Energy and reserve scheduling in a microgrid considering multiple demand response programs

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Abstract:

Microgrid (MG) is one of the important blocks in the future smart distribution systems. The scheduling pattern of MGs affects distribution system operation. Also, the optimal scheduling of MGs will be result in reliable and economical operation of distribution system. In this paper, an operational planning model of a MG which considers multiple demand response (DR) programs is proposed. In the proposed approach, all types of loads can participate in demand response programs which will be considered in either energy or reserve scheduling. Also, the renewable distributed generation uncertainty is covered by reserve prepared by both DGs and loads. The novelty of this paper is the demand side participation in energy and reserve scheduling, simultaneously. Furthermore the energy and reserve scheduling is proposed for day-ahead and real-time. The proposed model was tested on a typical MG system in connected mode and the results show that running demand response programs will reduce total operation cost of MG and cause more efficient use of resources.

Keywords: Microgrid, Demand response, Renewable generation, Operation, Reserve.

1. Introduction

The MG is operated by a Mirogrid operator (MGO) that manages the technical features of generation and consumption as well as economical aspect of operation. The MGO is responsible for optimal scheduling of MG generation units as well as making possible demand side participation in energy and reserve market. Also, the MGO is in charge to be MG’s agent in electricity market. The MGO has a mutual relation with Distribution System Operator (DSO) as its upper hand grid scheduler. The MGO has the right to receive the electricity price of wholesale market for day-ahead energy and reserve scheduling.

In [1], a smart energy management system (SEMS) was presented to optimize the operation of the MG. This paper also considered photovoltaic (PV) output in different weather conditions as well as hourly electricity price of main grid. However, this model did not allocate reserve for renewable uncertainty and did not consider load participation in demand response program. In [2], a model that optimizes MG generation in interconnected operation mode was proposed. This model was run by MG Central Controller (MGCC) and considered two market policies. Moreover, demand side biding was considered as a demand response program where all demand loads were divided into two categories: low priority and high priority loads. Unfortunately, this work did not considered renewable generation uncertainty and did not allocate reserve in its model. In [3], both emission and economic objectives were considered in MG operational scheduling. It used Mesh adaptive direct search algorithm to minimize the cost function of the system but did not consider demand side participation in energy market and ignored the wind and solar forecast error. The application of high reliability distribution system (HRDS) in the economic operation of a microgrid has been studied in [4]. HRDS, which offers higher operation reliability and fewer outages in microgrids, has been applied to looped networks in distribution systems.

The estimation model of spinning reserve requirement in MG was proposed in [5]. In this model, the uncertainty of wind and solar generation is considered as well as the unreliability of units and uncertainties caused by load. This approach aggregated various uncertainties to reduce computational burden. The demand side reserve and load participation in energy market was not considered in this model. The deterministic energy management system for a MG was proposed in [6]. This model included advanced PV generators with embedded storage units and a gas micro-turbine. The scheduling was implemented in two parts: a central energy management of the MG and a local power management at the customer side. However, the reserve requirement estimation and demand response program in MG were not considered in this work. In [7], the authors proposed an energy scheduling approach for buildings that have considered the uncertainty of load and PV generation. The objective function of this approach is to minimize the overall cost of electricity and natural gas while using CHP in building. The demand response program and reserve allocation is not considered in their model. The real-time pricing scheme for residential load management was proposed in [8] and [9]. These papers presented an automatic and optimal scheme for the operation of each appliance in household in presence of a real-time pricing tariff. A dynamic modeling and control strategy for a sustainable microgrid primarily powered by wind and solar energy has been presented in [10]. This study has considered both wind energy and solar irradiance changes in combination with load power variations.

The main focus of this paper is on proposing a scheduling approach in a MG and considering demand participation and renewable generation in energy and reserve operational planning. The renewable generation uncertainty is considered in this model and multiple demand response programs will be proposed for all types of MG's loads. This model has tried to use all reserves in real time not only for covering renewable forecast error but also for charging battery to use in subsequent periods. As a result, the proposed operational planning model guarantees that the generation and reserve allocation are scheduled economically. Moreover, this model proposes multiple types of demand response programs to facilitate all type of consumers' participation in energy and reserve scheduling.

The contributions of this paper are highlighted as follows:

- Simultaneous demand side participation in Energy and reserve scheduling program in a MG
- Schedule and manage various types of DR program through the model
- Propose day-ahead and real-time scheduling in a MG
- Consider both of shiftable and curtailable loads in residential DR program

The rest of this paper is organized as following. In section 2 the concept of the proposed model is described. The model formulation is detailed in Section 3. Simulation results are given in Section 4 and the paper is concluded in Section 5.

2. Proposed Model Concept

The MGO utilizes all resources in its grid to supply demands with objective of operating MG with acceptable reliability and security criteria. The MG operational planning data flow is shown in Figure 1. The assumptions used in proposed model are elaborated next.

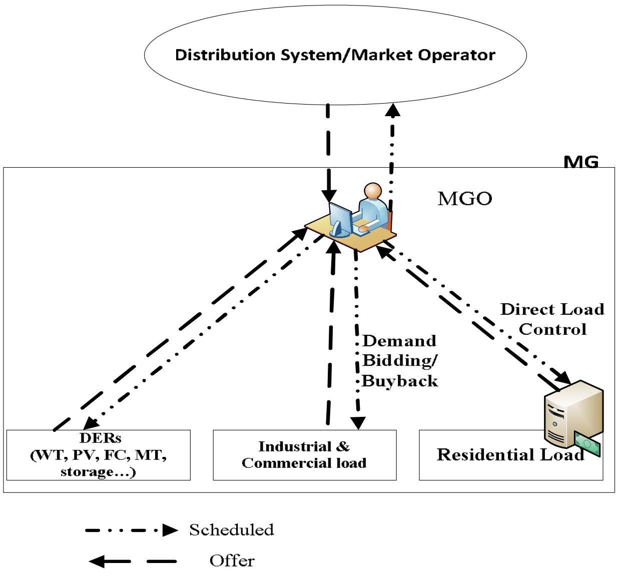


Figure 1 The microgrid operational scheduling data flow

Assumptions

- Wind and PV producers are not considered competitive agents and their generation should be totally purchased. Hence, wind and PV generations are both considered as negative demand, and thus, paid a regulated tariff.
- The MGO is allowed to access a day-ahead electricity price for following 24-hour scheduling. Also, in real time, MGO can access the electricity price of real-time market.
- After scheduling, MGO sends energy requirement for following 24 hours to DSO
- The effect of demand reduction on wholesale electricity price is not considered.
- The wind speed and solar radiation forecasts and their forecast errors are received form nearest weather broadcast service. The forecast error is considered as a percentage of wind and PV predicted output power.
- Because of small scale of MG and short distance between components, the power flow equation is not considered.

Demand side participation is one of the important resources that help the operator to schedule generation and consumption with lower cost and higher security. The load can participate in both energy and reserve operational scheduling and earn benefit from reducing or shifting their consumption. In the proposed model, both of MGO and customers receive benefits from running demand response programs.

In real world, it is hard to expect every residential load to take part in demand response programs, and have interaction with power market and system operator. In the daytime, people may not be at home or all the residents are not familiar with energy management procedures. So it is logical to use an automatic system to help residential consumers to participate in energy management programs. While it is usually difficult and confusing for the residential consumers to manually respond to prices that are changing every hour, MGO can help them to manage their consumption with objectives of cutting expenses and increasing welfare.

Residential demand response programs usually intend at one or both of the following objectives: reducing consumption and shifting consumption. Reducing consumption is performed by appliances like HVAC, lamp and refrigerator. In this type of household appliances, the energy consumption is reduced but is not shifted to another time. The appliances such as dishwasher and washer-dryer can shift their working period to another time. In the proposed model, every load type such as industrial, commercial and residential loads can participate in demand response programs.

In this paper, an incentive payment oriented demand response scheme is presented for microgrid operational planning. Incentive-based demand response programs provide a more active tool for load-serving entities, electric utilities, or grid operators to manage their costs and maintain reliability. Incentive payment oriented demand resources can be used as reserves during real-time as well as in day-ahead scheduling and dispatch, or as capacity resources in system planning. In this paper three types of incentive-based demand response programs are considered for load management program that are listed below [11]:

- ***Demand bidding/buyback programs***
- ***Ancillary Services Market Programs***
- ***Direct Load Control***

In the proposed model we have assumed that every house in MG control area has an automatic controller and energy management system. The configuration of this system is described below:

3. Model Formulation

The operational planning of MG will be carried out in two stages. The first stage is run for 24-hour day-ahead scheduling to calculate the hourly energy requirement form upstream grid for the next 24 hours. Also this scheduling will determine the generation output of DGs as well as demand participation. Moreover, the spinning reserve requirement will be calculated in this stage. The second stage is real-time scheduling which is completed a few minutes (10 minutes) before entering to a specific hour. In this stage the renewable output for next hour is exactly calculated. So, the reserve will be dispatched according to the energy curtailment.

Stage I- 24-hour day-ahead scheduling

In the proposed model, MGO intends to decrease the total operation cost of MG, and considers all technical constraints. The objective cost function of this model ($CF1$) is sum of overall hourly operation cost of MG which is given by (1):

$$Minimize, \tag{1}$$

$$\begin{aligned} CF1 = \sum_{t=1}^{T}\sum_{i=1}^{I}[C(i,t) + SU(i,t)] + \sum_{t=1}^{T}[CG(t) - RG(t)] \\ + \sum_{t=1}^{T}\sum_{l=1}^{L} IDE(l,t) \times IO_E(l,t) \\ + \sum_{t=1}^{T}\sum_{h=1}^{H} HDE(h,t) \times HO_E(t) + RC \end{aligned}$$

where $C(i,t)$ is the bid form ith DG at tth period that covers all fuel and maintenance costs as well as capital cost. $SU(i,t)$ is start-up cost of DG, $CG(t)$ and $RG(t)$ are the purchased energy cost and sold energy revenue to/from main grid, respectively. $IDE(l,t)$ and $IO_E(l,t)$ are the energy reduction amount in kWh and price offer in $\$/kWh$ by lth industrial or commercial loads, respectively. The residential (home) energy reduction by hth home is indicated with

$HDE(h,t)$, the incentive payment for reduction is shown by $HO_E(t)$, and the reserve commitment cost is indicated by RC.

The bid function of each DG should contain the fuel and maintenance cost (a_i) as well as a percentage of investment cost (b_i). The cost function of DG is given by (2):

$$C(i,t) = a_i . PG(i,t) + b_i \tag{2}$$

where $PG(i,t)$ is the active power output of ith DG at tth period of scheduling.

The MG in interconnected mode can exchange power with main grid. The cost and revenue of purchasing and buying power from upstream network is calculated as follows:

$$CG(t) = Ta_{PP}(t) \times Pg_{pp}(t) \tag{3}$$

$$RG(t) = Ta_{SP}(t) \times Pg_{SP}(t) \tag{4}$$

where $Ta_{PP}(t)$ and $Pg_{pp}(t)$ are the purchased electricity tariff and imported power from main grid at tth period, respectively. On the other hand, $Ta_{SP}(t)$ and $Pg_{SP}(t)$ are the sold electricity tariff and exported power from main grid at tth period, respectively. The electricity tariffs which are used for power exchange cost calculations are equal to hourly electricity price of main grid.

The reserve cost in the objective function is calculated by (5):

$$RC = \sum_{t=1}^{T}\sum_{l=1}^{L} IDR(l,t) \times IO_R(l,t) + \sum_{t=1}^{T}\sum_{h=1}^{H} HDR(h,t) \times HO_R(t) + \sum_{t=1}^{T}\sum_{h=1}^{H} R_{DG}(i,t) \times PR_{DG}(t) \tag{5}$$

where $IDR(l,t)$ and $IO_R(l,t)$ are the reserve amount and offer from lth load, respectively. Also $HDR(h,t)$ and $HO_R(t)$ are the residential load amount and price offer for participation in reserve scheduling, respectively. The other source of offering reserves is DGs with $R_{DG}(i,t)$ and $PR_{DG}(t)$ that indicate reserve amount and bid.

The start up cost of DG units is calculated as follows:

$$SU(i,t) = Scost(i) \times (u(i,t) - u(i,t-1)) \tag{6}$$

$$SU(i,t) \geq 0 \tag{7}$$

where $Scost(i)$ is the start up cost of ith DG, and $u(i,t)$ is a binary variable that shows the on-off state of DGs.

The constraints of the proposed model are:

- *power balance equation*

$$\begin{aligned}&\left(\sum_{i=1}^{I} PG(i,t)\right) + Pg_{pp} - Pg_{sp} + \eta^{+} \times P_B^{+}(t) - P_B^{-}(t) \\ &\qquad \geq D(t) - \sum_{l=1}^{L} IDE(l,t) - \sum_{h=1}^{H} HDE(h,t)\end{aligned} \tag{8}$$

where $D(t)$ is the predicted demand of whole MG at tth period, $P_B^{+}(t)$ and $P_B^{-}(t)$ are battery discharge and charge power at tth period. The charge and discharge efficiency coefficients of battery are considered by η^{-} and η^{+}, respectively. Power balance equation is the most important constraint in operation planning. If the total generation be less than consumption, system frequency drop occurs which is undesirable.

- *DG unit output constraint*

$$PG(i,t) \geq PG_i^{min}.u(i,t) \tag{9}$$

$$PG(i,t) + R_{DG}(i,t) \leq PG_i^{max}.u(i,t) \tag{10}$$

where PG_i^{min} and PG_i^{max} are the minimum and maximum limitation of ith DG output and $u(i,t)$ shows the on/off state of DG. The spinning reserve that is procured by ith DG is shown by $R_{DG}(i,t)$. The conventional DG like micro turbine, diesel generator and fuel cell may prepare spinning reserve, and WT and PV do not offer reserve.

- *Battery charge and discharge constraints*

The battery used in MG cannot charge and discharge arbitrary. The below constraint should be considered for scheduling program of battery:

$$SOC(t) = SOC(t-1) + \eta^- \times P_B^-(t) - P_B^+(t) \tag{11}$$

$$SOC_{Min} \leq SOC(t) \leq SOC_{Max} \tag{12}$$

where $SOC(t)$ is the battery state of charge that shows how much power is reserved in it, SOC_{Min} and SOC_{Max} are the minimum and maximum capacity of battery, respectively. Also the charge and discharge limitation should be considered as follows:

$$P_B^-(t) \leq P_{B\_Max}^- \tag{13}$$

$$P_B^+(t) \leq P_{B\_Max}^+ \tag{14}$$

$$X(t) + Y(t) \leq 1; \qquad X, Y \in \{0,1\} \tag{15}$$

where $X(t)$ and $Y(t)$ are the binary variables that show battery charge and discharge state in each period.

- *Reserve requirement*

The reserve requirement is determined based on renewable generation forecast error as given by (16):

$$\sum_{l=1}^{L} IDR(l,t) + \sum_{h=1}^{H} HDR(h,t) + \sum_{i=1}^{I} R_{DG}(i,t) \geq R(t) \tag{16}$$

where $R(t)$ is the minimum reserve requirement at period t that is calculated by (17):

$$R(t) = \alpha.PG(w,t) + \beta.PG(pv,t) \tag{17}$$

where $PG(w,t)$ and $PG(pv,t)$ are output power from wind turbine w and photovoltaic unit pv, α and β are the forecast error coefficients which are used to determine the uncertainty of output power of wind and solar units which may unexpectedly increase or decrease from their predicted values. These coefficients are calculated based on historical data and the geographical condition of MG.

- *Load constraint*

The load reduction should be constrained to maximum amount of their offers. Also the scheduling program should consider demands energy and reserve participation, simultaneously. Constraints (18) and (19) show that sum of energy reduction and reserve commitment of each individual load at every hour should be lower or equal to maximum amount of their offers.

$$IDE(l,t) + IDR(l,t) \leq ID^{Max}(t) \tag{18}$$

$$HDE(h,t) + HDR(h,t) \leq HD^{Max}(t) \tag{19}$$

where $ID^{Max}(t)$ and $HD^{Max}(t)$ are the maximum amount of reduction that are offered by industrial and residential loads at period t, respectively.

The shiftable loads constraint which shows the time limitation of their performance is given as follows:

$$\sum_{t=\tau s}^{\tau e} d(t,H,ty) = \tau w \tag{20}$$

$$HDA(t,H,ty) = \sum_{\tau w} d(t,H,ty)\,.\,HDA^{Max}(H,ty) \tag{21}$$

Where indices H and ty show the home number and shifable appliance, respectively. For shiftable load scheduling, we define a binary variable $d(t,H,ty)$ that indicate on/off state of some home appliances ty that can set their on/off time. τs and τe are the allowable start and end time of these shiftable appliances working period, and τw is the required time that they need to perform their applications. $HDA(t,H,ty)$ is the power consumption of shiftable appliances ty at home H that turn on at time t ($\tau s \leq t \leq \tau e$) where the nominal power of these appliances is shown by $HDA^{Max}(H,ty)$.

Stage II- Real-Time scheduling

Several minutes prior to time t, some uncertainties such as renewable generation and load level uncertainties might be cleared out. So, the MGO should run an economic dispatch to set the final generation output of DGs according to real WT and PVs output. That means the reserves will be dispatched based on energy requirements. In the proposed model, the extra energy at each hour is categorized as follows: the reserve capacity of DGs or load which was not used in real time and unpredictable increase in WT and PV output generation from their forecasted power. Theses extra energy can be consumed in three methods: 1- sell to real-time energy market, 2- redispatch generation and load to reduce hourly operational cost, and 3- charging batteries for using at some other time.

The objective function of this hourly scheduling is cost minimization as given by (22):

$Minimize,$ (22)

$$CF2 = \sum_{i=1}^{I}[C(i,k)] + [Ta^{RT}(k) \times Pg^{RT}(k)] + \sum_{l=1}^{L} IDE(l,k) \times$$

$$IO_E(l,k) + \sum_{h=1}^{H} HDE(h,t) \times HO(t) + \overline{P_B^{+}(t)} \times ET + \sum_{t=k+1}^{24} \overline{P_B^{-}(t)} \times Ta_{SP}(t)$$

where $Ta^{RT}(k)$ and $Pg^{RT}(k)$ are the electricity price and merchandised power in real-time energy market at time period k. $\overline{P_B^{+}(t)}$ and $\overline{P_B^{-}(t)}$ are used to show this extra energy that charge and discharge battery. The price of the extra energy that saved in battery at hour k is ET. This objective function should be minimized with considering the following constraints:

$$IDE(l,t) \le IDE^{S}(t) + IDR^{s}(l,t) \tag{23}$$

$$HDE(h,t) \le HDE^{S}(t) + HDR^{s}(h,t) \tag{24}$$

$$PG(i,t) \le PG^{S}(i,t) + R_{DG}^{s}(i,t) \tag{25}$$

$$P^{S}{}_{B}^{-}(t) + \overline{P_B^{-}(t)} \le P_{B\_Max}^{-} \tag{26}$$

$$P^{S}{}_{B}^{+}(t) + \overline{P_B^{+}(t)} \le P_{B\_Max}^{+} \tag{27}$$

These constraints allow the generation and demand response variables to be adjusted based on energy requirement at real time. The index s shows the scheduled variables in day-ahead programming (output results from stage-I scheduling). $IDE^{S}(t)$, $HDE^{S}(t)$ and $PG^{S}(i,t)$ are the scheduled amount of industrial load and residential loads curtailment as well as DGs output power in 24h operational planning model. The permissible changes in these variables are determined based on the reserves amount.

4. Case Study

The proposed operational planning model was tested on a typical MG in low voltage distribution network. This test system is depicted in Figure 2. Two types of loads are considered in MG: three residential and two medium industrial workshops loads. A variety of DERs, such as a proton-exchange membrane Fuelcell (FC), a Microturbine (MT), a directly coupled wind turbine (WT), and five Photovoltaic (PV) arrays are installed in MG. It is assumed that all DGs produce active power at a unity power factor. The technical aspects of MT and FC are obtained from [12-13] and their cost function calculation are described in [2].

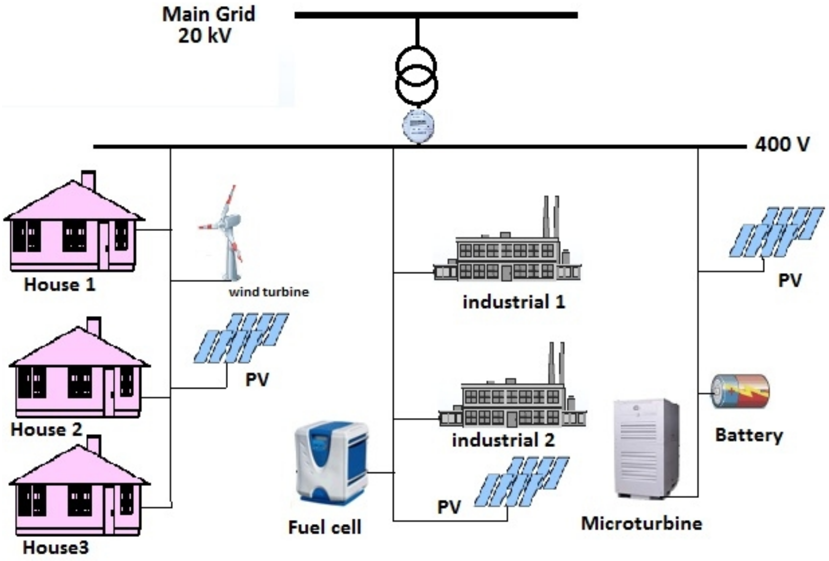


Figure 2 Typical microgrid test system

A battery as the energy storage system with capacity of 30kW is installed in MG which its charging and discharging ramp rate for each hour are 10 kW and 20kW, respectively. The minimum and maximum operating limits of DERs as well as their cost function coefficients are presented in Table 1. Data of actual wind and PV production are taken from [2]. Table 2 provides the hourly energy price of a real electricity market [2]. The total hourly load demand of the microgrid on a weekday is presented in Table 3. The industrial loads price and amount offers for load reduction is presented in Table 4. The residential loads reduction offers for each house can be found in Table 5. The WT and PV generation forecast errors are taken as 20% of their hourly forecasted outputs. The proposed model is solved using mixed-integer linear programming solver CPLEX 9.0 under GAMS [14] on a Pentium IV, 2.6 GHz processor with 4 GB of RAM.

Table 1 The technical and economical features of DERs

units	Min power (kW)	Max power (kW)	Start-Up cost (Ect)	$\boldsymbol{b_i}$ (Ect/kWh)	$\boldsymbol{c_i}$ (Ect/h)
MT	6	30	0.14	4.37	85.06
FC	3	30	0.24	2.84	255.18
WT	0	30	-	-	-
PV1	0	5	-	-	-
PV2	0	5	-	-	-
PV3	0	5	-	-	-
PV4	0	5	-	-	-
PV5	0	5	-	-	-
Battery	-30	+30	-	-	-

Table 2 Hourly price of open market

t	1	2	3	4	5	6
$\$/MWh$	47.47	31.64	31.65	32.60	40.78	38.64
t	7	8	9	10	11	12
$\$/MWh$	158.95	384.14	67.27	52.29	44.59	108.49
t	13	14	15	16	17	18
$\$/MWh$	60.64	40.88	28.50	38.75	35.55	112.42
t	19	20	21	22	23	24
$\$/MWh$	575.58	87.72	35.06	47.18	61.27	33.90

Table 3 Typical load data of the study case network

hour	Demand(kW)	hour	Demand(kW)
1	52	13	72
2	50	14	72
3	50	15	76
4	51	16	80
5	56	17	85
6	63	18	88
7	70	19	90
8	75	20	87
9	76	21	78
10	80	22	71
11	78	23	65
12	74	24	56

Stage I- Day-ahead scheduling

Two scenarios are considered to show the advantages of the proposed model: operational planning of MG with and without DR programs. In scenario 1, the DERs generation scheduling and spinning reserve settlement was performed without running demand response programs for

24 hours for which the results are presented in Figure 3. In this case, all required reserves are prepared by MT. So, a part of the MT capacity should be kept for covering renewable generation uncertainty. Also, for arranging spinning reserve, the MT is forced to be turned on in its minimum power output to be ready (stand-by) to deliver spinning reserve.

Table 4 The industrial load offer

Hour	Workshop 1		Workshop 2	
	Maximum Reduction (kW)	Price (Cent/ kWh)	Maximum Reduction (kW)	Price (Cent/ kWh)
8	15	12	15	14
9	9	14	24	13
10	5	15	5	12
13	7	9	-	-
14	7	10	-	-
15	21	11	16	12
16	7	8.5	19	10
17	10	10.5	25	12
18	4	12	18	10.5
19	15	10	10	10
20	28	11	18	13
21	10	10	21	10
22	3	12	8	20
23	6	18	-	-

Table 5 Residential load reduction offers in $Watt$

Hour	House 1	House 2	House 3
7	300	200	-
8	500	0	200
9	500	200	200
10	500	0	300
11	1000	1000	0
12	200	200	150
13	200	200	200
14	1000	0	1200
15	900	850	-
16	200	200	200
17	1000	900	850
18	1000	750	1000
19	200	150	200
20	1000	950	0
21	1000	750	800
22	950	-	-
23	1000	500	1000
24	200	200	150

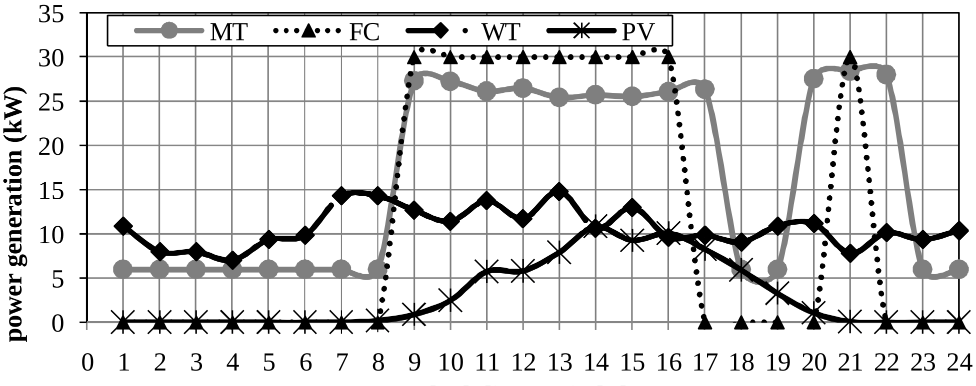
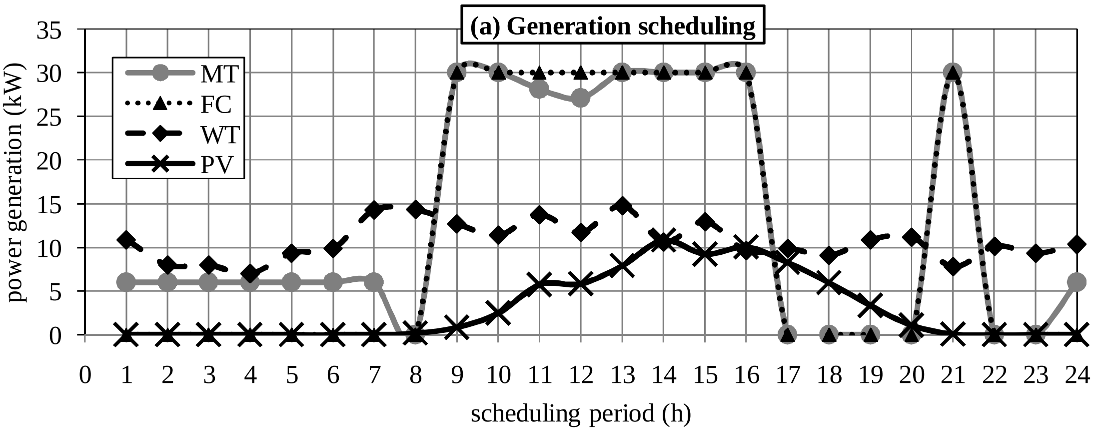


Figure 3 Energy scheduling in scenario 1

In scenario 2, the operational planning is performed by running multiple demand response programs. The generation scheduling of DERs and demand participation are shown in Figure 4a and 4b. While loads participate in energy and reserve scheduling, the MT and FC scheduled power are changed. The demand participation in energy scheduling was presented in Figure 4b.



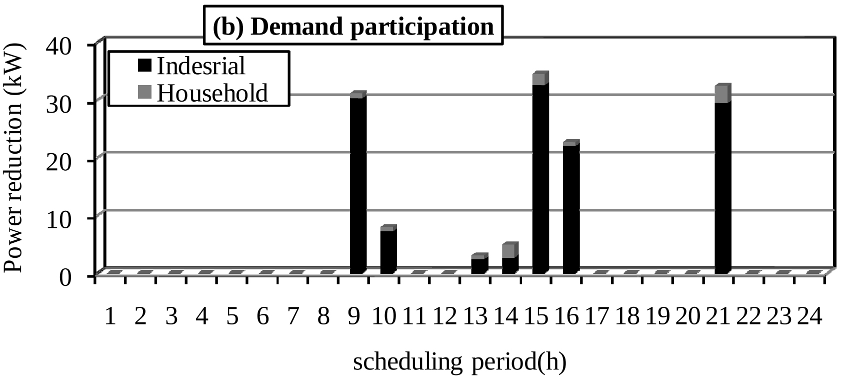


Figure 4 Energy scheduling in scenario 2: (a) Generation scheduling, (b) Demand participation

The results emphasize that the demand response in the hours with high energy price is higher than low energy price hours. That means the MGO intends to purchase load curtailment when the hourly electricity price is high. The results also show that MGO plans to arrange loads to prepare reserve; in some hours that the grid energy price is higher than DGs offer, it prefers to use all capacity of DGs for delivering energy.

The reserve scheduling for this MG with demand participation is shown in Figure 5. Comparing Figure 3 and Figure 4a, some capacity of MT were released because these DGs commitment for reserve was reduced and some reserve capacity was prepared by loads. So, these units' generation has increased in some hours to earn more profit.

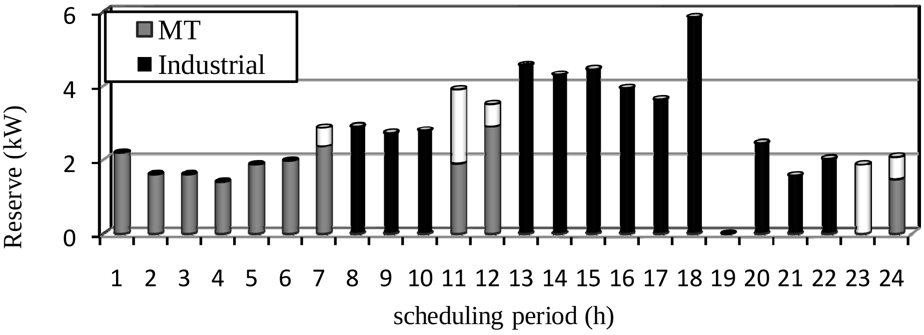


Figure 5 Reserve scheduling in scenario 2

The purchased power from main grid in scenarios 1 and 2 are shown in Figure 6. It shows when demand side participation is available in operational planning of a MG, the input power from upper hand grid is decreased. Comparing Figure 4b and Figure 6, it is recognized that the imported energy form main grid will decrease in some hours which the demand curtailment would occur. Fortunately, this lower requirement to import power form main grid occurred at peak hours; it means that the demand response reduces peak load for power system. On the other side, when loads participate in reserve scheduling, the DGs do not need to work in minimum output at standby mode. So, the scheduling approach prefers to switch them off and purchased power from main grid with lower price. Therefore the imported power is increased at hours 17, 20 and 22.

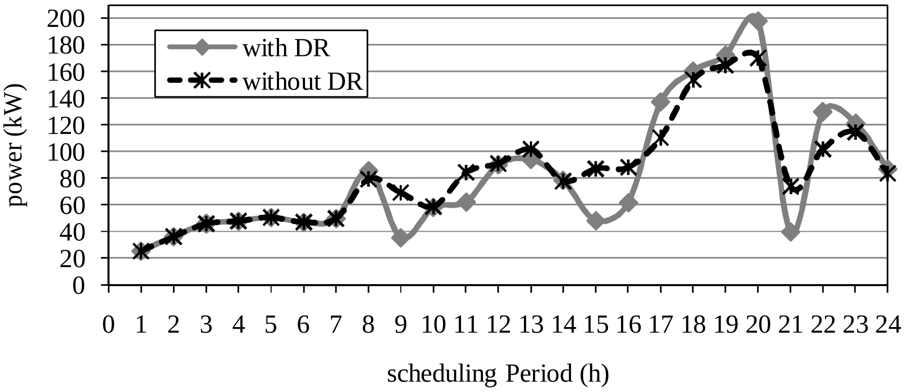


Figure 6 Import power from main grid in two scenarios

Table 6 compares the operational cost of MG with and without applying DR programs. The costs of grid and DGs purchased energy, reserve deployment and DR payment are compared in these two scenarios. These comparison shows that the proposed model deploying DR program has lower total operation cost.

Two shiftable loads are assumed at each home where they are categorized as: Dishwasher (DW) and Washer/Dryer (WD). The power consumption of dishwasher and Washer/Dryer are considered 500 and 1000 W, respectively [15]. The dishwasher works two times in every day for washing launch and dinner dishes which are showed with DW-1 and DW-2, respectively. Each washing procedure needs one hour to wash dishes. The scheduling of shiftable loads in each home was shown in Table 7. The acceptable time line for working these appliances are shown by grey cells and the selected hour for working is shown by black cells. These on/off arrangements of shiftable loads were performed based on minimization of total operation costs. As the result of this direct load control method, the total operation cost of MG as well as bills of household consumers will reduce.

Table 6 Cost comparison between two scenarios

Cost	Purchased Energy	DGs		DR		Total
		Energy	Reserve	Energy	Reserve	
Without DR programs	23932.153	6819.254	132.086	-	-	30883.493
With DR programs	21238.234	5879.125	38.578	1477.372	93.508	28726.817

Another scenario that was considered in this study is the effect of hourly electricity prices in demand response programs. In scenario 3, the grid electricity price is increased twice, to show the increasing of energy price because of some contingencies in peak hours. As seen from Figure 7, the load curtailment programs have increased in this scenario. That means in some events that system operator uses the critical peak pricing option, the MG's loads respond to this signal in order to minimize the overall cost of MG.

Table 7 The on-off scheduling of shiftable appliance

	Home 1			Home 2			Home 3		
hours	DW-1	WD	DW-2	DW-1	WD	DW-2	DW-1	WD	DW-2
11									
12									
13	▨						▨		
14	▨			▨			▨		
15	▨			▨			▨		
16	▨			▨			▨	▨	
17	▨			▨			■	▨	
18	■			▨				▨	
19			▨	■				■	▨
20			▨		▨			▨	▨
21			▨		▨	▨		▨	▨
22		▨	▨		▨	▨			▨
23		▨	■		▨	▨			▨
24		■			■	■			■

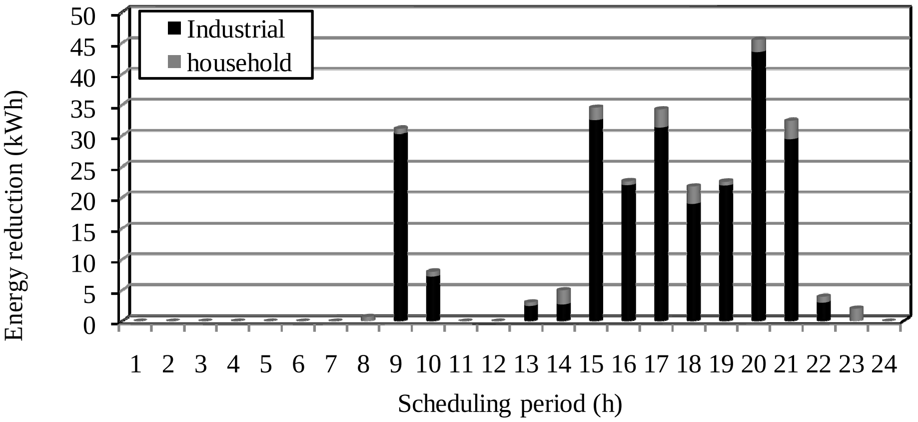


Figure 7 Demand side participation in scenario 3

Stage II- Real time scheduling

In this part, the scheduling approach in real time was performed. The load and generation are rescheduled five minutes prior to real time k $(1 \leq k \leq 24)$. For analyzing a specific time, it is assumed the time is approaching 13:00, and the real time scheduling for this hour should be carried out. In the real time, the PV and WT outputs are determined without alternation. That means there is no uncertainty in renewable generation five minutes before the real time.

The result of real time rescheduling is given in Table 8. The day-ahead scheduling parameters as well as the real-time scheduling parameters are given in this table. To analyze all the possible states, the real time scheduling is performed in three different states which each state is considered as follows: in state1, the PVs and WT output power decreased to 85% of their predicted outputs, in state 2 the PVs and WT output power increased to 115% of their predicted outputs, and in state 3, the PVs and WT output power are set to their predicted output power and MGO has an option to sell power to the real time market. In this study, the real time market price for sold or purchased power is considered two times more than hourly electricity price. In the third state, it is supposed that the system experiences a contingency and the operator should use critical peak pricing option to balance the generation and consumption. The battery scheduled state at this hour is discharging energy with power of 10 kW, and is depicted as negative value.

Table 8 Real time scheduling result

	Day-ahead scheduling(kW)	**Real-time scheduling(kW)**		
		State-1	State-2	State-3
MT	30	30	30	30
FC	30	30	30	30
WT	14.82	12.6	17.04	14.82
PVs	7.95	6.75	9.125	7.95
Battery	-10	-8.78	-2.06	-10
Pg_{pp}	84.18	84.18	84.18	84.18
Real-Time market	-	-	-	4.55
IDE	2.45	5.86	7.94	7.94
HDE	0.6	0.6	0.6	0.6
R_{DG}	0	-	-	-
IDR	4.55	-	-	-
HDR	0	-	-	-

As it is obvious from Table 8, in state 1 the industrial loads reserve is used for covering renewable generation curtailments. Also the program prefers to use additional load reserve to charge battery, for the reason that this reserving energy in battery can be used at the subsequent scheduling period at which the energy price is high. In state-2 the wind and solar output power will increase more than predicted amount at real time. So, because of renewable generation benefits, the MGO should use this additional renewable energy for supplying load. As it is obvious from the results, all the additional renewable energy as well as demand reserve will be used to charge the battery for subsequent energy production. In state-3 it is assumed that the real time market exists and wind and solar generation is equal to the predicted value. In this condition, the rescheduling program dispatches the reserve and sells this amount of electricity to the market.

5. Conclusion

In this paper, an energy and reserve scheduling approach, that manages generation and consumption through a MG by running multiple DR programs was proposed. This approach allows load to participate in both energy and reserve operational scheduling. Demand bidding/buyback programs, ancillary service market program and direct load control are considered as demand response programs. The results show that participating of loads in energy and reserve operational planning reduces total operational cost of MG. In addition, the renewable uncertainty will also be covered by reserve scheduling through the operational planning program. The proposed approach is run in two stages in order to use the benefits of all resources in real time. The proposed model allows the MG to participate in both day ahead and real time markets to earn the maximum profits. In real time, the MGO re-schedules all resources based on the real time conditions and its day ahead scheduling.

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