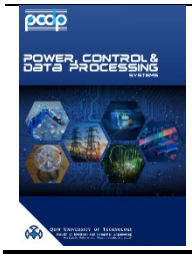
DOI: 10.30511/pcdp.2026.2090585.1080 - ISSN: 3060-8376 - Vol 3(4), 2026



POWER, CONTROL AND DATA PROCESSING SYSTEMS

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A Collaborative Energy Management in Renewable-based Water-energy Nexus Multi-microgrid System Using Dynamic Demand Response

ARTICLE INFO

Article Type
Original Research

Authors
Ahmad Ali Ahmadi
Hamid Karimi
Saeed Hasanzadeh

[1] Department of electrical and computer engineering, Qom University of Technology, Qom, Iran.

Karimi.h@qut.ac.ir,
Hasanzadeh@qut.ac.ir

**** Correspondence***
Address: Department of electrical and computer engineering, Qom University of Technology, Khodakaram Boulevard, Qom, Iran. Postal Code: 71551313.
Phone: 025-36169000
Hasanzadeh@qut.ac.ir

Article History
Received: June 03, 2026
Accepted: August 05, 2026
ePublished: December 01, 2026

ABSTRACT

This paper proposes a collaborative energy management in the water-energy nexus multi-microgrid systems. In this model, several microgrids collaborate together to form a large coalition and perform a centralized energy scheduling in order to minimize the total costs. In the water section, the microgrids utilize the water desalination unit and underground water sources to supply the freshwater. Also, they operate the water storage tank to enable the water flexibility for the microgrids. In the electrical section, the renewable energy sources, capstone microturbine, and battery storage systems are considered to keep the balance between the generation and demands. In this section, a dynamic demand response program is introduced that calculate the up-ward and down-ward potential of different microgrids based on their load consumption profiles. The numerical results shows that performing the dynamic demand response programs reduces the operating cost and energy not supplied of microgrids by 8.35 % and 91.43 %, respectively.

Keywords: multi-microgrid; collaborative mechanism; water-energy nexus; demand response program.

1 Introduction

The large-scale integration of renewable energy sources (RES) in the energy systems has created significant challenges such as stability, reliability, and power quality challenges [1, 2]. In response to these technical challenges, microgrid concept (MG) has been introduced to effectively integrate the RES with energy storage systems and local controllable energy sources. The MGs can be operated in both grid-connected and islanded modes [3, 4]. Therefore, they can supply critical loads during upstream network disturbances or blackouts when is needed [5].

In recent years, different research works are conducted on the operation scheduling of MGs. The authors in [6] utilized a genetic algorithm to determine the energy trading among MGs in the multi-microgrid systems. A stochastic framework has been developed in [7] to study the energy scheduling of MGs using the battery energy storage, electric vehicles, and renewable energy sources. In [8], the authors presented a coalition-based energy management for the distribution systems consist of different MGs. The proposed model incorporates the water and energy sectors to simultaneously provide the electricity and water demand. This study integrates the water storage tank and desalination unit with RES to increase the flexibility of MGs. However, the dynamic DR programs were not considered.

A long short-term memory deep learning and convolutional neural network have been utilized in [9] to investigate the photovoltaic-based MG. The battery energy storage systems are considered to cover the uncertain behavior of RES. The proposed model considers the impact of depth of discharge of the battery energy storage systems on the battery life cycles. However, the cooperation among neighbor MGs is not studied. Also, the proposed structure only considers the electricity network, while the water demand of the MG is neglected. Reference [10] presented a two-stage algorithm for cooperative scheduling of multi-carrier MGs. The proposed model considers the reliability, environmental, and economic characteristics to present a comprehensive scheduling for MGs. The first stage of the proposed model minimizes the total cost of MGs, while the energy not supplied and carbon emission are minimized at the second stage of the optimization algorithm. Although the proposed model studies the cooperation among MGs, an optimal algorithm is not developed to define the best coalition sets in the system. Also, the water-electricity nexus in the MGs is ignored. The optimal sizing and siting of distributed energy sources are discussed in [11] to minimize total annual costs of the MGs. The authors investigated the performance of the proposed model in both normal and emergency conditions. Also, a cost allocation method is utilized to divide the cost of the system among MGs. However, the efficiency of the proposed model on the power quality improvement is not studied. Besides, the role of water storage tank and water energy nexus are ignored.

The authors in [12] resented a multi-objective optimization to optimize the emission, cost, and RES integration in the system. The Gurobi solver is employed to handle the optimization problem. However, the impact of the coalition forming among MGs on the carbon reduction and RES integration were not studied. A two-layer framework has been developed in [13] to increase the efficiency of MGs. The first layer of the proposed model performs a centralized scheduling for each industrial MG. Also, the second layer determines the optimal trading among MGs. However, the dynamic demand response programs has not been developed. A stochastic approach has been developed in [14] to present a reliable energy management in MGs. However, the dynamic demand response program was not formulated. An adaptive reinforcement learning approach has been developed in [15] to present a sustainable scheduling for MGs. However, the water-energy nexus, water storage tank, desalination unit, and dynamic demand response programs were ignored. The authors in [16] proposes a sustainable and economic energy scheduling for renewable-based MG as the energy hub system. The battery energy storage systems are utilized to cover the uncertainty of RES. However, the dynamic demand response was not integrated to the proposed model.

In this paper, we propose a cooperative mechanism for optimal energy management of the grid-connected renewable-based MGs. The proposed cooperative model enables the cooperation among MGs to present an economic and reliable energy scheduling by the centralized mechanism. In the centralized scheduling, a central energy management system (EMS) handles the operating scheduling of all of MGs. Therefore, it determines the peer-to-peer energy trading among MGs. Each MG is equipped with renewable energy sources, battery energy storage system, and microturbine to supply the required electricity demand. Also, each MG is connected to the main grid and other MGs. Therefore, it can trade electricity with them. Also, a dynamic demand response program is introduced to create the demand-side flexibility according to the load profile of MGs. In the water section, each MG can supply the water by desalination unit. The desalination units consume the electricity to convert the salt water to potable water. Also, water storage tank is considered to store the potable water in MGs. The main contributions of the work are listed as:

1. Presenting a sector coupling structure that links the electricity and water sections together to increase the flexibility of the multi-microgrid system.

2. Proposing a dynamic demand response program that consider different potential for load shifting during various tie slots.

3. Providing a dynamic formulation for water section such as water storage tank and water desalination units.

The rest of the paper is organized as follows: section 2 models the mathematical formulation of the multi-microgrid system. Section 3 presents the input data. Section 4 presents the

simulation results and discussion. Finally, section 5 describes the conclusion and future works.

2 Mathematical formulation of multi-microgrid system

This section presents the mathematical formulation of the multi-microgrid system.

2.1 Renewable energy generation

The MGs utilize the photovoltaic and wind energy to generate clean energy. Equations (1) and (2) present the production of photovoltaic and wind turbines, respectively.

$$P_{i,t}^{PV} = \eta^{PV} S_i^{PV} I_i \left(1 - 0.005(T_i^{Out} - 25)\right) \tag{1}$$

$$P_{i,t}^{WT} = \begin{cases} 0 & 0 \le v_{i,t} \le v_{ci} \text{ or } v_{co} \le v_{i,t} \\ P_{i,r}^{WT} \dfrac{v_{i,t}^2 - v_{ci}^2}{v_{i,r}^2 - v_{ci}^2} & v_{ci} \le v_{i,t} \le v_{i,r} \\ P_{i,r}^{WT} & v_{i,r} \le v_{i,t} \le v_{co} \end{cases} \tag{2}$$

2.2 Battery energy storage system

Equations (3)-(8) provide the mathematical formulation of battery energy storage system.

$$0 \le P_{i,t}^{Ch} \le X_{i,t}^{Ch} \overline{P_i^{Ch}} \tag{3}$$

$$0 \le P_{i,t}^{Dich} \le X_{i,t}^{Dich} \overline{P_i^{Dich}} \tag{4}$$

$$SoC_{i,t+1} = SoC_{i,t} + \Delta T \left(\eta_i^{Ch} P_{i,t}^{Ch} - \frac{P_{i,t}^{Dich}}{\eta_i^{Dich}} \right) \tag{5}$$

$$SoC_{i,t}^{\min} \le SoC_{i,t} \le SoC_{i,t}^{\max} \tag{6}$$

$$SoC_{i,t1} = SoC_{i,t24} \tag{7}$$

$$X_{i,t}^{Ch} + X_{i,t}^{Dich} \le 1 \tag{8}$$

Equations (3) and (4) describe the charging and discharging power limits, respectively. The state-of-charge of batteries is developed in Eq. (5). Equation (6) limits the state-of-charge between minimum and maximum values. Equation (7) keeps the initial and final stored energy the same. Finally, Eq. (8) defines that the battery storage is in charging or discharging mode.

2.3 Diesel generator units

Equations (9)-(18) model the mathematical formulation of diesel generator units.

$$\text{Cost}_i^{DG} = \sum_{t=1}^{T} k_i U_{i,t} + \Delta T \sum_{n=1}^{N_n} \pi_{i,n} P_{i,n,t} \tag{9}$$

$$0 \le P_{i,n,t} \le P_{i,n} \tag{10}$$

$$P_i^{\min} U_{i,t} \le P_{i,t}^{DG} \le P_i^{\max} U_{i,t} \tag{11}$$

$$P_{i,t}^{DG} = P_i^{\min} U_{i,t} + \sum_{n=1}^{N} P_{i,n,t} \tag{12}$$

$$P_{i,t}^{DG} - P_{i,t-1}^{DG} \le IR_i^{DG} \tag{13}$$

$$P_{i,t-1}^{DG} - P_{i,t}^{DG} \le DR_i^{DG} \tag{14}$$

$$\sum_{h=t}^{t+IT_i-1} U_{i,h} \ge IT_i Y_{i,t} \tag{15}$$

$$\sum_{h=t}^{t+DT_i-1} (1 - U_{i,h}) \ge DT_i V_{i,t} \tag{16}$$

$$Y_{i,t} - V_{i,t} = -U_{i,t-1} \tag{17}$$

$$Y_{i,t} + V_{i,t} \le 1 \tag{18}$$

Equation (9) shows the generation cost of diesel generator units. Equations (10) and (11) limit the generation of diesel generator units. The total generation of diesel generator units is provided by Eq. (12). Equations (13) and (14) present the ramp-up and ramp-down limits of diesel generator units, respectively. Other equations are related the operating constraints of diesel generator units.

2.4 Fuel cell units

Equations (19)-(22) determine the operating constraints of fuel cell units.

$$\text{Cost}_i^{FC} = \sum_{t=1}^{T} \left(\frac{C_{ng}}{L_{ng}} \frac{P_{i,t}^{FC}}{\eta_{i,t}^{FC}} \right) \tag{19}$$

$$0 \le P_{i,t}^{FC} \le P_{i,r}^{FC} \tag{20}$$

$$P_{i,t}^{FC} - P_{i,t-1}^{FC} \le UR_i^{FC} \tag{21}$$

$$P_{i,t-1}^{FC} - P_{i,t}^{FC} \le DR_i^{FC} \tag{22}$$

Equation (19) presents the generation cost of fuel cell units. Equation (20) represents the minimum and maximum generation of fuel cell units. Finally, Equations (21) and (22) define the ramp-up and ram-down limits of fuel cell units, respectively.

2.5 Microturbine units

Equations (23)-(25) develop the mathematical formulation of microturbine units.

$$\text{Cost}_i^{MT} = \sum_{t=1}^{T} \left(\frac{C_{ng}}{L_{ng}} \frac{P_{i,t}^{MT}}{\eta_{i,t}^{MT}} \right) \tag{23}$$

$$0 \le P_{i,t}^{MT} \le 65 \text{ kW} \tag{24}$$

$$\eta_{i,t}^{MT} = 0.0753\left(\frac{P_{i,t}^{MT}}{65}\right)^3 - 0.3095\left(\frac{P_{i,t}^{MT}}{65}\right)^2 + 0.4147\left(\frac{P_{i,t}^{MT}}{65}\right) + 0.1068 \quad (25)$$

Equation (23) shows the operating cost of capstone C65 microturbine. Equation (24) limits the generation of microturbine. Finally, Equation (25) calculates the efficiency of microturbine.

2.6 Dynamic demand response programs

Equations (26)-(31) present the dynamic demand response programs.

$$P_{i,t}^{Flex} = P_{i,t}^{B} + P_{i,t}^{up,DR} - P_{i,t}^{down,DR} \quad (26)$$

$$P_{i,t}^{up,DR} = DR_{i,t}^{up} P_{i,t}^{Flex} u_{i,t}^{up} \quad (27)$$

$$P_{i,t}^{down,DR} = DR_{i,t}^{down} P_{i,t}^{Flex} u_{i,t}^{down} \quad (28)$$

$$0 \le DR_{i,t}^{up} \le DR_{i,t}^{up,\max} u_{i,t}^{up} \quad (29)$$

$$0 \le DR_{i,t}^{down} \le DR_{i,t}^{down,\max} u_{i,t}^{down} \quad (30)$$

$$u_{i,t}^{up} + u_{i,t}^{down} \le 1 \quad (31)$$

Equation (26) reshapes the load profile by load shifting. Equations (27) and (28) calculate the shifted-up and shifted-down electricity, respectively. Equations (29) and (30) limit the shifted-up and shifted-down electricity, respectively. Finally, Eq. (31) defines the shifted-up or shifted-down mode.

2.7 Desalination unit

Equations (32) and (33) demonstrate the electricity consumption of desalination units and their production limit, respectively.

$$P_{i,t}^{dw} = \eta_i^{dw} Q_{i,t}^{dw} \quad (32)$$

$$0 \le Q_{i,t}^{dw} \le Q_{i,\max}^{dw} \quad (33)$$

2.8 Underground water sources

Equations (34) and (35) present the extracted water from the underground sources and electricity consumption for extracting water to the MGs, respectively.

$$0 \le Q_t^{w} \le Q^{w,\max} \quad (34)$$

$$P_{m,t}^{pw} = Q_{m,t}^{w} L^{w} \frac{g\ \rho^{w}}{\eta^{p,w}(3.6\times10^{6})} \quad (35)$$

2.9 Water storage tank

Equations (36)-(41) present the dynamic formulation of water storage tank.

$$L_{i,t}^{sw} = L_{i,t-1}^{sw} + \frac{Q_{i,t}^{wch}}{A^{sw}} - \frac{Q_{i,t}^{wdish}}{A^{sw}} \quad (36)$$

$$P_{i,t}^{sw} = Q_{i,t}^{wch}\left(L_{i,t}^{sw} + L_{i,t-1}^{sw} + LL^{sw}\right)\frac{g^{w}\rho^{w}}{2\eta^{pw}(3.6\times10^{6})} \quad (37)$$

$$0 \le Q_{i,t}^{wch} \le Q_{i,\max}^{wch} WW_{i,t}^{wch} \quad (38)$$

$$0 \le Q_{i,t}^{wdish} \le Q_{i,\max}^{wdish} WW_{i,t}^{wdish} \quad (39)$$

$$0 \le L_{i,t}^{sw} \le L_{i,\max}^{sw} \quad (40)$$

$$0 \le WW_{i,t}^{wch} + WW_{i,t}^{wdish} \le 1 \quad (41)$$

Equation (36) develops the state of charge of water storage tank. Equation (37) calculates the power consumption of storage tank. The charging and discharging water limits are presented in Eqs. (38) and (39), respectively. Equation (40) limits the volume of water storage tank. Finally, Eq. (41) defines the charging or discharging mode of water storage tank.

2.10 Water and electricity balances

Equations (42) and (43) present the water and electricity balance in the multi-microgrid system, respectively.

$$\sum_{i=1}(P_{i,t}^{PV} + P_{i,t}^{WT} + P_{i,t}^{DG} + P_{i,t}^{MT} + P_{i,t}^{FC} + P_{i,t}^{Disch} + P_{i,t}^{Grid}) = \sum_{i=1}(P_{i,t}^{d,w} + P_{i,t}^{pw} + P_{i,t}^{ps}) + \sum_{i=1}(P_{i,t}^{Flex} + P_{i,t}^{Ch}) + \sum_{p,q\in Ap} B_{p,q}(\theta_{p,t} - \theta_{q,t}) \quad (42)$$

$$Q_{i,t}^{ww} + Q_{i,t}^{dw} + Q_{i,t}^{wdish} = Q_{i,t}^{wch} + L_{i,t}^{wdemand} \quad (43)$$

Also, Eq. (44) limits the trading electricity of each MG with the upstream grid. Besides, Equations (45) and (46) show the follow of electrical lines and voltage angle limits, respectively.

$$-P^{G\max} \le P_{i,t}^{Grid} \le P^{G\max} \quad (44)$$

$$-F_{p,q}^{Max} \le B_{p,q}(\theta_{p,t} - \theta_{q,t}) \le F_{p,q}^{Max} \qquad \forall t,p,q \quad (45)$$

$$-\pi \le \theta_{p,t} \le \pi \qquad \forall t,p \quad (46)$$

2.11 Objective function

Equation (47) shows the objective function of the multi-microgrid system. It can be seen that the multi-microgrid system aims to minimize its total cost. A centralized approach is utilized to perform the operation management for all of the MGs. The main advantage of the centralized approach is that it can find the optimal solution for the system.

$$\begin{aligned}&\min\left[\mathrm{Cos}t^{DG}+\mathrm{Cos}t^{FC}+\mathrm{Cos}t^{MT}+\mathrm{Cos}t^{Grid}\right]\\&=\sum_i\Big(\sum_{t=1}^{T}k_iI_{i,t}+\Delta T\sum_{n=1}^{N_n}\pi_{i,n}P_{i,n,t}\Big)\\&+\sum_i\sum_t\Big(\frac{C_{ng}}{L_{ng}}\frac{P_{i,t}^{Fc}}{\eta_i^{FC}}\Big)\\&+\sum_i\sum_t\Big(\frac{C_{ng}}{L_{ng}}\frac{P_{i,t}^{MT}}{\eta_{i,t}^{MT}}\Big)\\&+\sum_i\sum_t C_t^{Grid}P_{i,t}^{Grid}\end{aligned}\qquad(47)$$

3 Case study and input data

The proposed centralized cooperative model is tested on 6-bus IEEE test system with three water-based MGs. Each MG utilizes a 65 kW microturbine. The capacities of fuel cell units in MGs 1-3 are considered 350 kW, 400 kW, and 300 kW, respectively. The rated power of wind turbines in MGs 1-3 are considered 300 kW, 350 kW, and 250 kW, respectively. The capacities of diesel generators in MGs 1-3 are considered 250 kW, 200 kW, and 220 kW, respectively. The minimum generating power of diesel generators are assumed that 25 kW, 20 kW, and 22 kW, respectively. The minimum down/up time for all diesel units is 2 hours. Ramping up/down rate limit of diesel generators are 50 kW 40 kW, and 40 kW, for MGs 1-3, respectively. The efficiency of fuel cell units is 49 %. Table 1 shows the parameters of energy storage systems. Also, Table 2 provides the characteristic of wind turbines.

Table 1: Parameters of energy storage systems

MG	Max SoC (kWh)	Min SoC (kWh)	Efficiency (%)	Cha/discharging (kW)
MG1	400	10	90	80
MG2	200	5	90	40
MG3	200	5	90	40

Table 2: Parameters of wind turbines

Cut-in speed (m/s)	Cut-out speed (m/s)	Rated speed (m/s)
5	30	12

Also, figures 1 and 2 show the water and electricity demand of MGs, respectively. The maximum charging and discharging water of water storage tanks are considered 4 m^3/h. The water desalination energy efficiency is 3.03 KWh/m^3. The water well level is 10m.

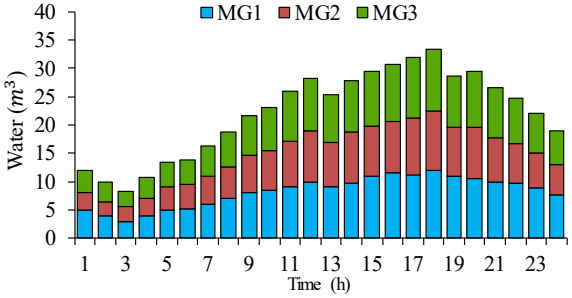


Figure 1: Water demand in MGs

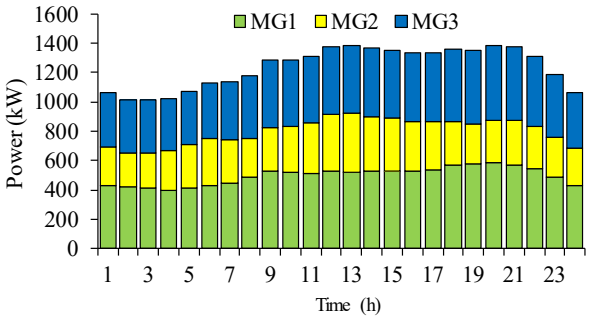


Figure 2: Electrical demand in MGs

4 Simulation results and discussion

Figures 3 and 4 show the maximum potential of MGs for down-ward and up-ward load shifting using the dynamic demand response programs, respectively. According to Fig. 3, it can be seen that during peak hours, the proposed dynamic demand response programs considers more ability for down-ward load shifting in MGs. However, the MGs have more ability for up-ward load shifting during off-peak hours according to Fig. 4.

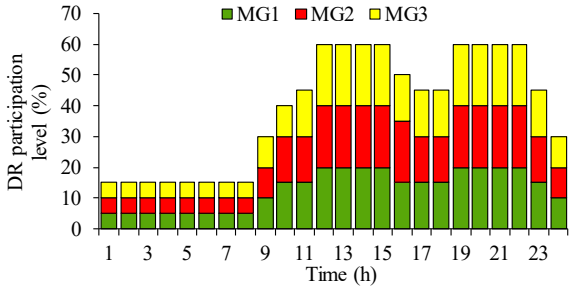


Figure 3: Maximum potential of MGs for down-ward load shifting

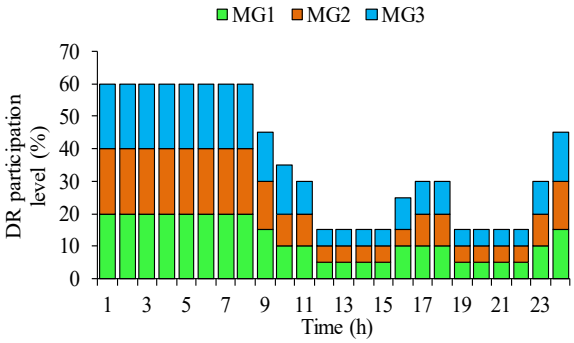


Figure 4: Maximum potential of MGs for up-ward load shifting

During peak hours, since most equipment in MGs is turned on, they have a greater ability to manage their load to reduce their energy consumption. Therefore, the down-ward participation is significant. In contrast, during off-peak hours, the MG consumption is low. Actually, each MG only consumes its base load. Therefore, the MGs have little capability to further consumption reduction and can only decrease their

consumption by about 5%. So, the down-ward load shifting of MGs is very low during off-peak hours.
On the other hand, during off-peak hours, MGs have a high capability to increase consumption. Therefore, the up-ward load shifting is high during off-peak hours, whereas during peak hours, the up-ward power capacity is low.
Table 3 shows the performance of dynamic demand response programs on the operating cost and energy not supplied (ENS) of MGs.

Table 3: Performance of dynamic demand response programs

Case study	Cost ($)	ENS (kWh)
Without DR	1398.3	129.85
Dynamic DR	1281.43	11.37
Improvement (%)	8.35	91.43

The results of Table 3 show that the dynamic demand response programs reduce the operating cost of the multi-microgrid system by 8.35 %. When demand response programs are not implemented, the operating cost is $ 1398.3. However, by performing demand response programs, the operating cost reduces to $ 1281.43. The dynamic demand response programs create the chance of load shifting for MGs. Therefore, MGs can shift their load from peak hours to off-peak hours. Due to higher electricity prices during peak hours, the dynamic demand response programs reduce the total cost of MGs. Also, the simulation results show that the proposed dynamic demand response model reduces the ENS from 129.85 kWh to 11.37 kWh. It shows that the dynamic demand response programs can increase the reliability of the MGs by 91.43% by load shifting from peak hours to off-peak hours.

Figures 5 and 6 present the produced water by desalination units and extracted water from the water well, respectively. The simulation results of Figures 5 and 6 show that the extraction of water from the water wells is more appreciated for MGs. The MGs extract the maximum water from water well because the water wells consume less electricity than desalination units. Since the centralized energy management system considers the total cost as the objective function of the optimization problem, it prefers to supply the water by the water wells.

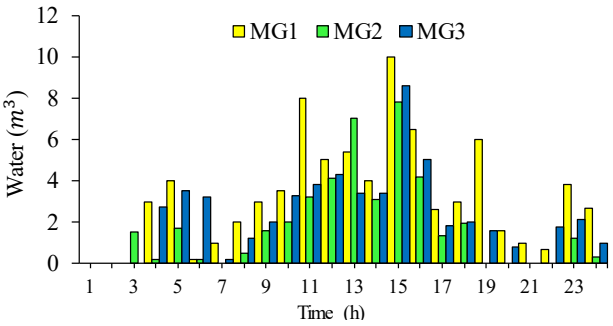


Figure 5: Produced water by desalination units

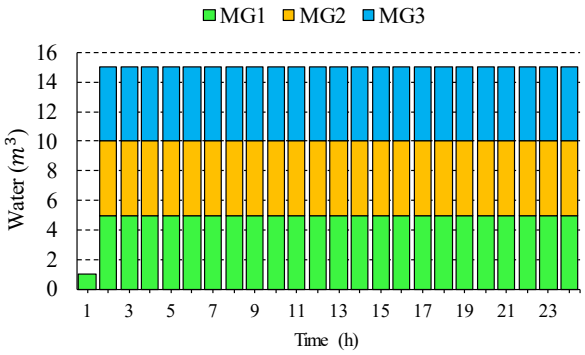


Figure 6: Extracted water from water wells

5 Conclusion

This paper presents a centralized energy management framework for optimal scheduling of renewable-based grid-connected multi-microgrid system. In the proposed model, the microgrids cooperate together to enjoy from the centralized scheduling in order to find minimum operating cost for day-ahead scheduling. The proposed structure incorporates the electricity section with renewable energy sources, battery energy storage, fuel cell, microturbine, and diesel generator with the water section to simultaneously provide the electricity and potable water for microgrids. Also, a dynamic demand response program is introduced that calculates the potential of load shifting for microgrids. The numerical test on a standard case study shows that the centralized algorithm and dynamic demand response programs reduce the operating cost and energy not supplied of the multi-microgrid system by $ 116.87 and 118.48 kWh, respectively.

Disclosure of Potential Conflicts of Interest

The Authors declare that there is no conflict of interest.

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Nomenclature

Parameters	Description
A^{sw}	Water storage capacity
$B_{p,q}$	Line supetance
L_{ng}	Low heat value of natural gas
DT_i,IT_i	Down-time and up-time of diesel units
I_i	Solar radiation
$P_{i,r}^{WT}$	Rated power of wind turbine
$P_{i,r}^{FC}$	Rated power of fuel cell
$\overline{P_i^{Ch}}$	Maximum charging power of battery storage
$\overline{P_i^{Dich}}$	Maximum discharging power of battery storage
$P_{i,n}$	Maximum generation of diesel generation at step n
P_i^{max}	Maximum generation of diesel generator
P_i^{min}	Minimum generation of diesel generator
P^{Gmax}	Maximum transaction with grid
$P_{i,t}^{B}$	Load profile without demand response
η^{PV}	Efficiency of photovoltaic
η_i^{dw}	Efficiency of desalination
η_i^{Ch},η_i^{Dich}	Efficiency of battery storage
$\eta^{p,w}$	Efficiency of water well pump
η^{pw}	Efficiency of water tank pump
UR_i^{FC}, DR_i^{FC}	Ramp-up and ramp-down of fuel cell
g	Earth gravity
$Q_{i,max}^{dw}$	Maximum desalinated water
$Q^{w,max}$	Maximum pumped water from well
$Q_{i,max}^{wch}$	Maximum charging of water tank
$Q_{i,max}^{wdish}$	Maximum discharging of water tank
S_i^{PV}	Are of photovoltaic panel
$SoC_{i,t}^{min}$	Minimum SoC of battery
$SoC_{i,t}^{max}$	Maximum SoC of battery
$L_{i,max}^{sw}$	Maximum capacity of water tank
$L_{i,t}^{wdemand}$	Water demand
T_i^{Out}	Ambient temperature
k_i	Start-up cost of diesel generator
$v_{i,t}$	Wind speed
$v_{i,r}$	Rated wind speed
v_{ci},v_{co}	Cut-in and cut-out speed
ρ^w	Water density
ΔT	Time length
$\pi_{i,n}$	Marginal cost of diesel generator
IR_i^{DG},DR_i^{DG}	Ramp-up and ramp-down generation of diesel

Variable	
Cost_i^{DG}	Cost of diesel generator
Cost_i^{FC}	Cost of fuel cell
Cost_i^{MT}	Cost of microturbine
$Cost^{Grid}$	Cost of grid
$DR_{i,t}^{up}$	Up-ward participation level in demand response
$DR_{i,t}^{down}$	Down-ward participation level in demand response
$L_{i,t}^{sw}$	Stored water in water tank
$P_{i,t}^{Grid}$	Trading energy from main grid
$P_{i,t}^{dw}$	Consumed electricity by desalination unit
$P_{i,t}^{FC}$	Fuel cell generation
$P_{i,t}^{MT}$	Microturbine generation
$P_{i,t}^{PV}$	Photovoltaic generation
$P_{i,t}^{WT}$	Wind turbine generation
$P_{i,t}^{Ch}$	Charging power of battery
$P_{i,t}^{Dich}$	Discharging power of battery
$P_{i,t}^{DG}$	Generation of diesel generator
$P_{i,n,t}$	Generation of n-th segment of diesel generator
$P_{i,t}^{Flex}$	Load profile with demand response
$P_{i,t}^{down,DR}$	Down-ward demand
$P_{i,t}^{up,DR}$	Up-ward demand
$P_{m,t}^{pw}$	Electricity consumption of well pump
$P_{i,t}^{sw}$	Electricity consumption of water tank pump
$SoC_{i,t}$	SoC of battery
$U_{i,t}$,$V_{i,t}$	Binary variable for diesel generator
$u_{i,t}^{up}$	Binary variable for up-ward demand response
$u_{i,t}^{down}$	Binary variable for down-ward demand response
$Q_{i,t}^{dw}$	Desalinated water
Q_t^w	Water of well
$Q_{i,t}^{wch}$	Water charging
$Q_{i,t}^{wdish}$	Water discharging
$\eta_{i,t}^{FC}$	Efficiency of fuel cell
$\eta_{i,t}^{MT}$	Efficiency of microturbine
$WW_{i,t}^{wch}$	Binary variable for charging of water tank
$WW_{i,t}^{wdish}$	Binary variable for discharging of water tank
$\theta_{p,t}$	Voltage angle
$X_{i,t}^{Ch}$	Binary variable for charging of battery
$X_{i,t}^{Dich}$	Binary variable for discharging of battery