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# Coordination of Load and Generation Sides to Reduce Peak Load and Improve Arbitrage of Smart Distribution Grid

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This paper proposes an approach to improve the system arbitrage and reduce peak load by managing both the generation and load sides simultaneously. The peak load reduction is achieved using a load control program, while the arbitrage is enhanced by minimizing the operating and emission costs. The load management and minimization of operating cost are combined in an optimization approach in a multi-objective framework. The storage battery is utilized to contribute in the shaving of the peak load and reducing the operating and emission cost, where the battery aging is taken into account in the proposed model. The management of load sides is considered as decision variables in the approach. A mixed-integer quadratic program is employed to formulate the optimization approach. The proposed approach is applied to a smart low-voltage distribution grid. The results show that the management of both the demand and generation sides reduces the operating and emission costs and improves the load factor of the system.

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## 1. INTRODUCTION

Balancing the generation and demand in microgrid (MG) is challenging because the intermittent nature of renewable energy resources (wind, solar). These sources are uncontrolled and their generation changes with weather condition. So, it is difficult to make these sources follow the load changes. Therefore, managing both the generation and demand sides play a vital role in the balance demand and generation. Besides, the reduction of peak load improves the overall energy efficiency and reduces the total cost.

In the open literature, the researchers proposed a peak load management and its integration with the operating of MGs. Wang and Huang [1] presented the demand response technique which is contributed to economic operation of MG, where end-user responses to the energy price. Aghajani et al. [2] proposed a formula to reduce the total cos of a MG, which includes renewable energy and mixed generation sources. The load management was considered in the model to reduce the total cost and balance the load and generation, where different types of loads are participated in the load management shifting program.

Huang and Billinton [3] presented a load algorithm on seven different load sectors and studied the effects of load management on the load shape and the system reliability. Hamidian and Sedighi [4] pointed out time of use strategy to smooth the load. They analyzed the impacts of load control to reduce losses and improve reliability. However, Huang and Billinton [3] Hamidian and Sedighi [4] ignored the impact of load management on system cost and other benefits of the load control on system operation and they also neglected the reactive load. Fotuhi-Firuzabad and Billinton [5] suggested the impact of a peak clipping, load shifting and load interrupting on the system cost function and system reliability; however, they ignored many important constraints and other benefits of load control. Logenthiran et al. [6] proposed a demand side technique that brought the load curve close to the objective load curve. The load cutting to reduce the operating cost of

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MG was argued by Parisio et al. [7]. The load cut was applied to the total load and ignored other load management techniques. Olamaei and Ashouri [8] analyzed the impact of load response on the cost of MG and the load response presented as a load shifting. The algorithm was applied to low voltage MG which consists of micro turbines, wind turbines, and storage devices. However, they ignored the emission cost and many important constraints and other benefits of load management and they applied load control program on active load only. The energy management from both generation, the total cost and demand were investigated by Wang et al. [9]. The problem was formulated by using receding horizon strategy. This algorithm applied on single residential home. They ignored the cost of storage device, the on/off and maintenance cost and they ignored the reactive production cost. Shi et al. [10] suggested a management algorithm to improve the total cost of a MG and the demand side management integrated with problem modelling and it is applied to total MG load; however, they override the emission cost, reactive cost, on/off cost and benefits of load response on operation of grid. Liu et al. [11] proposed an optimization approach to reduce the total cost of the MG and the load response program integrated with optimization problem and its applied on total MG load. They did not consider storage device and reactive power, emission cost, start up and shutdown cost. They also ignored the system constraints and the ramp rate constraints and load management were applied only on active load. Wu et al. [12] applied load management program on the system includes only photovoltaic and battery to minimize the cost of the system. Kinhekar et al. [13] applied load shifting technique on industrial load and they investigated the effect of load management on the whole system cost. The reactive and emission cost, other benefits of load management, and the cost of battery operation were not taken into account in the model. Jafari et al. [14] proposed an optimal operation approach of MG, where the demand response was considered as shifting technique in responding to energy market price. The optimal management and control of the microgrid is a hierarchical structure, where the optimal operation and unit commitment (UC) strategy is within the tertiary level [15, 16].

In this paper, a novel optimization approach with managing both the load and generation is presented to improve the arbitrage of the smart distribution grid and to shave a peak load. Both the active and reactive loads are managed and integrated with the optimization approach as decision variables. The load-shifting program is developed and integrated with the proposed optimization approach to analyze the effects of load management program on the total cost of MG and on the load factor. The UC is employed to consider the real and imaginary parts of the output generation of the generators. The battery is employed to reduce the peak load and improve the total cost, where the aging of battery is taking into account in the proposed approach. Furthermore, the isolated mode constraints are considered in the formulation of approach to ensure seamless transition when the connection with utility grid is lost.

In comparing with the previous papers in the literature, this paper develops an approach to manage both generation and load sides with taken into account the active and reactive loads, whereas majority of papers investigate the management of the generation side as given by Al-saadi and Luk [17]. This impacts on the results and the fidelity of the model. Besides, this paper considers the UC technique for both active and reactive power, while other papers consider only active power. Considering both generation and load side management with taken into account different constraints to reduce operating and emission cost makes the proposed model closed to real scenario.

## 2. MATHMATICAL MODELS

To model and formulate the proposed approach, the following models should be considered.

**2. 1. Distributed Generators Model** The cost of fuel of the distributed generators (DGs) at each time interval ***t*** is modelled as [18, 19]:

$$C_P^t = a + b.P_g^t + c.{P^2}_g^t \tag{1}$$

where $a$ (\$/h), $b$ (\$/kWh), and $c$ (\$/kW$^2$h) are the parameters of the cost function, and $P_g^t$ is the real power of the generators.

**2. 2. Cost Function of inactive Power** This cost is determined using the following equation [17]:

$$C_Q^t = aq + bq.Q_g^t + cq.{Q^2}_G^t \tag{2}$$

where $aq$ (\$/h), $bq$ (\$/kVArh), and $cq$ (\$/kVAr$^2$h) are the parameters of the expense of inactive power, and $Q_g^t$ is the output inactive power of the generators.

**2. 3. Maintenance Cost of the Generators** This cost is formulated as follows:

$$K_g^t = K_g.P_g^t \tag{3}$$

where $K_g$ (\$/kWh) is the parameter of the maintenance expense of the generators.

**2. 4. Storage Device Model** The following equation is employed to represent the operation of storage battery in the proposed optimization approach:

$$E^t_b = E^{t-1}_b + \Delta t.\ P^t_{bch}.\eta_{ch} - \Delta t.\left(\frac{P^t_{bdis}}{\eta_{dis}}\right) \tag{4}$$

where $E^t_b$ , $E^{t-1}_b$ are the capacity of the storage device at $t$and $t-1$ period. $P^t_{bch}$ and $P^t_{bdis}$are the absorbing and delivering power of the battery, while $\eta_{ch}$ and $\eta_{dis}$ are the efficiencies.

The battery aging cost is converted to the monetary concept by employing the following equations:

$$C^t_b = C_d\ .P^t_b.\Delta t \tag{5}$$

where $C_d$ is the aging expense of battery ($/kWh), $P^t_b$is absorbing or delivering power. The $C_d$ is determined as follows [20, 21].

$$C_d = \frac{c_b}{L_b} \tag{6}$$

where $c_b$ is the purchasing cost ($) of the battery, $L_b$ is the actual life (kWh), which is determined using the following equation:

$$L_b = DoD.E_b.L_c \tag{7}$$

where $DoD$ is the depth of discharge, $L_c$ is the battery cycle life.

### 2. 5. Trading Energy with the Upstream Grid

MG can exchange power with the upstream grid in case of connected mode. The expense of trading power with the upstream system is determined as follows:

$$C^t_{UP} = c^t_{UP}P^t_U \tag{8}$$

$$C^t_{UQ} = c^t_{UQ}Q^t_U \tag{9}$$

where $c^t_{UP}$ in ($/kW) and $c^t_{UP}$ in ($/kVAr) are the active and inactive price of exchanging energy with the upstream grid (OMPs). $P^t_U$ is the real trading power and $Q^t_U$ is the reactive trading power.

### 2. 6. Environmental Cost

The emission of $CO_2$, $SO_2$, $NO_x$, and PM are considered as greenhouse gases. The emission of $\boldsymbol{j^{th}}$ greenhouse gas from $\boldsymbol{i^{th}}$ DG is determined as follows:

$$C^t_e = \sum_{j=1}^{M}\sum_{i=1}^{N} E_{j,i}\ .C_j.P^t_g \tag{10}$$

where $C_j$ ($/kg) is the expense of emission of $j^{th}$ pollutant gases, and $E_{j,i}$ (kg/kWh) is the emitted amount of the harm gases from the generators. $M$ is the number of gases and N is the number of generators.

## 3. PROPOSED MODELS of the DIRECT LOAD CONTROL

The different types of loads are taken into account in this paper, residential (R), commercial (C) and industrial (I) consumers. All these kinds of loads are taken into consideration in the proposed optimization framework. The direct load control program is applied individually on different load sectors: residential, industrial and commercial. The load control strategy is also applied simultaneously on three types of loads. peak clipping and load shifting are considered as demand control program in this paper.

### 3. 1. Proposed Mathematical Model of the Peak Clipping and Load Shifting

The moving of the load changes the pattern of the original load profile according to the load management program. This technique aims to limit the maximum demand to a specified value, where the load is moved from high to low hours load demand. The following mathematical equation are employed to simulate the peak clipping and load shifting for active and reactive loads.

For active load

$$L^{-t}_{\ p} = \{L^t_p - (L^t_p - P^t_p).\delta^t_c\} + A^t_p \tag{11}$$

$$A^t_p = a_p.\left\{\frac{\sum_{t\in\Omega}(L^t_p - P^t_p).\delta^t_c}{h_p}\right\}.\delta^t_f \tag{12}$$

For reactive load

$$L^{-t}_{\ q} = \{L^t_q - (L^t_q - P^t_q).\delta^t_c\} + A^t_q \tag{13}$$

$$A^t_q = a_p.\left\{\frac{\sum_{t\in\Omega}(L^t_q - P^t_q).\delta^t_c}{h_p}\right\}.\delta^t_f \tag{14}$$

where $A^t_p$ and $A^t_q$ are active and reactive loads moved to low-peak hours, $a_p$ and $a_q$ are the percentage of the reduced active and reactive power during the on-peak hour and recovered during off-peak hours, $h_p$ and $h_q$ are the number of off-peak hours (h), $L^t_p$ and $L^t_q$are active and reactive base loads (kW) and (kVAr), $L^{-t}_{\ p}$ and $L^{-t}_{\ q}$ are modified active and reactive loads, $P^t_p$, $P^t_q$ are peak active and reactive loads, Ω is the set of on-peak hours during which the energy is reduced.

$$\delta^t_c = 1 \text{ for } L^t_p > P^t_p \ and\ L^t_q > P^t_q \tag{15}$$

$$\delta^t_c = 0 \text{ for } L^t_p \le P^t_p \ and\ L^t_q \le P^t_q \tag{16}$$

$$\delta^t_f = 1 \text{ for } t_1 \le t \le t_2 \tag{17}$$

$$\delta^t_f = 1 \text{ for other value of t} \tag{18}$$

$$0 \le a_p \le 1 \tag{19}$$

$$0 \le a_q \le 1 \tag{20}$$

### 3. 2. Load Management for Multi-load

The shaping of the load curve that is obtained from the load management programs can be achieved at the same time

in many sectors or areas of the distribution grid. It assumes that there are N sectors or areas in the system. The aggregated effects of load management are formulated as follows:
For active load

$$L^{-k}_{T-P} = L^{-k}_{1-P} + L^{-k}_{2-P} + \cdots L^{-k}_{NL-P} \quad (21)$$

For reactive load

$$L^{-k}_{T-Q} = L^{-k}_{1-Q} + L^{-k}_{2-Q} + \cdots L^{-k}_{NL-Q} \quad (22)$$

where $L^{-k}_{T-P}$ and $L^{-k}_{Tq}$ are the total modified active and reactive loads model, $L^{-k}_{NL-P}$ and $L^{-k}_{NL-Q}$ are the modified active and reactive loads model of NL load sectors.

**3. 3. Load Factor** The load factor (LD) is determined as follows:

$$LD = \frac{average\ load}{peak\ load} \quad (23)$$

## 4. FORMULATION OF OBJECTIVE FUNCTION

The proposed approach aims to reduce the peak load and minimize the total cost of the MG. The proposed approach involves the aforementioned costs. Besides, the objective function involves the expense of loads cutting. Based on the aforementioned mode of costs, the cost function is formulated as follows:

$$F = Min \sum_{t=1}^{T}\{\sum_{i=1}^{N}[[C_{Pi}^{t} + C_{Qi}^{t} + C_{gi}^{t}]\delta_{gi}^{t} + ST_{gi}^{t} + SD_{gi}^{t}] + C_{e}^{t} + C_{b}^{t} + C_{UP}^{t} + C_{UQ}^{t} + (1 - a_p).\rho_p.\sum_{h=1}^{NL} X_{h-p}^{t} + (1 - a_q).\rho_q.\sum_{h=1}^{NL} X_{h-q}^{t}\} \quad (24)$$

where $X_{h-p}^{t}$ and $X_{h-q}^{t}$ are the active and reactive power reduced during the on-peak hour and not recovered, $NL$ is the number of load sectors, $\rho_p$ and $\rho_q$ are the penalty of active and reactive uncovered loads ($), $i$ is $i^{th}$ DG, $\delta_{gi}^{t}$ is the state of the $i^{th}$ DG.

## 5. FORMULATION OF CONSTRAINTS

The proposed cost function undergoes to the following constraints.

**5. 1. Power Balance Constraints** The following constraints are expressed as follows for the active and reactive power.

$$\sum_{t=1}^{T}\{\sum_{i=1}^{N} \delta_{gi}^{t}.P_{g}^{t} + \sum_{i1=1}^{N1} P_{Wi1}^{t} + \sum_{i2=1}^{N2} P_{PVi2}^{t} + P_{b}^{t} + P_{U}^{t} = (L_{p}^{t} - (L_{p}^{t} - P_{p}^{t}).\delta_{c}^{t} + A_{p}^{t})\} \quad (25)$$

$$\sum_{t=1}^{T}\{\sum_{i=1}^{N} \delta_{gi}^{t}.Q_{g}^{t} + Q_{U}^{t} = (L_{q}^{t} - (L_{q}^{t} - P_{q}^{t}).\delta_{c}^{t} + A_{q}^{t})\} \quad (26)$$

**5. 2. Generating Limits** These constraints are formulated as follows:

$$\delta_{gi}^{t}.P_{gmin}^{t} \le P_{g}^{t} \le \delta_{gi}^{t}.P_{gmax}^{t} \quad (27)$$

$$\delta_{gi}^{t}.Q_{gmin}^{t} \le Q_{g}^{t} \le \delta_{gi}^{t}.Q_{gmax}^{t} \quad (28)$$

where $P_{gmin}^{t}$ and $P_{gmax}^{t}$ are the low and high possible output power of the genertors. $Q_{gmin}^{t}$ and $Q_{gmax}^{t}$ are the low and high possible reactive power of generators.

**5. 3. Trading Power with the upstream Grid Constraints** Trading energy with the upstream grid at period normally either delivering or taking power. There are also possibilities that no exchanging power occurs between the MG and the upstream grid at a certain period. Therefore, two binary variables $\boldsymbol{\delta_{Up}^{t}} \in [\mathbf{0}, \mathbf{1}]$ and $\boldsymbol{\delta_{Us}^{t}} \in [\mathbf{0}, \mathbf{1}]$, are assigned to represent this operation and the following equation $\boldsymbol{\delta_{Up}^{t} + \delta_{Us}^{t} \le 1}$ is defined to prevent purchasing or selling power at the same time. The exchanging power constraints are formulated as follows:

$$\delta_{Up}^{t}.P_{Upmin}^{t} \le P_{Up}^{t} \le \delta_{Up}^{t}.P_{Upmax}^{t} \quad (29)$$

$$\delta_{Up}^{t}.Q_{Upmin}^{t} \le Q_{Up}^{t} \le \delta_{Up}^{t}.Q_{Upmax}^{t} \quad (30)$$

$$\delta_{Us}^{t}.P_{Usmin}^{t} \le P_{Us}^{t} \le \delta_{Us}^{t}.P_{Usmax}^{t} \quad (31)$$

$$\delta_{Us}^{t}.Q_{Usmin}^{t} \le Q_{Us}^{t} \le \delta_{Us}^{t}.Q_{Usmax}^{t} \quad (32)$$

where $P_{Usmax}^{t}$, $Q_{Usmin}^{t}$, $Q_{Usmax}^{t}$, and power from are sold power from the upstream grid, $P_{Upmin}^{t}$, $P_{Upmax}^{t}$, $Q_{Upmin}^{t}$, $Q_{Upmax}^{t}$ are purchasing power from the upstream grid.

**5. 4. Constraints of the Battery** The operating constraints of the batteries are formulated as follows [22].

**5. 4. 1. Battery State of Charge Constraint**

$$E_{bmin}^{t} \le E_{b}^{t} \le E_{bmax}^{t} \quad (33)$$

where $E_{bmin}^{t}$ is the minimum state of charge and $E_{bmax}^{t}$ is the maximum state of charge at time t.

**5. 4. 2. Constraints of Battery Operation** The status of the battery at each time interval is explained with three possible states: absorbing, delivering and idle. Therefore, two binary variables, $\boldsymbol{\delta_{bch}^{t}} \in [\mathbf{0}, \mathbf{1}]$ and $\boldsymbol{\delta_{bdis}^{t}} \in [\mathbf{0}, \mathbf{1}]$, which are assigned and formulated the status of the battery operation. $\boldsymbol{\delta_{bch}^{t} + \delta_{bdis}^{t} \le 1}$ is considered to avoid absorbing or delivering power simultaneously. The operation constraints of the battery are formulated as follows:

$$\delta_{bch}^{t}.P_{bchmin}^{t} \le P_{bch}^{t} \le \delta_{bch}^{t}.P_{bchmax}^{t} \quad (34)$$

$$\delta_{bdis}^{t}.P_{bdismin}^{t} \le P_{bdis}^{t} \le \delta_{bdis}^{t}.P_{bdismax}^{t} \quad (35)$$

where $P_{bchmin}^{t}$ and $P_{bchmax}^{t}$ are the minimum and maximum possible absorbing, while $P_{bdismin}^{t}$ and $P_{bdismax}^{t}$ are the low and high delivering power of the storage device.

### 5. 5. Emission Limitation Constraints

The constraints that limit the emission of pollutant gases in the area of the MG is formulated as follows:

$$\sum_{i=1}^{N} E_{j\,i} \,.\, P_{g}^{t} \leq L_{j} \tag{36}$$

where $L_j$ (kg/h) is the acceptable level of emission of the pollutant $j$ in the MG, where $(j = 1, 2, 3 \ldots \ldots . M)$

### 5. 6. Isolated Mode Constraints

The following constraints are determined using the following equations:

$$\sum_{i=1}^{T}\{\sum_{i=1}^{N} \delta_{gi}^{t} . P_{gmax}^{t} \geq \left(L_{p}^{t} - \left(L_{p}^{t} - P_{p}^{t}\right) . \delta_{c}^{t} + A_{p}^{t}\right)\} \tag{37}$$

$$\sum_{i=1}^{T}\{\sum_{i=1}^{N} \delta_{gi}^{t} . Q_{gmax}^{t} \geq (L_{q}^{t} - \left(L_{q}^{t} - P_{q}^{t}\right) . \delta_{c}^{t} + A_{q}^{t})\} \tag{38}$$

## 6. PROPOSED MG FOR CASE STUDY

The proposed approach is applied to the standard multi-feeder low voltage distribution grid with voltage 0.4 kV as depicted in Figure 1. This grid is a standard multi-feeder LV microgrid which is taken from literature [17, 23, 24], where all the parameters are on the standard LV feeder. In this study, the microgrid impact is considered in all scenarios. The proposed MG encompasses of three feeders and seventeen bus bars. The power factor is presumed to be 0.9. Besides, the MG encompasses mixed of distributed generators technologies including three diesel engines (DE), two Micro turbines (MTs), one fuel cell (FC), one wind turbine, and PV panels. The cost functions parameters and the emission levels of the DGs are taken from the following sources [25-29]. Moreover, the grid involves a battery. The capacity of the battery is 50 kWh and the maximum charging and discharging power is 25 kWh. The operating efficiency is presumed to be 0.9. The hourly spectrums for a wind and PV output, OMPs and loads are summarized in Table 1.

## 7. RESULTS AND DISCUSSION

The optimization problem is solved by employing of IMB ILOG CPLEX version 12.6, where Microsoft Excel is interfaced with CPLEX to show the results [30]. Firstly, the direct load control program is applied to the residential, industrial, and commercial sectors separately. Secondly, the load control program is conducted on the all loads simultaneously. The LF without load control is 0.68.

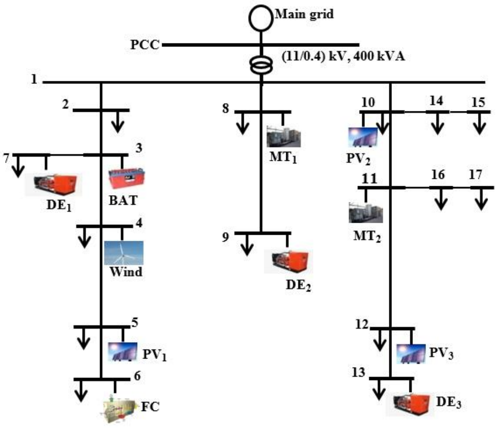

**Figure 1.** The MG under study

**TABLE 1.** Spectrum of wind turbine and solar panels, OMPs and total loads

| Time (h) | WT power (m/s) | PV power (kW) | Active power price ($/kW) | Inactive power price ($/kVAr) | Total load (kW) |
|---|---|---|---|---|---|
| 1 | 12 | 0 | 0.065 | 0.013 | 76.45 |
| 2 | 8 | 0 | 0.058 | 0.0116 | 70.01 |
| 3 | 8 | 0 | 0.048 | 0.0096 | 67.68 |
| 4 | 6.5 | 0 | 0.05 | 0.01 | 63.44 |
| 5 | 10 | 0 | 0.052 | 0.0104 | 69.64 |
| 6 | 12 | 0 | 0.07 | 0.014 | 80.08 |
| 7 | 14.25 | 0 | 0.087 | 0.0174 | 109.21 |
| 8 | 13.5 | 0.5 | 0.09 | 0.018 | 149.78 |
| 9 | 16 | 1.4 | 0.14 | 0.028 | 178.23 |
| 10 | 17 | 2 | 0.195 | 0.039 | 201.32 |
| 11 | 16 | 2.2 | 0.15 | 0.03 | 211.05 |
| 12 | 13.25 | 2.25 | 0.14 | 0.028 | 205.54 |
| 13 | 12.6 | 2.4 | 0.126 | 0.0252 | 223.24 |
| 14 | 13 | 2.5 | 0.0105 | 0.021 | 229.26 |
| 15 | 10.3 | 2.25 | 0.1 | 0.02 | 218.54 |
| 16 | 8.25 | 2 | 0.09 | 0.018 | 208.16 |
| 17 | 10.5 | 1.5 | 0.098 | 0.0196 | 193.91 |
| 18 | 16.2 | 0.6 | 0.098 | 0.0196 | 208.77 |
| 19 | 18 | 0.5 | 0.11 | 0.022 | 207.96 |
| 20 | 14 | 0 | 0.109 | 0.0218 | 212.31 |
| 21 | 11.6 | 0 | 0.098 | 0.0196 | 188.61 |
| 22 | 14 | 0 | 0.088 | 0.0176 | 159.30 |
| 23 | 13 | 0 | 0.064 | 0.013 | 129.07 |
| 24 | 15 | 0 | 0.045 | 0.009 | 79.87 |

**7. 1. Case 1: Applying Load Control on the Residential Sector** Figures 2 and 3 show the effect of the load shifting on the R load and the accumulated load. The demand is shifted from peak load to off-peak hours. These figure show that the peak of the total load is unaffected by demand side management (DSM) on residential load because the residential peak load occurs at a different time from peak load of total grid load. In this case, the load factor does not affect. Figures 4 and 5 depict the planning of the generators and power of the storage device and the trading power with the upstream system. These figure show that the highest generation from DGs occurs at 10 pm. This is because of the OMPs reach the highest values at this hour. Therefore, the MG delivers power to the main grid to reduce its cost. Besides, the MG purchases the possible highest power from the upstream grid during hours 14 to 18 because the load has the highest value and the OMPs arrive to low values and lower than the cost of power generation of the DGs. However, the DEs provide the lowest output power to fulfill the isolated mode constraints. In addition, the DEs uncommitted from hour 1 to 6 because they have the highest generation cost, where other generators can satisfy the isolated mode constraints and meet the demand with buying power from the upstream system. Moreover, at hour 24 solely the DE3 and MT2 supply their minimum output generation to fulfill the isolated mode constraints, where the load is met from purchasing power from the main grid and storage battery. This is because the OMPs reach the lowest value. The MG spends 425.445 $ per day with load management while it spends 428.872 $ per day without load management. This leads to cost reduction by 0.8% per day.

**7. 2. Case 2: Applying Load Control on the Industrial Sector** Figures 6 and 7 show the impact of load shifting on the industrial loads and the total loads, where the demand is shifted from peak load to off-peak hours. It can be noticed that the applied the DSM program on industrial load make significant reduction in the peak of the total load because the industrial peak load coincides with the peak of the total load. The new peak of load moved to hour 20. The decreasing of the peak of total load increases the load factor to 0.734 Figures 8 and 9 displays the optimal planning of the generators, battery

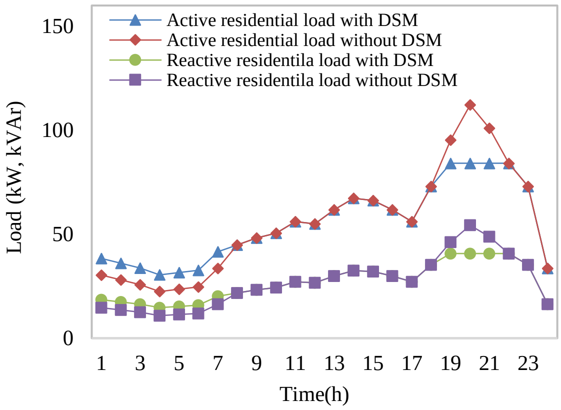

**Figure 2.** The profile of the residential load with and without load control

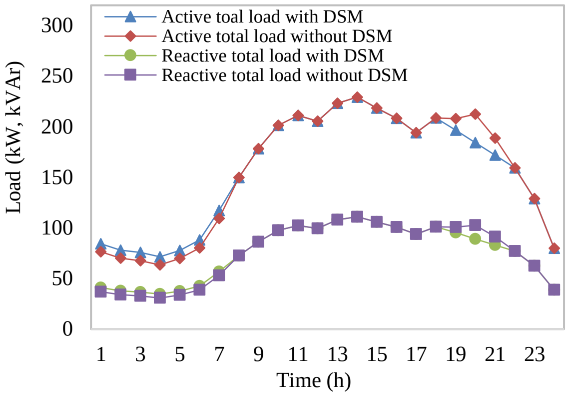

**Figure 3.** The profile of the total load with and without load control

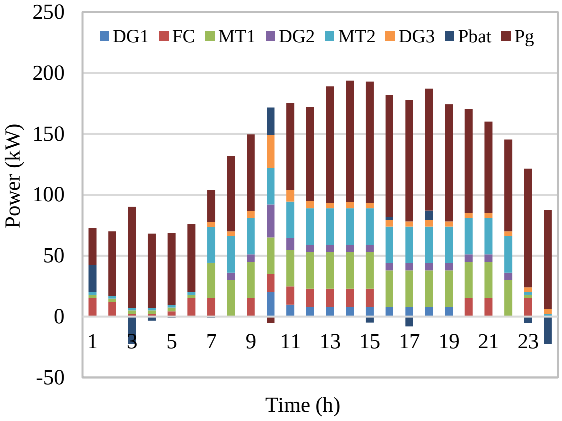

**Figure 4.** Optimal active power scheduling

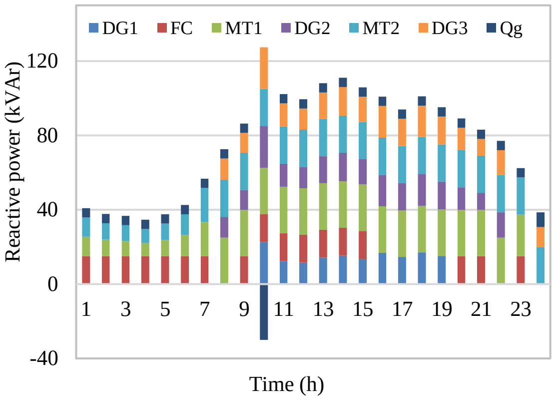

**Figure 5.** Optimal reactive power scheduling

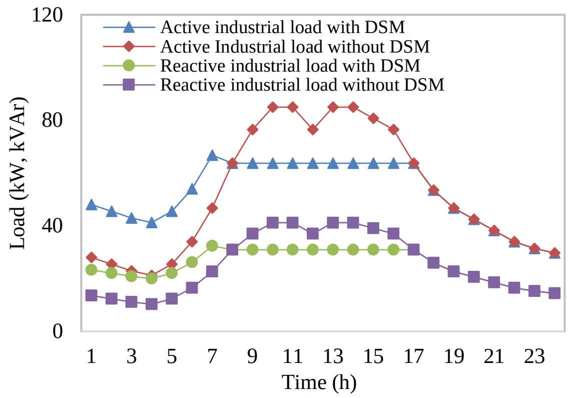

**Figure 6.** The profile of the industrial load with and without load control

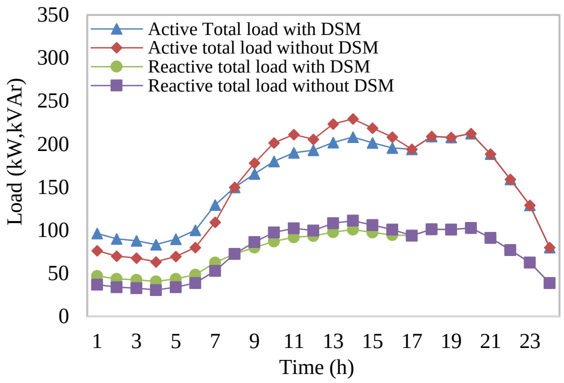

**Figure 7.** The profile of the total load with and without load control

and trading power with the upstream system. These figures show that at hour 10 the DGs generate the highest power and the battery discharges the highest discharging power to sell power to the upstream system because at this hour the price of selling power to utility grid has the highest value and the load at these hours is reduced as shown in Figures 8 and 9. The MG delivers power to the upstream grid at hour 10 because the power generation obtained from the DGs is less than the trading power with the main grid. The MG, in this case, sells higher power than in the previous case because the total load is reduced at this hour. Furthermore, at hour 24 only the DE3 and MT2 provide their minimum output power to satisfy the Isolated mode constraints, where the load is met from purchasing power from the main grid, storage battery, and renewable energy resources for exactly the same reason of the previous case. The total cost of load management is $418.726 per day. Therefore, the cost reduction, in this case, is 2.4% per the scheduling day.

### 7. 3. Case 3: Applying Load Control on the Commercial Sector

Figures 10 and 11 show the impact of load management on the commercial loads and the total grid loads. It can be seen that the applying of load management on the commercial load leads to a decrease in the peak of total MG load because the peak loads on the commercial sector coincides with the peak of the total load. This leads to increase the load factor to 0.728. However, the new peak load of the total load is still at hour 14. Figures 12 and Figure 13 depict the optimal scheduling of the generators, battery and trading power with the upstream system. It is observed that the

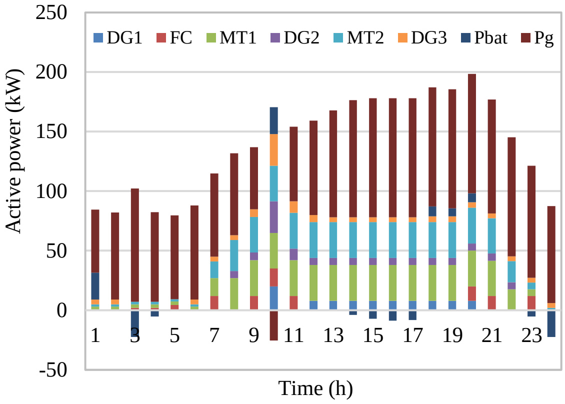

**Figure 8.** Optimal active power scheduling

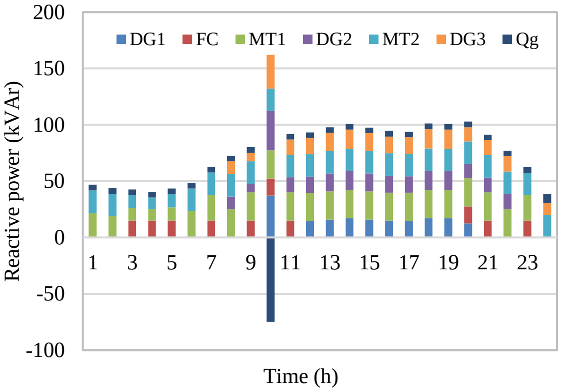

**Figure 9.** Optimal reactive power scheduling

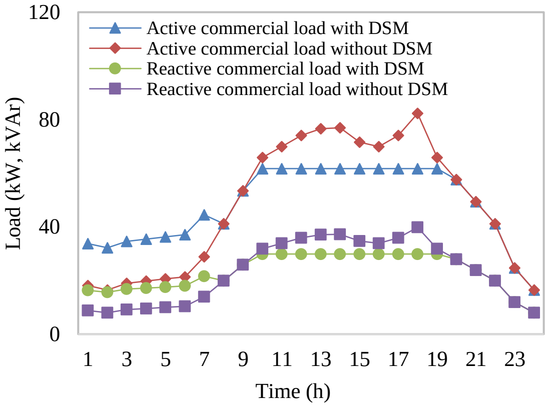

**Figure 10.** The profile of the commercial load with and without load control

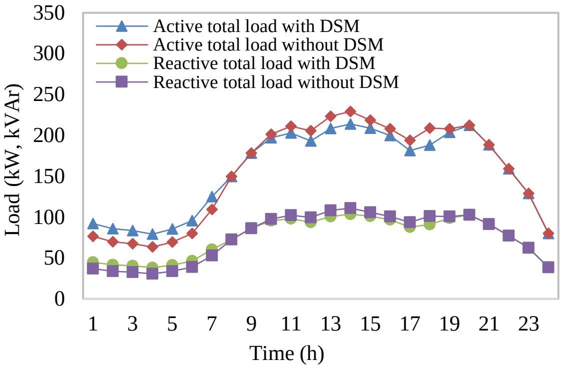

**Figure 11.** The profile of the total load with and without load control

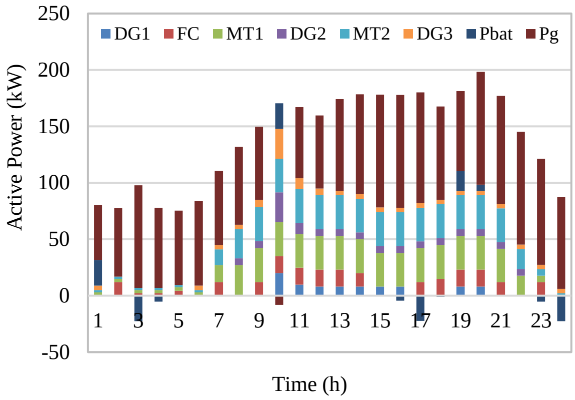

**Figure 12.** Optimal active power scheduling

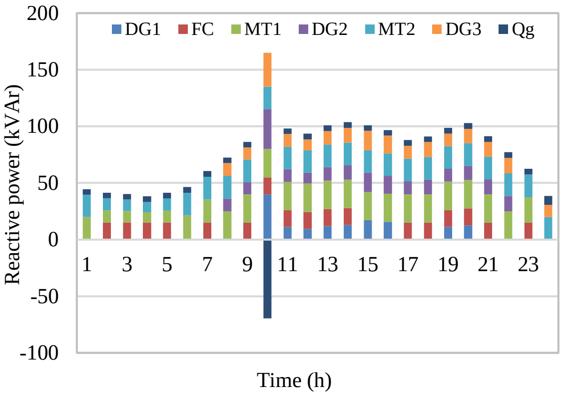

**Figure 13.** Optimal reactive power scheduling

MG delivers power to the upstream grid at hour 10 for the same reason as the previous cases. Besides, at hours 17 and 18 the MG sells less power from the upstream grid comparing with the previous two cases because in this case the load is reduced at this hour, while the total loads are not reduced. The MG spends $422.963 per day. Therefore, the cost reduction, in this case, is 1.4% per scheduling day.

### 7. 4. Case 4: Applying Load Control on the Residential, Industrial, and Commercial Sectors Simultaneously

Figure 14 shows the impact of the load management program on the accumulated loads of the grid. It is observed that the new peak of total loads is reduced by amount higher than the three previous cases because the reduction results from both the industrial and commercial sectors. This leads to reduce the load factor, where the increasing of load factor improves secure operation of the system. Figures 15 and 16 show the active and reactive optimal scheduling of the DGs and trading power with the upstream grid and the battery. It can be observed that the MG sells power to the main grid at hour10 to minimizes the cost because the OMPs reach the highest price at this hour. Therefore, the battery discharges its maximum power at this hour to sell more power to the main grid because the selling power at this hour is higher than the generation cost and charging cost. Furthermore, the MG purchases the possible highest power from the main grid at hours 13 and 14 and the committed DGs supply minimum output power. This is because the OMPs have quite low values at these hours. The total cost is 410.932 $ and the cost reduction is 4.18% per scheduling day. The LF increases to 0.808.

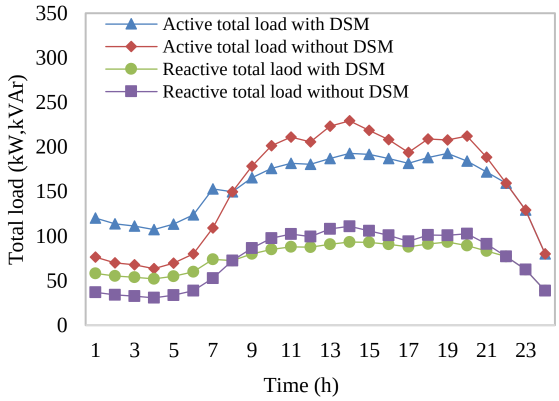

**Figure 14.** The profile of the total load with and without load control

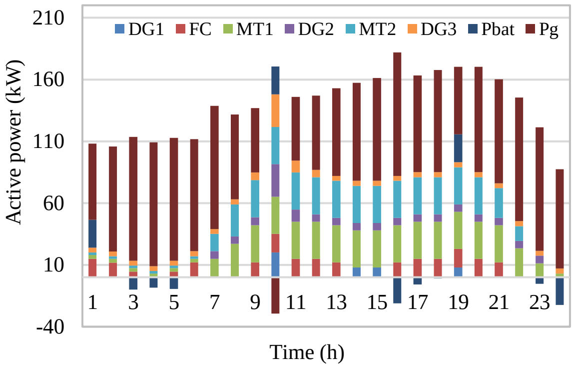

**Figure 15.** Optimal active power scheduling

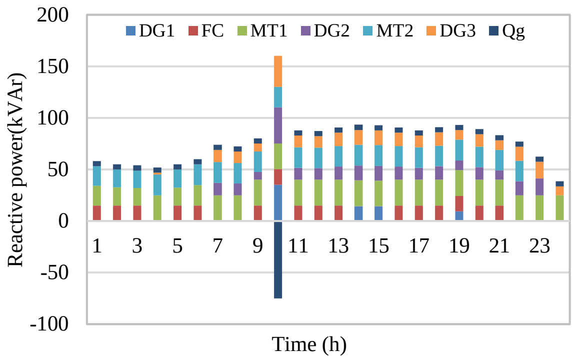

**Figure 16.** Optimal reactive power scheduling

It can be summarized that the highest cost reduction occurs at applying the load control on the residential, industrial and commercial loads simultaneously because in this case the highest load factor and peak loads reduction have the highest values, where the increase of the load factor leads to decrease the peak load and improving the security of supply. Besides, the high load factor postpones the investment of distribution grids. The highest peak loads reduction leads to improve the secure operation of MG. The lowest cost reduction in case of applying load control program on residential load because of the reduction of peak loads equal to zero.

## 8. CONCLUSIONS

An optimal management approach with integrating of load control program is proposed, where the load shifting program is conducted to the all types of loads. The load management is considered as decision variable in the proposed approach. The impacts of the load control on the economic planning of the generators, system peak load and load factor are analyzed and the system is validated through systematic testing in the low voltage distribution grid. The model considers solely the quadratic cost function. The results show that the proposed load management technique decreases not only the total cost but also decreases the peak of the total loads. This peak reduction of the total loads results in increasing the load factor. This leads to avoid of investment in terms of generation capacity. Furthermore, the security of supply and the spinning reserve are also improved.

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## Persian Abstract

**چکیده**

ین مقاله رویکردی را برای بهبود آربیتراژ سیستم و کاهش بار پیک با مدیریت هر دو طرف تولید و بار به طور همزمان پیشنهاد می‌کند. کاهش اوج بار با استفاده از یک برنامه کنترل بار حاصل می شود، در حالی که آربیتراژ با به حداقل رساندن هزینه عملیاتی و انتشار بهبود می یابد. مدیریت بار و به حداقل رساندن هزینه عملیاتی در یک رویکرد بهینه سازی در یک چارچوب چند هدفه ترکیب شده است. باتری ذخیره سازی برای کمک به پیک سایی بار اوج و کاهش هزینه عملیات و انتشار استفاده می شود، جایی که طول عمر باتری در مدل پیشنهادی در نظر گرفته شده است. مدیریت سمت های بار به عنوان متغیرهای تصمیم گیری در رویکرد در نظر گرفته می شود. یک برنامه درجه دوم عدد صحیح مختلط برای فرمول‌بندی رویکرد بهینه‌سازی استفاده می‌شود. رویکرد پیشنهادی بر روی یک شبکه توزیع ولتاژ پایین هوشمند اعمال می‌شود. نتایج نشان می دهد که مدیریت هر دو طرف تقاضا و تولید باعث کاهش هزینه های عملیاتی و انتشار و بهبود ضریب بار سیستم می شود.