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Optimal Energy Procurement of Smart Large Consumers Incorporating Parking Lot, Renewable Energy Sources and Demand Response Program

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Abstract

Large commercial and industrial loads known as large energy consumers are always seeking to reduce their energy costs and consequently they are utilizing renewable and non-renewable energy sources in procurement of their required energy. Use of renewable energy sources (RESs) and plug-in electric vehicles (PHEVs) parking lot without proper planning will make technical and economic problems for the owner of the large consumers. This study provides a model for energy management of a smart large consumer (SLC), concluding PHEVs parking lot, RESs (photovoltaic (PV), wind turbines (WT)) and non-renewable sources (fuel cell (FC), micro-turbine (MT)). In this study, an optimal exploitation for the PHEVs parking is proposed, which has the potential of utilizing as an energy generation source with the goal of reducing operational costs of SLC. In addition, this study considers the demand response (DR) program as an energy source and reducing the costs. The purpose of objective function is decreasing the operation cost of SLC to the minimum amount while considering physical and technical constraints of the sources. The proposed model is considered both DR programs and PHEVs parking lot, and the results of the simulation illustrated the positive impact of the demand response program (DRP) and parking lot in reducing operation costs.

Keywords: Smart large consumer, Demand response program, Plug-in electric vehicles, Parking lot, Dispatchable generators microgrid;

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1. Introduction

In the traditional structure of large electrical consumers, the required energy was totally provided by the upstream network or conventional DGs. As a result, the large electricity consumers are not benefited from the advantages and profits of electricity market and do not have skills and necessary information to participate in providing their required energy. Also, the occurrence of some problems such as increase energy costs, reduce efficiency and system performance and the voltage drop at peak hours led the large consumers to provide their required energy by themselves. In addition to the mentioned problems, other problems such as reduce carbon-based sources and increase greenhouse emissions [1, 2], decision-makers and electrical policymakers encourage large consumers to utilize renewable energy sources such as WTs in most of the countries. The strategies, until now, have been done in the field of improving the efficiency and performance of the electricity procurement for large consumers. For this purpose RESs, DR programs and PHEVs parking lot can take place. Many large consumers have electric vehicles parking lots that are related to the staff and personnel of these large consumers or their customers. For example, Kourosh commercial complex in Tehran, Iran has a parking lot with 1600 parking spaces, with 600 units for owners and 1,000 parking spaces for guests [3]. In the near future, these parking lots which are related to large consumers can potentially contribute to the huge supply of large consumer needs. A parking lot can perform as an energy storage system which store energy in low price hours and use stored energy in high price hours [4, 5]. DR programs as effective instruments in order to contribute consumers at the electricity grid, it has provided contribution of load-side in order to improve the operation of the SLC and DR program in critical condition can decrease load quickly [6].Type of DR program used in this paper is time of use (TOU) [7]. TOU changes the demand from peak hours to non-peak hours, making the load curve smoother and reducing operating costs.

A) Literature review of power procurement by renewable energy sources

Nowadays, some issues such as the increasing need of electrical energy, reduce power purchase from upstream grid, increasing carbon-based emissions cause increase study about RESs and DG units [8, 9]. By modifying the structure of large consumers, RESs and DGs will be able to participate more in the supply of energy at a lower cost [10]. Utilizing RESs such as WT [11], PV [12, 13], and DG units such as MT [14, 15], FC [16, 17] will improve efficiency, operational costs and environmental pollutions.

B) Literature review of power procurement by PHEVs parking lot

The study was done by researchers in the field of incorporating PHEVs of a parking lot in energy management was done by many valuable works of the past. For example, in [18] while the parking lots are connecting grid and PHEV together in order to exchange power between them some suggestions are presented and according to statistical data and general rules on charging electric vehicles, a random method is presented in order to estimate the daily effect of existence PHEVs in the parking lot on the net. The problem of charging PHEV in the parking lot is solved by using game theory method in [19]. In [20], two studies presented, which compared together in order to determine the optimal charge strategy which one of them services besides the commercial areas and another one services beside the residential areas. In [21] optimal action of PHEV in the energy market and with considering DR program and the satisfaction of the PHEV owner is presented. In [22] PHEVs battery in the PHEVs parking lot is considered as a source of the energy storage in the multifunctional systems and for this purpose according to the profitable role of PHEVs parking lot , hub energy model has been modified in order to consider reservation resources as the ancillary services and participation in power generation. In [23] presented model of energy resources management with considering some constraint related to energy production and some constraint related to PHEVs and PHEV owners.

C) Literature review of power procurement of large consumers

A research about the tools that the large consumers require to contribute in upstream grid (UG) markets is presented in [24]. In [25] with considering load elasticity the optimal responses of a large consumer to the wholesale market prices is investigated. The energy procurement of a large consumer has been studied in [26], while it is considered that all necessary information are available, regardless of any uncertainty in UG prices or consumer consumption. A model based on concepts of information gap decision theory is presented in [27, 28] to evaluate the various methods for large consumers to provide their required consumption from various sources, e.g., UG market, bilateral contracts, and through local generation units. In addition, in [29], the second-order stochastic method is utilized for mid-term management of a large consumer.

D) Procedure and contributions

In this paper, energy management of a large consumer with contribution of PHEVs parking lot in providing the required energy is presented and DR program is utilized in order to decrease the operational costs of large consumer. In addition to the amount of charging and discharge of PHEV, generated power of conventional DG units which contains MT and FC compared and solved in two different cases in order to show the effects of the PHEVs parking lot participation in energy of the large consumer and the use of DR program in reducing costs.

According to the above, innovations proposed in this paper are as follows:

- Integrated management and operational scheduling of DG units and parking lot of the PHEVs in the large consumer.
- Using the DR program in order to decrease operation costs.
- Participation of the PHEVs parking lot for providing the energy required of large consumer and considering DR program at the same time (simultaneously).
- Modeling problem with mixed integer linear programming (MILP) which guaranteed the global optimum.

E) Paper organization

The structure of paper is categorized as follows: mathematical modeling is presented in section 2 which related to the optimum utilization of the PHEVs parking lot and reduces the cost of the large consumer in the presence of DRP. The model has been evaluated by two cases which were compared with each other to see the participation effect of the PHEVs parking lot in large consumer in the presence of the DR program in section 3. At last, in section 4 final conclusions based on the obtained results is presented.

2. Formulation

The presented large consumer in this paper contains several distributed resources such as WT, PV and PHEVs parking lot. In order to increase the reliability, large consumer is also connected to UG to purchase energy base on load requirement. Another factor that plays an important role in reducing costs is the PHEVs parking lot which can utilize as an energy generator with discharging PHEVs and plays the role of load with charging PHEVs. PHEVs while entered to the parking lot, the owners of the PHEV share information concluding charging and discharging cost restricts, the primary amounts for SOC of the PHEVs, passed time of batteries life and expected SOC of the PHEVs at exiting time from the parking. After that PHEVs parking lot sends received information to the operator of SLC to do proper scheduling in order to reduce the costs. This operator of SLC creates a communication path between SLC and UG. The major task of the operator is optimizing operation of the SLC. In short, the overall shape of this set will be as follows:

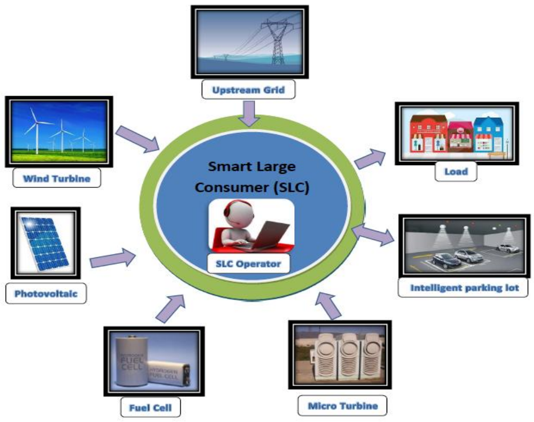

Fig. 1. Topology of the smart large consumer

A) *Objective function*

The purpose of this study is reducing the operation costs of the SLC which is mathematically presented as following model:

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

Formula (1) consists of three parts. The first part includes the costs of the exchanged power between the SLC and UG. The second part includes the start-up and operation costs of DGs in the SLC. And the third part includes the cost of charge/discharge and exchange power between SLC and PHEVs. About the costs and constraints related to the costs will be discussed in the following.

B) *wind turbine*

WT have a considerable influence in large consumer. Mathematical equivalent of the output power from the WT based on the air speed is presented as below [30].

$$P_{W}^{k,t}=\begin{cases}0 & V^{t}<V_{c}^{k}\ or\ V^{t}\geq V_{F}^{k}\\ \dfrac{V^{t}-V_{c}^{k}}{V_{R}^{k}-V_{c}^{k}}\times P_{R}^{k} & V_{c}^{k}\leq V^{t}<V_{R}^{k}\\ P_{R}^{k} & V_{R}^{k}\leq V^{t}<V_{F}^{k}\end{cases} \quad (2)$$

C) *photovoltaic system*

The mathematical equations of the PV and the effect of the solar radiation and temperature changes on the PV is presented as below [31].

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

D) *DG*

Operation costs and Start-up costs of the DG which contains MT and FC are presented in equations (4)–(6), respectively [32].

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

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

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

Constraints (7)-(12) are utilized to model DG units as follows:

$$P_{LDG}^{j,t}+SR_{LDG}^{j,t}\leq P_{LDG,\max}^{j}\times U^{j,t} \quad (7)$$

$$P_{LDG}^{j,t}\geq P_{LDG,\min}^{j}\times U^{j,t} \quad (8)$$

$$P_{LDG}^{j,t}-P_{LDG}^{j,t-1}\leq RU^{j}\times U^{j,t} \quad (9)$$

$$P_{LDG}^{j,t-1}-P_{LDG}^{j,t}\leq RD^{j}\times U^{j,t-1} \quad (10)$$

$$U^{j,t}-U^{j,t-1}\leq U^{j,t+Up_{j,f}} \quad (11)$$

$$U^{j,t-1}-U^{j,t}\leq 1-U^{j,t+Dn_{j,f}} \quad (12)$$

$$\mathrm{Up}_{j,f}=\begin{cases}f & f\leq \mathrm{MUT_{j}}\\ 0 & f>\mathrm{MUT_{j}}\end{cases} \quad (13)$$

$$\mathrm{Dn}_{j,f}=\begin{cases}f & f\leq \mathrm{MDT_{j}}\\ 0 & f>\mathrm{MDT_{j}}\end{cases} \quad (14)$$

DG Produced power shows in equations (7) and (8) including minimum and maximum amounts .Equations (9) and (10), respectively presented the rate of increasing and decreasing produced power from the DG for two consecutive hours. Finally, limits related to the minimum up/down times of the DG are presented in equations (11) and (12). In equations (13) and (14) linear modeling of minimum up/down times of the DG are presented, respectively.

E) Constraint of the UG

Constraint (15) is presented in order to limit the exchanged power between the SLC and UG in order to comply the constraints of the feeder and the conductor wire which connected SLC to grid.

$$\left|P_{UG}^{t}\right| \le P_{UG}^{\max} \qquad (15)$$

F) PHEVs parking lot

PHEVs in order to charging and discharging and participate in providing energy of the SLC through parking should respect the following constraints:

G) Charging and discharging constraints

Each charger has the highest rate of charge/discharge which constraints (16) and (17) are mentioned to determine this rate.

$$P_{Ch,PHEV}^{i,t} \le P_{Ch,\max}^{i} \times W_{ch}^{i,t} \times M^{i,t} \qquad (16)$$

$$P_{Dch,PHEV}^{i,t} + SR_{PHEV}^{i,t} \le P_{Dch,\max}^{i} \times W_{Dch}^{i,t} \times M^{i,t} \qquad (17)$$

H) Asynchronous of charge/ discharge

Constraint (18) is presented to avoid simultaneous charging and discharging of PHEV batteries.

$$W_{ch}^{i,t} + W_{Dch}^{i,t} \le 1 \times M^{i,t} \qquad (18)$$

I) Switching among the charging/discharging states

Constraint (19) is presented in order to allow operator to consider the maximum amount of the switchable times among the conditions of charging/discharging which should be restricted according to the PHEV battery life.

$$\sum_{t=t_a^i}^{t_d^i} W_{ch}^{i,t} + W_{Dch}^{i,t} \le N_{\max} \qquad (19)$$

J) Limitations relevant to the capacity of the PHEV batteries during charge/discharge

At each period of the time, amount of stored energy in the PHEV is equal to the PHEV charge and discharge plus efficiency of the PHEVs charging and discharging. The mathematical model of this statement provided in equation (20).

$$SOC^{i,t} = SOC^{i,t-1} + P_{Ch,PHEV}^{i,t} \times \eta_{G2V} - P_{Dch,PHEV}^{i,t} / \eta_{V2G} \qquad (20)$$

K) Limitations relevant to the PHEV SOC

At each period of the time, the amount of stored energy in the PHEV should be between the minimum and maximum level of stored energy. For this reason, equation (21) is presented.

$$SOC_{\min}^{i} \le SOC^{i,t} \le SOC_{\max}^{i} \qquad (21)$$

L) Constraints related to the rate of PHEV charge/discharge

Constraint (22) allow the operators to consider the maximum rates of charging/discharging and restricts the SOC variation of PHEVs during every hour.

$$-\Delta SOC_{\max}^{i} \le SOC^{i,t} - SOC^{i,t-1} \le \Delta SOC_{\max}^{i} \qquad (22)$$

M) Constraints related to SOC of the PHEVs at departure time

Constraint (23) Guarantees that SOC of the PHEVs at leaving and departure time from the parking should address the SOC which determined by the owner of the PHEVs. It is supposed that the owners of PHEVs are determined that SOC of the PHEVs in departure time should be more than 80 percent of their maximum SOC. In addition to, constraint (24) restricts the amount of PHEV energy when entering to the parking.

$$SOC_{\text{Departure}}^{\text{i,t}} \ge 0.8 * SOC_{\max}^{i} \qquad (23)$$

$$SR_{PHEV}^{i,t} \le \alpha \times P_{Dch,\max}^{i} \times W_{Dch}^{i,t} \times M^{i,t} \qquad (24)$$

N) Demand Response Program

The TOU rates of the DR program have been used in this paper. This program transfer the SLC consumption from peak hours to non-peak hours and make the demand curve more smoothen which it would reduce costs of SLC. It is supposed that the shift-able load by utilized DR program is only 20 percent of the load of SLC. Mathematical equations of the mentioned sentences are presented in equations (25) and (26).

$$load^{t} = (1 - DR^{t}) \times load_{0}^{t} + idr^{t} \qquad (25)$$

$$load_{0}^{t} - load^{t} = DR^{t} \times load_{0}^{t} - idr^{t} \qquad (26)$$

Technical constraints related to DRP are expressed in equations (27)-(30).

$$\sum_{t=1}^{T} idr^{t} = \sum_{t=1}^{T} DR^{t} \times load_{0}^{t} \tag{27}$$

$$load_{inc}^{t} \le inc^{t} \times load_{0}^{t} \tag{28}$$

$$DR^{t} \le DR_{\max} \tag{29}$$

$$inc^{t} \le inc_{\max} \tag{30}$$

Amount of transferred load depends on the differences of the price in the market at any period of time. Amount of shifted loads at any period will have different amount and size which mathematical model of these sentences is mentioned in the equation (27). Equation (28) cause limitation of increasing load at any period. DR program will transfer the 20 percent of the consumption from one period to another period which equations (29) and (30) expressed for this reason. Finally, it should be pointed out increasing and decreasing shifts should be equal during the operation.

O) Power balance constraints

The objective function contains one constraint which cause balance among produced or purchased energy and demand of the SLC. The mathematical formulation of these sentences is provided by equation (31). In this equation, instead of the base load, a new load with considering the effect of the DRP had been replaced.

$$P_{UG}^{t} + \sum_{k=1}^{K} P_{W}^{k,t} + \sum_{p=1}^{P} P_{PV}^{p,t} + \sum_{j=1}^{G} P_{LDG}^{j,t} + \sum_{i=1}^{N} P_{Dch,PHEV}^{i,t} = load^{t} + \sum_{i=1}^{N} P_{Ch,PHEV}^{i,t} \tag{31}$$

3. Case Study and Simulation Results

This study is looking for optimal operation of a SLC with considering the presence of the DR program and PHEVs parking lot in providing both energy of the SLC with contribution of the DGs. The main goal of this paper is decreasing operational costs of the SLC with considering some constraints related to DGs, PHEVs parking lot and UG. The proposed objective function is simulated as MILP and solved utilizing GAMS optimization software.

A) Case study

Table 1. and 2. are providing the input parameters of the PV and WT respectly [33]. The MT and FC input parameters are presented by Table 3. The next 24 hours prediction for load consumption and the price of UG are expressed by figures 2 and 3. In addition, the prediction of weather station for next 24 hours wind speed and solar irradiation is presented by figure 4 and 5 [34]. In order to bring the study closer to reality and according to presence of various types of PHEVs with different SOCs (period between 8 to 48 kWh) [35], the utilized PHEVs have a SOC in a period of 10 and 20 kWh. The capacity of the PHEVs parking lot is 230 PHEV and SOC of ith-PHEV at arrival time to the PHEVs parking are considered an amount between 0.1 and 0.7 randomly. The charging price of every PHEV in parking lot is considered an amount between 0.15 and 0.3 and the discharging price of every PHEV is intended an amount between 0.25 and 0.4 randomly. Other information of the PHEVs are proposed in Table 5. Exchanged power between the SLC and UG is also limited and only 1000KW can be exchange between the SLC and UG. It should be mentioned that DR program has the ability of the shifting 20 percent of the SLC consumption in every hour.

B) Simulation results

In order to participate PHEVs parking lot in the energy providing of SLC and also assess the effect of parking lot on the operational costs of SLC, the objective function has been investigate in two cases as follows:

Case 1: In case one, the model is solved with considering the constraints of the UG, DR program and DGs without considering the contribution of the parking lot.

Case 2: In case two, in order to investigate the effect of PHEVs parking lot on the demand curve and operation costs, the model is solved with considering the contribution of PHEVs parking in providing energy of the SLC near the considering the constraints of the UG, DR program and DGs.

Finally, the results of operational costs for two cases are compared. Output energy production of WT and PV are presented in Figures 6 and 7 respectively. Due to the fact that in the short term operation of PV and WT, costs are not considered, these two units work in both cases at their maximum power.

The obtained results of the two cases which are related to operation costs of the SLC are shown in Table 4. According to this table, in the first case, which PHEVs parking lot has not participated in providing the energy of SLC, operating costs was 1782.477$. In the second case, model is studied in order to observe the positive effect of the PHEVs parking lot on the reducing the operation costs of the SLC. With comparing cases 1 and 2, we see that PHEVs parking lot cause 40.08 percent reduction in costs. Reducing the produced power by the second MT and increasing the produced power by the first MT cause reduction in operation costs.

Table.1.
Parameters of the PV

Parameter	***Value***	***Unit***
η	15.7	%
S	1500	m^2
T_a	25	$^\circ C$
ω_{PV}	20	%

Table.2.
Parameters of the WT

Parameter	***value***	***unit***
P_R	500	*KW*
V_C	3	*m/s*
V_R	12	*m/s*
V_F	30	*m/s*
ω_W	20	%

Table.3.
Parameters of the DGs

DG	***type***	***a***	***b***	***p^{min}***	***p^{max}***
		$	***$/KW***	***KW***	***KW***
1	MT	0.02	0.15	150	700
2	MT	0.04	0.25	100	450
3	FC	0.09	0.45	50	300
DG	MUT,MDT	t_{on} t_{off}	UDC	RU	RD
	h	h	$		
1	3	4	0.1	350	350
2	2	-6	0.02	200	200
3	1	-8	0.02	150	150

Table.4.
Parameters of the PHEVs

α	T_P^i	$P^i_{Ch,\max}$	$P^i_{Dch,\max}$	$SOC^i_{\max}$
0.2	2−8	5−10	5−10	10-20
$SOC^i_{\min}$	$\Delta SOC^i_{\max}$	η_{G2V}	η_{V2G}	$N_{\max}$
·	5-10	0.9	0.8	10

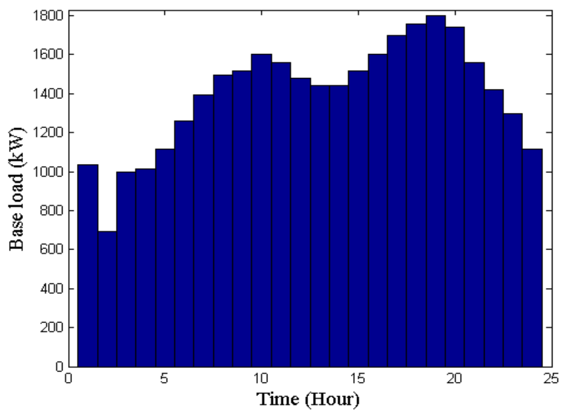

Fig. 2. Load prediction for SLC

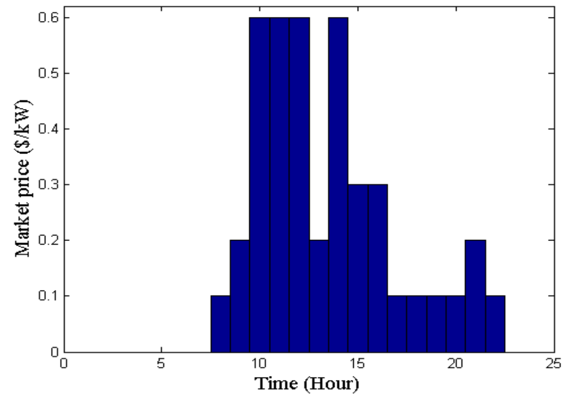

Fig. 3. Predicted UG market price

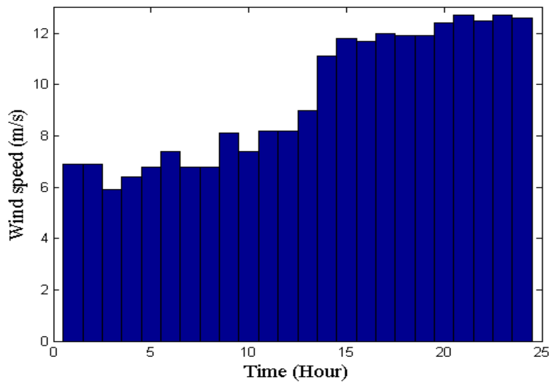

Fig. 4. Predicted next 24 hour wind speed

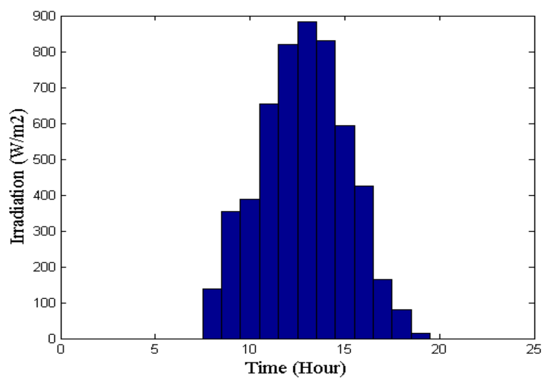

Fig. 5. Predicted next 24 hour solar irradiation

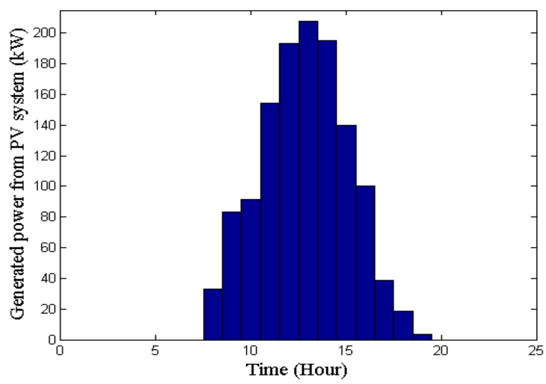

Fig. 6. Output power of the Photovoltaic system

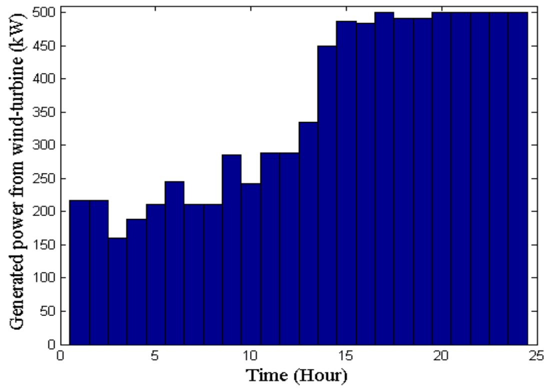

Fig. 7. Output power of the Wind turbine

Table.5.
Simulation Results of the objective function in two cases

	Case 1	Case 2
Operation costs	5110.046	3650.456
Decrease cost compared to case 1	--	40.%

Figs. 8 and 9 shows the charging and discharging and SOC of the PHEVs in the parking, respectively. As shown in Fig. 8 in hours witch the UG price is high the PHEVs are discharged through parking lot in order to decrease SLC cost and in hours with low price hours the PHEVs are charged. As can see in Fig. 9 the SOC are high in low price hours which PHEVs are charged and the SOC of PHEVs are low in high price hours which the PHEVs are discharged in this hours.

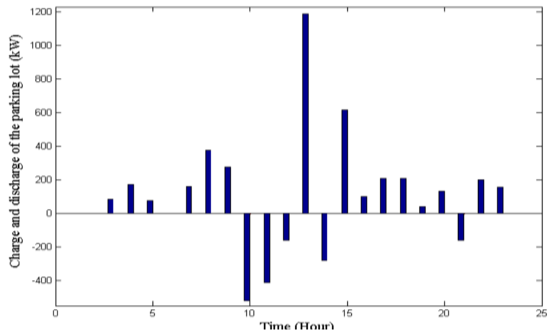

Fig. 8. Charging and discharging of the PHEVs

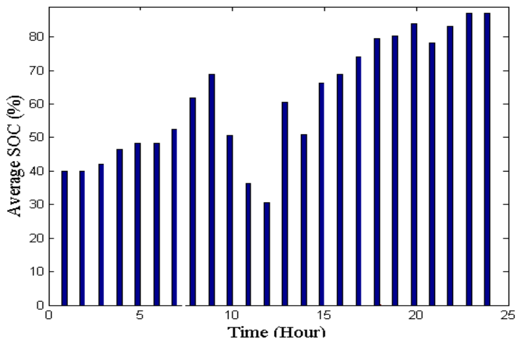

Fig. 9. SOC of the PHEVs

Fig. 10 shows the exchanged power between the SLC and UG. In case two during peak periods, due to production of parking lot, there is more power for selling to UG than case one and there is less require to purchasing power than case one and cause reduction in the operation costs of the SLC. Output power of the DGs which includes two MT and one FC, are shown in Figs. 11-13, respectively. As can be seen in these figures with contribution of parking lot through case 2, MT1 due to fewer costs has more contribution in power production and MT2 and FC because of being more expensive have less contribution in power production. In addition, as can see in Fig. 14 DR program will smooth the demand curve and will transfer the consumption from peak hours to non-peak hours cause the decrease in operational costs of both of two cases.

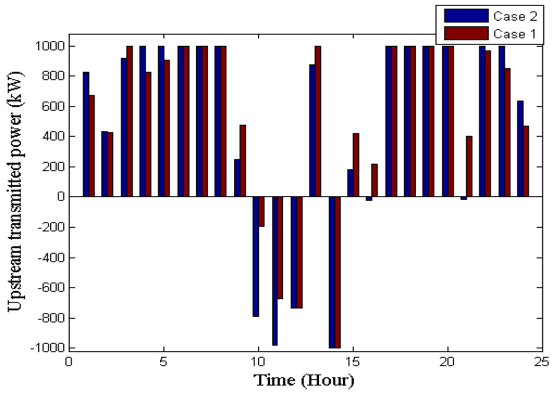

Fig. 10. Exchanged power with the UG

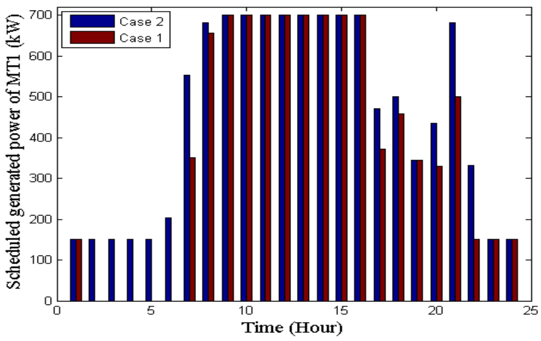

Fig. 11. Output power of the MT1

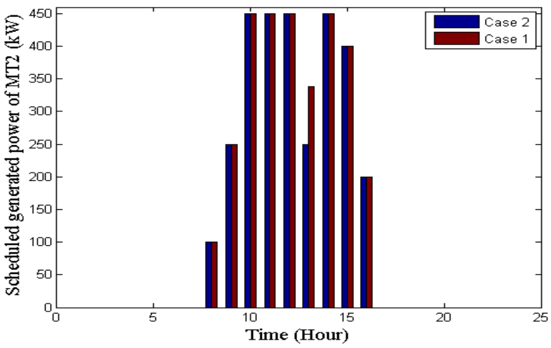

Fig. 12. Output power of the MT2

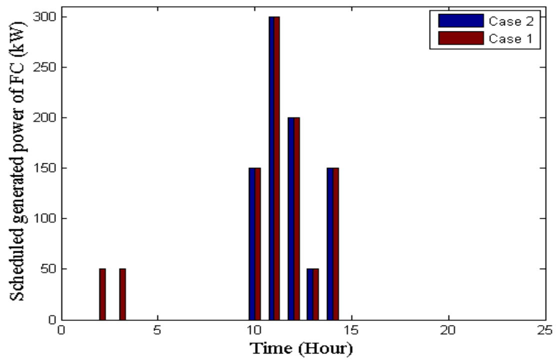

Fig. 13. Output power of the FC

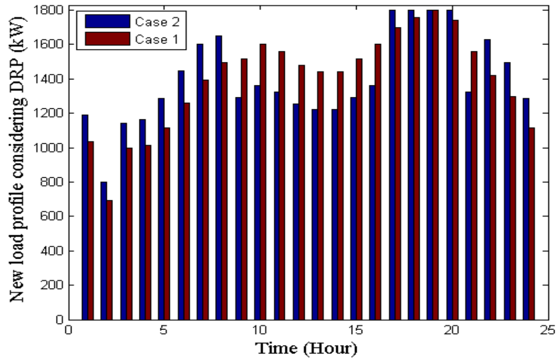

Fig. 14. New load curve with considering the DRP

4. Conclusion

In this paper, an optimal short term scheduling for proper operation of a SLC is presented. In addition, the effect of a PHEVs parking lot which plays the roles of the load and energy source is evaluated in reducing operating costs. RESs and DG units such as WT, PV, MT and FC and DR programs are considered in energy production of SLC. The proposed model is formulated as mixed-integer linear programming (MILP) and solved using GAMS software. In this paper, DR program are utilized to shift the load from peak hours to non-peak hours and parking lot are utilized to help the SLC in providing energy and decreasing costs. Results showed that parking lot had a positive effect on reducing the operation costs. On the other hand, by analyzing the obtained results we understand that PHEVs parking lot play a collector role and with managing charge/discharge of the PHEVs prevented SLC from purchasing power with high prices.

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Nomenclature

Indices

t	Index for time
j	Index for DG units
i	Index for PHEVs
k	Index for WT
p	Index for PV system
f	Index for modeling minimum on/off time of DG constraints.

Parameters

P_R^k	Rated production for *k*th WT
$P_W^{k,t}$	The output production for *k*th WT at time t
V_c^k	Minimum speed of WT k
V_R^k	The nominal speed of WT k
V_F^k	Maximum speed of WT k
V^t	The speed predicted for wind at time t
$P_{PV}^{p,t}$	The production of PV p at time t
η^p	The conversion efficiency of PV arrays
s^p	The area of PV
T_a	The ambient temperature around the PV
G^t	The predicted radiation on PV
a^j , b^j	the coefficients of DG j produced power cost
$P_{LDG,\max}^j$	The maximum DG j produced power
$P_{LDG,\min}^j$	The minimum DG j produced power
MUT_j , MDT_j	The *j*th DG minimum up/down time
$t_{ON}^{j,t}$, $t_{OFF}^{j,t}$	Duration of continuously on or off the DG j at time t
UDC^j	Startup Costs of the DG j
RD^j , RU^j	The rate of increase/decrease of the DG j
$TU^{j,n}$	The minimum on time of the DG j
$TD^{j,n}$	The minimum down time of the DG j
π_{UG}^t	The price of power purchasing from upstream-grid at time t
N_{Ev}	The number of PHEV parked in the PHEVs parking lot
$P_{UG}^{\max}$	The maximum exchangeable power between the SLC and the UG
Δt	The sampling time to count available PHEV in the PHEVs parking lot
$P_{Ch,\max}^i$	The maximum charging rate of PHEV i
$P_{Dch,\max}^i$	The maximum discharging rate of PHEV i
$SOC_{\max}^i$	The maximum SOC of the PHEV i
$SOC_{\min}^i$	The minimum SOC of the PHEV i
$\Delta SOC_{\max}^i$	The maximum allowable charge/discharge rate of PHEV i
T_p^i	The approximate time of presence PHEV i in the PHEVs parking lot
$\pi_{Ch,PHEV}^i$	Favorable PHEV i charging price for the PHEVs parking lot
$\pi_{Dch,PHEV}^i$	Favorable PHEV i discharge cost for the PHEVs parking lot
η_{V2G}	The efficiency of discharging PHEV battery
η_{G2V}	The efficiency of charging PHEV battery

$SOC_{Arrival}^{i,t}$	Initial SOC of the PHEV i at arrival time to PHEVs parking lot at time t
$N_{\max}$	The maximum allowable switching amount among the charge state and discharge state
ω_{W}	The error of forecasted wind speed
ω_{Pv}	The error of forecasted solar radiation
$load_0^t$	Base load at time t
$DR\max$	The maximum amount of the load participating in DR program
$inc\max$	The maximum amount of increase load at time t
$M^{i,t}$	Equal to 1 if the PHEV i be in the PHEVs parking lot at time t otherwise 0
t_a^i	Approximate entrance time of PHEV i into the parking
t_d^i	Approximate time for PHEV i departure out of parking

Variables

P_{UG}^t	Exchanged power between the SLC and UG
$C_{LDG}^{j,t}$	The DG j scheduled power cost at time t
$SC_{LDG}^{j,t}$	The startup cost of DG j at time t
$P_{Ch,PHEV}^{i,t}$	The power of PHEV i charging at *t*th time
$P_{Dch,PHEV}^{i,t}$	The power of PHEV i discharging at *t*th time
$P_{LDG}^{j,t}$	The scheduling power of DG j at time t The DG j scheduled power at time t
$SOC^{i,t}$	SOC of PHEV i at *t*th time
$\Delta SOC^{i,t}$	Amount of energy changes in two consecutive hours at *t*th time
$SOC_{Departure}^{i,t}$	Final PHEV i SOC when leaving the PHEVs parking
$load^t$	The new load after Placement DRP at time t
DR^t	The amount of DRP participation at time t
idr^t	Transferred load from one period to another period at time t
$load_{inc}^t$	The amount of increased load at each period of time t
inc^t	The size of increased load at each period of time t
$W_{ch}^{i,t}$	variable which is 1 when the PHEV i in the parking be in charging mode at time t otherwise 0
$W_{Dch}^{i,t}$	variable which is 1 when the PHEV i in the parking be in discharging mode at time t otherwise 0