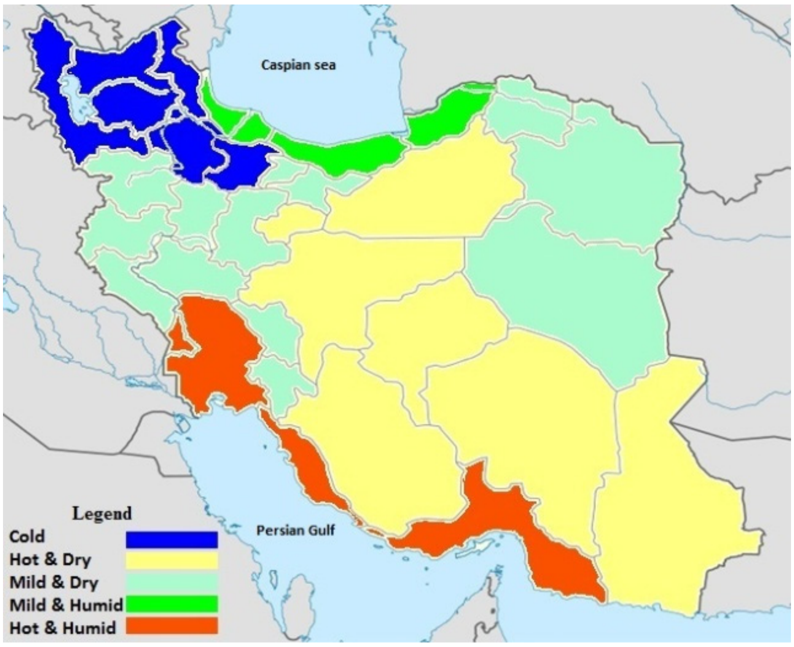

Fig. 2.Climate map of Iran

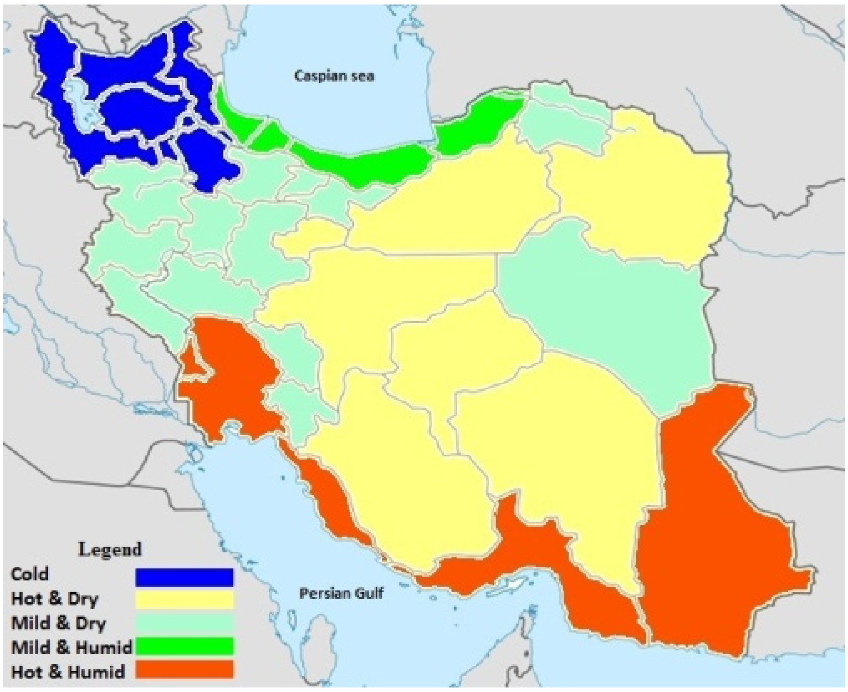

Fig. 3. Modified climatic map of Iran due to load-density classifications

equal to 7*number of climate classes. In this study, the total number of scenarios is equal to 35 (7*5). If there were more than one type of load (e.g. rural or industrial, the number of scenarios), it would also be multiplied by the number of load types.

- In theory, the total number of scenarios for each climate class should be more than 7 because there are 3 parameters that could have 27 permutations (3*3*3). Since there is no major dependency between load density and load/loss factors (Table 2), load density changes are applied independently from the load/loss factors. Scenarios No. 1 to 3 devote to load density variation when the load/loss factors have their average values. In contrast, scenarios No. 4 to 6 belongs to load/loss factor changes when the load density has the average value. Comparisons between the real data and the selected scenarios in table 4 shows a good compliance between them.

Table 3. Power factor ranges for different types of the load

Customer type	Power factor
residential	0.95 - 1
agriculture	0.9 – 0.95
industrial	0.8 – 0.9

Table 4. Definition of scenarios in each climatic condition

Parameters	Scenarios						
	1	2	3	4	5	6	7
Load density	Average	Minimum	Maximum	Average	Average	Average	Average
Load factor	Average	Average	Average	Minimum	Maximum	Average	Average
Loss factor	Average	Average	Average	Minimum	Maximum	Minimum	Maximum

Table 5. Affecting parameters for hot & humid climate class

Parameters	Scenarios						
	1	2	3	4	5	6	7
Residential load density [W/m^2]	2.43	1.26	4.35	2.43	2.43	2.43	2.43
Load factor	0.56	0.56	0.56	0.45	0.66	0.56	0.56
Loss factor	0.39	0.39	0.39	0.23	0.53	0.23	0.53

6- PLANNING PROCESS FOR SCENARIO-BASED NETWORKS

In this paper, distribution network study accomplishes under certain conditions as mentioned below:

- Since a huge part of the distribution system in Iran is the overhead type, plans and results are related to the overhead networks.
- Urban areas (residential) are only included in studies.
- Case studies are traditional networks (without DG).
- Complementary economic\technical data are reported in appendix.

In order to provide the optimal plans for the network scenarios, it is required to provide real data for. For example, Table 5 shows the values of the affecting parameters for the scenarios of hot & humid climate condition (based on Table 2). Four further tables like Table 5 have been conformed for other scenarios.

In order to achieve the results that are close to reality in each climatic class, the real network of a city belonging to the climate class was used to implement the scenarios relating to that class. For example, the network of Fig. 1 was used for the scenarios of hot & dry climate class. Based on this, the planning process was run by the optimization tool [19-24] for every scenario. Afterwards, comprehensive statistical analysis were carried out to study the changes of technical-economic indicators defined in section 3. Tables and graphs are reported in the next section.

7- RESULTS AND DISCUSSION

After achieving the optimum plan for every scenario, all the ten technical-economic indicators are calculated for any individual plan. In Fig. 4, the flowchart of all stages, from beginning to end, is shown. This flowchart depicts how the network indicators are calculated in the networks with specific climate conditions and their special load characteristics.

In the following, the range of changes of indicators that are extracted from optimal plans are reported in Tables and Figures. First, the values of indicators for hot & dry climate class are mentioned with details in Table 6.

Indicator No. 1 in Table 6 means that to electrify any individual customer in hot & dry area, a 19.2 m – 21 m low voltage feeder is required. Indicator No. 2 means that the length of low voltage feeders in this area is around 2.2 – 2.5 times the length of the medium voltage feeders. Results of indicator No. 3 show that the capacity of transformer per customer strongly depend on the load density and other factors do not have quite influence. Indicator No. 4 expresses that two most prevalent capacities in all load densities and load/loss factors in hot & dry area are 50 and 100 kVA

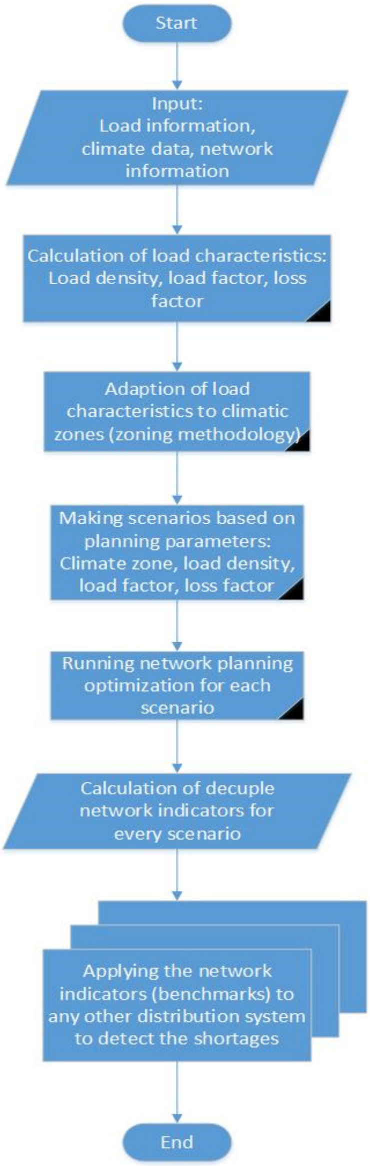

Fig. 4. Flowchart of network indicators for configuration optimality

Table 6. Values of indicators for hot & dry scenarios

Indicator number	Unit		Scenario						
			1	2	3	4	5	6	7
1	[m]		21	20.2	19.2	19.5	21	21	21
2	-		2.5	2.2	2.2	2.3	2.5	2.5	2.5
3	[kVA/Customer]		4.42	1.93	6.77	4.16	4.42	4.42	4.28
4	[kVA]		50, 100	50, 100	50, 100	50, 100	50, 100	50, 100	50, 100
5	-		0.50	0.44	0.58	0.53	0.50	0.50	0.52
6	[%]		98.03	97.93	98.25	98.02	98.02	98.02	97.98
7	-		1.86	1.72	1.74	1.91	1.89	1.89	1.88
8	[m]	50 kVA	118.9	285.8	69.8	105.7	119.2	118.6	118.6
		100 kVA	267.8	546.2	149.2	274.9	262.7	259.3	269.1
9	[%]	Transformers	2.17	2.17	1.79	2.03	2.17	2.17	2.22
		LV network	2.00	2.02	2.30	2.06	1.99	1.99	1.99
		MV network	0.20	0.42	0.23	0.15	0.20	0.17	0.20
10	[US $]		1053.1	380.6	1382.0	927.7	1121.6	1054.2	1056.2

transformers. Analysis of indicator No. 5 are interesting. In the first three scenarios, the value of this indicator is under the effect of load density. In scenario 4, the load density is similar to scenario 1 but the load factor has its minimum value. This means that the duration of the peak period is very small. Hence, it is cost beneficial if the same load is served by smaller transformers comparing to scenario 1 (indicator No. 3 also confirms this hypothesis). Therefore, the value of utilization factor increases in this scenario. In scenario 7, the value of utilization factor also increases because the loss factor takes its maximum value, which means that the loss acts as an increased load. The efficiency of transformers does not have considerable variation due to the affecting parameters in different scenarios. Indicator No. 7 tells that most of the transformers serve 2 or only 1 LV feeder. It seems normal because the most prevalent capacities are 50 and 100 kVA. The average length of the LV feeders in indicator No. 8 mainly depends on the load density, whereas in the scenarios with maximum load density, the feeder lengths decreases and vice versa. Changes in the percentile of the power loss in the network components depicts by indicator No. 9, and its analysis is also interesting. As can be seen in Table 6, the level of MV network losses in scenario 2 is double times more than the corresponding value in scenario 1. The reason lies in the network structure with minimum load density, because when the load density decreases, the geographical dispersion of transformers enhances and the length of MV network increases. In scenario 3, the level of LV network losses increase which is normal, because the LV feeders are more resistive and any increase in the current carrying value leads to more losses. However, in this scenario, the level of the transformer losses decreases. It cannot be concluded that the absolute value of transformer losses decreases, but it means that the share of transformer losses in total loss of the network decreases. It is due to this fact that transformers are operating in higher efficiency level. Of course, the optimization process tries to keep the cost of losses in an acceptable level comparing to other costs existing in the objective function (e.g. installation cost, repair and maintenance cost, outage cost, etc.). It is noteworthy that the total loss (sum of transformers, LV and MV network) of the network in all scenarios are very close to each other. Judging indicator No. 10, it is required to mention that the number of customers (load nodes) in different scenarios is almost the same. Therefore, when the load density increases in some scenarios, the load magnitude of the customers increases. Based on this, scenario 2 has small loads, and less price is required for their electrification. In addition, when the load factor increases, it is beneficial to use equipment with higher capacities which yields higher cost per customer and vice versa

Similar tables like Table 6 were provided for all of the climate classes and are summarized in Table 7 and graphs, as depicted in Figs. 5 to 12.

Table 7. Two most prevalent capacities in different scenarios and climatic conditions and their average length of LV feeders

	Climate											
	Cold		Hot & Dry		Mild & Dry		Mild & Humid			Hot & Humid		
Capacities [kVA] (Indicator Number 4)	50	100	50	100	50	100	50	100	200	100	200	315
Average length of LV feeders [m] (Indicator Number 8)	229.2 to 459.7	485.5 to 948.8	69.8 to 285.8	149.2 to 546.2	343.6 to 692.1	557.6 to 922.7	74.3 to 157.5	223.2 to 256.9	270.2 to 419.5	66.8 to 96.0	101.6 to 208.8	160.7 to 279.2

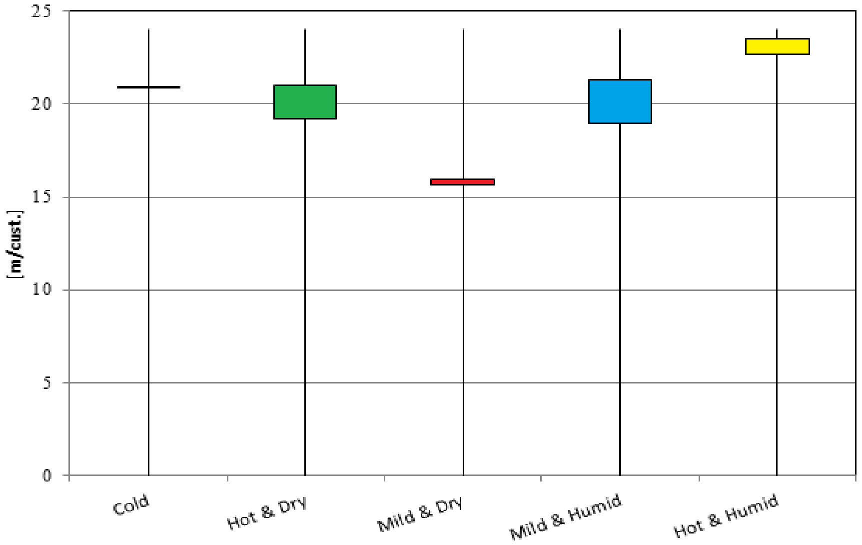

Fig. 5. LV feeder length per customer in different scenarios and climatic conditions (Indicator No. 1)

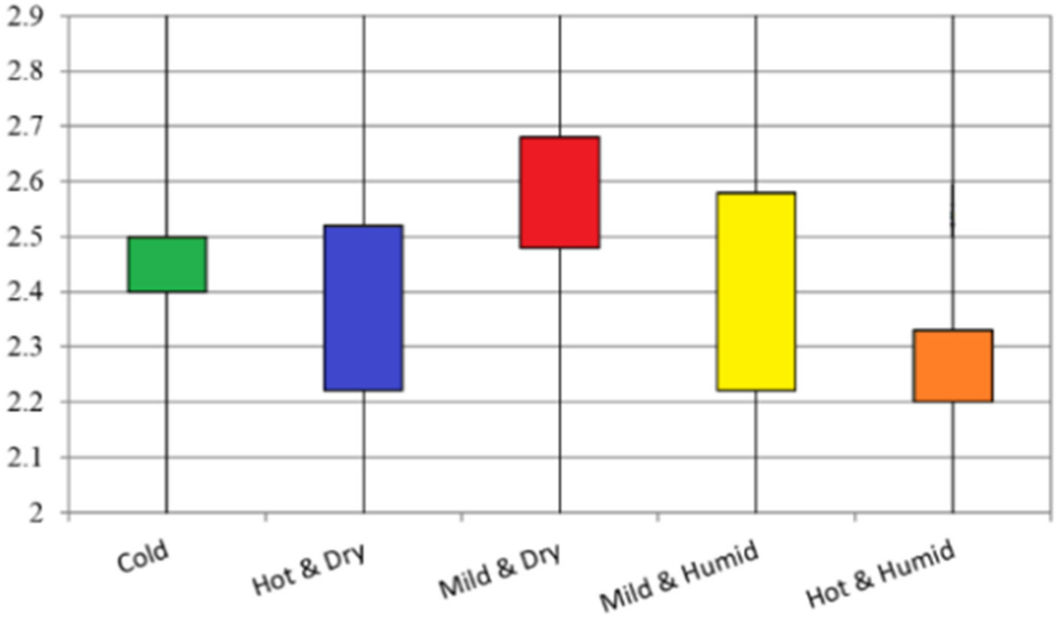

Fig. 6. LV feeder length to MV feeder length in different scenarios and climatic conditions (Indicator No 2)

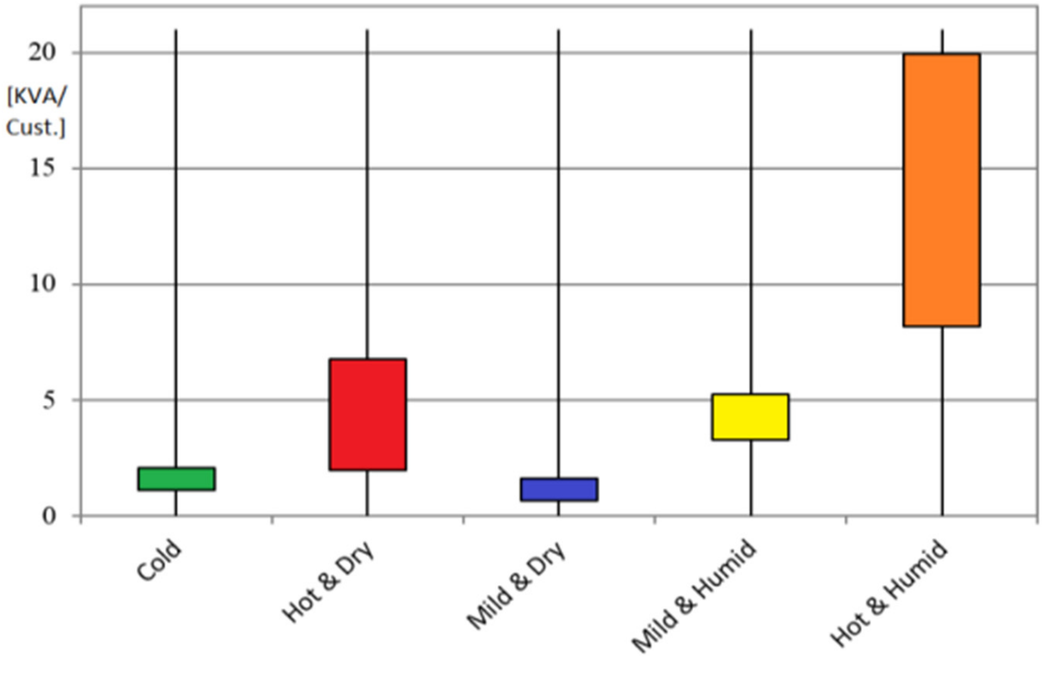

Fig. 7. Transformer capacity per customer in different scenarios and climatic conditions (Indicator No. 3)

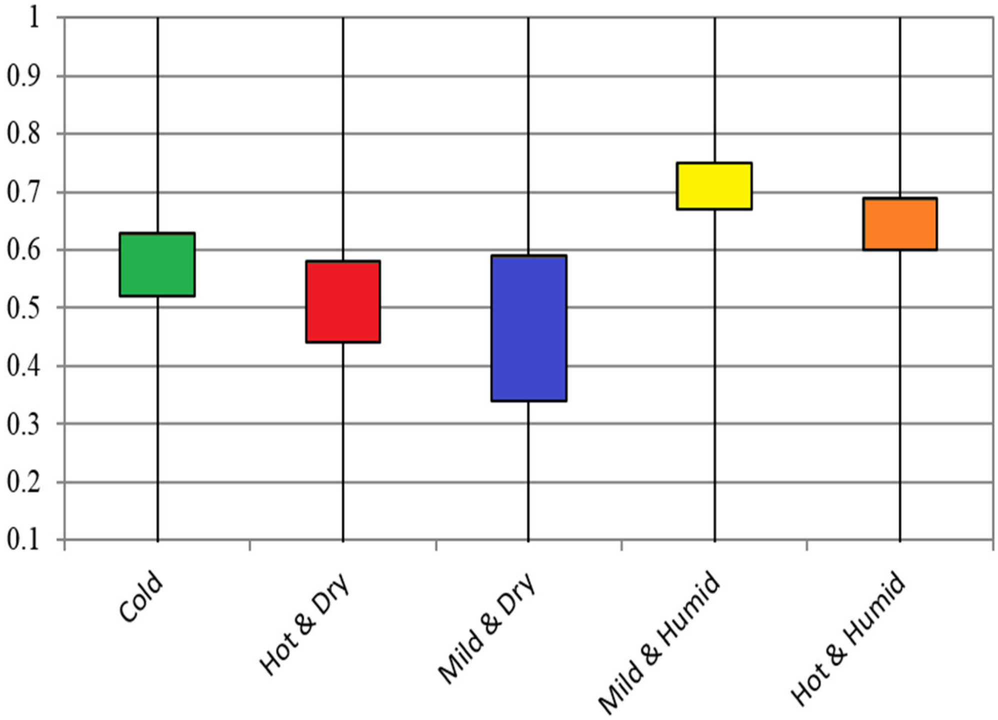

Fig. 8. Average utilization factor of transformers in different scenarios and climatic conditions (Indicator No 5)

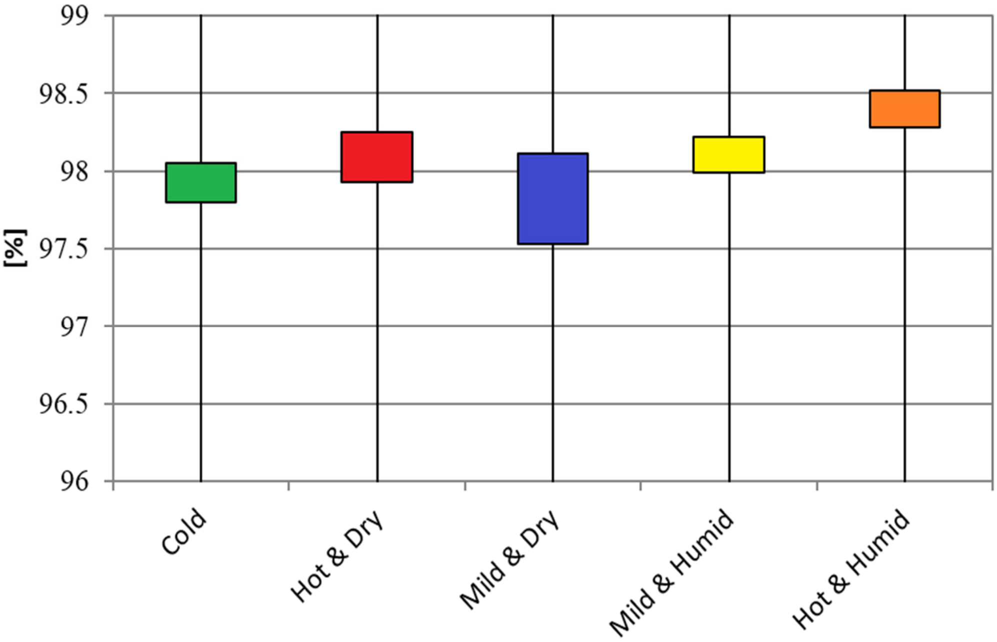

Fig. 9. Average efficiency of transformers in different scenarios and climatic conditions (Indicator No. 6)

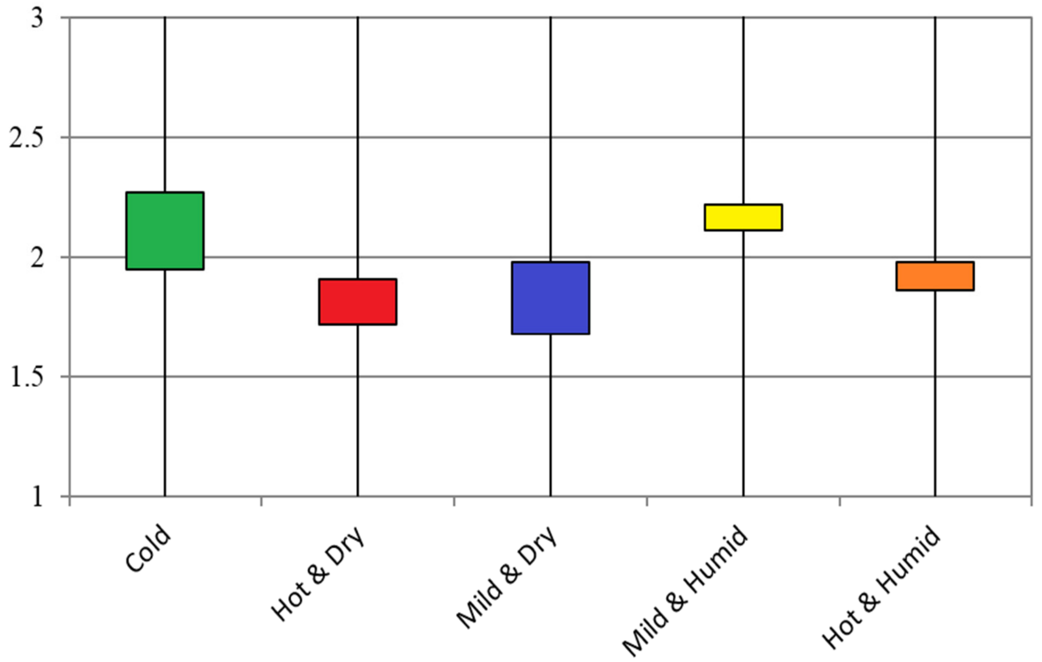

Fig. 10. Average number of LV feeders per transformer in different scenarios and climate condition (Indicator 7)

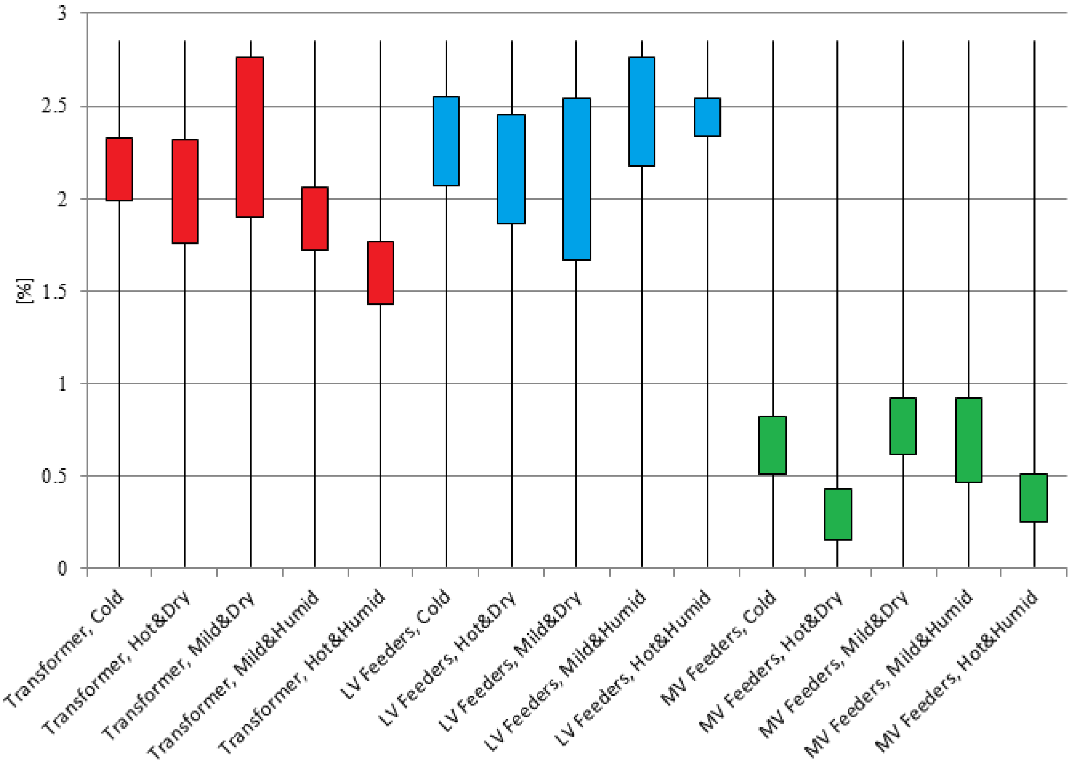

Fig. 11. Power loss in network components in different scenarios and climatic conditions (Indicator No. 9)

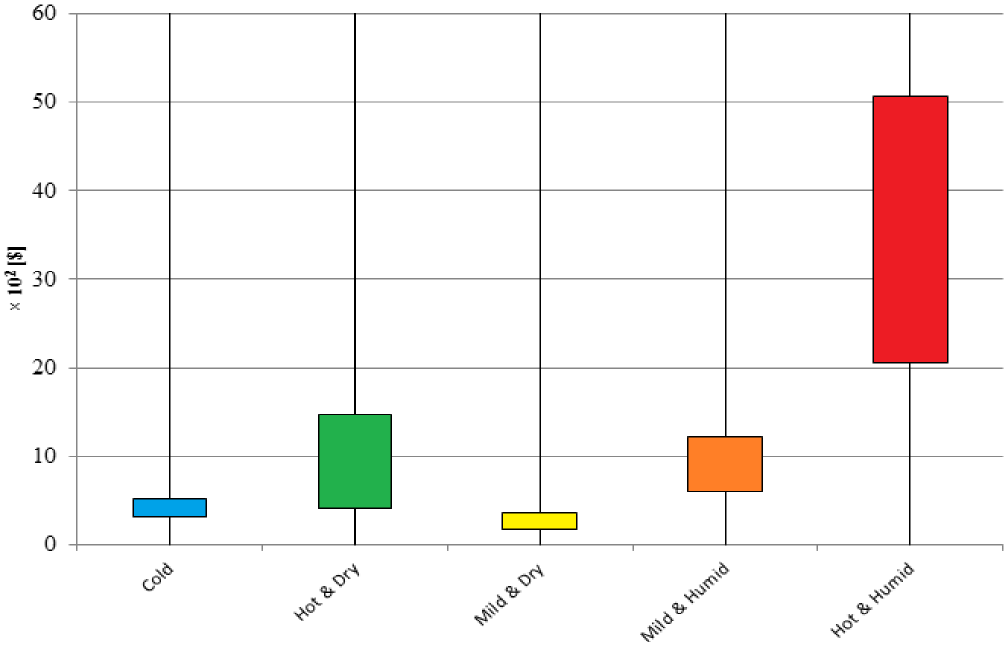

Fig. 12. Cost of energizing per customer in different scenarios and climatic conditions (Indicator No 10)

Using these summarized results, it is possible to provide better judgement about the quality of an already existing network configuration. It is possible to make a better decision through comparing the values of its current indicators with their counterparts as reported in Table 7 and Figs. 5 to 12.

More precise attention to these figures and table gives some more interesting findings. A brief description of the main items is as follows. Fig. 5 shows the required LV feeder length per customer is almost independent from the load and climate conditions, and is almost the same for all electrical networks.

Another fact is that Mild &Dry climatic class is the best condition for electrical distribution network where almost all of the indicators have their extreme values in good direction. On the other hand, humid conditions (mostly in Hot &Humid) provide the worst cases. Fig. 6 shows that the ratio of LV feeder length to MV feeder length is limited between 2 and 3 in all scenarios and conditions. Fig. 7 says that the required transformer capacity in all load characteristics and all climatic conditions is less than 5 kVA for each customer, except in hot areas. It can exceed this bound in hot areas and takes higher values. Based on Table 7, nominal rating of 100 kVA in an overhead network is the best choice for transformer capacity in all load and climate conditions. Nominal rating of 50 kVA and 200 kVA are the second choices for dry & humid situations. Furthermore, Fig. 10 shows that these transformers mainly serve 2 LV feeders.

Fig. 11 gives another interesting comment that the similar range of power loss percentile in transformers and LV feeders. As can be seen in Fig. 11, the range of power loss percentile in transformers and LV feeders is between 1.5% to 3%. Meanwhile, the power loss percentile of MV feeders is less than 1 percent in all load scenarios and climate conditions.

According to Fig. 12, cost of energizing in all cases remain under 1500 $ per customer, except for Hot & Humid climate class. In Hot&Humid areas, load nodes normally have higher values (higher load density) due to the huge amount of cooling loads. In addition, network equipment can serve lower levels of loads due to the derating factors due to environmental conditions.

Regarding these reasons, cost of energizing in Hot&Humid conditions highly increases and exceeds the bound of 1500 $/Cust. Above items and similar ones which can be obtained from deep probe in statistical data can provide some guidelines for better assessment of existing network configurations.

8- CONCLUSION

In this paper, an optimization method that had already been developed by the authors was applied to some real distribution networks and its results were exploited to study the structure of already existing networks. In this regard, Iran electrical distribution networks was considered. At the first step, total area of the country was classified into 5 climate/load –related zones. Afterwards, load characteristic scenarios were defined and applied in network planning process. In order to quantify the study result, ten economic and technical indicators were defined and calculated for all climate classes and load conditions. Results of analyzing the values of indicators and their changes in different cases were reported in tables and figures. Some important guidelines were extracted from more accurate studies of the result, as follows:

- LV feeder length per customer is almost independent from the load and climate conditions.

Table A. Planning constants

item	value
Low voltage [V]	400
Medium voltage [kV]	20
Network lifetime [year]	20
Electrical energy worth [$/kWh]	0.08
Outage cost [$/kWh]	0.7
Load growth [%]	4.5
Rate of interest [%]	14

- Mild &Dry climatic class is the best condition for electrical distribution network. On the other hand, humid conditions (mostly in Hot &Humid) provide the worst cases.
- Transformer capacity per customer in the Hot &Humid condition is different from other climate conditions. The minimum value of capacity per customer in Hot&Humid condition is bigger than the maximum values of its counterpart in other climatic condition.
- Nominal rating of 100 kVA is the best choice for transformer capacity in all load and climate conditions. Nominal rating of 50 kVA and 200 kVA are the second choices for dry and humid situations (which also include cold conditions). These transformers mainly serve two LV feeders.
- Range of power loss percentile in transformers and LV feeders is almost similar to each other in all load scenarios and climate conditions. MV feeder loss is always less than transformer and LV feeder losses.
- Cost of energizing per customer in Hot&Humid condition is quite high in comparison with other climate conditions and load scenarios. The minimum value of energizing cost in Hot &Humid condition is bigger than the maximum values of its counterpart in other climatic condition.

These findings can be used as optimum configuration rules in judgement about the status of already existing distribution networks.

APPENDIX

Items that are assumed as fixed values in all scenarios are listed in Table A.

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