Integrated Planning of Renewable-Dominated Energy Systems and Demand Side Resources

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ABSTRACT:
In the present paper, the effect of an integrated planning of renewable energy resources, electrical and thermal storage, electric vehicles charger strategy, and various side demand response programs on electrical and thermal load supplying cost of a residential area was investigated. In this regard, a mathematical model was presented for an optimal integrated planning of renewable energy resources, heating equipment of buildings, thermal and electrical storages, electrical vehicles with respect to demand side management. The proposed model for optimal planning has been formulated as a mixed integer linear programing model. In this model, operational constraints of distribution network were considered. In order to evaluate the performance of the proposed model, its efficiency on electrical and thermal resources of a residential area with certain number of buildings was analyzed. The simulation obtained results revealed that using thermal and electrical storages and side demand response programs as well as the presence of a high number of electric vehicles can be followed by many merits when it is controlled by an energy management system. The outmost advantage is power absorption in low-load hours and releasing it in peak hours. This advantage causes decreasing load peak for electricity network and subsequently, decreasing the cost of supplying a residential area's electricity. It is useful for both residents and operator. As found, it can be generally stated that an optimal and integrated planning of energy resources with respect to side demand management significantly decrease energy supply costs. According to simulation results, an integrated planning of all energy resources of a residential area can decrease consumption power in peak hours, energy supply cost as well as the need of buying it from a distribution network. This is in favor of both consumers and distributor company.

KEYWORDS: Integrated Planning, Renewable Energy Resources, Demand Response Program, Energy Storage, Electric Vehicles.

1. INTRODUCTION

Energy storage is an effective tool for energy management. Reviewing the related literature shows that using storages in power system and in small sizes to very large sizes positively influence power system. However, electrical storage in large scale is not affordable and sometimes impossible due to some problems such as high cost, limited capacity and environmental problems. To solve such problems, various types of energy storages have been presented or improved during the recent years. The most important type of storage is thermal storage. During the recent decades, thermal storages have been used to supply heating and cooling systems in commercial buildings. Using them in residential buildings, however, have many advantages. In addition, during the recent years, plug in electric vehicle (PEV) including plug in hybrid electric vehicle (PHEV) and electric vehicles (EV) have been highly popular due to their advantages compared to other transportation technologies. They are environment-friendly. The other advantages include, low noise, high energy return, operational costs decrease, high potential of locally using renewable energies, and providing ancillary services through vehicle to grid (V2G) energy exchange. One of the main advantages of using electric vehicles in power systems is to use their battery as mobile storage, which highly reduces the need of buying and installing electrical storage in network.

Accordingly, distribution systems should be planned with respect to renewable resources, electrical and thermal energy storages, electric vehicles, as well as demand response programs. In the present work, we are focused on the residential areas. Additionally, in order to the maximum use of the mentioned resources, it is necessary to plan for all residential resources of buildings in simultaneously. Moreover, various Demand Side Management (DSM) methods have been considered and the effect of various demand response resources and DSM on cost have been studied. To increase the flexibility of the proposed modeling, flexible alternatives such as smart charge and discharge of electrical and thermal storage, smart charge and discharge of electric vehicles, using renewable energy resources, demand response of power factor correction have been also presented in the results. A mathematical model is proposed which is a Mixed Integer Linear Programming (MILP) problem.

In [1], a new random model for risk management and electric vehicles participation in demand response has been proposed. New opportunities for demand response has been discussed with respect to electric vehicles. In this research, electric vehicles have been considered as scattered energy sources with power absorption and injection capability. Also, it has been stated that the electric vehicles participation in time of use-based demand response and incentive-based demand response can improve stability and decrease probable dangers for electric network. In addition, it has been proved that optimal charge planning provides the opportunity of a high penetration of renewable energies in power systems.

In [2], electrical and thermal loads flexibility of an area with different electrical and thermal resources have been investigated. In other words, the concept of demand response and flexibility has been used to evaluate the effect of various side demand management methods. In order to enhance the flexibility of modelling, different flexibility alternatives such as electrical and thermal storages, alternative energy resources, reducing service providing for customers, and power factor correction have been considered. One of the key features of the proposed model is its resistance against required reserves and ensuring meeting residents' welfare in terms of temperature.

In electric vehicles' charge planning, three main members are usually involved, including vehicle owner, charge services supplier and distribution system operator. Previous works presented electric vehicles' optimal charge methods are classified based on the mentioned three members. In new researches, all three members have been considered. In [3], for example, an optimal charge method for electric vehicles for three-phase system has been proposed. In this method, charge planning has been performed based on cost function with respect to electricity network constraints and charge planning has been solved by solving linear planning for all three parts. Reference [4] has proposed a method for electric vehicles' optimal charge in which the three parts have been considered separately. In this method, charge services provider predict and collect electric vehicles demand and their accessibility hours. This paper presents a linear planning and its cost function is charge cost minimization and network and electric vehicles constraints are considered.

Most of early studies on electric vehicles have been carried on with the purpose of omitting or decreasing electric vehicles charge effect on network. Using controlled charge of electric vehicles, transmission lines congestion and voltage loss in peak hours can be avoided [5]. Given to the fact that common structure in electric vehicles is able to transmit power from vehicle to network, these vehicles' battery can be considered as short-term storage. In reference [6], this capability of electric vehicles has been employed to decrease electric lines congestion caused by conventional loads. It is performed by distribution system operator. Planned charge also helps the maximum congestion of renewable energies-based dispersed generation resources [7].

Other studies have focused on the second member or charge services supplier. The studies in this domain have a common cost function with the aim of energy supply cost minimization for electric vehicles charge. Reference [8] has aimed at minimizing electric vehicles charge cost through optimizing charge power amount and time. Some researchers have emphasized on distribution system operator. The empirical studies carried on this category have also presented a common cost function with the aim of reducing electric vehicles charge effect on electricity network. References [9, 10] also aimed at minimizing power losses of network due to electric vehicles charge through time and charge amount optimization.

In reference [11], a scenario-based resistant energy management method has been proposed to consider uncertainty of scattered generation resources and demand. In this work, interval prediction has been used to model uncertainty of scattered resources and demand. Demand response is one of the effective tools to provide the opportunity of renewable energies congestion with micro-grids and decrease their output power oscillations. In some studies, demand response has been employed to manage uncertainty of dispersed generation's output power. In [12], a new method of smart distribution systems line congestion has been proposed. This method has been based on demand response and uncertainty of dispersed generations has been considered.in this study, a two-level optimization model has been proposed.

In [13], the problem of mutual contract with respect to uncertainty for a retailor has been solved. The considered energy generation resources include energy supply, mutual contract, dispersed generations, energy storages, and demand response. Researcher has employed scenario-based random structure to model uncertainty. In [14], a two-stage resistant coordinating strategy has been proposed for micro-grid. At the first stage, output power and demand of non-distributable resources are predicted and an optimal planning is performed a day before price-based demand response. Then, the output power of distributable resources are planned in such a way that load uncertainty and non-distributable resources are covered. At the second stage, a more precise prediction is made for output power of non-distributable resources and demand responses. The overall aim of this optimizations is to maximize micro-grid efficiency by satisfying the problem's constraints with respect to load uncertainty and dispersed generations.

In [15], a comprehensive sensitivity analysis has been performed to identify uncertainty parameters with the highest effect on decision making process in investing on dispersed generations and measure their effect degree.in this regard, an investment planning model was formulated for dispersed production in multi-scenario and multi-stage optimization. This model has been formulated and solved as a mixed integer linear programming. In [16], a probable framework has been proposed to operate distribution networks with respect to dispersed generation resources and energy storage systems. In this framework, uncertainty of electricity price and output power of dispersed generations have been considered. To consider uncertainty, probability distribution function and Mont Carlo simulation has been used. It has been done to calculate daily profit of distribution network and risk analysis. Value at risk was used for risk analysis.

Using thermal loads for side demand management is not a new method. In some previous works used local experiments, it was shown that a set of electric refrigerators and heaters can provide the power required by frequency reserve [17]. In some studies, day-ahead planning for thermal loads and algorithm-based control methods have been proposed to control thermal loads [18, 19]. In some references, the aspects of thermal loads dynamic control have not been considered. It has been investigated in [20] with the aim of improving voltage using thermal storages. In this work, technical details have been focused to reach instant demand response in real time. In Table 1, the advantages of using energy storage are glanced.

Table 1. Technical and economic advantages of using energy storage

Technical advantages	Economic advantages
Supplying a part of reserve power Improving energy supply conditions during load peak Increasing using renewable energies	Reducing operating costs Reducing the need of installing new power plants Decreasing paid bill of customers Reducing costs of power outage

This paper is organized as follows. In section 2, the Study Prerequisites are presented. The methodology will be described in section 3. The results of the proposed method are presented in section 4, and finally, the paper will be concluded in section 5.

2. STUDY PREREQUISITES

This kind of storages functions through short-time energy saving at high or low temperature. Thermal storages are not regarded new since they have been employed for several decades. Such storages are used for periods when there are imbalance between production and consumption, to compensate variability of electrical energy due to renewable energies as well as compensating the changes of thermal energy resulted by sun light in solar systems. Thermal storages have three different technologies which are briefly described.

2.1. Thermal Energy Storage

In the first type, energy is stored through heating a liquid or solid without changing its phase, which is called rational heat storage. The energy stored in this mode depends on temperature change in the substance used in storage. In the second type, energy is stored through heating a substance with phase change, which is called latent heat storage. The energy stored in this kind of storage depends on the amount and latent heat of substance melting used in the storage.

In the third type, heat is used to create physical or chemical activity and store the resulted substance. During the reverse reaction, thermal energy is released. The mentioned chemical activity is performed in thermal insulation conditions to prevent thermal energy loss.

Using thermal energy storages has many advantages. One of the main advantages is that they can provide the opportunity of using cold or warm renewable resources which is impossible without thermal storage. For these systems, storage duration can be short or long. Short time storage usually means day-to-night or nigh-to-day storage. On the other hand, long time storage refers to storage between seasons, or seasonal storage. For example, solar energy storage from morning to night or long time storage from summer to winter can be used to decrease the energy purchased to heat house [21].

Overnight conditioning of buildings is another example of short time cold storage in which building and its constituents cooled overnight decrease the need of activating cooling system during day. Snow storage in winter is also another example for long term cold storage which is used for cooling in summer. Buildings with high internal efficiency have excessive heat which can be stored during day, leading to decrease cooling demand. Additionally, releasing the heat stored overnight also decreases thermal demand. The mentioned cases are the examples of the way of using variable heat or cold resources to decrease building demand and subsequently, decreasing the purchased energy [21].

Thermal energy storage are used to decrease thermal energy demand as well as displacing heating or cooling time. It is known as "load shifting [22, 23]. Although these strategies are used for both heating and cooling, they are often propounded for buildings cooling.

Increasing efficiency or decreasing harmful pollutions, thermal energy storage can enhance the performance of heating or cooling systems. Increasing efficiency of thermal system in load straightening strategy, chiller can often work out with optimum efficacy. Using phase changing substances as both storage and heat transmission liquid can increase cooling system efficacy, causing the decrease of the power required by fans or pumps [24]. In references [25, 26], using one unit thermal storage decreases the number of boiler set up and stop and decrease harmful pollutions

2.2. Demand response programs

According to U.S Department of Energy, demand response programs are fallen into two general classes [27]:

1. Incentive programs
2. Time tariffs

Each of the above mentioned programs include various methods. In incentive programs, awards are given to motivate customers who tend to participate load management program. The awards are paid at peak time or critical times in terms of reliability. These programs are implemented by both retailors and operator. In time of use programs, customers are interested in decreasing their consumption at times with high using price. The programs have been designed to level out electricity price in different hours [27]. Table 2 presents a summary of both programs.

Table 2. The technical and economic advantages of energy storage.

Time tariffs	Incentive
Programs of time of use price Programs of real time price	Direct load control [28] Blackout or load reduction Diamond sale Emergency load demand response Market capacity programs Ancillary services programs

2.3. Electric Veicles

Vehicle to grid (V2G) allows power mutually passes through battery and power system. Due to energy storage capacity, using these vehicles creates more desirable conditions for employing renewable energy resources in power system. On the other hand, if electrical energy required by electric vehicles is supplied by energy generated through renewable resources or fossil units with low pollutants emission at non peak hours, using these vehicles cause the decrease of air pollutant gases. Environmental issues and battery technology advancements have increased the tendency to use electric vehicles. Hybrid electric vehicles are regarded a good start to change electric vehicles but the distance they can travel with a charge period is limited. Due to the mentioned problem, V2G hybrid electric vehicles were introduced since they can be connected to network at any point with embedded output electric energy. These vehicles have internal battery and combustion engine. Normally, most of the energy required by these vehicles is supplied by electrical energy and combustion engine is used to supply the required energy if their battery charge is not adequate.

When V2G hybrid electric vehicles are not used, power network supplies their energy for recharge. These vehicles have a high electrical energy consumption. Since they can be connected to distribution network for recharge any time, their wide use will be followed by some challenges. It is due to the fact that distribution networks are usually operated in their maximum capacity. As a result, adding load due to irrational use of electric vehicles endanger system stability. In other words, just like storages, electric vehicles should be charged in non-peak time and should be used at other times. These vehicles can inject and sale the additional energy to the network when the stored electrical energy of battery is more than required amount. That is, using V2G technology when vehicles are parked or not used, they can be connected to the network and receive it electrical energy or inject it. Furthermore, just like storages, these vehicles are regarded as a support for wider use of renewable energy. According to the aforementioned, in order to optimally use these vehicles and appropriately control power system by connecting them into the network, it seems necessary to employ a smart and advanced measuring system. It is attributed to the fact that received or injected electrical energy amount should be precisely determined. By creating smart energy networks, due to these networks' features, electric vehicles will be also more employed [29].

3. METHODOLOGY

3.1. Goals

In presented model, it is attempted to maximize the utilization of the renewable energies such as photovoltaic resources and wind turbine energy. Thermal and electrical energy stores are used to supply a part of the heating and electrical load of the building in peak hours.

3.2. Hypotheses

The focus of the present paper is on utilization and investment on equipment is not taken into account. Moreover, it is assumed that owner of the utilities and equipment of the area such as electrical energy stores, thermal energy store and photovoltaic and wind turbines is the network utilizer. Therefore, for these resources, no utilization cost is considered.

Statistical data is available for electrical vehicles and based on it, behavior of the vehicles can be modeled and predicted. It is assumed that prediction is in accordance with exact historical data. Number of the buildings in intended area is known and the capacity of the transformers connecting the area to the upstream network is determined.

3.3. Operational Constraints of Energy Stores and Heat Resources

One of the most important constraints for electrical and heating equipment is the maximum and minimum produced and consumed power which must be modeled exactly. Minimum and maximum capacity of resources and equipment including gas boiler, combined heat and power cycle, electrical electrothermal and electrical boiler are modeled based on constraints 1-4

$$H_l^{GB\min} \le G_{s,i,l}^{GB} \eta_l^{GB} \le H_l^{GB\max} \quad (1)$$

$$H_l^{CHP\min} \le \frac{P_{s,i,l}^{CHP} \eta_l^t}{\eta_l^e} \le H_l^{CHP\max} \quad (2)$$

$$H_l^{EHP\min} \le P_{s,i,l}^{EHP} \eta_l^t \le H_l^{EHP\max} \quad (3)$$

$$H_l^{EB\min} \le P_{s,i,l}^{EB} \eta_l^{EB} \le H_{s,i,l}^{EB\max} \quad (4)$$

$$For\ all\ s = 1\ to\ N_s,\ i = 0\ to\ N_i,\ l = 1\ to\ N_l$$

For the sake of comfort of the residents in various climatic conditions, temperature of the building must be controlled appropriately. For this end, residents determine their intended temperature for the operator as $T^{set}_{i,l}$ and operator must maintain the internal temperature in accordance with this value. On the other hand, sometimes, operator is free to adjust the internal temperature in a defined range with specific tolerance whose lower and upper limit are defined as $\delta_{i,}^{low}$ and $\delta_{i,l}^{high}$, respectively. Based on what stated above, constraint corresponding to the internal temperature of the building is modeled using Eqs. 5 and 6.

$$O_{s,i,l}(T_{s,i,l} - T_{s,i,l}^{+}) \le O_{s,i,l}(T_{i,l}^{set} + \delta_{i,l}^{high}) \quad (5)$$

$$O_{s,i,l}(T_{i,l}^{set} - \delta_{i,l}^{low}) \le O_{s,i,l}(T_{s,i,l} + T_{s,i,l}^{-}) \quad (6)$$

Where, $T^{+}_{s,i,l}$ and $T^{-}_{s,I,l}$ stand for temperature increase and decrease with respect to the adjusted temperature when it is not possible to exactly adjust the temperature of the building. In these conditions, temperature is defined as a range and it cannot exceed a predetermined value. These variables are considered as a compromise between residents' comfort and other constraints and they lead to the significant improvement in convergence of the problem since it results in adjustment of the temperature with a minor error when it is not possible to exactly adjust the building temperature. The value of this error is multiplied by a relatively large factor and used in an objective function. It is taken as a penalty for the operator.

Intended area can either have a heating or electrical storage in the form of battery. Allowable operational range for heating storage is defined as constraint 7. Constraints 8-10 are for maximum and minimum capacity of the battery storage and maximum and minimum capacity for discharge as well as charge of battery. Binary variable $z_{s,I,l}$ ensures that the battery is not charged and discharged simultaneously.

$(X_l^{\min} - T_{s,i,l})Cx_l \le X_{s,i,l} \le (X_l^{\max} - T_{s,i,l})Cx_l$	(7)
$B_l^{\min} \le B_{s,i,l} \le B_l^{\max}$	(8)
$z_{s,i,l} P_l^{BES\min} \le P_{s,i,l}^{BES+} \le z_{s,i,l} P_l^{BES\max}$	(9)
$(1 - z_{s,i,l})P_l^{BES\min} \le P_{s,i,l}^{BES-} \le (1 - z_{s,i,l})P_l^{BES\max}$ $For\ all\ s = 1\ to\ N_s,\ i = 0\ to\ N_i,\ l = 1\ to\ N_l$	(10)

3.4. Initial Value of Variables

One of the economic constraints corresponding to the energy stores in short-term planning is equal level of storage in the initiation and the end of the optimization period. This constraint ensures the ineffectiveness of the planning in a day for other days. For intended problem, storage level of the heating and battery energy store in the last time step (24) must be equal to the first one. This constraint is modeled using Eq. 11 and 12 for heating and electrical storage.

$$X_{s,0,l} = X_{s,N_i,l} \quad (11)$$

$$B_{s,0,l} = B_{s,N_i,l} \quad (12)$$

$$For\ all\ s = 1\ to\ N_s,\ l = 1\ to\ N_l$$

3.5. Heating Modeling of the Building and Energy Store

Building temperature can be computed instantly based on the temperature of the previous time step, heat losses and heating storage coefficient. Accordingly, thermal coefficient of the energy store represents the heat lost in building environment and can be calculated as follows.

$$T_{s,i+1,l} = T_{s,i,l} + \begin{pmatrix} H_{s,i,l}^{SH} + (1 - \alpha_{s,i,l}) \\ (Int_{s,i,l} + Sol_{s,i,l}) \\ -(T_{s,i,l} - T_{s,i}^{out})tR_l^{b^{-1}} \end{pmatrix} c_l^{b^{-1}} + X_{s,i,l}^{loss} \quad (13)$$

$$X_{s,i,l}^{loss}=\frac{\left(\frac{X_{s,i,l}}{Cx_l}-T_{s,i,l}\right)t}{Rx_l} \tag{14}$$

Eq. 13 reveals that building temperature depends upon the energy store's heat as well as solar thermal coefficient and internal thermal coefficient. It is possible that for adjustment of the building temperature, solar thermal coefficient and internal thermal coefficients decrease. This effect is modeled using $\alpha_{s,i,l}$ variable. According to Eq. 15, sum of the heat produced by heat resources is defined by H_{in} variable. A part of this value is consumed for space heating and another part is consumed for domestic hot water. The rest is exchanged by the heating energy store taking into account the thermal coefficient of the energy store and change its storage level in accordance with Eq. 16

$$G_{s,i,l}^{GB}\eta_l^{GB}+\frac{P_{s,i,l}^{CHP}\eta_l^t t}{\eta_l^e}+P_{s,i,l}^{EHP}\gamma_{s,i,l}^{EHP}t+P_{s,i,l}^{EB}\eta_{s,i,l}^{EB}t=H_{s,i,l}^{in} \tag{15}$$

$$X_{s,i+1,l}=X_{s,i,l}+H_{s,i,l}^{in}-X_{s,i,l}^{loss}-H_{s,i,l}^{SH}-H_{s,i,l}^{DHW} \tag{16}$$

For battery, energy level in the next time step is calculated based on the current energy level of the battery as well as the charge and discharge capacity of the current time step taking battery efficiency based on Eq. 17 into consideration. In this relationship, φ_l represents the battery efficiency. Since the external temperature is assumed to be always lower than internal one, SH is always positive and modeled using Eq. 18.

$$B_{s,i+1,l}=B_{s,i,l}+(P_{s,i,l}^{BES-}-P_{s,i,l}^{BES+}/\varphi_l)t \tag{17}$$

$$H_{s,i,l}^{SH}\geq 0$$
$$For\ all\ s=1\ to\ N_s,\ i=0\ to\ N_i,\ l=1\ to\ N_l \tag{18}$$

3.6. Reserve modeling

An important part of the problem formulation is the set of constraints defining the reserve value. Formulation is only presented for low reserve. Its development for high consumption reserve can be calculated easily. In [30], a formulation for this reserve is presented. However, in this model, robustness against thermal comfort of the residents is not considered.

Available reserve for flexible resources in each hour and area as well as each scenario can be obtained using Eq. 19. Lowe and upper limit of the available resources is limited and modeled using Eq. 20 and 23. According to these relations, it is evident that reserve of the electrothermal pump and electrical boiler must not exceed the upper limit of the resource. Moreover, lower reserve limit of combined heat and electrical cycle unit cannot exceed the upper limit of the resource. For battery, lower limit cannot be higher than the maximum discharge rate modeled using Eq. 23.

$$R_{i,l}^{resd}=R_{s,i,l}^{EHPd}+R_{s,i,l}^{EBd}+R_{s,i,l}^{CHPd}+R_{s,i,l}^{BESd} \tag{19}$$

$$0\leq R_{s,i,l}^{EHPd}\leq P_{s,i,l}^{EHP}-P_l^{EHP\min} \tag{20}$$

$$0\leq R_{s,i,l}^{EBd}\leq P_{s,i,l}^{EB}-\frac{H_l^{EB\min}}{\eta_l^{EB}} \tag{21}$$

$$0\leq R_{s,i,l}^{CHPd}\leq\frac{H_l^{CHP\max}\eta_l^e}{\eta_l^t}-P_{s,i,l}^{CHP} \tag{22}$$

$$0\leq R_{s,i,l}^{BESd}\leq P_l^{BES\max}+P_{s,i,l}^{BES-}-P_{s,i,l}^{BES+} \tag{23}$$
$$For\ all\ s=1\ to\ N_s,\ i=0\ to\ N_i,\ l=1\ to\ N_l$$

To ensure that presented formulation is robust taking into account the thermal comfort of the residents, i.e. each reserve demand will not result in violation of thermal comfort standards, it is necessary to ensure the enough thermal energy is available in energy store of building and or alternative thermal resource is present. For modeling of the aforesaid conditions, reserve assigned to each resource is constrained using stored thermal energy. It was done through constraints 24-28. Constraint 24 limits the lower limit of electrothermal resource based on the sum of upper limit of energy stored in thermal energy store, lower limit of building reserve and upper limit of gas boiler. Since robustness is only necessary when there are residents in the building, constraint 24 is only applied when aforementioned condition is satisfied.

$$O_{s,i,l}(R_{s,i,l}^{EHPd}\gamma_{s,i,l}^{EHP}+R_{s,i,l}^{EBd}\eta_l^{EB}-R_{s,i,l}^{CHPd}\eta_l^t/\eta_l^e)\leq O_{s,i,l}\left(\frac{\left(\frac{X_{s,i,l}}{Cx_l}+T_{s,i,l}-X_l^{\min}\right)Cx_l+Bres_{s,i,l}^d}{call^{\max}t}+\left(H_l^{GB\max}-\frac{H_{s,i,l}^{GB}}{t}\right)\right) \tag{24}$$

(25)

$$O_{s,i,l} R_{s,i,l}^{CHPd} \eta_l^t / \eta_l^e \leq O_{s,i,l} \left(\frac{\left(X_l^{\max} - \frac{X_{s,i,l}}{Cx_l} + T_{s,i,l} \right) Cx_l + Bres_{s,i,l}^u}{call^{\max} t} + \frac{H_{s,i,l}^{GB}}{t} \right)$$

(26)

$$0 \leq Bres_{s,i,l}^d = \frac{o_{s,i,l}(T_{s,i,l} - (T_{i,l}^{set} - \delta_{i,l}^{low}) + Tr_{s,i,l}^-) c_l^b}{t}$$

(27)

$$0 \leq Bres_{s,i,l}^u = \frac{o_{s,i,l}((T_{i,l}^{set} + \delta_{i,l}^{high}) - T_{s,i,l} + Tr_{s,i,l}^+) c_l^b}{t}$$

(28)

$$R_{s,i,l}^{BESd} \leq B_{s,i,l} / (call^{\max d} t)$$

$$For\ all\ s = 1\ to\ N_s,\ t = 0\ to\ N_i,\ l = 1\ to\ N_l$$

Constraint 26 shows the upper limit of the building structure which is defined in accordance with the building temperature, set temperature and flexibility parameter of the building temperature. Variable $Tr^{-}_{s,i,l}$ makes the compromise between reserve demand and thermal comfort possible. Similarly, constraint 28 ensures that there is sufficient lower limit reserve for battery to make all demands robust.

3.7. Constraints for Active and Reactive Power of Equipment

Relationship between active and reactive power and the value of apparent power defined as Eq. 29. Therefore, it is not possible to use this relation directly in complex integer linear programming models. In many of the earlier works, it is tried to solve this problem using a linear approximation for Eq. 29.

(29)

$$\left(P_{s,i,l}^{\alpha}\right)^2 + \left(Q_{s,i,l}^{\alpha}\right)^2 \leq \left(S_{s,i,l}^{\alpha}\right)^2$$

In this work, linear approximation given in [31] is used for modeling the relationship between active, reactive and apparent power. This approximation is defined as Eq. 30. In this relationship, A is the set of flexible equipment including electrothermal pump, electrical boiler, combined thermal and electrical cycle and N_b is the half of the number of intervals in linear approximation of Eq. 29 which is set by the user.

(30)

$$\left(Q_{s,i,l}^{\alpha} - S_{s,i,l}^{\alpha} \cos\left(\frac{(b-1)\pi}{N_b}\right)\right)\left(\frac{\sin\left(\frac{b\pi}{N_b}\right) - \sin\left(\frac{(b-1)\pi}{N_b}\right)}{\cos\left(\frac{b\pi}{N_b}\right) - \cos\left(\frac{(b-1)\pi}{N_b}\right)}\right)$$

$$+S_{s,i,l}^{\alpha} \sin\left(\frac{(b-1)\pi}{N_b}\right) \leq P_{s,i,l}^{\alpha} \leq \left(Q_{s,i,l}^{\alpha} + S_{s,i,l}^{\alpha} \cos\left(\frac{(b-1)\pi}{N_b}\right)\right)\left(\frac{\sin\left(\frac{b\pi}{N_b}\right) - \sin\left(\frac{(b-1)\pi}{N_b}\right)}{\cos\left(\frac{b\pi}{N_b}\right) - \cos\left(\frac{(b-1)\pi}{N_b}\right)}\right)$$

$$-S_{s,i,l}^{\alpha} \sin\left(\frac{(b-1)\pi}{N_b}\right)$$

$$For\ all\ s = 1\ to\ N_s,\ i = 0\ to\ N_i,\ l = 1\ to\ N_b, \alpha \in A$$

3.8. Reserve, Power and Energy Balance

For implementation of the presented optimized model in a specific region, it is necessary to satisfy the constraints corresponding to the limits of power received from the network, balance between received and consumed power, consumed gas and received gas as well as the balance between available and demanded reserve in the region. Eq. 31, 32 and 34 apply the constraints for electrical power balance, gas balance and reserve balance. As stated earlier, electrical power is supplied from the day ahead market and balance market. Since it is probable that the price of input energy is different from that of the output energy, it is mandatory to set the input and output energies in each hour.

(31)

$$D_i^- - D_i^+ + I_{s,i}^- - I_{s,i}^+ = \frac{E_{s,i,l}^{load}}{t} + P_{s,i,l}^{EHP} + P_{s,i,l}^{EB} - P_{s,i,l}^{CHP} - P_{s,i,l}^{solar} - P_{s,i,l}^{wind} + P_{s,i,l}^{BES} - P_{s,i,l}^{BES+}$$

(32)

$$G(d)_{s,i}^- = \frac{P_{s,i,l}^{CHP} \eta_l^t t}{\eta_l^e} + G_{s,i,l}^{GB}$$

(33)

$$D_i^-, D_i^+, I_{s,i}^-, I_{s,i}^+, G(d)_{s,i}^- \geq 0$$

$$For\ all\ s = 1\ to\ N_s,\ i = 0\ to\ N_i$$

To ensure the satisfaction of the constraints corresponding to the active and reactive power of the region, i.e. maximum capacity of the network in regional access point which is equal to the capacity of the transformer connecting the regional power system to the network, active and reactive power of the area and regional loads are summed up which is modeled using Eq. 34.

(34)

$$Q(d)_{s,i} = \sum\nolimits_{l=1}^{N_l} \left(\frac{\gamma E_{s,i,l}^{load}}{t} + \sum\nolimits_{\alpha \in A} Q_{s,i,l}^{\alpha} \right)$$

$$For\ all\ s = 1\ to\ N_s,\ i = 0\ to\ N_i$$

3.9. Constraints for active and reactive power

As stated before, input and output active and reactive power of the area are limited and it is necessary to apply this constraint in modeling. Due to nonlinearity of the active and reactive power relations and based on the linear approximation provided for active and reactive power of equipment, in regional level, this constraint is modeled using Eq. 35

(35)

$$\begin{aligned}
&\left(Q(d)_{s,i} - S(d)_{s,i} \cos\left(\frac{(b-1)\pi}{N_b} \right) \right) \left(\frac{\sin\left(\frac{b\pi}{N_b} \right) - \sin\left(\frac{(b-1)\pi}{N_b} \right)}{\cos\left(\frac{b\pi}{N_b} \right) - \cos\left(\frac{(b-1)\pi}{N_b} \right)} \right) \\
&+ S(d)_{s,i} \sin\left(\frac{(b-1)\pi}{N_b} \right) \leq P(d)_{s,i} \\
&\leq \left(Q(d)_{s,i} + S(d)_{s,i} \cos\left(\frac{(b-1)\pi}{N_b} \right) \right) \left(\frac{\sin\left(\frac{b\pi}{N_b} \right) - \sin\left(\frac{(b-1)\pi}{N_b} \right)}{\cos\left(\frac{b\pi}{N_b} \right) - \cos\left(\frac{(b-1)\pi}{N_b} \right)} \right) \\
&- S(d)_{s,i} \sin\left(\frac{(b-1)\pi}{N_b} \right) \\
&For\ all\ s = 1\ to\ N_s,\ i = 0\ to\ N_i,\ l = 1\ to\ N_l,\ b = 1\ to\ N_b,
\end{aligned}$$

3.10. Output power for wind turbines and photovoltaic resources

Output power of wind turbines can be obtained using Eq. 36 presented in [32].

$$\begin{cases}
0 & V < V_{cut-in},\ V > V_{cut-out} \\
V^3 \left(\frac{P_r}{V_r^3 - V_{cut-in}^3} \right) - P_r \left(\frac{V_{cut-in}^3}{V_r^3 - V_{cut-in}^3} \right) & V_{cut-in} \leq V < V_{rated} \\
P_r & V_{rated} \leq V \leq V_{cut-out}
\end{cases} \quad (36)$$

Where, P_r is the rated power of generator, V is the wind velocity in each hour and parameters V_{cut-in}, V_{rated} and $V_{cut-out}$ are the generator's cut-in velocity, generator's rated velocity and generator's cut-out velocity, respectively. In velocities higher than V_{cut-in} and $V_{cut-out}$, turbine is stopped using brakes to prevent damage to its parts. For this reason, in these cases, output of the generator will be zero which is shown in Eq. 35. In [33], a photovoltaic in each hour is presented using solar radiation and ambient temperature and shown in Eq. 37.

$$P_{pv-out} = P_{N-pv} \times \frac{G}{G_{ref}} \times \left[1 + K_t \left((T_{amb} + (0.0256 \times G)) - T_{ref} \right)\right] \quad (37)$$

Where, P_{pv-out} is the output power of photovoltaic panel in each hour, P_{N-pv} is the nominal power of photovoltaic resource in standard conditions, G is the solar radiation (W/m^2), G_{ref} is the reference radiation equal to 1000 W/m^2. T_{amb} is the ambient temperature in centigrade and equal to 25°C. K_t is equal to $-3.7 \times 10^{-3} \, (1/^{\circ} c)$.

3.11. Modeling of electrical vehicles

As mentioned above, in considered residential area, it is assumed that each block has a lot for electrical vehicles. Therefore, it is necessary to model the constraints of these vehicles' charge and discharge. Plans for load response of electrical vehicles is explained in section 2. In this work, plans based on smart charge, discharge and trip time reduction are used. The first constraint for electrical vehicles is no simultaneous charge and discharge. For modeling of this constraint, two binary decision variables, $X_{v,i,l}$ and $Y_{v,i,l}$ are defined the former is for charge and will be equal to one when the vehicle is in charging state. The latter is for discharge and will be equal to one when vehicle is in discharge state. Based on this, constraint of no simultaneous charge and discharge of electrical vehicles is expressed as Eq. 38.

$$X_{V,i,l} + Y_{V,i,l} \le 1 \quad (38)$$

$$E_{Stored\_V,i,l} = E_{Stored\_V,i-1,l} + \eta_c(V) \times P_{Charge\_V,i,l} \times \Delta t - E_{Trip\_V,i,l} - \frac{1}{\eta_d(V)} \times P_{Discharge\_V,i,l} \times \Delta t \quad (39)$$

Where, $\eta_c(V)$ and $\eta_d(V)$ are the efficiency of vehicle battery's charge and discharge considered for modeling of battery during charging and discharging periods. The value of energy consumed in trip based on the consumed energy is calculated using Eq. 40. The power which can be delivered by battery discharge is limited and modeled using Eq. 41-43.

$$E_{Trip\_V,i,l} = P_{Trip\_V,i,l} \times \Delta t \quad (40)$$

$$P_{Discharge\_v,i,l} \le P_{DischargeLimit\_v,i,l} \times X_{V,i,l} \quad (41)$$

Charging rate of electrical vehicles is limited by the charging system and the battery itself. This limitation is modeled using Eq. 42.

$$P_{Charge\_v,i,l} \le P_{ChargeLimit\_V,i,l} \times Y_{V,i,l} \quad (42)$$

In practice, maximum energy which can be discharged from the battery depends upon the energy of battery in previous period. Maximum charging level is limited by the energy of battery and capacity of battery expressed as Eq. 44. In this relation, parameter $E_{BatCap}(V)$ is the capacity of the vehicle's battery. Maximum energy which can be stored in battery depends upon the battery capacity expressed as Eq. 45.

$$\frac{1}{\eta_d(V)} P_{Discharge\_v,i,l} \times \Delta t \le E_{Stored\_V,i-1,l} \quad (43)$$

$$\eta_c(V) \times P_{Charge\_v,i,l} \times \Delta t \le E_{BatCap\_v,i,l} - E_{Stored\_v,i-1,l} \quad (44)$$

$$E_{Stored\_V} \le E_{BatCap}(V) \quad (45)$$

At the end of all periods, it is necessary that the energy stored in battery exceeds the minimum energy set by the owners. This issue is taken as reserved energy which is required for normal and unexpected trips. This constraint is given as Eq. 46 and 47. The energy reduced as a result of trip $E_{TripRed\_V,i,l}$ is another limitation for electrical vehicles given in Eq. 48 [34].

$$E_{Stored\_V,i,l} \ge E_{MinCharge\_V,i,l} - E_{TripRed\_V,i,l} \quad (46)$$

$$E_{MinCharge\_V,i(end)),l)} \ge E_{Trip\_V,i,l} \quad (47)$$

$$E_{TripRed\_V,i,l} \le E_{TripRedMax} \quad (48)$$

3.12. Objective Function

This function must be defined in a way that it can include all of the model expenses. In other words, this relation represents the cost paid to supply electrical and thermal load of the buildings and it is suitable to minimize it. Costs of the electrical and thermal loads include the following:

- Cost of electrical power exchanged by the network including market price in next day and balance market
- Gas price

- Cost of compromise between reserve demand and thermal comfort
- Cost of electrical vehicles' discharge and trip reduction time

For the latter, it is supposed that the operator has a contract with owners of electrical vehicles to discharge energy from their batteries upon demand and or ask them reduce their trip time during daytime so that they need less energy. According to this agreement, owners are compensated based on their discharged energy and or reduced level of energy demand. This compensation is set based on their kWh in dollars between owner and operator. Based on what explained above, objective function of the problem is regional level is defined as Eq. 49. It is clear that utilizer buys power with various prices in day ahead market and balance market while gas is imported with a specific price. Increase in decrease in price is added to the objective function as a penalty. This condition applies for reactive power consumption and is added to the function as a χ to the function to control the consumption of the reactive power. This penalty is the of utilization of inverters which is useful though it is small and inhibits the change of reactive power as much as possible.

$$\begin{aligned} Min\Bigg\{\sum_{s=1}^{N_s}\Bigg[p_s \sum_{i=1}^{N_i}\Big(&\lambda_i^{-} D_{i,d}^{-} t - \lambda_i^{+} D_{i,d}^{+} t \\ &+ \mu_{s,i}^{-} I_{s,i}^{-} t - \mu_{s,i}^{+} I_{s,i}^{+} t + \rho_i G(d)_{s,i}^{-} t - \pi_i^{d} R(d)^{resd} t \\ &+ \sum_{l=1}^{N_l}\Big(\varsigma_i^{+} T_{s,i,l}^{+} + \varsigma_i^{-} T_{s,i,l}^{-} + P^{dcall} \varsigma_i^{-} Tr_{s,i,l}^{-}\Big) + \chi \sum_{\alpha\in A} Q_{s,i,l}^{\alpha}\Big)\Big)\Bigg\} \\ &+ \sum_{V=1}^{N_V}\sum_{i=1}^{N_i} P_{dch\_V,i,l} C_{dch} + \sum_{V=1}^{N_V}\sum_{i=1}^{N_i} E_{TripRed\_V,i,l} C_{tr} \end{aligned} \tag{49}$$

Eq. 49 is composed of different parts. The first one is for cost of energy import in day ahead market and balance market. Cost of gas price and profit of the reserve supply is added to this part. Second part is for fine of increased or decreased temperature and cost of reserve demand as a result of temperature reduction. In third part, fine of unlimited reactive power is modeled. Finally, the cost which must be paid by the operator to the owners of electrical vehicles is given. Furthermore, compensation for reduced trip time is given in this part leading to the reduced energy consumption. Compensation of this method is based on the energy saved by reduced trip time and is determined based on the agreement

4. RESULTS

4.1. The Case Study

A specific residential area with 50 blocks is selected for evaluation of the proposed model. each of the blocks has many electrical and thermal resources. Resources for thermal energy of the buildings include electrothermal pump, gas boiler, electrical boiler and thermal energy store. Electrical energy resources include photovoltaic, wind turbine, lots and battery of electrical vehicles. Buildings have combined heat and energy units used for balancing of electrical and thermal energies. Moreover, for implementation of the concept of load response for thermal loads, it is assumed that deviation from reference value of the building temperature is allowable for minor values. Simulation is performed for a winter day and the aim is to supply electrical energy and thermal energy for heating of building and its hot water. Simulation is done for a 24-hour period with 30min intervals to improve the accuracy of results.

In the studied system, 50 blocks constitute a specific area which is connected to the main network through a transformer and can exchange active and reactive power with it. However, this exchange is limited for active and reactive power depending on the nominal power of transformer. Base on the rated capacity of the transformer connecting the areal network to the main one, maximum input and output power is taken as much as 85 kVA. Buildings have electrical equipment using electrical power. Power consumed by buildings is considered as the basic electrical load. For all of the electrical load of the subscribers, power factor is set as 0.92. Using this factor and having the active power consumed by the equipment, reactive power of the equipment can be calculated. Electrical load of each block is shown in Fig. 1.

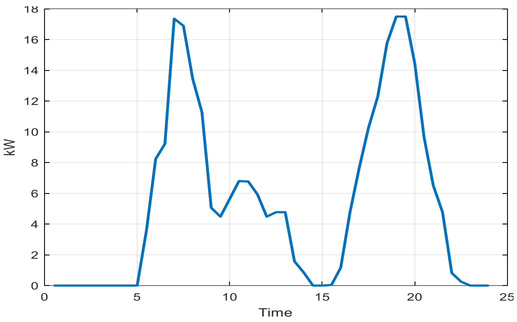

Fig. 1. Electrical power consumed in a building in a day.

Capacity of the electrothermal pump is set so that when ambient temperature is equal to -4°C, the internal temperature equal to -21°C in combination with the combined heat and power unit. Supply of hot water is done by gas boiler, combined heat and power unit and electrical boiler. Accordingly, rated capacity of the thermal pump is 5 kWh. Rated capacity of the combined heat and power unit is set as much as 1 kWh. Gas price is 0.004 dollars per kWh [2].

Efficiency of the gas boiler is 75%. COP of the electrothermal pump is considered as a linear function so that in 20°C, COP is 3.51 and in -4°C, COP is 1.97. having these two points, a linear function can be extracted for COP based on ambient temperature and COP of electrothermal pump can be calculated in each temperature. Thermal storage capacity of the hot water tank is 240L which is completely isolated and has negligible losses. Maximum and minimum value of the thermal energy store temperature are 55 and 40°C, respectively [35]. Penalty factor for temperature increase or decrease is set as much as 1000 dollars/°C so that the deviation is minimized. Efficiency of the electrical energy store (battery) is 90%.

In Fig. 2, energy price in day ahead market is presented for each hour. In this figure, day ahead energy import price and export price are taken as the price of energy import and export, respectively.

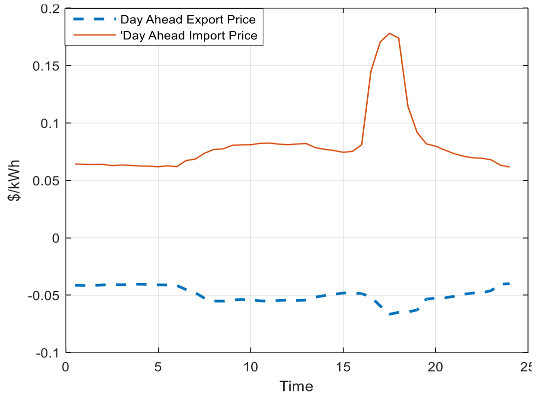

Fig. 2. energy import and export in day ahead market.

Three scenarios are considered for ambient temperature. In addition, ten scenarios are presented for energy price in market. Combination of these scenarios yields 30 scenarios for various conditions of market and ambient temperature. Scenarios corresponding to the energy prices are given in Fig. 3. In Fig. 4, scenarios corresponding to the ambient temperature are represented.

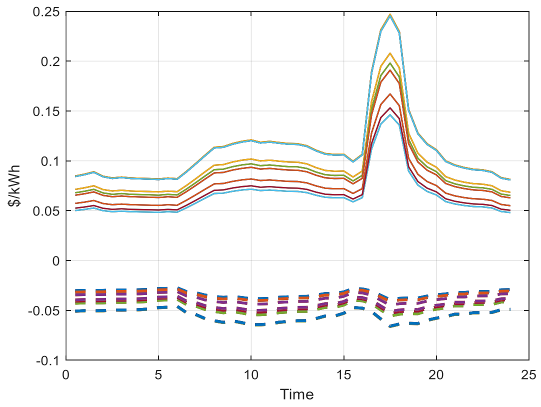

Fig. 3. scenarios of energy price in market.

4.2. Resources

Solar radiation is simulated according to Fig. 5 as 30 different scenarios. In Fig. 6, scenarios presented for wind velocity are illustrated.

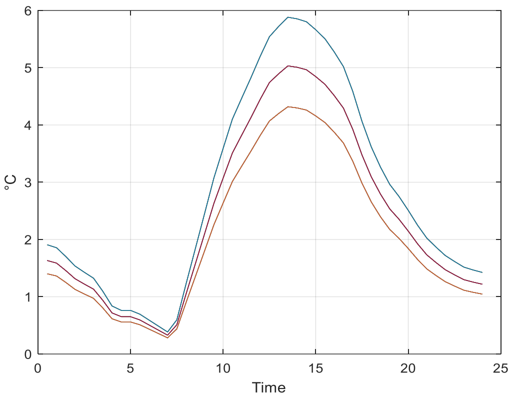

Fig. 4. Scenarios of ambient temperature.

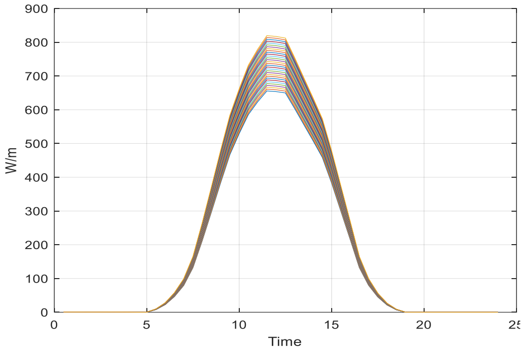

Fig. 5. Solar radiation in each scenario.

In this section, following scenarios are considered for evaluation of the proposed model.

Scenario 1: building has all of the equipment and resource such as photovoltaic, wind turbine and electrical vehicle lot. Electrical vehicle charging is assumed to be uncontrolled.

Scenario 2: all of the conditions are same of above except that charging is done in a smart manner.

Scenario 3: all of the conditions are same of above except that charging and discharging are done in a smart manner.

Scenario 4: all of the conditions are same of above except that charging is done in a smart way and trip reduction is possible for electrical vehicles.

In the first scenario, it is assumed that electrical vehicles are charged upon connection to the lot and they remain there until being fully charged. For this case, charging power for electrical vehicles is as shown in Fig. 7. Results of this scenario are summarized in Fig. 8. It can be seen that uncontrolled charging of vehicles leads to considerable increase in energy imported from the network so that in most of the hours, especially in peak hours, power imported from the network is equal to or near to the maximum capacity of the transformer.

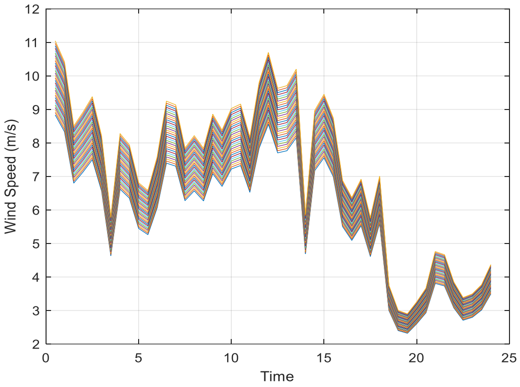

Fig. 6. Wind velocity for each of the scenarios.

For the first scenario, as a result of limitation in power importation from the network, temperature is lower than optimal value in some hours which is the result of uncontrolled charge of vehicles and results in full capacity of the transformer and lack of power in other parts.

For first scenario, energy import price is 124.041 dollars and price of energy supplied by wind turbine and photovoltaic resources is as much as 5.814 dollars. Therefore, overall cost is 129.85 dollars while power consumed as a result of adding electrical vehicles lot increases significantly. However, in this scenario, photovoltaic and wind turbine resources are used as well. Hence, it can be said generally that using renewable energy resources for vehicle charging is effective even for the case of uncontrolled charging. Similar to the first scenario, in this scenario, gas price is constant and equal to 75.5 dollars.

In second scenario, electrical vehicle charging is done smartly. Here, electrical vehicles are not charged upon connection to the lot, but, based on an optimal planning, their charging time is set. For this scenario, power imported from the network and the power consumed for electrical vehicles' charging are illustrated in Fig. 8.

It can be observed from Fig. 8 that compared to first scenario; the power imported from the network increased in non-peak hours but decreases in peak hours. The reason it that through optimal planning, electrical vehicle charging is transferred to the non-peak hours. For this scenario, the cost of energy is as much as 119.226 dollars and cost of renewable energy resources reduces as much as 1.8 dollars which is about 1.5% of the overall costs. This matter illustrates the importance of smart charging of electrical vehicles.

It must be noted that based on the results of simulation, if renewable resources are not taken into account, operator fails to supply the energy required for the area in uncontrolled charging condition since in most of the hours, more than 85 kVA energy is required which is not possible owing to the limitation of the transformer connecting the areal network to the main one. Therefore, using renewable energy resources plays a more pronounced role in balance of the power consumption of the area. For second scenario, cost of energy imported from the network is 123.523 dollars which shows 1.3 dollars increase compared to the case of photovoltaic and wind resources.

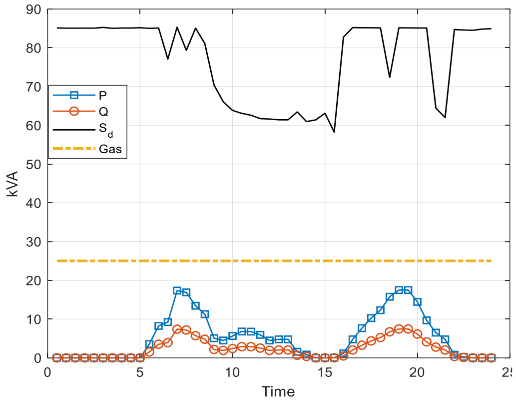

Fig. 7. active and reactive power consumed in electrical loads, power imported from network and the value of gas purchased in scenario 1.

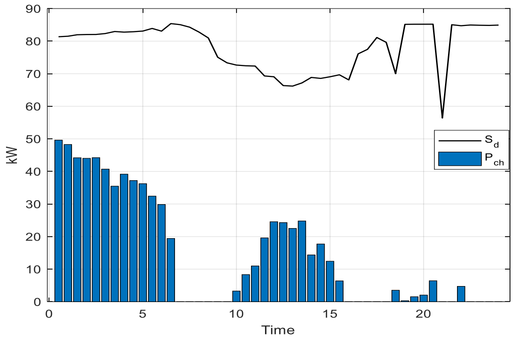

Fig. 8. Active and reactive power consumed for electrical vehicles charging in scenario 2.

It can be inferred from results that through smart charging of electrical vehicles, renewable energies lead to considerable reduction of costs of energy supply so that energy costs reduce as much as 1%.

In scenario 3, it is assumed that in addition to the smart charging of electrical vehicles, it is possible to discharge batteries during peak hours. Discharge cost is considered to be 0.05 dollars/h which is lower than average energy price of the day ahead market. In Fig. 9, power imported from the network and charge and discharge power of electrical vehicles for scenario 3 are shown. It can be seen that in some hours, specifically before peak hours, electrical charge of vehicles increases. However, in peak hours, operator supplied the required energy by means of discharging the electrical vehicles. Comparison of Fig. 9 with results of the previous scenario suggests that discharge of electrical vehicles leads to reduction of energy imported from the network during peak hours. This matter results in reduction of energy costs.

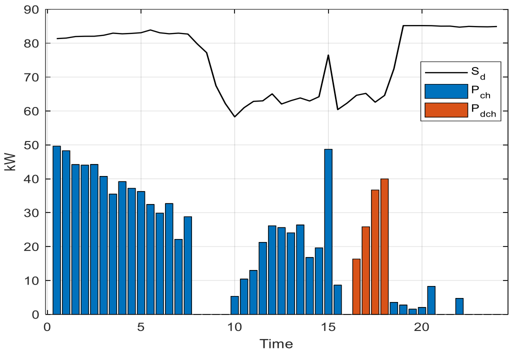

Fig. 9. Power imported from network and electrical vehicles charging power.

For scenario 3, energy cost is 113.2 dollars and cost of energy supplied by renewable energy resources is 2.128 dollars. Compensation of electrical vehicles owners is 3.824 dollars. Therefore, overall cost of energy is 119.17 dollars which is 3 dollars less than that of scenario 6 (122.17 dollars) equal to 2.5% reduction in energy costs. For scenario 7, without photovoltaic and wind turbines, energy cost is 116.004 dollars and compensation of electrical vehicles owners is 4.594 dollars. Hence, overall cost of energy is 120.63 dollars which shows 2.9 dollars reduction in costs equal to 3% reduction in overall costs.

Finally, it is assumed that maximum 10% of electrical vehicles trips can be reduced. Compensation paid for trip reduction is taken as equal to the compensation paid for discharge. For this scenario, charging power of vehicles and the energy saved as a result of trip reduction are illustrated in Fig. 10. It can be seen that during day, trips of electrical vehicles decreased and hence, charging power of vehicles in near-peak hours reduces.

For this scenario, cost of energy imported from network is 110.92 dollars and cost of energy supplied by renewable resources is as much as 5.625 dollars. Therefore, overall cost is 118.673 dollars. It is clear that the cost of this scenario is less than that of previous ones. As a result, trip reduction strategy and compensation for owners of electrical vehicles is a useful way for reduction of costs of energy. For this scenario, cost of energy without photovoltaic resources and wind turbines is as much as 113.66 dollars and compensation of electrical vehicles owners is 6.27 dollars. Therefore, overall cost of energy of this scenario is 119,93 dollars which is again less than that of previous ones.

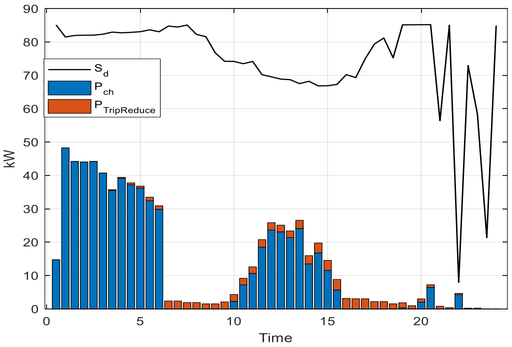

Fig. 10. Power imported from network and electrical vehicles charging and discharging power.

Results of the scenarios 1-4 are summarized in Table 3. In this table, availability of photovoltaic and wind turbine resources is noted by case 2 and their absence is given by case 1. Based on results, it is evident that minimum cost of energy, either by renewable resources or without them, corresponds to the smart charging of electrical vehicles and consideration of the load response program. This case occurs in scenario 4 which is noted in table 4. The reason is that in this scenario, control flexibility of electrical vehicles is more than other cases since operator can set the optimal time of charging and use the reduced energy as a result of trip reduction during energy shortage.

Table 3. Results of scenarios 1-4.

Utilization mode	Scenario		Power import cost	Renewable cost	Load response cost	Overall cost
Uncontrolled charge of vehicles	Case 1	1	-	-	-	-
	Case 2		124.041	5.814	0	129.85
Smart charge of vehicles	Case 1	2	123.523	0	0	123.523
	Case 2		119.226	2.951	0	122.17
Smart charge of vehicles	Case 1	3	116.004	0	4.594	120.63
	Case 2		113.20	2.128	3.842	119.17
Smart charging and trip reduction	Case 1	4	113.66	0	6.27	119.93
	Case 2		110.92	2.128	5.625	118.673

5. CONCLUSION

In this paper, the effect of using electrothermal energy store, various methods o electrical vehicles charging and different programs of demand response on energy costs of a residential area is investigated. For this purpose, an integrated optimal planning is proposed for electrical and thermal energy resources taking into account the electrical vehicles and load response programs. It was shown that using electrothermal energy store and demand response programs as well as electrical vehicles can bring about considerable benefits when all of them are controlled integrally through building energy management system. One of the most important benefits is to attract power in non-peak hours and its freeing-up during peak hours. Aforesaid characteristics result in less load during peak hours and reduced costs of power in a residential area which can be beneficial for residents and the operator.

Proposed optimal planning model for integrated planning of renewable resources, heating equipment of building an electrothermal energy store as well as electrical vehicles leads to reduced imported power during peak hours which results in less energy costs in a residential area and residents will pay less accordingly. Presented model is formulated as a complex integer linear programming model taking into account all of the operational constraints for network and thermal energy store system.

To evaluate the performance of the presented model, its efficiency in a residential area having a certain number of blocks is investigated. In four scenarios, contribution of the renewable resources as well as electrical vehicles having different controlled charging modes to the energy costs of the building is evaluated. Results revealed that renewable energy resources have a significant effect on overall cost of energy in the residential area so that they can reduce costs as much as 1%. Another important result is the effect of various strategies for electrical vehicles charging. Based on the results of simulation, uncontrolled charging of electrical vehicles leads to considerable increase in required power during peak hours and consequently, higher costs for energy supply. However, controlled charging of electrical vehicles eliminated the negative effect from the network. Results suggested that using smart charging and discharging of electrical vehicles as well as smart charging together with trip reduction leads to lower costs of energy.

According to results, it was found that either by renewable resources or without them, minimum cost is for smart charging of electrical vehicles taking into account the load response program for trip reduction. The reason is that in this scenario, control flexibility of vehicles is more than other cases since operator can set the optimal time for charging and use the energy saved as a result of trip reduction.

In general, it can be said that optimal and integrated planning of energy resources taking into account the demand response programs contributes significantly to the reduction of energy costs. Results of simulation proved that through an integrated planning for all of the energy resources of a residential area, power consumed during peak hours, energy costs and demand for energy import from network decrease which is useful for both subscribers and the power distribution company.

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