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Article

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Research Paper

Optimal planning of multi-micro grids based-on networks reliability

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ABSTRACT

Traditional electrical grid as the largest and most complex industry in the world is currently under fundamental development. According to the IEEE Std1547.4, large distribution systems can be clustered into a number of micro-grids (MGs) to facilitate the control and operation infrastructure in future distribution systems. A distribution network with distributed energy resources serving a group of loads, can be operated as a MG, in grid-connected or isolated grid modes. Most recently, the concept of MGs has become an important subject in smart grid area, demanding a systematic method for their optimal planning. The prosperous development of the micro-grid concept implies the definition of an appropriate regulation for its integration on distribution systems. The MG operators are responsible for a reliable energy supply to their consumers. MG formation represents a suitable solution for uninterrupted supplying of critical loads, in the absence of network.

In this study, a systematic approach is presented for optimal construction of micro-grid. The problem is solved in two stages. In the first stage, the network is designed as an integrated and active distribution network considering the importance of reliability by using Backward–forward load flow. Next, the distribution network is designed to be divided in to several MGs in order to minimize the cost of electricity generation, improve reliability and voltage profile. In the presented study, stochastic models are considered for representing generation availability related to wind energy and solar energy. The generated power of distributed generation resources such as wind turbines and photovoltaic, have been modeled per hours of the day and the amount of important network parameters are obtained from the results of probabilistic load flow. Practical and important factors such as problem solving space reduction, load controllability, load priority, bus voltage limitation, line capacity limitation and the possibility of forming larger micro-grids by connecting switches between the obtained initial MGs from the first stage are considered in the proposed method.

The proposed methodology is implemented for a standard 69-bus distribution system by applying the Imperialist Competitive Algorithm (ICA) in MATLAB software. Results verify the usefulness of the proposed approach in transforming an existing radial distribution network into several autonomous MG.

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1. Introduction

In recent years, electrical engineers are facing with new experiments for the planning and operation of power systems due to the changes in the construction of power systems (Ghadimi et al., 2020). Increasing the system reliability, system upgrade postponing and reduction in energy and power loss are some of the examples that have incited usefulness companies for local connection of renewable energy resources at the distribution level. This issue cause changes in traditional distribution systems

and lead to multiple modern, interrelated distribution systems called micro-grids. Micro-grids are small distribution systems which are connecting to a group of electricity consumers and consists a number of distributed generators and storage units. A MG generally operates while connected to the grid, but essentially, it can break off and operate on its own using local energy generation in times of emergency like storms, power outages, or for other reasons (Carrasco et al., 2006). There are numerous subjects regarding appropriate planning and operation of MGs in order to be useful for utilities and consumers (Tohidi et al., 2016; Kanchev et al., 2011a; Majumder et al., 2009a; Lasseter, 2011a; Bastholm and Fiedler, 2018; Elsied et al., 2016).

The supply-adequacy and the reliability can be known as two main subjects that have emotional effect on the system's general

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Nomenclature

Indices

t	time index
i	DG index
f	Feeder index
b	Bus index
g	MG index

Parameters

P_{rated}	Rated output power of wind turbine
v_{ci}	Cut-In Wind turbine Speed
v_r	Nominal wind turbine speed
v_{co}	Cut-Off Wind turbine Speed
P_{rs}	The rated capacity of the solar installation
R_{STD}	The solar radiation in the standard environment
R_c	Specific radiation threshold level up
P_{pv}^{max}	Maximum production capacity of PV
P_{pv}^{min}	Minimum production capacity of PV
P_{wind}^{max}	Maximum production capacity of WT
P_{wind}^{min}	Minimum production capacity of WT
r	The resistance of feeders
$price_i^{DG}$	Cost of generating power in DG _i
V_{max}	Maximum voltage of the buses
V_{min}	Minimum voltage of the buses

Variables

P_{WT}	The output power of wind turbine
v	Speed of wind
$f(v)$	Probability density function of a Weibull random variable
β	shape parameter
α	Scale parameter of distribution function
$P(R)$	PV output power
R	Solar irradiance
$P_{WT}(s)$	Production capacity of WT sources in scenario s
$P_{PV}(s)$	Production capacity of PV sources in scenario s
$C(s)$	Generated power in scenario s
π_s^{wt}	Probability related to WT resources in scenario s
π_s^{pv}	Probability related to PV resources in scenario s
π_s^c	Probability for each scenario
$ENS_{(g,t)}^{MG}$	Energy not supplied in MG _g at time t
$P_{DG(i,t)}$	Generated power of DG at time t
$P_{loss(f,t)}$	Power losses of feeder at time t
$P_{load(b,t)}$	Load for each busbar at time t
$i_{feeder(f,t)}$	Current of feeders at time t
$price_g^{MG}$	Production cost of MG _g
$price_g^{critical}$	The price of not supplying the critical loads in MG _g
$price_g^{not-critical}$	The price of not supplying the not-critical loads in MG _g

$P_t^{critical}$	Not supplied critical loads in a micro-grid at time t
$P_t^{not-critical}$	Not supplied not-critical loads in a micro-grid at time t
$V_{i(t)}$	The voltage of the bus i
$f_{outage.MG(g,t)}$	Possibility of withdrawing micro-grids
N_g^{bus}	Number of buses in MG _g
N_g^{DG}	Number of DG units in MG _g
N_g^F	Number of feeders in MG _g
N_{MG}	Number of created MG

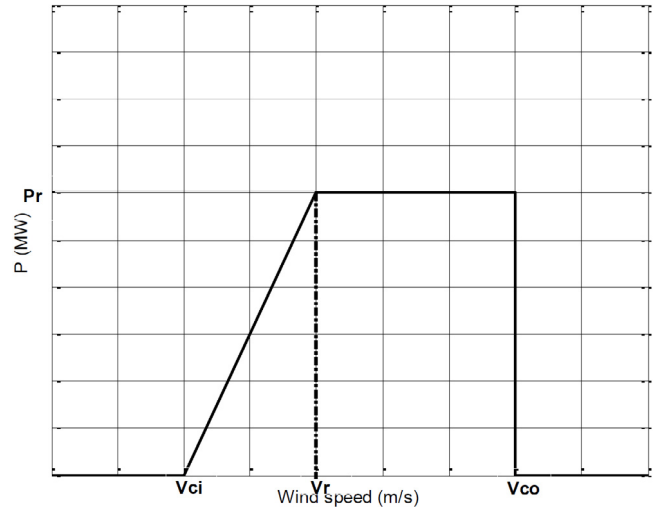


Fig. 1. The output power of wind turbine.

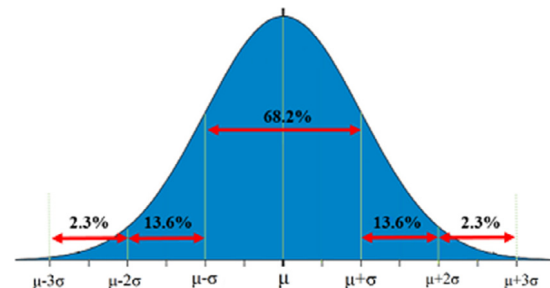


Fig. 2. Modeling of uncertainty for WT and PV sources.

efficiency (Moslehi and Ranjit Kumar, 2010). Another methodology to guaranty reliable service to consumers is installing new DGs in micro-grids. Furthermore, In order to avoid additional costs of installation, it is better that DGs already be installed by consumers (Dielmann and van der Velden, 2003; Celli et al., 2005; Caldon et al., 2004; Panwar et al., 2015; Ma et al., 2017).

In the smart grid environment or generally in micro-grid strategy, considering the reliability-related subjects will also have several technical and economic advantages for productivity and customers. The reliability calculation and evaluation in a distribution system with distributed generations have been studied in various papers such as Shahabi et al. (2009), Kanchev et al. (2011b), Majumder et al. (2009b), Lasseter (2011b), Motevasel and Seifi (2014) and Najibi and Niknam (2015); but, they have not been considered the planning of multiple MGs. It is notable that by considering the reliability at the planning level, through changing the number of ingredients in a MG, the failure rate and

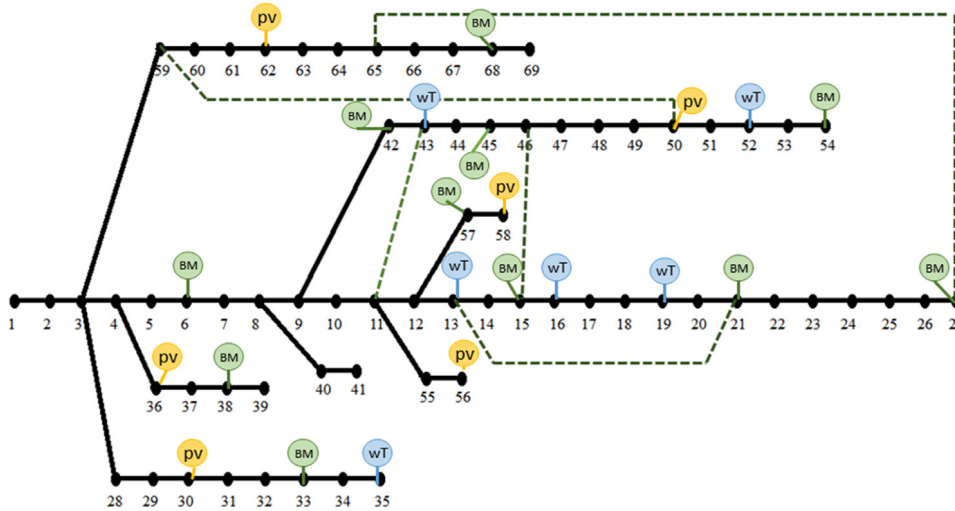


Fig. 3. Diagram of the standard 69-bus IEEE distribution system.

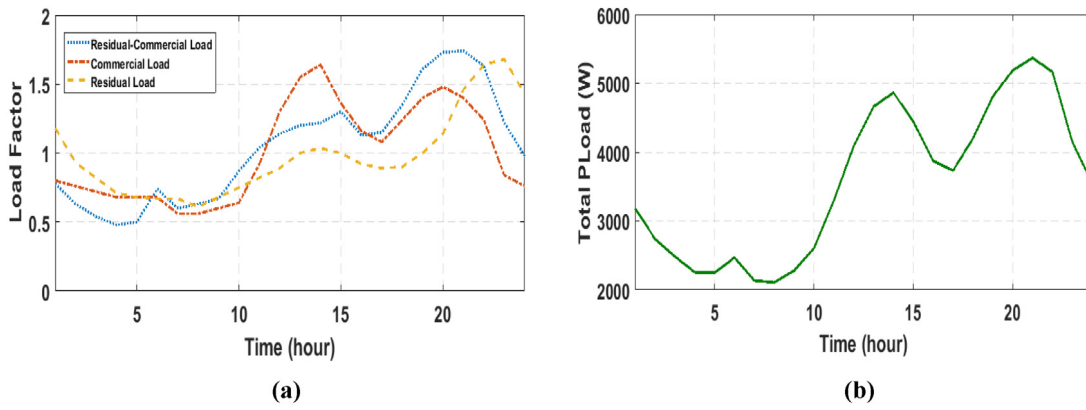


Fig. 4. (a) The coefficients of load profiles, (b) The total daily load curve.

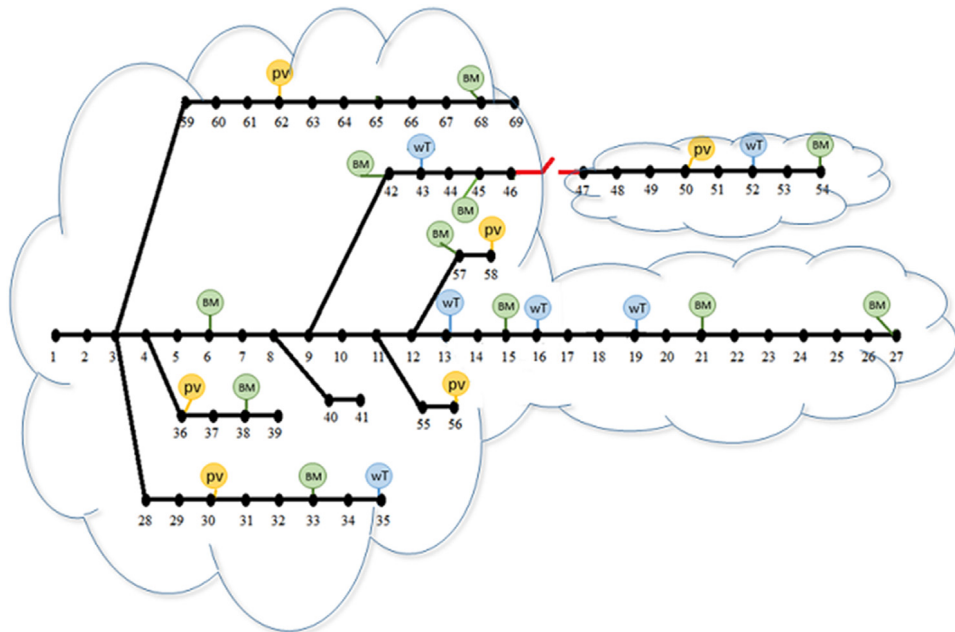


Fig. 5. Obtained micro grids for scenario 1.

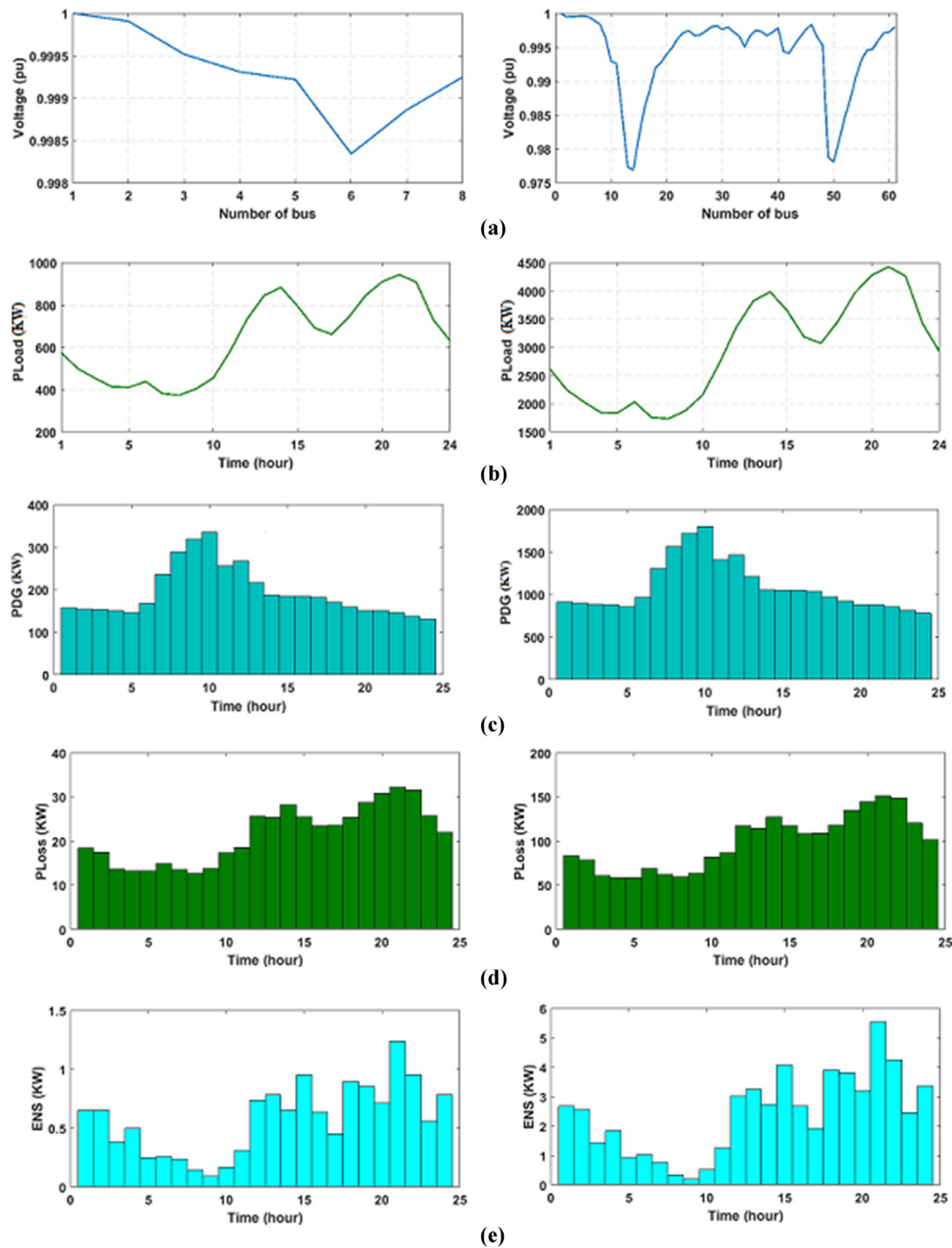


Fig. 6. (a) Voltage profile, (b) Load profile, (c) Generated power of DG sources, (d) Power losses, (e) Energy not supplied.

average repair time per year will be changed. In other words, by applying less number of components in a MG, the number of created MGs will be greater than before and the number of storage units and DG's per MG will be reduced. Therefore, the average repair time per year for the MGs will be increased. So, an optimization algorithm should be applied to determine the best configuration for MGs.

Moreover, in order to simplify successful islanded operation and a powerful infrastructure for self-healing control under the smart grid environment, it is feasible to design MGs with optimum supply-security (Conti et al., 2011). If the generation-load disbalance in the MGs becomes less, reliability and supply-secure

quality will be improved. When MGs work in independent-mode in a distribution system, have such advantages like supplying more loads and minimizing losses on connected micro-grids power lines. Also, the reduction of the power imbalance is another serious factor in construction of a MG. There are various papers relevant to micro-grids and their advantages for the utility and customers (Bae and Kim, 2008; Arya et al., 2011; Bae and Kim, 2007; Arefifar et al., 2012; Bagheri et al., 2018; Alavi et al., 2015); but, the idea of how to create multiple interrelated MGs and what factors should be considered in their planning have not been studied well. In order to evaluate the effect of renewable energy DGs on the reliability of islanded distribution systems,

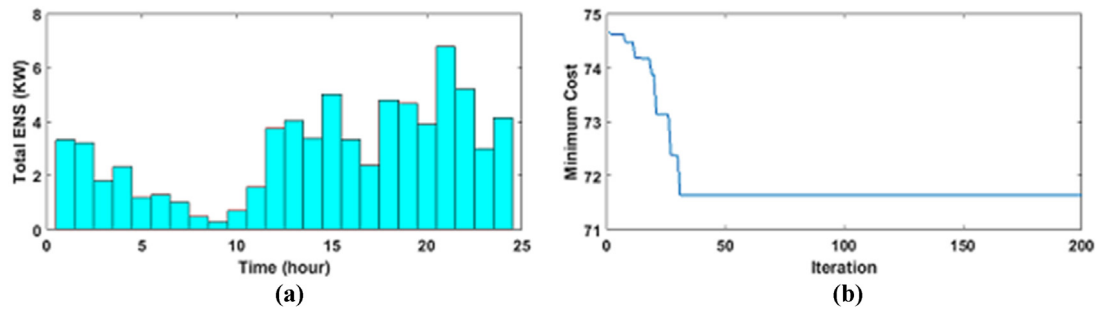


Fig. 7. (a) Total energy not supplied in network, (b) Convergence curve.

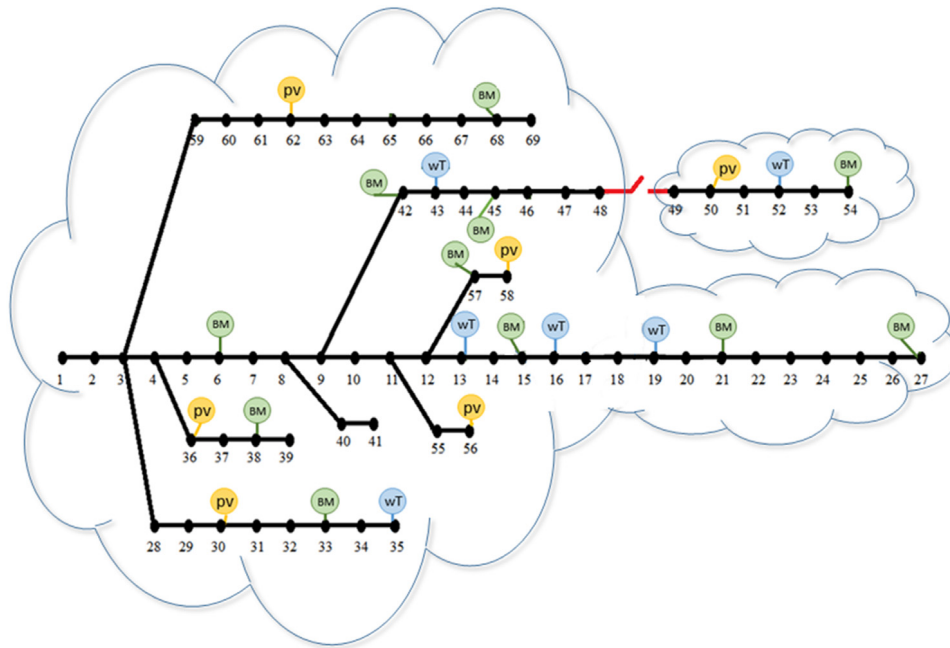


Fig. 8. Obtained micro-grids for scenario 2.

a probabilistic technique is presented in [Atwa and El-Saadany \(2009\)](#). In [Atwa et al. \(2011\)](#), the adequacy indices of distribution system applying both analytical and MCS methods while distributed energy resources are operated in either grid-connected mode or islanded mode, are computed. One of the most Practical and useful methods to reduce the losses of distribution networks is determining the optimal structure of them by choosing the correct position of the network switches and determining Micro-grid boundaries. Clustering large distribution systems into a set of micro-grids with high reliability and security is not considered in recent studies. paper ([Arefifar et al., 2013](#)) presents an organized method for designing Micro-grids considering system reliability. The mentioned paper studies on a network that is clustered into several Micro-grids while the optimal clustering of the network to multiple micro-grids is not considered. Therefore, in order to improve the planning of Micro-grids, a new procedure is presented in this article. The network in the presented method is initially considered loop and a radial network is extracted from that by applying the appropriate optimization algorithm with the aim of reducing losses. Then, with the goal of increasing reliability and reducing the total costs, the network is clustered in to multiple Micro-grids.

Apart from introduction part, the rest of the paper is prepared as follows:

Section 2 presents the uncertainty modeling of distributed generations by applying scenario base procedure. Section 3 explains the optimal planning of Multi-Micro grids. The proposed method is presented in Section 4. Constraints and case study are given in Sections 4.2 and 5, respectively. At the end, Section 6 is devoted to the conclusions of the proposed procedure.

2. Uncertainty modeling of distributed generations

Wind power and solar energy are dependent strictly to environmental conditions such as wind speed, solar radiation, ambient temperature, etc. So, in order to model renewable DG units in distribution systems, the analysis of wind speed and solar radiation characteristics on site installation is necessary.

In this paper, the model of wind and solar energy are based on hourly wind speed and solar radiation data in Iran that has been modeled applying probability density function. The active output power of wind turbines is affected by wind speed. There is a non-linear relationship between these two parameters. By using this dependency which is known as “power-speed” characteristic and is depend on operational parameters of the turbine, the possibility of calculating the active output power of the wind turbine is provided. This feature shows the active power of the wind turbine for various wind speeds. The Weibull distribution function is the best method for modeling the wind speed changes ([Kenari et al.,](#)

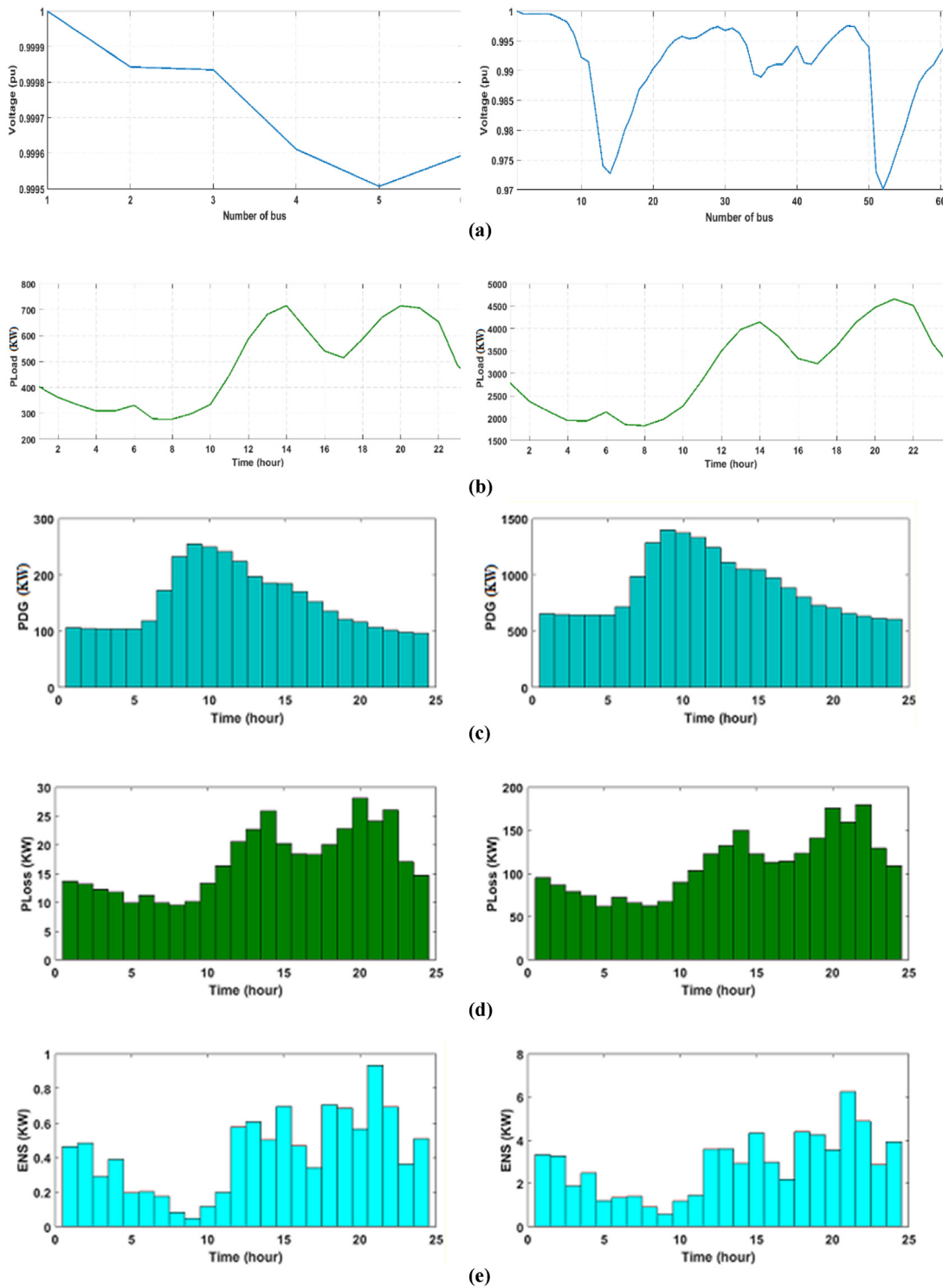


Fig. 9. (a) Voltage profile, (b) Load profile, (c) Generated power of DG sources, (d) Power losses, (e) Energy not supplied.

2017). The Mathematical model of this PDF can be expressed as follow:

$$f(v) = \frac{\beta}{\alpha} \left(\frac{v}{\alpha}\right)^{\beta-1} e^{-\left(\frac{v}{\alpha}\right)^\beta} \quad (\beta > 0, \alpha > 0, v > 0) \quad (1)$$

Therefore, by using wind probability distribution function and the wind turbine’s production power curve, or by applying the related mathematical relation, the output power of wind turbines can be calculated. In the presented study, the wind turbine output

power curve is assumed to be linear as follows Roy (2002) and Ackerman and Morthorst (2005);

As seen in Fig. 1, the output power of wind turbine is calculated as follow;

$$P_{WT} = \begin{cases} 0 & v < v_{ci} \\ p_{rated} \times \frac{(v - v_{ci})}{(v_r - v_{ci})} & v_{ci} < v < v_r \\ p_{rated} & v_r < v < v_{co} \\ 0 & v > v_{co} \end{cases} \quad (2)$$

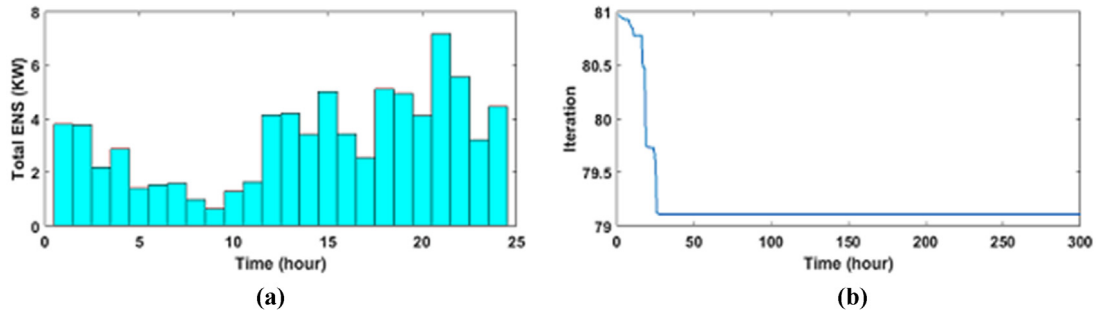


Fig. 10. (a) Total energy not supplied in network (b) Convergence curve.

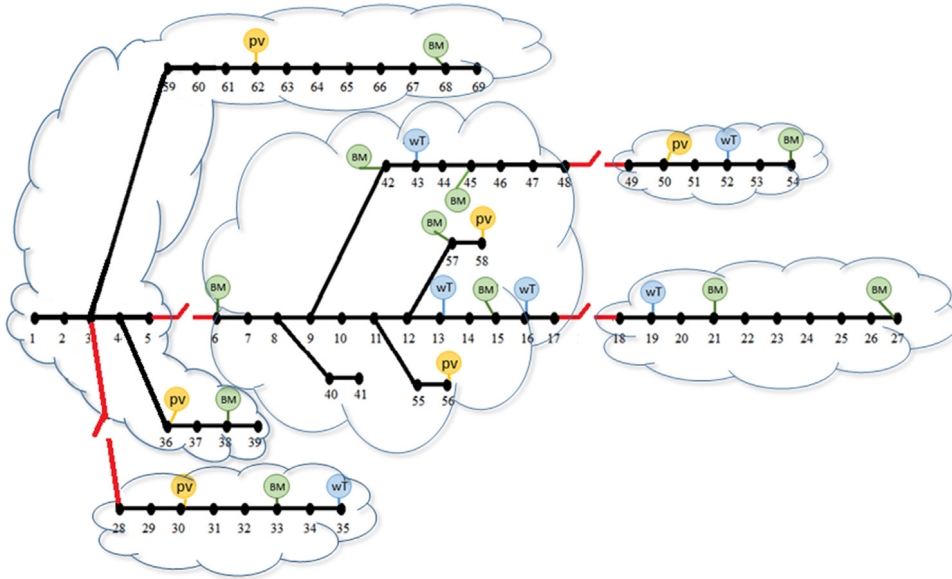


Fig. 11. Obtained micro-grids for scenario 3.

Reactive power of wind turbine depends on the turbine and the amount of active output power.

The most available power of PV in a specific location is a function of time, sun angle and the geographic coordinates (Abedinia et al., 2017). So modeling the output power will be required to model the solar radiation. In this paper, the beta distribution function is used for radiation prediction errors. So, the PV output power per irradiation will be calculated by using radiation data.

$$P(R) = \begin{cases} P_{rs} \left(\frac{R^2}{R_{STD} R_C} \right) & \Leftarrow \text{if } 0 \leq R \leq R_C \\ P_{rs} \times \frac{R}{R_{STD}} & \Leftarrow \text{if } R_C \leq R \leq R_{STD} \\ P_{rs} & \Leftarrow \text{if } R_{STD} \leq R \end{cases} \quad (3)$$

In this research, the normal probability distribution density function is used to model the output power of distributed generation resources. The mean and standard deviation are two basic parameters for applying this function. So, at first the output power of WT and PV should be calculated by applying the mentioned principles for statistical data at different hours. Then, the mean and standard deviation should be calculated from data obtained at different times. It should be noted that when sun is not shining, the output power of solar cells is considered equal to zero.

Given that the production of WT and PV units are independent from each other, different modes can be obtained by combining the different states of these two parameters as follows:

$$C(s) = [P_{WT}(s) \ P_{PV}(s)] \quad (4)$$

$$\pi_s^c = \pi_s^{wt} \pi_s^{pv} \quad (5)$$

As it can be seen, for a large number of scenarios, the volume of optimization calculations will be so large. In order to overcome this problem it is necessary to reduce the number of scenarios so that the characteristics of the new scenarios remain the same as the previous original scenarios.

As shown in Fig. 2, the normal probability density function is divided into 5 areas and the possibility related to each episode is specified.

3. Optimal planning of multi-micro grids

Power system planning and development is a decision-making process to add new equipment or improving existing equipment to meet the growing demand in a specified period of time. Optimal planning of distribution systems will usually follow various purposes while the relevant costs should be minimized according to the existing limitations. Therefore, the optimal planning of

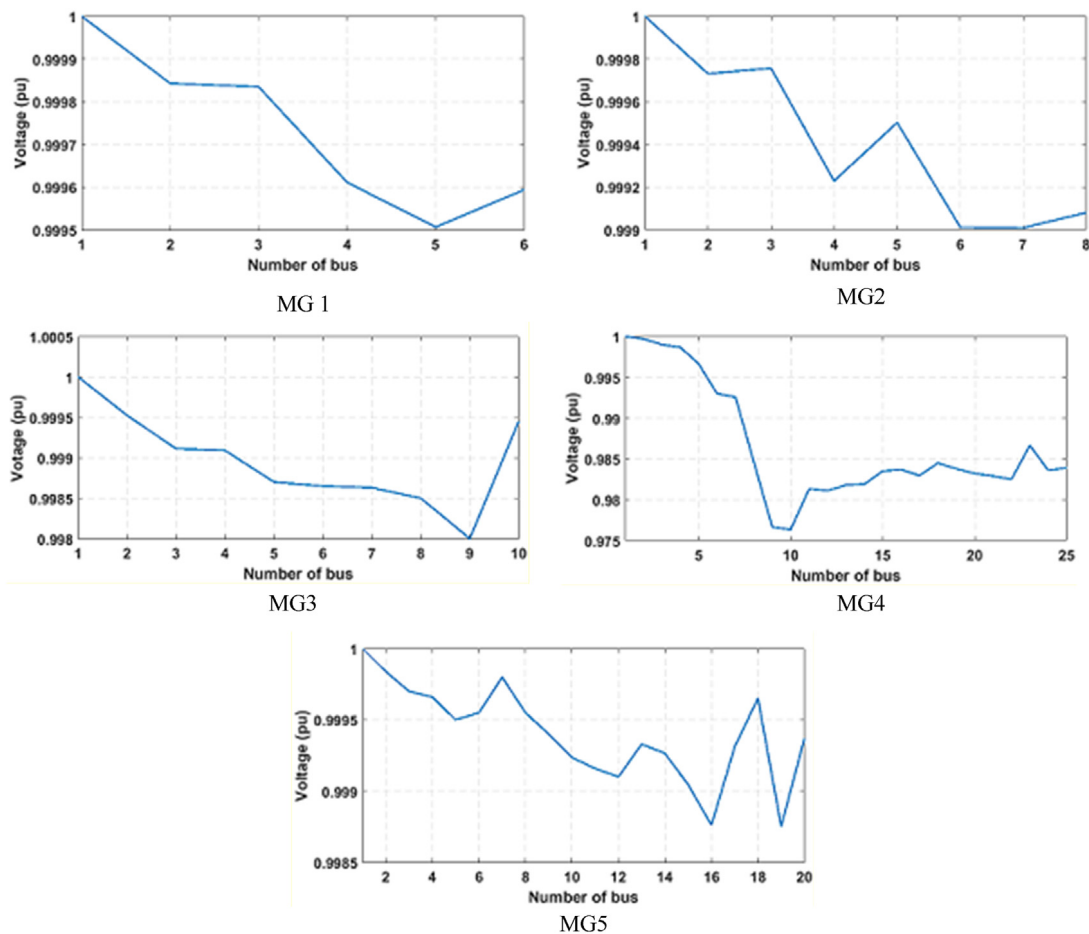


Fig. 12. Voltage profile of micro-grids.

Table 1
Technical parameters for DG units.

Type of DG	Location in the system	Nominal capacity	The average cost of operation in 2017 (2010 USD/MWh)
Wind turbine	52-43-35-19-16-13	110	96.8
Photo voltaic	62-58-56-50-36-30	150	156.9
Biomass	68-57-54-45-42-38-33-27-21-15-6	75-75-75-50-50-50-75-50-25-50-25-75	120.2

distribution networks should be such that the required power consumption with high reliability and low cost be available to consumers.

It is obvious that conversion an existing radial distribution system into several autonomous MGs requires DGs to be integrated into the network. It is mandatory that the total demand and the system losses need to be satisfy by the DG units connected to the distribution system.

Determining the optimal structure of distribution networks is one of the most effective and low-cost methods to reduce the losses. The structure of the distribution network can optimally change with the correct position choice of the network switches. Restructuring in distribution networks in addition to improving voltage profiles and increasing reliability, also balances loads. In the network structure change discussion, the following three principles must always be noticed: maintaining the radial structure of the network, reaching electricity to all of the loads and consumers, considering to the voltage range of the busbars and the current range of the loads.

The exact size and the optimal placement of these generators are assumed to be like paper (Arefifar et al., 2013). In general,

renewable sources driven synchronous generators and inverter-based sources are supposed to be controlled for constant power and power factor operation.

Distribution systems are provided with two types of switches named sectionalizing switches and TIE switches that are initially in closed and opened positions at the outset, respectively. The first stage of this study is determining the optimum structure of network by considering the failure rate of the feeders with specified standard deviation. As indicated in above, tie switches are normally open but to get the best configuration for overall network, they have been considered to be closed. So, the primary configuration of the network is assumed to be looped as shown in Fig. 3. A radial structure for overall network will be obtained by using the proposed ICA optimization algorithm.

In the next step, the optimal division of network in to multiple micro-grids with the aim of minimizing the reliability index will be obtained. The division to multiple MG is realized by sectionalizing keys.

The load flow analysis for MGs will be done and finally, the MGs which have energy not supplied, will be communicate with each other to improve reliability by power exchanging. This paper

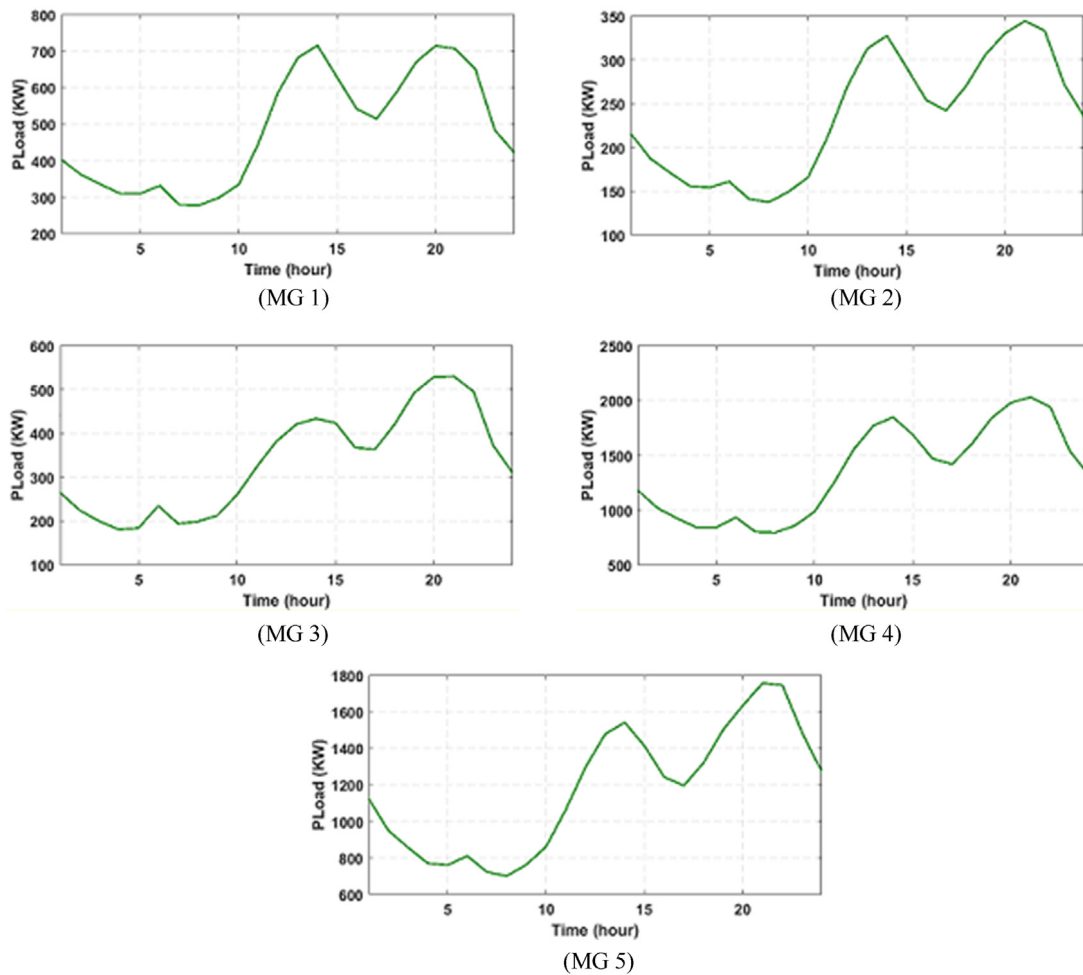


Fig. 13. Load profile of micro-grids.

attempts to renew the configuration and division of MGs in the presence of DG, to improve an indicator of reliability (energy not supplied). At the end, the optimal mode (on or off status) of the switches between MGs will be determined according to load flow results and the analysis of reliability parameter.

4. Proposed method

One of the most important and fundamental issues in distribution networks for energy supply and distribution companies is improving the reliability indicators to increase customer satisfaction and profit of the companies. Several methods have been proposed to increase the reliability of power systems and distribution networks.

Locating switches, protection system and control devices require the initial investment cost. Therefore, the most important issue in placing this equipment on distribution networks is to find the best places for them. So, the highest reliability for the network will be obtained and the best return on investment will be brought for distribution companies.

Imperialist Competitive Algorithm is applied to solve the problem of dividing the network to multiple MGs by considering distributed resources in the network. By optimizing the economic reliability indicator for different modes and different number of MGs, the best places for the boundaries of the MGs will be obtained. The following assumptions have been made in this study to apply the suggested methodology:

- The cost of produced power in every MG will be the average production costs of distributed sources in the MG that are listed in the Table 1.
- The proposed method is studied on the IEEE 69-bus network in presence of DGs.
- Modeling of wind and solar energy has been adjusted based on the hourly data of wind speed and solar radiation in Iran (Iran Meteorological Organization, 0000).
- Power factor of all the bass with DG resources are considered fixed and 0.85.
- In the implementation of backward–forward load flow, all of the buses except slack bus have been considered to be PQ buses.
- The location of distributed generation units presented in Table 1, are considered to have been fixed in locations which are selected by optimal placement in Arefifar et al. (2013).
- It is assumed that PV modules can generate online activate power just in the presence of sunlight and otherwise the productive power will be zero.
- The base amounts of power and voltage have been considered to be 1 MW and 12 kV, respectively.
- 30% of energy not supplied in every MG will be related to critical loads and 70% remaining of it will be non-critical loads.
- The rate of costs related to the critical loads will be 20% higher than non-critical loads.
- In designing for the 5-year horizon, the annual load growth rate is assumed to be 5% and the growth rate related to

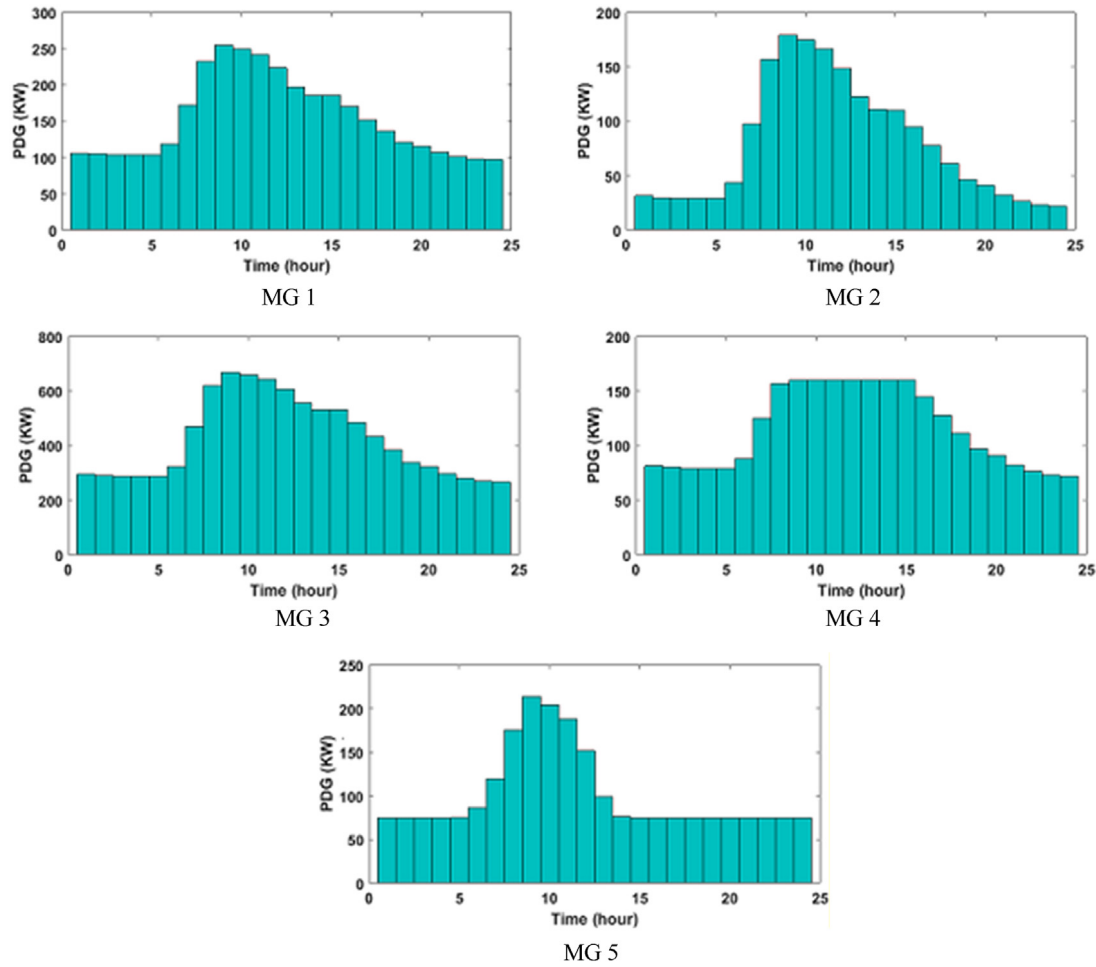


Fig. 14. Generated power of DG sources in micro-grids.

Table 2

The possibility of withdrawing micro-grids at different time intervals.

Hour	1	2	3	4	5	6
Possibility	0.0015	0.0018	0.0012	0.0018	0.0015	0.0009
Hour	7	8	9	10	11	12
Possibility	0.0015	0.0015	0.0009	0.0012	0.0009	0.0015
Hour	13	14	15	16	17	18
Possibility	0.0012	0.0009	0.0015	0.0012	0.0009	0.0015
Hour	19	20	21	22	23	24
Possibility	0.0012	0.0009	0.0015	0.0012	0.0009	0.0015

installed capacity of distributed generation because of lower installation cost of this resources in future, is intended to be 10%.

- The possibility of withdrawing every MG varies at different times which are given in Table 2.

4.1. Problem formulation

The purpose of this study is determining the optimum borders of multiple MGs in distribution system. In all of the MGs, the balance of the power consumption and generated power of DG units should be established.

The ENS index of reliability according to the purposes of this article has been selected for further study which is obtained using

the following formula.

$$ENS_{(g,t)}^{MG} = \sum_{i=1}^{N_g^{DG}} P_{DG(i,t)} - \sum_{f=1}^{N_g^F} P_{loss(f,t)} - \sum_{b=1}^{N_g^{bus}} P_{load(b,t)} \quad (6)$$

And the loss related to each feeder will be calculated as follows:

$$P_{loss(f,t)} = r_{feeder} i_{feeder(f,t)}^2 \quad (7)$$

The amount of current for each feeder can be achieved from backward–forward load flow. Also, the rate of the micro-grid's production costs can be obtained from the following equation;

$$price_g^{MG} = \frac{\sum_{i=1}^{N_g^{DG}} price_i^{DG}}{N_g^{DG}} \quad (8)$$

In case that the DG's could not provide the required loads in MG, the cost of disservice caused by that MG is determined as follow;

$$price_g^{critical} = price_g^{MG} * 1.2 \quad (9)$$

$$price_g^{not-critical} = price_g^{MG}$$

$$p_t^{critical} = ENS_t^{MG} * 0.3 \quad (10)$$

$$p_t^{not-critical} = ENS_t^{MG} * 0.7$$

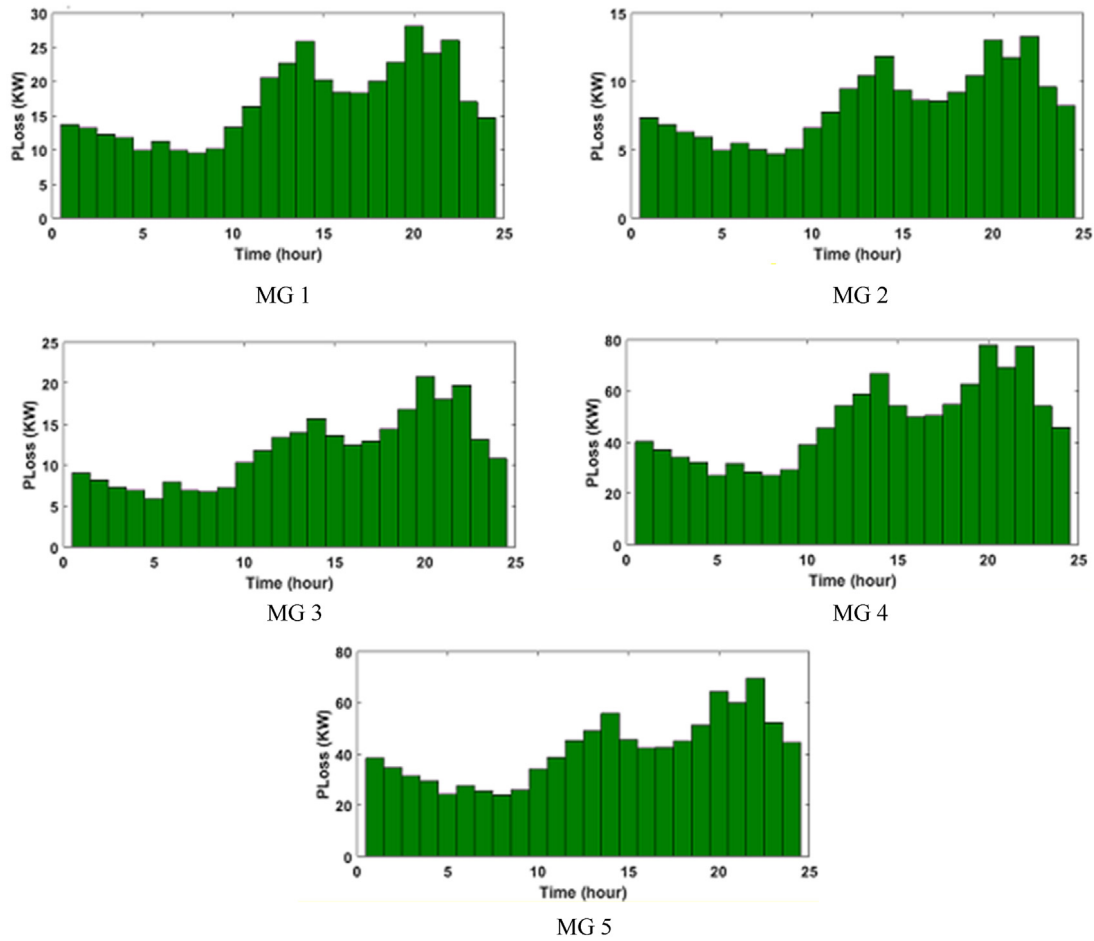


Fig. 15. Power losses in micro-grids.

Table 3

The number of buses in micro-grids.

Number of micro-grid	Number of buses
1	49-50-51-52-53-54
2	28-29-30-31-32-33-34-35
3	18-19-20-21-22-23-24-25-26-27
4	6-7-8-9-10-11-12-13-14-15-16-17-40-41-42-43-44-45-46-47-48-55-56-57-58
5	1-2-3-4-5-36-37-38-39-59-60-61-62-63-64-65-66-67-68-69

After calculating the cost of disservice related to energy not supplied in MGs, and comparing it with the cost of purchasing energy from neighboring MGs, the switching operation will be done.

As mentioned before, the objective is to minimize the total ENS in MGs.

$$\text{objective function} = \sum_{t=1}^{24} \sum_{g=1}^{N_{MG}} ENS_{MG(g,t)} \cdot f_{outage, MG(g,t)} \quad (11)$$

4.2. Constraints

The considered limitations in this paper are presented as follows:

- The standard deviation for feeder's failure rate is assumed to be 20%.
- There must have been at least one DG unit in every MG.
- Power balance constraint: The balance of production and consumption should be established for MGs.

- The maximum number of micro-grids is considered to be 10 in optimization, but no limitation is intended for the least number of MGs.
- Voltage constraint: the permissible range of bus voltages is intended to be in [0.95–1.05].

$$V_{\min} \leq V_i(t) \leq V_{\max} \quad t \in \{1, 2, \dots, 24\} \quad (12)$$

- power generation constraints of renewable resources:

$$P_{pv}^{\min} \leq P_{pv}(t) \leq P_{pv}^{\max} \quad t \in \{1, 2, \dots, 24\} \quad (13)$$

$$P_{wind}^{\min} \leq P_{wind}(t) \leq P_{wind}^{\max} \quad t \in \{1, 2, \dots, 24\}$$

5. Numerical results and analysis

In this study, the standard 69-bus IEEE distribution system is applied as the case study which is shown in Fig. 3. The test system is presumed to involve 23 DG units which are connected to the network, the location and their nominal capacity is given in Table 1.

The electrical parameters for the test system are given at paper (Arefifar et al., 2013). In this study, consumers are considered

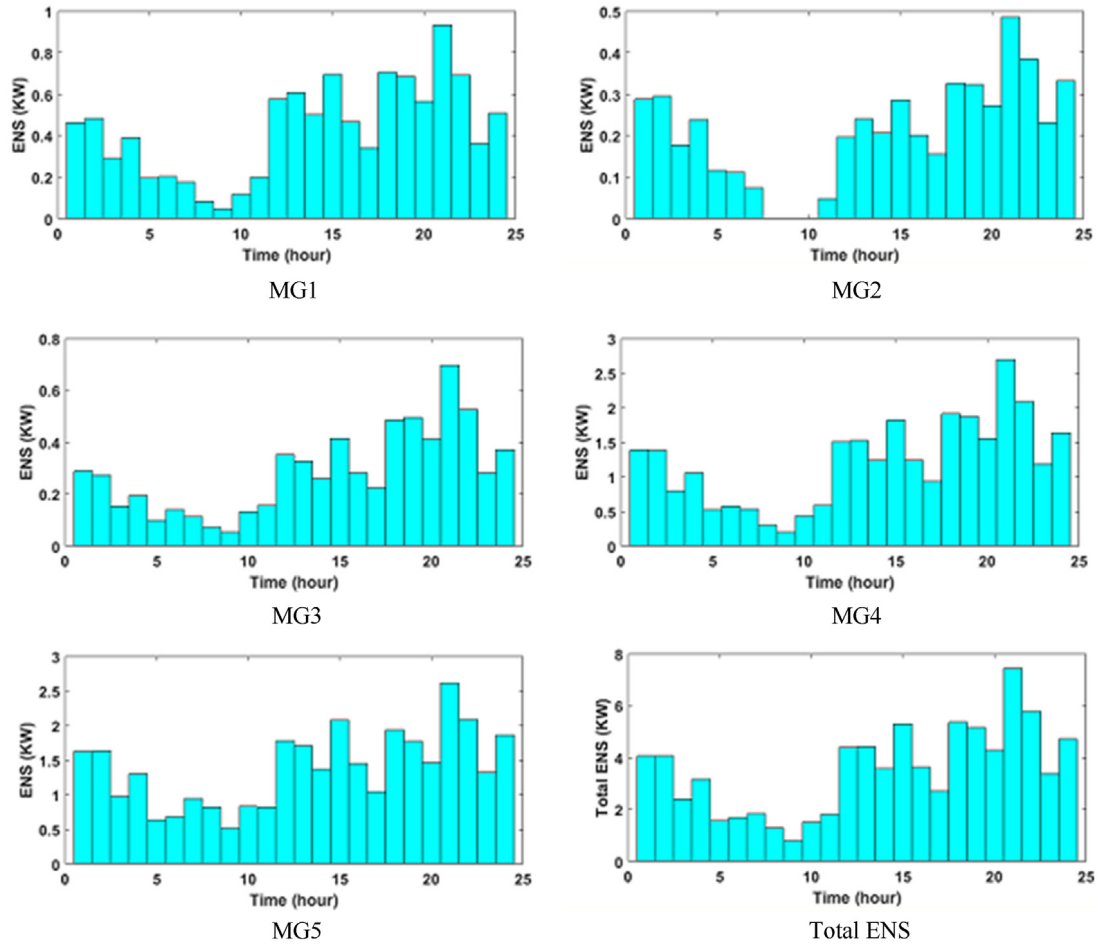


Fig. 16. Energy not supplied in each MG and total energy not supplied in network.

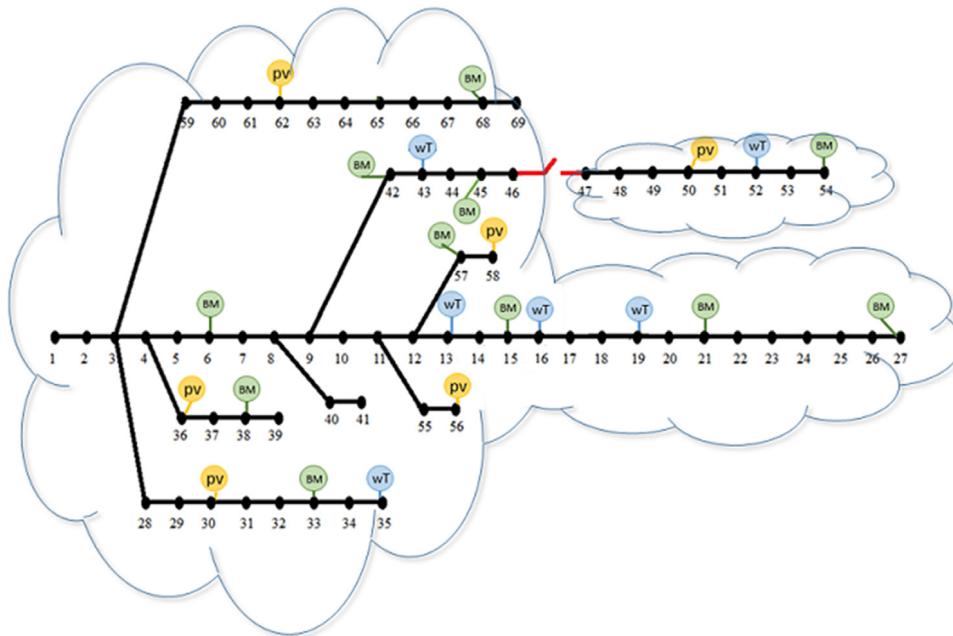


Fig. 17. Obtained micro-grids for scenario 4.

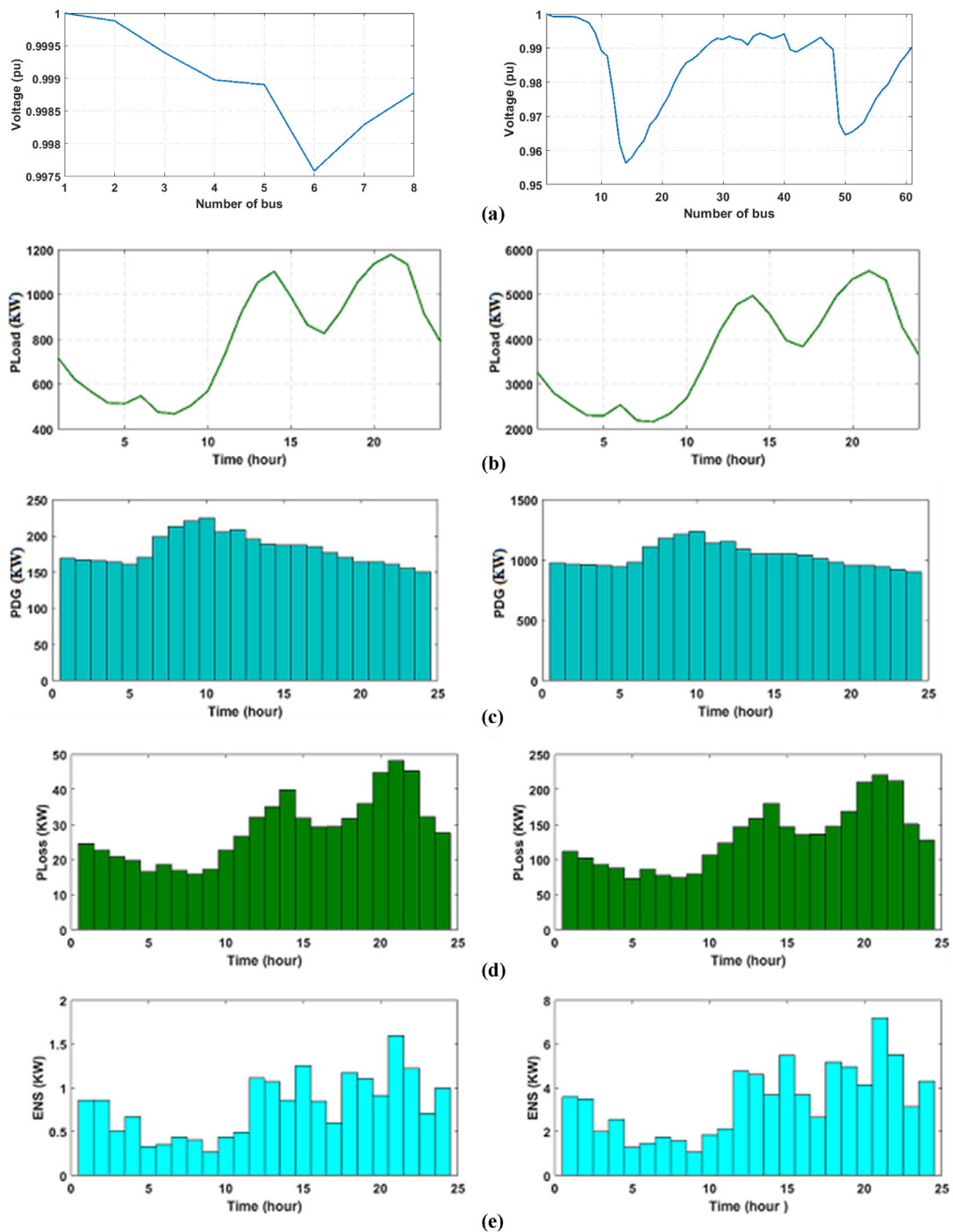


Fig. 18. (a) Voltage profile, (b) Load profile, (c) Generated power of DG sources, (d) Power losses, (e) Energy not supplied.

as residential, commercial and residential–commercial types. The Coefficients of load profiles and the total daily load curve of the studied network is illustrated in Fig. 4.

In this section, results are presented for each scenario. Due to the limitations in presentation of the results, the simulation of the micro-grid's voltage profile just presented at 19:00. Also, it should be noted that the results for the amount losses in the feeder is considered for the state that micro-grids are work independently in annual peak load.

Scenario 1: optimal planning for the first year without probable modeling of DGs

In this case, the system is divided into two blocks as shown in Fig. 5. Also, the voltage profile, load profile, generated power of DG sources, power losses, and energy outcomes are presented in Fig. 6.

Achieved information for displayed MGs by applying the proposed method is illustrated in Fig. 6:

According to Fig. 7(b), the numerical value of the objective function in this scenario is 71/6361. Also, the mode of considered Switch for this scenario is off at all times, in other words, there is no power exchange between the micro-grids.

Scenario 2: optimal planning for the first year with probable modeling of DGs

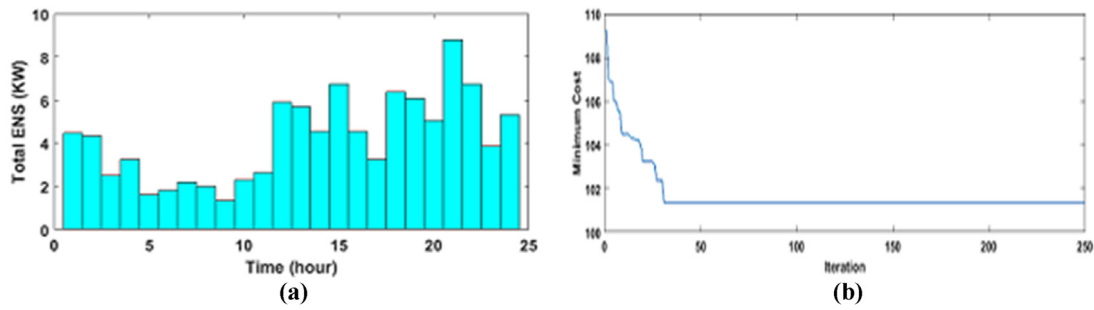


Fig. 19. (a) Total energy not supplied in network (b) Convergence curve.

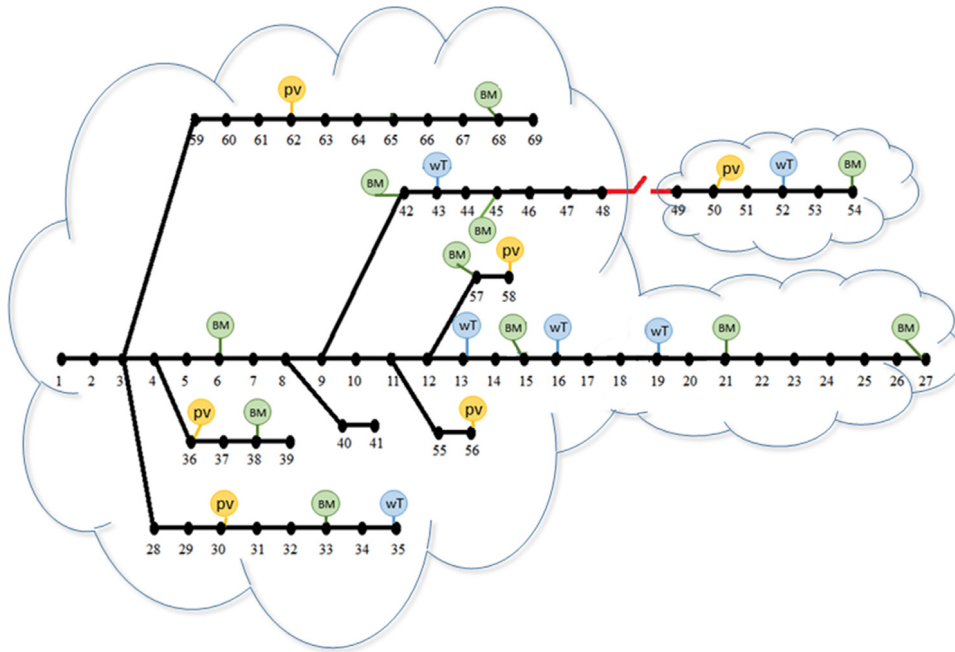


Fig. 20. Obtained micro-grids for scenario 5.

As displayed in Fig. 8, there are two MGs in this case. Also, the voltage profile, load profile, generated power of DG sources, power losses, and energy outcomes for this scenario are presented in Fig. 9.

Obtained diagrams for achieved micro-grids are shown in Fig. 9:

As shown in Fig. 10(b), the numerical value of the objective function in this scenario is 79.1074 which is more in comparison with the first scenario. Also, the state of the Switch for this scenario is off at all times.

In the first scenario, the amount of generated power of DGs is considered for a particular day. It is possible that on the mentioned day, the wind speed or solar radiation be in such a way that the generated power of distributed resources be close to their rated capacity and as a result, the amount of not supplied energy of the MG will be less than the state that the generated power of DGs is considered for a period of a few days.

Scenario 3: optimal planning with probable modeling of DGs and 5 specified micro-grids for the first year

The intended micro-grids for this scenario which have been chosen randomly are shown in Fig. 11 and the voltage and load profile of micro-grids is presented in Figs. 12 and 13, respectively. Also, the number of each micro-grid’s buses is presented in Table 3.

The achieved results by using the presented method for this state are displayed as Figs. 12–16.

Table 4

The mode of switches between micro-grids in different hours of a day.

Time	S1	S2	S3	S4	Time	S1	S2	S3	S4
	5-6	17-18	3-28	48-49		5-6	17-18	3-28	48-49
1	0	0	0	0	13	0	0	0	0
2	0	0	0	0	14	0	0	0	0
3	0	0	0	0	15	0	0	0	0
4	0	0	0	0	16	0	0	0	0
5	0	0	0	0	17	0	0	0	0
6	0	0	0	0	18	0	0	0	0
7	0	0	0	0	19	0	0	0	0
8	0	0	1	0	20	0	0	0	0
9	0	0	1	0	21	0	0	0	0
10	0	0	1	0	22	0	0	0	0
11	0	0	0	0	23	0	0	0	0
12	0	0	0	0	24	0	0	0	0

The generated power of DG sources in micro-grids and energy in each MG are presented in Figs. 15 and 16, respectively.

This scenario is just studied as an example to be compared with the second scenario. The amount of cost function is gained 84.4045 in this scenario. As it can be seen, by increasing the number of micro-grids, the total amount of not supplied energy in MGs will be increase. The mode of the switches for this scenario is presented in Table 4.

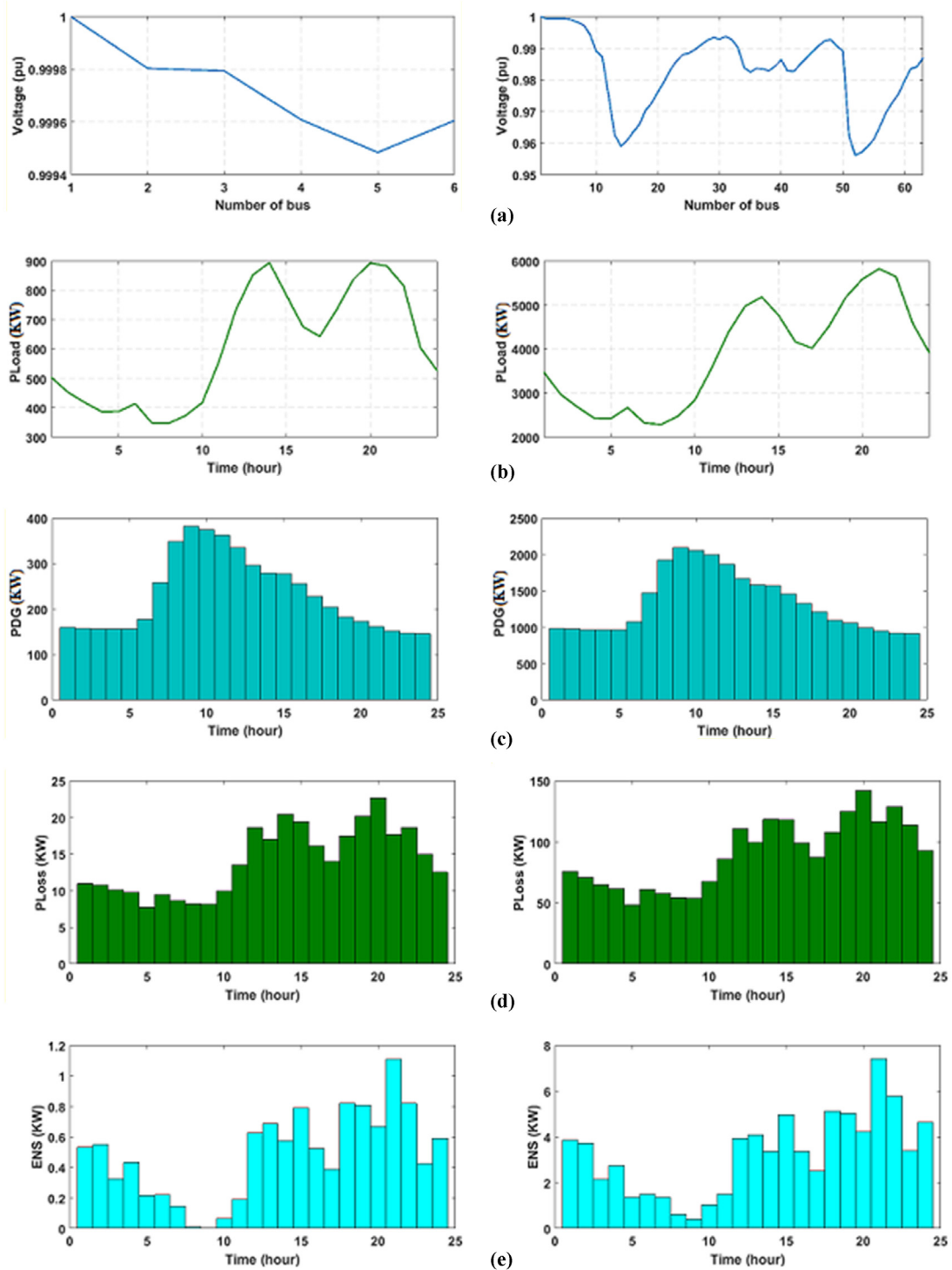


Fig. 21. (a) Voltage profile, (b) Load profile, (c) Generated power of DG sources, (d) Power losses, (e) Energy not supplied.

It is obvious that in hours 8, 9 and 10, the switch S3 is in connected mode and the second and fifth MGs are linked together to exchange power. The obtained micro-grids for scenario 4 is presented in Fig. 17. Also, the voltage profile, load profile, generated power of DG sources, power losses, is presented in Fig. 18 and the total energy in network is presented in Fig. 19.

Scenario 4: optimal planning for the fifth year without probable modeling of DGs

It is clear from the results that, the objective function is converged to 101.3466 and the switch between micro-grids is

in disconnected mode for all the times. Table 5 is presented to compare the total amount of energy not supplied for different numbers of micro-grids. The micro-grids for scenario 5 is presented in Fig. 20 and obtained results for voltage profile, load profile, generated power of DG sources, power losses is presented in Fig. 21. Also, total energy in network for this scenario is presented in Fig. 22.

Table 5 demonstrates the effectiveness of the proposed method. In other words, the best result would be the answer of the Imperialist Competitive Algorithm that has the minimum

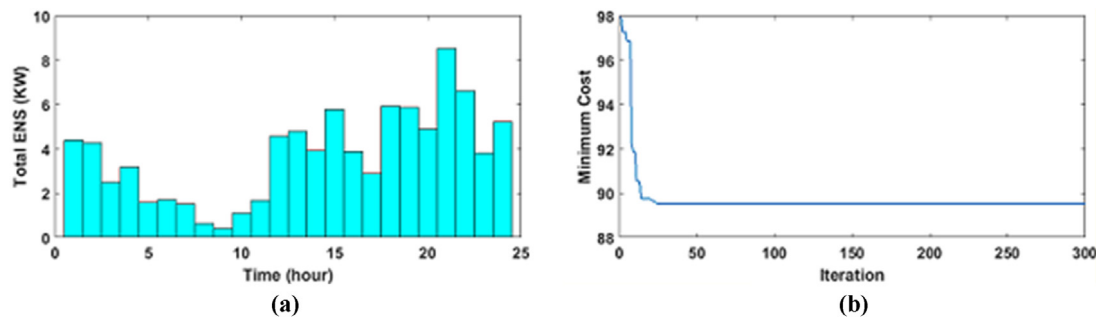


Fig. 22. (a) Total energy not supplied in network (b) Convergence curve.

Table 5

The amount of objective function for different numbers of micro-grids.

Number of micro-grids	Switch position	The amount of objective function
3	5-6, 59-60	109.1616
4	6-7, 15-16, 46-47	110.8924
5	3-4, 9-10, 13-14, 19-20	111.4116
6	3-4, 9-10, 13-14, 19-20, 28-29	114.7866

Table 6

The mode of switch in different hours of a day for scenario 5.

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Switch mode	0	0	0	0	0	0	0	0	1	0	0	0
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Switch mode	0	0	0	0	0	0	0	0	0	0	0	0

number of micro-grids (see Table 6). The micro-grids for scenario 5 is presented in Fig. 20 and obtained results for voltage profile, load profile, generated power of DG sources, power losses is presented in Fig. 21. Also, total energy in network for this scenario is presented in Fig. 22.

Scenario 5: optimal planning for the fifth year with probable modeling of DGs

The amount of optimized objective function is 89/5302 for this case and the switch is in connected mode at 9:00 o'clock. In other words, the second MG will be purchase energy from the first one at this time.

In the last two scenarios, the annual growth rate of load on each bus and generated capacity of DG's are considered to be 5% and 10%, respectively. By comparing the results for the first and fifth years, it is obvious that, the amount of load on the studied network is much higher than the capacity of the existing generation resources, so the rate of increase in the quantity of load will be more than the capacity of DG's. Thus, the amount of energy not supplied in the fifth year will be more than the first year.

6. Conclusion

The provision of safety and security features of a micro-grid and performance of them is one of the most important concerns of the electric power distribution companies.

MGs can provide safer and better quality of electrical energy for consumers and bring the immense benefits for electric power distribution companies and community. This research offers a powerful and comprehensive approach to divide a distribution network to several MGs. The proposed control scheme controls the appropriately function of MGs in interaction with each other. The results show that a set of MGs including loads and DGs can be operated nearby to achieve the goal of creating smart distribution networks.

The proposed model involves renewable resources and fossil fuels at the network level which is close to the real smart distribution network that would satisfy the expectations of a modern network. The Performance of the presented method is evaluated by simulation on the standard 69-bus IEEE distribution system. A probable modeling of wind turbine and PV resources per hours a day makes it possible to analyze different variables of the network. The results confirm that the suitable and optimal planning of micro-grids can play an important role in reducing the amount of energy not supplied (in independent mode of upstream network). In the presented paper, an effective step has been taken to reduce the costs of distribution companies, and by applying the results of this project, the electrical behavior of the network will be greatly improved. Also, by applying the proposed methodology, appropriate development plans for the future network will be identified which will greatly reduce the network development costs.

CRediT authorship contribution statement

Guo Wang: Formal analysis, Funding acquisition, Methodology, Software, Supervision, Validation, Writing - original draft, Writing - review & editing. **Qinqin Wang:** Data curation, Formal analysis, Funding acquisition. **Zhi Qiao:** Investigation, Methodology, Data curation. **Jiuhui Wang:** Project administration, Resources, Software, Supervision. **Simon Anderson:** Data curation, Formal analysis, Resources, Software, Visualization, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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