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Energy Management in Microgrids Containing Electric Vehicles and Renewable Energy Sources Considering Demand Response

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Abstract- *Microgrid and smart electrical grids are among the new concepts in power systems that support new technologies within themselves. Electric cars are some advanced technologies that their optimized use can increase grid efficiency. The modern electric cars sometimes, through the necessary infrastructure and proper management, can serve as an energy source to supply grid loads. This study was conducted to investigate the energy management for production and storage resources. For this purpose, we considered the market price of energy, the prices quoted by distributed generation sources, and electric vehicles in the grid and responsive loads. The load response programs used include the time of use and direct load control. The problem has a linear mixed-integer planning structure that was simulated using the GAMS software. The results show that with this planning, the proposed load response programs have a positive impact on cost reduction.*

Keyword: Microgrid, energy management, electric vehicles, renewable resources, demand response program.

NOMENCLATURE

Indices

t	Time index
j	Local generation resources index
i	Electric vehicles index
k	Wind turbine index
p	Photovoltaic system index
f	Auxiliary index for linear modeling of constraints for the minimum up/down time of local generation resources from 1 to maximum level (MUT_j, MDT_j)

Parameters

P_R^k	Nominal power of the k-th wind turbine
$P_W^{k,t}$	Output power of the k-th wind turbine at time interval t
V_C^k	Minimum velocity of the k-th wind turbine (minimum required velocity for power generation by wind turbine)
V_R^k	Nominal velocity of the k-th wind turbine
V_F^k	Maximum velocity of the k-th wind turbine (maximum required velocity for power generation by wind turbine)
V^t	Predicted wind velocity
$P_{PV}^{p,t}$	Output power of the p-th photovoltaic panel in time interval t
η^p	Conversion array efficiency interval of the p-th photovoltaic system
S^p	Area of the p-th photovoltaic system
T_a	Ambient temperature of the p-th photovoltaic system
G^t	Solar radiation on the p-th photovoltaic system
b^j, a^j	Coefficients of generation power cost function of j-th local generation resource
$P_{LDG,\max}^j$	Maximum power generation by j-th local generation resource
$P_{LDG,\min}^j$	Minimum power generation by j-th local generation resource
MUT_j	Minimum up time of the j-th local generation resource
MDT_j	Minimum down time of the j-th local generation resource
UDC^j	operation cost of the j-th local generation resource
RU^j, RD^j	Increasing/decreasing rate of the j-th local generation resource
$\psi_{LDG}^{j,t}$	Spinning reserve cost of the j-th local generation resource at time interval t
$\psi_{EV}^{i,t}$	Reserve cost of i-th electric vehicle at time interval t
π_{UG}^t	Power price in the free market at time interval t

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N_{Ev}^{t}	Number of electric vehicles in the intelligent parking lot at time interval t
$P_{UG}^{\max}$	Maximum permissible power exchange between microgrid and upstream grid
Δt	Sampling time to count the number of electric vehicles in the intelligent parking lot
$P_{Ch,\max}^{i}$	Maximum charging power of the i-th charger
$P_{Dch,\max}^{i}$	Maximum discharging power of the i-th charger
$SOC_{\max}^{i}$	Maximum state of charge of the i-th electric vehicle
$SOC_{\min}^{i}$	Minimum state of charge of the i-th electric vehicle
$\Delta SOC_{\max}^{i}$	Maximum permissible charging / discharging rate of the i-th electric vehicle
ΔSOC_{F}^{i}	Minimum additional charging requested by the owner of the i-th electric vehicle at the time of departure from the intelligent parking lot
T_{P}^{i}	Approximate time for the presence of the i-th electric vehicle in the intelligent parking lot
$\pi_{Ch,Ev}^{i}$	Desirable charging price of the i-th electric vehicle in the intelligent parking lot
$\pi_{Dch,Ev}^{i}$	Desirable discharging price of the i-th electric vehicle in the intelligent parking lot
η_{V2G}	Discharging battery efficiency of the i-th electric vehicle
η_{G2V}	Charging battery efficiency of the i-th electric vehicle
$SOC_{Arrival}^{i,t}$	Initial state of charge of the i-th electric vehicle at the time of arrival to the intelligent parking lot at the time interval t
$N_{\max}$	Maximum number of permissible switching between charging/discharging state
ω_{W}	Predicted error of wind velocity
ω_{Pv}	Predicted error of solar radiation
$load_{0}^{t}$	Base load at time interval t
$Tdrload_{0}^{t}$	Percentage of the base load participating in TOU demand response program in time interval t
$Ddrload_{0}^{t}$	Percentage of base load controllable by DLC demand response program in time interval t
$load_{0}^{\max}$	Maximum predicted base load per day
$DR\max$	Maximum load size participated in TOU-based demand response program
$inc\max$	Maximum load size increase in TOU-based demand response program at time interval t
$DLC\max$	Maximum load size participating in DLC demand response program
$M^{i,t}$	If the i-th electric vehicle at the time interval t is in the intelligent parking lot, it is equal to 1; otherwise 0.
α	Percentage of discharging power of electric vehicles to participate in the spinning reserve market
t_{a}^{i}	Approximate time of arrival of the i-th electric vehicle to the intelligent parking lot
t_{d}^{i}	Approximate time of departure from the i-th electric vehicle to the intelligent parking lot
$Pt_{shed,s}$	Start time of some equipment disconnection or decreased load percent of subscribers in DLC demand response program
$Pt_{shed,e}$	End time of some equipment disconnection or decreased load percent of subscribers in DLC demand response program
$Pt_{add,s}$	Start time of some equipment connection or increased load percent of subscribers in DLC demand response program
$Pt_{add,e}$	End time of some equipment connection or increased load percent of subscribers in DLC demand response program

Variables

OBJ	The objective function
P_{UG}^{t}	Power exchange between microgrid and upstream grid at the time interval t
$Change^{t}$	Controlled load (decreased/increased) by DLC demand response program in time interval t
$C_{LDG}^{j,t}$	Scheduled power cost of the j-th local generation resource at time interval t
$SC_{LDG}^{j,t}$	operation cost of the j-th local generation resource at time interval t
$SR_{LDG}^{j,t}$	Spinning reserve program of the j-th local generation resource at time interval t
$W_{Dch}^{i,t}$	Binary variable: If the i-th electric vehicle in the intelligent parking lot at time interval t is in the state of discharge, it is equal to 1; otherwise 0.
$P_{Ch,Ev}^{i,t}$	Charging power of the i-th electric vehicle at time interval t
$P_{Dch,Ev}^{i,t}$	Discharging power of the i-th electric vehicle at time interval t
$SR_{Ev}^{i,t}$	Spinning reserve programing of the i-th electric vehicle at time interval t
$P_{LDG}^{j,t}$	Scheduled power of the j-th local generation resource at time interval t
$SOC^{i,t}$	State of charge of the i-th electric vehicle at time interval t
$\Delta SOC^{i,t}$	Changes in state of charge of the i-th electric vehicle in two successive hours at time interval t
$SOC_{Departure}^{i,t}$	Final state of charge of the i-th electric vehicle at the time of departure from parking lot
$SOC_{Average}^{t}$	Average state of charge of the electric vehicles in the intelligent parking lot at time interval t
$Up_{j,f}$	Auxiliary variable for linear modeling of the constraint for the minimum up time of the local generation resources
$Dn_{j,f}$	Auxiliary variable for linear modeling of the constraint for the minimum down time of the

	local generation resources
$load^{t}$	A new load after the effect of TOU-based demand response program at time interval t
DR^{t}	The implementing potential (participation rate) of the TOU-based demand response program at time interval t
idr^{t}	Load shifted from one interval to another by TOU-based demand response program at time interval t
$Up_{j,f}$	Auxiliary variable for linear modeling of the constraint for the minimum up time of the local generation resources
$Dn_{j,f}$	Auxiliary variable for linear modeling of the constraint for the minimum down time of the local generation resources
$load^{t}$	A new load after the effect of TOU-based demand response program at time interval t
DR^{t}	The implementing potential (participation rate) of the TOU-based demand response program at time interval t
idr^{t}	Load shifted from one interval to another by TOU-based demand response program at time interval t
$load_{inc}^{t}$	Load increase rate in the TOU-based demand response program at time interval t
inc^{t}	Increased load size in the TOU-based demand response program at time interval t
$drload^{t}$	Percentage of the new load after applying DLC demand response program in time interval t
$Change_{Pos}^{t}$	Load size increased by DLC demand response program in time interval t
$Change_{Neg}^{t}$	Load size decreased by DLC demand response program in time interval t
$SRS^{i,t}$	Binary variable: If the i-th electric vehicle in the intelligent parking lot at time interval t participates in the spinning reserve, it is equal to 1; otherwise 0.

1. INTRODUCTION

Today, with the increasing penetration of electric cars, electricity grids encounter challenges such as grid congestion and increased demand in the high-voltage system mode, which nictitates grid development and the creation of new capacity in electricity generation [1]. In this regard, the use of price monitoring by the user and consumer side management methods and changes in the pattern of use of electrical devices (e.g., transferring the device performance and electric vehicle charging process to another time) can significantly reduce the load times in parallel with grid congestion management [2]. In addition, the pattern of electric car use can have a significant impact on the performance of a micro-grid [3]. From the point of view of the electric grid, the most important part of an electric car is its storage part. A two-way converter is required to exchange power between the electric car and the grid [4]. Uncontrolled charging of electric vehicles can cause problems; however, if it is done in a planned way, it can help solve some grid problems [5]. The purpose of this paper is to investigate the effect of accidental entry and exit of electric vehicles from intelligent parking on the performance of power generation management system with the presence of responsive loads to reduce user costs. This is done randomly and based on the charging and discharging mode of the electric vehicle batteries. In this case, the car charging model is considered as a random load.

Few authorities have addressed the issue of demand response in the presence of electric vehicles, indicating the necessity of studying this issue. In Ref. [6], an optimization-based problem was proposed, in which in addition to determining the optimal size and location of intelligent parking lots for electric vehicles, the optimal scheduling for charging/discharging of the parked electric vehicles was considered. A smart grid containing power plants, DG resources, photovoltaic panels, and wind turbines as well as electric vehicles was introduced as the energy storage device [7]. In this research, the placement of intelligent parking lot and modeling of power exchange between the intelligent parking lot of electric vehicles, network, and DG resources was investigated. For this purpose, a nonlinear multi-objective problem was designed and solved to provide a practical solution for dealing with the challenges of integrating renewable energy resources and electric vehicles into the power grid. In Ref. [8], a probabilistic method based on the point estimation method was proposed to determine the appropriate location of the electric vehicle parking lot in the power distribution network. Next, it was tried to define the optimal capacity considering the uncertainty parameters of the driving patterns of electric vehicles. The optimal placement of intelligent parking lot in distribution systems aims to reduce costs, reduce losses, and increase network reliability [9]. In Ref. [10], a multi-objective approach was proposed to determine the size and optimal location of the intelligent parking lot. The lot plays the role of the energy source in the microgrid, considering the reliability of the electrical energy distribution system and the reduction of losses. In Ref. [11], a multi-objective algorithm was presented to determine the number, location, and optimal size of the intelligent parking lot in the electrical energy distribution system and to determine the amount of power generated by each electrical energy generation resources in the distribution system. Besides, several studies have been conducted regarding the optimal operation of the intelligent parking lot of electric vehicles in the field of intelligent parking energy management for charging and discharging the existing electric vehicles. In Ref. [12], a university building with a large parking lot for electric vehicles was examined. In this study, the building power consumption was adjusted through the parking energy management to charge/discharge the electric vehicles if needed and to peak shaving and fill the valley of the electrical power consumption curve. In Ref. [13], a method was proposed for developing the interaction between the intelligent parking lot of electric vehicles and the operator of the power distribution system in the energy and reserve market considering the load uncertainty and wind energy. In this method, two high- and low-level objectives were mentioned. The high-level objective was to minimize the total operating cost from the perspective of the distribution system operator and the low-level objective was energy and reserve scheduling to minimize the intelligent parking cost from the perspective of the owner of the parking lot. The authors of this research were looking for a balance between two decisions. In Ref. [14], given that the parking lots were an interface for power exchange between the network and the electric vehicle, the terms of vehicle energy to the parking lot (or vice versa) were suggested instead of concepts of vehicle energy to the network (or vice versa). Based on the statistical data and general regulations on electric vehicle charging, a random method was presented to estimate the daily effect of electric vehicles in the intelligent parking lot on the network. The problem of charging electric vehicles in the parking lot was investigated using game theory [15]. In Ref. [16], two studies were compared to determine the optimal charging strategy. One was related to the day time parking lot of electric vehicles that were next to commercial centers. The other was the night time parking of electric vehicles located next to residential centers. A discharging scheduling system was presented for the electric vehicles focused on parking lots using a parking pattern and real movement of electric vehicles with a focus on personal parking lots [17]. In Ref. [18], online smart load coordination was provided between the electric vehicles in electrical energy distribution systems based on the score allocation method through a fuzzy system. A mathematical model was proposed to estimate the power capacity discharge in an intelligent parking lot with the photovoltaic system shade that was based on the supply/load model of the electric vehicles in Ref. [19]. In Ref. [20], a management model of the microgrid energy resources was investigated considering some constraints related to the power generation resources in the microgrid and some other constraints related to the electric vehicles and their owners. A smart management and scheduling model was studied for a large number of electric vehicles in the urban intelligent parking lot by considering some constraints related to the battery of electric vehicles and the battery capacity of these vehicles [21]. In Ref. [22], a model was presented for the optimal management of intelligent parking of electric vehicles including renewable energy resources (wind turbines and photovoltaic systems) and local generation resources (microturbines). In this model, the optimal charge/discharge rate of the hydrogen storage system including the electrolysis, hydrogen storage tank, and fuel cell were also considered. The time of use-based demand response program was employed to reduce operating costs. In Ref. [23], the researchers reduced the operating costs by providing an energy management method based on demand response in a distribution network consisting of several microgrids, in which the loads were considered electrically and thermally. A scenario-based two-stage model was presented for optimal decision-making of the aggregator of electric vehicles [24] to model the uncertain nature of power pool prices and the probable behavior of the owners of these types of vehicles. In this problem, the integrator participated in future markets and power pool to purchase the energy required for vehicles and propose the charging/discharging prices to the vehicle owners. In Ref. [25], the researchers used a fuzzy logic controller to control and manage the charging process of electric vehicles to maximize the profit of upstream network and vehicle owners. In this paper, the intelligent parking lot energy management is proposed in the smart grid space in the presence of the time of use-based demand response program and direct load control to reduce operating costs. Besides, the charging/discharging rate of electric vehicles and the scheduled power of local generation units such as microturbines and fuel cells are investigated in different states to indicate the effect of time of use-based demand response program and direct load control.

Briefly, the main suggestions for this article are as follows:

- Intelligent parking lot energy scheduling using the time of use-based demand response program
- Intelligent parking lot energy scheduling using the direct load control demand response program
- Local generation units’ scheduling to reduce operating costs

- Determining the charging/discharging rate of electric vehicles
- Spinning reserve scheduling required for the microgrid

The remainder of this paper is organized as follows: In Section 2, the problem statement and the introduction of the objective function considering its governing constraints are presented. In Section 3, the studied microgrid model is proposed. In Section 4, the results and analyses are discussed. Finally, Section 5 presents the conclusion.

2. PROBLEM STATEMENT

In this paper, the modeling and mathematical Eqns. governing the cost of different parts of the studied system and the constraints of distributed generation resources, electric vehicles, demand response, spinning reserve, and power balance are investigated in the following sections:

2.1. Objective function

In this section, the mathematical model of the objective function including the operating costs of microgrid is presented in accordance with the following Eq.:

$$OBJ = \sum_{t=1}^{T}\left[\begin{pmatrix} P_{UG}^{t} \times \pi_{UG}^{t} + \\ \sum_{j=1}^{G}\left(C_{LDG}^{j,t} + SC_{LDG}^{j,t} + \left(SR_{LDG}^{j,t} \times \psi_{LDG}^{j,t}\right)\right) + \\ \sum_{i=1}^{N}\left(-P_{Ch,EV}^{i,t} \times \pi_{Ch,EV}^{i} + P_{Dch,EV}^{i,t} \times \pi_{Dch,EV}^{i} + SR_{EV}^{i,t} \times \psi_{EV}^{i,t}\right) \end{pmatrix} \times \Delta t\right] \quad (1)$$

Eq. (1) consists of three parts: the first part contains the costs related to the power exchange between the upstream grid and microgrid, the second part involves operating costs and setting up local generation resources in the microgrid, and finally, the third part contains charging/discharging costs for power exchange between electric vehicles and microgrid.

2.2. Wind turbine

Wind turbine converts wind energy into electrical energy. The output power of wind turbine depends on the parameters such as wind availability, power curve of wind turbine, wind speed, turbine shape, and size. Eq. (2) shows the power output of wind turbine based on wind speed [26]:

$$P_W^{k,t} = \begin{cases} 0 & V^t < V_C^k \text{ or } V^t \geq V_F^k \\ \dfrac{V^t - V_C^k}{V_R^k - V_C^k} \times P_R^k & V_C^k \leq V^t < V_R^k \\ P_R^k & V_R^k \leq V^t < V_F^k \end{cases} \quad (2)$$

2.3. Photovoltaic system

Photovoltaic generators are the systems that convert sunlight into electricity. The solar system output entirely depends on the amount of radiation. The proposed model based on the mathematical Eqns. governing the photovoltaic system and considering the effects of solar radiation and temperature variations on the photovoltaic system are in accordance with Eq. (3) [26]:

$$P_{PV}^{p,t} = \eta^p \times S^p \times G^t \times (1 - 0.005 \times (T_a - 25)) \quad (3)$$

2.4. Local generation resources

The operating costs of power generation resources and setting up costs of local generation resources including micro turbine and fuel cell are in accordance with Eqns. (4) to (6), respectively [27].

$$C_{LDG}^{j,t} = a^j \times U^{j,t} + b^j \times p_{LDG}^{j,t} \quad (4)$$

$$SC_{LDG}^{j,t} \geq (U^{j,t} - U^{j,t-1}) \times UDC^j \quad (5)$$

$$SC_{LDG}^{j,t} \geq 0 \quad (6)$$

2.5. Time of use-based demand response program

The demand response resources are considered as proper resources due to the fast response and no need for investment in developing power system capacity from different viewpoints such as reduced costs and contribution to providing reserve in the scheduling and power system operation. Thus, in this regard, the time of use-based demand response program (TOU) is used in this paper. The basis of TOU demand response program is that load shift from peak to non-peak intervals and load curve smoothing would reduce the costs. It should be noted that TOU demand response program is only capable of shifting a percentage of the load and, in this paper, 15% load shift is allowed. The mathematical equivalent of the aforementioned sentences is in accordance with Eqns. (7) and (8) [22].

$$load^t = (1 - DR^t) \times load_0^t + idr^t \quad (7)$$

$$load_0^t - load^t = DR^t \times load_0^t - idr^t \quad (8)$$

The technical constraints considered for the TOU program are in accordance with Eqns. (9) to (12) [22].

$$\sum_{t=1}^{T} idr^t = \sum_{t=1}^{T} DR^t \times load_0^t \quad (9)$$

$$load_{inc}^t \leq inc^t \times load_0^t \quad (10)$$

$$DR^t \leq DR\max \quad (11)$$

$$inc^t \leq inc\max \quad (12)$$

Eq. (9) shows the load transfer per interval. Limiting the increase in load in each interval is applied in accordance with Eq. (10). A load percent shift from one interval to the others is achieved by Constraints (11-12).

In order to preserve and increase the lifetime of equipment and power grid under microgrid operation, after demand response program, the new load should not exceed a certain value. In this paper, the maximum predicted base load value is considered as a scheduling criterion and Eq. (13) shows this matter.

$$load^{t} \le load_{0}^{\max} \tag{13}$$

2.6. Demand response by direct load control method

In direct load control (DLC) demand response program, the basis of reducing operating costs is to wear away the peaks and fill the curve load valleys considering the cost and benefit, i.e. reducing the load value at the times, when the electrical energy supply of subscribers for microgrid requires high cost and low profits, and in contrast, increasing the load of subscribers at the times, when the electrical energy supply of subscribers for microgrid has low cost and higher profit. This is done through connecting and disconnecting a number of loads of subscribers, or in fact, reducing or increasing a load percent of subscribers at certain time intervals and paying an amount of money as an incentive to subscribers who are participating in this program.

In practice, a base load percent is participated in DLC demand response program, which is considered 15% in the present article. However, the effect of this program with the participation of 1% to 15% is also analyzed in the total operation cost of the microgrid.

The mathematical equivalent of the above sentences is in accordance with Eqns. (14) through (21).

$$Change^{t} \le 0 \quad \forall t \quad Pt_{shed,s} \le t \le Pt_{shed,e} \tag{14}$$

$$Change^{t} \ge 0 \quad \forall t \quad Pt_{add,s} \le t \le Pt_{add,e} \tag{15}$$

$$\begin{aligned} &Change^{t} = 0 \ \forall t \ (t < Pt_{add,s} \ or \ t > Pt_{add,e}) \\ &and \, (t < Pt_{shed,s} \ or \ t > Pt_{shed,e}) \end{aligned} \tag{16}$$

$$\sum_{t=Pt_{shed,s}}^{t=Pt_{shed,e}} Change^{t} = -\sum_{t=Pt_{add,s}}^{t=Pt_{add,e}} Change^{t} \tag{17}$$

$$drload^{t} = Ddrload_{0}^{t} + change^{t} \tag{18}$$

$$Change^{t} = Change_{Pos}^{t} - change_{Neg}^{t} \tag{19}$$

$$Ddrload_{0}^{t} = load_{0}^{t} \times DLC \max \tag{20}$$

$$Tdrload_{0}^{t} = load_{0}^{t} \times (1 - DLC \max) \tag{21}$$

In this method of demand response program, to preserve and increase the lifetime of equipment and power grid under microgrid operation, the new load after applying the demand response program should not exceed a certain amount and Eq. (22) shows this matter.

$$Tdrload_{0}^{t} + drload^{t} \le load_{0}^{\max} \tag{22}$$

2.7. Constraints

2.7.1. Local generation resource constraints

The technical constraints related to local generation resources are according to Eqns. (23) through (30) [28].

$$P_{LDG}^{j,t} + SR_{LDG}^{j,t} \le P_{LDG,\max}^{j} \times U^{j,t} \tag{23}$$

$$P_{LDG}^{j,t} \ge P_{LDG,\min}^{j} \times U^{j,t} \tag{24}$$

$$P_{LDG}^{j,t} - P_{LDG}^{j,t-1} \le RU^{j} \times U^{j,t} \tag{25}$$

$$P_{LDG}^{j,t-1} - P_{LDG}^{j,t} \le RD^{j} \times U^{j,t-1} \tag{26}$$

$$U^{j,t} - U^{j,t-1} \le U^{j,t+Up_{j,f}} \tag{27}$$

$$U^{j,t-1} - U^{j,t} \le 1 - U^{j,t+Dn_{j,f}} \tag{28}$$

$$Up_{j,f} = \begin{cases} f & f \le MUT_{j} \\ 0 & f > MUT_{j} \end{cases} \tag{29}$$

$$Dn_{j,f} = \begin{cases} f & f \le MDT_{j} \\ 0 & f > MDT_{j} \end{cases} \tag{30}$$

Eqns. (23) and (24) show the minimum and maximum power generated by local generation resources. Eqns. (25) and (26) show the increased and decreased slope rate of the power of local generation resources for two consecutive hours, respectively. Finally, Constraints (27) and (28) indicate the limitations for minimum On/Off time, respectively. Eqns. (29) and (30) respectively determine the linear modeling of the constraints for minimum On/Off time of the local generation resources.

2.7.2. Upstream grid constraints

The Eq. 31 presents the power exchange limitation between the upstream grid and microgrid.

$$\left| P_{UG}^{t} \right| \le P_{UG}^{\max} \tag{31}$$

2.7.3. Intelligent parking lot's electric vehicles constrains

For charging/discharging and participating in power exchange with intelligent parking, the intelligent parking lot's electric vehicles must comply with their own technical constrains in accordance with what follows.

2.7.3.1. Charge and discharge-related constraints

In this paper, it is assumed that the owners of electric vehicles are charging/discharging batteries in accordance with Constraints (32) and (33) at a scheduled time [21].

$$P_{Ch,EV}^{i,t} \le P_{Ch,\max}^{i} \times W_{Ch}^{i,t} \times M^{i,t} \quad (32)$$

$$P_{DCh,EV}^{i,t} + SR_{EV}^{i,t} \le P_{DCh,\max}^{i} \times W_{DCh}^{i,t} \times M^{i,t} \quad (33)$$

2.7.3.2. Charging/discharging non-synchronization

The Eq. 34 presents the constraint on preventing synchronized charging and discharging of the battery of electric vehicles [21].

$$W_{Ch}^{i,t} + W_{DCh}^{i,t} \le 1 \times M^{i,t} \quad (34)$$

2.7.3.3. Number of switching between charging/ discharge modes

Eq. (35) allows the operator to consider the maximum possible number of switching between charging/ discharge modes given the battery life of electric vehicles. The departure time of electric vehicles from intelligent parking lot as well as the number of electric vehicles parked in intelligent parking lot in time intervals can be expressed using Eqns. (35) to (37), respectively [21].

$$\sum_{t=t_a^i}^{t_d^i} W_{Ch}^{i,t} + W_{DCh}^{i,t} \le N_{\max} \quad (35)$$

$$\sum_{t=t_a^i}^{t=t_d^i} M^{i,t} = T_P^i \quad (36)$$

$$\sum_{i=1}^{N} M^{i,t} = N_{EV}^{t} \quad (37)$$

2.7.3.4. Constraints for spinning reverse of electric vehicles

Electric vehicles will play a very effective role in providing spinning reverse of microgrid due to having power storage source (battery). Hence, the constraints related to spinning reserve of electric vehicles that can only participate in discharging mode in the reserve market are shown in Eqns. (38) and (39) [21].

$$SR_{EV}^{i,t} \le \alpha \times P_{DCh,\max}^{i} \times SRS^{i,t} \times M^{i,t} \quad (38)$$

$$SR_{EV}^{i,t} \le \alpha \times P_{DCh,\max}^{i} \times W_{DCh}^{i,t} \times M^{i,t} \quad (39)$$

2.7.3.5. Constraints related to battery capacity of electric vehicles during charging/ discharging

The amount of stored energy of electric vehicle at any moment of time that is a function of vehicle charging/discharging along with charging and discharge efficiency is considered in accordance with Eq. (40) [21].

$$SOC^{i,t} = SOC^{i,t-1} + P_{Ch,EV}^{i,t} \times \eta_{G2V} - P_{DCh,EV}^{i,t} / \eta_{V2G} \quad (40)$$

2.7.3.6. Constraints related to energy status of electric vehicles

The amount of energy in an electric vehicle at any moment of time must be in accordance with Eq. (41) between its own minimum and maximum values.

$$SOC_{\min}^{i} \le SOC^{i,t} \le SOC_{\max}^{i} \quad (41)$$

2.7.3.7. Constraints related to the battery charging/ discharging rate of electric vehicles

Constraint (42) allows the operator to consider the maximum battery charging/discharging rate of the electric vehicles in its scheduling. In other words, some batteries are fast charging and some are slow charging which should be considered in operator scheduling.

$$-\Delta SOC_{\max}^{i} \le SOC^{i,t} - SOC^{i,t-1} \le \Delta SOC_{\max}^{i} \quad (42)$$

2.7.3.8. Constraints related to battery status of electric vehicles at the time of departure from the parking lot

Constraint (43) ensures that the battery status of electric vehicles at time of departure from the parking lot is equal to or greater than the status that is determined by the vehicle owner based on the initial charging at the time of arrival at the parking lot. Moreover, Constraint (44) shows the amount of battery power of the electric vehicle at time of arrival at the parking lot [20].

$$SOC_{Departure}^{i} \ge SOC_{Arrival}^{i,t} + \Delta SOC_{F}^{i} \quad (43)$$

$$SOC^{i,t} \ge SOC_{Arrival}^{i,t} \quad (44)$$

Eq. (45) is considered to calculate the average energy level of electric vehicles in intelligent parking lot [20].

$$SOC_{Average}^{t} = \sum_{i=1}^{N} (SOC^{i,t} / (SOC_{\max}^{i} \times N_{EV}^{t})) \quad (45)$$

2.7.4. Spinning reserve constraints of microgrid

Beside many benefits of using renewable energies, the uncertainty in the generation rate of these resources and dependence of their values on the natural resources cause difficulties for the growing trend of these resources. The power system operation and scheduling in the presence of renewable resources, because of the governing uncertainties, have increased the complexity of the problem. Thus, the use of controlled DG resources with rapid changes in power generation rate, power storage resources, and load side resources has been considered by the power system operators to reduce the effect of uncertainty in the presence of renewable resources.

In case of any problem in power injection into the microgrid by renewable sources, the local generators and intelligent parking lots, in accordance with Eq. (46), must be able to prevent the occurrence of any problem in the microgrid by injecting enough power into the microgrid and maintaining the balance between power generation and power consumption [20].

$$\sum_{j=1}^{G} SR_{LDG}^{j,t} + \sum_{i=1}^{N} SR_{EV}^{i,t} \geq \left(\omega_w \times P_W^{k,t} + \omega_{PV} \times P_{PV}^{p,t}\right) \qquad (46)$$

2.7.5. Power balance constraints

In order to make a balance between power generation and power consumption in the microgrid, in accordance with Eq. (47), the constraint of power balance should be considered. Thus, on the right-hand side of the Eq., instead of the base load, the new load influenced by demand response program should be replaced.

$$P_{UG}^{t} + \sum_{k=1}^{K} P_W^{k,t} + \sum_{p=1}^{P} P_{PV}^{p,t} + \sum_{j=1}^{G} P_{LDG}^{i,t} + \sum_{i=1}^{N} P_{Dch,EV}^{i,t} = load^{t} + \sum_{i=1}^{N} P_{Ch,EV}^{i,t} \qquad (47)$$

3. SAMPLE MICROGRID SYSTEM

The studied microgrid system consists of wind turbine, photovoltaic system, micro turbines, fuel cell, intelligent parking lot of electric vehicles, and local load. The microgrid is connected to the upstream grid for power exchange. Fig. 1 shows this structure. In this system, it is assumed that the intelligent parking lot has received information, such as charging/discharging price limits, initial charge status, elapsed time of battery life, and expected condition of the electric vehicle battery leaving the parking lot from the electric vehicle owner and sends them to the operator who is in control center of local parking lot, so that a proper scheduling is carried out to reduce the network costs.

The parameters related to wind turbine and photovoltaic system are presented in Table 1 [26]. Table 2 shows the parameters related to the fuel cell and micro turbine. Today, there are various types of electric vehicles with various capacities from 8 to 48 kWh [27]. In this paper, it is assumed that the electric vehicles in the intelligent parking lot have the capacity of 10 to 20 kWh and the capacity of vehicles is randomly assigned between these two values. The reserve cost of the ith electric vehicle ($\psi_{EV}^{i,t}$) is considered 10% of the optimal discharging price ($\pi_{Dch,EV}^{i}$) of the ith electric vehicle. The spinning reserve cost of the jth local generator resource ($\psi_{LDG}^{j,t}$) is considered 10% of electricity price in the free market in the t time interval (π_{UG}^{t}). The intelligent parking lot capacity is 230 electric vehicles and the approximate arrival time of the ith electric vehicle t_a^i to the intelligent parking lot is randomly from 6 to 22. The initial charging status of the ith electric vehicle at the time of arrival to the parking lot ($SOC_{Arrival}^{i,t}$) is randomly considered between 0.1 and 0.7 of the maximum capacity of the ith electric vehicle. The minimum additional charge requested by the owner of the ith electric vehicle at time of departure from the intelligent parking lot (ΔSOC_F^{i}) is a random number between 0.1 and 0.3 of the initial charge at the time of arrival and the maximum charge of that electric vehicle ($SOC_{\max}^{i}$). The optimal charging price of the ith electric vehicle in the intelligent parking lot ($\pi_{Ch,EV}^{i}$) is a random number between 0.15 and 0.3. The optimal discharging cost of the ith electric vehicle in the intelligent parking lot ($\pi_{Dch,EV}^{i}$) has been a random number between 0.25 and 0.4 $/kWh. Table 3 shows the other parameters of an electric vehicle as random numbers between two minimum and maximum constrained values. Sampling time (Δt) is also considered as 1 hour, because it is a proper time for sampling 230 electric vehicles.

In order to limit the power exchanged with the upstream grid, the microgrid is capable of maximum 1000 kW exchange with upstream gird ($P_{UG}^{\max}$). Table 4 shows the predicted values of wind speed and solar radiation along with their generation power [29]. The estimated base load rates and market prices during the 24-h study period are shown in Table 5 [21]. It should be noted that the uncertainty resulting from wind speed, solar radiation, load, and market price is not considered in this paper. Besides, the wind turbine and photovoltaic system used in the studied microgrid participate in the scheduling with maximum available power from these units given the wind speed and solar radiation at any time interval. No cost is considered in the general cost of the microgrid for their installation, maintenance, and operation. The implementation of the proposed objective function in the software is as follows: The set of indicators, parameters, tables, and variables of the problem is first defined. After defining the Eqns. and limitations, the proposed model that is a model with mixed integer programming (MIP) is evaluated in the optimization software GAMS by the CPLEX tool.

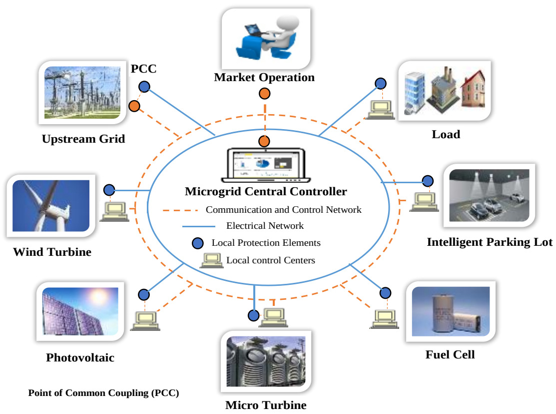


Fig. 1. Structure of the microgrid

Table 1. Parameters for wind turbine and photovoltaic system

Parameter	Photovoltaic system				Wind turbine				
	η	S	T_a	ω_{Pv}	P_R	V_C	V_R	V_F	ω_W
Unit	%	m^2	℃	%	KW	m/s	m/s	m/s	%
Value	15.70	1500	25	20	500	3	12	30	20

Table 2. Parameters for local generation resources

Resource	Type of resource	a	b	p^{min}	p^{max}	MUT	MDT	UDC	RU	RD
		$	$/$kW$	kW	kW	h	h	$		
1	Micro turbine	0.02	0.15	150	700	3	3	0.10	350	350
2	Micro turbine	0.04	0.25	100	450	3	2	0.02	200	200
3	Fuel cell	0.09	0.45	50	300	1	1	0.02	150	150

Table 3. Parameters for electric vehicles

α	T_P^i	$P_{Ch,\max}^i$	$P_{Dch,\max}^i$	$SOC_{\max}^i$	$SOC_{\min}^i$	$\Delta SOC_{\max}^i$	η_{G2V}	η_{V2G}	$N_{\max}$
	h	kW	kW	kWh	kWh	kWh			
1	2-8	5-10	5-10	10-20	0	5-10	0.90	0.80	10

Table 4. Wind and photovoltaic system data

Time (Hour)	Wind Speed Forecast (m/s)	Output Power of the Wind Turbine (kW)	Solar Radiation Forecast (W/m2)	Output Power of the Photovoltaic System (kW)	Time (Hour)	Wind Speed Forecast (m/s)	Output Power of the Wind Turbine (kW)	Solar Radiation Forecast (W/m2)	Output Power of the Photovoltaic System (kW)
1	6.90	217.00	0.00	0.00	13	9.00	335.00	887.40	207.00
2	6.90	217.00	0.00	0.00	14	11.10	449.00	833.00	195.00
3	5.90	160.00	0.00	0.00	15	11.80	486.00	594.40	140.00
4	6.40	188.00	0.00	0.00	16	11.70	483.00	431.20	100.00
5	6.80	211.00	0.00	0.00	17	12.00	500.00	167.40	39.00
6	7.40	246.00	0.00	0.00	18	11.90	492.00	83.70	19.00
7	6.80	211.00	0.00	0.00	19	11.90	492.00	16.70	3.00
8	6.80	211.00	146.50	33.00	20	12.40	500.00	0.00	0.00
9	8.10	286.00	360.00	83.00	21	12.70	500.00	0.00	0.00
10	7.40	243.00	393.50	91.00	22	12.50	500.00	0.00	0.00
11	8.20	289.00	661.40	154.00	23	12.70	500.00	0.00	0.00
12	8.20	289.00	824.70	193.00	24	12.60	500.00	0.00	0.00

4. SIMULATION RESULTS

In order to evaluate the role of intelligent parking lot in power exchange and to provide the spinning reserve as well as the effect of demand response programs on load curves and to reduce the operating costs of microgrids, the proposed model and objective function are examined in two states of the proposed energy and reserve model in the basic state without the presence of the consumption side management program and taking into account the presence of TOU and DLC demand response programs.

4.1. First scenario

In order to analyze the precision and accuracy of the energy and reserve model proposed in this paper, the first scenario is analyzed in three different sections.

Section A: In this section, the intelligent parking lots (IPL) of electric vehicles are not involved in any energy and reserve scheduling and only play the role of a variable load, i.e. the grid to vehicle (G2V) charging. The required spinning reserve of microgrid is also provided by local generation resources.

Section B: In this section, the intelligent parking lot of electric vehicles, in addition to charging, contribute to scheduling through a discharge option of grid to vehicle (G2V), but it still plays no role in the reserve scheduling, and the required spinning reserve of the microgrid is still provided by local generation resources.

Section C: In this section, the intelligent parking lot of electric vehicles participates in both energy and reserve scheduling and the required spinning reserve of the microgrid meets the participation of the intelligent parking lot of electric vehicles and local generation resources. The power exchanged between the microgrid and upstream grids as well as the scheduled power for local generation resources in these 3 sections are in Table 5. Given the results obtained during time intervals at low power prices, the charging rate in sections (b) and (c) are increased in contrast to section (a) due to the capability of electric vehicles to sell the stored energy to the upstream grid (UG). Moreover, the comparison between sections (c) and (b) shows that, in section (c), the energy sold from intelligent parking lot is slightly reduced, because due to the supply of spinning reserve, a certain amount of energy should remain stored in the battery of electric vehicles.

The scheduled spinning reserve is shown in Table 6 by intelligent parking lots of electric vehicles and local generation resources. According to this table, the results presented related to the supply of microgrid spinning reserve at different times and the effect of electric vehicles can be seen in the results of three sections. As shown in Table 6, in sections (a) and (b), the spinning reserve is provided in low power price intervals by micro turbine 1 (MT1), while micro turbine 2 (MT2) and the fuel cell (FC) provide the spinning reserve in peak power price intervals. Therefore, a part of the capacity of the micro turbines and the fuel cell is assigned for the supply of spinning reserve, and the required energy must be purchased at a higher cost than the upstream grid; these conditions increase the operating costs of micro turbines. In section (c), similar to sections (a) and (b), micro turbine 1 provides the spinning reserve in low power price intervals. However, in the peak price intervals, the power of electric vehicles in the intelligent parking lots is provided by spinning reserve at lower price.

Table 7 shows the total operating cost of the microgrid in the three studied sections. In section (a), where the intelligent parking lots of electric vehicles only play the role of the controllable load; the total operating cost is 2464.11 $. In section (b), where the intelligent parking lots of electric vehicles allows the vehicle to grid (V2G) power exchange for the microgrid central controller and the spinning reserve is only provided by local generation resources, the total operating cost of microgrid is $2222.23. In section (c), where the intelligent parking lots of electric vehicles participate in both energy scheduling and spinning reserve, the total operating cost of microgrid is $2184.15. Comparing the results of section (c) and those of sections (a) and (b), it is observed that the total daily operating cost of the studied microgrid is 11.36%, 1.7%, respectively, and section (b) is decreased by 9.8% compared to section (a). In sections (b) and (c), in conditions of high power price in the free market, the local control factor of intelligent parking lots through the central controller of microgrid is preferred to selling the energy stored in the battery of electric vehicles to the upstream grid, and through this, a greater profit is obtained by the parking investor. Due to the high energy cost at 10:00-13:00 and 14:00-17:00, most of the electric vehicles parked in intelligent parking lot are willing to sell energy to the upstream grid in order to gain profit. Therefore, the mean stored energy of electric vehicles in the intelligent parking lots is significantly reduced. Hence, the load is increased by intelligent parking lots in order to reach the mean energy level of electric vehicles in the intelligent parking lots to the optimum level at 13:00-17:00 and due to the low power price in the free market.

On the other hand, by approaching the final hours of the presence of electric vehicles in intelligent parking lots and low power price, most of the electric vehicles are switched to the charging mode. Thus, at 13:00 and 17:00-19:00, the peak consumption conditions in intelligent parking lots are observed. At 19:00-21:00, most of the vehicles are in the charging mode to reach their energy levels to the desired value requested by vehicle's owner at the departure time. At 21:00 and due to the average energy level of electric vehicles in the parking lot, the vehicles with desired charging status sell energy given the increased power price compared to the previous hour in the free market.

Table 5. Scheduled power of electric vehicles in intelligent parking lot, power exchange between microgrid and upstream grid, scheduled power for local generation resources, and power generation by renewable energy sources per kilowatt in three sections of the first scenario

Time	Intelligent Parking Lot Charging (-)/ Discharging (+) (kW)			Upstream Grid Selling (-)/Purchasing (+) (kW)			Micro-Turbine 1 (kW)			Micro-Turbine 2 (kW)			Fuel Cell (kW)			Renewable Generation (kW)	Forecasting Load (kW)	Real Time Market Price (Cent/kWh)
	First Scenario Sections			First Scenario Sections			First Scenario Sections			First Scenario Sections			First Scenario Sections					
	a	b	c	a	b	C	a	b	c	a	b	c	a	B	c			
1	0.00	0.00	0.00	673.00	673.00	673.00	150.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	217.00	1040.00	3.30
2	0.00	0.00	0.00	333.00	333.00	333.00	150.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	217.00	700.00	2.70
3	0.00	0.00	0.00	690.00	690.00	690.00	150.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	160.00	1000.00	2.00
4	0.00	0.00	0.00	677.00	677.00	677.00	150.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	188.00	1015.00	1.70
5	0.00	0.00	0.00	759.00	759.00	759.00	150.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	211.00	1120.00	1.70
6	-114.20	-114.20	-114.20	978.20	978.20	978.20	150.00	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	246.00	1260.00	2.90
7	-57.60	-58.86	-58.90	1000.00	1000.00	1000.00	242.90	242.90	242.90	0.00	0.00	0.00	0.00	0.00	0.00	211.00	1395.00	3.30
8	-194.00	-194.00	-194.00	1000.00	1000.00	1000.00	350.00	350.00	350.00	100.00	100.00	100.00	0.00	0.00	0.00	244.00	1500.00	10.00
9	-95.60	-157.20	-157.20	291.60	353.20	353.20	700.00	700.00	700.00	250.00	250.00	250.00	0.00	0.00	0.00	369.00	1515.00	20.00
10	-5.00	122.60	96.40	-29.00	-156.60	-130.40	700.00	700.00	700.00	450.00	450.00	450.00	150.00	150.00	150.00	334.00	1600.00	60.00
11	-18.20	81.70	102.90	-270.50	-370.40	-435.90	700.00	700.00	700.00	450.00	450.00	450.00	255.70	255.70	300.00	443.00	1560.00	60.00
12	-7.60	218.40	208.00	-349.40	-575.40	-565.00	700.00	700.00	700.00	450.00	450.00	450.00	200.00	200.00	200.00	482.00	1475.00	60.00
13	-376.10	-714.70	-714.70	274.10	612.70	612.70	700.00	700.00	700.00	250.00	250.00	250.00	50.00	50.00	50.00	542.00	1440.00	20.00
14	0.00	376.50	392.00	-554.00	-930.50	-896.00	700.00	700.00	700.00	450.00	450.00	450.00	200.00	200.00	150.00	644.00	1440.00	60.00
15	-18.00	-207.10	-191.70	-243.00	-53.90	-19.30	700.00	700.00	700.00	400.00	400.00	400.00	50.00	50.00	0.00	626.00	1515.00	30.00
16	-15.90	26.90	11.50	132.90	90.10	105.50	700.00	700.00	700.00	200.00	200.00	200.00	0.00	0.00	0.00	583.00	1600.00	30.00
17	-485.10	-446.50	-430.30	1000.00	1000.00	1000.00	607.50	607.50	591.30	0.00	0.00	0.00	0.00	0.00	0.00	539.00	1700.00	10.00
18	-202.20	-398.90	-312.60	1000.00	1000.00	1000.00	647.90	647.90	561.60	0.00	0.00	0.00	0.00	0.00	0.00	511.00	1760.00	10.00
19	-51.50	-104.80	-163.70	1000.00	1000.00	1000.00	409.80	409.80	468.70	0.00	0.00	0.00	0.00	0.00	0.00	495.00	1800.00	10.00
20	-60.00	-60.00	-127.90	1000.00	1000.00	1000.00	300.00	300.00	367.90	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1740.00	10.00
21	0.00	50.70	36.50	410.00	359.30	373.50	650.00	650.00	650.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1560.00	20.00
22	-36.10	-71.60	-103.10	651.10	686.60	718.10	300.00	300.00	300.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1415.00	10.00
23	-39.20	-83.90	-43.90	689.20	733.90	843.90	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1300.00	4.30
24	-67.10	-71.70	-34.60	532.10	536.70	649.60	150.00	150.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1115.00	3.70

Table 6. Spinning reserve scheduled by the intelligent parking lot of electric vehicles and local generation units in 3 parts of the first scenario

Time	Micro-Turbine 1 (kW)			Micro-Turbine 2 (kW)			Fuel Cell (kW)			Intelligent Parking Lot (kW)		
	First Scenario Sections			First Scenario Sections			First Scenario Sections			First Scenario Sections		
	a	b	c	a	b	c	a	b	c	a	B	c
1	21.70	21.70	21.70	-	-	-	-	-	-	-	-	-
2	21.70	21.70	21.70	-	-	-	-	-	-	-	-	-
3	16.00	16.00	16.00	-	-	-	-	-	-	-	-	-
4	18.80	18.80	18.80	-	-	-	-	-	-	-	-	-
5	21.10	21.10	21.10	-	-	-	-	-	-	-	-	-
6	24.60	24.60	24.60	-	-	-	-	-	-	-	-	-
7	21.10	21.10	21.10	-	-	-	-	-	-	-	-	-
8	-	-	-	24.40	24.40	24.40	-	-	-	-	-	-
9	-	-	-	36.90	36.90	36.90	-	-	-	-	-	-
10	-	-	-	-	-	-	33.40	33.40	-	-	-	33.40
11	-	-	-	-	-	-	44.30	44.30	-	-	-	44.30
12	-	-	-	-	-	-	48.20	48.20	-	-	-	48.20
13	-	-	-	54.20	54.20	54.20	-	-	-	-	-	-
14	-	-	-	-	-	-	64.40	64.40	-	-	-	64.40
15	-	-	-	50.00	50.00	-	12.60	12.60	-	-	-	62.60
16	-	-	-	58.30	58.30	-	-	-	-	-	-	58.30
17	53.90	53.90	53.90	-	-	-	-	-	-	-	-	-
18	51.10	51.10	51.10	-	-	-	-	-	-	-	-	-
19	49.50	49.50	49.50	-	-	-	-	-	-	-	-	-
20	50.00	50.00	50.00	-	-	-	-	-	-	-	-	-
21	50.00	50.00	50.00	-	-	-	-	-	-	-	-	-
22	50.00	50.00	50.00	-	-	-	-	-	-	-	-	-
23	50.00	50.00	-	-	-	-	-	-	-	-	-	50.00
24	50.00	50.00	-	-	-	-	-	-	-	-	-	50.00

Table 7. Comparing operation costs of the different sections of microgrid in the three studied sections of the first scenario

Different costs	First scenario - Section (a)	First scenario - Section (b)	First scenario - Section (c)
Purchase cost from upstream grid ($)	185.61	-193.00	-159.68
operation cost of local generation resources ($)	2694.82	2726.72	2644.71
Charging/discharging costs of electric vehicles ($)	-416.31	-311.49	-300.88
Total cost ($)	2464.11	2222.23	2184.15
Percentage reduction in total cost (%)	-	9.8	1.70-11.36

Table 8. Comparing the operation costs of different sections of the microgrid with/without TOU-based demand response program

Different costs	First scenario of Section (c)	Second scenario
Purchase cost from upstream gird ($)	-159.68	-904.60
operation cost from local generation resources ($)	2644.71	2749.13
Charging/discharging costs of electric vehicles ($)	-300.88	-306.89
Total cost ($)	2184.15	1537.63
Percentage reduction in total cost (%)	-	29.60

Table 9. Comparing operating costs of different parts of microgrid w/ and w/o DLC demand response program

Various costs	First scenario of section (c)	Third scenario
Purchase cost from upstream grid ($)	-159.68	-822.36
Operating and setting up cost of local generation resources ($)	2644.71	2599.25
Charging/discharging cost of electric vehicles ($)	-300.87	-306.52
Incentive cost for subscribers participating in DLC program	-	92.47
Total cost ($)	2184.15	1562.84
Percent reduction in total cost (%)	-	28.40

Table 10. Comparing operating costs of different sections of microgrid w/ and w/o TOU and DLC demand response programs

Various costs	First scenario of section (c)	Third scenario
Purchase cost from upstream grid ($)	-159.68	-1315.01
Operating and setting up cost of local generation resources ($)	2644.71	2642.96
Charging/discharging cost of electric vehicles ($)	-300.87	-307.29
Incentive cost for subscribers participating in DLC program	-	68.92
Total cost ($)	2184.15	1089.57
Percent reduction in total cost (%)	-	50.10

At the time intervals of 22, 23, and 24, the vehicles are in the parking lot to supply the desired energy at time of departure in charging mode and as consumers. Comparison of the results of section (c) with section (b) demonstrates that the energy sold by the intelligent parking lot of electric vehicles is declined. These conditions are due to the point that a certain amount of energy should remain stored in the battery of electric vehicles and not be discharged for sale, so that the electric vehicles can provide a part of spinning reserve required by the microgrid.

4.2. Second scenario

This scenario examines the model presented in section (c) of the first scenario with the presence of TOU demand response program to determine the effect of TOU demand response program on the load curve and reduction of the operating costs of the microgrid.

Table 8 shows the operating costs of different sections of the studied microgrid for section (c) of the first and second scenarios. According to this table, the operating costs of microgrid in section (c) of the first scenario is $2184.15. The total operating cost of microgrid in the second scenario is $1537.63, which shows a 29.6% decline compared to the first scenario. Thus, according to the results, the TOU program has a positive and effective impact on the reduction of operating costs.

As shown in Fig. 2, TOU program with load shift from expensive to inexpensive intervals leads to reduced operating costs and smooth load curve. In this figure, according to the predicted market price, it is observed that at 9:00 to 17:00, the power market price is increased. Thus, TOU load response program reduces THE load percent of these hours and transfers IT to inexpensive intervals. The power exchange between the microgrid and upstream grid, as well as scheduled power for local generation resources in these two scenarios is shown in Table 9.

Table 11. Scheduled power of electric vehicles in the intelligent parking lot, power exchange between microgrid and upstream grid, as well as scheduled power for local generation resources, and power generation of the renewable energy sources per kW with/without TOU program

Time	Intelligent Parking Lot Charging (-)/ Discharging (+) (kW)		Upstream Grid Selling (-)/ Purchasing (+) (kW)		Micro-Turbine 1 (kW)		Micro-Turbine 2 (kW)		Fuel Cell (kW)		Renewable Generation (kW)	Forecasting Load (kW)	New Load After Effect of TOU (kW)	Real Time Market Price (Cent/kWh)
	Scenarios		Scenarios		Scenarios		Scenarios		Scenarios					
	First Section (c)	Second	First Section (c)	Second	First Section(c)	Second	First Section(c)	Second	First Section(c)	Second				
1	0.00	0.00	673.00	959.70	150.00	150.00	0.00	0.00	0.00	0.00	217.00	1040.00	1326.70	3.30
2	0.00	0.00	333.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	217.00	700.00	1367.00	2.70
3	0.00	0.00	690.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	160.00	1000.00	1310.00	2.00
4	0.00	0.00	677.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	188.00	1015.00	1338.00	1.70
5	0.00	0/00	759.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	211.00	1120.00	1361.00	1.70
6	-114.20	-114.20	978.20	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	246.00	1260.00	1281.80	2.90
7	-58.90	-58.90	1000.00	1000.00	242.90	242.90	0.00	0.00	0.00	0.00	211.00	1395.00	1395.00	3.30
8	-194.00	-194.00	1000.00	1000.00	350.00	350.00	100.00	100.00	0.00	0.00	244.00	1500.00	1500.00	10.00
9	-157.20	-157.20	353.20	353.20	700.00	700.00	250.00	250.00	0.00	0.00	369.00	1515.00	1515.00	20.00
10	96.40	110.80	-130.40	-384.80	700.00	700.00	450.00	450.00	150.00	150.00	334.00	1600.00	1360.00	60.00
11	102.90	115.10	-435.90	-682.10	700.00	700.00	450.00	450.00	300.00	300.00	443.00	1560.00	1326.00	60.00
12	208.00	207.50	-565.00	-785.80	700.00	700.00	450.00	450.00	200.00	200.00	482.00	1475.00	1253.80	60.00
13	-714.70	-714.70	612.70	396.70	700.00	700.00	250.00	250.00	50.00	50.00	542.00	1440.00	1224.00	20.00
14	392.00	296.00	-896.00	-1000.00	700.00	700.00	450.00	450.00	150.00	134.00	644.00	1440.00	1224.00	60.00
15	-191.70	-125.90	-19.30	-312.40	700.00	700.00	400.00	400.00	0.00	0.00	626.00	1515.00	1287.80	30.00
16	11.50	38.80	105.50	-161.80	700.00	700.00	200.00	200.00	0.00	0.00	583.00	1600.00	1360.00	30.00
17	-430.30	-444.00	1000.00	1000.00	591.30	350.00	0.00	0.00	0.00	0.00	539.00	1700.00	1445.00	10.00
18	-312.60	-276.50	1000.00	1000.00	561.60	525.50	0.00	0.00	0.00	0.00	511.00	1760.00	1760.00	10.00
19	-163.70	-186.70	1000.00	1000.00	468.70	491.70	0.00	0.00	0.00	0.00	495.00	1800.00	1800.00	10.00
20	-127.90	-127.20	1000.00	1000.00	367.90	367.20	0.00	0.00	0.00	0.00	500.00	1740.00	1740.00	10.00
21	36.50	36.50	373.50	373.50	650.00	650.00	0.00	0.00	0.00	0.00	500.00	1560.00	1560.00	20.00
22	-103.10	-103.10	718.10	718.10	300.00	300.00	0.00	0.00	0.00	0.00	500.00	1415.00	1415.00	10.00
23	-43.90	-43.90	843.90	843.90	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1300.00	1300.00	4.30
24	-34.60	-34.60	649.60	649.60	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1115.00	1115.00	3.70

Table 12. Scheduled power of electric vehicles in intelligent parking lot, power exchange between the microgrid and upstream grid, as well as the scheduled power for local generation resources and power generation by renewable resources per kW w/ and w/o the DLC program

Time	Intelligent Parking Lot Charging (-)/ Discharging (+) (kW)		Upstream Grid Selling (-)/ Purchasing (+) (kW)		Micro-Turbine 1 (kW)		Micro-Turbine 2 (kW)		Fuel Cell (kW)		Renewable Generation (kW)	Forecasting Load (kW)	New Load After Effect of DLC (kW)	Real Time Market Price (Cent/kWh)
	Scenarios		Scenarios		Scenarios		Scenarios		Scenarios					
	First Section (c)	Third	First Section(c)	Third	First Section(c)	Third	First Section(c)	Third	First Section(c)	Third				
1	0.00	0.00	673.00	959.70	150.00	150.00	0.00	0.00	0.00	0.00	217.00	1040.00	1326.70	3.30
2	0.00	0.00	333.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	217.00	700.00	1367.00	2.70
3	0.00	0.00	690.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	160.00	1000.00	1310.00	2.00
4	0.00	0.00	677.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	188.00	1015.00	1338.00	1.70
5	0.00	0.00	759.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	211.00	1120.00	1361.00	1.70
6	-114.20	-114.20	978.20	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	246.00	1260.00	1281.80	2.90
7	-58.90	-58.90	1000.00	1000.00	242.90	242.90	0.00	0.00	0.00	0.00	211.00	1395.00	1395.00	3.30
8	-194.00	-194.00	1000.00	1000.00	350.00	350.00	100.00	100.00	0.00	0.00	244.00	1500.00	1500.00	10.00
9	-157.20	-157.20	353.20	353.20	700.00	700.00	250.00	250.00	0.00	0.00	369.00	1515.00	1515.00	20.00
10	96.40	110.80	-130.40	-384.80	700.00	700.00	450.00	450.00	150.00	150.00	334.00	1600.00	1360.00	60.00
11	102.90	115.10	-435.90	-682.10	700.00	700.00	450.00	450.00	300.00	300.00	443.00	1560.00	1326.00	60.00
12	208.00	207.50	-565.00	-785.80	700.00	700.00	450.00	450.00	200.00	200.00	482.00	1475.00	1253.80	60.00
13	-714.70	-714.70	612.70	396.70	700.00	700.00	250.00	250.00	50.00	50.00	542.00	1440.00	1224.00	20.00
14	392.00	296.00	-896.00	-1000.00	700.00	700.00	450.00	450.00	150.00	134.00	644.00	1440.00	1224.00	60.00
15	-191.70	-125.90	-19.30	-312.40	700.00	700.00	400.00	400.00	0.00	0.00	626.00	1515.00	1287.80	30.00
16	11.50	38.80	105.50	-161.80	700.00	700.00	200.00	200.00	0.00	0.00	583.00	1600.00	1360.00	30.00
17	-430.30	-444.00	1000.00	1000.00	591.30	350.00	0.00	0.00	0.00	0.00	539.00	1700.00	1445.00	10.00
18	-312.60	-276.50	1000.00	1000.00	561.60	525.50	0.00	0.00	0.00	0.00	511.00	1760.00	1760.00	10.00
19	-163.70	-186.70	1000.00	1000.00	468.70	491.70	0.00	0.00	0.00	0.00	495.00	1800.00	1800.00	10.00
20	-127.90	-127.20	1000.00	1000.00	367.90	367.20	0.00	0.00	0.00	0.00	500.00	1740.00	1740.00	10.00
21	36.50	36.5.00	373.50	373.50	650.00	650.00	0.00	0.00	0.00	0.00	500.00	1560.00	1560.00	20.00
22	-103.10	-103.10	718.10	718.10	300.00	300.00	0.00	0.00	0.00	0.00	500.00	1415.00	1415.00	10.00
23	-43.90	-43.90	843.90	843.90	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1300.00	1300.00	4.30
24	-34.60	-34.60	649.60	649.60	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1115.00	1115.00	3.70

Table 13. Scheduled power of electric vehicles in intelligent parking lots, power exchanged between the microgrid and upstream grid, as well as the scheduled power for local generation units and power generation by renewable resources per kW w/ and w/o TOU and DLC programs

Time	Intelligent Parking Lot Charging (-)/ Discharging (+) (kW)		Upstream Grid Selling (-)/ Purchasing (+) (kW)		Micro-Turbine 1 (kW)		Micro-Turbine 2 (kW)		Fuel Cell (kW)		Renewable Generation (kW)	Forecasting Load (kW)	New load after TOU+DLC effect (kW)	Real Time Market Price (Cent/kWh)
	Scenarios		Scenarios		Scenarios		Scenarios		Scenarios					
	First Section (c)	Fourth	First Section(c)	Fourth	First Section(c)	Fourth	First Section(c)	Fourth	First Section(c)	Fourth				
1	0.00	0.00	673.00	1000.00	150.00	282.10	0.00	0.00	0.00	0.00	217.00	1040.00	1499.00	3.30
2	0.00	0.00	333.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	217.00	700.00	1367.00	2.70
3	0.00	0.00	690.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	160.00	1000.00	1310.00	2.00
4	0.00	0.00	677.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	188.00	1015.00	1338.00	1.70
5	0.00	0.00	759.00	1000.00	150.00	150.00	0.00	0.00	0.00	0.00	211.00	1120.00	1361.00	1.70
6	-114.20	-107.60	978.20	1000.00	150.00	282.20	0.00	0.00	0.00	0.00	246.00	1260.00	1420.70	2.90
7	-58.90	-113.40	1000.00	1000.00	242.90	475.30	0.00	0.00	0.00	0.00	211.00	1395.00	1572.90	3.30
8	-194.00	-146.10	1000.00	1000.00	350.00	435.10	100.00	100.00	0.00	0.00	244.00	1500.00	1633.00	10.00
9	-157.20	-157.20	353.20	160.10	700.00	700.00	250.00	250.00	0.00	0.00	369.00	1515.00	1321.80	20.00
10	96.40	152.50	-130.40	-630.50	700.00	700.00	450.00	450.00	150.00	150.00	334.00	1600.00	1156.00	60.00
11	102.90	101.70	-435.90	-867.60	700.00	700.00	450.00	450.00	300.00	300.00	443.00	1560.00	1127.10	60.00
12	208.00	194.30	-565.00	-910.60	700.00	700.00	450.00	450.00	200.00	150.00	482.00	1475.00	1065.780	60.00
13	-714.70	-708.00	612.70	472.40	700.00	700.00	250.00	250.00	50.00	0.00	542.00	1440.00	1256.40	20.00
14	392.00	246.40	-896.00	-1000.00	700.00	700.00	450.00	450.00	150.00	0.00	644.00	1440.00	1040.40	60.00
15	-191.70	-96.30	-19.30	-535.10	700.00	700.00	400.00	400.00	0.00	0.00	626.00	1515.00	1094.60	30.00
16	11.50	42.40	105.50	-369.40	700.00	700.00	200.00	200.00	0.00	0.00	583.00	1600.00	1156.00	30.00
17	-430.30	-419.10	1000.00	1000.00	591.30	646.10	0.00	0.00	0.00	0.00	539.00	1700.00	1766.00	10.00
18	-312.60	-261.20	1000.00	1000.00	561.60	550.20	0.00	0.00	0.00	0.00	511.00	1760.00	1800.00	10.00
19	-163.70	-193.00	1000.00	1000.00	468.70	498.00	0.00	0.00	0.00	0.00	495.00	1800.00	1800.00	10.00
20	-127.90	-152.80	1000.00	1000.00	367.90	452.80	0.00	0.00	0.00	0.00	500.00	1740.00	1800.00	10.00
21	36.50	32.10	373.50	179.00	650.00	650.00	0.00	0.00	0.00	0.00	500.00	1560.00	1361.10	20.00
22	-103.10	-114.20	718.10	909.60	300.00	300.00	0.00	0.00	0.00	0.00	500.00	1415.00	1595.40	10.00
23	-43.90	-34.20	843.90	1000.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1300.00	1465.70	4.30
24	-34.60	-34.50	649.60	791.80	0.00	0.00	0.00	0.00	0.00	0.00	500.00	1115.00	1257.20	3.70

Fig. 3 shows the impact of the participation in the TOU program on the total operating cost of microgrid from 1% to 15%. In this figure, the maximum load increase in time interval t (inc max) varies proportionally to the maximum load size of the participant in TOU demand response program.

4.3. Third scenario

The third scenario investigates the effect of DLC demand response program on the load curve and reduced operating cost of the microgrid. In this scenario, the microgrid operator schedules a plan and presents it to the subscribers of the system under supervision.

The mechanism of this plan is to cut off a number of electric appliances of consumers or to reduce the load percent in the certain and predetermined time intervals, so that paying the incentive money based on participation rate ($/kWh) encourages the consumers to participate in demand response program. The operator will allow the subscribers of the microgrid to increase load in certain and predetermined time intervals (up to the maximum base load to preserve and increase the lifetime of power grid equipment in the microgrid). The customer can increase his/her load in these intervals when the electricity price is low. The microgrid operator ensures the implementation of this program by concluding a contract with subscribers. In this paper, the maximum load participating in DLC program is intended to be 15% of the base load and the participants in the program are entirely committed to the contract.

Table 10 shows the operating costs of different sections of the studied microgrid for section (c) of the first and third scenarios. It is observed in Table (10) that the total operating cost of the microgrid in section (c) of the first scenario is $2184.15, which is reduced to $1562.84 in case of using DLC program (28.40% compared to the first scenario).

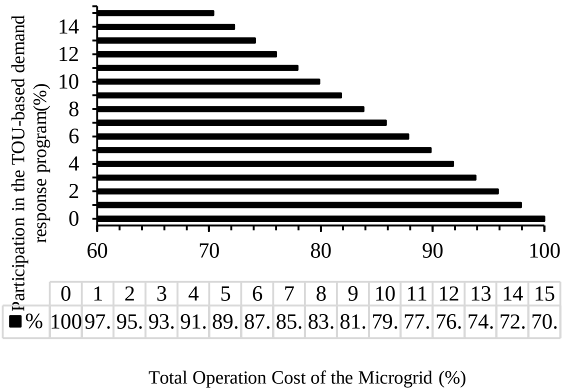


Fig. 2. Load curve after applying TOU program

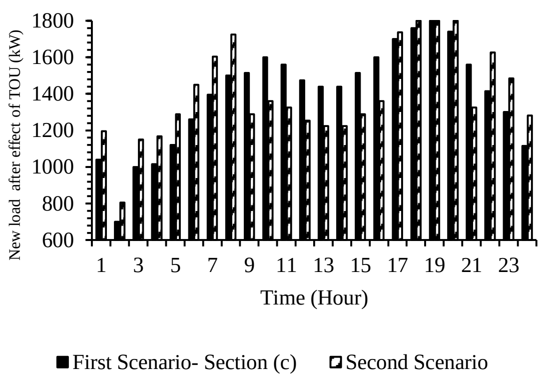


Fig. 3. Effect of participation percentage in the TOU program on total operation cost of the microgrid

Given the predicted price of the power market in

Table 9, the DLC demand response program reduces the operating costs and smooth the load curve by shifting load from expensive to inexpensive intervals as shown in Fig. 4. This figure shows that due to the use of DLC program, the consumed load declined from 10:00 to 17:00 is transferred to 01:00-07:00.

Table 11 shows the amount of power exchanged between microgrid and upstream grid as well as the scheduled power for local generation resources in the third scenario. Fig. 5 shows the impact of the participation percent in DLC program on the total operating cost of microgrid from 1% to 15%.

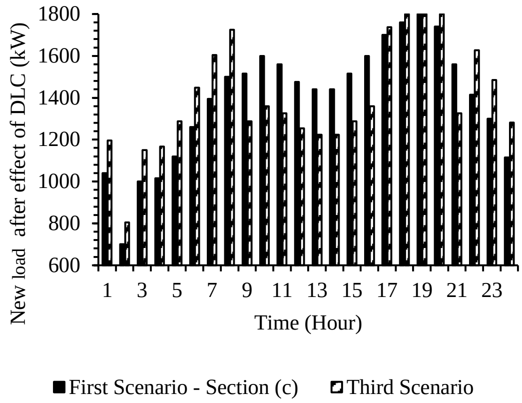
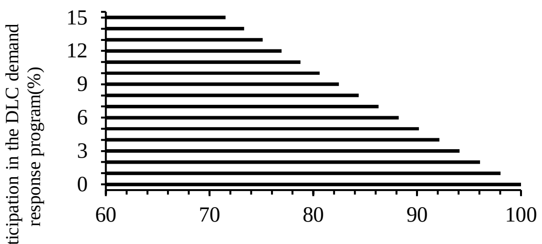


Fig. 4. Load curve after applying the DLC program



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
■ %	100	98	96	94	92	90	88	86	84	82	81	79	77	75	73	72

Total Operation Cost of the Microgrid (%)

Fig. 5. Effect of the participation percent in DLC demand response program on the total operating cost of microgrid

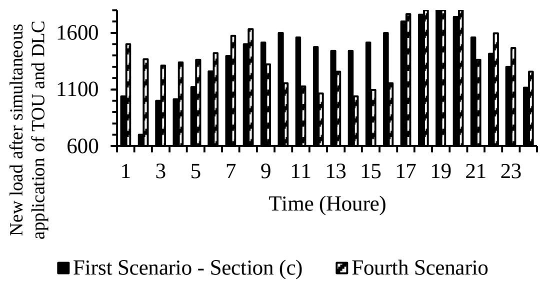


Fig. 6. Load curve after simultaneous application of TOU and DLC demand response program

4.4. Fourth scenario

In this scenario, the simultaneous effect of TOU demand response programs and DLC demand response program on load curves and reduction of operating costs of microgrid is investigated.

Table 12 shows the operating costs of different sections of the studied microgrid for section (c) of the first and fourth scenarios. According to this table, the total operating costs of the microgrid in section (c) of the first scenario are $2184.15. In the fourth scenario, adding the constraints of both TOU and DLC demand response programs to the objective function, the total operating costs of microgrid is in this scenario is $1089.57, which shows a reduction of 50.10% compared to the first scenario.

Fig. 6 shows the effect of simultaneous application of TOU and DLC demand response programs on the load curve. The power exchanged between the microgrid and upstream grid as well as the scheduled power for local generation resources in the fourth scenario is shown in Table 13.

5. CONCLUSIONS

In this paper, the optimal operation scheduling of an intelligent parking lot is considered, which plays two roles of load and energy generation resource for the distribution network. The effects of TOU and DLC demand response program to reduce the operating costs of the microgrid including intelligent parking lots, renewable energy resources such as wind and solar, and local generation resources such as fuel cell and micro turbine are investigated. This problem is modeled as mixed integer programming (MIP) and solved using the GAMS optimization software. Use of intelligent parking lots for charging/discharging management of electric vehicles reduced the risk of increased load during peak load that might occur due to the popularity of these vehicles. The proposed model helped the intelligent parking lot play the role of an integrator to collect the scattered electric vehicles in an accumulated area and load management. Presenting an appropriate V2G infrastructure by the intelligent parking lots also provided the possibility of selling the stored energy of electric vehicles or providing the required spinning reserve of microgrid to overcome the predicted errors of renewable power generation that would have serious risks for the power system. The results of the simulation showed that TOU and DLC demand response programs had a positive and effective impact on the cost reduction and load curve smoothness. Thus, the simulation results in four scenarios showed that TOU, DLC, and simultaneous use of TOU and DLC demand response programs led to the reduction of the operating cost by 29.60%, 28.40%, and 50.10% compared to the basic scenario, respectively. Thus, it can be said that the fourth scenario is preferable to the other three scenarios.

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