Optimal Placement and Sizing of Distributed Generation in Microgrid for Power Loss Reduction and Voltage Profile Improvement

Ferinar Moaidi, Mahdi Moaidi

Abstract**—**Environmental issues and the ever-increasing in demand of electrical energy make it necessary to have distributed generation (DG) resources in the power system. In this research, in order to realize the goals of reducing losses and improving the voltage profile in a microgrid, the allocation and sizing of DGs have been used. The proposed Genetic Algorithm (GA) is described from the array of artificial intelligence methods for solving the problem. The algorithm is implemented on the IEEE 33 buses network. This study is presented in two scenarios, primarily to illustrate the effect of location and determination of DGs has been done to reduce losses and improve the voltage profile. On the other hand, decisions made with the one-level assumptions of load are not universally accepted for all levels of load. Therefore, in this study, load modelling is performed and the results are presented for multi-levels load state.

Keywords**—**Distributed generation, genetic algorithm, microgrid, load modelling, loss reduction, voltage improvement.

I. Introduction

THE excessive increase in emissions from fossil fuel plants has led to the signing of the Kyoto agreement by EU countries. Accordingly, these countries required a substantial reduction in greenhouse gas emissions. According to the US Environmental Protection Agency [1], greenhouse gases have been the main cause of climate change, and their presence in the atmosphere has increased by about 7% between 1990 and 2014. Most of the environmental pollution caused by greenhouse gases is due to the electric power generation, and according to the annual report released in 2014, the electric power generation system occasions to 29% of the pollution [1].

So far, many studies [2]-[7] have been done to optimize DGs presence in the distributed network. Turning to dispersed production sources with the goal of generating clean energies and using unlimited lifetime resources was the first reason why the idea of using these resources was more important, then the voltage profile as an index of power quality assessment in the distribution system will increase the importance of the issue. DG can have positive or negative effects on the voltage profile of distribution networks. Therefore, determining the appropriate location of these resources can reduce or increase the losses, so studying methods that determine the location and capacity of the optimal production of DGs are important. This is well illustrated in Fig. 1.

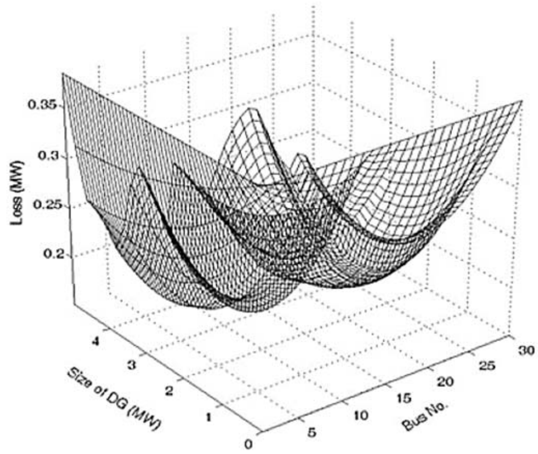

Fig. 1 The Impact of DG Capacity and Position on System Losses [2]

In [2] the weighting factor method is applied for converting the multi-objective function to a unique function, and optimization with two objectives is done to reduce losses and improve the voltage profile. Using this method, with easy understanding and simple implementation has its own barriers. The need for a method of generating weight factors to improve the accuracy of the optimization results and the necessity of existing a convex space, are among the main restrictions in this regard. Meanwhile, in this method, the use of the power flow algorithm has increased the enormous amount of problem-solving time, while the existence of an initial random population in artificial intelligence algorithms decreases over time.

In [3], an improved analytical method has been used, but only the reduction of power losses has been achieved and the voltage profile has not been considered, while the presence of DG sources in different buses can affect the bus voltage profile. Increasing the voltage profile at low load hours due to the reactive power injected by these resources and the unreasonable reduction of the voltage profile in network pick hours can greatly affect the power quality of the network, in addition, the program is just considered for one level of load.

In [4] and [5], an analytical method has been used to determine the optimal capacity of DGs. In general, numerical and analytical methods are less accurate than artificial

Ferinar Moaidi is with the Faculty of Electrical Engineering, K. N. Toosi University of Technology, Tehran, Iran (e-mail: ferinar_moaidi@yahoo.com).
Mahdi Moaidi is with VEFAGH NIROO Company of research and executive projects on electricity distribution network expansion and operation, Ahvaz, Iran (e-mail: m.moaidi@yahoo.com).

intelligence algorithms. Using the derivation to achieve minimal loss rates requires the definition of a differentiable function, so this method is not responsive in the absence of a differentiable objective function. In [4], this method is only used to determine the optimal resource capacity. The DG installation is limited to two specified buses by the user, thus the exact optimal point cannot be accessed. Accordingly, power loss is not minimized, but both parameters of power losses and DG power factor are targeted. In [5], the optimal location and capacities of the DGs are determined and both the power loss and DG power factor parameters are targeted, however, DGs with different power coefficients increase the costs of the proposed algorithm. In addition, the use of DG sources in the voltage regulation mode is not allowed according to the IEEE-1547 standard, and it is usually planned for the worst conditions with a power factor of 0.9. Also, schedules are only done for the nominal load, and results cannot be generalized to all conditions.

In [6], an intelligent GA is used for optimization, and load levels including low load, average load and pick load are considered in scheduling, which allows the use of the results obtained for all conditions in the network. Also, regarding the IEEE-1547, the lack of use of DGs in the voltage control mode is considered to be the worst condition for the power factor, but the use of the weight coefficient method for converting a multi-objective problem to a single object has the same problems as [2] which reduces the accuracy of the solutions and limits the optimizer discovering space.

In [7], the method of plant growth simulator algorithm (PGSA) is used to determine the location and optimal capacity of DGs to reduce losses and improve the voltage profile of the grid. The proposed method of [7] is compared with the proposed algorithm of this paper.

The rest of this paper is organized as follows. In Section II, the mathematical formulation of the problem is described. Section III presents the GA strategy. Section IV will give experimental results and analysis by defining a test case. Finally, the research will be concluded in the last section.

II. Mathematical Modelling

Optimization is done with the goal of reducing losses and improving the voltage profile. Solving the multi-objective problem in the format of single objective function is fulfilled by certain methods. Here, with the aid of the bounded constraints method, the problem will be converted into a single objective function. The objective function is defined as:

$$Function = loss \tag{1}$$

We consider that the objective function includes power losses, only. This function is used as an indicator of optimal DG location. The second goal of the problem that concerns the improvement of the voltage profile is considered as a constraint of the optimization problem, which is one of the principles of converting multi-objective optimization to single-objective optimization in bounded constraint method.

Adding DG to the network should not cause network hazardous operation, so the requirements for the correct operation of the network are considered as:

1. Bus Voltage Limit: The maximum allowable voltage drop in this research is considered to be 5%.

$$0.95 \le |v_{bus}(i)| \le 1.05 \tag{2}$$

in which $v_{bus}(i)$ is the voltage in bus i^{th}.

2. Limit of active power generated by DGs:

$$P_{DGi}^{\min} \le P_{DGi} \le P_{DGi}^{\max} \tag{3}$$

3. Reduction of reactive power generated by DGs:

$$Q_{DGi}^{\min} \le Q_{DGi} \le Q_{DGi}^{\max} \tag{4}$$

4. DG-power factor: According to the description in Section I, we are not authorized to use DGs in voltage control mode, and these results are obtained after the IEEE-1547 standard review, while [8] emphasizes that the power factor of DG sources ranges from 0.9 to 1, and this number is usually very close to 1, but it is planned to be 0.9% as the worst possible conditions.
5. Limit on the number of DGs: If there is a limitation on the number of DGs, this restriction will be entered into the target function.
6. Restrictions on DG Installation Points: If the potential for installing a DG does not exist in a number of network buses, this restriction will be considered in the target function.

P_{DGi} and Q_{DGi} denote the active and reactive power produced by DG, respectively. For simplicity, DG units are modelled as PQ bus with a negative value for active and reactive power.

III. Genetic Algorithm

The GA considers the creation of a random population of a location for each DG source. After executing the load flow program, it calculates the losses in the predicted states for the position of the DG per bus, then separates the optimal states from non-optimal modes. And these optimal states are used by the parent to generate population in the next generation, and this process will be repeated until the conditions for stopping the algorithm will be satisfied. The summary of the proposed GA is as follows:

A. Create a random population with n2 numbers for each gene composed of n locations and n capacity (n is the selected number of DGs).
B. Calculate the power loss function for each gene and select some of the best members of the population as parents and practice combining (intersection) on them to create children.
C. Select some members of the population randomly, a mutation on them and create a population of the mutated members.

D. Integrate the main population, the population of children and the population of the mutated members in order to create a new population.
E. Evaluate and sort the answers and remove additional answers.
F. Review the condition for stopping the GA if the results are satisfied, the process will stop; otherwise, the algorithm returns to step (B).

IV. CASE STUDY

The microgrid in this dissertation shown in Fig. 2 has a radial system of 12.66 kV with 33 buses and 32 lines; the base power is considered 1 MW. The total network load is 72.3 MW. The network total load is 3.2 MW active power and 2.3 MVAr reactive power. Power losses in this network before installing DG units is 211 kW which is equal to 5.6% of the total load.

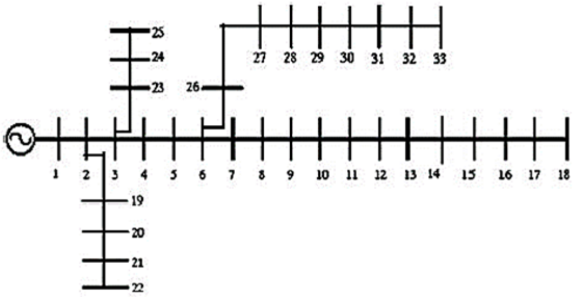

Fig. 2 IEEE-33 buses test case

The importance of installing DG sources in the microgrid is examined in two scenarios, which primarily show the impact of the DGs in reducing losses and improving the voltage profile. Secondly, the ineffectiveness of the results is expressed in terms of the different levels of the network load.

A. First Scenario: Optimal Determination of the Location and Capacity of DGs in Nominal Load Condition

At this stage, the load is considered in constant power and scheduling is performed for a single load level (nominal load). The results of this scenario are compared with the results in [7]. In [7] the plant growth simulator algorithm (PGSA) is utilized for addressing the optimal DG allocation problem.

Our method gradually reduces the amount of active power losses by comparing the pre-DG setting with the increase in the number of DG sources. The results for DG locations and capacities and the reduction of losses are summarized in Tables I and II. Fig. 3 demonstrates the power loss results graphically.

It is observed that the presence and increment of DG sources significantly reduced the active power losses in the network. As it is clear, the installation of one DG source reduces the power losses of the network by approximately 45%, and the installation of two sources and three sources leads to 59 % and 67% reduction in losses, respectively.

Fig. 4 shows the effect of increasing the number of DGs in improving the voltage profile exclusively by using the proposed algorithm in this project. According to the network diagram, having a minimum voltage of 0.9131 and a maximum voltage of 1 per-unit, there is a voltage drop of 8.69% in the network before the DG application. After the installation of DG units and increase their number, it is possible to obtain flattened voltage graphs with percentages of lower voltage variations.

Table III gives an overview of the results of loss reduction and improvement of the voltage profile of the PGSA and the proposed algorithm in this research. By analyzing the results recorded in Table III for the optimal placement and allocation of three DGs for both methods, we will conclude that the proposed GA in this research has better results in reducing losses and improving the voltage profile.

TABLE I
SELECTIVE DGS CAPACITY AND LOCATION USING GA FOR THE 33-BUSES NETWORK

Number of DGs	Point of DG installation	DG capacity (MW)	Total DG capacity (MW)
0	-	-	-
1	7	2.886	2.886
2	13	0.844	2.023
	30	1.179	
3	14	0.761	3.013
	24	1.17	
	30	1.082	

TABLE II
ACTIVE POWER LOSS FOR 33-BUSES NETWORK FOR INCREASING THE NUMBER OF DGS

Number of DGs	Power loss (kW)	Percentage of loss reduction
0	211	-
1	114.1464	45%
2	84.7206	59%
3	68.6484	67%

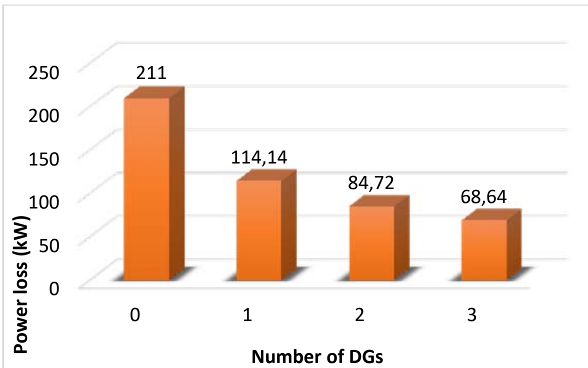

Fig. 3 Active power loss for the test network for increasing the number of DGs

TABLE III
COMPARING TWO METHODS

Method	Point of DG installation	DG capacity (MW)	Power loss (kW)	Percentage of loss reduction	Minimum Voltage
GA	14	0.761	68.6484	67%	0.9861
	24	1.17			
	30	1.082			
PGSA [7]	17	0.5735	97	52%	0.9664
	18	0.1818			
	33	0.9836			

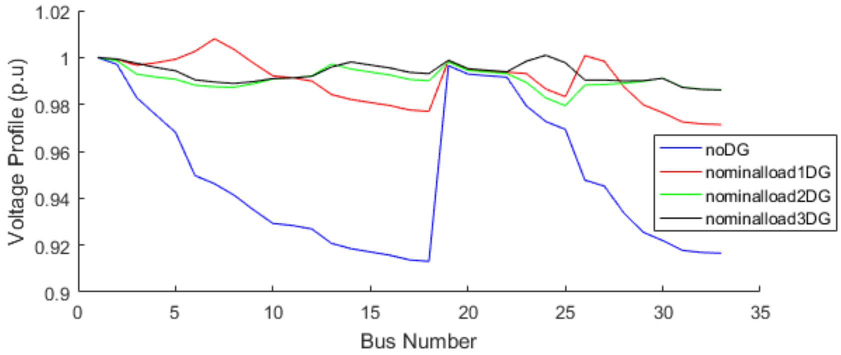

Fig. 4 Comparison of the changes made in the voltage profile for increasing the DG number in the proposed method

TABLE IV
THE VALUES OF A AND B COEFFICIENTS FOR DIFFERENT LOAD STATES [9]

Season	Subscriber Type	Day		Night	
		α	β	α	β
Summer	Residential	0.72	2.96	0.92	4.04
	Commercial	1.25	3.5	0.99	3.95
	Industrial	0.18	6	0.18	6
Winter	Residential	1.04	4.19	1.30	4.38
	Commercial	1.5	3.15	1.51	3.4
	Industrial	0.18	6	0.18	6

TABLE V
DETERMINING THE LOAD TYPE FOR EACH BUS [9]

Bus Number	Subscriber Type	Bus Number	Subscriber Type
2	Commercial	18	Residential
3	Commercial	19	Commercial
4	Commercial	20	Commercial
5	Residential	21	Commercial
6	Residential	22	Commercial
7	Industrial	23	Commercial
8	Industrial	24	Industrial
9	Residential	25	Industrial
10	Residential	26	Residential
11	Residential	27	Residential
12	Residential	28	Residential
13	Commercial	29	Commercial
14	Commercial	30	Industrial
15	Residential	31	Commercial
16	Residential	32	Industrial
17	Residential	33	Commercial

B. Second Scenario: Determination of the Location and Capacity of DGs in Multi-Levels Load Condition

In this scenario, the load is modelled by considering the dependence of the load on the voltage. In fact, the load power is not constant and it is dependent on the bus voltage. This will increase the accuracy of calculations in losses. Load models are mathematically summed as [9]:

$$P_i = P_{oi}\left(\frac{v_i}{v_{oi}}\right)^{\alpha} \quad (5)$$

$$Q_i = Q_{oi}\left(\frac{v_i}{v_{oi}}\right)^{\alpha} \quad (6)$$

in which v_i is the voltage in bus i^{th} and P_i and Q_i are the active and reactive power in the bus i, respectively. Consequently, v_{oi} is the rated voltage in bus i^{th} and P_{oi} and Q_{oi} are the active and reactive power in the bus i, at the nominal condition.

α and β coefficients illustrate the commercial, industrial and residential loads by applying different quantities. Also, different load levels consumption do not occur simultaneously for all types of load, and accordingly the values of these coefficients are calculated for taking load variations at the 24 hours in the day and the changes in the summer and winter seasons. The values of these coefficients are given in Table IV. Note that, in the first scenario, these coefficients are assumed to be zero.

In order to take account of various commercial, industrial, and residential loads in the network, Table V shows the paper assumptions for load types in all buses. Bus-1 is the slack bus (reference) and is not included in this categorization.

The results presented in the second scenario are based on the three load levels in a typical region with the following conditions:

a. Minimum load on the winter days
b. Average load on the summer nights
c. Maximum load on the summer days

In these results which are summarized in Table VI, by considering the three levels of load, the results of the location and optimal capacity of the DG sources are different from the first scenario. In other words, the results of the decisions in unrealistic situations without considering the daily change in the load and the load dependence on the voltage profile cannot be generalized to the real situation of the network, and moreover, it can have devastating effects on the network operation.

The obtained amount of power loss before load modelling is different from the second scenario outputs. So, we do not have the correct information on the amount of network losses before load characteristics modelling and the delivered answers that were given for the amount and location of the DG sources in the first scenario are completely different from the second scenario and should not be applied to the actual network conditions. This illustrates the importance of load modelling in dependence on voltage variations, as well as changes in daily and annual climate.

The proposed approach has reduced the power loss significantly for all three load levels, and approximately maintains network losses for all three levels by equal quantities after DG installation, and thus will not create more costs for the network operator. Also, the comparison of the results at three levels of load indicates that, in the low load and pick load conditions after DG placement, the losses are slightly higher than the average load status of the network, which is due to the voltage imbalance at these two levels of load that leads to more reactive power flow. The results are thus to be considered in order to present a proposal for installing a distributed source in the surveyed network:

1. If we can only accommodate two DGs in the network, 24 and 30 buses are appropriate candidates.
2. If we can only accommodate three DGs in the network, the buses 13, 24, and 30 are appropriate.
3. For accommodation of four DGs, we recommend the buses 13, 14, 24 and 30.

TABLE VI
RESULTS OF LOSS REDUCTION, LOCATION AND CAPACITY OF DG FOR DIFFERENT LOAD LEVELS

Network Condition	Point of DG installation	DG capacity (MW)	Power loss before DG installation (kW)	Power loss after DG installation (kW)	Percentage of loss reduction
Before load modelling	14	0.761	211	68.6	67.48%
	24	1.17			
	30	1.082			
Low Load	30	1.001	161.96	40.27	75.13%
	24	1.133			
	13	0.733			
Medium Load	30	1.012	164.01	39.58	75.86%
	13	0.745			
	24	1.134			
Pick Load	13	0.748	165.58	40.91	75.29%
	24	1.135			
	30	1.009			

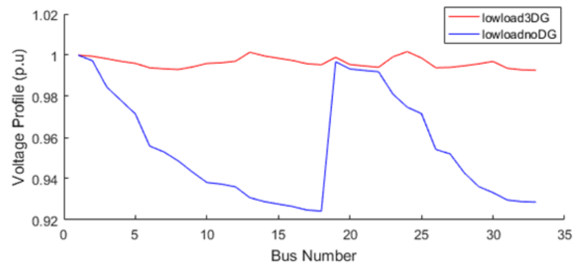

Fig. 5 Voltage profile improvement at low load

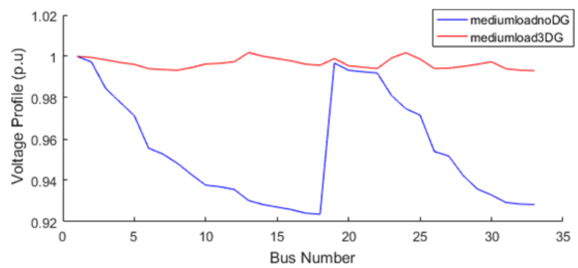

Fig. 6 Voltage profile improvement at medium load

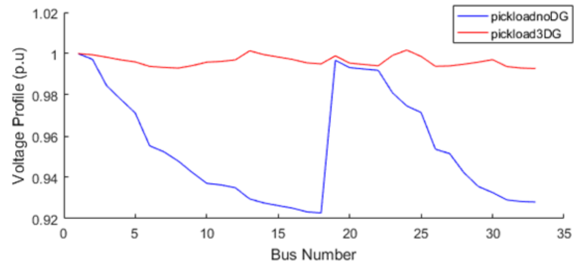

Fig. 7 Voltage profile improvement at high load

Figs. 5-7 show the results of the improvement of the voltage profile after modelling the load for three levels of low load, average load and peak load.

Bus-18 is more clearly marked for a comparison of the cases at three levels of load prior to the installation of a DG source, which indicates an increase in the voltage profile due to the network load reduction. This is elaborated in the blue lines of Figs. 5-7. In Fig. 8, the voltage stability of bus-18 which is fixed at 0.995, is noticeable at all three levels. It is emphasized that bus number 18 has the highest voltage drop before DG installing due to the distance from the slack bus.

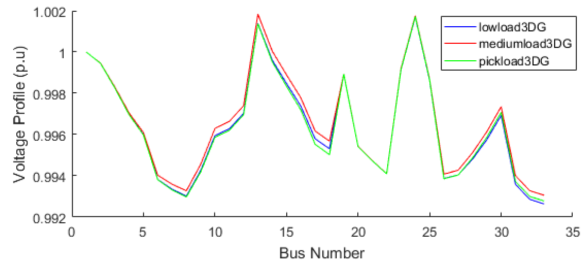

Fig. 8 Results of voltage profile at three load levels after DG installation

V. CONCLUSION

In this project, a GA has been used to find the optimal solution of the problem of positioning and the capacity determination of dispersed generation units to reach two goals of reducing power losses and improving the voltage profile. Considering the first goal as the main objective and the second goal as the limitation of the optimization problem made it easier for handling a multi-objective problem in a single objective format with limited constraints method. The research shows that the presence of DG sources in the microgrid can dramatically reduce the power losses of the network. Decisions are not secure before modelling the load for real network conditions, and in order to obtain more accurate answers, annual and daily changes in load pattern should be considered for all types of industrial, residential and commercial subscribers. In other words, the results obtained for the single-level load in nominal condition cannot be generalized to all levels of load.

REFERENCES

[1] "Sources of Greenhouse Gas Emissions | Greenhouse Gas (GHG) Emissions | US EPA", Epa.gov, 2017. (Online). Available: https://www.epa.gov/ghgemissions/sources-greenhouse-gasemissions#

transportation. (Accessed: 01- Apr- 2017).

[2] G. Zareiegovar, R.R. Fesaghandis, M.J. Azad," Optimal DG location and sizing in distribution system to minimize losses, improve voltage stability, and voltage profile," Proceedings of 17th Conference on Electrical Power Distribution Networks (EPDC), 1-6,2012, 1-6,2012.

[3] Duong Quoc Hung, N. Mithulananthan, "Multiple Distributed Generator Placement in Primary Distribution Networks for Loss Reduction ", IEEE Transactions on Industrial Electronics, Vol. 60, no. 4, 1700-1708, 2013.

[4] M. Shahzad, I. Ullah, P. Palensky, and W. Gawlik, "Analytical approach for simultaneous optimal sizing and placement of multiple distributed generators in primary distribution networks" *IEEE*, 2014.

[5] M. Shahzad, I. Ahmad, W. Gawlik, and P. Palensky, "Load Concentration Factor Based Analytical Method for Optimal Placement of Multiple DistributionGenerators for Loss Minimization and VoltageProfile Improvement", *MDPI, energies*,2016/4/12.

[6] D. Singh, D. Singh, K.S.Verma, , "Multiobjective Optimization for DG Planning With Load Models ", IEEE Transactions on Power Systems, Vol. 24, no. 1, 427-436, 2009.

[7] S.A. Heydari, T. Heydarzadeh, Naser M. Tabatabaei, "A combined approach for loss reduction and voltage profile improvement in distribution systems" *International Journal on Technical and Physical Problems of Engineering*, Vol. 8, No. 1, March 2016, Pp 30-35.

[8] IEEE P1547 *Standard for Distributed Resources Interconnected with Electric Power Systems, IEEE P1547 Std*. Sep 2002.

[9] R. Baghipour, S.M. Hosseini, "A Hybrid Algorithm for Optimal Location and Sizing of Capacitors in the presence of Different Load Models in Distribution Network", *Journal of Operation and Automation in Power Engineering*, Vol. 2, No. 1, Winter & Spring 2014, Pages: 10-21.

Ferinar Moaidi was born in Ahwaz, Iran in 1994. She received the B.Sc. degree in Electrical Power Engineering and the MSc degree in Electrical Engineering-Power Systems from K. N. Toosi University of Technology, Tehran, Iran, in 2016 and in 2018, respectively. She always ranked as the top student of Superior Talent Center for entering the higher degree of studies without examination. She was the Ph.D. candidate of top-ranking universities of Iran for entering directly to interviews without examination as the top student of Superior Talent Center in June 2018.

Her research interests are in the fields of electricity distribution network, demand-side management, electric vehicles, and the smart grid.

Since September 2016, she is the chairwoman of VEFAGH NIROO Company of research and executive projects on electricity distribution network expansion and operation in Ahvaz, Iran.

Mahdi Moaidi was born in Ahwaz, Iran in 1963. He received the B.Sc. degree in Electrical Power Engineering and the MSc degree in Executive Management, in 1994 and in 2018, respectively.

His research interests are in the fields of electricity distribution network, operation, planning, and distributed generation.

Since September 2004, he is the Chief Executive Officer (CEO) of VEFAGH NIROO Company of research and executive projects on electricity distribution network expansion and operation in Ahvaz, Iran.