



Research article

Optimal energy management of distributed generation in micro-grids using artificial bee colony algorithm

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Abstract: The use of renewable energy sources in energy distribution networks as distributed generation sources for dispersed and low consumption loads in remote areas such as remote villages and islands with low population can be a proper solution for reducing economic costs, reducing environmental pollutions and increasing energy efficiency. The purpose of this paper is optimal operation management of micro-grids by considering the existing capacities in the electricity market. In fact the microgrid operator, which is responsible for the safe operation of the network, should consider a process for planning in the network that takes into account all benefits of micro-grid's components. In other words, enough reliability for generation resources in these networks should be created in order to reduce costs and environmental pollution from energy production. In this paper, the artificial bee colony (ABC) algorithm has been used to minimize the costs and environmental pollutions by providing the optimal production power of distributed generation.

Keywords: micro-grid; artificial bee colony algorithm; energy management; distributed generations; pollution; cost

1. Introduction

Electric power generation by large power plants at very distant consumption locations has a lot of disadvantages, such as high losses during power transmission and loss of reliability. As a result, to overcome such a problem, attention was drawn to the smaller scale generation and near to the place of

consumption. One of the current solutions is using distributed generation resources. By using distributed generation resources, it would be possible for us to provide the required power of consumer with the lowest losses and maximum reliability. The optimal way to use these resources is to create a micro-grid. In fact, the micro-grid is a set of loads and producers that can be worked in an island mode or connected to the network. Micro-grid producers are generally producers with distributed resources because of low load and micro-grid nature. Micro-grids, especially in remote areas, have good potential for producing energy from wind, solar cells, micro turbines, fuel cells and diesel generators working interconnected and as a low voltage system. In order to evaluate a micro-grid, technical and economic aspects can be considered as well as its positive effects on the environment, also its derived benefits can be investigated. On the other hand, the growing trend of privatization, the competitiveness of the electricity market, and the conversion of large investors to small ones, will lead the electricity industry managers to consider increasingly their generation capacity and network equipment with maximum energy efficiency and minimum operating cost. In fact the grid operator, responsible for the safe operation of this grid, should consider the process for planning in this network in which benefits of all the components of the micro-grid should be considered. In other words, enough assurance on the generation sources of these networks should be created to reduce the costs and release of environmental pollution caused by energy generation. To do this, we will use the honey colony algorithm. The trend to the distributed generations and especially to the micro-grids has increased because the traditional networks' problems mentioned in the previous section. But among these, the most critical issue is the issue of energy management in the micro-grid. There are a number of sources of power and storing resources in the micro-grid that each of which has the cost of producing power, emissions and their specific constraints. These resources should be controlled in such a way to minimize the cost of energy generation as well as reducing their environmental pollutions considering the constraints. This paper purpose is achieving to a comprehensive and complete plan in the field of implementation of micro-grids by considering the available capacity of electricity market space. The operator should select a model for the implementation of a micro-grid to consider the benefits of all parts of the micro-grid, including power and load generation sources. In other words, a solution should be proposed to ensure that the grid loads can supply their required with reliability and high power quality, also minimize the cost of generation of energy and pollutions created by the micro-grid. Regarding this, different methods have been conducted in the paper that some of which are mentioned in the previous section.

2. The review on studied research in micro-grid operation

In the field of new energies, distributed generations and micro-grid networks, a large number of researches have been studied. The papers in line with this research's purposes have been cited in this section. A review of the research done on micro-grid networks can be found in references [1–4]. First, the structure of operation and control of micro-grids with the responsibility of operation from these networks should be considered in order to short term planning and operation of micro-grids [5]. Distribution networks are defined with the concept of multiple micro-grids despite sources like low voltage grids, larger distributed generation sources, and a collection of disconnect-able and non-disconnect-able loads [6]. In reference [7], a review has been conducted on different modeling methods and energy management. In this research, accomplished studies about this kind of micro-grids have been revised.

In reference [8], a predictive model has been used for having a high reliability micro-grid. Another purpose of this paper is to reduce the cost of power generation in a micro-grid. Also, in [9], this method has been exerted for the optimization in a micro-grid practically. In reference [10], the planning details of a micro-grid have been explained on the basis of decentralized strategy. In reference [11], the planning of a micro-grid has been modeled to maximize the income of distributed generation resources by defining the factors for buying and selling for each of resources and loads. In reference [12], some methods for participating and modeling of market mechanisms have been presented for micro-grid networks. In reference [13], based on the multi-factor method, a 24-hour plan has been carried out for the micro-grid with no consideration of the connection between its operation hours. In reference [14], taking each micro-grid into account as a factor in a multiple micro-grid separated from network, a 24-hour plan has been carried out, at first with the goal of minimizing generation costs, considering the cost of switching units on and off and the supply of the internal load. Then the proper values have been executed for suggesting to the multiple micro-grid markets. In references [15,16], the optimization issue is presented in an island mode for a time interval of one-hour. In reference [17], daily plan has been presented for optimization of a micro-grid without any connection between its various hours in an island mode. In reference [18], in addition to maximizing the income of generation resources from energy sales and economic studies, optimization with the purposes of reducing pollution and in line with environmental objectives has been executed in the micro-grid. In reference [19], the objective function has been minimized by considering generation costs, pollution costs and operation costs and repairs. In this micro-grid, the strategy is based on the supply of loads by domestic sources and the battery has been modeled in it. In reference [20], a linear plan has been used for an optimize control of a domestic micro-grid and the cost-effectiveness of applying a micro-grid in the structure. In reference [21], the energy management of micro-grid has been carried out by considering a possible function for solar and wind generations. In reference [22], has proposed an optimal power solution that comprises of the dynamic load, wind turbine generator (WTG), battery storage system (BSS), photovoltaic (PV) and DG. Reference [23], has presented an enhanced bee colony optimization (EBCO) approach to solve the energy management strategy of MGs by considering renewable energy and battery storage systems. Reference [24], has proposed an improved energy hub consisting of different types of renewable energy-based DG units considering electricity and heating storage systems, which models the system's operation and planning aspects. Furthermore, optimal planning and scheduling of multi-carrier energy hub system has modeled considering the stochastic behavior of wind and photovoltaic units. In [25], the proposed energy management optimization objective aims to minimize the microgrid expenditure for fuel, operation and maintenance and main grid power import. The optimization model is formulated for a day-ahead optimization timeline with one-hour time steps, and it is solved using the ant colony optimization (ACO)-based metaheuristic approach. Reference [26], has presented an optimal energy management and sizing of a smart community microgrid (MG) with the uncertainty in load demand. The Overall problem is formulated to fix the optimal size of distributed generations (DGs) used in the MG by using a heuristic approach to minimize the net cost-based optimization problem. Also, in [27] a new comprehensive objective function is proposed for designing solar-wind hybrid system. The proposed objective function is a combination of life cycle cost and reliability cost. A microgrid system allows the incorporation of numerous generating units as a measure to minimize the number of power outages and the operating cost of the power system [28–30].

In this paper, the honey bee optimization algorithm has been used to achieve a comprehensive and complete planning of micro-grid operation based on the potential of electricity market. This

algorithm has a high convergence and high accuracy helping us in achieving our purposes. The algorithm has been coded by considering the generation limitations of any generation equipment or energy storages. In this paper, the following three scenarios are considered:

- The power generation costs should be minimized.
- The pollutions should be minimized.
- Cost and pollution should be minimized simultaneously.

Finally, a comparison will be studied between the achieved results derived from the simulation using the ABC algorithm and the results of other papers.

3. The statement of the objective function

Nowadays optimal operation by using multi-objective functions is one of the most important problems, since various purposes should be considered simultaneously and all of them should be optimized. In order to a better optimization of such functions, the equations, non-equations and constraints should be considered that can be expressed as follows.

$$\begin{aligned}
 & \text{Minimize } F = [f_1(x), f_2(x), \dots, f_n(x)] \\
 & \text{Subject to: } g_i(x) < 0 \quad i = 1, 2, \dots, N \\
 & h_i(x) = 0 \quad i = 1, 2, \dots, N
 \end{aligned} \tag{1}$$

In equation (1) f is a vector for target functions, and x is a vector containing optimization variables, and $f_i(x)$ is also the i^{th} target function. $g(x)$ and $h(x)$ are also equations and non-equations and N is the number of target functions.

For an optimal operation of a micro-grid can be used by applying multi-objective functions in order to reduce the cost and pollution emissions so that they can meet the considered purposes, using the following constraints and math equations expressed in terms of two objectives.

3.1. First objective (reduction the costs of power generation)

The operation costs that the micro-grid is facing are as follows: the cost of fuel, the cost of initiation of the power exchange cost, and so on. For this purpose, the equation (2) can be used.

$$\min f_1 = \sum_{t=1}^{24} \left\{ \sum_{i=1}^{N_g} [u_i(t)P_{Gi}(t)B_{Gi}(t) + S_{Gi} |u_i(t) - u_i(t-1)|] + \sum_{j=1}^{N_s} [u_j(t)P_{Sj}(t)B_{Sj}(t) + S_{Sj} |u_j(t) - u_j(t-1)|] + P_{Grid}(t)B_{Grid}(t) \right\} \tag{2}$$

In which u_i means the presence or absence of the considered element. Also $P_{Gi}(t)$ and $P_{Sj}(t)$ are the amount of power generated by distributed generation sources and storages at t hour respectively. $B_{Gi}(t)$ And $B_{Sj}(t)$ values are the cost of per kilowatt of generation capacity of distributed generation sources and storages. S_{Gi} And S_{Sj} are the cost of turning DGs and storages off or on respectively.

$P_{Grid}(t)$ Is the amount of purchased power from the network and $B_{Grid}(t)$ is the price of electricity at t hour. It should be noted that the amount of $P_{Grid}(t)$ can be negative, which indicates the sale of electricity to the network.

3.2. Second objective (reducing pollution emissions)

In the second step, to consider the effect of pollution emissions as the second purpose, the most important pollutants related to the distributed generation sources has been considered in the micro-grid which are NO_x , CO_2 and SO_2 [31]. The target function related to pollutions can be stated as Eq. (3).

$$\min f_2 = \sum_{t=1}^{24} \left\{ \sum_{i=1}^{Ng} [u_i(t)P_{Gi}(t)E_{Gi}(t)] + \sum_{j=1}^{Ns} [u_j(t)P_{Sj}(t)E_{Sj}(t)] + P_{Grid}(t)E_{Grid}(t) \right\} \quad (3)$$

In equation (3), $E_{Gi}(t)$, $E_{Sj}(t)$ and $E_{Grid}(t)$ are considered as the amount of pollution emissions in Kg / MWh for each generation unit at t hour. These variables are defined as follows:

$$E_{Gi}(t) = NO_x^{DGn}(t) + CO_2^{DGn}(t) + SO_2^{DGn}(t) \quad (4)$$

In which $CO_2^{DGn}(t)$, $SO_2^{DGn}(t)$ and $NO_x^{DGn}(t)$ are the values of all CO_2^{DGn} , SO_2^{DGn} and NO_x^{DGn} that the ith DG dispersed at t hour.

$$E_{Sj}(t) = NO_x^{Storage\ m}(t) + CO_2^{Storage\ m}(t) + SO_2^{Storage\ m}(t) \quad (5)$$

In equation (5), $CO_2^{storage\ m}(t)$, $SO_2^{storage\ m}(t)$ and $NO_x^{storage\ m}(t)$ are the values of all $CO_2^{storage\ m}(t)$, $SO_2^{storage\ m}(t)$ and $NO_x^{storage\ m}(t)$ dispersing at t hour.

$$E_{Grid}(t) = NO_x^{grid}(t) + CO_2^{grid}(t) + SO_2^{grid}(t) \quad (6)$$

In equation (6), $CO_2^{grid}(t)$, $SO_2^{grid}(t)$, and $NO_x^{grid}(t)$ are the values of all of the $CO_2^{grid}(t)$, $SO_2^{grid}(t)$ and $NO_x^{grid}(t)$ are the values of all $CO_2^{grid}(t)$, $SO_2^{grid}(t)$, and $NO_x^{grid}(t)$ generated by the network at the t hour.

3.3. Limitations of the power generation of micro-grid

In order to exploiting the micro-grid, some obligations should be considered as follows:

3.3.1. Balance of power generation and consumption

In a micro-grid, the generated power of the micro-grid and the amount of received power from the whole network should be responsive to the demanded power. To do this, the following equation can be considered:

$$\sum_{i=1}^{Ng} P_{Gi}(t) + \sum_{j=1}^{Ns} P_{Sj}(t) + P_{Grid}(t) = \sum_{k=1}^{Nk} P_{Lk}(t) \quad (7)$$

In the above equation, the P^{lk} is the amount of K^{th} load and N_k is the number of loads.

3.3.2. Generation Capacity of Distributed Generation Units and Storage Resources

In the operation of the micro-grid, the generation capacity of each of the distributed generations should be considered and we must not permit the activity of distributed generation in unauthorized spans by exerting these constraints. The power generation capacity constraints are as follows:

$$\begin{aligned} P_{\min}^{gn}(t) &\leq P^{gn}(T) \leq P_{\max}^{gn}(t) \\ P_{\min}^{sm}(t) &\leq P^{sm}(T) \leq P_{\max}^{sm}(t) \\ P_{\min}^{grid}(t) &\leq P^{grid}(T) \leq P_{\max}^{grid}(t) \end{aligned} \quad (8)$$

In the above equations, the lower and upper bound of generators' power generation and power storages have been presented.

3.3.3. The limitations of battery operation

There are limitations for charging and discharging batteries at any time intervals. This limitation can be expressed in the following form:

$$V_t^{ess} = V_{t-1}^{ess} + \mu^{charge} P^{charge} \Delta t - \frac{1}{\mu^{discharge}} P^{discharge} \Delta t \quad (9)$$

$$\begin{aligned} V_{\min}^{ess} &\leq V_t^{ess} \leq V_{\max}^{ess} \\ P_t^{charge} &\leq P_{\max}^{charge} \\ P_t^{discharge} &\leq P_{\max}^{discharge} \end{aligned} \quad (10)$$

In which, V_t^{ess} and V_{t-1}^{ess} are the values of energy storage in a battery in two continuous hours. P^{charge} and $P^{discharge}$ are the allowed values of charge and discharge of battery in a specific time interval. Also, μ is the efficiency of charge and discharge. In above equations, V_{\max}^{ess} and V_{\min}^{ess} are the maximum and minimum of authorized span related to energy storage in battery respectively and P_{\max}^{charge} and $P_{\min}^{discharge}$ are the maximum and minimum bounds of charge and discharge of battery in time interval of $t-1$.

Optimization means finding of best answer to a problem under determined conditions leading to an optimized answer. According to this definition, a mathematical equation can be optimized when its variable values can be determined as a maximum or minimum up to the possible point (related to its physical and real conditions).

In recent decade, some evolutionary and meta-analytic methods have been used as a research and

optimization tool in different fields like science, business and engineering. The extent of application scope, ease of use and achievability of a near answer to absolute optimality are among the reasons of the success of these methods. In this section, the ABC algorithm has been introduced for an optimized management of electrical energy.

4. Simulation and analysis of results

In this section, a pattern is presented for generating the power for each distributed generation resource in a micro-grid. The result of optimization is reducing the costs of power generation power and minimizing the environmental pollutions caused by distributed generations. To achieve this goal, the honey bee algorithm has been used. This algorithm should act in a way that in addition to search for optimal variables, meet he related constraints to power generation from each source. The proposed method in this paper is applied on 16-bus bar of low-voltage standard of a micro-grid.

4.1. Introduction of micro-grid

The single line diagram of studied low voltage micro-grid has been presented in figure 1 [32]. In the studied micro-grid, photo voltaic (PV), wind turbines (WT), micro turbines (MT) and fuel cells (FCs) have been used as power generation resources and batteries (Bat) as storage source and power generation at various points in the micro-grid. The power range of each distributed generation elements has been presented in Table 1. In Table 1, negativity of power for the battery means storage by the battery, and this negative value for the network means the sale of electricity to the whole network by micro-grid.

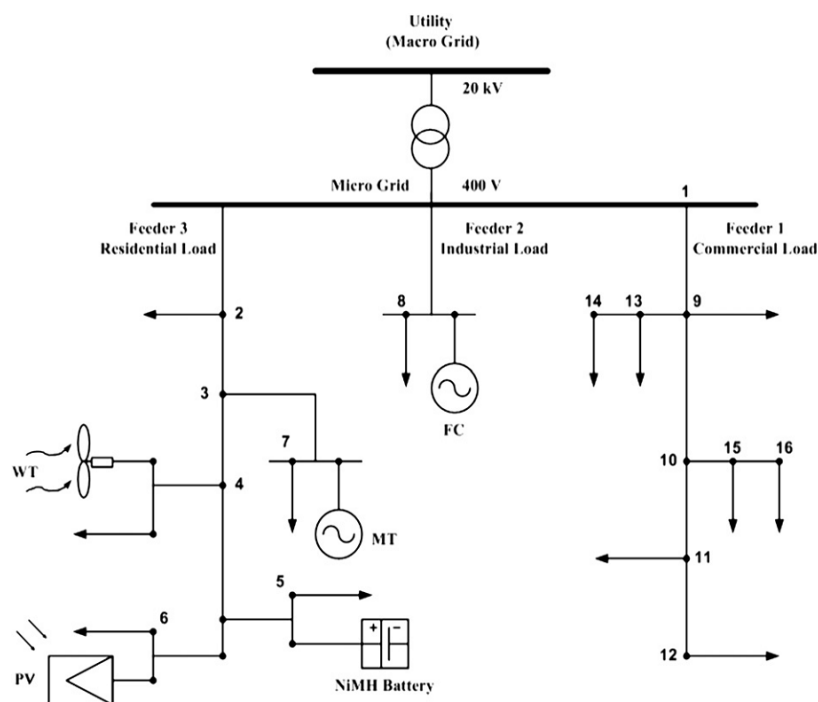


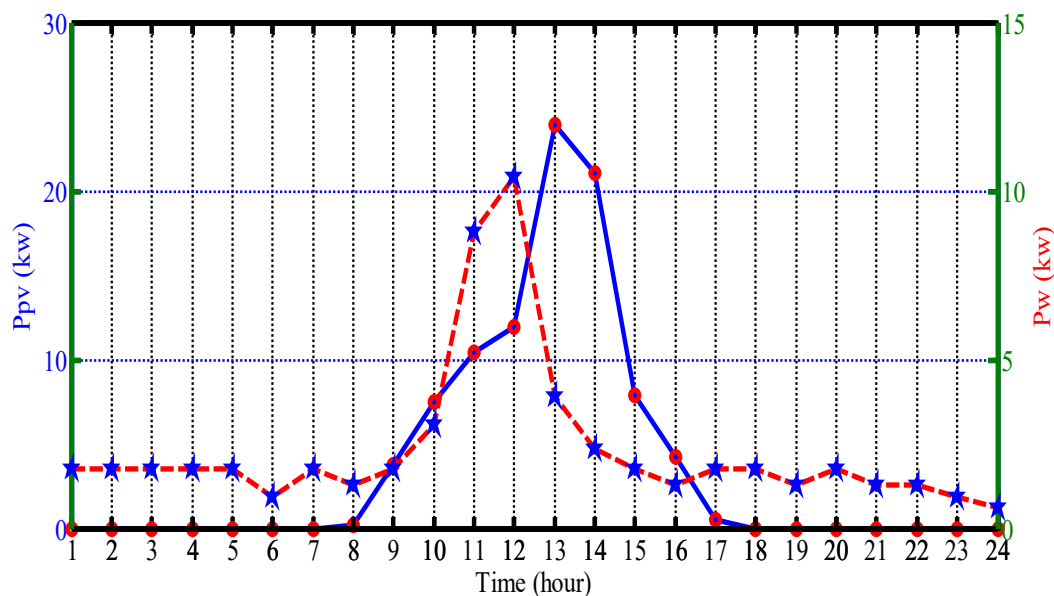
Figure 1. The studied micro-grid [32].

Table 1. The fluctuating range of distributed generation power.

	Net	Bat	MT	FC
Minimum limit	-30	-30	6	3
Maximum limit	30	30	30	30

There are some limitations in a micro-grid for power generation by photovoltaic and wind turbines. In Figure 2, the amount of power generation produced by photovoltaic and wind turbines has been presented.

In figure 2, the power generation produced by the wind turbines and the solar cell have been shown by the red curve, with the star profile and the blue curve with the circle profile. The amount of received power extracted by each of these two elements depends on the amount of wind and the intensity of the sun's radiation.

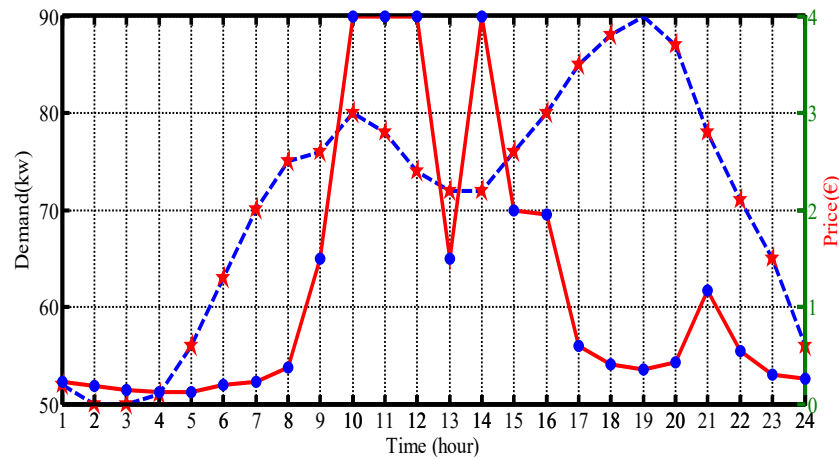
**Figure 2.** The amount of solar and wind generation power.

The micro-grid is connected to whole electricity network by a $\frac{0.4 \text{ kv}}{20 \text{ kv}}$ transformer. The local loads and the cost of per kilowatt-hour in 24 hours a day are unsteady as these values shown in Figure 3. In Figure 3, the blue dash line with star profiles indicates the amount of demanded load in different hours, and the red line with blue circle profiles also indicates the price of electrical energy in different hours.

The Studies have been accomplished in three scenarios. In the first scenario, the reduction of power generation costs, in the second scenario the reduction of pollution and in the third scenario the simultaneous reduction of cost and pollution has been studied. To confirm the results obtained by the honey bee colony algorithm, we will compare the achieved results of the ABC algorithm and some other algorithms (GA, PSO, FSAPSO, CPSO-T, CPSO-L, AMPSO-T and AMPSO-L). The parameters of the ABC algorithm have been presented in Table 2.

Table 2. Parameter values of optimization parameter.

	nScoutBee	Iterations	nSelectedSite	nEliteSite	nSelectedSiteBee	nEliteSiteBee
ABC	100	50	50	20	50	100

**Figure 3.** Load fluctuations and electricity prices in 24 hours a day [32].

4.2. Reduction of the power generation costs

In this scenario, our goal is reducing the cost of power generation. For this purpose ABC optimization algorithm will operate so that only the cost of power generation is minimized.

The cost of generating energy produced by each distributed generation in euros per kilowatt-hour is given in Table 3. For a fuel cell, the cost of launching is 1.65 euros and for micro turbines the considered cost is 0.96 euros. Power values of each distributed generating elements has been obtained after optimization by using a honey bee colony algorithm. These results have been summarized in table 4. By considering the distributed power generation based on table 4, the supply of energy costs has been minimized.

The achieved results of optimization of ABC algorithm have been stored by executing program for 20 times. The amount of minimum cost is 159.323 euros, the maximum cost is 159.328 euros and the average cost of 20 times of running program is 159.325 euros.

Table 3. The costs of power generation resources [32].

	Bat	FC	MT	WT	PV
Power generation cost (€/ KWh)	0.38	0.29	0.47	1.07	2.58

Table 4. The values of generation with the goal of cost reduction in first scenario.

H	MT	FC	PV	WT	Bat	Net
1	6	16.0011	0	0	0.0005	29.9984
2	6	14.0001	0	0	0.0004	29.9995
3	6	13.9977	0	0	0.0023	30
4	6	14.9994	0	0	0.0041	29.9965
5	6	20.0003	0	0	0.0012	29.9985
6	6	26.9944	0	0	0.0056	30
7	6	30	0	0	4	30
8	6	30	0	0	21.9121	17.0879
9	30	30	0	1.785	30	-15.785
10	30	30	7.525	3.09	30	-20.615
11	30	30	9.225	8.775	30	-30
12	30	30	3.59	10.41	30	-30
13	30	30	0	3.915	30	-21.915
14	30	30	9.63	2.37	30	-30
15	30	30	0	1.785	30	-15.785
16	30	30	0	1.305	30	-11.305
17	30	30	0	0	30	-5
18	6	30	0	0	30	22
19	6	30	0	0	24	30
20	6	30	0	0	30	21
21	30	30	0	1.302	30	-13.302
22	30	30	0	0	30	-19
23	6	30	0	0	0.0001	28.9999
24	6	20.0006	0	0	0.0004	29.999

4.3. Reduction of environmental pollution

One of the discussed issues in the micro-grids is the argument about the distributed generation equipment. In this scenario, the reduction of pollution caused by the micro-grid is the goal of the optimization issue. The ABC algorithm should determine the generation capacity of distributed generations of power generation so that the amount of pollution caused by power supply reaches to its minimum amount. The amount of pollution emissions from each power source per kilowatt of electrical power is given in Table 5. After optimization with the goal of reducing pollutions, the amount of generated power by each power source is presented in Table 6.

The amount of produced pollution is 431.248 kg by choosing a pattern like table 6. Also, the worst answer in 20 times of executing honey bee algorithm was 431.327 kg. The average amount of pollution is calculated 431.287 kg in 20 times of executing algorithm. Through analyzing achieved results obtained from optimization in 24 hours a day, it can be said that this algorithm tries to use

distributed generations with high amount of pollution and these equipment can be active with their minimum amount of their power. This equipment can be used in case of other equipment inability in supplying required load power.

Table 5. The amount of pollution in each resource of power generation.

	MT	FC	PV	WT	Bat	Net
CO_2 (Kg/MWh)	720	460	0	0	10	30
SO_2 (Kg/MWh)	0.0036	0.003	0	0	0.0002	0.003
NO_x (Kg/MWh)	0.1	0.0075	0	0	0.001	0.04

Table 6. The values of distributed power generation with the goal of reducing the amount of pollution in first scenario.

	MT	FC	PV	WT	Bat	Net
1	6	3	0	1.785	30	11.215
2	6	3	0	1.785	30	9.215
3	6	3	0	1.785	30	9.215
4	6	3	0	1.785	30	10.215
5	6	3	0	1.785	30	15.215
6	6	3	0	0	30	24
7	6	3	0	1.785	30	29.215
8	6	7.495	0.2	1.305	30	30
9	6	4.465	3.75	1.785	30	30
10	6	3.385	7.525	3.09	30	30
11	6	3	10.45	8.775	30	19.775
12	6	3	11.95	10.41	30	12.64
13	6	3	23.9	3.915	30	5.185
14	6	3	21.05	2.37	30	9.58
15	6	3	7.875	1.785	30	27.34
16	6	8.47	4.225	1.305	30	30
17	6	16.665	0.55	1.785	30	30
18	6	20.215	0	1.785	30	30
19	6	22.698	0	1.302	30	30
20	6	19.215	0	1.785	30	30
21	6	10.698	0	1.302	30	30
22	6	3.698	0	1.302	30	30
23	6	3	0	0.915	30	25.085
24	6	3	0	0.615	30	16.385

4.4. Reduction of cost and the amount of pollution simultaneously

In this scenario, we are going to plan the distributed power generation in a way that the costs and the amount of pollution reduced simultaneously. For this purpose, by considering the weighting coefficient for the two cost and pollution functions, we define a new target function to achieve the favorable results by minimizing this target function.

$$F = \alpha F_{\text{cost}} + \beta F_{\text{emission}} \quad (11)$$

The values of $\alpha = 2.7$ and $\beta = 1$ are considered to do the simulation. With such a choice, the two target functions will be weighed the same, and we can say that both functions are minimized simultaneously. These coefficients are achieved by dividing the obtained answers from the two previous scenarios (cost reduction and pollution reduction). For example, if we divide the achieved result from the ABC algorithm in reducing pollution reduction (431) into the result of cost reduction (159), we will have: $\frac{431}{159} \approx 2.7$.

The amount of generation for each generating elements has been presented in table 7 with the goal of reducing cost and amount of pollution. The amount of target function in this scenario is 976.655. The worst answer was 976.531 and the average of answers was 976.941 in 20 times of executing program. The basis of selection of these elements' power is a way that in hours with expensive price for electricity, the priority is with the reduction of costs and in hours with low price for electricity, the reduction the amount of pollution has been considered as first priority. The costs reduction of power generation causes an increase in environmental pollutions and vice versa. This means that we are not able to put costs and the amount of pollution in their minimum amount simultaneously so that the obtained minimum points derived from simulation of first scenario (cost reduction) and second scenario (pollution reduction) can be equaled with minimum points in third simulation (simultaneous reduction of cost and pollution).

So, a new working point should be found in a way that in that point, the combination of cost and amount of pollution with their weighting coefficients reduced to their minimum amount. Hence, the obtained result from the third scenario is greater than the sum of previous scenarios' weighting. $(2.7 \times 159.323) + (431.248) < 980.655$.

In this equation, 159.323 is the minimum amount of power generation cost, 431.248 is the minimum amount of pollution and 980.655 is the best answer in minimizing cost and amount of pollution simultaneously.

4.5. The analysis and evaluation of results

In this scenario, we are investigating the application of mentioned algorithms in this paper in different situations. For this purpose, the achieved results derived from simulation are compared with the achieved results derived from applying algorithms of GA, PSO, FSAPSO, CPSO-T, CPSO-L, AMPSO-T and AMPSO-L. For this purpose, the best answer, the worst answer and the average of answers in 20 times of executing algorithms have been presented. The results derived from the optimization with the goal of reducing costs are given in table 8.

Table 7. The values of distributed power generation with the goal of simultaneous reduction of cost and amount of pollution.

H	MT	FC	PV	WT	Bat	Net
1	6	3	0	0	30	13
2	6	3	0	0	30	11
3	6	3	0	0	11	30
4	6	3	0	0	12	30
5	6	3	0	0	17	30
6	6	3	0	0	30	24
7	6	4	0	0	30	30
8	6	7.695	0	1.305	30	30
9	14.215	30	0	1.785	30	0
10	30	30	7.525	3.09	30	-20.615
11	30	30	9.225	8.775	30	-30
12	30	30	3.59	10.41	30	-30
13	30	30	0	3.915	30	-21.915
14	30	30	9.63	2.37	30	-30
15	30	30	0	0	30	-14
16	30	30	0	1.305	30	-11.305
17	6	17.215	0	1.785	30	30
18	6	20.215	0	1.785	30	30
19	6	23.7066	0	0.2934	30	30
20	6	19.215	0	1.785	30	30
21	6	30	0	0	30	12
22	6	3.698	0	1.302	30	30
23	6	3	0	0	30	26
24	6	3	0	0	30	17

By considering the results of reducing the power generation costs, it can be said that the honey bee algorithm (ABC) has the minimum amount of cost in comparison to other algorithms and the weakest function is for genetic algorithm. In the case of standard deviation, it can also be said that an algorithm with a lower standard deviation has a more accurate and appropriate performance and has not obtained the optimal response randomly. Another important parameter in the energy management of micro-grid is the amount of its pollution. In Table 9, a comparison has been studied between the obtained results from optimization by honey bee colony algorithm and other algorithms.

Table 8. The comparison of various algorithms in reducing costs.

	Best solution (€)	Worst solution (€)	Average (€)	Standard Deviation (€)
GA	162.9469	198.5134	179.6502	24.5125
PSO	162.0083	180.2282	171.2103	12.6034
FSAPSO	161.5561	175.5402	168.2442	10.0025
CPSO-T	161.0580	165.3110	162.9845	2.9971
CPSO-L	160.7708	163.5512	162.1614	1.9660
AMPSO-T	159.9244	160.4091	160.2368	0.3427
AMPSO-L	159.3628	159.56813	159.5143	0.0963
ABC	159.323	159.328	159.25	0.0658

Table 9. The comparison of the results of different algorithms in reducing the amount of pollution.

	Best solution (€)	Worst solution (€)	Average (€)	Standard Deviation (€)
GA	435.2363	457.4680	445.3862	14.2299
PSO	435.8227	454.5917	445.1072	13.9708
FSAPSO	435.0830	451.3821	443.4396	11.6525
CPSO-T	434.9973	444.9398	440.1036	6.9950
CPSO-L	434.9354	443.6383	439.2369	6.1538
AMPSO-T	434.8611	435.1126	434.9983	0.1786
AMPSO-L	434.8193	434.0099	434.9235	0.0681
ABC	431.248	431.327	431.287	0.0432

In the third scenario optimization, simultaneous reduction of the cost and the amount of pollution was studied. By placing weighting coefficients for the two cost and pollution functions, the cost function was obtained which minimized this function, cost, and pollution. In table 10, the results of the results of simulation have been presented by the ABC algorithm and other algorithms.

Table 10. The comparison of the results of different algorithms in simultaneous reduction of the cost and the amount of pollution.

Best solution	Worst solution	Average	Standard Deviation	Best solution
GA	987.326	1021.361	1012.698	20.6524
PSO	985.231	1005.261	998.687	12.5471
FSAPSO	983.457	998.752	994.681	9.9864
CPSO-T	982.974	987.649	986.249	2.8541
CPSO-L	982.247	985.367	984.214	1.8974
AMPSO-T	981.743	982.012	981.876	0.2845
AMPSO-L	981.362	981.874	981.468	0.1123
ABC	976.655	976.531	976.941	0.0842

5. Conclusion

Using renewable energy sources in energy distribution networks, called distributed generating sources for dispersed and low consuming loads in an area, can be a proper solution for reducing economical costs, reducing environmental pollutions and increasing the energy efficiency. Since the main purpose of using renewable energy sources is reducing costs, therefore it is necessary to accomplish accurate economic analyzes for the favorable distribution networks, and the type of renewable energy source and the amount of produced energy, considered by other parameters like consumed loads, the cost of establishment and operation of these power plants and their comparison with the cost of fuel used by existing power plants and whole network of electricity. Using renewable energy sources in renewable energy distribution networks and in energy distributing networks called dispersed and low generating sources in remote areas like remote villages and islands with a low population is an appropriate solution for reducing economic costs, reducing environmental pollution and increasing energy efficiency. Also, since the most important purpose of using renewable energy sources is reduction in costs, it is necessary to consider accurate economic analysis for favorable distributing networks and the type of required energy source for supplying consumed loads and the amount of produced amount of energy should be considered in comparison to other parameters like the type and amount of consumed loads and their variation rate, the cost of establishment and operation of whole electricity network in region and the rate of consuming electricity by consumers, environmental geographic conditions for using different kinds of renewable energies and so on. On the other hand, the growing trend to privatization, the competitiveness in the electricity market, and turning large investors to small ones, will force the electricity industry managers to increasingly focus on enhancing their generation capacity and network equipment with maximum energy efficiency and minimum operating cost. The purpose of accomplishment of this paper was optimized operation management of micro-grids, by considering the available capacities in the electricity market. Actually the grid operator, responsible for the safe operation of this network, should consider the process for planning in this network to consider the benefits of all the components of the micro-grid. In other words, enough reliance on the sources of these networks should be considered to reduce the cost and emission of environmental pollution caused by generating energy. To accomplish this, we have used the ABC honey bee algorithm to minimize the costs and environmental pollutions caused by electric power generation by providing a suitable model for power generation by distributed generations. The simulation results have been presented in three scenarios: cost reduction, pollution reduction and simultaneous reduction of the cost and the amount of pollution by executing the honey bee colony algorithm and comparing with the results of other algorithms. The ABC algorithm as proposed algorithm has a more proper performance in the reduction of target functions in all conditions.

Conflict of interest

All authors declare no conflicts of interest in this paper.

References

1. N. W. A Lidula, A. D. Rajapakse, Micro grids research, A review of experimental micro grids and test systems, *Renew. Sust. Energ. Rev.*, **15** (2011), 186–202.

2. S. Chowdhury, S. P. Chowdhury, P. Crossley, Micro grids and active distribution networks, *IET Renew. Energy*, **6** (2009).
3. C. Marnay, H. Asano, S. Papathanassiou, G. Strbac, Policy making for micro grids, power and energy magazine, *IEEE*, **6** (2008), 66–77.
4. A. G. Tsikalakis, N. D. Hatziargyriou, Centralized control for optimizing Micro grids operation, *IEEE Trans. Energy Convers.*, **4** (2008), 241–248.
5. F. Katiraei, R. Itavani, N. Hatziargyriou, A. Dimeas, Micro grid management, *IEEE Power Electron. Mag.*, **6** (2008), 54–65.
6. J. A. Pecos Lopes, A. Madureira, Advanced architectures and control concepts for more microgrids, work package D-DDI, *INESC porto*, 2007.
7. W. Gu, Z. Wu, R. Bo, Modeling, planning and optimal energy management of combined cooling, heating and power microgrid: A review, *Int. J. Electr. Power Energy Syst.*, **54** (2014), 26–37.
8. I. Prodan, E. Zio, A model predictive control framework for reliable microgrid energy management, *Int. J. Electr. Power Energy Syst.*, **61** (2014), 399–409.
9. A. Parisio, E. Rikos, G. Tzamalīs, L. Glielmo, Use of model predictive control for experimental microgrid optimization, *Appl. Energy*, **115** (2014), 37–46.
10. A. L. Dimeas, N. D. Hatziargyriou, Operation of a multiage system for micro grid control, *IEEE Trans. Power Syst.*, **20** (2005), 1447–1455.
11. T. Funabashi, T. Tanabe, T. Nagata, R. Yokoyama, An autonomous agent for reliable operation of power Market and Systems including Micro grids, *IEEE Electric Utility Deregul. Restruc. Power Technol.*, **23** (2008), 173–177.
12. D. Rui, G. Deconinck, Market mechanism of smart grids: Multi-agent model and interoperability, *IEEE conference Networking, sensing and control (ICNSC)*, **3** (2001), 8–13.
13. R. B. Swari, S. K. Srivastava, C. S. Edrington, D. A. Cartes, S. Subramanian, Intelligent agent based auction by economic generation scheduling for Microgrid Operation, *Innov. Smart Grid Technol. (ISGT)*, **14** (2010), 106–117.
14. T. Logenthiran, D. Srinivasan, A. M. Khambadkone, Multi-agent system for energy resource scheduling of integrated micro grids in a distributed System, *Electr. Power Syst. Res.*, **81** (2012), 138–148.
15. B. Ren, C. Jiang, A review on the economic dispatch and risk management considering wind power in the power market, *J. Renew. Sust. Energy Rev.*, **13** (2013), 751–767.
16. C. A. Hernandez, T. C. Green, N. Mugniot, Fuel consumption minimization of a micro grid, *IEEE Trans. Ind. Appl.*, **41** (2008), 673–681.
17. F. A. Mohamed, H. N. Koivo, System modeling and alone optimal management of micro grid using multi objective optimization, *IEEE conf. Clean Electr. Power*, **1** (2007), 148–153.
18. N. D. Hatziargyriou, A. J. Anastasiadis, J. Vasiljevska, A. G. Tsikalakis, Quantification of economic, environmental and operational benefits of micro grids, *IEEE Power. Tech.*, **23** (2013), 1–8.
19. F. A. Mohamed, H. N. Koivo, System Modeling and alone optimal management of micro grid with battery storage, *Int. Conf. Renew. Energ. Power Qual.*, **1** (2011), 23–37.
20. M. Mazidi, A. Zakariazadeh, S. Jadid, P. Siano, Integrated scheduling of renewable generation and demand response programs in a microgrid, *Energy Convers. Manag.*, **86** (2014), 1118–1127.
21. W. El-Khattam, M. M. A. Salama, Distributed generation technologies, definitions and benefits, *Electric Power Syst. Res.*, **6** (2004), 119–128.

22. T. Adefarati, R. C. Bansal, M. Bettayeb, R. Naidoo, Optimal energy management of a PV-WTG-BSS-DG microgrid system, *Energy*, **217** (2021).
23. W. M. Lin, C. S. Tu, M. T. Tsai, Energy management strategy for microgrids by using enhanced bee colony optimization, *Energies*, **9** (2016).
24. E. Shahrabi, S. M. Hakimi, A. Hasankhani, G. Derakhshan, B. Abdi, Developing optimal energy management of energy hub in the presence of stochastic renewable energy resources, *Sustain. Energy Grids Netw.*, **26** (2021).
25. H. Wu, H. Li, X. Gu, Optimal energy management for microgrids considering uncertainties in renewable energy generation and load demand, *Processes*, **8** (2020).
26. M. Kumar, B. Tyagi, Optimal energy management and sizing of a community smart microgrid using demand side management with load uncertainty, *ECTI-CIT*, **15** (2021), 186–197.
27. E. Eslami, M. A. Kamarposhti, Optimal design of solar–wind hybrid system-connected to the network with cost-saving approach and improved network reliability index, *SN Appl. Sci.*, **1** (2019), 1–12.
28. V. V. S. N. Murty, A. Kumar, Multi-objective energy management in microgrids with hybrid energy sources and battery energy storage systems, *Prot. Control Mod. Power Syst.*, **5** (2020), 1–20.
29. T. Adefarati, G. D. Obikoya, Evaluation of wind resources potential and economic analysis of wind power generation in South Africa, *Int. J. Eng. Res. Afr.*, **46** (2019), 146–167.
30. Y. Li, P. Wang, H. B. Gooi, J. Ye, L. Wu, Multi-objective optimal dispatch of microgrid under uncertainties via interval optimisation, *IEEE Trans. Smart Grid.*, **10** (2019), 2046–2058.
31. M. Elsied, A. Oukaour, H. Gualous, O. A. Lo Brutto, Optimal economic and environment operation of micro-grid power systems, *Energy Convers. Manag.*, **122** (2019), 182–194.
32. A. A. Moghaddam, A. Seifi, T. Niknam, M. R. A. Pahlavani, Multi-objective operation management of a renewable MG with back-up micro-turbine/fuel cell/battery hybrid power source, *Energy*, **36** (2011), 6490–6507.



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