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Economic Scheduling of Microgrid Based on Energy Management and Demand Response

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Abstract **– Currently, microgrids are regarded one of the main substations in distribution networks that generate electrical energy locally. The advantages of microgrids include easy management, optimization, and highly reliable supply. In this paper, the recommended model is based on economic and emission optimal scheduling in connection to the main grid mode; implementation model implies the short-term mode with optimal operation units and the use of real-time pricing (RTP) plan. In this study, a multi-objective function for operating costs and emission with the augmented ε-constraint method has been considered; fuzzy decision-making process has been employed to obtain the best solution. In addition, it has been considered that a microgrid has interruptible and shiftable loads that can participate in demand response programs. The presented results have been evaluated based on different demand response programs.**

Keywords **– Augmented ε-constraint method; Economic and emission optimal scheduling; Demand response different programs.**

Nomenclature

i	Time period
s	CHP unit index
n	DG unit index
k	Heat only unit index
j	Thermal unit index
l	Load demand index
S	Number of CHP units
N	Number of DG units
K	Number of heat only units
J	Number of thermal units
Υ_{LR}	Price quantity offer for load reduction
ΔP_{LR}	Power quantity offer for load reduction
$P_L^{IN,max}$	Maximum power of interruptible load
$P_L^{SH,max}$	Maximum power of shiftable load
P_L^{SH}	Power of shiftable load
ψ	Load shift factor
$P_{L,A}^{SH}$	Power load of shiftable load after shift
$P_{L,B}^{SH}$	Power load of shiftable load before shift
P_L	Total load (including shiftable loads, interruptible loads and non-interruptible loads)
C_{LR}	Load reduction cost
C_{CHP}	Operational costs of a CHP unit
C_{DG}	Operational costs of a DG unit
C_H	Operational costs of a heat only unit
C_{TH}	Operational costs of a thermal unit
C_{ES}	Operational costs of an energy storage unit
$C^B{}_G$, $C^S{}_G$	Purchased power cost and sold power cost with main grid
α, β, λ	Cost factors of units
ϕ, π, ρ	Cost factors of boiler
σ, τ, γ	Emission factors of units and the main grid
$\mu^B{}_G$, $\mu^S{}_G$	Cost of purchased and sold power factors
P_{CHP}	Power generated by CHP units
P_{DG}	Power generated by DG units
H_H	Heat generated by heat only units
P_{TH}	Power generated by thermal units
H_{CHP}	Heat generated by CHP units
$C^{ES}{}_{CA}$	Capital cost of an energy storage unit
$C^{ES}{}_{O\&M}$	Operation and maintenance cost of an energy storage unit
L_{dis}	Lifetime of an energy storage unit in discharge state
L_{ch}	Lifetime of an energy storage unit in charge state
P_{ch}	Power of an energy storage unit in charge state
P_{dis}	Power of an energy storage unit in discharge state
η_{dis}, η_{ch}	Discharge and charge efficiency of an energy storage unit
N_C	Number of discharge and charge cycles of an energy storage unit
N_B	Number of energy storage units
V_B	Voltage of an energy storage unit
Q_B	Capacity of an energy storage unit
x	Binary variable
R^u, R^d	Ramp-up and ramp-down limit of units
MUT, MDT	Minimum-up and minimum-down time of DG

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I. INTRODUCTION

Growing use of fossil fuels and increasing volume of environmental pollutants have made countries use smart microgrids to solve these problems in recent years. The use of smart microgrids can reduce the amount of pollutants and energy generation costs [1], [2]. Hence, the need to use electrical and heat generation sources and the existing demand for microgrids necessitate introduction of a smart system of energy management. Energy management system tries to reduce the costs and amount of pollutants by establishing connection between production units and demand [3]. Therefore, using bilateral communicate base between users and producers to use controllable loads for correcting consuming plan can be regarded one of the capabilities of a smart microgrid, which employs Advanced Metering Infrastructure (AMI) as one of the main technologies.

The existing body of research shows that economical scheduling includes various modelling and demand responses [4]. One of the main criteria of energy management system in employing AMI is adaptability with a smart microgrid topology for managing optimal energy and demand response [4], [5]. For example, in [6] economic and reliability issues of grids have been analyzed. In [7], the authors focused on the advantages of microgrids in increasing local reliability coefficient, reducing lines loss and improving local voltage. In [8] short-term generation scheduling in microgrids has been discussed. Reference [9] analyses the distributed energy resources (DER) based on the simultaneous production of power and heat for increasing reliability of microgrids. Authors in [10] suggest an energy management system responsible for the optimal scheduling of production of the existing units in microgrid and demand side management. [11] presents a demand response model using the concept of demand price elasticity. In [12]–[14], the impact of demand response on total energy cost and market energy pricing has been studied. In [15]–[17], multi-objective optimization of microgrids considering economic, environmental and demand response issues has been evaluated.

In this paper, energy management and demand response are considered as a smart strategy for day-ahead scheduling. The existing loads in microgrid request electric and heat power from generation units, which include combined heat and power unit (CHP), diesel generator (DG) unit, thermal unit, heat only unit, energy storage (ES) unit, and the main grid. In addition, in this study, the effect of demand response has been studied through load reduction and load shift on the objective function. With regard to the mentioned issues, the lowest operational costs and emission can be ensured in microgrids through smart management of generation and demand. Therefore, novelty and contributions of this paper include:

1. Multi-objective function including operational and emission cost by ε-augmented constraint method has been suggested.
2. Different demand response programs have been studied in each objective function.
3. The best solution for optimization has been presented by fuzzy decision-making.

This paper is organized as follows: demand response program and load model are analyzed in Section II. The objective functions are introduced in Section III. The constraints are presented in Section IV. In Section V, the solution method is suggested by augmented ε-constraint method, numerical simulation and case studies have been presented in Section VI, and conclusions are presented in Section VII.

II. DEMAND RESPONSE AND LOAD MODEL

Loads can be divided into three types based on the consuming characteristics in each hour: interruptible load, non-interruptible load and shiftable load [23]. Demand response is considered for the interruptible and shiftable loads. Interruptible loads can be reduced based on offer price per kilowatt, cost of reduction load in interruptible load is given in equation (1) [17]:

$$C_{LR} = \Delta P_{LR}(t) \times \Upsilon_{LR} \tag{1}$$

Constraint (2) shows the interruptible load limit.

$$0 \le \Delta P_{LR}(t) \le P_L^{IN,\max} \tag{2}$$

Shiftable loads can be moved from peak to off-peak loads. In fact, load shift is due to reducing electricity purchase from the main grid at peak load [23], constraint (3) shows the limit of shiftable loads at the time of working. Equations (4) and (5) show loads after shift and shiftable load range.

$$0 \le P_L^{SH}(t) \le P_L^{SH,\max} \tag{3}$$

$$P_{L,A}^{SH}(t) = \left(\psi(t) \times P_{L,B}^{SH}(t), t\right) \tag{4}$$

$$\psi^{\min} \le \psi(t) \le \psi^{\max} \tag{5}$$

$$\sum_{i=1}^{t} \left\{ P_{L,A}^{SH}(t) + P_{L,B}^{SH}(t) \right\} = P_L^{SH,\max} \tag{6}$$

Constraint (6) shows load balance constraint before and after the shift load. Load balance constraint is used because shiftable loads are not omitted, but they are shifted from one time period to another time period.

III. OBJECTIVE FUNCTIONS

In this study, the following objective functions are considered:

A. Operational Cost

The first objective function is introducing operational cost of units as CHP unit, DG unit, heat only unit, thermal unit, ES unit and purchasing energy from the main grid, the objective function of which is presented as follows:

$$F_1 = \sum_{i=1}^{t} \left(\sum_{s=1}^{S} C_{CHP}^{t,s} + \sum_{n=1}^{N} C_{DG}^{t,n} + \sum_{k=1}^{K} C_{H}^{t,k} + \sum_{j=1}^{J} C_{TH}^{t,j} + C_{ES} + \sum_{i=1}^{t} C_G^B - C_G^S + \sum_{l=1}^{L} C_{LR}^{t,l} \right) \quad (7)$$

The operational costs of a CHP unit include the cost of the generated power and heat by a boiler, which is presented as follows [18]:

$$C_{CHP}^{t,s} = \alpha_{t,s} + \beta_{t,s} P_{CHP}(t,s) + \lambda_{t,s} P_{CHP}(t,s)^2 + \phi_{t,s} + \pi_{t,s} H_{CHP}(t,s) + \rho_{t,s} H_{CHP}(t,s)^2 \quad (8)$$

Operational cost of DG can be defined as [19]:

$$C_{DG}^{t,n} = \alpha_{t,n} + \beta_{t,n} P_{DG}(t,n) + \lambda_{t,n} P_{DG}(t,n)^2 \quad (9)$$

The cost of operating heat only unit and thermal unit is calculated as follows [18]:

$$C_{H}^{t,k} = \alpha_{t,k} + \beta_{t,k} H_H(t,k) + \lambda_{t,k} H_H(t,k)^2 \quad (10)$$

$$C_{TH}^{t,j} = \alpha_{t,j} + \beta_{t,j} P_{TH}(t,j) + \lambda_{t,j} P_{TH}(t,j)^2 \quad (11)$$

In this paper, ES unit is considered a lithium battery, the calculation of operational cost in charging and discharging states is done as follows [20]:

$$C_{ES} = \begin{cases} \dfrac{C_{CA}^{ES} / L_{ch} + C_{O\&M}^{ES}}{\eta_{ch}\eta_{dis}} \\ C_{CA}^{ES} / L_{dis} + C_{O\&M}^{ES} \end{cases} \quad (12)$$

where [20]:

$$L_{dis} = \frac{N_B \times V_B \times Q_B \times N_C}{P_{dis}(t) \times \eta_{dis}} \quad (13)$$

$$L_{ch} = \frac{N_B \times V_B \times Q_B \times N_C}{P_{ch}(t)} \quad (14)$$

The operational cost of ES unit based on battery lifetime is considered, which can be calculated in charge state and discharge state by equations (13) and (14), respectively. On the other hand, for purchased and sold energy modelling between the main grid and microgrid, the cost of exchange energy can be calculated as follows:

$$C_G^B = \mu_G^B(t) \times P_G^B(t) \quad (15)$$

$$C_G^S = \mu_G^S(t) \times P_G^S(t) \quad (16)$$

B. Pollution Emission

The second objective function is polluting emission by CHP unit, DG unit, thermal unit, heat only unit, and the main grid. The objective function formulation is as follows:

$$F_2 = \sum_{i=1}^{t} \left(\sum_{s=1}^{S} E_{CHP}^{t,s} + \sum_{n=1}^{N} E_{DG}^{t,n} + \sum_{k=1}^{K} E_{H}^{t,k} + \sum_{j=1}^{J} E_{TH}^{t,j} + \sum_{i=1}^{t} E_G^B \right) \quad (17)$$

Pollution of CHP unit can be calculated as quadratic polynomial function [18]:

$$E_{CHP}^{t,s} = \sigma_{t,s} + \tau_{t,s} P_{CHP}(t,s) + \gamma_{t,s} P_{CHP}(t,s)^2 \quad (18)$$

It is necessary to mention that pollution of the DG, thermal, heat only units and the main grid are similar to CHP unit.

IV. Constraints

A. Power Balance and Heat Balance Constraints

To reach a balance between generation units and load demand in microgrid the total generated heat and electrical power of units must be equal to power and heat demand at each time.

$$\sum_{i=1}^{t} \begin{Bmatrix} P_L(t) + \Delta P_{LR} \\ + P_G^S(t) \times x_G^S \\ + P_{ch}(t) \times x_{ch} \end{Bmatrix} = \sum_{i=1}^{t} \begin{Bmatrix} P_{CHP}(s) \times x_{CHP(t,s)} \\ + P_{DG}(n) \times x_{DG(t,n)} + P_{TH}(j) \times x_{TH(t,j)} \\ + P_{dis}(t) \times x_{dis} + P_G^B(t) \times x_G^B \end{Bmatrix} \quad (19)$$

$$\sum_{i=1}^{t} \{ H_L(t) \} = \sum_{i=1}^{t} \{ H_{CHP}(s) \times x_{CHP(t,s)} + H_H(k) \times x_{H(t,k)} \} \quad (20)$$

where:

$$x_{dis} + x_{ch} \le 1 \quad (21)$$

$$x_G^S + x_G^B \le 1 \quad (22)$$

Constraints (19) and (20) indicate electrical power and heat balance between generation and demand at the time of operation, respectively. Constraint (21) supposes that ES unit at each time can be in charge or discharge state, and constraint (22) supposes that the main grid can inject or receive electrical power at any time.

B. Power Limit Constraints

Constraints (23)–(29) are generation power limit of CHP unit, DG unit, heat limit of CHP unit, thermal unit, heat only unit, thermal unit, the maximum and minimum power of charge and discharge of ES unit, respectively.

$$P_{CHP}^{\min} \le P_{CHP}(t,s) \le P_{CHP}^{\max} \quad (23)$$

$$P_{DG}^{\min} \le P_{DG}(t,n) \le P_{DG}^{\max} \quad (24)$$

$$H_{CHP}^{\min} \le H_{CHP}(t,s) \le H_{CHP}^{\max} \quad (25)$$

$$H_{H}^{\min} \le H_{H}(t,k) \le H_{H}^{\max} \quad (26)$$

$$P_{TH}^{\min} \le P_{TH}(t,j) \le P_{TH}^{\max} \quad (27)$$

$$0 \le P_{dis}(t) \le P_{dis}^{\max} \quad (28)$$

$$0 \le P_{ch}(t) \le P_{ch}^{\max} \quad (29)$$

C. Technical Constraints

Technical constraints of units include ramp rate limit, minimum-up and minimum-down time, which are presented as the following constraints:

$$\sum_{i=1}^{t} P_{CHP}(t,s) - \sum_{i=1}^{t} P_{CHP}(t-1,s) \le R^{u} \quad (30)$$

$$\sum_{i=1}^{t} P_{CHP}(t-1,s) - \sum_{i=1}^{t} P_{CHP}(t,s) \le R^{d} \quad (31)$$

$$\sum_{i=1}^{t} x_{CHP(t,s)}(t+1,s) \ge MUT \quad (32)$$

$$\sum_{i=1}^{t} 1 - x_{CHP(t,s)}(t+1,s) \ge MDT \quad (33)$$

Constraints (30)–(33) are considered similarly for DG unit, heat only unit, and thermal unit. On the other hand, technical constraint for ES unit is as follows:

$$SOC^{\min} \le SOC(t) \le \%100 \quad (34)$$

$$SOC(t) = SOC(t-\Delta t) - \frac{(P_{dis}(t)/\eta_{dis}) + (P_{ch}(t)\eta_{ch})}{N_B V_B Q_B} \quad (35)$$

Constraint (34) show state of charge (SOC) limit, whose SOC is given by (35).

V. Solution Method

Generally, solving multi-objective functions, there are some problems in determining optimal solutions. So, in these cases, a set of solutions are obtained, which are called the Pareto optimal solution (non-dominated optimal). Hence, one of the multi-objective optimization problems is augmented ε-constraint, which is stated as follows [21], [22]:

$$\min\left(F_i - \delta \times \left(\frac{S_j}{r_j}\right)\right) \quad (36)$$

Subject to:

$$F_j + S_j = \varepsilon_j$$

where:

$$\varepsilon_j^k = F_j^{\max} - \left(\frac{F_j^{\max} - F_j^{\min}}{q_j}\right) \times k$$
$$k = 0,1,2,\ldots,q_j \quad (37)$$
$$S_j \in \Re^{+}$$

In this method, one of the objective functions (F_i) is considered as the main objective function and the other functions (F_j) is considered as constraint. Then, the maximum and minimum amount of F_j is calculated in pay-off table, and divided equally as ($k + 1$), with change of k the total Pareto optimal solution will be obtained. In this method, δ is a small number (which is considered between 10^{-3} and 10^{-6}); S_j is a slack variable and is an element of real numbers; r_j is the maximum and minimum range of jth objective function; q_i is the number of equal parts of jth objective function [21].

In simulation section, the cost of operation as the main objective function and emission objective function is considered as constraint.

Considering the set of Pareto optimal solutions obtained, the best Pareto solution must be selected. Thus, to determine the best Pareto solution, fuzzy decision-making process will be used and the best Pareto solution from membership function will be selected by (38), membership function for operational cost and emission is stated

$$f_{\xi}^{k} = \begin{cases} 1 & F_{\xi}^{k} \le F_{\xi}^{\min} \\ \dfrac{F_{\xi}^{\max} - F_{\xi}^{k}}{F_{\xi}^{\max} - F_{\xi}^{\min}} & F_{\xi}^{\min} \le F_{\xi}^{k} \le F_{\xi}^{\max} \\ 0 & F_{\xi}^{k} \ge F_{\xi}^{\max} \end{cases} \quad (38)$$

where f_{ξ}^{k} and F^{k}_{ξ} show membership function ξth objective function and the amount of objective function in kth Pareto solution, respectively. Also, for normalizing kth, membership function, formula (39) can be used.

$$f^{k} = \frac{\sum_{\xi=1}^{P} w_{\xi} \cdot f_{\xi}^{k}}{\sum_{k=1}^{K}\sum_{\xi=1}^{P} w_{\xi} \cdot f_{\xi}^{k}} \quad (39)$$

where w_{ξ} is weight factor of ξth objective function. Weight factor will be selected based on the economic and environmental conditions of the microgrid, in this study, the weight factors in each objective function is equal to 0.5.

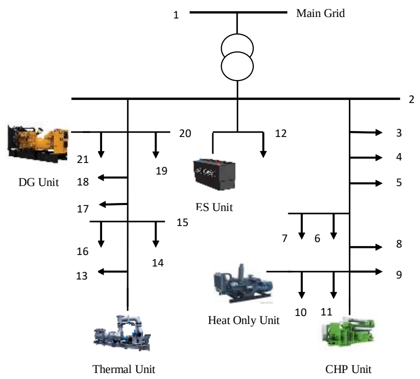

Fig. 1. Configuration of the 21-bus microgrid system.

TABLE I
COST FACTORS OF UNITS

Units	α	β	λ	φ	π	ρ
CHP	112.54	10.32	0.45	40.27	12.87	1.44
DG	86.35	16.74	0.21	–	–	–
Thermal	88.64	11.86	0.34	–	–	–
Heat Only	24.97	7.54	0.42	–	–	–

TABLE II
EMISSION FACTORS OF UNITS AND THE MAIN GRID

Units	σ	τ	γ
CHP	114.87	2.681	3.65
DG	118.97	1.981	2.27
Thermal	110.41	1.111	4.87
Heat Only	112.57	7.54	3.77
Main Grid	122.54	15.55	6.88

VI. NUMERICAL SIMULATION AND CASE STUDIES

In this section, the suggested approach is implemented based on numerical simulation and case study; case studies are presented based on demand response programs.

Case1: economical scheduling takes into account load reduction method.

Case 2: economical scheduling takes into account load shift method.

Case 3: economical scheduling takes into account load reduction and load shift methods.

In this way, to analyze the mentioned cases, a radial distribution network 21-bus is used in Fig. 1. The generation units in distribution network include one CHP unit, one DG unit, one heat only unit, one thermal unit and one ES unit in connection to the main grid mode. In Tables I and II, the cost and emission factors of units are provided.

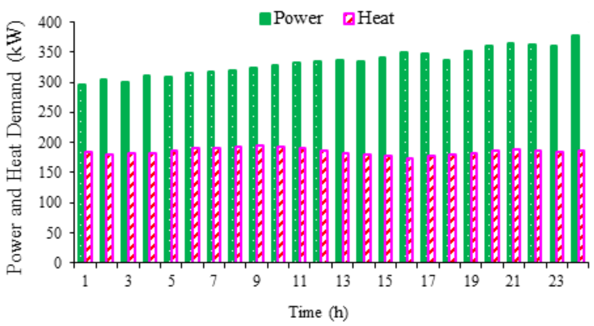

Fig. 2. Power and heat demand in the microgrid system.

TABLE III
TECHNICAL DATA OF UNITS AND THE MAIN GRID

Units	*MUT*	*MDT*	R^u	R^d	P^{min}	P^{max}	H^{min}	H^{max}
CHP	5	1	25	0	0	230	0	210
DG	6	2	10	0	0	250	–	–
Thermal	4	2	15	0	0	200	–	–
Heat Only	6	3	–	–	–	–	0	190
Main Grid	–	–	–	–	0	400	–	–

It is worth mentioning that emission factors have resulted from CO_2, SO_2, and NO_x. Technical data of units are shown in Table III.

Since augmented ε-constraint method is used, the range of objective function in each case is presented in Table IV (pay-off table).

Economic and technical data of ES unit are presented in Table V. Fig. 2 shows heat demand and electrical power demand in 24 hours.

Energy price in day-ahead and based on energy market at off-peak, middle peak and peak are shown in Fig. 3.

Simulation was performed using GAMS software and through mixed integral nonlinear programming (MINLP) using intel^R core^{TM} i5 system with CPU 2.5 GHz and 6 GB of RAM.

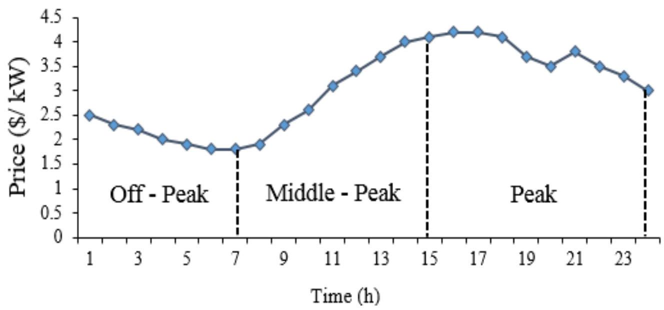

Fig. 3. Real-time pricing (RTP) in the energy market.

In turn, the offer price for load reduction is provided in Table VI. Also, load shift factor is considered as $-20 < \psi < 20$, which is presented in Fig. 4.

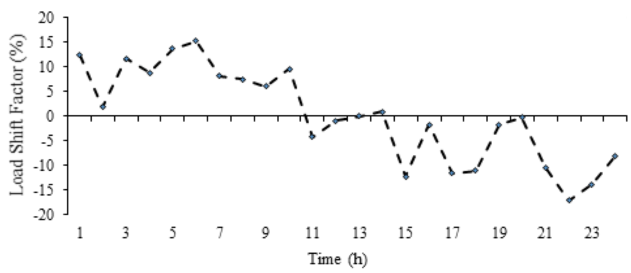

Fig. 4. Load shift factor (ψ) in 24 hours.

TABLE IV
RANGE OF OBJECTIVE FUNCTIONS IN EACH CASE (PAYOFF TABLE)

	Case 1		Case 2		Case 3	
Function	Min Cost	Min Emission	Min Cost	Min Emission	Min Cost	Min Emission
Cost (k$)	32.12	12.94	39.92	12.31	31.74	12.11
Emission (ton)	96.44	8.15	85.73	7.64	74.16	7.30

A. First Case: Economic Scheduling Takes Into Account Load Reduction Method

In this case, the economical scheduling is simulated with load reduction method. Fig. 5(a) shows Pareto optimal solution in 15 iterations. In Fig. 6(a), 6th solution is regarded as the best compromise solution in fuzzy decision-making process. As it has been demonstrated, purchase power from the main grid is not considered from 14:00 to 21:00, which is due to high price of energy in the mentioned hours. Demand in these hours is provided by DG, thermal, CHP and ES units. In this case, load decrease is observable from 14:00 to 24:00, and the total reduction is equal to 431 kW due to a high price of energy in middle peak and peak.

Fig. 7(a) shows the generated heat by CHP unit and heat only unit. In this case, the total operational cost is equal to 37 069 $, where the maximum cost is for purchased power from the main grid and heat only unit. In addition, the total emission is equal to 9.8848 ton.

TABLE V
ECONOMIC AND TECHNICAL DATA OF ES UNIT

Parameters	**Values**
C^{CA}	150
$C^{O\&M}$	0.5
N_B	156
V_B	12
N_C	500
SOC_{min}	0.3
Q_B	150
P_{dis}^{max}	120
P_{ch}^{max}	120
η_{dis}	85
η_{ch}	90

TABLE VI
OFFER PRICE FOR LOAD REDUCTION QUANTITY

Parameters				
Cost ($)	1	5	15	25
Quantity (kW)	1–40	41–70	71–85	86–100

B. Second Case: Economical Scheduling Takes Into Account Load Shift Method

This case presents the effect of shiftable loads in economical scheduling. In this study, shiftable loads are shifted from high price intervals to low price intervals. In Fig. 5(b) the best compromise solution is the 5th solution in the process of fuzzy decision-making, generation of units for providing electric power in this solution is shown in Fig. 6(b). In this case, the main grid supplies the demand from 1:00 to 9:00, when the price of energy is low. Hence, at middle peak and peak, DG and CHP units yield the most generation power in providing demand. These units are used to reduce the main grid emission.

Fig. 7(b) shows generated heat by CHP unit and heat only unit, where heat only unit has the maximum participation in providing heat demand. In this case, the maximum cost of operation and emission is attributable to DG and heat only unit whose total operation cost and emission are 42 682 $ and 8.8953 ton, respectively.

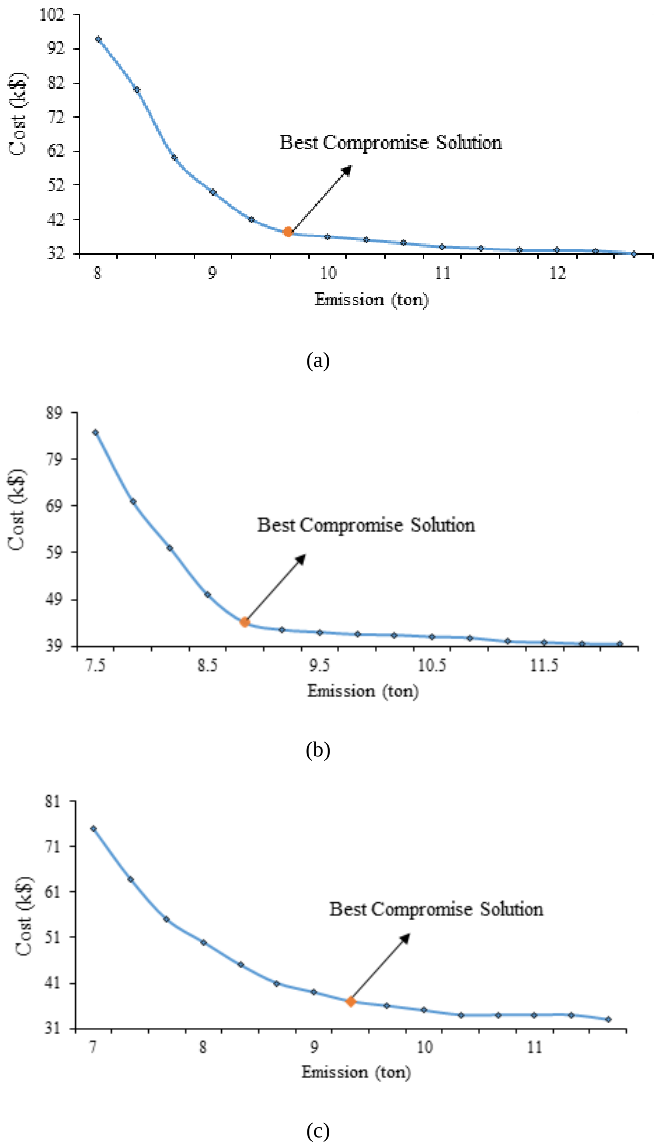

Fig. 5. The best compromise solution determined by fuzzy decision-making process in Pareto-optimal front. a) first case; b) second case; c) third case.

C. Third Case: Economical Scheduling Takes Into Account Load Shift Method

This case has analyzed the effects of reduced load and shift load methods on economical scheduling. The 8th solution has been selected as the best compromising solution in fuzzy decision-making process, which is presented in Fig. 5(c). In Fig. 6(c) load reduction in comparison to the first case has reduced and is equal to 335 kW. In this case, the costs of operation in CHP unit, DG unit, thermal unit, heat only unit, the main grid, ES units and the cost of load reduction are 4984.9 $, 8139.7 $, 10 871.1 $, 10 701.4 $, 0.03 $, 283 $, respectively. Table VII shows compromise scheduling of units in each of the cases. Fig. 7(c) shows heat generated by CHP unit and heat only unit, which are similar to the first case.

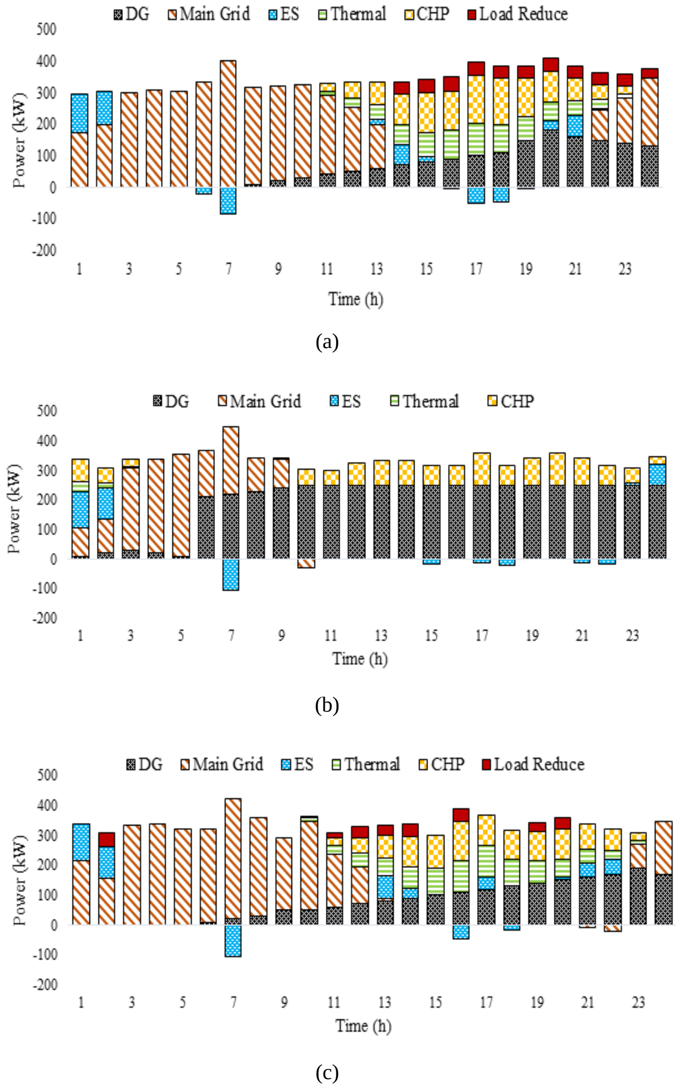

Fig. 6. Generated electrical power of units and the main grid, a) first case; b) second case; c) third case.

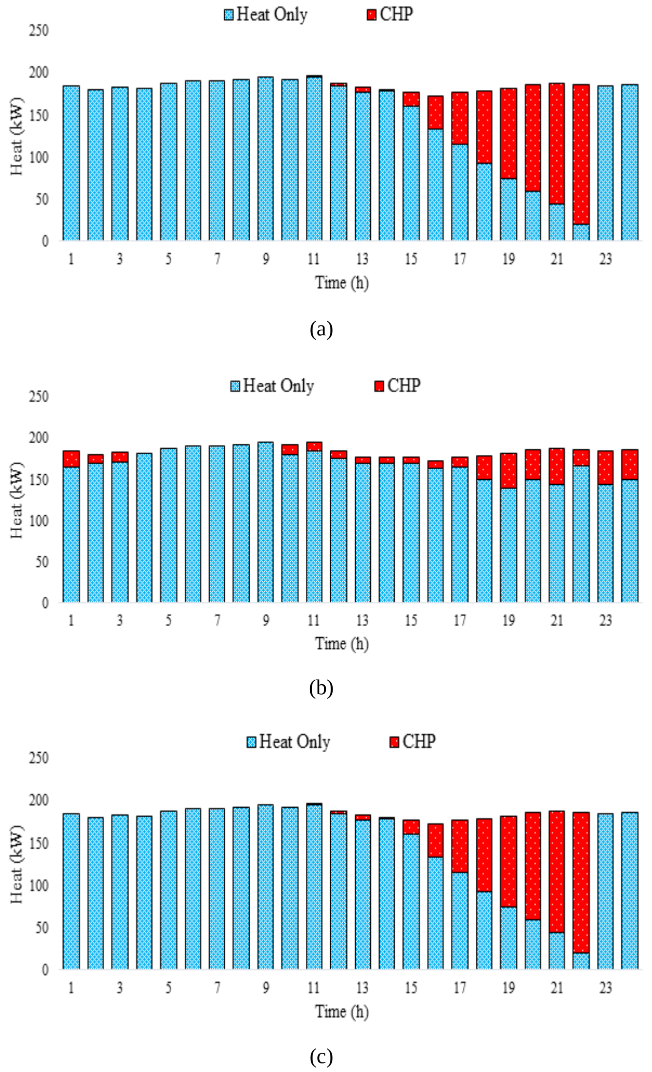

Fig. 7. Generated heat of CHP and heat only units, a) first case; b) second case; c) third case.

VII. Conclusion

In this paper, multi-objective function for short-term scheduling in a microgrid in connection to the main grid mode is suggested taking into account the demand response programs. The approach of the suggested method in three considered cases has been analyzed using reducing load and shift load scheduling. The results show that an optimal energy management procedure has been suggested in the third case, in which emission and operational cost of microgrid have been reduced compared to the first and second case study, respectively. On the other hand, in the third case shiftable loads are shifted from peak to off-peak, which has caused decrease in the cost of operation as well as smaller decrease in load than in the first case. So, in Table VII, the cost of operation in the third case has been reduced by 9.85 % compared to the second case, which is due to satisfied demand by the main grid at off-peak. On the other hand, the polluting emission in the third case has been reduced compared to first case by up to 3.1 %, high emission in the first case was conditioned by the participation of the main grid in emission up to 12.04 %.

TABLE VII
SCHEDULING COST AND EMISSION COMPARISON IN THREE CASES

	Case 1		Case 2		Case 3	
	Cost (k$)	Emission (ton)	Cost (k$)	Emission (ton)	Cost (k$)	Emission (ton)
CHP	7.7241	0.8734	5.6581	0.8736	4.9849	1.2827
DG	6.7824	1.4835	21.543	3.0007	8.1397	1.2883
Thermal	3.3148	0.5341	0.2706	0.4359	3.7884	0.6104
Heat Only	10.871	2.0288	11.667	2.3916	10.871	2.0288
Main Grid	8.5563	4.9647	3.5507	2.1935	10.701	4.3668
ESU	0.00003	–	0.00002	–	0.00003	–
Load Reduction	0.421	–	–	–	0.283	–
Total	37.669	9.8845	42.689	8.8953	38.483	9.5782

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