

Reliability Assessment of the Smart Distribution System in the Presence of Microgrids Using Monte Carlo Method

Masoud Jokar Kouhanjani*^{ID}, Farshad Jafari^{ID}, Somayeh Najibi^{ID}

Shiraz Electricity Distribution Company

* Corresponding Author: masoudjokar@hotmail.com

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Abstract

This research paper aims to introduce a novel approach for evaluating the reliability of smart distribution system in the presence of microgrids. Microgrids, predominantly utilizing wind turbines and solar cells, pose a unique challenge to assessing distribution system reliability. To tackle this, the study employs the Monte Carlo method to calculate the availability of wind and solar energy. Subsequently, the presented method in this article is utilized to obtain reliability indices for the distribution system with integrated microgrids. Importantly, the proposed method takes into account the influence of renewable resources during system recovery. By incorporating this method, the assessment of distributed generation resources within microgrids becomes more straightforward for evaluating the reliability of the distribution system. The effectiveness of this method was assessed by modeling the desired indices on a distribution feeder comprising 13 distribution posts. It is assumed that each of these 13 points incorporates a microgrid dedicated to supplying local customers. Wind turbines and solar cells are installed as backup power sources for each customer.

Keywords: Microgrid, Distribution system, Reliability, Solar cell, Wind turbine

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1. Introduction

With increasing government emphasis on reducing environmental pollution, the adoption of renewable energy has gained substantial momentum. This has given rise to a new paradigm in the electricity industry known as microgrids. Microgrids leverage nearby renewable resources to minimize losses, transmission line costs, and voltage drop, thereby facilitating a more efficient and sustainable energy ecosystem. Operating at low voltage levels, microgrids serve as miniature versions of the conventional power grid, fueling new avenues of exploration within the electricity industry. One prominent research area is

the intelligentization of power systems, particularly the distribution system, which has become a subject of considerable discussion and exploration.

Guo-hua et al. [1] employ the Monte Carlo method to evaluate the reliability of grid-connected solar cells at the distribution level. This pioneering study compares load-based and system-based reliability indices for two distinct modes of the distribution system: with and without the presence of solar cells. Furthermore, Billinton and Wang [2] introduce distribution system reliability indices and offer a comprehensive evaluation using Monte Carlo simulation methods.

Wei et al. [3] define a microgrid as a system for the distribution of low or medium voltage, which includes generators such as wind turbines, solar cells, microturbines, etc., that supply thermal and electrical loads. These references indicate that a microgrid can be operated in two states: A) connected to the main grid, B) islanded mode. When it is connected to the main grid, in case of a fault, it can switch to islanded mode to improve reliability indices and supply the corresponding loads. This assumption is used in this article.

Ahmad et al. [5] and Arunkumar et al. [6] present an overview of optimal operation and energy management strategies in microgrids. These references survey various algorithms, optimization techniques, and control approaches implemented to optimize microgrid operation and maximize the utilization of renewable energy resources. Addressing the critical issue of cybersecurity in microgrid systems, Huang et al. [7] propose solutions to ensure resilience against potential cyber threats, highlighting the significance of robust security measures and protocols to protect microgrid infrastructure and ensure reliable and secure operation.

Further expanding on the topic, Marimuthu [8] explores advanced control techniques for microgrids, encompassing hierarchical control, predictive control, and distributed control approaches. This paper evaluates the performance of these strategies across different microgrid configurations, shedding light on their effectiveness in achieving optimal operation.

Mansouri et al. [9], Miao et al. [10], and Mizani and Yazdani [11] delve into the planning and modeling of microgrids connected to the distribution system, with a specific emphasis on wind turbines and solar cells. These studies determine optimal microgrid structures by considering the costs of renewable energy production and energy exchange with the grid, with a focus on cost minimization. Moreover, Miao et al. [10] evaluate the reliability and costs associated with various microgrid-to-distribution-system connection modes, including radial connection, ring connection, station switching with two different sources, radial connection in the presence of a microgrid, ring connection in the presence of a microgrid, and station switching with two different sources in the presence of a microgrid. These modes are compared using resource availability indices and connection costs.

By considering the increased reliability during the microgrid planning phase, Costa and Matos [13] delve into the economic evaluation of microgrids. The case study presented in Costa and Matos [13] involves a microgrid connected to the distribution system at a low voltage level, with the economic evaluation incorporating insights from this reference.

To summarize, this article primarily focuses on the evaluation of reliability in microgrids powered by wind and solar renewable sources. These microgrids are typically interconnected with the distribution system and utilize renewable resources as backup sources when necessary. The evaluation methods for reliability differ from conventional energy producers due to the dependence on factors such as wind speed and solar radiation intensity. The proposed approach employs the Monte Carlo method to calculate the unavailability of output from wind turbines and solar cells, providing valuable data for the assessment of microgrid reliability.

2. Calculation of Distribution System Reliability Indices

The distribution systems are designed in a ring way, but they are used in a radial way, therefore, in case of a fault along the feeder, it is possible to feed the load from sources in other feeders. The effect of this load transfer can be considered in the calculation by changing the repair duration [14] and [15]. By generalizing this method, a model for evaluating the reliability of the distribution system in the presence of microgrids is presented, which is explained below.

The consumption amount of a microgrid varies with time, so when the error occurs, the amount of consumption is calculated (the worst conditions can be considered as the maximum consumption). Of course, considering that several microgrids are connected to the distribution system along a medium voltage feeder and the consumption curve of each one is different, therefore, the time of the fault occurrence is considered as a specific time and according to that time and the corresponding curves, the amount of consumption of each microgrid is obtained. In this article, it is assumed that the fault occurred at 7:50 AM. As mentioned, at the moment of the fault, the microgrid is separated from the distribution system and the wind turbine and solar cell will take over the role of supplying the load. Considering that the production by these sources is also probabilistic, therefore, the probability of supplied load by these sources is less than the amount of consumption at the moment of the fault will be obtained, and this probability ($P_{nos}(i)$) is obtained by the Monte Carlo method. Due to the lengthening of the equations, only the results related to the Monte Carlo method are mentioned in the article. ($P_{nos}(i)$) is the probability of not supplying the load of the microgrid i in case of a fault. This probability should be included in the calculation of reliability indices. $P_{nos}(i)$ is considered in the problem during equipment repair and the system recovery time changes.

Considering that at the time of the fault, it is assumed that the microgrid is completely separated from the main grid, and it is possibly fed by distributed generation in the microgrid, so this possibility is included in the problem according to (1):

$$r_{new} = P_{nos}(i) * r_{old} + (1 - P_{nos}(i)) * r_{sec} \quad (1)$$

In this equation, r_{new} is the system recovery time in the microgrid, r_{old} is the equipment repair time, and r_{sec} is the switching time of load break switch that connects renewable energy sources to the microgrid.

3. Case Study

3-1. Assumptions of the Problem

- The entire load of the microgrid is supplied by the system before the fault occurs.
- Solar cells and wind turbines are error-free and only production is affected by their uncertainty.
- When a fault occurs, the microgrid is disconnected from the system
- 30% of microgrid load is considered as essential load. (The cost of not providing essential loads is assumed to be 5 times the cost of not providing normal loads)
- After isolating the fault location, the microgrid is not connected to the main grid again.

The method presented in the previous section is applied to a feeder from the distribution system of Shiraz city. The map of this feeder is given in Fig. 1 [16].

As seen in Fig. 1, the sample feeder has 13 distribution posts, which are considered 13 microgrids in these 13 load points to increase the reliability of the feeder, and the entire load of these microgrids is provided by the system. In Each microgrid, 2kW of wind turbines and solar cells is considered for each customer. The information about

the distribution posts of this feeder is given in Table 1. The daily consumption curve of microgrids is shown in Fig. 2. in this figure MG stands for Micro-Grid.



Fig. 1. Safir Jonoubi feeder of Amirkabir power station in Shiraz city

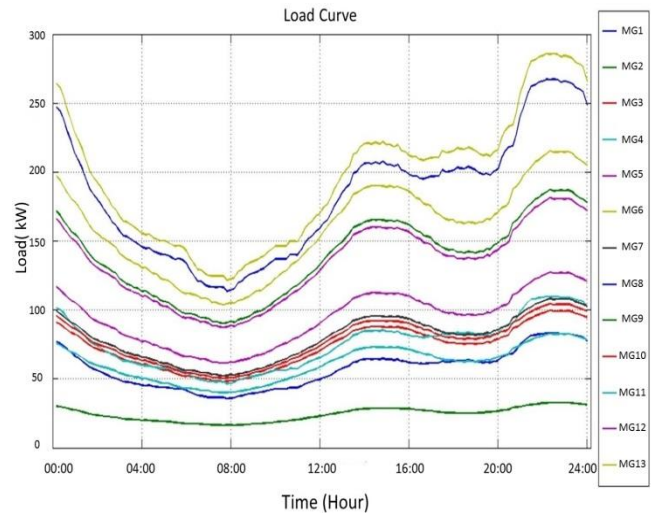


Fig. 2. Daily consumption curve of microgrids [16]

Table 1. Information of microgrids and feeders

installed Solar cell capacity (kW)	Installed capacity of wind turbine (kW)	Distribution post capacity (kW)	Average consumption load (kW)	Customers number	Microgrid
20	36	100	58	28	1
40	70	200	110.6	55	2
26	46	200	73.5	36	3
51	91	315	142.5	71	4
46	82	315	129.1	64	5
57	102	315	158.4	79	6
44	80	315	125.8	62	7
66	116	630	182.9	91	8
9	24	50	24.26	12	9
28	76	200	76.8	38	10
22	38	200	60.9	30	11
48	84	315	133.4	66	12

70	124	630	195.6	97	13
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Now, the average consumption of microgrids in terms of kW is obtained, and then, using the Monte Carlo method, the probability that the production of the microgrid itself is less than the amount of consumption in this particular hour is calculated. To obtain this probability, real information about the Shiraz city extracted from the SATBA organization website, is used [17].

Table 2 shows the probability of not supplying the load according to the average consumption of microgrids for all loads and separately for essential loads.

Table 2. The probability of not supplying all microgrid loads and not supplying essential loads

The probability of not supplying important loads	The probability of not supplying the microgrid entire load	Microgrid
0.12	0.63	1
0.12	0.74	2
0.17	0.81	3
0.09	0.33	4
0.11	0.41	5
0.11	0.21	6
0.1	0.38	7
0.12	0.45	8
0.06	0.77	9
0.12	0.78	10
0.12	0.75	11
0.12	0.77	12
0.11	0.45	13

Table 3 shows the information related to the studied system equipment. In this table, λ is the failure rate and r is the equipment repair time. Reliability is assumed 100% for air and ground distribution posts and the switching time is considered to be one hour. Information about the length of the feeder is given in Table 4.

Table 3. Information of equipment failure rates

r (Hour)	λ (f/yr.km)	Equipment
3	0.31	underground cable
1.5	1.7	overhead line

Table 4. Information about the length of the feeder

Length (m)	type	node
386	cable	1-2
113	Overhead line	2-3
1085	Overhead line	3-4
73.3	Overhead line	4-5
12	Overhead line	5-6
125	Overhead line	6-7
160	Overhead line	7-8
60	Overhead line	8-9
58	Overhead line	9-10
46	Overhead line	10-11
16.9	Overhead line	11-12
156	Overhead line	12-13

156	Overhead line	13-14
15	Overhead line	14-15
204	Overhead line	15-16

3-2. Calculation of the Customer Interruption Cost

Table 5 has been used for economic calculations and obtaining power interruption costs of customers.

Table 5. Estimation of power intrusion costs of normal loads(\$/KW)[7]

customers' electricity outage period			
4hours	1 hour	20 minutes	Tariff type
18.99	7.14	4.52	residential

Interruption of less than 20 minutes are considered free of charge and the cost of outage of essential loads is assumed to be 5 times the cost of power outage of normal loads.

Using Curve Expert software, the linear curve of the power interruption function is calculated (Fig. 3) and this curve is used for the interruption duration that are not listed in Table 5.

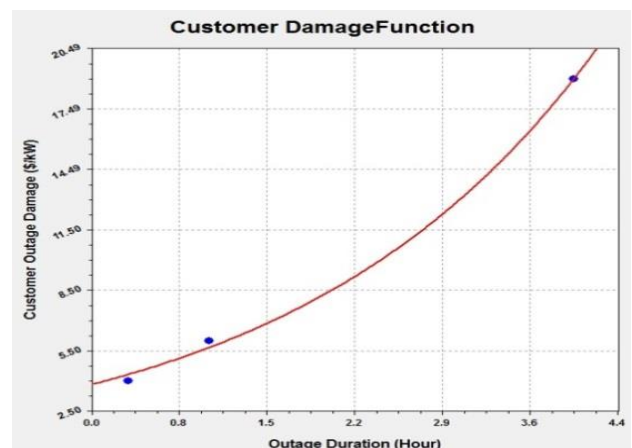


Fig. 3. customers' interruption cost function curve

3-3. Calculation of desired indices in different modes

Now, using Tables 1 to 3, Equation 1 and the definition of parameters ENS(Energy Not Supplied), ECOST(Expected Customer Interruption Cost), SAIDI (System Average Interruption Duration), CAIDI (Customer Average Interruption Duration Index) which is found in [1,2,14] and [18], distribution system reliability indices can be obtained. The following three situations are assumed and the evaluation is done for these three cases.

- case 1: without the generator in the microgrid
- case 2: With the presence of the generator in the microgrid

case 3: With the generator in the microgrid and only supplying essential loads when a fault occurs.

In case 1, it is assumed there are no distributed generation sources in microgrids, and the only source of power generation is the main grid, so there is no source of power generation in microgrids in the event of a fault. In Mode 2, the wind turbine along with the solar cell has been used as distributed generation sources in microgrids, and these sources will be activated as generators in the microgrid only when a fault occurs. Mode 3 is the same as mode 2, with the difference that in the event of a fault, the resources in the microgrid are only responsible for providing electricity to essential loads. In fact, it is assumed that microgrids can participate in load response programs. A microgrid that participates in load response programs removes unnecessary loads from the system by the controller installed on site in case of a fault in the system. In the following, the reliability indices of the distribution system in these 3 modes are calculated and the results are evaluated and reviewed.

In Table 6, the energy not supplied (ENS) and the expected cost of this energy (ECOST) are given for all 3 modes and also the reduction rate of these indices is given as a percentage of the initial value (mode 1). Load and energy-based indices for each microgrid are calculated and shown in Table 6, as well as customer-based indices (average time of system blackout (SAIDI) and average customer interruption time (CAIDI)) are calculated and shown in Table 7. The graphs related to these indices are also drawn in Figs. 4 to 8.

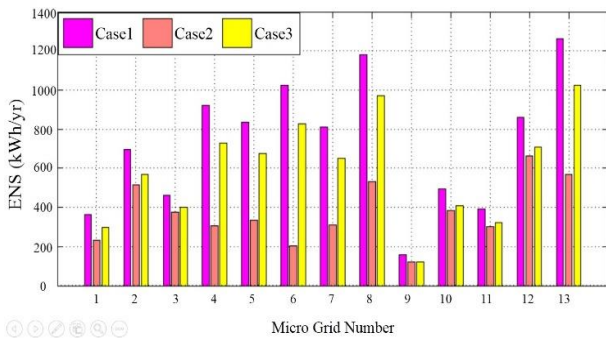


Fig. 4. Unsupplied energy diagram of microgrids

Table 6. The results of the analysis (unsupplied energy and value of unsupplied energy)

reduction Percentage e ECOST	reduction Percentage e ENS	Case3 ECOST (\$/yr)	Case3 ENS (kW/h/yr)	reduction Percentage e ECOST	reduction Percentage e ENS	Case2 ECOST (\$/yr)	Case2 ENS (kW/h/yr)	Case1 ECOST (\$/yr)	Case1 ENS (kW/h/yr)	Microgrid
% 65.1	% 18	1817.9	298.62	% 22.2	% 36.6	4053	230.9	5209.8	364.2	1
% 65.1	% 18	3466.6	569.44	% 15.8	% 26	8367.1	513.9	9934.6	694.4	2
% 64.7	% 13	2329.8	401.50	% 11.5	% 19	5840.8	373.8	6602.1	461.5	3
% 68.2	% 21	4147.6	727.93	% 64.5	% 67	4632.2	304.1	13035.3	921.4	4
% 68.1	% 19	3754.9	675.70	% 45.4	% 60	6439.2	333.7	11801.3	834.2	5
% 68.2	% 19	4607.2	829.06	% 99.9	% 80	10.2	204.7	14479.6	1023.5	6
% 68.1	% 20	3659	650.30	% 38	% 62	7124.2	308.9	11499.6	812.9	7
% 68.1	% 18	5337.4	969.11	% 33.7	% 55	11076.1	531.8	16719.2	1181.8	8

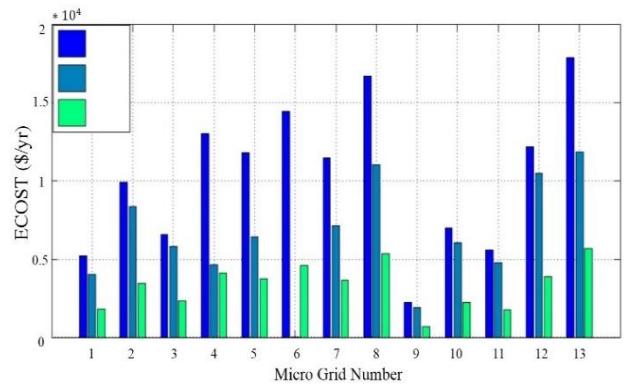


Fig. 5. Diagram of microgrids unsupplied energy costs

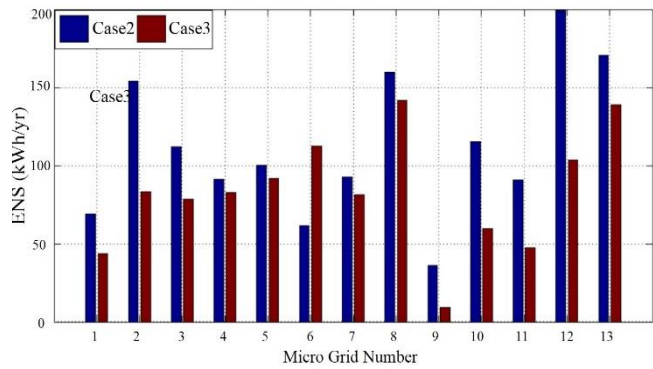


Fig. 6. Diagram of unsupplied energy of microgrids essential loads

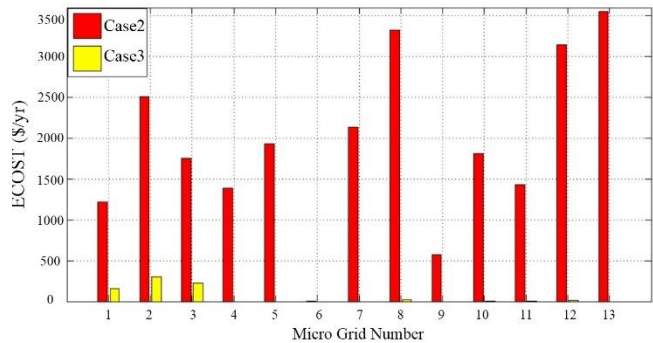


Fig. 7. Unsupplied energy cost of microgrids essential loads

% 68.2	% 24	705.6	119.14	% 14.1	% 23	1904.6	120.7	2217.6	156.8	9
% 68.1	% 18	2241.2	406.93	% 13.8	% 22.5	6051	384.6	7020.4	496.3	10
% 68.1	% 18	1777.2	322.683	% 14.1	% 23	4781.2	303	5566.9	393.5	11
% 68.1	% 18	3892.9	706.83	% 14.1	% 23	10473.1	663.7	12194.3	862	12
% 68.1	% 18	5689.1	1023.8	% 33.7	% 55	11845.2	568.8	17880.1	1263.9	13
% 67.6	% 18.65	43426.4	7701	% 38.4	% 48.9	82603.1	4842.6	134161.1	9466.4	

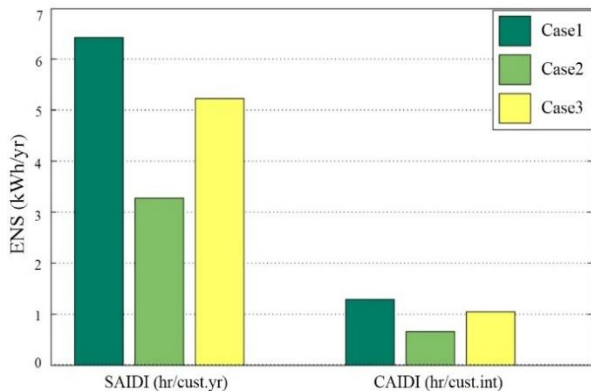


Fig. 8. The curve of the analysis results of customer-based indices

Table 7. The results of customer-based indices

	SAIDI (h / customer.year)	CAIDI (h /customer.interruption)
Case 1	6.43	1.28
Case 2	3.28	0.65
Case 3	5.21	1.04

4. Conclusion

Based on the analysis of Table 6 and Figs. 4 and 5, it is evident that microgrid 6 exhibits the highest percentage reduction in unsupplied energy compared to other microgrids in case 2. This can be attributed to the findings in Table 2, which indicate that microgrid 6 has the lowest probability of not supplying the load when a fault occurs. Furthermore, the expected value of unsupplied energy in mode 2 for microgrid 6 is close to zero, primarily due to the high probability (79%) that the load in this microgrid is provided by distributed generation during faults. Consequently, the duration of blackouts in microgrid 6 is reduced to less than 20 minutes, resulting in a cost reduction in unsupplied energy to zero.

Additionally, Fig. 6 illustrates that the amount of unsupplied energy for essential loads in microgrid 6 is lower in mode 2 compared to mode 3, in contrast to other microgrids. This can be attributed to the high probability of load supply in mode 2 for this particular microgrid, along with its consumption load.

Examining Table 4 and Figs 4 and 5, it is observed that while the unsupplied energy in mode 2 (except for microgrid 9) is lower than mode 3, the expected cost associated with unsupplied energy in mode 2 is higher than mode 3. This discrepancy can

be attributed to the high cost of not providing essential loads in mode 2, as indicated in Fig. 6, where the rate of not providing vital loads is higher compared to mode 3. However, in mode 3, the probability of providing necessary loads significantly increases, leading to a significant reduction in expected blackout time for these loads, often below 20 minutes. Consequently, the expected cost of unsupplied energy in mode 2 is reduced. It is worth noting that the average power consumption also influences unsupplied energy.

In the case of microgrid 9, the probability of providing necessary loads in the event of a fault is 94%, which explains the lower unsupplied energy in mode 3 compared to mode 2 for this microgrid. However, the high probability of not supplying the load in mode 2 for microgrid 9 should also be considered. In general, the larger the difference in probability of being supplied or not between modes 2 and 3 (Tables 2-4), as well as the higher the average consumption, the closer the unsupplied energy in mode 2 and 3 become. This means that, similar to microgrid 9, unsupplied energy may be lower in mode 3 than mode 2.

As expected, the total unsupplied energy in mode 2 is significantly lower than in mode 3. This is attributed to the fact that in mode 3, only 30% of the load needs to be supplied during faults, resulting in a loss of 70% of the total load in each microgrid. Consequently, necessary loads are supplied in mode 3 with higher reliability compared to modes 2 and 1. However, the expected unsupplied energy in mode 3 increases compared to mode 2.

Regarding customer-based indices, as anticipated, the reduction in mode 3 is lower compared to mode 2, considering that only the most important loads are fed in case of a fault.

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Biography



Masoud Jokar Kouhanjani received a B.S. degree in electrical engineering and an M.S. degree in Power engineering from Shiraz University, Shiraz, Iran, in 2011 and 2014, respectively. He is currently a member of department of technical study in Shiraz Electric Distribution Company, Shiraz, Iran. His research interests include power electronic converters, Renewable Energy Integration to Electric Grids and Power System Dynamics and Optimization.



Farshad Jafari received B.S. degree in electrical engineering from Sharif University in 2010, M.S. degree and Ph.D. degree in electrical power engineering in 2013 and 2018 respectively from Tehran University and Shiraz University. He is currently the head of network intelligence group in Shiraz Electric Distribution Company, Shiraz, Iran. His research interests are Power system optimization, Energy Management, Reliability and Multi carrier energy systems.



Somaye Najibi received B.S. degree from Yazd University in electrical engineering in 2006 and M.S. degree in electrical power engineering in 2008 from Hamadan University. She is currently the head of project management office in Shiraz Electric Distribution Company, Shiraz, Iran. Her research interests are Renewable Energy, Optimal Control, Smart Distribution Systems.
