U.P.B. Sci. Bull., Series C, Vol. 80, Iss. 2, 2018 ISSN 2286-3540

MULTI-OBJECTIVE MODELING OF ROBUST MULTI-STAGE FEEDER ROUTING PROBLEM WITH CONSIDERING UNCERTAINTIES

Navid TAGHIZADEGAN[1], Mohammad Reza JANNATI OSKUEE[2], Tohid FARHOUDI[3]

In regard to widespread impacts of uncertainties in power system planning and operation, some strategies must be devised to incorporate the uncertainties in power system modeling, therefore achieving the best possible strategy. The most important uncertainties in long-term distribution network planning are due to errors in forecasting of load demand and market price. This paper presents a stochastic multistage expansion planning method to consider the forecasting errors, pseudo dynamic behavior of the network parameters and geographical constraints. In this paper, the optimal routes of MV feeders as the backbone of distribution networks are obtained for both mid and long-term cases with probabilistic modeling. To enhance the accountability of the power system and improve system performance parameters simultaneously to the best possible condition, multi-objective functions are proposed and solved using NSGA II (Non-Dominated Sorting Genetic Algorithm). The employed objectives contain all economic, environmental and technical aspects of distribution network e.g. cost of Feeders installations, active and reactive power losses cost, cost of purchased power from power market, Reliability cost, Voltage Stability enhancements, Minimization of Voltage Deviation and Emission reduction. One of the most important advantages of the proposed multi-objective formulation is obtaining non-dominated solutions and allowing system operator to exercise personal preference in selecting each of those solutions based on the system operating conditions and the costs. To validate the effectiveness of the proposed scheme, the simulations are carried out on a relatively large-scale distribution network.

Keywords: Optimal Feeder Routing (OFR), Multistage Planning, Uncertainty modeling, Scenario Based-Stochastic Programming, Multi-Objective, Genetic Algorithm

[1] Smart Distribution Grid Research Lab., Electrical Engineering Department, Azarbaijan Shahid Madani University, Tabriz, Iran, e-mail: taghizadegan@azaruniv.edu

[2]* Young Researchers and Elite Club, Tabriz Branch, Islamic Azad University, Tabriz, Iran, e-mail: m.r.jannati@gmail.com

[3] Smart Distribution Grid Research Lab., Electrical Engineering Department, Azarbaijan Shahid Madani University, Tabriz, Iran, e-mail: tf286@yahoo.com

NOMENCLATURE			
$\deg(v_i)$	Degree of the vertex *i*.	A	Adjacency matrix
D	Degree matrix	dl	Demand level
s	State	ρ	Peak electricity price
$S_{i,peak}^{D}$	Demand peak load in *i*-th bus	π_s^c	Probability of each combined state
π_s^l	Probability of load	π_s^λ	Probability of Market Price
f_{VD}	Voltage deviation.	V_k	Voltage of the *k*-th bus.
V_{rated}	Nominal voltage	VSF	Voltage stability factor
K_{Grid}	Carbon footprint for the energy purchased from power market through Transmission lines	K_{CO_2-Grid}	CO_2 emissions due to energy purchased from grids
$K_{CO_2-NO_2}$	Carbon dioxide equivalency factor for NO_2	$K_{NO2-Grid}$	NO_2 emissions due to energy purchased from power market through Transmission lines
C_{Feeder}	Feeder Installation Costs	$P_{loss(dl,s)}$	Active power loss corresponding to state *s* and load level dl
$Q_{loss(dl,s)}$	Reactive power loss corresponding to state *s* and load level dl	C_{P-loss}	Cost of active losses
C_{Q-loss}	Cost of reactive losses	$PD_{(dl,s)}$	Load demand corresponding to state *s* and load level dl
$PM_{(dl,s)}$	Purchased active power from power market through Transmission lines	λ_b	Failure rate of feeder b
r_b	Repair time of feeder b	$LNS_{(ld,s,b)}$	Load not supplied
C_{RC}	Reliability cost		

1. Introduction

Distribution network has an essential role of transferring electrical power to the end-user consumers, leading issues concerning the planning, expansion and operation of electric distribution networks. In this regard, financial constraints and the uncertainties in load demand and market price are the most important challenges for decision makers. To solve this large-scale problem, planners employ multistage planning method to evaluate and resolve the planning problem in distinct periods of time considering the previous time periods. Multistage planning is known as an efficient method, able to overcome the pseudo dynamic behavior of the network parameters from the techo-economical points of view considering the basic constraints. Trying to have a distribution network as efficient as possible, is the most energized issues of electric utilities which can be treated as an optimization problem with the aim of minimization of the costs and achieving acceptable levels for network technical parameters. The network planning is directly related to voltage quality and power losses [1-5]. Power distribution system; basically, a group of radial feeders connected together, garners a lot of attention for its complexity and difficulty of distribution planning [6]. In article [7], authors consider voltage stability improvement and loss minimization as objective functions in solving OFR problem while in [8], they use simulated annealing technique to solve the optimal planning problem, aiming to obtain the radial distribution network with minimum costs. Article [9] study distribution network modeling and planning, under normal conditions and using various optimization algorithms. Due to the characteristics of the geographical area, author of [10] believes that, the major difficulty in optimal distribution planning is the large number of variables resulting from several candidates for the network configurations. Mathematical programming techniques detailed in many and various approaches [11-13] are employed, with the main feeder distribution system consideration, to solve complex formulations including cost model and radial feeder planning with the concept of horizon year which minimizes the future costs by specifying optimal design parameters, given assumptions about the future [14]. Multistage expansion planning is proposed in [15] to consider the dynamic behavior of the system parameters, asset management and geographical constraints. In [16-17] distribution system planning is formulated as multi-objective procedure with the two conflicting objectives of minimizing of total costs and maximizing reliability. The multi-objective problem, framework of which can provide flexible tool for system operators who are responsible for decision making, is solved using tradeoff analysis of the Pareto-optimality principle [18]. Recently, multistage feeder routing problem is solved using ICA [19]. Sum of feeders' installation cost and loss cost is the objective function of this paper. Monte Carlo Simulation is used for probabilistic modeling of load forecasting error. Whereas, it is evident that this method is highly time consuming for uncertainty modeling. Thus, the review shows that considerable works have been done towards the OFR; however, most of the works presented assumes that the load demand and/or market price is constant in time horizon in planning period with no associated uncertainties Since, electrical consumption is ever increasing and the increment rate is related to several parameters, e.g. economical, geographical, climate change and *etc*., there is no accurate forecast for future load demand and the actual one may differs from calculations. Nonetheless, even within moments and always, load and generation balance must be maintained in real time. So, the power grid must be able to transfer the required energy of the consumers to them. In this regard, power system must be designed properly and well operate. Another feature is that the electric system is highly capital intensive, and the investments have long lead times and multi-decade economic lifetimes. Also because of financial constraints of electrical utilities, the investments must be reasonable. These features of electric power systems require power grids planning and management to assure the reliability of the system. These challenges and uncertainties make planning problem higher valuable since it offers higher reliability at relative low cost. So, this paper is organized to provide a comprehensive study on the planning of distribution network aims to find an optimal solution for the robust multistage feeder routing problem considering the uncertainties in future load demand and market price by optimizing several objective functions including economical, technical and environmental issues. So this study is excellent to estimate and determine the planning problem in different distinct periods of time with the planned network in the previous time periods consideration.

2. Problem Formulation

The main aim of this paper is to find an optimal solution for the robust multistage feeder routing problem considering the uncertainties in future load demand and market price using NSGA II optimization algorithm while applying a novel algorithm to analyze the radial structure of the network in each GA iterative process. GA generates solutions to optimization problems using techniques inspired by natural evolution including selection, crossover, and mutation. In GA, a population of candidate solutions (called individuals) to an optimization problem is evolved towards better solutions. Each candidate has a set of properties (its chromosomes or genotype) which can be mutated and altered. Solutions, traditionally represented in binary strings of 0s and 1s, are also encoded with real and decimal codifications [20]. The evolution, an iterative process, usually starts from a population of randomly generated individuals called a generation. In each generation, the fitness (the value of the objective function in the optimization problem being solved) of every individual is evaluated. The more fit individuals are stochastically selected from the current population, and each individual's genome is modified (crossed over and possibly randomly mutated) to form a new generation. Then, the new generation is used in the next iteration of the algorithm. When a maximum number of generations is produced, or a satisfactory fitness level is reached, the algorithm terminates. The initial step in multistage distribution system planning is to specify the optimum sites and sizes of HV and MV substations. Due to this, the planning process is applied for two five-year and ten-year cases with regards to the pseudo dynamic behavior of the network (Table 1).

TABLE 1: LOCATION AND LOADING OF HVAND MVSUBSTATIONS FOR TWO PLANNING STAGES

Substation Number	Substation Location (X,Y) (km)	Mid-Term (Year of 5)		Long-Term (Year of 10)	
		Capacity (kw)	Loading (%)	Capacity (kw)	Loading (%)
1(HV)	(12.00, 9.75)				
2	(7.50, 9.00)	1762	70.5	1296	64.8
3	(13.50, 8.25)	3229	64.6	1888	75.5
4	(6.75, 11.25)	2672	66.8	1138	75.9
5	(13.50, 12.00)	2105	70.2	2376	79.2
6	(2.625, 7.875)	857	68.6	1549	77.5
7	(5.625, 5.625)	1285	64.3	1091	72.7
8	(9.75, 4.50)	2308	76.9	1795	71.8
9	(14.25, 15.75)	2719	68.0	1775	71.0
10	(19.50, 13.50)	2579	64.5	1466	73.3
11	(9.75, 9.75)			1538	76.9
12	(10.50, 13.5)			1745	69.8
13	(10.50, 7.50)			1353	67.7
14	(8.25, 6.00)			825	66.0
15	(6.75, 3.75)			997	79.8
16	(12.375, 1.875)			1941	77.6

17	(14.25, 6.00)	2098	69.9
18	(17.25, 5.25)	4089	64.9
19	(19.125, 7.875)	1289	64.5
20	(19.50, 9.75)	2308	76.9
21	(20.625, 5.625)	1459	73.0
22	(22.50, 3.75)	2149	71.6
23	(17.25, 15.00)	2227	74.2
24	(9.00, 15.00)	1425	71.3
25	(12.00, 15.00)	1080	72.0
26	(5.625, 13.875)	1556	77.8
27	(1.875, 14.625)	1891	75.6
28	(4.875, 9.375)	1285	64.3

A vision of the optimally planned network is accessible from graphical results which are significant from the network experts and designers' viewpoints. Hence a graphical representation of the results is represented in Figs.1 (a)-(b), respectively. The outcomes are the sites and sizes of HV and MV substations supplying all MV substations in the system modeled as network load points. Based on the cost of construction and operation, the candidate routes for MV feeders are specified from solving the multistage planning problem with electrical, geographical and asset constraints considerations. So, in the final solution, the network main components including HV and MV sites and sizes, MV feeder's route, radial structure or the topology of MV distribution network, must be specified.

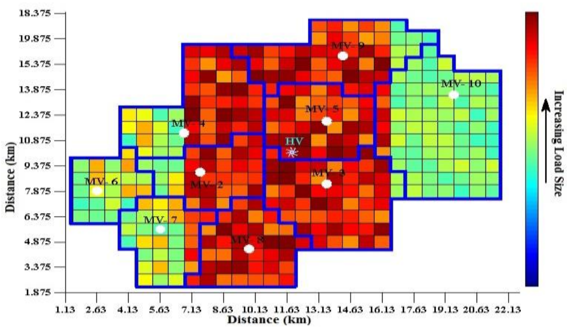


Fig. 1 a) Substations supplied area
in Mid-term case

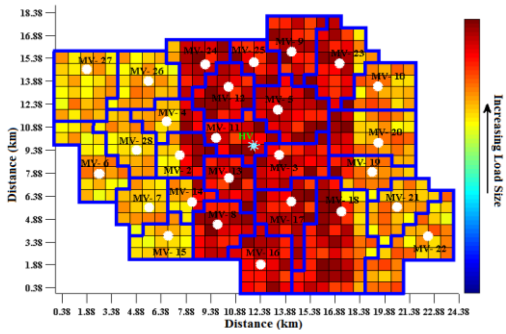


Fig. 1. b) Substations supplied area
in long-term planning case

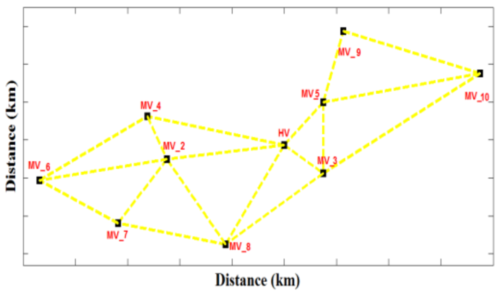


Fig. 2. a) The candidate routes
for mid-term planning

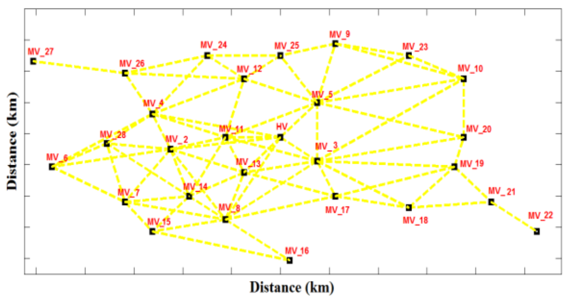


Fig. 2. b) The candidate routes
for long-term planning

A new method is used to check the radial structure of the distribution network during simulation, detail of which is mentioned later and is used to check the radial structure of the network with two properties of a tree in a graph; that are:

1. Number of the edges in a tree is equal to the number of the vertices minus one.
2. A tree is a connected graph.

During simulation process, number of the "1" entries in any chromosome (Fig. 3) is equal to the number of the nodes minus one.

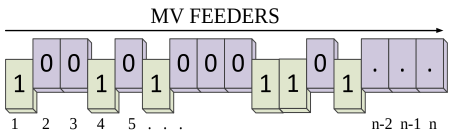


Fig. 3. Structure of the proposed chromosome

In other words, vector entries must be arranged in order that the graph to be connected. Supposing that, new chromosomes are generated to meet the above conditions. The information illustrating the configuration of power distribution network must be encoded in the genes of chromosome. From programming viewpoint, a subroutine is required to implement above conditions during GA's "Generate New Population", "Mutation" and "Cross-over" processes; only a solution is accepted that satisfies both conditions and the others must be removed. OFR aims to find the optimal structure of distribution network, maximizing or minimizing specific objective functions that in some cases have conflicting manner, persuading operators to trade-off among these factors. Using multi-objective optimization framework provides flexible tool for operators. It is tough or impossible to convert all system technical aspects into correct monetary value such as voltage profile in schemes with single objective function and from the experiments, the obtained results do not necessarily guarantee the optimal value. In trying to solve multi-objective optimization problems, traditional methods scalarize the objective vector into a single objective, resulting in a highly sensitive solution to the weight vector used in process and the knowledge of user about the problem. Moreover, designers may be interested in a set of Pareto-optimal points, instead of a single solution and use a population of points because of genetic algorithms to be able to find multiple Pareto-optimal solutions simultaneously. The proof-of-principle simulation results indicates that NSGA II maintains stable and uniform reproductive potential across non-dominated individuals. Given OFR being an optimization problem, NSGA II is an appropriate alternative. Note that distribution company (DisCo) is responsible for providing customer's demand and planning and operation of distribution system is based on cost reduction and improving system performance parameters.

2.1 Novel algorithm for determining the radial structure of the network configuration

This section presents the algorithm solving the spanning tree problem [21-22] which checks two features to find out the graph is tree or not. Defining two features of tree with n vertices:

- The number of edges in the tree is $n-1$.
- The tree is a connected graph.

Graph Connectivity algorithms are useful for finding the connectivity or dis-connectivity of a graph. Now assuming Laplacian matrix and incidence matrix are defined as L and E respectively, hence:

$$L = EE^T \tag{1}$$

Then,

$$rank(L) = rank(E) \tag{2}$$

From [17], if connected, then:

$$rank(L) = n-1 \tag{3}$$

and, if disconnected:

$$rank(L) < n-1 \tag{4}$$

Matrix L can be obtained with G being a graph with n vertices, its Laplacian matrix L defined as the difference of the graph's degree matrix D (a diagonal matrix with vertex degrees on the diagonals) and its adjacency matrix A (a (0,1)-matrix with 1's at places corresponding to entries where the vertices are adjacent and 0's otherwise) :

$$L = D - A \tag{5}$$

Where the elements of L will be given by:

$$l_{ij} = \begin{cases} \deg(v_i) & ; if\ i = j \\ -1 & ; if\ i \neq j\ and\ v_i\ is\ adjacent\ to\ v_j \\ 0 & ; otherwise \end{cases} \tag{6}$$

And $\deg(v_i)$ is degree of the vertex i.

3. Uncertainty Modeling of Future Load Demand and Market Price

The uncertain parameters of electric load and price are strongly related and increase or decrease of each parameter causes a direct effect on another. In order to model these parameters, the price and load duration curves were divided into N_{dl} levels in each year (Fig. 4). The vertical axis shows the demand/price level factors[4]. τ_{dl} shows the duration of each level and demand/price level factors (D_{dl}, λ_{dl}) are assumed To be normally distributed around their specified expected

[4] the ratio of load/price to the peak value of load/price in this level

values, each distribution is divided into five states and their probability is specified. Although dependent in each demand level, the variation of price and electric load around the expected price and demand values can be assumed to be independent.

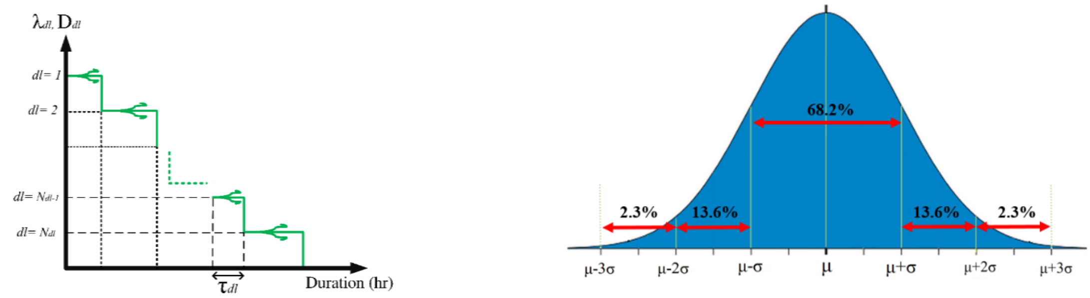


Fig. 4. Demand and price level factor uncertainty modelling

The uncertainty of the electricity price, a quantity competitively determined by the behaviors of the electricity market participants, should be correctively taken into account. Assuming a peak electricity price of ρ, the electricity price in demand level dl and state s can be calculated as:

$$EP^{\lambda}_{dl,s} = \rho \lambda_{dl,s} \quad (7)$$

Assuming a peak load of $S^{D}_{i,peak}$ and a demand growth rate of α, the demand in bus i, demand level dl and state s can be obtained as follow:

$$S^{D}_{i,t,dl,s} = S^{D}_{i,peak} D_{dl,s} \quad (8)$$

Based on the assumption of each demand level states being independent (the correlation between load and price is already considered in their mean value of D_{dl} and λ_{dl}), the probability of any combination of load and price (π^{c}_{s}) can be obtained by convolving these probabilities in the following equation:

$$C(s) = [load(s) \quad price(s)] \quad (9)$$

$$\pi^{c}_{s} = \pi^{l}_{s} \pi^{\lambda}_{s} \quad (10)$$

For larger number of states, the number of optimization calculation increases greatly and to overcome this, number of scenarios are reduced, while the main features don't change, making it necessary to approximate the original scenarios with a much smaller subset of scenarios that can approximate the original scenario set well [1].

4. Objective Functions

Many real-world optimization problems are characterized by multiple objectives that are often in conflict. The goal here is to find a set of non-dominated solutions with a multi-objective optimization approach proposed based on NSGA II for robust multistage feeder routing problem considering the uncertainties in the future load demand and market price. The implemented objective functions are: (1) voltage deviation minimization, (2) voltage stability Improvements, (3) Emission Reduction, and (4) costs minimization.

I. Minimizing the Voltage Deviation

The voltage deviation from the desired value is an important parameter affecting the security and power quality of the system [12]. This objective function to be minimized is as follows:

$$f_{VD} = \sum_{dl} \sum_{s} \pi_s^c \times \left(\sum_{k}^{N_{bus}} \left(V_k - V_{rated} \right)^2 \right) \tag{11}$$

II. Maximizing Voltage Stability

Maintaining voltage stability in an accepted level is a major concern in planning and operation of power network, defined as the ability of a power system to maintain voltage in acceptable level where the system is able to control both power and voltage with the increasing load. The manifestation of voltage instability can lead to a gradual total black out. Equation (12) is used to formulate the voltage stability factor [1] and supposing two bus section of distribution system, voltage stability factor for any bus '$m+1$' is accessible as follows:

$$VSF_{m+1} = 2V_{m+1} - V_m \tag{12}$$

where'$m+1$' is the receive bus. Distribution system voltage stability situation can be justified aggregating the values of VSF_{m+1} for all the buses.

$$VSF_{total(\mathrm{dl},s)} = \sum_{k=1}^{N_{bus}-1} \left(2V_{k+1} - V_k \right) \tag{13}$$

The higher value of VSF_{total} indicates more voltage stable operation.

$$f_{VSI} = \sum_{dl} \sum_{s} \pi_s^c \times \min\left(VSF_{total(\mathrm{dl},s)} \right) \tag{14}$$

where f_{VSI} is voltage stability factor of power system which must be maximized to improve the voltage stability.

III. Environmental Impacts

Global trends in energy supply are patently unsustainable in a lot of aspects and without decisive action, increased use of fossil fuel and its related carbon dioxide emissions will double by 2050. So, the current path must be changed, but this will take an energy revolution and low carbon energy technologies will have a crucial role to play. Hence, in planning and operation contexts, minimization of the emission amount is treated as a significant purpose. If the fuel consumption rate is decreased, the amount of producing carbon dioxide and other air pollutant emissions will be reduced. The formula for calculating the emission amount from network is as follows:

$$f_{Emission} = \sum_{dl}\sum_{s} \pi_s^c \times \tau_{dl} \times PM_{(\mathrm{dl},s)} \times K_{Grid} \quad (15)$$

A carbon footprint in a system can be calculated respectively:

$$K_{Grid} = K_{CO_2-Grid} + M_{CO_2/NO_2} K_{NO_2-Grid} \quad (16)$$

IV. Costs

The main objective of an electrical distribution system is providing cost effective service to consumers. Therefore, the proposed cost function is a combination of four criteria: feeder installation costs, power loss cost, cost of purchased active power from power market and reliability cost. The details related to these criteria are as followed.

$$f_{\mathrm{Cost}} = C_{Feeder} + C_{losses} + CM + C_{RC} \quad (17)$$

- **Feeder Installation Costs**

Due to supporting planners' decision for distribution network planning, authors propose a method based on lower costs that can be obtained by searching all the candidates which satisfy the routes for MV feeders, considering voltage drop and geographical restrictions. The proposed method implements, NSGA II to obtain a superior route for MV feeders. Note that, for a specific conductor type, the feeder cost is in direct relation with its length.

- **Cost of Power Loss**

Reducing the losses of power distribution systems is an exactly essential goal for the electrical utility. The most impressive configuration for minimization of power losses is an interested context for power companies. So, the results of this action are saving energy and enhancement of the operation performance of distribution system. By reducing the power losses, the total electricity cost will be decreased, and the total cost of producing electricity will be reduced as well. And as a result, the economic growth of utilities will be accelerated. Also, from the electricity market viewpoint, less power losses leads improving the efficiency and flexibility of distribution companies. Following equations are used to compute the cost of losses:

$$P_{loss(\mathrm{dl},s)} + jQ_{loss(\mathrm{dl},s)} = \sum_{n} I^2_{(\mathrm{n,dl},s)} \times \left(R_{(n)} + jX_{(n)}\right) \quad (18)$$

$$C_{losses} = \sum_{dl}\sum_{s} \pi_s^c \times \tau_{dl} \times \left[\left(P_{loss(\mathrm{dl},s)} \times C_{P-loss}\right) + \left(Q_{loss(\mathrm{dl},s)} \times C_{Q-loss}\right)\right] \quad (19)$$

- **Cost of Purchased Active Power from Power Market**

Electricity purchasing from power market by DisCo is the final process in the delivery of electricity from generation to the consumers. Portion of this purchased power is for distribution system customers and another portion is spent as losses in lines and equipment. This purchased power from market is evaluated by:

$$PM_{(\mathrm{dl},s)} = PD_{(\mathrm{dl},s)} + P_{Loss(\mathrm{dl},s)} \quad (20)$$

Cost of purchasing active power from power market through upstream network can be formulated as the following equation:

$$CM = \sum_{dl}\sum_{s} \pi_s^c \times \tau_{dl} \times PM_{(dl,s)} \times EP_{(dl,s)} \tag{21}$$

- **Reliability Cost**

The distribution networks are the main distinguished foundation to energy demand in directly or indirectly integrated. In power grids, failures due to human or natural factors and outage occurrences are common. The load not supplied (LNS) is estimated due to interruptions and must be evaluated for all customers. According to the failure rate in each branch and the amount of the interrupted loads, C_{RC} can be calculated. In case of failures, the lower quantity of this index guarantees more stable operation level of electrical grids.

$$C_{RC} = \sum_{dl}\sum_{s}\left(\sum_{n} \pi_s^c \times \tau_{dl} \times r_n \times C_{LNS} \times \lambda_n \times LNS_{(ld,s,n)}\right) \tag{22}$$

Constraints:

In this paper, OFR is defined as an optimization process formulated as hard-limit constraint:

These constraints must be satisfied in all states during all demand levels.

1. Power Flow Equation;

$$P_{HV} - \sum_{i} P_{MV,i} - V_i \sum_{k=1}^{N_{bus}} V_k Y_{ik} \cos(\delta_i - \delta_k - \theta_{ik}) = 0 \tag{23}$$

$$Q_{HV} - \sum_{i} Q_{MV,i} - V_i \sum_{k=1}^{N_{bus}} V_k Y_{ik} \sin(\delta_i - \delta_k - \theta_{ik}) = 0 \tag{24}$$

Where *i* is the Bus number.

2. HV Substation Voltage and Angle;

$$V_{HV} = 1\, p.u. \tag{25}$$

$$\delta_{HV} = 0 \tag{26}$$

3. Voltage Limits at other Buses

$$|V_{\min}| < |V_i| < |V_{\max}| \tag{27}$$

$$|\delta_{\min}| < |\delta_i| < |\delta_{\max}| \tag{28}$$

4. Line Thermal Limits;

$$\left| V_i \times \left(\left[(V_i - V_j) \times y_{ij} \right]^* \right) \right| < S_{ij}^{\max} \tag{29}$$

Where, $S_{ik}^{\max}$ and y_{ik} are maximum apparent power flow established in line and admittance of line that connected bus i and bus j. Due to limitations in land availability in real worlds and geographical constraints, the candidate feeder routes are selected but it can be expanded to others, depending on the case studies.

5. Simulation and Results

In a multistage procedure, the optimal routes of feeders are applied for two cases containing mid (5 years) and long-term (10 years) planning periods. In order to validate the practicability and efficiency of the proposed method, this method is applied for a real large-scale distribution network which is the output of MV substation placement problem, see section 2. Due to the matter of the problem, multiple objective functions are considered and solved using multi objective GA, so the output will be several non-dominated solutions that each of them can be selected to be implemented as the final strategy. It should be noted that all constraints are satisfied in all the obtained structures of non-dominated solutions, and the different selected feeder routes results the differences in the values of the objective functions. Statistical studies on the obtained structures is provided below. With all non-dominated solutions consideration, the probability of selection of each feeder for mid and long-term planning's considering all the obtained pareto-fronts are presented in the Tables 2-3.

Table 2: MEAN AND STANDARD DEVIATION OF FEEDERS SELECTION IN MID-TERM CASE

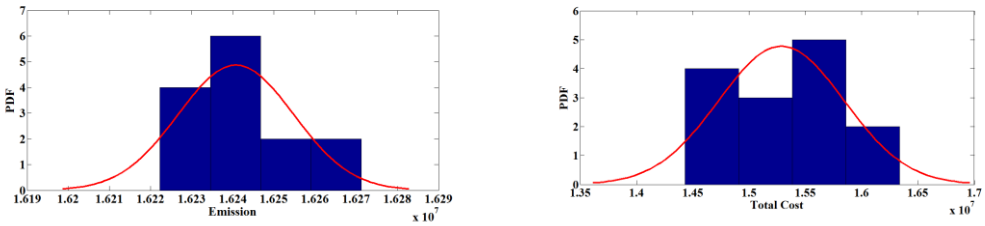
Feeder Number	From Bus	To Bus	Probability%	Feeder Number	From Bus	To Bus	Probability%
1	1	3	100	10	3	10	0
2	1	5	100	11	3	8	7.142
3	1	4	35.71	12	8	7	42.85
4	1	8	71.42	13	8	2	7.14
5	1	2	92.85	14	7	2	71.42
6	5	3	0	15	7	6	78.5
7	5	9	100	16	6	4	0
8	5	10	71.428	17	4	2	71.42
9	9	10	28.57	18	2	6	21.42

Table 3: MEAN AND STANDARD DEVIATION OF FEEDERS SELECTION IN LONG-TERM CASE

Feeder Number	From Bus	To Bus	Probability%	Feeder Number	From Bus	To Bus	Probability%
1	1	3	100	38	2	11	11
2	1	5	100	39	4	24	5
3	1	4	100	40	4	12	0
4	1	8	100	41	4	11	0
5	1	2	100	42	12	24	94
6	3	5	0	43	24	25	5
7	5	9	100	44	8	13	0
8	5	10	100	45	8	16	100
9	9	10	0	46	8	17	0
10	3	10	0	47	11	13	9
11	3	8	0	48	13	17	15
12	7	8	0	49	3	13	2
13	2	8	0	50	11	12	8
14	2	7	100	51	3	11	0
15	6	7	100	52	5	11	0
16	4	6	0	53	12	25	82

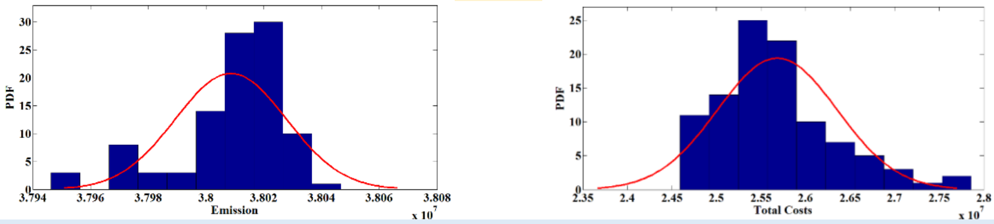
17	2	4	0	54	5	12	54
18	2	6	0	55	9	25	47
19	1	11	84	56	3	17	84
20	6	28	30	57	17	18	27
21	26	27	100	58	5	23	0
22	7	15	76	59	9	23	12
23	14	15	29.	60	18	19	45
24	8	15	12	61	18	21	38
25	15	16	0	62	19	20	99
26	7	28	0	63	19	21	81
27	7	14	1	64	10	20	35
28	14	28	12	65	10	23	88
29	2	28	4	66	21	22	100
30	4	28	63	67	5	20	0
31	4	26	84	68	3	20	0
32	24	26	23	69	3	19	24
33	12	26	0	70	17	19	0
34	2	14	0	71	3	18	52
35	8	14	38	72	5	25	0
36	13	14	49	73	11	14	4
37	2	13	0	74	1	13	74

Also, the probability distribution functions for some of the objective functions are obtained in order to show the variation of these objective functions values. As explained before, multi-objective algorithm leads to several non-dominated solutions. So, several topologies of feeders have been obtained. A statistical investigation on the obtained networks and the value of emission amount and also the total costs are accomplished to study the efficiency of the obtained optimal networks under load and market price uncertainties.



(a) Probability Density Function for Emission for non-dominated solutions in mid-term planning

(b) Probability Density Function for Costs for non-dominated solutions in mid-term planning



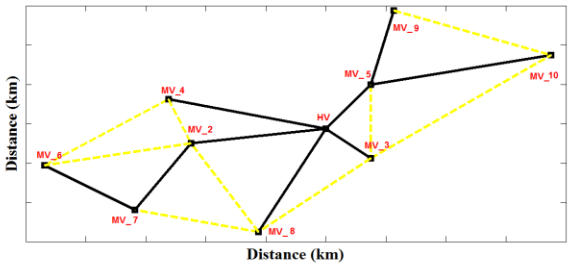
(c) Probability Density Function for Emission for non-dominated solutions in long-term planning

(d) Probability Density Function for Costs for non-dominated solutions in long-term planning

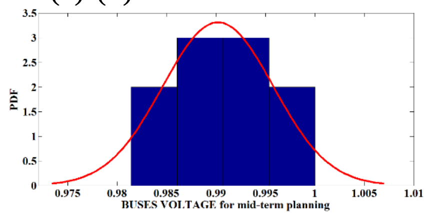
Fig. 6. Probability Density Function for non-dominated solutions

In Fig. 6, probability density functions for non-dominated solutions in the case of

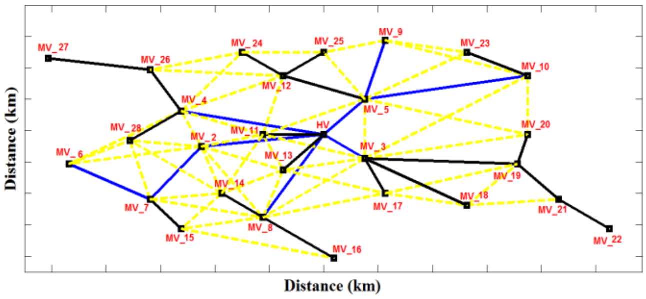
emission and costs are described for both mid-term and long-term planning.
There is generally only one procedure in practice. From the Pareto optimal set, the designer must select one solution. Here, fuzzy set theory is capable of specifying the best compromised solution [1]. Applying fuzzy set theory to non-dominated solutions obtained from NSGA II to find the best compromise solution leads to the following configurations, represented in Figs. 7 (a)-(c). These structures preserve all the technical constraints such as voltage range. In this regard, probability distribution functions of buses voltages are defined by taking into account all the scenarios provided. It is clear that buses voltages are always within the standard ranges. Due to the fact that VSF_{total} is affected by buses voltages, resulting from the variations in the values of active and reactive loads during different scenarios, probability distribution function of VSF_{total} are represented for both mid-term and long-term configurations in Figs. 8 (a)-(b).



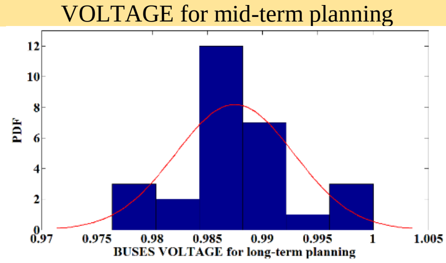
a) Configuration for mid-term planning



b) Probability Density Function of BUSES VOLTAGE for mid-term planning

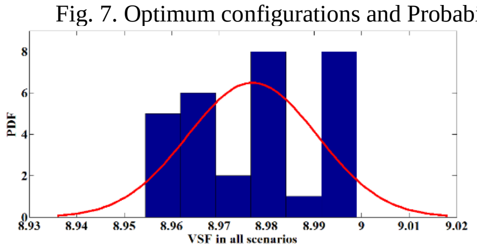


c) Configuration for long-term planning

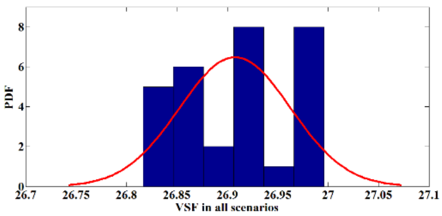


d) Probability Density Function of BUSES VOLTAGE for long-term planning

Fig. 7. Optimum configurations and Probability Density Function of BUSES VOLTAGE



a) Voltage Stability Factor for mid-term planning



b) Voltage Stability Factor for long-term planning

Fig. 8. Voltage Stability Factor

Another objective function is network's implementation cost. The values of the proposed cost function for these designs are given as below.

Table. 4: **Costs Analysis**

Mid-Term Planning	15.950 M$
Long-Term Planning	26.002 M$

It is clear from the results that the proposed method is more effective leading to proper technical network structures and causing lower environmental pollution. Implementation costs of the designs are also as low as possible. Considering geographic constraints, the proposed method is implemented on real network based on the GIS data. Regarding the uncertainties in forecasting future load and market price, applying uncertainties in design scheme to have more efficient power network is desirable. Therefore, power network must be able to provide energy for the future demand at higher reliability. Lower network capacity causes technical problems, disturbing the proper performance of the grid. Meanwhile, investing too much is not reasonable due to the limited financial resources. In addition, considering different objective functions besides the implementation cost, gives high visibility to designers to implement a comprehensive plan that covers all the technical aspects of the network as well as environmental issues.

6. Conclusion

This paper presents a stochastic multistage expansion planning method to consider the forecasting errors as well as the pseudo dynamic behavior of the network parameters and geographical constraints. The optimal MV feeders routing in distribution networks are found for both mid and long-term cases with probabilistic modeling. Multi objective formulations from the DisCo viewpoints have been provided in order to find the strategy which is suitable from the economic, environmental and technical aspects. Final solution reduces the voltage deviation and emission, enhances the voltage stability and has the lower costs to be implemented. The increasing responsibility of the power system and improving the system performance parameters are achieved simultaneously when the best possible condition with multi-objective functions are offered and solved using NSGA II. The proposed multi-objective formulation has the advantages of obtaining non-dominated solutions and allowing the system operator (decision maker) to exercise his/her personal preference in selecting each of those solutions based on the operating conditions of the system and the costs. To validate the effectiveness of the proposed scheme, the simulations are carried out on a relatively large-scale distribution network.

R E F E R E N C E S

[1] Karimi, Masoumeh, Mohammad Reza Jannati Oskuee, Mohammad Javad Amroony Boushehry, and Sajad Najafi Ravadanegh. "Optimal planning of distributed generation with application of multi-objective algorithm including economic, environmental and technical issues with considering uncertainties." International Journal of Ambient Energy (2016): 1-9.

[2] Abdulrazzaq, Ali Abdulwahhab, Mircea Eremia, Lucian Toma, And Corneliu Alexandru Mandiş. "Optimal Distributed Generators Placement in A Radial Distribution Network", University Politehnica of Bucharest Scientific Bulletin, Series C-Electrical Engineering and Computer Science, 2016
[3] Ravadanegh, Sajad Najafi, Mohammad Reza Jannati Oskuee, and Masoumeh Karimi. "Multi-objective planning model for simultaneous reconfiguration of power distribution network and allocation of renewable energy resources and capacitors with considering uncertainties." Journal of Central South University 24, no. 8 (2017): 1837-1849.
[4] Brenna, Morris, Federica Foiadelli, Michela Longo, and Dario Zaninelli. "Correlation Between Renewable Power Plants and Voltage Dips In Electrical Distribution Systems." University Politehnica Of Bucharest Scientific Bulletin Series C-Electrical Engineering and Computer Science 79, No. 3 (2017): 153-170.
[5] Salehi, Javad, and Mohammad Reza Jannati Oskuee. "Optimal planning of distributed generation from the DisCo and the DGO viewpoints considering the uncertainties in future demand and electricity price." International Journal of Ambient Energy (2017): 1-10
[6] Gonen T. 1986 Electric power distribution system engineering. New York McGraw-Hill.
[7] Joong Rin Shin Byung Seop Kim Jong Bae Park and Lee K Y 2007 A New Optimal Routing Algorithm for Loss Minimization and Voltage Stability Improvement in Radial Power Systems. IEEE Trans. Power Syst. 22(2): 648-657.
[8] Nahman J M and Peric D M 2008 Optimal Planning of Radial Distribution Networks by Simulated Annealing Technique. IEEE Trans. Power Syst. 23(2): 790-795.
[9] Khator S. K. and Leung L. C. 1997, Power distribution planning: a review of models and issues. IEEE Trans. Power Syst. 12(3): 1151-1159.
[10] Willis H L 1997 Power Distribution Planning Reference Book. New York. Marcel Dekker.
[11] Gonen T and Ramirez-Rosado I J 1987 Optimal Multi-Stage Planning of Power Distribution Systems. IEEE Trans. Power Delivery. 2(2): 512 – 519
[12] Jonnavithula S. and Billinton R. 1996 Minimum cost analysis of feeder routing in distribution system planning. IEEE Trans. Power Deliv. 11(4):1935 - 1940.
[13] Nicholas B G and Papadopoulos M P 2002 Optimal feeder routing in distribution system planning using dynamic programming technique and GIS facilities. IEEE Trans. Power Delivery. 17(1): 242-247.
[14] Fletcher R H and Strunz K 2007 Optimal Distribution System Horizon Planning–Part I: Formulation. IEEE Trans. Power Syst. 22(2): 791–799.
[15] Ravadanegh S N and Roshanagh R G 2014 On optimal multistage electric power distribution networks expansion planning. Int. J. Electr. Power Energy Syst. 54(): 487–497.
[16] Ganguly S Sahoo N C and Das D 2011 Mono- and multi-objective planning of electrical distribution networks using particle swarm optimization. Appl. Soft Comput. 11(2): 2391–2405.
[17] Sahoo N C Ganguly S and Das D 2011 Simple heuristics-based selection of guides for multi-objective PSO with an application to electrical distribution system planning. Eng. Appl. Artif. Intell. 24(4): 567–585.
[18] Deb K. Pratap A Agarwal S. and Meyarivan T. 2002, A fast and elitist multiobjective genetic algorithm: NSGA-II." Evolutionary Computation. IEEE Trans. Evolutionary Computation. 6(2): 182-197.
[19] Khatami H. and Najafi Ravadanegh S (2015) Probabilistic Optimal Robust Multistage Feeder Routing Under Load Forecasting Uncertainty. IET Generation, Transmission & Distribution. 10(1): 65-74.
[20] Ramirez-Rosado I J and Bernal-Agustin J L 1998 Genetic algorithms applied to the design of large power distribution systems. IEEE Trans., Power Syst. 13(2) 696-703.
[21] Biggs N 1993 Algebraic graph theory. Cambridge Mathematical Library. Cambridge. Cambridge University Press.
[22] Salehi, Javad, Mohammad Reza Jannati Oskuee, and Arman Amini. "Stochastics multi-objective modelling of simultaneous reconfiguration of power distribution network and allocation of DGs and capacitors." International Journal of Ambient Energy (2017): 1-12.