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Thermal and Electrical Load Management in Smart Home Based on Demand Response and Renewable Energy Resources

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Abstract—**In Smart grids, the implementation of demand response in residential area has a significant importance and help the integration of renewable energy resources and electric vehicles. The current paper presents a novel mathematical optimization model for a future smart home including grid, photovoltaic panels and wind turbine, electrical storage system with penetration of electric vehicles. Moreover, mathematical models of different type of thermal and electrical appliances such as air conditioning, refrigerator, water heater, vacuum cleaner, dishwasher and others are proposed. The proposed optimal scheduling energy management is considered using mixed-integer linear programming to find out operation modes of different loads, to schedule the charging and discharging of electric vehicles and the electrical storage system and to organize between the diverse considered productions systems. The formulated model has been solved with four different scenarios to prove the efficacy with various grouping. The objective function intends to minimize the day-ahead energy cost of the customer with taking into consideration of some desired appliances temperature and with decreasing the electricity imported from the grid in order to reduce the CO_2 emission. Results illustrate the optimistic impact of implementing the proposed energy management model on electricity cost reduction and on finding the optimization results.**

Keywords: Demand Response; Electric Vehicles; Energy Management; Linear Programming; Renewable Energy Resources; Scheduling; Smart Home.

I. INTRODUCTION

Smart grids consider supporting the large employment of distributed energy resources (DERs) such as generators, renewable energy systems and energy storage devices coupled with demand response (DR) program. As well, utilities are looking for demand side management (DSM) covering the energy efficiency and demand response programs to improve the handling of their networks. Smart homes seem as small models in smart grids where smart appliances are used instead of conventional home appliances with communication interface and automatic management for more control.

Several studies have developed mathematical models for residential sector to find out the operation mode of different considered elements whether production or consumption systems. There is a growing need to develop small-scale renewable energy resources as wind or solar generators due to the smart home application integration. A multi-objective stochastic economical and environmental operational scheduling model is proposed in [1], to manage energy and reserve in a smart distribution system with integration of wind system. A novel energy management algorithm is proposed for residential based on heuristic dynamic programming [2]. In [3-4], a schedule of energy resources is conducted, considering the employment of renewable energy resources and electric vehicles without a load control and scheduling. An electrical demand-side management system in a realistic solar house is developed in [5] to improve the efficiency of the electrical grid and to perform a new regulation level in the local electric behavior. In [6], a home energy management model is presented so as to control a battery system connected to a rooftop photovoltaic (PV) system taking into account of PV generation and energy demand forecast errors. A time-of-use-based bottom-up model of residential electricity load is introduced in [7], taking into account the existence of multiple individuals in the home, their performance and the associated use of electrical devices. In [8], a mixed integer linear programming (MILP) model is considered to manage the energy demand in smart homes using a microgrid system and the objectives are to minimize the energy cost and CO_2 emissions. Additionally, the electricity consumption can be reduced in [9] by varying the customers living performance by a DSM approach intended at matching generation values with demand through managing the operation of appliances from the customer side. Furthermore, few researchers have been introduced energy management algorithm with controlling thermal and electrical loads with integrating renewable energy resources (RER) and electric vehicles integration.

This research aims to develop a powerful mixed integer linear programming for a future smart home in order to coordinate the grid, photovoltaic system, wind turbine, electrical storage system and electric vehicles with satisfying the thermal and electrical loads. A demand response program is applied by managing the operation of appliances with shifting the loads to the periods with low price rates or according to consumer temperature preferences. The optimization algorithm has been solved with four different scenarios to prove the efficacy by various grouping with aiming to minimize the day-ahead energy cost of the consumer and by taking into consideration of some desired appliances temperature.

The rest of the paper is organized as follows: a proposed smart home architecture is described in Section two. The problem formulation is developed in Section three. Case studies are discussed in Section four. Simulation and results are presented in Section five and finally conclusion is given in Section six.

II. PROPOSED SMART HOME ARCHITECTURE

The most important purpose of the optimization algorithm in this paper is to minimize the day-ahead energy cost of the consumer by shifting the loads to the periods with low price rates and by taking into consideration of some desired appliances temperature. In the proposed model, smart appliances are divided in two categories: thermal controllable (TCL) loads like air conditioning (AC), refrigerator (Ref) and electric water heater (EWH); and electrical controllable loads (ECL) such as vacuum cleaner, dishwasher, etc. A controlling of energy production between the different considered systems is also considered. We have integrated beside to the conventional power plant, a residential photovoltaic system and a micro-wind turbine due to the best grouping between these sources. Weather forecasting gives 24 hours solar irradiation and wind speed data. Also electric battery and electric vehicles are integrated in the smart home. The considered problem is modeled along the horizon T with t time steps. The time slot is suggested to be one hour, therefore each day will be 24 slots. The proposed smart home architecture system is given in Fig.1.

III. PROBLEM FORMULATION

In this research, the energy management problem is formulated as a MILP model. The following binary variables are considered in the system:

- $V(i,t)$ is the state of starting of appliance i at t (= 1, appliance *i* starts; = 0, otherwise);
- $B_{ac}^{c}(t)$ and $B_{ac}^{h}(t)$ are the states of the AC at t (= 1, AC turn on in cooling or heating mode; = 0, otherwise);
- $B_{ref}(t)$ is the state of the Ref at t (= 1, Ref turn on; = 0, otherwise);
- $B_{ewh}(t)$ is the state of the EWH at t (= 1, EWH turn on; = 0, otherwise);
- $W(t,j)$ is the state of the EV battery j at t (= 1, charging; = 0, otherwise);

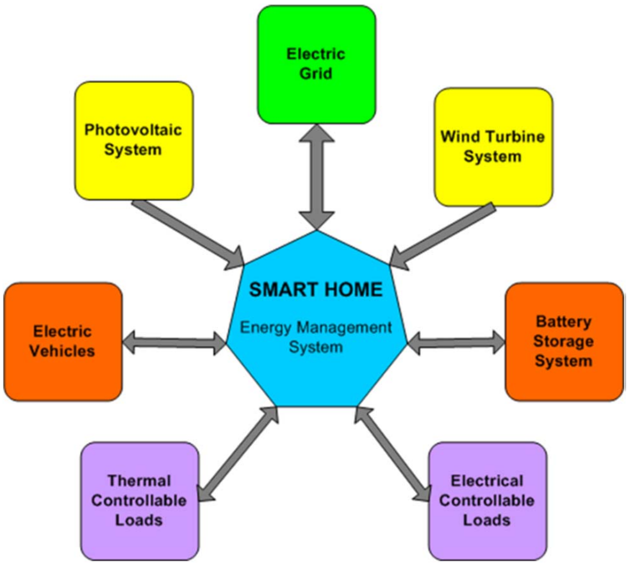

Fig. 1. Main components of the proposed smart home architecture

- $X(t,j)$ designs the state of the EV battery j at t (= 1, discharging; = 0, otherwise);
- $Y(t)$ is the state of the battery at t (= 1, charging; = 0, otherwise);
- $Z(t)$ designs the state of the battery at t (= 1, discharging; = 0, otherwise);
- $M(t)$ and $N(t)$ are the states of the injection into the grid and the gird production at period t.

Afterwards, the associated constraints are presented in the following equations.

A. Electrical Controllable Loads:

The operation time of the electrical appliances must be within the given time window:

$$\begin{cases} V(i,t) = 0 & if\ t < T_{start}(i)\ and\ t > T_{finish}(i) \\ V(i,t) = T_{treat}(i) & if\ t \geq T_{start}(i)\ and\ t \leq T_{finish}(i) \end{cases} \tag{1}$$

Where $T_{start}(i), T_{finish}(i)$ and $T_{treat}(i)$ are the earliest starting time, latest finishing time and the operation time of different appliances *i*, respectively.

B. Thermal Controllable Loads:

1) Air conditioning:

The operation model of the AC in cooling mode:

$$T_{ins}(t) = \left(\epsilon \times T_{ins}(t-1)\right) + (1-\epsilon) \times \left(T_{out}(t) - \left(\frac{\mu \times B_{ac}^{c}(t) \times P_{ac}}{A}\right)\right) \tag{2}$$

The operation model of the AC in heating mode:

$$T_{ins}(t) = \left(\epsilon \times T_{ins}(t-1)\right) + (1-\epsilon) \times \left(T_{out}(t) + \left(\frac{\mu \times B_{ac}^{h}(t) \times P_{ac}}{A}\right)\right) \tag{3}$$

Forbidden the activation and deactivation simultaneously:

$$B_{ac}^{c}(t) + B_{ac}^{h}(t) \leq 1 \tag{4}$$

Limitation of the inside temperature between desired bound:

$$T_{ins}^{\min\_des}(t) \leq T_{ins}(t) \leq T_{ins}^{\max\_des}(t) \tag{5}$$

State to activate the AC in cooling mode:

$$B_{ac}^{c}(t) = \begin{cases} 0 & if\ T_{ins}(0) < T_{ins}^{\min\_des}(1) \\ 1 & if\ T_{ins}(0) > T_{ins}^{\max\_des}(1) \end{cases} \quad (6)$$

State to activate the AC in heating mode:

$$B_{ac}^{h}(t) = \begin{cases} 1 & if\ T_{ins}(0) < T_{ins}^{\min\_des}(1) \\ 0 & if\ T_{ins}(0) > T_{ins}^{\max\_des}(1) \end{cases} \quad (7)$$

Time window that AC can operate in cooling mode:

$$B_{ac}^{c}(t) = \begin{cases} 0\ or\ 1 & if\ t \in T_C \\ 0 & if\ t \notin T_C \end{cases} \quad (8)$$

Time window that AC can operate in heating mode:

$$B_{ac}^{h}(t) = \begin{cases} 0\ or\ 1 & if\ t \in T_H \\ 0 & if\ t \notin T_H \end{cases} \quad (9)$$

Where $T_{ins}(t)$ designs the inside room temperature in *t*; P_{ac} represents the power consumption of the AC; ϵ is the system inertia; μ is the coefficient of performance of the AC; A designs the thermal conductivity of the construction; $T_{out}(t)$ is the outside temperature in *t*; $T_{ins}^{\min\_des}(t)$ and $T_{ins}^{\max\_des}(t)$ represent the lower and upper desired limit of inside room temperature in *t,* respectively.

2) Refrigerator:

The operation model of the refrigerator:

$$T_{ref}(t) = T_{ref}(t-1) + dt\left((\beta_{ref} \times P_{ref}) - (\alpha_{ref} \times B_{ref}(t)) + \gamma_{ref}\right) \quad (10)$$

Limitation of the Ref temperature between desired bound:

$$T_{ref}^{\min\_des}(t) \le T_{ref}(t) \le T_{ref}^{\max\_des}(t) \quad (11)$$

State to activate the refrigerator:

$$B_{ref}(t) = \begin{cases} 1 & if\ T_{ref}(0) > T_{ref}^{\max\_des}(1) \\ 0 & if\ T_{ref}(0) < T_{ref}^{\min\_des}(1) \end{cases} \quad (12)$$

Where $T_{ref}(t)$ is the refrigerator temperature in *t*; P_{ref} designs the power consumption of the refrigerator; β_{ref} designs the activity probability effect on the Ref temperature; α_{ref} is the effect of the ON and OFF states on the Ref temperature; γ_{ref} is the thermal leakage due to the difference between the refrigerator and room temperature; $T_{ref}^{\min\_des}(t)$ and $T_{ref}^{\max\_des}(t)$ design the lower and upper desired limit of refrigerator temperature in *t,* respectively.

3) Electric water heater:

The operation model of the EWH:

$$C_{ewh} \times \left(\frac{T_{ewh}(t) - T_{ewh}(t-1)}{dt}\right) = \frac{-1}{R_{ewh}} \times \left(T_{ewh}(t) - T_{ins}(t)\right) + \left(B_{ewh}(t) \times P_{ewh}\right) - \left(c_p \times q \times \left(T_{ewh}^{\max\_des}(t) - T_{ewh}^{\text{cold}}\right)\right) \quad (13)$$

Limitation of the water temperature between desired bound:

$$T_{ewh}^{\min\_des}(t) \le T_{ewh}(t) \le T_{ewh}^{\max\_des}(t) \quad (14)$$

State to activate the EWH:

$$B_{ewh}(t) = \begin{cases} 0 & if\ T_{ewh}(0) > T_{ewh}^{\max\_des}(1) \\ 1 & if\ T_{ewh}(0) < T_{ewh}^{\min\_des}(1) \end{cases} \quad (15)$$

Where $T_{ewh}(t)$ designs the water temperature in *t*; P_{ewh} is the power consumption of the EWH; C_{ewh} is tank thermal capacity; R_{ewh} represents the thermal resistance of tank walls; c_p designs the specific heat constant for water; q designs the flow of the hot water; T_{ewh}^{cold} represents the temperature of the entrance water into the EWH; $T_{ewh}^{\min\_des}(t)$ and $T_{ewh}^{\max\_des}(t)$ represent the lower and upper desired limits of EWH in *t,* respectively.

C. Electric Grid:

The bound of the amount power imported from the grid:

$$0 \le P_{Grid}(t) \le P_{Grid}^{max}(t) \quad (16)$$

Where $P_{Grid}(t)$ designs the power generated in *t* by the grid and $P_{Grid}^{max}(t)$ represents the maximum power imported from the gird in *t*.

D. Photovoltaic System:

The bound of the amount power generated by PV system:

$$0 \le P_{PV}(t) \le P_{PV}^{max}(t) \quad (17)$$

The generated output power from photovoltaic system [10]:

$$P_{PV}(t) \le A \times \rho \times SI(t) \quad (18)$$

Where $P_{PV}(t)$ designs the power generated in *t* by PV system and $P_{PV}^{max}(t)$ is the maximum allowed PV power in t; ρ is the efficiency; A designs the PV system area and $SI(t)$ represents the solar irradiation in t.

E. Wind Turbine System:

The bound of the amount power generated by wind system:

$$0 \le P_W(t) \le P_W^{max}(t) \quad (19)$$

The generated output power from wind system [11]:

$$\begin{cases} P_W(t) = 0 & if\ v_f < v_{ci}\ and\ v_f > v_{co} \\ P_W(t) = P_{rated} & if\ v_r \le v_f \le v_{co} \\ P_W(t) = P_{rated} \times \dfrac{v_f - v_{ci}}{v_r - v_{ci}} & if\ v_{ci} \le v_f \le v_r \end{cases} \quad (20)$$

Where $P_W(t)$ designs the generated power in *t* by wind turbine and $P_W^{max}(t)$ represents the maximum allowable wind power in *t*; P_{rated} designs the rated power of the wind turbine; v_f is the forecasted wind speed; v_r, v_{ci} and v_{co} represent rated speed, cut-in speed and cut-off speed of the wind system, respectively.

F. Battery Storage System:

The limit of allowed charging power:

$$P_B^{Ch}(t) \le P_B^{Cmax} \times Y(t) \quad (21)$$

The limit of allowed discharging power:

$$P_B^{Disch}(t) \le P_B^{Dmax} \times Z(t) \quad (22)$$

Forbidden the charging/discharging simultaneously:

$$Y(t) + Z(t) \le 1 \quad (23)$$

Power stored in the battery at *t* > 1:

$$Nom_B \times SOC_B(t) = Nom_B \times SOC_B(t-1) + \left(\frac{P_B^{Ch}(t) \times dt}{e_c} - \left(e_d \times P_B^{Disch}(t) \times dt\right)\right) \quad (24)$$

Initial state of the battery:

$$Nom_B \times SOC_B(1) = Nom_B^{int} + \left(\frac{P_B^{Ch}(1) \times dt}{e_c} - \left(e_d \times P_B^{Disch}(1) \times dt\right)\right) \quad (25)$$

Bound of state of charge of the battery:

$$SOC_B^{min} \le SOC_B(t) \le 1 \quad (26)$$

Maximum battery charge limit:

$$\frac{P_B^{Ch}(t) \times dt}{e_c} + \left(Nom_B \times SOC_B(t-1)\right) \le Nom_B \quad (27)$$

Where $P_B^{Ch}(t)$ and $P_B^{Disch}(t)$ represent the charge and discharge power by battery storage in *t*. P_B^{Cmax} and P_B^{Dmax} design the allowable maximum power charge and discharge battery respectively; $SOC_B(t)$ represents the state of charge of the battery; Nom_B is the battery nominal capacity; e_c and e_d are the coefficient factors of charging and discharging; Nom_B^{int} represents the initial battery capacity and SOC_B^{min} designs the minimum state of charge of battery storage.

G. Electric Vehicles:

The bound of allowed charging power:

$$\begin{cases} P_{EV}^{Ch}(t,j) \le P_{EV}^{Cmax}(j) \times W(t,j) & \forall\, t \in T_{stay} \\ P_{EV}^{Ch}(t,j) = 0 & \forall\, t \notin T_{stay} \end{cases} \quad (28)$$

The bound of allowable discharging power and EV travel demand:

$$\begin{cases} P_{EV}^{Disch}(t,j) \le P_{EV}^{Dmax}(j) \times X(t,j) & \forall\, t \in [1,\ldots,T] \\ P_{EV}^{Disch}(t,j) \times dt = D_{EVdriv}(t,j) & \forall\, t \notin T_{stay} \end{cases} \quad (29)$$

Forbidden the charging/discharging simultaneously:

$$W(t,j) + X(t,j) \le 1 \quad (30)$$

Power stored in the EV battery at *t* > 1:

$$\begin{aligned} Nom_{EV}(j) \times SOC_{EV}(t,j) &= Nom_{EV}(j) \times SOC_{EV}(t-1,j) \\ &+ \left(\frac{P_{EV}^{Ch}(t,j) \times dt}{e_c} - \left(e_d \times P_{EV}^{Disch}(t,j) \times dt\right)\right) \end{aligned} \quad (31)$$

Initial state of EV battery:

$$\begin{aligned} Nom_{EV}(j) \times SOC_{EV}(1,j) &= Nom_{EV}^{int}(j) \\ &+ \left(\frac{P_{EV}^{Ch}(1,j) \times dt}{e_c} - \left(e_d \times P_{EV}^{Disch}(1,j) \times dt\right)\right) \end{aligned} \quad (32)$$

Limit of state of charge of EV battery:

$$SOC_{EV}^{min}(j) \le SOC_{EV}(t,j) \le 1 \quad (33)$$

Maximum EV battery charge limit:

$$\frac{P_{EV}^{Ch}(t,j) \times dt}{e_c} + \left(Nom_{EV}(j) \times SOC_{EV}(t-1,j)\right) \le Nom_{EV}(j) \quad (34)$$

Where $P_{EV}^{Ch}(t,j)$ and $P_{EV}^{Disch}(t,j)$ design the charge and discharge power by EV *j* in *t*. $P_{EV}^{Cmax}(j)$ and $P_{EV}^{Dmax}(j)$ are the allowable maximum power charge and discharge of EV battery *j* respectively; $SOC_{EV}(t,j)$ designs the state of charge of the EV battery *j* at *t*; $Nom_{EV}(j)$ represents the EV battery nominal capacity; e_c and e_d design the coefficient factors of the charging and discharging; $SOC_{EV}^{min}(j)$ represents the minimum state of charge of EV battery *j*; $Nom_{EV}^{int}(j)$ is the initial EV battery capacity and $D_{EVdriv}(t,j)$ designs the driving electricity demand of EV *j* at *t*.

H. Grid Power Balance:

The power grid must guarantee the balance between consumption and production systems:

$$\begin{aligned} P_{Grid}(t) + P_{PV}(t) + P_W(t) + \sum_j^{N_{EV}} P_{EV}^{Disch}(t,j) + P_B^{Disch}(t) &= \sum_i \left(D_{appl}(i) \times V(i,t)\right) + D_{th}(t) \\ &+ \sum_j^{N_{EV}} P_{EV}^{Ch}(t,j) + P_B^{Ch}(t) + P_{inject}(t) \end{aligned} \quad (35)$$

Forbidden the injection into the grid simultaneously with gird production, battery discharging and EV battery discharging:

$$P_{inject}(t) \le P_{inject}^{max} \times M(t) \quad (36)$$

$$P_{Grid}(t) \le P_{Grid}^{max}(t) \times N(t) \quad (37)$$

$$M(t) + N(t) \le 1 \quad (38)$$

$$M(t) + X(t,j) \le 1 \quad (39)$$

$$M(t) + Z(t) \le 1 \quad (40)$$

Where $D_{appl}(i)$ denotes the power consumption of electrical controllable appliance i and $D_{th}(t)$ of thermal controllable loads; $P_{inject}(t)$ designs the electricity amount sold to the grid in t; N_{EV} designs the total number of EVs. This equality is assured when $t \in T_{stay}$ (T_{stay} = period when EV stays at home), otherwise the EV power have to be removed from the equation because in this study we considered that there is no charging process when the electric vehicle is away from home.

I. Objective Function:

The objective function of the system is formulated as follows:

$$\min f(cost) = \sum_{t=1}^{T} \left\{ \begin{gathered} [(P_{Grid}(t) \times dt) \times C_{Grid}(t)] + \\ [(P_{PV}(t) \times dt) \times C_{PV}] + \\ [\,(P_W(t) \times dt) \times C_W] + \\ \left[\left(\sum_j^{N_{EV}} P_{EV}^{Disch}(t,j) \times dt\right) \times C_{EV}^{Disch}\right] + \\ \left[\left(P_B^{Disch}(t) \times dt\right) \times C_B^{Disch}\right] - \\ \left[\left(P_{inject}(t) \times dt\right) \times C_{Sell}\right] \end{gathered} \right\} \quad (41)$$

The objective of this function aims to minimize the day-ahead electricity bill of the residential customer. $C_{Grid}(t)$ denotes the cost of the generated power by the grid in t; C_{PV} and C_W design the generation and maintenance cost of PV system and wind turbine; C_{EV}^{Disch} and C_B^{Disch} represent the maintenance costs of EV and battery storage; C_{Sell} designs the electricity cost when it is sold to the utility.

IV. CASE STUDY

The proposed mathematical model is executed with different case studies, given in Table I, to prove the efficiency and robustness of the smart home energy management model

TABLE I. RESUME OF CONSIDERED SCENARIOS

Case studies	Production system		DR program		Battery	V2G
	Grid	RER	ECL	TCL		
Scenario 1	✓	x	x	x	x	x
Scenario 2	✓	x	✓	x	x	x
Scenario 3	✓	✓	✓	x	✓	✓
Scenario 4	✓	✓	✓	✓	✓	✓

and the impact in reducing the electricity cost and finding the optimal result. The model is implemented with the GNU mathematical programming language (GMPL) and GUROBI optimizer is used as optimization solver. Four different scenarios are presented:

Scenario 1: residential consumer with only grid production.

Scenario 2: scenario 1 with adding the demand response program by shifting some electrical controllable loads to the periods with low price tariffs.

Scenario 3: scenario 2 with integrating renewable energy resources (solar and wind), battery storage and electric vehicles.

Scenario 4: scenario 3 with adding to the demand response program, the thermal controllable loads to maintain some desired temperature at a predefined level range.

The data of the 18 appliances used in this paper such as earliest starting time, latest finishing time, power consumption and the duration of the operation is adopted from [12]. The most of input data in the proposed model is taken from [13], like the forecasting solar irradiation and wind speed data, the electricity tariffs from the utility, maintenance cost of renewable energy systems and electric vehicles battery, and all the dimensioning data of battery, solar and wind system. The cost of the sold power to the grid is considered 0.10 €/kWh.

V. SIMULATION AND RESULTS

The effectiveness of the proposed mathematical model has been tested with the above considered scenarios after the implementation with the GNU mathematical programming language (GMPL), generation of input data with python programming language and using GUROBI optimizer as optimization solver. The results of the minimization of the day-ahead energy cost are given in Table II, and the management of different energy production systems with load curve is exposed in Fig 2. As we can deduce that the cost decreased between scenario 1 and 2 by the fact of introducing the demand response program with ECL. In scenario 3, with considering RER, battery and V2G, the cost also decreased, and the consumer can benefit by selling the excess energy to the utility (26.66 kW). Moreover, the purchased power from the grid is reduced that means that the CO_2 emission is also reduced. And finally in scenario 4, when the TCL is considered, a high reduction of the electricity cost (-106.89 cents/day) is realized by benefiting from controlling and scheduling the renewable energy resources and the charging and discharging of EVs and battery storage system. The profit by selling electricity to the utility is increased to 29.52 kW and the purchased power from the grid is reduced to 36.28 kW instead of 45.33 kW in scenario 3. Fig. 3 shows the scheduling and the operation time of the eighteen thermal and electrical controllable appliances during the day for scenario 4. Beside the minimization of the day-ahead electricity cost of the consumer, Fig. 4 shows the preferred temperature of the indoor, EWH and refrigerator, where the proposed model has taken into consideration the

TABLE II. SIMULATION RESULTS

Scenarios	Cost (cents)	Purchased power (kW)	Sold power (kW)	Computing time (ms)
1	1008.56	64.70	-	305
2	642.03	64.70	-	520
3	-39.42	45.33	26.66	470
4	-106.89	36.28	29.52	16230

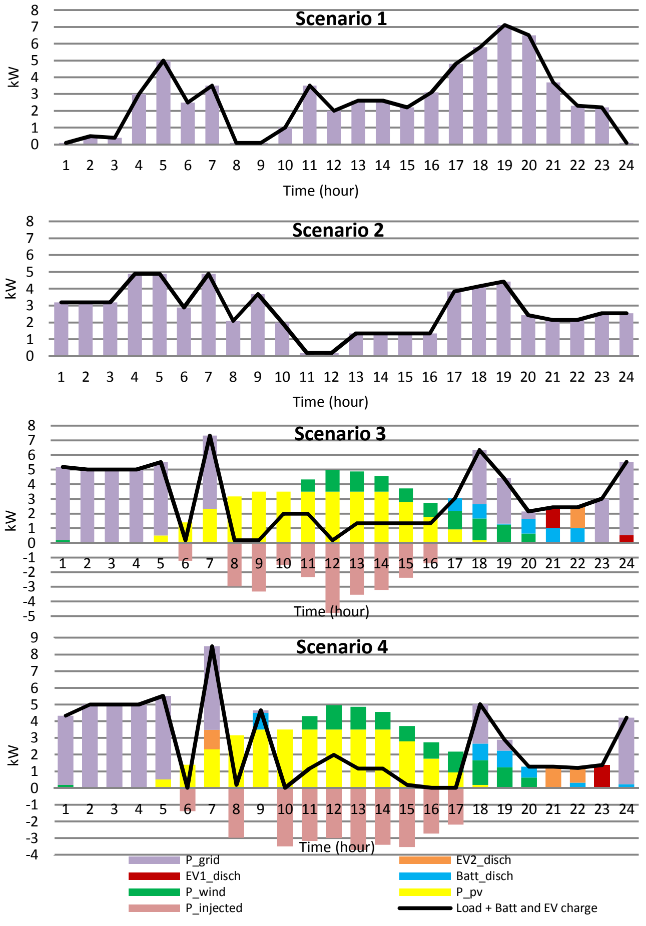

Fig. 2. Simulation results of studied scenarios

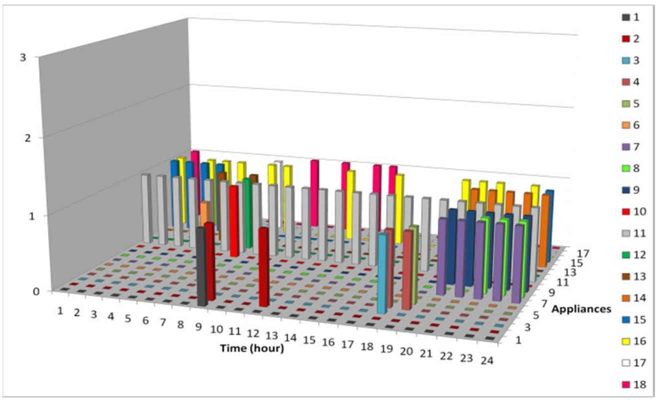

Fig. 3. Scheduling of appliances for scenario 4

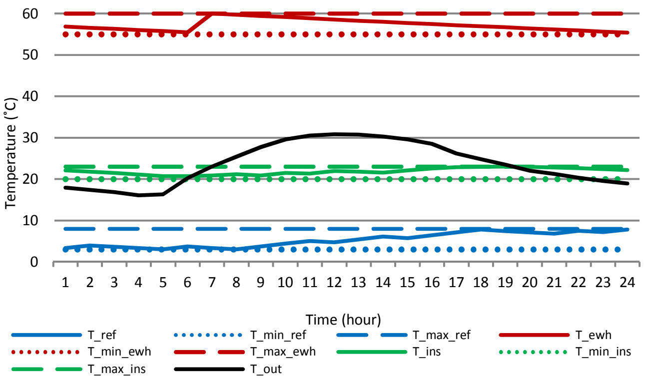

Fig. 4. Desired temperatures of TCL for scenario 4

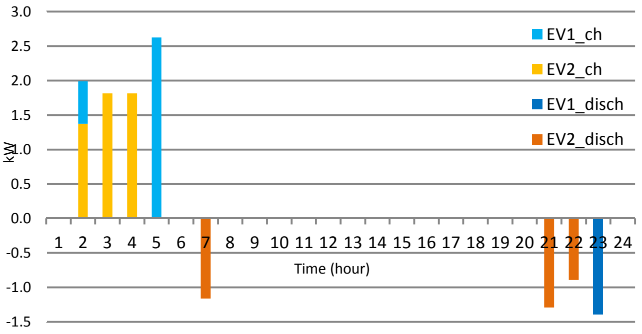

Fig. 5. Schedule of charging/discharging of EVs for scenario 4

predefined desired limit to maintain a minimum comfort level. As well as, the scheduling of the charging and discharging mode of the two electric vehicles integrated in the system is given in Fig. 5, where they have positive effects in future smart home.

VI. CONCLUSIONS AND FUTURE WORKS

This paper presents a robustness mathematical optimization model for a residential consumer in a smart grid environment. Scheduling and determination of operation of different type of thermal and electrical appliances are obtained as well as the coordination and management between considered energy production systems. Also, the scheduling of the charging and discharging mode of electric vehicles and the battery storage system is presented. By implementing this algorithm in different case studies, the best minimization of the day-ahead energy cost is obtained in scenario 4 with taking into consideration of some desired appliances temperature predefined by the customer to maintain a minimum comfort level. Future works tend to promote the proposed model and implement it with many smart homes or a district in order to optimize a more complex system.

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