Optimal design of medium voltage distribution networks based on possible risk criteria to increase reliability - Part I: Redesigning the existing network

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Abstract– In this paper, a part of the results from the research project entitled 'Optimal Design of Medium Voltage Distribution Networks Based on Risk Criteria to Enhance Reliability' is presented. The purpose of this research is to develop a methodology for optimally and resiliently designing distribution networks within a probabilistic framework, by incorporating uncertainties in input parameters to enhance network reliability. In solving the problem, the three main questions, namely location, time and capacity of each of the important elements of the medium voltage network, will be answered in the presence of these uncertainties. In this approach, three key questions in the design of medium-voltage distribution networks are examined: the optimal location of key network elements, the appropriate time for equipment expansion or replacement, and the appropriate capacity of each network component. These questions are analyzed in the presence of various uncertainties including load demand, renewable energy source output, equipment reliability, and environmental conditions. The results show that the proposed approach can significantly improve the overall reliability of the distribution network while reducing operational and financial risk. This method performs better than traditional deterministic design methods, especially in conditions of high uncertainty.

Keywords: Active distribution network; Medium voltage; Operation; Reliability; Redesign; uncertainty.

I. Nomenclature

$P_{WT}(s)$: Power generation of wind turbine resources in scenario s

$P_{PV}(s)$: Power generation of solar cell sources in scenario s

$P_l(s)$: The load power of the all network in scenario s

$V_{Fr}(s)$: The amount of equipment failure rate in scenario s

π_s^c : Probability of each scenario

π_s^l : Probability related to load sources

π_s^{Fr} : Probability related to the exit of the equipment

π_s^{WT} : Probability related to WT resources

π_s^{PV} π_s^{pv} : Probability related to PV sources

V_{Inf} : The amount of inflation rate in scenario s

π_s^{Inf} : The probability of the inflation rate is V_{Inf} .

II. Introduction

A medium voltage distribution network is considered to be the backbone of modern distribution systems. Principled, optimal design based on electrical, geographic and financial limitations can play a significant role in reducing the costs of distribution companies and prevent non-scientific estimates, and on the other hand, respond to the needs of consumers in an efficient manner. Every year, a huge part of the electric energy produced in our country is lost at the distribution level [1-4].

For example, reference [5] proposes a hybrid AC/DC network, aiming to improve distribution network reliability through strategic utilization of network elements. In a different study in [6], a physical/cyber testbed for distribution networks is presented, which uses remote accessibility tools in network design to study security issues and reliability of power networks. Also, in [7], an integrated assessment method of the distribution network in terms of self-robustness and potential damages is presented.

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This research aims to develop a methodology for optimally designing MV distribution networks under uncertainty to enhance their reliability.

Presenting new methods in the design and operation of future distribution networks will not only assist distribution companies in advancing their current goals, but will also prepare them in planning to face new future events. There is no provision of a comprehensive design method that can be considered in solving real problems and in large dimensions, and also covers the important limitations and future needs related to distribution networks [8-9].

III. Methodology and Flow Chart of Optimal Designe of Medium Voltage Distribution Networks in a Probabilistic Environment

In this part, the general flowchart of solving the problem of optimal design of distribution networks based on risk assessment and in the presence of technical and financial uncertainties will be presented. In figure (1), this general flowchart is presented.

One of the key components in solving this problem is analyzing all available statistical data related to the network, which are essential for modeling future conditions. It should be noted that all the statistical information of the network, such as the exit of equipment in the past, will appear in the form of probability for the future of the network. Therefore, accurate input data is crucial as it forms the foundation for defining appropriate probability distribution functions for input variables in network analysis. According to the problem solving flowchart, all the information whose probabilistic model is supposed to be used in solving the problem should be obtained and modeled to determine the appropriate probability distribution function.

After modeling uncertainties with appropriate probability distribution functions, enough scenarios will be generated for network design in the presence of uncertainties. If the number of necessary scenarios exceeds a certain limit, so that solving the optimal design problem requires too much time. With the appropriate method, the number of scenarios will be reduced so that the problem can be solved in a reasonable time. On the other hand, considering that the main goal of designing with the approach of increasing the reliability of the network, reliability indicators will be calculated for each designed network. which is the most important indicator of expected lost energy distribution networks for the network designed in the future [10-11].

IV. MOdeling the Problem of Optimal Design of Medium Voltage Distribution Networks in the Presence of DIstributed Generation Sources By Considering Uncertainty

Based on the portfolio scenario modeling (investment-based approach), the distribution network design encompasses super-distribution substations, medium voltage feeders, distribution substations, low voltage feeders and the use of small-scale renewable sources, such as wind and photovoltaic sources. In this model, the uncertainties of the above vector include five different parameters that will be used as input to production the scenario. Some simplifying assumptions such as the independence of random variables related to the above uncertainties have been included, which may not be true in practice. For example, there may be a correlation between the variable of wind and solar radiation, and this correlation can also be added in the production of scenarios and calculations. According to the long-term design problem, the uncertainties of the problem are considered long-term. The suitable equipment and optimal design of different types of equipment in this issue is a decision and optimal design issue for the distribution company. This decision can have many effects on the short-term and long-term issues of the distribution companies, such as cost savings, increasing the security and reliability of the network, reducing the operation risk and using renewable resources in the cost portfolio of the distribution company.

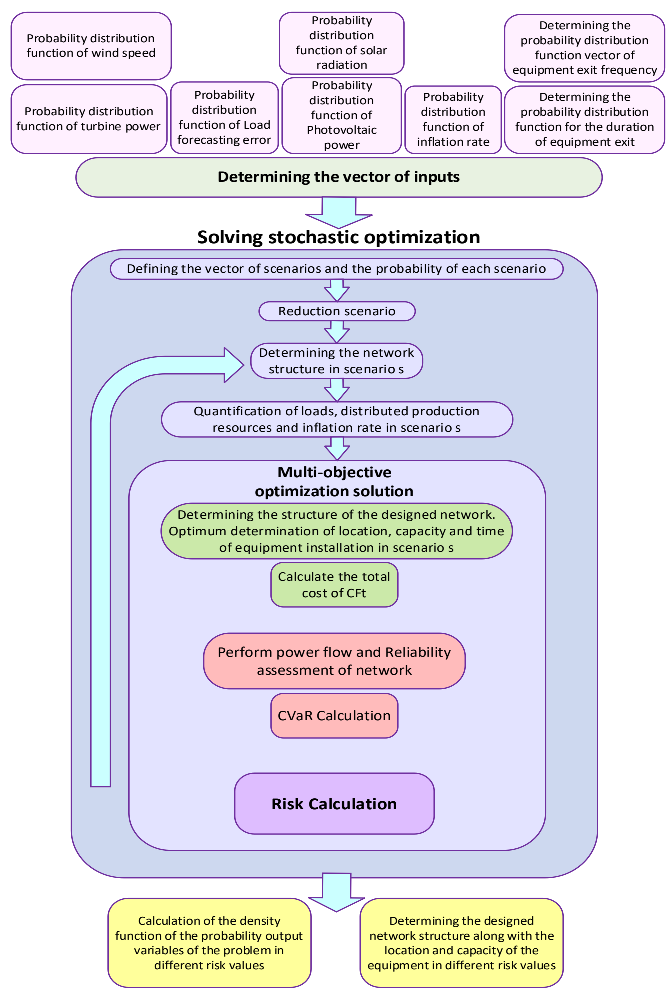

Fig. 1. flowchart of solving the problem of optimal design of the distribution network based on risk assessment and in the presence of uncertainties in order to increase reliability

For the distribution company, consider a portfolio that includes conventional distribution network equipment and renewable resources. The solution of the problem corresponds to what equipment with what capacity and at what time should enter the distribution network up to the design horizon so that the company's costs are minimized and the profit of its investment portfolio is maximized. This problem, in the presence of existing uncertainties, is a random portfolio asset optimization problem in which investment decisions have certain limitations as follows. One way to solve these problems is to merge two problems, i.e. investment and operation into a single problem. The second method of solving the problem is by separating two problems from each other and solving the first problem (operation) and entering the result of the first problem to solve the second problem, i.e. investment optimization. Assuming that load, output of equipment, generation of wind and solar resources are independent random processes, different states of the problem are obtained by combining different states of these parameters as follows:

$$C(s) = [P_l(s)\ V_{Fr}(s)\ P_{WT}(s)\ P_{PV}(s)] \tag{1}$$

$$\pi_s^c = \pi_s^l\ \ \pi_s^{Fr}\ \ \pi_s^{WT}\ \ \pi_s^{PV} \tag{2}$$

Equation (1) is modified as follows when uncertainty from inflation rate variations is considered:

$$Sc(s) = [P_l(s)\ V_{Fr}(s)\ P_{WT}(s)\ P_{PV}(s)\ V_{Inf}] \tag{3}$$

where Sc is the vector of scenarios. By determining the probability of each scenario and assuming the independence of random variables, the probability of scenario s will be calculated from the following relationship.

$$\pi_s^c = \pi_s^l\ \ \pi_s^{Fr}\ \ \pi_s^{WT}\ \ \pi_s^{PV}\ \ \pi_s^{Inf} \tag{4}$$

V. PREPARATION OF STUDY SOFTWARE

The study software includes two NETPLAN software sections (Figure 2) for optimal design of advanced distribution networks in the MATLAB environment, as well as creating the studied network in the DIgSILENT computing software environment and the relevant interface.

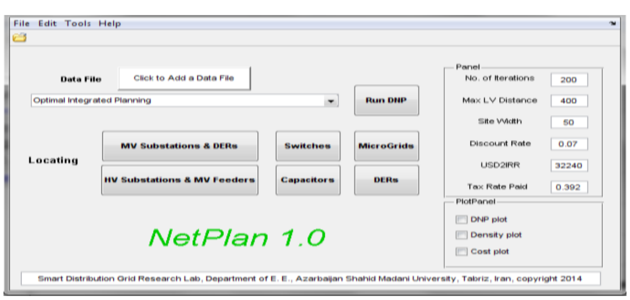

Fig. 2. The main menu of the software for the optimal design and operation of distribution networks

VI. OPTIMUM DESIGN OF THE FUTURE MEDIUM VOLTAGE DISTRIBUTION NETWORK WITH THE ABOVE METHODOLOGY IN THE PILOT AREA

In this chapter, the results of the optimal design of the distribution network of the pilot area will be presented in detail based on possible criteria to increase the reliability of the network. In the first stage, optimization and design of the network has been done based on the defined scenarios, in this case, since there was no need to use the combined methods and interface of DIgSILENT software with MATLAB software, the optimization methods of DIgSILENT software itself were used. The primary objective of this research was not to focus on the optimization algorithm itself, but rather to utilize it as a means to achieve the optimal solution. Distribution networks face various changes in load and network structure. The increasing penetration of distributed generation has also led to the increase of these changes and its possible behavior. Another important goal of this research is to determine these maneuver points and suitable substations for increasing the automation level of the pilot area network in the presence of widespread and possible penetration of distributed generation, including photovoltaic cell. For this purpose, in general, optimization has been done in MATLAB software and the main studies have been done in DIgSILENT software. The purpose is to use the computational power and accuracy of DIgSILENT software and the optimization power of MATLAB software. For this purpose, the interface between two software’s has been prepared and the necessary codes have been created in both software’s to implement the goals of network design.

A. *Introduction of the studied network*

The studied network is the medium voltage network of a large part of the Tabriz Electricity Distribution Company, which includes Roshanaei, Golestan, and Emamieh. A part of the Emamieh feeders is out of the scope of the study. In terms of structure, almost all of this area is operated by cable, and in its limits, it includes parts of the above distribution substation of Emamieh with medium voltage air network. In figure (3) the geographic point of the study area is presented in the GIS software environment. In figure (3), all available land and air substations are shown with circle and triangle symbols, respectively.

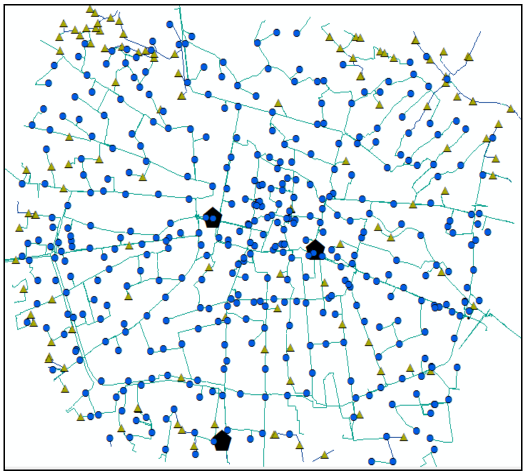

Fig. 3. Geographical map of the study area in the GIS software environment

TABLE I

NAMES AND GIS CODES OF AUTOMATION SUBSTATION IN THE STUDY AREA

NO	Name of the Substation	Substation code
1	Seraji	SB020154
2	Mantash	SB020068
3	Janbe edare	SB020055
4	Nanvaei miyaneh	SB020111
5	Bimarestane zanan	SB010066
6	Baghe Golestane	SB020056
7	Mokhaberateh Nesferahe	SB020077
8	Borje Shahriyar	SB010145
9	Maskouchi	SB020040
10	17 Shahrivar	SB020017
11	Hajimanverdi	SB010120
12	Tofigh	SB010021
13	Hakim Nezami	SB020125
14	Shahrbani ghadim	SB010036
15	Shahrdari	SB010053
16	Padegan	-------

VII. EVALUATION OF NETWORK RELIABILITY RESULTS

In this section, the results of network reliability evaluation are presented. In table (2), the general reliability results of the study area according to the information of feeders exit in 121 software and after calculation in DIgSILENT software are shown in table (3). As shown in the table, the reliability index value (specifically the Average Service Availability Index – ASAI) for the studied area is 99.968% and the average amount of energy not supplied Index (ENS) is equal to 342 megawatt hours per year.

Also, in table (3), the reliability indicators are shown separately for medium voltage feeders in the study area. According to this table, a comparison can be made between the reliability of each feeder and its blackout value compared to other feeders.

TABLE II

RESULTS OF RELIABILITY SYSTEM INDICATORS OF THE STUDIED AREA

SAIFI	4.843494	1/Ca
CAIFI	4.843494	1/Ca
SAIDI	2.741	h/Ca
CAIDI	0.566	h
ASAI	0.9996871433	
ASUI	0.0003128567	
ENS	342.299	MWh/a
AENS	1.126	MWh/Ca
ACCI	0.000	MWh/Ca
EIC	0.000	M$/a
IEAR	0.000	$/kWh
SES	0.000	MWh/a
ASIFI	4.677306	1/a
ASIDI	2.655966	h/a
MAIFI	0.000000	1/Ca

VIII. REDESIGNING THE BASIC DISTRIBUTION NETWORK OF THE PILOT AREA IN TERMS OF IMPROVING MANEUVERING POINTS

Figure (4) shows the automation stations of the study area. In figure (4), the position of the sub-distribution substation is also presented to provide a better picture of the conditions of the medium voltage network. These substations are equipped with remote-controlled switches, enabling remote operational maneuvers. In this study, it is assumed that all the switches inside the automation stations have remote control capability. The purpose of this part of the study is to determine whether the existing automation substation are designed properly or not. For this purpose, the optimal points of the network maneuver are determined in the basic load of studies.

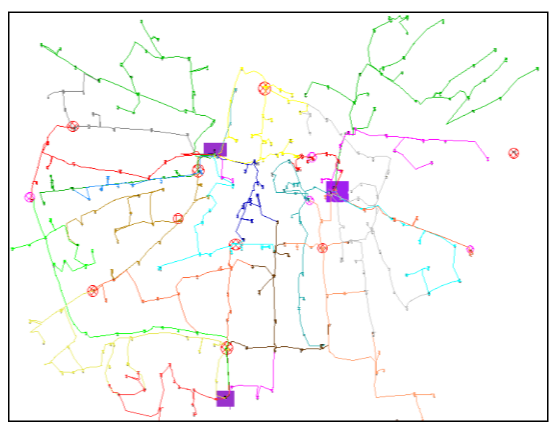

Fig. 4. Automation substations of the region along with sub-distribution substations

A. *Creating the main skeleton (Backbone) of the network to install remote control switches to increase reliability*

As mentioned before, in order to determine the optimal maneuvering points of the network and increase the level of automation, it is necessary to identify the main paths of the feeders or their backbone, so that the physical conditions of the system in terms of the cross section of the feeders and their load are effective in determining the main route of the feeder. There are various methods for this purpose, among them, we can mention the determination of the main backbones based on the cross-sectional area, the amount of feeder load. Based on this, for the feeders in the study area, the main structure is determined based on the cross section. For the 25 feeders in the study area, including the maximum order 7 to determine the main backbones, 72 backbones have been determined. It is noted that the number of main paths increases with the increase of the maximum order to calculate the backbones, but after a certain number, the number of backbones remains constant. In the studied network, the number of backbones does not change much after the 3rd order, so for this network, the maximum number of backbones is 72. Considering that there are a number of automation substations in the area of the study, in this section, there are 58 switches inside these substations and they are actually the same remote-control switches. Presenting all the main routes for all 72 routes will be limited in the space of the article, therefore, in this part, one of the main routes from the 72 routes is presented as examples. In Figure (5), all 72 backbones where the remote-control switches are supposed to be placed on these routes have been specified in a centralized and unified manner.

In Figure (6) the backbones related to F14_Golestan_F2_Emamiyeh_01 is shown between feeder No. 14 of Golestan and a part of feeder No. 2 of Emamiyeh. Between these two feeders, the DCS1595387 switches is placed between the two feeders. The rank of this Backbone is of the second rank and its total length is 7.33 km.

Now, the results of determining the remote-control switches for the studied area are presented on 72 main routes. Since the main purpose of locating these switches is to improve the reliability of the network, therefore, the amount of energy not supplied of the system or balancing the lost energy of the system is considered as the objective function of optimization. Since the cost of automating a substations is usually much higher than creating a maneuvering point on aerial feeders, even though the length of aerial feeders is very short in the scope of the study, therefore, in this study, the possibility of creating a maneuvering point is also considered. The maximum number of new switches can be chosen for each main path, which can be calculated depending on the amount of investment and the desired reliability.

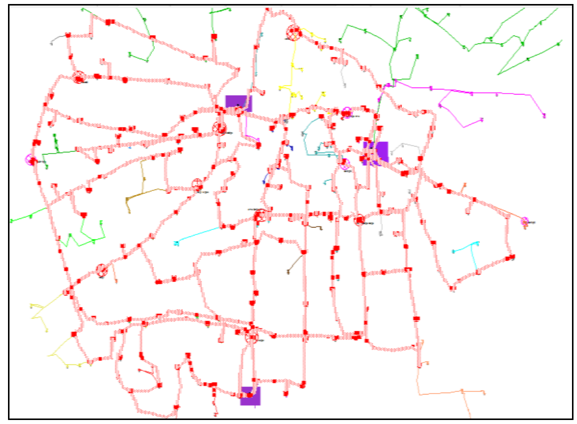

Fig. 5. all 72 backbones (Backbone) in the study area

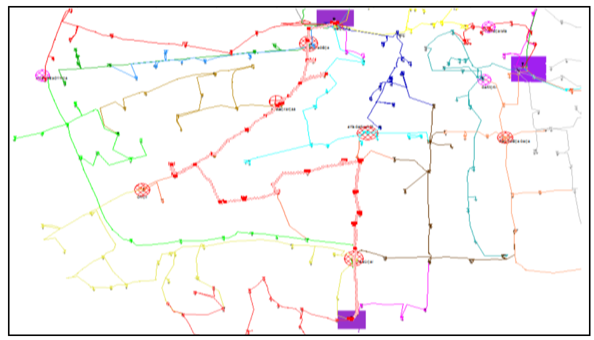

Fig. 6. backbones related to F14_Golestan_F2_Emamiyeh_01, which is between feeder No. 14 of Golestan and a part of feeder No. 2 of Emamiyeh

In this section, while evaluating the reliability of the existing network, the effect of increasing the number of remote control switches on the reliability of the network is considered. For this purpose, the maximum number of RCS switches has been determined as input and the reliability of the entire network as output, so that the optimal number of switches can be calculated according to the reliability improvement. In this case, the possibility of choosing a new switches is not given to the optimization program, and only the existing switches and their optimal points are considered. Table (3) shows the results of determining the optimal maneuvering points with the existing switches of the network. According to the table and figures (7) and (8), it can be seen that in the studied network, the most appropriate number of switches to install on the feeder to significantly improve reliability and reduce energy not supplied is 3, and it shows that The slope of the curve will reach saturation after this number.

TABLE III
THE RESULTS OF DETERMINING THE OPTIMAL MANEUVER POINTS WITH THE EXISTING SWITCHES OF THE NETWORK

	ASAI	ENS	SAIFI	SAIDI	CAIFI	CAIDI
		MWh/a	1/Ca	h/Ca	1/Ca	h
Base case (No RCS)	0.9995	368.4	5.62	3.5	9.38	0.63
Existing RCS	0.9995	366.4	5.62	3.5	9.38	0.63
New RCS per Feeder=1	0.9996	334.0	5.62	3.2	9.38	0.58
New RCS per Feeder=3	0.9996	308.5	5.62	3.0	9.38	0.53
New RCS per Feeder=5	0.9996	297.2	5.62	2.9	9.38	0.52
New RCS per Feeder=7	0.9996	292.1	5.62	2.8	9.38	0.51
New RCS per Feeder=9	0.9996	289.5	5.62	2.8	9.38	0.51
New RCS per Feeder=11	0.9996	289.2	5.62	2.8	9.38	0.51
New RCS per Feeder=13	0.9996	289.5	5.62	2.8	9.38	0.51

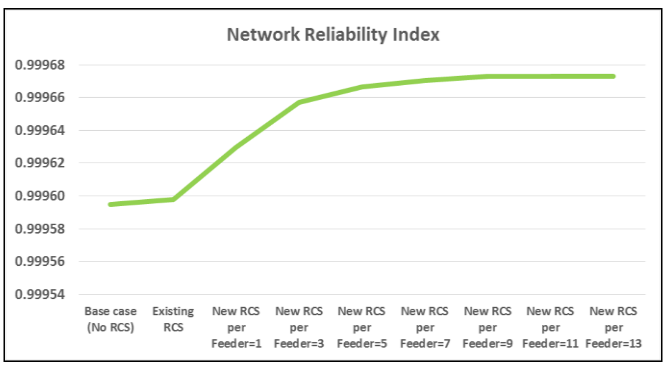

Fig. 7. Increasing the network reliability index by increasing the maximum number of RCS switches on each feeder

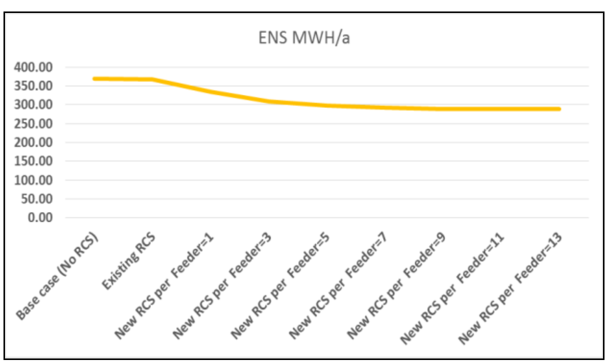

Fig. 8. Reducing the amount of lost energy of the system by increasing the maximum number of RCS switches on each feeder

According to the results of the study, it is clear that excessive installation of switches on feeders does not significantly reduce the reliability of the studied network. According to the results obtained for the existing network, it can be seen that the reliability of the system does not improve significantly by increasing the number of remote control switches to a certain number (3) for each feeder, so for the existing network with the presence of automatic switches In the existing network, the level of reliability will reach 99.967 percent. The blackout rate will reach from 368.4 to 308.5 megawatt hours per year, which will improve by about 16%. By increasing the number of switches for each feeder to more than 5, there is not much change in the reliability of the system.

IX. CONCLUSION

In this article, a part of the results of the medium voltage distribution network design research project was examined in terms of reliability and according to possible risk criteria. The network under study is a large part of the medium voltage network of Tabriz city, including the Golestan, Roshanaei, and Emamiya. This study was conducted comprehensively, aligned with the defined research objectives, and detailed results were reported. The main Backbone of the network is based on the identification and selection path of RCS automatic switches on these paths. In this study, the values of the maximum reliability that can be obtained are calculated and corresponding to those optimal values that can be obtained at an acceptable cost.

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