

# Charge/Discharge Scheduling of Electric Vehicles and Battery Energy Storage in Smart Building: a Mix Binary Linear Programming model

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**Abstract.** Nowadays, the buildings have an important role in the high demand for electrical energy. Therefore, the energy management of the buildings may have significant influence on reducing the electricity consumption. Moreover, Electric Vehicles (EVs) have been considering as a power storage device in Smart Buildings (SBs) aiming to reduce the cost and consuming energy. Here, an energy management framework is proposed in which by considering the flexibility of the contracted power of each apartment, an optimal charging-discharging scheduled for EVs and Battery Energy Storage System (BESS) is defined over a long time period to minimize the electricity cost of the building. The proposed model is designed by a Mixed Binary Linear Programming formulation (MBLP) that the charging and discharging of EVs as well as BESS in each period is treated as binary decision variables. In order to validate the model, a case study involving three scenarios are considered. The obtained results indicate a 15% reduction in total electricity consumption cost and consumption energy by the grid over one year. Finally, the impact of capacity and charge/discharge rate of BESS on the power cost is analyzed and the optimal size of the BESS for assumed SB in the case study is also reported.

## 1 INTRODUCTION

Up to now, significant investment in Distributed Generation (DG) has been made worldwide. The main goal of the investment is to popularize Renewable Energy Sources (RES) in order to reduce energy consumption of grid mainly in residential buildings [7]. In this regard, the Japanese government implemented 70,000 photovoltaic generations (PV) in 1994, an investment that was 50% subsidized. The German government in 1999 launched the 100,000 Roofs Solar Program and in 2017, China had the largest power capacity of wind turbines in the world with 164 GW installed and the United States and Germany have reached 89 GW and 56.1 GW, respectively. The European Union (EU) intends that the new buildings could be more efficient in terms of electricity consumption and it encourages increasing the number of nearly Zero Energy Buildings (nZEB) [17]. To achieve this, the EU has strongly promoted the development of RES and adequate strategies for their operation [7]. In recent years, EVs have had remarkable development to reduce energy consumption and electricity cost. New techniques are investigated that use the

electrical energy stored in EVs to inject into the grid at appropriate times (Vehicle-to-Grid (V2G)) [11, 6]. The advantages of EVs have motivated many researchers to model the concepts of EVs. Many of these studies have considered the impact of EVs charging and discharging processes as well as BESS on power systems and electricity costs [16, 4, 10].

In [5], a consumer-dependent system is proposed for the SBs to reduce the CO<sub>2</sub> emission as well as electricity cost. In this system, a Linear Programming (LP) is proposed in which the manager of an SB decides to use renewable energy even if it is more expensive than the non-renewable sources. In this model, the energy cost of SBs is minimized by considering some weights related to each type of the source (renewable and non-renewable) that the building manager prefers to use the initially provided, acceptability of consumer and their price. Moreover, renewable and non-renewable sources and supply of energy by a diesel generator and restriction of minimum and maximum for BESS are limited, which are used as some constraints in the LP model. The work developed by Molina et al. [8] proposed an LP model that results in an optimal scheduling for charging and discharging processes for EVs in SBs. In this work, the demand power of SBs and the produced energy by PV is predicted using Artificial Neural Networks (ANN). In addition, some limitations for the State of Charge (SOC) of EVs and the rate of charging and discharging is considered in minimizing the total energy cost. Besides, the EVs must charge fully at the end of the period and the system cannot inject into the grid. The model developed by [12] and [13] considers the use of local projections in SBs and EVs as an energy resource. The model in [12] minimizes the building's power demand and its electricity costs by optimizing the charging and discharging process of Plug-In Hybrid Electric Vehicles (PHEVs). The restrictions contain limitations for the SOC of the PHEV and impose that the energy grid is not sold and bought at the same time. The work by [14] proposed an MILP model to analyze the impact of a PHEV fleet on SBs in Belgium in which the energy demand and electricity costs were minimized as in [12] such that SOC of PHEVs should be between a given range and the balance of energy system must be satisfied as well. Here, the charging and discharging process of PHEV does not happen at the same time that is modeled using binary variables. The proposed MILP model in [9] optimizes the charging and discharging process in EVs as well as an energy storage system to find an appropriate daily schedule time. In this model, the arrival and departure time periods of the EVs and initial SOC of EVs and an energy storage system are considered to be known.

In [15], an MILP model is considered in which the PV generation is included via a forecasting model, and the objective function is to

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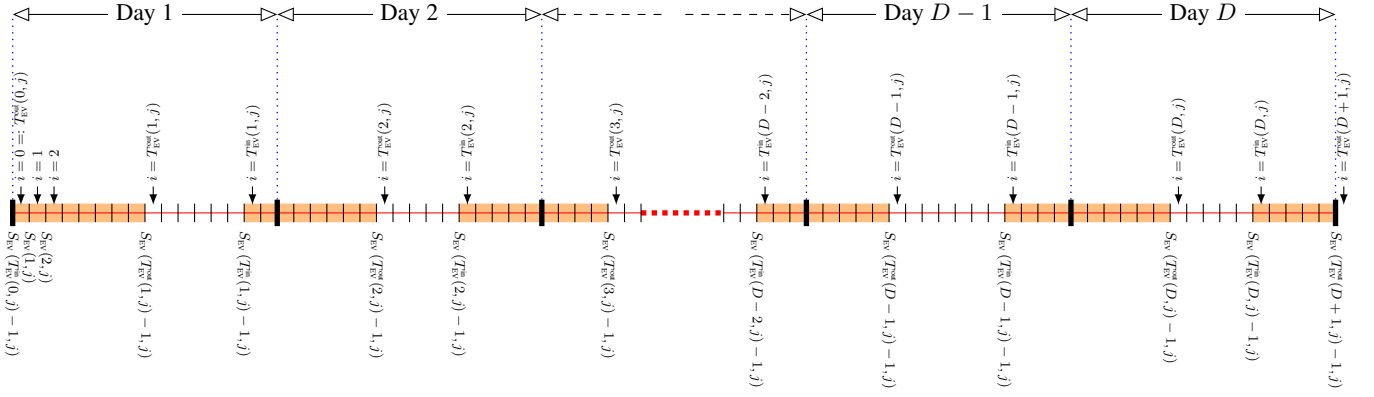


Figure 1. Visualizing the exit and arrival times for  $j$ -th EV and the relevance parameters.

minimize EVs charging cost and increase the energy consumption from the PV generation. In [2], a Home Energy Management (HEM) system is considered that contains a small-scale renewable energy generation and BESS. The model is based on an MILP formulation in which V2G and demand response strategies are considered. In paper [17], an energy management system was aiming to minimize the peak load power demand in an SB where the contract for each apartment is assumed to be flexible. In this work, the schedule of the EVs/BESS charge and discharge is optimized using an MBLP model in which the charging/discharging of EVs and BESS in each time period is modeled by binary variables.

In this paper, a mathematical optimization problem is proposed seeking to reduce the total cost of consuming energy. We consider energy resources such as EVs, BESS and PC, and assume flexible contracts for all customers and that there is a single contract for the whole building. Moreover, the data of the SB load consumption, arrival and departure time of EVs and PV are considered according to a forecasting strategy. The presented model is an MBLP problem on the management of energy resources in a SB that results in an optimal schedule for charging/discharging of EVs and BESS with a lower total cost. Here, the considered time period is long and the EVs can perform the V2G process. And finally, the impact of the size of BESS on the total price is analyzed. This paper contains five following sections: In Section 2, a brief of methodology, problem description and some assumptions that are used in this work are presented. Section 3 presents the MBLP model. Then, the details of the case study such as the definition of three different scenarios and the parameters value are reported in Section 4. In section 5, the proposed method is implemented for scenarios and then comparison and discussion of the obtained results are provided. Finally, a conclusion is presented in the last section 6.

## 2 PROBLEM DESCRIPTION

We consider a Smart Building (SB) which manages its local grid containing apartments, PhotoVoltaic (PV) generation panels, Electric Vehicles (EVs) and a Battery Energy Storage System (BESS). In the considered SB, the power generated by PVs is used for apartment consumption and charging batteries of EVs and BESS. Moreover, PVs can inject their power to the external grid. In addition, EVs have bidirectional embedded chargers, such that their batteries can

be charged from the grid, PVs and BESS; and discharged to apartments and grid. In the considered SB, BESS is used to balance the demand and supply power. It can be discharged to apartments, EVs and grid, and charged from grid and PVs. In addition, the following assumptions are made during this article.

- Each EV has only one trip each day. EVs are plugged in as soon as they arrive home. Moreover, the times of arrival and departure are known.
- For each EV, the initial SOC is known at arrival time in each day. The EV battery could be charged/discharged between arrival and departure time. However, the SOC of each EV, in the departure time, must be greater than a predefined value.
- There are known physical limitations in the charging rate and capacity of EVs' batteries and BESS.

We study SB in a given long time-period, which contains many days. It is presented a charging/discharging EVs schedule and BESS such that minimizes the total cost of grid energy in the time-period. Of course, the mentioned constraints must be maintained.

## 3 MATHEMATICAL MODEL

In this Section, an MBLP is proposed to mathematically model the stated problem in Section 2. Let the considered time-period contains  $D$  day(s) and then we divide each day to some step-times with duration  $\tau$ . Let  $I$  be the number of all time-steps in the time-period. Moreover, let  $J$  denotes the number of EVs. Before developing the model, we declare the needed sets, parameters and decision variables. The sets of the model are defined in Table 1.

Table 1. List of Sets considered in the Model (17).

Symbol	Set	Running Index	Description
$\mathbb{I}$	$\{1, \dots, I\}$	$i$	Set of time-step numbers
$\mathbb{J}$	$\{1, \dots, J\}$	$j$	Set of Vehicle numbers
$\mathbb{D}$	$\{1, \dots, D\}$	$d$	Set of day numbers

Based on the discussions of Section 2, the required parameters are listed in Table 2, in which the description of parameters is presented as well.

However, we should note that  $d \in \mathbb{D}$  stands for index of days, whereas  $d = 0$  and  $d = D + 1$  appear as the index of some parameters in 2. Indeed, these indices stand for the beginning and end times of the considered time-period. In this way, for  $d \in \mathbb{D}$ ,  $T_{EV}^{in}(d, j)$  refers to arrival time-step in  $d$ -th day, but  $T_{EV}^{in}(0, j)$  and  $T_{EV}^{in}(D + 1, j)$  refer to the first and last time-steps. To make a better sense of the role of parameters, see Figure 1.

**Table 2.** Parameters of the model (17).

Parameter	Index	Description
$D$		Number of Days per Time-Study
$I$		Number of time-steps per Time-Study
$\tau$		time-step duration (hour)
$J$		Number of apartments (or EVs) in the building
$T_{EV}^{in}(d, j)$	$j \in \mathbb{J}$ , $d \in \{0\} \cup \mathbb{D}$	For $d = 0$ , $T_{EV}^{in}(d, j) = 1$ and for $d \in \mathbb{D}$ , $T_{EV}^{in}(d, j)$ is the number of period-time in which $j$ th EV enters to the parking in day $d$
$T_{EV}^{out}(d, j)$	$j \in \mathbb{J}$ , $d \in \mathbb{D} \cup \{D+1\}$	For $d \in \mathbb{D}$ , $T_{EV}^{out}(D + 1, j)$ is the number of period-time in which the $j$ th EV leaves in day $d$ and for $d = D + 1$ , $T_{EV}^{out}(d, j) = I + 1$
$S_{EV}^{max}(j)$	$j \in \mathbb{J}$	Maximum allowable State of Charge(SOC) of $j$ th EV
$S_{EV}^{initial}(d, j)$	$j \in \mathbb{J}$ , $d \in \{0\} \cup \mathbb{D}$	The initial SOC of $j$ th EV at the beginning departure in time period $T_{EV}^{in}(d, j)$
$S_{EV}^{min.out}(d, j)$	$j \in \mathbb{J}$ , $d \in \mathbb{D}$	The minimum allowable SOC for $j$ th EV at exit time of each day $d$
$S_{BE}^{max}$		Maximum State of Charge(SOC) for BESS
$S_{BE}^{initial}$		Initial State of Charge(SOC) for BESS at the beginning of time-period
$S_{BE}^{min}(j)$		Minimum State of Charge(SOC) for BESS
$P_{SB}(i)$	$i \in \mathbb{I}$	Total power demand of Smart Building (SB) at period $i$
$P_{PV}(i)$	$i \in \mathbb{I}$	Total generated power by PhotoVoltaics (PVs) at period $i$
$P_G^{max}(i)$	$i \in \mathbb{I}$	Maximum power that can get form Grid at time-step $i$
$C_G^{buy}(i)$		Purchased electricity cost from the grid in $i$ -th time-step
$C_G^{sell}(i)$		
$P_{EV}^{ch}(j)$	$j \in \mathbb{J}$	Active power related to the charging process of the $j$ th EV (kW)
$P_{EV}^{diss}(j)$	$j \in \mathbb{J}$	Active power related to the discharging process of the $j$ th EV
$E_{EV}^{ch}(j)$	$j \in \mathbb{J}$	The charge efficiency of EV $j$
$E_{EV}^{diss}(j)$	$j \in \mathbb{J}$	The discharge efficiency of EV $j$
$P_{BE}^{ch}(i)$	$i \in \mathbb{I}$	Active power related to the charging process of the BESS in period $i$ (kW)
$P_{BE}^{diss}(i)$	$i \in \mathbb{I}$	Active power related to the discharging process of BESS in period $i$ (kW)

Moreover, the considered decision variables are presented in Table 3. The binary variables  $\alpha_{EV}(i, j)$  and  $\beta_{EV}(i, j)$  are used to define the charging and discharging state of  $j$ -th EV in  $i$ -th time-step.  $\alpha_{EV}(i, j) = 1$  ( $\beta_{EV}(i, j) = 1$ ) means that the battery of  $j$ -th EV is charging (discharging) in time-step  $i$ . The binary variables  $\alpha_{BE}(i, j)$  and  $\beta_{BE}(i, j)$  are similarly used for the charging and discharging state of BESS.

It is noted that, if  $j$ -th EV is out of SB in time-step  $i$ , then the

variable  $S_{EV}(i, j)$  is meaningless and should not be considered in the model. On the other hand, as we see in Table 1, the index  $i$  of  $S_{EV}(i, j)$  is considered in  $\mathbb{I}$ . Indeed, for simplicity in presentation, we consider index  $i \in \mathbb{I}$  for  $S_{EV}$  and we will care about in this issue in the objective function and constraints.

**Table 3.** Decision variables of the model (17)

Variable	Type	Index	Description
$\alpha_{EV}(i, j)$	$\{0,1\}$	$i \in \mathbb{I}$ , $j \in \mathbb{J}$	Binary variable that represents EV $j$ charging process in period $i$
$\beta_{EV}(i, j)$	$\{0,1\}$	$i \in \mathbb{I}$ , $j \in \mathbb{J}$	Binary variable that represents EV $j$ discharging process in period $i$
$\alpha_{BE}(i)$	$\{0,1\}$	$i \in \mathbb{I}$	Binary variable that represents the BESS charging process in period $i$
$\beta_{BE}(i)$	$\{0,1\}$	$i \in \mathbb{I}$	Binary variable that represents the BESS discharging process in period $i$
$S_{EV}(i, j)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$ , $j \in \mathbb{J}$	SOC of the EV $j$ at the start of period $[T_{EV}^{in}, T_{EV}^{out}]$
$S_{BE}(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	SOC of the BESS at the start of period $i$
$P_G(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	Active power extracted from the grid in period $i$ (kW)
$P_{G \rightarrow BE}(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	Active power related to charging the BESS by grid in period $i$
$P_{G \rightarrow EV}(i, j)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$ , $j \in \mathbb{J}$	Active power related to charging the EV $j$ by grid in period $i$
$P_{EV \rightarrow B}(i, j)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$ , $j \in \mathbb{J}$	Active power related to discharging of EV $j$ to SB in period $i$ .
$P_{PV \rightarrow B}(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	Active power related to cover the consumption SB by PV in period $i$
$P_{PV \rightarrow BE}(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	Active power related to charging the BESS by PV in period $i$
$P_{PV \rightarrow G}(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	Active power related to inject of PV to grid in period $i$
$P_{BE \rightarrow G}(i)$	$\mathbb{R}_0^+$	$i \in \mathbb{I}$	Active power related to inject of BESS to grid in period $i$

### 3.1 Objective Function

In this paper, it is intended to minimize the total cost of the power grid. In this regard, the following objective function is considered

$$\sum_{i=1}^I \left( P_{G \rightarrow B}(i) + P_{G \rightarrow BE}(i) + \sum_{j=1}^J P_{G \rightarrow EV}(i, j) \right) C_G^{buy} - \sum_{i=1}^I \left( P_{PV \rightarrow G} + P_{BE \rightarrow G} + \sum_{j=1}^J P_{EV \rightarrow G}(i, j) \right) C_G^{sell} \quad (1)$$

Here, the first term of the (1) corresponds to the energy cost that is delivered by the grid to the building, BESS and EVs. And the second term represents the cost of the energy that is injected into the grid by PVs, BESS and EVs.

### 3.2 Constraints

In what follows, we present the constraints should be considered in the MBLP model. These constraints are necessary to ensure that the physical limits of resource and problem assumptions do not violate.

### 3.2.1 EVs Constraints

The capacity of  $j$ -th EV's battery is  $S_{EV}^{\max}(j)$ . Thus, the following capacity constraints must be considered

$$0 \leq S_{EV}(i, j) \leq S_{EV}^{\max}(j), \quad i \in \mathbb{I}, \quad j \in \mathbb{J}. \quad (2)$$

We recall that, the arrival time and initial charge of  $j$ -th EV in each day  $d$  are known and referred by  $T_{EV}^{\text{in}}(d, j)$  and  $S_{EV}^{\text{initial}}(d, j)$ , respectively. Accordingly, we consider the following constraints

$$S_{EV}(T_{EV}^{\text{in}}(d, j) - 1, j) = S_{EV}^{\text{initial}}(d, j), \quad j \in \mathbb{J}, \quad d \in \{0\} \cup \mathbb{D} \quad (3)$$

For  $i \in \mathbb{I}$  and  $j \in \mathbb{J}$ , if  $\alpha_{EV}(i, j) = 0$ , then no power from the grid is consumed for charging EV  $j$ , i.e.,  $P_{G \rightarrow EV}(i, j) = 0$ . Otherwise, if  $\alpha_{EV}(i, j) = 1$ , then EV  $j$  could be charged from the grid in time-step  $i$ . In this case, during time-step  $i$ , EV can consume at most  $P_{EV}^{\text{ch}}(j)\tau$  power from the grid to charge its battery. At all, the consumed power from grid to charge EVs satisfies the following constraint

$$P_{G \rightarrow EV}(i, j) \leq \alpha_{EV}(i, j)P_{EV}^{\text{ch}}(j)\tau, \quad i \in \mathbb{I}, \quad j \in \mathbb{J}. \quad (4)$$

Also, batteries of EVs can be discharged to feed the demand power of the building or injected to the grid. In similar manner, the following constraints are considered for the power obtained by discharging EVs

$$P_{EV \rightarrow G}(i, j) + P_{EV \rightarrow B}(i, j) \leq \beta_{EV}(i, j)P_{EV}^{\text{dis}}(j)\tau, \quad i \in \mathbb{I}, \quad j \in \mathbb{J}. \quad (5)$$

In each time-step, SOC of EVs may be changed due to charging or discharging. Note that,  $\alpha_{EV}(i, j)$  and  $\beta_{EV}(i, j)$  show the charging and discharging state of  $j$ -th EV in  $i$ -th time-step. Consequently, at the end of time-step  $i$ , the SOC of  $j$ -th EV is updated as

$$S_{EV}(i + 1, j) = S_{EV}(i, j) + \left[ P_{G \rightarrow EV}(i, j)E_{EV}^{\text{ch}} - (P_{EV \rightarrow G}(i, j) + P_{EV \rightarrow B}(i, j))/E_{EV}^{\text{dis}} \right], \\ j \in \mathbb{J}, \quad d \in \{0\} \cup \mathbb{D}, \quad i = T_{EV}^{\text{in}}(d, j) - 1, \dots, T_{EV}^{\text{out}}(d + 1, j) - 2 \quad (6)$$

The minimum allowable SOC for  $j$ -th EV at the departure time is  $S_{EV}^{\text{min.out}}(j)$ . In this respect, the following constraints are considered at the departure time-steps.

$$S_{EV}(T_{EV}^{\text{out}}(d, j) - 1, j) \geq S_{EV}^{\text{min.out}}(j), \quad j \in \mathbb{J}, \quad d \in \mathbb{D} \quad (7)$$

In day  $d \in \mathbb{D}$ , in time-steps  $i = T_{EV}^{\text{out}}(i, j), \dots, T_{EV}^{\text{in}}(i, j) - 1$ , EV  $j$  is not in the parking. In these time-steps the charging and discharging should not occur. Accordingly, we consider the following constraints in the mentioned time-steps

$$S_{EV}(i, j) = 0, \quad j \in \mathbb{J}, \quad d \in \mathbb{D}, \quad i = T_{EV}^{\text{out}}(d, j), \dots, T_{EV}^{\text{in}}((d + 1, j) - 2 \quad (8)$$

The following constraints are taken into the account, to guarantee that the charging and discharging of EVs do not occur at the same time

$$\alpha_{EV}(i, j) + \beta_{EV}(i, j) \leq 1, \quad i \in \mathbb{I}, \quad j \in \mathbb{J}. \quad (9)$$

### 3.2.2 BESS Constraints

Due to the capacity limitation of BESS, in each period  $i \in \mathbb{I}$ , the following constraints are considered on the SOC of BESS

$$S_{BE}^{\text{min}} \leq S_{BE}(i) \leq S_{BE}^{\max}, \quad i \in \mathbb{I}. \quad (10)$$

In each time-step  $i$ , if  $\alpha_{BE}(i) = 1$ , then BESS can be charged by the grid or PVs. Moreover, if  $\beta_{BE}(i) = 1$ , then BESS can feed the

grid and apartments of the building. This charging/discharging can be modeled by the following constraints

$$P_{G \rightarrow BE}(i) + P_{PV \rightarrow BE}(i) \leq \alpha_{BE}(i)P_{BE}^{\text{ch}}\tau, \quad i \in \mathbb{I}, \quad (11)$$

$$P_{BE \rightarrow G}(i) + P_{BE \rightarrow B}(i) \leq \beta_{BE}(i)P_{BE}^{\text{dis}}\tau, \quad i \in \mathbb{I}. \quad (12)$$

Off course, the BESS cannot charge and discharge at the same period  $i$ . To force this point, the following constraints are considered

$$\alpha_{BE}(i) + \beta_{BE}(i) \leq 1, \quad i \in \mathbb{I}. \quad (13)$$

Similar to EVs, the SOC of BESS is updated as

$$S_{BE}(i + 1) = S_{BE}(i) + \left[ (P_{G \rightarrow BE}(i) + P_{PV \rightarrow BE}(i))E_{BE}^{\text{ch}} - (P_{BE \rightarrow G}(i) + P_{BE \rightarrow B}(i))/E_{BE}^{\text{dis}} \right], \quad i \in \mathbb{I}. \quad (14)$$

### 3.2.3 Load Grid Constraints

In each period  $i \in \mathbb{I}$ , the power of the grid is used to feed the building, EVs and BESS. Accordingly, the following constraints should be considered

$$P_G(i) = P_{G \rightarrow B}(i) + P_{G \rightarrow BE}(i) + \sum_{j=0}^J P_{G \rightarrow EV}(i, j), \quad i \in \mathbb{I}. \quad (15)$$

Moreover, we have bound  $P_G^{\max}$  on consuming the grid power. Accordingly, we consider the following bound constraints

$$0 \leq P_G(i) \leq P_G^{\max}, \quad i \in \mathbb{I}, \quad (16)$$

## 3.3 Summary

Based on the above discussions, the mathematical model of the problem is as

$$\begin{aligned} &\text{minimize objective function (1),} \\ &\text{subject to constraints (2) -- (16)} \end{aligned} \quad (17)$$

The decision variables are those that are sketched in Table 3. This optimization problem is an MBLP.

## 4 CASE STUDY

As a case study, we consider a real residential building with 15 apartments, 15 cars, and 3 PVs. Our aim is to study this building in 2019. In this building, for every 15 minutes, the energy consumption of apartments, generated power by PVs, and arrival/departures of cars are recorded. These recorded data are considered as input data, which evaluate the parameters  $P_{SB}$ ,  $P_{PV}$ ,  $T_{EV}^{\text{in}}$  and  $T_{EV}^{\text{out}}$ . However, due to some technical issues, some records are missed in the collected data. In this regard, we used regression and adjacent interpolation to estimate and forecast the missed records.

As mentioned, the data are collected every 15 minutes of the year. Accordingly, the time-period is equal to one year (365 days) and  $\tau = 0.15$  minutes. In this way, each day is divided to  $24 \times 4 = 96$  time-steps and consequently, the time-period contains  $I = 96 \times 365 = 35040$  time-steps.

Now, we suppose that each car in the building is replaced by an EV with the following configurations (come from the BMW i3 94 Ah)

$$S_{EV}^{\max} = 27.2, \quad P_{EV}^{\text{ch}} = 3.7, \quad P_{EV}^{\text{dis}} = 3.33$$

Moreover, we assume that the building is equipped with a BESS with the following features

$$S_{BE}^{max} = 50, P_{BE}^{ch} = 6.3, P_{BE}^{diss} = 5.67.$$

We mentioned that, in order to validate the developed model close to real situations, the above characteristics of the EVs and the BESS are considered based on the market specifications. In addition, the initial SOC of BESS at the beginning of time-period ( $S_{BE}^{initial}$ ) and initial SOS of EVs at each arrival time of day ( $S_{EV}^{initial}(j, d)$ ) are set randomly.

Our aim in this paper is to investigate the advantages of the considering battery of EVs and an extra BESS as power storage devices. In this regard, the following scenarios are considered.

- In the base scenario, the discharge process of the EVs does not consider. Moreover, BESS is not considered, too. In this scenario, just the charging time of EVs is scheduled and for this purpose, the presented MBLP (17), with  $\beta_{EV}(i, j) = 0$  and  $\alpha_{BE}(i) = \beta_{BE}(i) = 0$  is considered.
- In the second scenario, the charging and discharging process of EVs are considered but similar to the base scenario, the BESS is not used. In this scenario, MBLP (17), with  $\alpha_{BE}(i) = \beta_{BE}(i) = 0$  is considered to provide the charging/discharging schedule of EVs.
- The proposed problem in Section 2 is considered as the third scenario. In this scenario, we intend to optimize the charging/discharging schedule of EVs and BESS by solving MBLP (17).

## 5 SIMULATION RESULTS

In this section, the mentioned three scenarios of the case study are studied by solving the proposed MBLP model (17). Our aim is to highlight the advantages of Scenario 3 over the other scenarios in terms of power price and peak load demand.

To solve MBLP (17), it is modeled in AMPL (A Mathematical Programming Language) [3] and the CPLEX solver [1] is used.

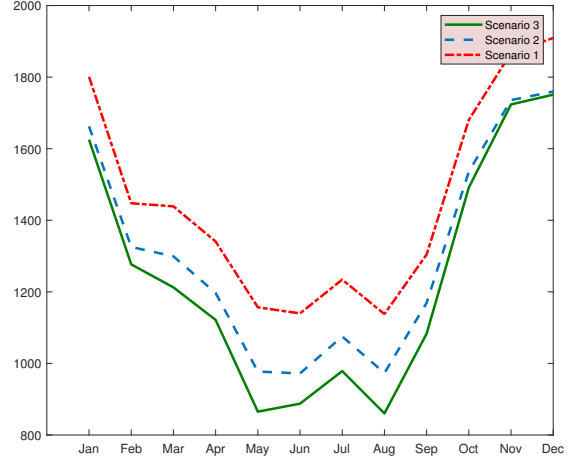
### 5.1 Experiment 1: Visualizing the results of the three scenarios

As the first experiment, we solve the model (17) for three scenarios and report the obtained total costs (Objective functions) in Table 4. Moreover, the monthly values of the energy cost in Scenarios 1, 2 and 3 are compared in Figure 2.

**Table 4.** Total Cost and Energy For All Scenario during 1 year.

	Objective Function	$P_G$
Scenario 1	17458.0895	100270.995
Scenario 2	15682.2486	90034.118
Scenario 3	14814.65992	84002.393

As we see, in the middle months (May-Aug), thanks to more efficiency of PVs, the total cost is reduced in the three scenarios. Moreover, allowing EVs to discharge and using BESS lead to reducing the power cost, such that the cost of power in Scenario 3 is less than Scenario 2 and also Scenario 2 is less than Scenario 1. More precisely, it can be seen that Scenario 2 leads to 11% reduction, whereas Scenario 3 was able to reduction of 15%. In what follows, we illustrate why these reductions are happen.



**Figure 2.** Total Cost and Energy For All Scenario during 1 year.

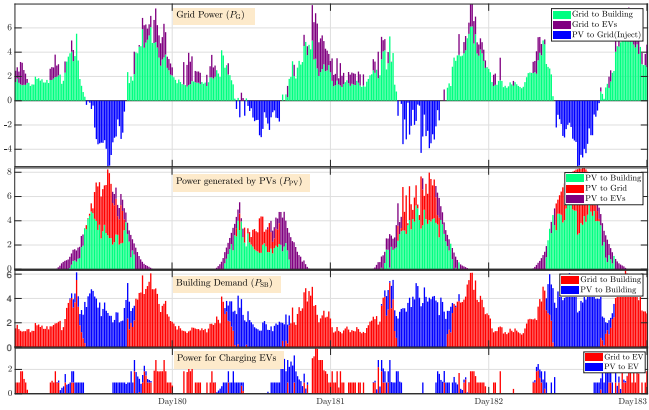
In Figure 3, the consumed power from the grid, generated power by PVs, the building demand and power consumed for charging EVs are plotted for days 180 to 183 of the year. Moreover, the interactions between producers and consumers are specified in different colors. In a similar fashion, Figure 4 shows the results of Scenario 2.

As we see, in Scenario 2, in some step-times, some amounts of power generated by PVs are used for charging EVs' battery and at other time-steps, the batteries of EVs are discharged to reduce the consumed power from the grid. Indeed, in Scenario 2, EVs are used as a storage for PVs, such that the consuming/injecting power from/to the grid is reduced. Consequently, since the cost of selling power in comparison with buying power is insignificant, in Scenario 2, the power cost is reduced.

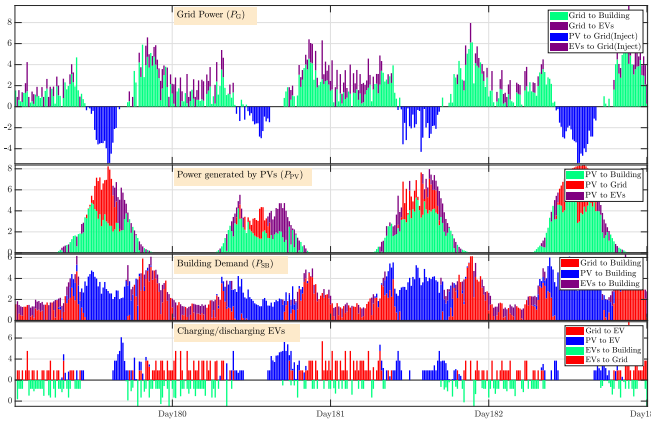
However, in both scenarios in the middle of days, a significant amount of the power generated by PVs is injected into the grid. At these times, the EVs are outside of the building and their batteries could not be used as storage for EVs. As we mentioned before, the idea of Scenario 3 is to store the extra power and use it at other times. To show the impact of considering BESS, in Figure 5, the interaction between SB components is illustrated. As this figure shows, just a little power is injected into the grid and BESS stores the generated power by PVs and discharges in peak loads time-steps.

### 5.2 Experiment 2: Optimal Battery sizing and charge/discharge rate

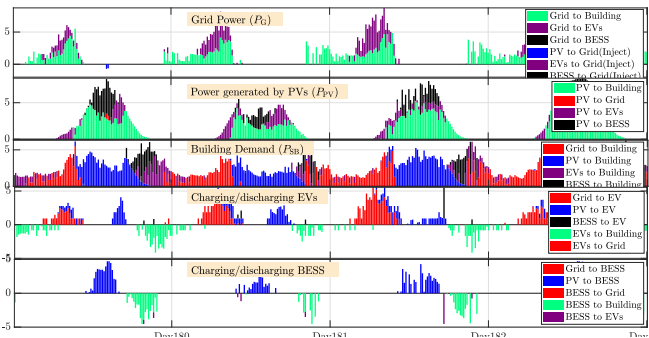
In this paper, BESS is used to improve the power consumption in the building. Here, we provide some results that help the managers of the building to select optimal characteristics of the BESS. More precisely, we report the impact of capacity and charge/discharge rate of BESS on the power price of the building. In Figure 6, the power cost of SB for various values of capacity and charge/discharge rate is plotted. Based on this figure, we see that in this case study, there is no need for a battery with high capacity. Moreover, the rates of charge and discharge are effective factors. As we see, for the building in the considered case study, if the charging and discharging times of BESS are 1 and 0.9 hours, respectively, the capacity 40 is optimal.



**Figure 3.** [Scenario 1, days 180 to 183]: Trace of power between Grid, Building's apartments, Pvs and EVs

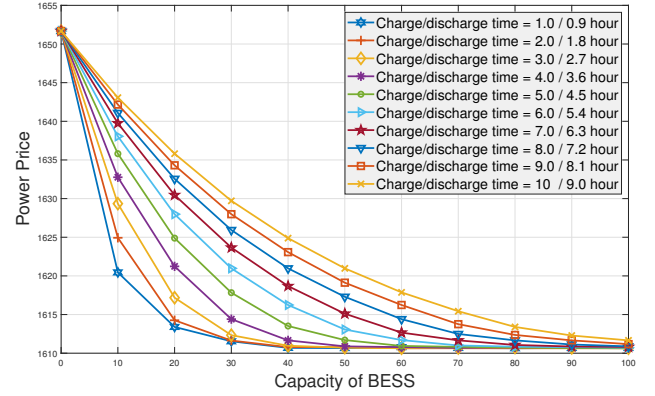


**Figure 4.** [Scenario 2, days 180 to 183]: Trace of power between Grid, Building's apartments, Pvs and EVs



**Figure 5.** [Scenario 3, days 180 to 183]: Trace of power between Grid, Building's apartments, Pvs, EVs and BESS

Moreover, if charging/discharging time is 6/5.4 hour, then capacity 70 is optimal.



**Figure 6.** The power price of SB for based on various values of BESS capacity and charge/discharge rate

## 6 CONCLUSION

This work proposes an MBLP model that minimizes the total cost of energy for the SB. The model considers the PV generation panel, EVs and a BESS. The main contribution of this work is the flexibility of the contract power for each apartment and considering single contract power for the whole building. Therefore, each apartment can consume electricity energy as long as it does not exceed the installed contract power of the building. Otherwise, the demand response programs are used to impose a fine. The results of our three scenarios show the efficiency of the model. In the first scenario that only the charging processes of EVs are considered, the total cost was incurred. The proposed MBLP formulation is aiming to decrease the total cost by adding the discharging process of EVs in Scenario 2 and also considering the charging and discharging process of BESS and EVs in Scenario 3. The applied strategy in Scenario 2 leads to reducing the total cost and consumption from the grid by 11% in comparison with Scenario 1. Then, the impact of the optimization of the charging and discharging schedule of EVs and BESS in energy management in the SB is analyzed in Scenario 3. It is implied that this process reduces the cost of energy consumption from the grid by 15% compared to Scenario 1. Finally, The impact of the capacity and charging/discharging rate of the BESS on the total cost is studied.

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