International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2013 Issue 14 Volume 5 Number 1 Pages 149-162

BI-OBJECTIVE FUNCTION MICRO GRID OPTIMAL OPERATION USING A HYBRID ALGORITHM

M. Keshavarz [1] **A.M. Ranjbar** [2] **M. Sedighizadeh** [3] **A. Sheikhi** [2]

1. Department of Electrical and Computer Engineering, Science and Research Branch, Islamic Azad University, Saveh, Iran, mohsen.keshavarz3@gmail.com
2. Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran
amranjbar@sharif.edu, aras.sheikhi@yahoo.com
3. Faculty of Electrical and Computer Engineering, Shahid Beheshti University, Tehran, Iran, m_sedighi@sbu.ac.ir

Abstract- Nowadays, given the rapid growth of socio-economic issues, more emphasis is being placed upon providing the consumers with higher quality services. Consequently, many modern societies are seeking to use new energy management systems to reduce the environmental pollutions and operational costs resulting from electrical energy generation systems. So, benefiting from various renewable energy resources, Micro Grid (MG) could be considered as a substantial tool to reach such objectives. According to this matter, the present paper is aimed at introducing the, multiobjective Hybrid Big Bang - Big Crunch (HBB-BC) algorithm to be used for optimizing a sample MG. The problem is assumed to be an optimization problem with nonlinear multiple objectives, having different qualities and non-equal limitations in order to reduce the cost and distribution of pollutants. The proposed algorithm is applied in a sample MG and the results are compared with other optimizing algorithms such as particle swarm optimization (PSO) and Big Bang - Big Crunch (BB-BC).

Keywords: Distributed Generation, Micro Grid, Distributed Energy Resource, Micro Grid Central Controller, Renewable Energy Source.

I. INTRODUCTION

Todays, given the increase of environmental pollutions and high costs of generating electrical energy, electricity suppliers have focused their attention on producing power at the distribution voltage level, using renewable resources such as wind, sun, etc. In fact, generating electricity by means of these resources is believed reduce emission significantly and also increase reliability and security by diversifying energy generation portfolio. On the other hand, it is assumed that distributed generations (DGs) such as battery, photovoltaic (PV), phosphoric acid fuel cell (PAFC) and micro turbine (MT), play an important role in producing electricity in the future. In this respect, MG can be utilized in order to coordinate DGs in smaller scales in some parts of the network [1-2].

Accordingly, taking into account the generators used in MG, it appears that, as the main tools for independence in energy production, energy systems and coordinators of generating resources should have the capacity to maintain and save energy. Therefore, there is felt to exist a strong need for a more precise design and planning of energy resources to be used as MGs [3-4]. In this respect, a lot of attempts has been made so far In order to better exploit an MG, which can be divided in to two categories. Earlier works focused mostly on individual objectives [5-7], while more recent studies, in addition to the individual purposes, have followed various dual approaches such as those which consider financial and environmental issues simultaneously. Most optimizing algorithms have been aimed at individual objectives, among which is the one proposed by Park et al. In their study, Park et al. presented a linear planning based on optimizing that deals with the objectives one at a time [8]. Similarly, Boqiang and Chuanwen attempted to propose a hierarchical approach for economic objectives [9].

Elswehere, Gaing has used PSO algorithms in order to account for economic limitations of units [10]. Taking into consideration the time pass and emergence of different objectives, the single objective algorithms have been found to be no longer much applicable. Therefore, the researchers have tended to follow new approaches in order to manage optimized exploitation of algorithms, among which the following are noteworthy. Sadegheih has presented a methodology for optimized design of carbon distribution with the proposing a rather innovative method [11]. Moghaddam et al. have also used two different algorithms for optimizing multiple objective functions [1-3]. In the same vein, Dhillon et al. have put forward a method which accounts for uncertainties; however their method has turned out not to work properly when it comes to EED [12]. Venkatesh et al. have also used genetic algorithm (GA) and ant colony optimization (ACO) for planning to solve economic / environmental dispatch (EED), from which acceptable results have been obtained regarding optimizing purposes [13].

On the other hand different methods such as genetic algorithms, evolutionary programming (EP) and simulated annealing (SA) innovative methods, similar thermal algorithm, BB-BC, etc. [14-19] are used for optimized exploitation. In the present paper, following an analysis of the results obtained from PSO and BB-BC algorithms, the HBB-BC algorithm is being introduced for the purpose of optimizing a micro grade in a way that it helps reducing both distribution and cost. Subsequently, the objectives and limitations of optimizing will be discussed in the second section and in the third part, the MG used in the present study will be described in details. In fourth section deals with the issues related to optimizing followed by an introduction of the proposed HBB-BC algorithm. And finally, the execution of HBB-BC algorithm is being explained and comparisons are being made between the proposed algorithm and the other similar ones.

II. MANAGEMENT OF EXPLOITING MICRO GRID FOR ECONOMIC AND BIOLOGICAL OBJECTIVES

In order to exploit a sample micro grid, a series of special settings need to be taken into consideration, in order to reduce the costs and distribution of environmental pollution while saving quality and reliability. So, the following mathematical models are recommended.

A. Objective 1: Reducing Costs of Micro Grid

The costs for the fuel, launching and accomplishing the project, energy exchange, etc. are among the costs a micro grid is encountered with. The output of this part is a flow of optimized force for a particular period of time. Moreover, energy saving devices can be used to reduce these costs. In order to decrease the costs, the following mathematical formulation can be of much help.

$$OptimCost=\sum_{t=1}^{T}cost(t)=\sum_{t=1}^{T}[\sum_{n=1}^{S_g}(A)+\sum_{m=1}^{S_r}(B)]$$

$$\begin{aligned}&\sum_{n=1}^{S_g}(A)=K_n(T)P^{gn}(T)B^{gn}(T)+\\&+S^{gn}\left[K_n(T)-K_n(T-1)\right]+P^{grid}(T)B^{grid}(T)\\&\sum_{m=1}^{S_r}(B)=K_m(T)P^{sm}(T)B^{sm}(T)+\\&+S^{sm}\left[K_m(T)-K_m(T-1)\right]+P^{grid}(T)B^{grid}(T)\end{aligned}\tag{1}$$

where, $P^{gn}(T)$ and $B^{gn}(T)$ are the proposed values for DGs and means of power generation and expenses for *n*th DG at time *T*, respectively, $P^{sm}(T)$ and $B^{sm}(T)$ represent start-up power storage and end expenses for *m*th DG at time *T*, respectively, $P^{grid}(T)$ is power purchased or sold at time *T*, and $B^{grid}(T)$ indicates used energy at time T. The X represents variables of a vector consisting of units' active power and the states associated to them, which is expressed as follows:

$$\begin{aligned}&Y=\left[P^G,P^G\right]_{1\times 2nT}\\&P^G=\left[P^g,P^s\right]\\&K=S_g+S_r+1\end{aligned}\tag{2}$$

where, n is the number of variables in the scenario, S_g and S_r total number of energy generation and storage units, respectively, P^g is power of a vector which encompasses all active powers in whole U^G and DGs, indicating ON or Off setting of the units at each time of the day. These variables can be defined as follows:

$$\begin{aligned}&P^g=\left[P^{g1},P^{g2},.....P^g,S_r\right]\\&P^{gn}=\left[P^{gn}(1),P^{gn}(2),.....,P^{gn}(t),....,P^{gn}(T)\right]\\&n=1,2,...,S_r+1\\&P^s=\left[P^{s1},P^{s2},.....,.P^s,S_g\right]\\&P^{sm}=\left[P^{sm}(1),P^{sm}(2),.....,.P^{gsm}(t),....,P^{sm}(T)\right]\\&m=1,2,...,S_g+1\end{aligned}\tag{3}$$

where, *T* denotes total number of hours, $P^{grid}(T)$ and $P^{sm}(T)$ are power outputs from the *i*th generators and generator's *j*th storage at time T.

$$\begin{aligned}&U^G=\left[U^1,U^2,.....,U^n\right]=\{U_n\}_{1\times n\in\{0,1\}}\\&U_q=\left[U_q(1),U_q(2),....,U_q(t),....,U_q(T)\right]\\&x=1,2,...,n\end{aligned}\tag{4}$$

where, U_q is the state of unit *k* at times T.

B. Objective 2: Reducing Distribution of Pollutants in a Micro Grid

In this section, the distribution of pollutants is being dealth with. Among the most important atmospheric pollutants which result in an increase in the distribution of pollutants are NO_x, CO_2 and SO_2. Therefore, one of the main objectives is to reduce the amount of these pollutants as the most important environmental pollutants. To do this, the following mathematical formulations are believed to be helpful.

$$OptimEmission=\sum_{t=1}^{T}Emission(t)=\sum_{t=1}^{T}[\sum_{n=1}^{S_g}(A)+\sum_{m=1}^{S_r}(B)]$$

$$\begin{aligned}&\sum_{n=1}^{S_g}(A)=K_n(T)P^{gn}(T)B^{gn}(T)+P^{grid}(T)E^{grid}(T)\\&\sum_{m=1}^{S_r}(B)=K_m(T)P^{sm}(T)B^{sm}(T)+P^{grid}(T)E^{grid}(T)\end{aligned}\tag{5}$$

where, $E^{gn}(T)$, $E^{sm}(T)$ and $E^{grid}(T)$ are considered the values of *c* contaminators' emission at KgMWh^{-1} for each DG at time t. These variables are delineated as follows.

$$E^{gn}(t)=NO_x^{DGn}(t)+CO_2^{DGn}(t)+SO_2^{DGn}(t)\tag{6}$$

where, the values of $CO_2^{DGn}(T)$, $SO_2^{DGn}(T)$ and $NO_x^{DGn}(T)$ are emitted from *i*th DG at time t.

$$E^{sm}(t) = NO_x^{storagem}(t) + CO_2^{storagem}(t) + SO_2^{storagem}(t) \qquad (7)$$

where, the values of $CO_2^{storagem}$, $SO_2^{storagem}$ and $NO_x^{storagem}$ are emitted from jth of the storage unit during time t of the day.

$$E^{grid}(t) = NO_x^{grid}(t) + CO_2^{grid}(t) + SO_2^{grid}(t) \qquad (8)$$

where, the values of $CO_2^{grid}(T)$, $SO_2^{grid}(T)$ and $NO_x^{grid}(T)$ are emitted from MG utilization at time t.

C. Limitations

C.1. Battery Charge and Discharge Limitation

In order to exploit a battery in a period of time, a series of limitations for battery charge and discharge are to be considered.

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

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

where, V_t^{ess} and V_{t-1}^{ess} are the amounts of energy storage in battery at time t and $t-1$, respectively, $P^{charge}, P^{discharge}$ are the allowed amounts for charge and discharge during a specific period of time interval Δt, $\eta^{charge}, \eta^{discharge}$ are battery's efficiency during the process of charging and discharging, $V_{\min}^{ess}$ and $V_{\max}^{ess}$ are the minimum and maximum limits for the amount of energy storage in battery, and $P_{\max}^{charge}, P_{\max}^{discharge}$ are the maximum limits for the amount of charge and discharge during each time interval Δt.

C.2. Generation and Consumption Balance

The amount of power produced by DGs in a micro grid needs to be proportioned to the amount of daily load demand inside a grid. In order to investigate these limitations, we can take advantage of the following mathematical formulation. Moreover, it is worth mentioning here that, in this state, the amount that in this state the amount of damages and exploitations are disregarded.

$$\begin{aligned} &\sum_{x=1}^{Nk} P^{lk}(t) = \sum_{n=1}^{Sg} (A) + \sum_{m=1}^{Sr} (B) \\ &\sum_{n=1}^{Sg} (A) = \sum_{n=1}^{Sg} P^{gn}(t) + P^{grid}(t) \\ &\sum_{m=1}^{Sr} (B) = \sum_{m=1}^{Sr} P^{sm}(t) + P^{grid}(t) \end{aligned} \qquad (11)$$

where, P^{lk} is the value of the charge level k and N_k is the total amount of charge levels.

C.3. Generation's Limits of DGs

In order to exploit DGs, attention should be paid to a series of limitations, according to the formulations below.

$$\begin{aligned} &P_{\min}^{gn}(t) \le P^{gn}(t) \le P_{\max}^{gn}(t) \\ &P_{\min}^{sm}(t) \le P^{sm}(t) \le P_{\max}^{sm}(t) \\ &P_{\min}^{grid}(t) \le P^{grid}(t) \le P_{\max}^{grid}(t) \end{aligned} \qquad (12)$$

where, $P_{\min}^{gn}$, $P_{\min}^{sm}$ and $P_{\min}^{grid}$ are minimum and $P_{\max}^{gn}$, $P_{\max}^{sm}$ and $P_{\max}^{grid}$ are maximum power generation, power storage and power purchased/sold, respectively.

III. MICRO GRID MODELING

The MG is a general outlook. In such a network, different DGs including PV, MTWT, etc., simultaneous use of which can lead into the decrease in distribution and cost and cost and energy saving generators such as batteries that cause a drastic reduction in energy purchase in peak hours are used widely. The input of these generators includes the load inside the grid and the power produced by DGs, and their output is optimized regulation points for DGs. In this paper, as illustrated in figure a sample micro grid of diverse DGs such as MT, PAFC, PV, WT and energy saving tools such as batteries is used. All of these generators are producing dynamic power. As a result, they don't need activity powers [3]. Furthermore, this micro grid is connected to the main network via Micro Grid Central Controller (MGCC) to generate and trade electricity based on decisions of MGCC in different hours of the day.

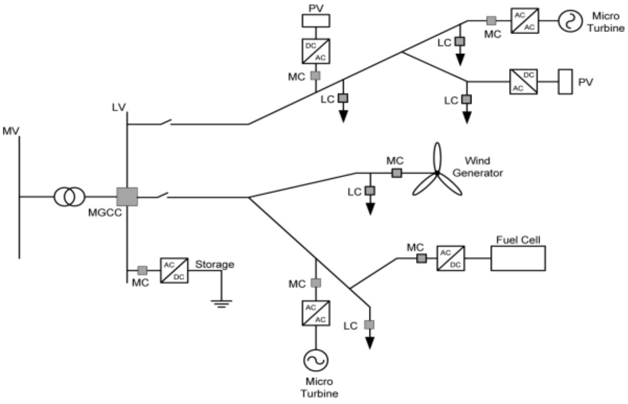

Figure 1. A typical micro grid (MG)

IV. PROBLEM DESCRIPTION

The multiple objective optimizing is a concept that is related to many optimizing problems in the real world, which aim to find optimized ways for achieving diverse objectives simultaneously. However, it has to be noted that individual solutions cannot be used for multiple objectives, as individual objectives cannot meet all the requirements of optimized objectives. Moreover, multiple objective optimizing includes a series of objectives. In order to accomplish these objectives, it is necessary to consider a series of equalities and non-equalities and requirements, as being stated below.

$$\begin{aligned} &\text{minimize } F = \left[f_1(x), f_2(x), ..., f_n(x) \right]^T \\ &\text{subject to: } g(x) < 0 \\ &i = 1, 2, ..., N_{ueg} \end{aligned} \qquad (13)$$

where, F is a vector for target functions, x is a vector consisting of optimization variables, $f_i(x)$ is target function, $g(x)$ is non-equation constraints, respectively, and N_{ueg} is the number of target functions.

V. THE PROPOSED BB-BC AND HBB-BC ALGORITHMS

In this study, BB-BC and HBB-BC algorithms are applied to optimize the stated objectives.

A. Proposed BB-BC Algorithm

The BB-BC algorithm was first proposed by Erol and Eksin and included two phases. The big bang phase and the big explosion phase. This algorithm is based on one of the theories of the world creation saying that the universe was formed as a result of a huge explosion [20]. In big bang phase, a primary population is extended in the research space as some disorders and in the second phase, i.e. the big explosion, the distributed particles are converted into a regular format accidentally by a compressive method [21]. The big explosion phase has many inputs, but it has only one output known as the center of mass [22]. In fact, similar to other algorithms, the primary population in big bang phase is extended in the research space as some disorders and then in the big explosion phase, and the center of mass is calculated by a compressive method, using the current situation of particles. The center of mass is calculated as below.

$$A_b^{(n)} = \frac{\sum_{i=1}^{m} \frac{1}{X_i} A_b^{(n,i)}}{\sum_{i=1}^{m} \frac{1}{X_i}} \tag{14}$$

where, $A_b^{(n)}$ denotes mass center, m is population size, X_i expense for the intended i, and $A_b^{(n,i)}$ is the location of the intended particles. To limit the disorders in research space, using the following equation the intended scope can be restricted.

$$A_b^{(n)} = L_n + \sigma \tag{15}$$

where, σ is a small positive or negative value which is used to attain new points around the research scope.

After calculating the center of mass, the algorithm creates new spots using the big explosion phase that are used as next replications in the big bang phase. To iterate the algorithm for the next big bang, the following formula is applied.

$$A_b^{(n+1,i)} = A_b^{(n)} + \frac{\gamma^i \delta_1 (A^{\max} - A^{\min})}{n+1} \tag{16}$$

where, γ^i is a random quantity which changes for each amount, δ_1 is the research scope restricting parameter, $A^{\min}$ and $A^{\max}$ are lower and upper limits of research scope, n number of iterations, and $A_b^{(n+1)}$ is a new intended value.

In order to terminate optimizing, consecutive explosions take place repeatedly one after another. Thus, maximum replications can be used as a criterion for cessation. In spite of the fact that BB-BC algorithm is one of the best algorithms in optimizing, there are still a few problems in its proper application. There are two ways to prevent the problems and improve the efficiency, the best of which is believed to be combining BB-BC algorithm with PSO.

B. Proposed HBB-BC Algorithm

Having the abovementioned data about BB-BC algorithm in mind, one of the problems in exploiting it can be described as follows. If all of the particles resulting from the big bang accumulate in a small part of research space, BB-BC algorithm might be faced with the lack of an optimized response due to the existence of sub-cavities. There are two ways to remove this problem. The first is to enlarge the amount of the mentioned particles to prevent this problem, but this would cause an increase in the computational costs [23].

The second solution is to use HBB-BC algorithm in order to increase the capacity of BB-BC algorithm which is based on the capacity of PSO [24]. PSO algorithm was first proposed by Kennedy and Eberhart in 1995, based on the social behavior of groups of fish and birds which are of both population and members [25]. PSO includes particles that regulate their movement according to the best previous situation and the best global situation. In fact, each of these particles can be considered as a solution for removing optimizing problems. In HBB-BC algorithm, besides the mass center, the best previous global situations are used to generate section [23] candidates.

$$\begin{gathered} A_b^{(n+1,i)} = \delta_2 A_b^{(n)} + (1-\delta_2)[\delta_3 A_{gbest(n)}^{b} + \\ +(1-\delta_3) A_{lbest(n,i)}^{i}] + \frac{\gamma^i \delta_1 (A^{\max} - A^{\min})}{n+1} \\ N = 1,2,\ldots,m \quad , \quad i = 1,2,\ldots,j \end{gathered} \tag{17}$$

where, $A_{gbest(n)}^{b}$ is the best global position of particle j up to over n time repetition and $A_{lbest(n,i)}^{i}$ is the best local position of particle l after k times repetition, and δ_2, δ_3 are the regulating parameters which control the effect of the best global and local position in candidates' new position.

Hence, the following formula which is the completed version of the above formula can be applied.

$$\begin{gathered} A_b^{(n+1,i)} = Q\{\delta_2 A_b^{(n)} + (1-\delta_2)[\delta_3 A_{gbest(n)}^{b} + \\ +(1-\delta_3) A_{lbest(n,i)}^{i}] + \frac{\gamma^i \delta_1 (A^{\max} - A^{\min})}{n+1}\} \end{gathered} \tag{18}$$

where, Q is a performance which rounds x elements to the closest integer. Now, to find new areas and prevent HBB-BC entanglement in local optimization, the following formula can be used.

$$A_b^{(n+1,i)} = \left\{\left(A_n^{\min} + Q(x)(A_n^{\max} - A_n^{\min})\right)\right\} \tag{19}$$

where, $Q(x)$ stands for the created random number within interval [0, 1].

VI. MAKING HBB-BC OPERATIONAL

For management of a multi-purpose function optimization using the proposed algorithm, a hierarchical structure, as described below, should be observed.

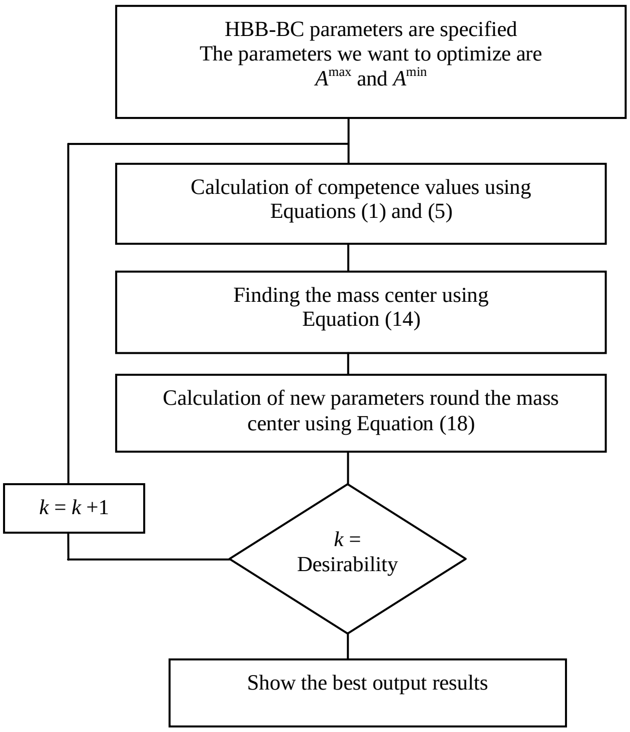

Figure 2. HBB-BC flowchart

Stages of HBB-BC algorithm are as follows:
Step 1: Introduction of a random method, parameters, upper and lower limits, ….
Step 2: Calculation of the values of the intended target functions using Equations (1) and (5).
Step 3: Finding the mass center based on Equation (14).
Step 4: Finding new instances around the mass center through adding or subtracting a random value using relation 18.
Step 5: Returning to step 2 and iteration of the process until it stops.
If the desirable value is obtained via the maximum number of HBB-BC iterations, the task is accomplished; otherwise, the algorithm returns to step 2 and repeats all steps until it reaches a constant value.

VII. EXECUTION AND COMPARISON

In this section of the paper, HBB-BC algorithm is used in order to solve the management and exploitation problems of a micro grid with the help of multiple objective algorithms and subsequently, the results are being compared with those obtained from other algorithms. The mentioned objectives are studied in a sample MG for the following states as shown in Figure 1.
1- All DGs in determined areas of energy production for generators,
2- due to their free fuel (sun and wind), PV and WT are used in their maximum expected output and the other elements in the determined areas of energy production.

In this section, all units act in a way that they keep producing electricity and as a result, no heat is required for the test. The mentioned charge demand is supposed on a typical business day for a residential area. Maximum and minimum DG production is displayed in Table 1. Moreover, energy expense in a market for a specific day is expressed in Figure 3. For each kilogram emission per MWh and for DGs per kWh, proposed coefficients in Euro cent are presented in Table 2.

Table 1. Maximum and minimum DG production

ID	Type	Min Power (kW)	Max Power (kW)
1	MT	0	25
2	PAFC	0	20
3	PV	0	25
4	WT	0	15
5	Batt	-20	20
6	Utility	-20	40

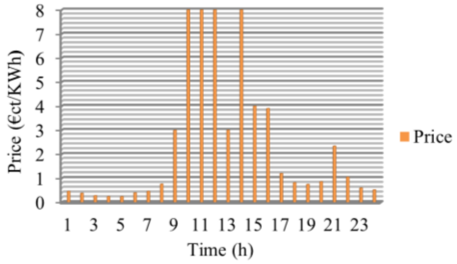

Figure 3. Expense of energy generation per hour

Table 2. Emission from DG sources

ID	Type	Bid (€ct/kWh)	Start-up/ shut-down cost (€ct)	CO_2 (Kg/MWh)	SO_2 (Kg/MWh)	NO_x (Kg/MWh)
1	MT	0.457	0.96	720	0.0036	0.1
2	PAFC	0.294	1.65	460	0.003	0.075
3	PV	2.584	0	0	0	0
4	WT	1.073	0	0	0	0
5	Batt	0.38	0	10	0.0002	0.001

Note that the reason for the choice of the above stages for optimization is availability of information on power market planning, and to ensure that there will not be any expenses for the start and termination of the units, all DGs are assumed to be either 0 or 1. The amount of energy required by a residential area for one day is demonstrated in Figure 4. Additionally, estimated amounts for Res maximum output in one day are provided in Figure 5, and the same amounts for PV and WT are presented in Table 3.

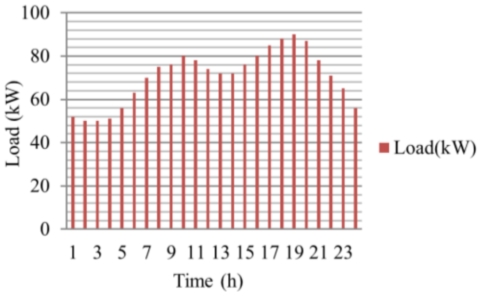

Figure 4. Curve of daily charge

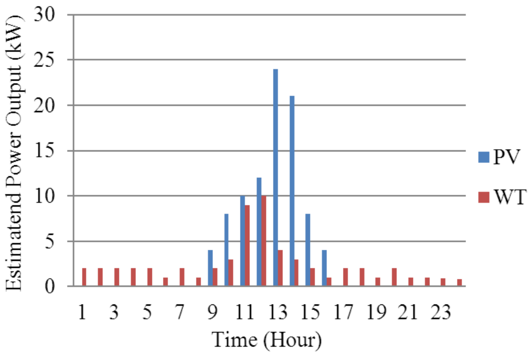

Figure 5. Res maximum output for one day

Table 3. Maximum amount of PV and WT output in one day

H	WT (kW) / installed (kW)	PV (kW) / installed (kW)
1	0.119	0
2	0.119	0
3	0.119	0
4	0.119	0
5	0.119	0
6	0.061	0
7	0.119	0
8	0.087	0.008
9	0.119	0.150
10	0.206	0.301
11	0.585	0.418
12	0.694	0.478
13	0.261	0.956
14	0.158	0.842
15	0.119	0.315
16	0.087	0.169
17	0.119	0.022
18	0.119	0
19	0.0868	0
20	0.119	0
21	0.0867	0
22	0.0867	0
23	0.061	0
24	0.041	0

A. The First Scenario

In this state, the proposed algorithms for optimization of a multi-purpose function, as shown in Figure 1, are applied in a way that all the MGs are utilized within their specified boundaries, as presented in Table 1. If they have energy surplus, they can trade it with the network, provided that all constraints and requirements are met by them.

The optimization results by HBB-BC and their comparison with the outcomes of other algorithms are provided in Figures 6, 7 and 8. The results obtained from different algorithms to optimize the costs for the first state are summarized in Table 4. In order to have a better understanding of the results, a detailed description of each algorithm is provided in Table 5.

The results indicate that as for the HBB-BC algorithm, the best, worst states, mean and standard deviation values are 0.058 €ct, 164.967 €ct, 22.115 €ct and 35.0466 €ct compared to PSO and 2.058 €ct, 40.417 €ct, 15.866 €ct and 9.5005 €ct in comparison to BB-BC have caused improvement in optimization results. Restating the results in percentage, the best, worst, mean and standard deviation are 99%, 80%, 96% and 0.1% than PSO with 99%, 94%, 97% and 3% than BB-BC have caused improvement in optimization results.

The results gained with respect to the costs for 24 hours for the first state is summarized in Table 6. These results are indicative of maximum energy production by MT, PAFC and Batt generators, as these generators lower the costs to a significant extent. The other generators are used in different times of the day based on the demand of the network. Moreover, in the middle of the day some energy is sold to the network.

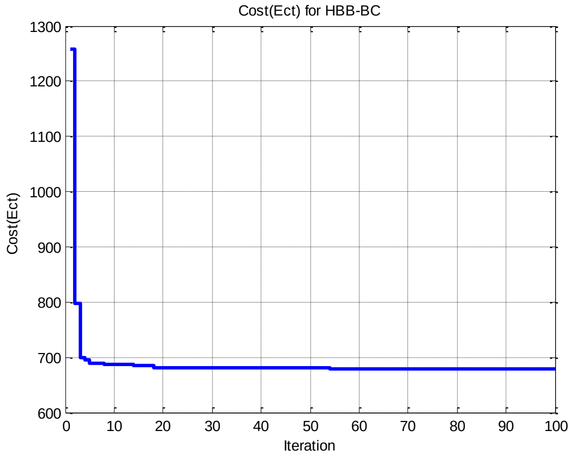

Figure 6. The best optimization results on expense obtained by HBB-BC in the first scenario

Table 4. Obtained optimization results on expense in the first scenario

Type	Cost (€ct)			
	Best solution	Worst solution	Average	Standard deviation
PSO	681.803	849.208	703.998	35.4347
BB-BC	683.83	724.658	697.748	9.8886
HBB-BC	681.745	684.241	681.883	0.3881

Table 5. Obtained results from HBB-BC and comparing them with the outcomes from other algorithms regarding expense, in the first scenario

Cost (€ct)												
Type	Best solution	optimized value	optimized percentage	Worst solution	optimized value	optimized percentage	Average	optimized value	optimized percentage	Standard deviation	optimized value	optimized percentage
HBB-BC	681.745	2.085	99%	684.241	40.417	94%	681.883	15.866	97%	0.3881	9.5005	3%
BB-BC	683.83			724.658			697.748			9.8886		
HBB-BC	681.745	0.058	99%	684.241	164.967	80%	681.883	22.115	96%	0.3881	35.0466	0.1%
PSO	681.803			849.208			703.998			35.4347		

Table 6. Expense using HBB-BC and BB-BC algorithms in the first scenario

Time (h)	Units											
	HBB-BC						BB-BC					
	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)
1	25	20	0	0	20	-13	25	20	0	0	20	-13
2	0	20	0	0	1.2623	28.7377	0	20	0	0	4.9264	25.0736
3	0	9.9739	0	0	0.0579	39.9682	0	10.4312	0	0	0.0458	39.5230
4	0	11.0500	0	0	0.0088	39.9411	0	11.1860	0	0	-0.0123	39.8264
5	0	15.9456	0	0	0.0700	39.9844	0	15.8321	0	0	0.3194	39.8485
6	0	20	0	0	20	23	0	20	0	0	20	23
7	25	20	0	0	20	5	25	20	0	0	20	5
8	25	20	0	1.7850	20	10	25	20	0	0	20	10
9	25	20	3.7500	3.0900	20	5.4650	25	20	1.2116	1.7850	20	8.0034
10	25	20	7.5250	8.7750	20	4.3850	25	20	7.5250	3.0900	20	4.3850
11	25	20	10.4500	10.4100	20	-6.2250	25	20	10.4500	8.7750	20	-6.2250
12	25	20	11.9500	3.9150	20	-13.3600	25	20	11.9500	10.4100	20	-13.3600
13	25	20	23.0824	2.3700	20	-19.9974	25	19.9751	23.2709	3.7150	20	-19.9649
14	25	20	21.0500	1.7850	20	-16.4200	25	20	21.0500	2.3700	20	-16.4200
15	25	20	7.8750	1.3050	20	1.3400	25	20	7.8750	1.7850	20	1.3400
16	25	20	4.2250	1.7850	20	9.4700	25	20	4.2250	1.1517	20	9.6233
17	25	20	0	0	20	18.2150	25	20	0	1.7850	20	18.2150
18	25	20	0	0	20	23	25	20	0	0	20	23
19	25	20	0	0	20	25	25	20	0	0	20	25
20	25	20	0	0	20	22	25	20	0	0	20	22
21	25	20	0	1.3020	20	11.6980	25	20	0	1.3020	20	11.6980
22	25	20	0	0	20	6	25	20	0	0.3426	20	5.6574
23	25	20	0	0	20	0	25	20	0	0.3653	20	-0.3653
24	25	20	0	0	20	-9	25	20	0	0	20	-9

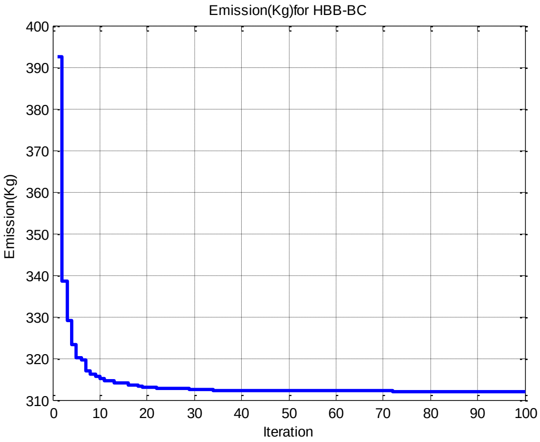

Figure 7. The best optimization result on emission obtained by HBB-BC regarding the polluters' emission in the first scenario

Table 7. Obtained optimization results on emission in the first scenario

Type	Emission (Kg)			
	Best solution	Worst solution	Average	Standard deviation
PSO	312.133	321.206	315.196	2.4414
BB-BC	313.458	316.07	314.675	0.6245
HBB-BC	312.068	313.166	312.54	0.2703

The results obtained from different algorithms to optimize the costs for the first state are summarized in Table 7. A detailed description of each algorithm is provided in Table 8. These results indicate that as for the HBB-BC algorithm, the best, worst states, mean and standard deviation values are 0.065 Kg, 8.04 Kg, 2.656 Kg and 2.1711 Kg compared to PSO and 1.39 Kg, 2.904 Kg, 2.135 Kg and 0.3542 Kg in comparison to BB-BC have caused improvement in optimization results. Restating the results in percentage, the best, worst, mean and standard deviation are 99%, 97%, 99% and 11% than PSO with 99%, 99%, 99% and 43% than BB-BC have caused improvement in optimization results.

Table 9 represents the results of the distribution for 24 hours for the first state. The results reveal that in 24 hours, the Batt is exploited in its maximum production, utility is in its maximum production in most hours of the day, MT produces energy only for the period of 4 hours due to its rate of distribution, and the other generators are used in accordance with the network requirements and limitations. Such load distribution between the generators based on their rate of distribution results into provision of load with minimum distribution.

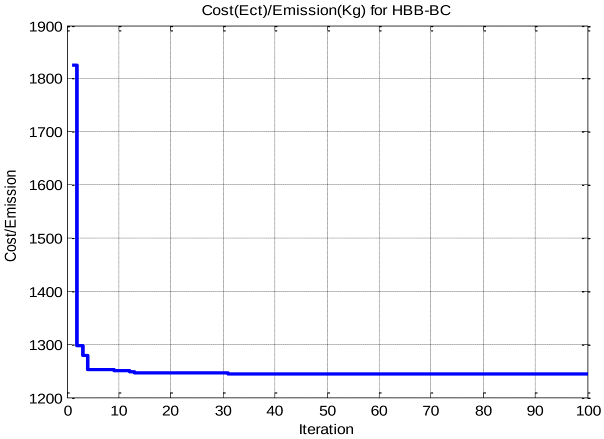

Figure 8. Best optimization results on pollution emission and expense obtained by HBB-BC in the first scenario

Table 10. Obtained optimization results on emission/expense in the first scenario

Type	Emission (Kg) / Cost (€ct)			
	Best solution	Worst solution	Average	Standard deviation
PSO	1241.33	1331.38	1256.07	20.891
BB-BC	1243.37	1288.7	1257.92	11.8829
HBB-BC	1241.17	1241.41	1241.26	0.05768

Table 8. Obtained results from HBB-BC and comparing them with the outcomes from other algorithms regarding emission in the first scenario

Emission (Kg)												
Type	Best solution	optimized value	optimized percentage	Worst solution	optimized value	optimized percentage	Average	optimized value	optimized percentage	Standard deviation	optimized value	optimized percentage
HBB-BC	312.068	1.39	99%	313.166	2.904	99%	312.54	2.135	99%	0.2703	0.3542	43%
BB-BC	313.458			316.07			314.675			0.6245		
HBB-BC	312.068	0.065	99%	313.166	8.04	97%	312.54	2.656	99%	0.2703	2.1711	11%
PSO	312.133			312.206			315.196			2.4414		

Table 9. Emission using HBB-BC and BB-BC algorithms in the first scenario

Time (h)	Units											
	HBB-BC						BB-BC					
	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)
1	0	0	0	1.7850	20	30.2150	0	0	0	1.7850	20	30.2150
2	0	0	0	1.7850	20	28.2150	0	0	0	1.7850	20	28.2150
3	0	0	0	1.7850	20	28.2150	0	0	0	1.7850	20	28.2150
4	0	0	0	1.7850	20	29.2150	0	0	0	1.7850	20	29.2150
5	0	0	0	1.7850	20	34.2150	0	0	0	1.7850	20	34.2150
6	0	2.0874	0	0.9150	20	39.9976	0	2.3419	0	0.7670	20	39.8911
7	0	8.2340	0	1.7850	20	39.9810	0	8.4174	0	1.6514	20	39.9311
8	0	13.5252	0.1747	1.3050	20	39.9951	0	13.7595	0.0881	1.1753	20	39.9772
9	0	10.4664	3.7500	1.7850	20	39.9986	0	10.8084	3.6837	1.5111	20	39.9968
10	0	9.4046	7.5250	3.0900	20	39.9804	0	9.8863	7.4885	2.9348	20	39.6904
11	0	0	10.4500	8.7750	20	38.7750	0	0	10.4500	8.7750	20	38.7750
12	0	0	11.9500	10.4100	20	31.6400	0	0	11.9500	10.4100	20	31.6400
13	0	0	23.9000	3.9150	20	24.1850	0	0	23.9000	3.9150	20	24.1850
14	0	0	21.0500	2.3700	20	28.5800	0	0	21.0500	2.3700	20	28.5800
15	0	6.3423	7.8750	1.7850	20	39.9977	0	6.8387	7.6272	1.7005	19.9954	39.8383
16	0	14.5004	4.2250	1.3050	20	39.9696	0	14.6271	4.2084	1.2387	20	39.9258
17	2.6797	20	0.5500	1.7850	20	39.9853	2.8642	20	0.3644	1.7850	20	39.9865
18	6.2223	20	0	1.7850	20	39.9927	6.4794	20	0	1.6306	20	39.8900
19	8.7557	20	0	1.3020	20	39.9796	8.8666	20	0	1.1631	20	39.9703
20	5.2188	20	0	1.7850	20	39.9962	5.3923	20	0	1.6566	20	39.9511
21	0	16.7126	0	1.3020	20	39.9854	0	16.7302	0	1.2800	20	39.9897
22	0	9.7091	0	1.3020	20	39.9889	0	9.7746	0	1.2578	20	39.9676
23	0	4.0856	0	0.9150	20	39.9994	0	4.2223	0	0.7849	20	39.9828
24	0	0	0	0.6150	20	35.3850	0	0	0	0.6150	20	35.3850

The results obtained from different algorithms to optimize the costs for the first state are summarized in Table 10. Similar to the two previous sections, a detailed description of each algorithm is presented in Table 11.

These results indicate that as for the HBB-BC algorithm, the best, worst states, mean and standard deviation values are 0.16, 89.97, 14.81 and 20.83 compared to PSO and 2.2, 47.29, 16.66 and 11.8243 in comparison to BB-BC have caused improvement in optimization results. Restating the results in percentage, the best, worst, mean and standard deviation are 99%, 93%, 98% and 0.2% than PSO with 99%, 96%, 98% and 0.4% than BB-BC have caused improvement in optimization results.

The results gained with regard to emission/expense for 24 hour for the first state are provided in Table 12. The results show that the rate of production of each generator is approximately a combination of both 2 previous states. In 24 h, the main part of the load is provided by Batt and PAFC because of their low particle production. Due to growth in demand at different hours of the day, the other generators are used based on less cost and distribution.

Table 11. Obtained results from HBB-BC and comparing them with outcomes from other algorithms regarding emission/expense, in the first scenario

Emission (Kg) / Cost (€ct)												
Type	Best solution	optimized value	optimized percentage	Worst solution	optimized value	optimized percentage	Average	optimized value	optimized percentage	Standard deviation	optimized value	optimized percentage
HBB-BC	1241.17	2.2	99%	1241.41	47.29	96%	1241.26	16.66	98%	0.0576	11.8243	0.4%
BB-BC	1243.37			1288.7			1257.92			11.8829		
HBB-BC	1241.17	0.16	99%	1241.41	89.97	93%	1241.26	14.81	98%	0.0576	20.83	0.2%
PSO	1241.33			1331.38			1256.07			20.891		

Table 12. Emission /expense using HBB-BC and BB-BC algorithm, in the first scenario

Time (h)	Units											
	HBB-BC						BB-BC					
	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)
1	0	0	0	0	20	32	0	0	0	0	20	32
2	0	0	0	0	20	30	0	0	0	0	20	30
3	0	0	0	0	20	30	0	0	0	0	20	30
4	0	0	0	0	20	31	0	0	0	0	20	31
5	0	0	0	0	20	36	0	0	0	0	20	36
6	0	3	0	0	20	40	0	3.0295	0	0.0149	20	39.9556
7	0	10.0125	0	0	20	39.9848	0	10.0053	0	0	20	39.9947
8	0	20	0	0	20	35	0	20	0	0	20	35
9	25	20	3.7500	1.7850	20	5.4650	25	20	3.7500	1.7850	20	5.4650
10	25	20	7.5250	3.0900	20	4.3850	25	20	7.5250	3.0900	20	4.3850
11	25	20	10.4500	8.7750	20	-6.2250	25	20	10.4500	8.7750	20	-6.2250
12	25	20	11.9500	10.4100	20	-13.3600	25	20	11.9500	10.4100	20	-13.3600
13	25	20	23.0795	3.9150	20	-19.9945	25	20	22.6606	3.9150	20	-19.5756
14	25	20	21.0500	2.3700	20	-16.4200	25	20	21.0500	2.3700	20	-16.4200
15	25	20	7.8750	1.7850	20	1.3400	25	20	7.8750	1.7850	20	1.3400
16	25	20	4.2250	1.3050	20	9.4700	25	20	4.2250	0.6583	20	10.1167
17	25	20	0	1.7850	20	18.2150	25	20	0	1.7850	20	18.2150
18	6.22156	20	0	1.7850	20	39.9994	6.5951	20	0	1.4072	20	39.9977
19	8.7028	20	0	1.3019	20	39.9953	8.9191	20	0	1.0970	20	39.9839
20	5.2335	20	0	1.7850	20	39.9815	5.7440	20	0	1.3037	20	39.9524
21	25	20	0	1.3020	20	11.6980	25	20	0	1.3020	20	11.6980
22	25	20	0	1.3020	20	4.6980	25	20	0	1.2349	20	4.7651
23	0	20	0	0	20	25	0	20	0	0	20	25
24	0	20	0	0	20	16	0	20	0	0	20	16

B. The Second Scenario

In this state, the proposed algorithms are used to optimize a multi-purpose function for a state in which the five renewable sources present in MG (Figure 1) are utilized; PV and WT operate at maximum production capacity and the other generators, i.e. battery, micro-turbine, and fuel cell, each operates within the boundaries specified for them, as presented in Table 1. Not to mention that these generators should comply with the constraints and requirements, and if they have any energy surplus, they can trade it with the network.

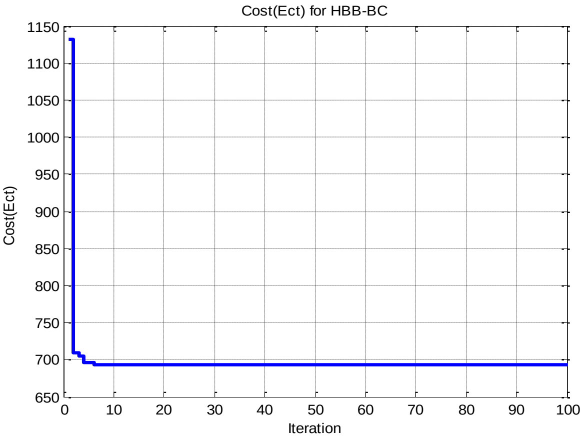

Figure 9. Best optimization results obtained by HBB-BC regarding expenses in the second scenario

Table 13. Comparison of optimization results on expense in the second scenario

Type	Cost (€ct)			
	Best solution	Worst solution	Average	Standard deviation
PSO	695.329	696.551	695.507	0.2877
BB-BC	695.386	696.271	695.654	0.1988
HBB-BC	695.348	695.494	695.395	0.03873

The optimization results and their comparison with the outcomes of other algorithms are provided in Figures 9, 10 and 11.

In this state, comparable to the previous section, the proposed algorithms are used to investigate multiple-objective optimizing problems as was explained earlier. Table 13 summarizes the best function of the proposed multiple-objective optimizing algorithms for reducing the cost in this state.

Like the first state, an in-depth look at the results, as shown in Table 14, reveals that the proposed algorithm is properly managing the cost operation. These results indicate that as for the HBB-BC algorithm, the best, worst states, mean and standard deviation values are -0.019 €ct, 1.057 €ct, 0.112 €ct and 0.249 €ct compared to PSO and 0.002 €ct, 0.777 €ct, 0.259 €ct and 0.1401€ct in comparison to BB-BC have caused improvement in optimization results. Restating the results in percentage, the best, worst, mean and standard deviation are -1%, 99%, 99% and 13% than PSO with 99%, 99%, 99% and 19% than BB-BC have caused improvement in optimization results.

The results gained concerning the costs for the second state are shown in Table 15 which it is observed that sending cost in this state is much the same as that of the first state. The results obtained from different algorithms to optimize the costs for the first state are summarized in Table 16. A detailed description of each algorithm is provided in Table 17.

These results indicate that as for the HBB-BC algorithm, the best, worst states, mean and standard deviation values are -0.009 Kg, 8.228 Kg, 1.759 Kg and 2.1074 Kg compared to PSO and 0.054 Kg, 0.1919 Kg, 0.112 Kg and 0.0293 Kg in comparison to BB-BC have caused improvement in optimization results.

Table 14. Obtained results from HBB-BC and comparing them with the outcomes from other algorithms regarding expense in the second scenario

Type	Cost (€ct)											
	Best solution	optimized value	optimized percentage	Worst solution	optimized value	optimized percentage	Average	optimized value	optimized percentage	Standard deviation	optimized value	optimized percentage
HBB-BC	695.348	0.002	99%	695.494	0.777	99%	695.395	0.259	99%	0.0987	0.1401	19%
BB-BC	695.386			696.271			695.654			0.1988		
HBB-BC	695.348	-0.019	-1%	695.494	1.057	99%	695.395	0.112	99%	0.0987	0.249	13%
PSO	695.329			696.551			695.507			0.2877		

Table 15. Expenses using HBB-BC and BB-BC algorithms in the second scenario

Time (h)	Units											
	HBB-BC						BB-BC					
	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)
1	25	20	0	1.7850	20	-14.7850	25	20	0	1.7850	20	-14.7850
2	0	20	0	1.7850	6.9773	21.2377	0	20	0	1.7850	13.0239	15.1911
3	0	8.2207	0	1.7850	0.0008	39.9935	0	8.5253	0	1.7850	-0.0061	39.6957
4	0	9.3330	0	1.7850	0.00018	39.8802	0	9.4028	0	1.7850	0.1055	39.7068
5	0	14.2731	0	1.7850	0.0132	39.9287	0	14.2762	0	1.7850	-0.0142	39.9530
6	0	20	0	0.9150	20	22.0850	0	20	0	0.9150	20	22.0850
7	25	20	0	1.7850	20	3.2150	25	20	0	1.7850	20	3.2150
8	25	20	0.2000	1.3050	20	8.4950	25	20	0.2000	1.3050	20	8.4950
9	25	20	3.7500	1.7850	20	5.4650	25	20	3.7500	1.7850	20	5.4650
10	25	20	7.5250	3.0900	20	4.3850	25	20	7.5250	3.0900	20	4.3850
11	25	20	10.4500	8.7750	20	-6.2250	25	20	10.4500	8.7750	20	-6.2250
12	25	20	11.9500	10.4100	20	-13.3600	25	20	11.9500	10.4100	20	-13.3600
13	24.2510	20	23.9000	3.9150	20	-19.9973	24.1831	20	23.9000	3.9150	19.9730	-19.9963
14	25	20	21.0500	2.3700	20	-16.4200	25	20	21.0500	2.3700	20	-16.4200
15	25	20	7.8750	1.7850	20	1.3400	25	20	7.8750	1.7850	20	1.3400
16	25	20	4.2250	1.3050	20	9.4700	25	20	4.2250	1.3050	20	9.4700
17	25	20	0.5500	1.7850	20	17.6650	25	20	0.5500	1.7850	20	17.6650
18	25	20	0	1.7850	20	21.2150	25	20	0	1.7850	20	21.2150
19	25	20	0	1.3020	20	23.6980	25	20	0	1.3020	20	23.6980
20	25	20	0	1.7850	20	20.2150	25	20	0	1.7850	20	20.2150
21	25	20	0	1.3020	20	11.6980	25	20	0	1.3020	20	11.6980
22	25	20	0	1.3020	20	4.6980	25	20	0	1.3020	20	4.6980
23	25	20	0	0.9150	20	-0.9150	25	20	0	0.9150	20	-0.9150
24	25	20	0	0.6150	20	-9.6150	25	20	0	0.6150	20	-9.6150

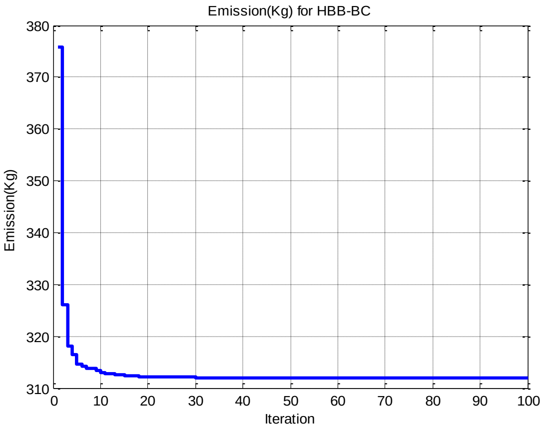

Figure 10. Best optimization results obtained by HBB-BC regarding polluter emission in the second scenario

Table 16. Comparison of optimization results on emission in the second scenario

Type	Emission (Kg)			
	Best solution	Worst solution	Average	Standard deviation
PSO	311.984	320.246	313.765	2.1125
BB-BC	312.047	312.209	312.118	0.0344
HBB-BC	311.993	312.018	312.006	0.0051

Restating the results in percentage, the best, worst, mean and standard deviation are -1%, 97%, 99% and 0.2% than PSO with 99%, 99%, 99% and 14% than BB-BC have caused improvement in optimization results.

In addition, Table 18 provides an account of the results as obtained regarding the sending distribution for the second state. According to this table it can be viewed that, similar to the sending cost, in this state again the results do not differ greatly from those obtained given the sending distribution in the first state.

The results obtained from different algorithms to optimize the costs for the first state are summarized in Table 19. Similar to the two previous sections, a detailed description of each algorithm is presented in Table 20. These results indicate that as for the HBB-BC algorithm, the best, worst states, mean and standard deviation values are 0, 2.44, 0.16 and 0.5001 compared to PSO and 0.06, 1.78, 0.33 and 0.3044 in comparison to BB-BC have caused improvement in optimization results. Restating the results in percentage, the best, worst, mean and standard deviation are 1%, 99%, 99% and 3% than PSO with 99%, 99%, 99% and 5% than BB-BC have caused improvement in optimization results. Table 21 illustrates the obtained results for both sending cost and distribution for the second state.

It is observed that in this state the results are once again similar to the first state. In the second state, operational cost of a micro-grid has increased to 98 when compared to the first state. Given the distribution of pollutants in this state, a 99% reduction is observed in the distribution of pollutants when compared to the first state. This could indicate that, in the network state there are lower distributions but higher operational costs. Thus, in the general state, in order to the distribution and economy objectives simultaneously, each of the generators shall be used appropriately with its high capacity.

For either of the two abovementioned states, there are a number of points to be considered. First, it has to be noted that the battery is charged in the earlier hours of the day when the costs are low, and the process of battery discharge takes place when the load curve reaches to its peak. Regarding the use of other renewable energy resources such as wind and sun, it is noteworthy that these two generators will increase the costs, yet reduces the in environmental pollutions. All the related values have been obtained by different algorithms for 40 cases in both states. It has been observed that the HBB-BC algorithm is significantly faster in responding in comparison to PSO. These results are gained only in 100 replications.

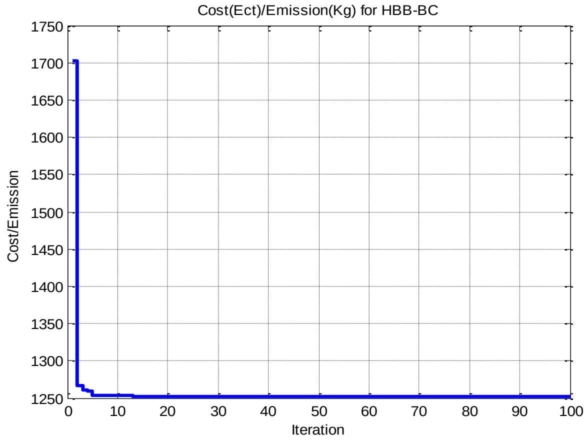

Figure 11. Best optimization results obtained by HBB-BC regarding polluters' expense - emission combination in the second scenario

Table 19. Comparison of optimization results on emission / expense in the second scenario

Type	Emission (Kg) / Cost (€ct)			
	Best solution	Worst solution	Average	Standard deviation
PSO	1249.18	1251.68	1249.36	0.5167
BB-BC	1249.24	1251.02	1249.53	0.3210
HBB-BC	1249.18	1249.24	1249.2	0.0166

Table 17. Obtained results from HBB-BC and comparing them with the outcomes from other algorithms regarding emission in the second scenario

Type	Emission (Kg)											
	Best solution	optimized value	optimized percentage	Worst solution	optimized value	optimized percentage	Average	optimized value	optimized percentage	Standard deviation	optimized value	optimized percentage
HBB-BC	311.993	0.054	99%	312.018	0.1919	99%	312.006	0.112	99%	0.0051	0.0293	14%
BB-BC	312.047			312.209			312.118			0.03446		
HBB-BC	311.993	-0.009	-1%	312.018	8.228	97%	312.006	1.759	99%	0.0051	2.1074	0.2%
PSO	311.984			320.246			313.765			2.1125		

Table 18. Emission using HBB-BC and BB-BC algorithms in the first scenario

Time (h)	Units											
	HBB-BC						BB-BC					
	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)
1	0	0	0	1.7850	20	30.2150	0	0	0	1.7850	20	30.2150
2	0	0	0	1.7850	20	28.2150	0	0	0	1.7850	20	28.2150
3	0	0	0	1.7850	20	28.2150	0	0	0	1.7850	20	28.2150
4	0	0	0	1.7850	20	29.2150	0	0	0	1.7850	20	29.2150
5	0	0	0	1.7850	20	34.2150	0	0	0	1.7850	20	34.2150
6	0	2.0862	0	0.9150	20	39.9988	0	2.0885	0	0.9150	20	39.9965
7	0	8.2224	0	1.7850	20	39.9926	0	8.2293	0	1.7850	20	39.9857
8	0	13.4963	0.2000	1.3050	20	39.9987	0	13.5392	0.2000	1.3050	19.9858	39.9700
9	0	10.4684	3.7500	1.7850	20	39.9966	0	10.4723	3.7500	1.7850	20	39.9927
10	0	9.3858	7.5250	3.0900	20	39.9992	0	9.4014	7.5250	3.0900	20	39.9836
11	0	0	10.4500	8.7750	20	38.7750	0	0	10.4500	8.7750	20	38.7750
12	0	0	11.9500	10.4100	20	31.6400	0	0	11.9500	10.4100	20	31.6400
13	0	0	23.9000	3.9150	20	24.1850	0	0	23.9000	3.9150	20	24.1850
14	0	0	21.0500	2.3700	20	28.5800	0	0	21.0500	2.3700	20	28.5800
15	0	6.3404	7.8750	1.7850	20	39.9996	0	6.3455	7.8750	1.7850	20	39.9945
16	0	14.4710	4.2250	1.3050	20	39.9990	0	14.4778	4.2250	1.3050	20	39.9922
17	2.6674	20	0.5500	1.7850	20	39.9976	2.6971	20	0.5500	1.7850	20	39.9679
18	6.2158	20	0	1.7850	20	39.9992	6.2245	20	0	1.7850	20	39.9905
19	8.6994	20	0	1.3020	20	39.9986	8.6993	20	0	1.3020	20	39.9987
20	5.2150	20	0	1.7850	20	40	5.2186	20	0	1.7850	20	39.9964
21	0	16.7076	0	1.3020	20	39.9904	0	16.7194	0	1.3020	20	39.9786
22	0	9.6984	0	1.3020	20	39.9996	0	9.7343	0	1.3020	20	39.9637
23	0	4.0901	0	0.9150	20	39.9949	0	4.1001	0	0.9150	20	39.9849
24	0	0	0	0.6150	20	35.3850	0	0	0	0.6150	20	35.3850

Table 20. Obtained results from HBB-BC and comparing them with the outcomes from other algorithms regarding emission/expense in the second scenario

Emission (Kg) / Cost (€ct)												
Type	Best solution	optimized value	optimized percentage	Worst solution	optimized value	optimized percentage	Average	optimized value	optimized percentage	Standard deviation	optimized value	optimized percentage
HBB-BC	1249.18	0.06	99%	1249.24	1.78	99%	1249.2	0.33	99%	0.0166	0.3044	5%
BB-BC	1249.24			1251.02			1249.53			0.3210		
HBB-BC	1249.18	0	1%	1249.24	2.44	99%	1249.2	0.16	99%	0.0166	0.5001	3%
PSO	1249.18			1251.68			1249.36			0.5167		

Table 21. Emission / expense using HBB-BC algorithm in the second scenario

Time (h)	Units											
	HBB-BC						BB-BC					
	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)	MT (KW)	FC (KW)	PV (KW)	WT (KW)	Batt (KW)	Utility (KW)
1	0	0	0	1.7850	20	30.2150	0	0	0	1.7850	20	30.2150
2	0	0	0	1.7850	20	28.2150	0	0	0	1.7850	20	28.2150
3	0	0	0	1.7850	20	28.2150	0	0	0	1.7850	20	28.2150
4	0	0	0	1.7850	20	29.2150	0	0	0	1.7850	20	29.2150
5	0	0	0	1.7850	20	34.2150	0	0	0	1.7850	20	34.2150
6	0	2.0913	0	0.9150	20	39.9937	0	2.1265	0	0.9150	20	39.9585
7	0	8.2156	0	1.7850	20	39.9994	0	8.2785	0	1.7850	20	39.9365
8	0	20	0	1.3050	20	33.4950	0	20	0	1.3050	20	33.4950
9	25	20	3.7500	1.7850	20	5.4650	25	20	3.7500	1.7850	20	5.4650
10	25	20	7.5250	3.0900	20	4.3850	25	20	7.5250	3.0900	20	4.3850
11	25	20	10.4500	8.7750	20	-6.2250	25	20	10.4500	8.7750	20	-6.2250
12	25	20	11.9500	10.4100	20	-13.3600	25	20	11.9500	10.4100	20	-13.3600
13	24.1850	20	23.9000	3.9150	20	-20	24.1578	20	23.9000	3.9150	20	-19.9728
14	25	20	21.0500	2.3700	20	16.4200-	25	20	21.0500	2.3700	20	-16.4200
15	25	20	7.8750	1.7850	20	1.3400	25	20	7.8750	1.7850	20	1.3400
16	25	20	4.2250	1.3050	20	9.4700	25	20	4.2250	1.3050	20	9.4700
17	25	20	0.5500	1.7850	20	17.6650	25	20	0.5500	1.7850	20	17.6650
18	6.2208	20	0	1.7850	20	39.9942	6.2889	20	0	1.7850	20	39.9261
19	8.7052	20	0	1.3020	20	39.9928	8.6999	20	0	1.3020	20	39.9981
20	5.2161	20	0	1.7850	20	39.9989	5.2272	20	0	1.7850	20	39.9878
21	25	20	0	1.3020	20	11.6980	25	20	0	1.3020	20	11.6980
22	25	20	0	1.3020	20	4.6980	25	20	0	1.3020	20	4.6980
23	0	20	0	0.9150	20	24.0850	0	20	0	0.9150	20	24.0850
24	0	20	0	0.6150	20	15.3850	0	20	0	0.6150	20	15.3850

VIII. CONCLUSIONS

In the present paper, the proposed HBB-BC algorithm is used to solve the problem optimal management of sample micro-grid. In order to evaluate the execution of the proposed algorithm, a number of tests were proposed and the related results have been presented. The paper indicates that the proposed method provides evidence for the practical implementation and the satisfactory performance of algorithm as well as the dynamic stability and convergence of the system. Therefore, the proposed method has managed to provide the required design based on the economic and environmental concerns and which leads into the selection of an appropriate approach towards the desired objectives.

NOMENCLATURES

MGCC: Micro Grid Central Controller
CLS: Chaotic Local Search
PV: Photovoltaic
WT: Wind Turbine
PAFC: Phosphoric Acid Fuel Cell
NiMH-Battery: Nickel-Metal-Hydride Battery
MT: Micro Turbine
$P_{\max}^{charge}, P_{\max}^{discharge}$: Maximum rate of charge and discharge during each time interval
$V_{\min}^{ess}, V_{\max}^{ess}$: Lower and upper bounds on battery energy storage
$P^{charge}, P^{discharge}$: Permitted rate of charge and discharge through a definite period of time
$\eta^{charge}, \eta^{discharge}$: Charge and discharge efficiency of the battery
V_t^{ess} : Battery energy storage at time *t*
$P_{\max}^{grid}, P_{\min}^{grid}$: Maximum and minimum active power production of the utility at hour *t*
$P_{\max}^{sm}, P_{\min}^{sm}$: Maximum and minimum active power production of *j*th storage at hour *t*
$P_{\max}^{gn}, P_{\min}^{gn}$: Maximum and minimum active power production of *j*th DG at hour *t*
P^{lk} : The amount of *k*th load level
$NO_x^{grid}(T), CO_2^{grid}(T), SO_2^{grid}(T)$: Nitrogen, Carbon and Sulfur oxide pollutants of utility at hour *t*

$NO_x^{storagem}, CO_2^{storagem}, SO_2^{storagem}$: Nitrogen, Carbon, Sulfur oxide pollutants of *j*th storage device at hour *t*

$NO_x^{DGn}(T), CO_2^{DGn}(T), SO_2^{DGn}(T)$: Nitrogen, Carbon and Sulfur oxide pollutants of *j*th DG utility at hour *t*

$E^{grid}(T), E^{sm}(T), E^{gn}(T)$: Emission in KgMWh^{-1} for utility at hour *t*

$B^{grid}(T), B^{sm}(T), B^{gn}(T)$: Bid of utility, *j*th storage options and *j*th DG source at hour *t*

$P^{sm}(T), P^{gn}(T)$: Active power output of *j*th storage and *j*th generator at time *t*

X : Vector of the optimization variables

T : Total number of hours

N : Total number of optimization variables

S_g, S_r : Total number of generation and load units

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BIOGRAPHIES

Mohsen Keshavarz was born in Tehran, Iran. He received his B.Sc. degree in Power Electrical Engineering at Saveh Branch, Islamic Azad University, Saveh, Iran. He is now working for M.Sc. degree at Power Electrical Engineering Department, Science and Research Branch, Islamic Azad University, Saveh, Iran. His research fields include distribution of electrical energy, energy management and optimization.

Ali Mohammad Ranjbar was born in Borujerd, Iran, in 1943. He received the M.Sc. degree in from University of Tehran, Tehran, Iran and the and Ph.D. degree from Imperial College London, UK all in Electrical Engineering in 1967 and 1975, respectively. Since then, he has been at Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran where he is currently a Full Professor. He is the Editor-in-Chief of the Journal of Electrical Science and Technology since 1989. His main research interests are in the areas of electric power systems protection and operation, electrical machines and smart grids.

Mostafa Sedighizadeh received the B.Sc. degree in Electrical Engineering from the Shahid Chamran University, Ahvaz, Iran in 1996, and M.Sc. and Ph.D. degrees in Electrical Engineering from the Iran University of Science and Technology, Tehran, Iran, in 1998 and 2004, respectively. From 2000 to 2007 he was with Power System Studies Group of Moshanir Company, Tehran, Iran. Currently, he is an Assistant Professor in Faculty of Electrical and Computer Engineering, Shahid Beheshti University, Tehran, Iran. His research interests are power system control and modeling, FACTS devices, artificial intelligence, application of optimization in power systems and distributed generation.

Aras Sheikhi received the B.Sc. and M.Sc. degrees in Electrical Engineering from Sharif University of Technology, Tehran, Iran in 2009 and 2011, respectively. Currently, he is a Ph.D. student of Power and Energy Systems at the same university. His research interests include energy management, optimization, and economic studies in power systems.