SETSCI Conference Proceedings
21, 43-48, 2024

International Trend of Tech Symposium
7-8 December 2024, İstanbul - Türkiye

https://doi.org/10.36287/setsci.21.8.043
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Grid-Aware Electric Vehicle Charging Interface Design

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***Abstract* –** Fossil fuels used by traditional internal combustion vehicles today are quite damaging to environment. Because of these fuels, global warming has reached a very dangerous point. However, fossil fuels are gradually depleting. Therefore, it is inevitable that electric vehicles, which are more environmentally friendly, more economical and quieter, will become widespread. However, since fully electric vehicles will receive all of their energy from the grid, the electrical grid must be ready for this situation and load. Since conventional grids will be insufficient to manage this load, smart grids, which are flexible, adaptive, synchronous and strong, are needed. The energy quality problems due to electric vehicles can only be minimized with smart grids. When energy demands and distribution over time compared, demands of electric vehicles is much greater and, more importantly, it demands this energy in a much shorter time demand of a residence. For this reason, before electric vehicles become widespread, grids need to become smart and possible problems and solution suggestions need to be examined. In this study, instead of classical fast or slow electric vehicle charging, a flexible charging interface that interacts with grid, vehicle user and vehicle was designed.

Keywords – Electric Vehicle (EV), Smart grid, Grid flexibility, Lithium-ion battery, Battery charging, Battery healty.

I. INTRODUCTION

As Electric Vehicles (EV) become more widespread, load on grid will increase. Load of charging vehicles from grid requires redesign of electric power distribution system [1],[2]. Conventional grids will be inadequate to manage this extra load, which causes short-term large demand changes and whose timing is uncertain. By smart grids, control over this load will increase, and effects of this inflow will be reduced by taking necessary precautions and guidance. Smart grids will prevent system collapse, interruptions and quality problems monitoring this consumption and taking precautions where necessary. For this reason, smart grids that are dynamic, adaptive and efficient are needed. Following widespread use of EVs, if vehicle battery charging processes are left solely to user's initiative without taking precautions and developing new charging algorithms, this will create major problems for grid and encompassing all elements. The foundations of conventional power systems were laid in the 19th century and have survived to present day without much change. On the other hand, production, consumption, human behavior and demands in the world have undergone radical changes. For this reason, smart grids that are more flexible, more adaptive and in communication with consumer have gained great importance. Smart grid has bidirectional communication between consumer and producer so continuous energy monitoring and control supply-demand balance can be management. Smart grids as interactive grids electrical energy deliver efficiently, continuously, economically and reliable to all users. In other words, a smart grid is an electricity grid that can intelligently integrate actions of all users connected to it to efficiently provide sustainable, economical and safe electricity supply [17].

In the literature on this subject, a case study was conducted on a residential model in the Matlab/Simulink environment, which developed an energy management system strategy to increase energy efficiency [3]. Additionally, a smart charging algorithm was developed in an experimental study [4]. Another study was examined impact of electrification of a bus fleet on grid [5]. A smart charging algorithm adopting deep learning approach has been developed [6]. An intelligent bidirectional charging algorithm using grid-to-vehicle and vehicle-to-grid concepts has been proposed [7]. Coordinated charging application was carried out with particle swarm optimization technique [8]. A study has been conducted on minimizing cost of charging EVs [9]. There is a study that considers a practical electric bus charging station configuration operating in Pamplona, Spain [10]. Demand management method has been developed to shift load (EV charging) to fill overnight electricity demand valley and consume when there is a surplus of renewable energy in the system [11]. EVs driving and charging behavior was simulated with a Monte Carlo simulation-based algorithm [12]. A smart charging application integrated with Internet of Things (IoT) architecture was developed to connect to charging station via web application [13]. There is a study that aims to improve grid load profile [14]. In addition, a fuzzy logic controller design was carried out on EV charging [15].

In this study, instead of an EV charger that charges with constant current, a design that divides the day into hours according to the demand curve and is more sensitive to increasing the grid load was implemented. For this purpose, an interface has been designed that charges with lower current during high electricity consumption time and with higher current during low electricity consumption time.

II. SMART GRID AND CONVENTINOAL GRID

A. Conventional Grid

A grid established to deliver generated electrical energy to users is called a conventional grid [16]. Conventional grids have maintained their basic structure for many years and have not undergone major changes. Conventional grids have unidirectional energy flow and centralized generation. It consists of electromechanical systems that cannot benefit sufficiently from intelligent electronic systems. There is a necessity to extra generation for instantaneous increases in demand.

B. Smart Grid

Smart grid is an electrical grid that can intelligently integrate actions of all users connected to it, including plants, consumers, and prosumers that both generate and consume energy, to efficiently provide sustainable, economical and safe electricity supply [17].

Smart grids can better integrate Renewable Energy Sources (RES) into power system. They improve control and management of transmission and distribution companies over the system. Briefly, they offer a more flexible grid opportunity. Smart grid interaction is given in Fig. 1.

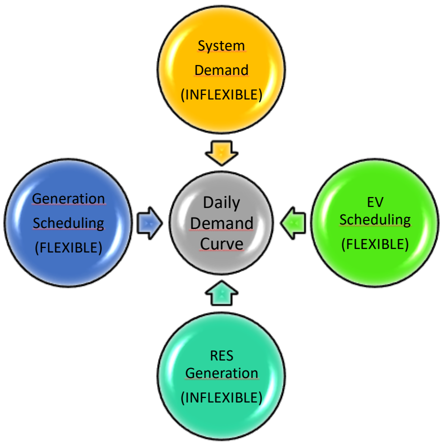


Fig. 1. Smart Grid Interaction between EVs and electricity market components [18].

Smart grids can use the stored energy during times of high energy demand, as they have a structure that can meet need for distributed storage as well as distributed production. They can determine faults locations in grid more quickly and effectively. Smart grids consist of three main components as Distribution grid RESs (DRESs), Distribution grid Storage Devices (DSDs) and users and all components are given in Fig. 2. In Fig. 2, EVs are seen as both storage devices and consumers depending on grid needs and battery status. This situation can be managed according to need by smart grid.

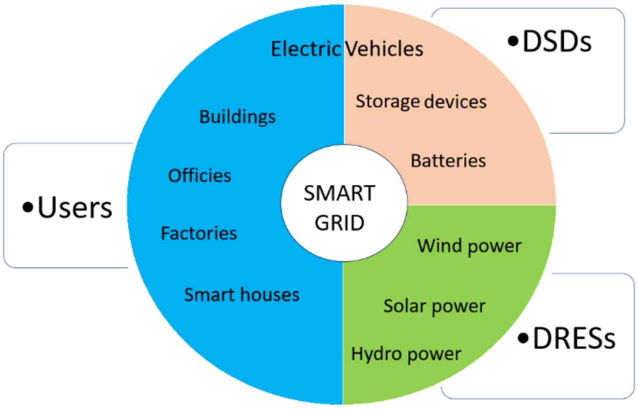


Fig. 2. Smart Grid componenets [19].

C. Effects of EV charging on the grid

Forecasting load growth for EVs is complex and may require grid reinforcements beyond budget allocated to grid planning. With the increase in EV penetration into distribution system, the power drawn by system will be more, which will require additional system infrastructure by distribution company. EV inverters can create power quality problems such as harmonics. Uncontrolled vehicle charging can overload components, increase power system losses, create phase imbalance, and shorten transformer life. They can also cause reactive power problems. For this reason, it is necessary to avoid uncontrolled vehicle charging. From daily load curve of grid in Fig. 3, it is seen that the highest consumption is during day and evening hours. The least consumption is seen in early hours of day and in morning. People desire to charge their vehicles when they come home; load profile which is already at its peak without these vehicles, will be further disrupted by creating larger peaks. For this reason, multi-price tariffs should be applied by dividing the daily pricing into multiple levels in a way that the most expensive pricing being during peak hours through smart meters. Thus, the consumer may prefer to charge in early hours of day in order to pay less bill. A more effective method is to plan charging process according to hours of day, as we did, by doing slow charging during peak hours and fast charging during day when demand is low.

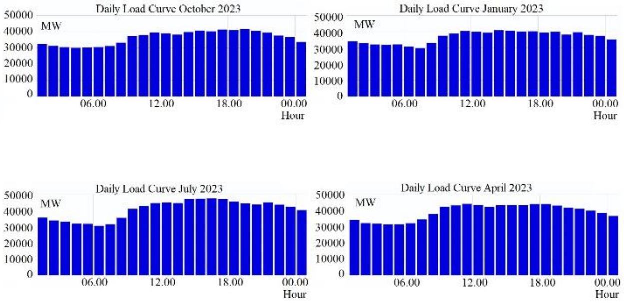
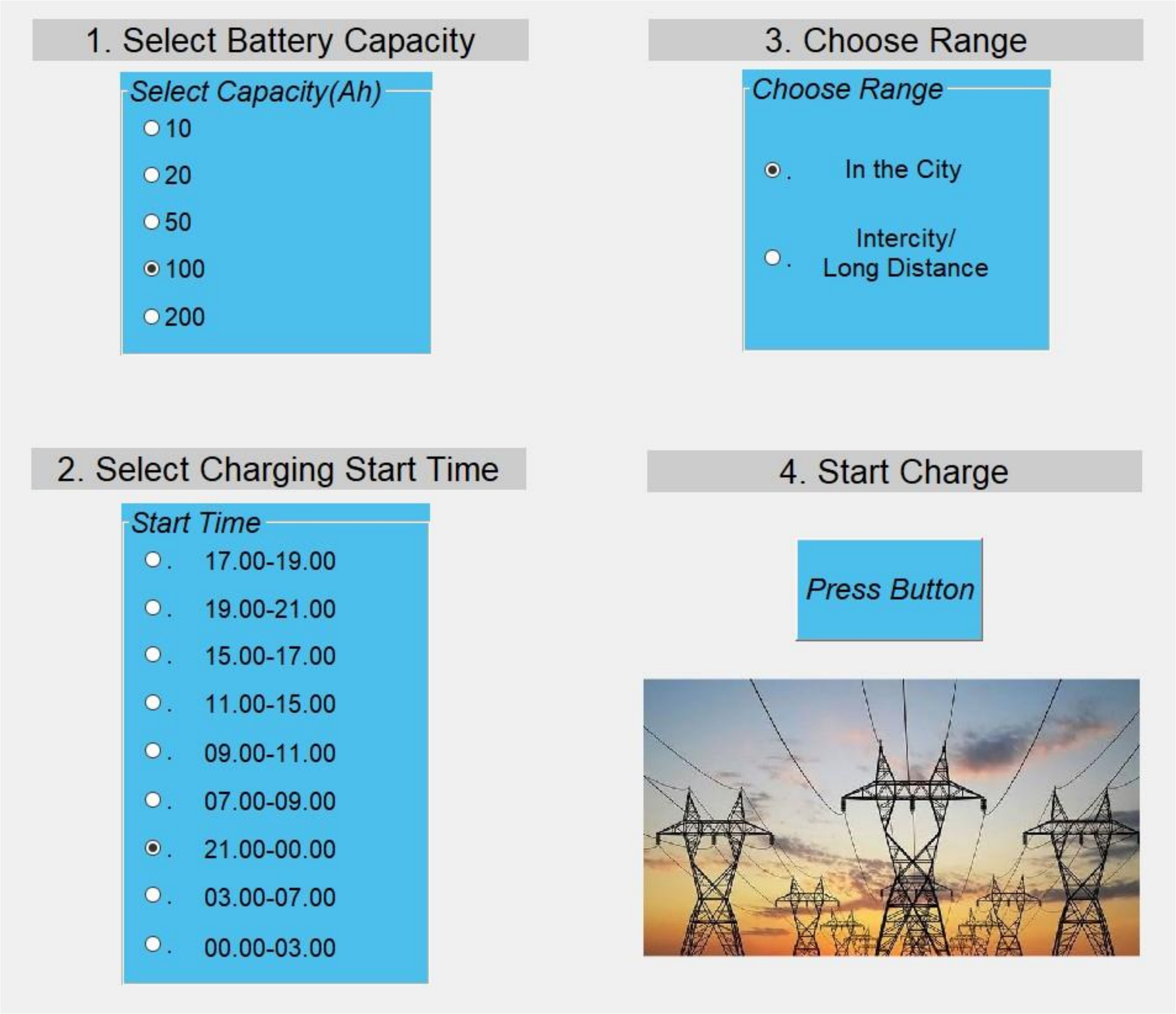


Fig.3. Daily load curve samples of Turkey [20]

III. MODELLING OF EV CHARGE



1. Select Battery Capacity

Select Capacity(Ah)

○ 10
○ 20
○ 50
● 100
○ 200

2. Select Charging Start Time

Start Time

○ . 17.00-19.00
○ . 19.00-21.00
○ . 15.00-17.00
○ . 11.00-15.00
○ . 09.00-11.00
○ . 07.00-09.00
● . 21.00-00.00
○ . 03.00-07.00
○ . 00.00-03.00

3. Choose Range

Choose Range

● . In the City
○ . Intercity/ Long Distance

4. Start Charge

Fig. 4. EV charging simulator Matlab Guide interface.

Fig. 4 shows EV charging interface designed with Matlab guide. This interface consists of four stages. Firstly, the battery capacity is selected, and in second stage, information about the time interval at which charging process will begin is entered. At this stage, day is divided into nine different charge levels according to load curve in Fig. 3. In this way, it is aimed to create a smoother curve by shaving off the peaks in the load curve. The grid load is taken into account according to time and charging speed of each option is different. At this stage, grid needs are prioritized. In third stage, purpose of first driving after charging is selected. If you will drive within city and EV will be charged again in evening, the first option is chosen, if you will drive a long range for intercity roads, the second option is chosen. In the first option, the battery is charged to 85% of its capacity, if long distance option is selected, capacity is fully charged, that is, battery is charged to 100%. At this stage, needs of vehicle driver are at the forefront. In addition, unnecessary full capacity charging is prevented at this stage, thus preserving battery health.This option is user and vehicle responsive. By this interface, needs of grid, vehicle driver and vehicle are combined and taken into account. Finaly, button is pressed to start charging process, an overhead line image appears on screen and charging process begins. In the interface in Fig. 4, for example, battery capacity is 100 Ah, charging start time is 21:00-00:00, and it is stated that next drive will be in city.

The dynamic model of battery used in simulator is shown in Fig. 5. The block diagram of flexible EV charging simulator designed with Matlab/Simulink is given in Fig. 6.

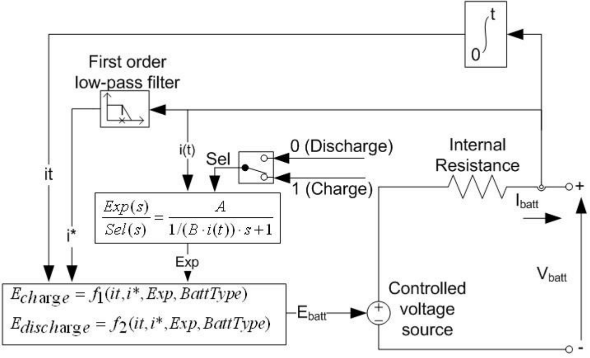


Fig. 5. Dynamic model of the battery used in the simulator.

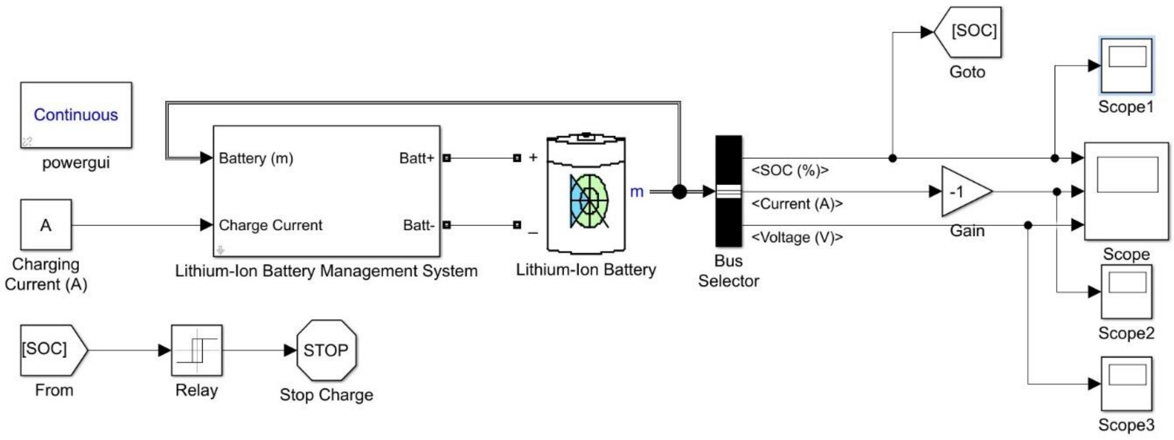


Fig. 6. Flexible charge simulator Matlab/Simulink block diagram.

E_{Batt}:is nonlinear voltage (V),

E_0:is constant voltage (V),

Exp(s): is exponential zone dynamics (V),

Sel(s): represents the battery mode. *Sel(s)* = 0 during battery discharge, *Sel(s)* = 1 during battery charging,

K: is polarization constant (Ah^{-1}) or Polarization resistance (Ohms),

*i**: is low frequency current dynamics (A),

i: is battery current (A),

it: is extracted capacity (Ah),

Q: is maximum battery capacity (Ah),

A: is exponential voltage (V),

B: is exponential capacity (Ah^{-1}).

The charge model of lithium-ion battery used in simulator is expressed by equation (1).

$$\left.\begin{aligned} f_2(it,i^*,i) &= E_0 - K.\frac{Q}{it+0,1.Q}.i^* \\ -K.\frac{Q}{Q-it}.it &+ A.\exp(-B.it) \end{aligned}\right\} \tag{1}$$

IV. DISCUSSION AND RESULTS

In this study, as seen in Fig. 4, battery capacity is selected in the first stage, and charging time and distance is selected respectively, and then charging process starts when start button is pressed. An overhead line image appears on the screen to indicate that the charging process has started. The selection of the charging time in second stage of operation directly affects charging current, fast charging with high current cause even more load on grid operating at peak load. The daily load curve is made smoother by performing slow charging with low current at the peak points of daily load curve and fast charging with high current at valley points of load curve. An attempt is made to capture controlled charging curve in Fig. 7. In third stage, in city/intercity selection is made. If city driving is to be done, it is unnecessary to fully charge battery, so charging process is stopped at 85% SoC (State of Charge) level. In this way, battery is not fatigued by a full charge and grid is not given a full load in one day. Instead, intermittent load distribution is made.

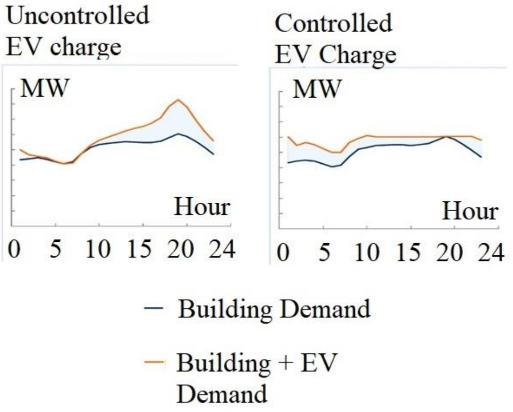


Fig. 7. Uncontrolled and controlled EV charging.

Fig. 8 shows the time/SoC curve of a 100 Ah battery that starts charging between 17:00 and 19:00 and is charged from 20% SoC to 85% SoC. The charging process was automatically terminated at 85% SoC level since city driving was preferred.

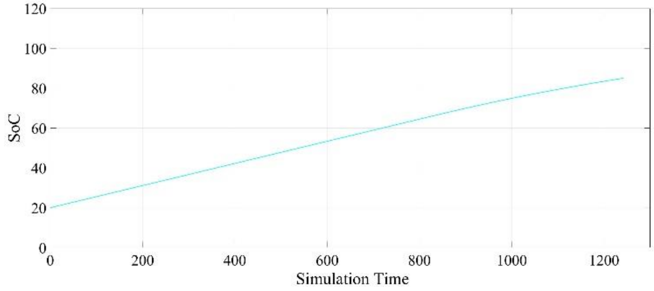


Fig. 8. Charging curve of 100 Ah battery for city driving between 17:00-19:00.

Fig. 9 shows time/SoC curve resulting from 100 Ah battery starting to charge between 00:00-03:00 and charging from 20% SoC level to 85% SoC level. The charging process was automatically terminated at 85% SoC level since city driving was preferred.

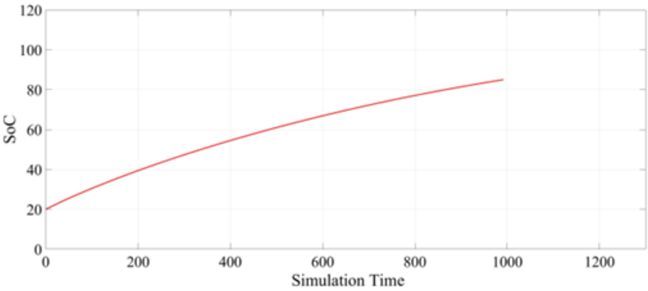


Fig. 9. Charging curve of 100 Ah battery for city driving charging between 00.00-03.00.

Fig. 10 shows time/SoC curve of 100 Ah battery that starts charging between 21:00-00:00 and is charged from 20% SoC to 85% SoC. The charging process was automatically terminated at 85% SoC level since city driving was preferred.

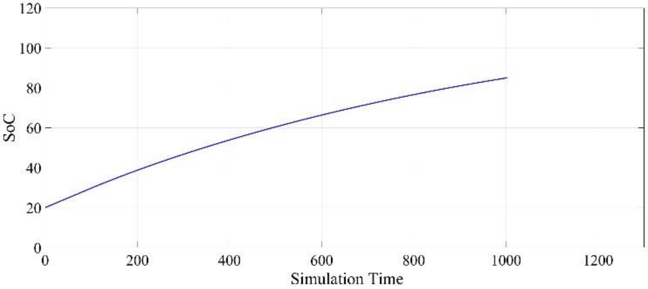


Fig. 10. Charging curve of 100 Ah battery for city driving between 21:00-00:00

Fig. 11 shows time/SoC curve of 100 Ah battery that starts charging between 11:00-15:00 and is charged from 20% SoC to 85% SoC. The charging process is automatically terminated at 85% SoC since city driving is preferred.

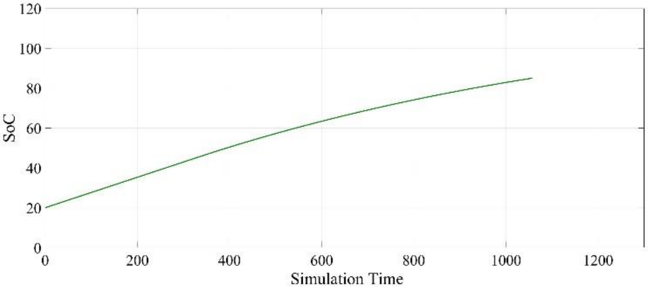


Fig. 11. Charging curve of 100 Ah battery for city driving between 11:00-15:00

When Fig. 8 and 9 are examined in particular, it is seen that the curve in the eighth figure is more horizontal and the curve in the ninth figure is more vertical. Because time/SoC curve in eighth figure was obtained during a peak hour of electricity consumption and so more horizontal. The curve in ninth figure was recorded when electricity consumption was low and so it is more vertical. This situation is shown in Fig. 12. All the situation curves examined in Fig. 8-11 are combined in Fig. 12.

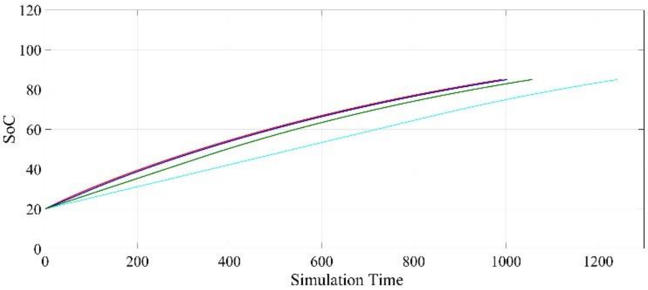


Fig. 12. Charging curves of 100 Ah battery for city driving in different time zones

V. CONCLUSION

This study is based on charging batteries of various capacities at various speeds, taking daily load curve as reference for electricity consumption. In addition, charging rate of battery capacity can be decided by selecting driving distance. In this way, EV charging curve is aligned with grid needs, contributing to power system flexibility. In future studies, online grid needs can be included and a more sensitive charging process with more data can be achieved.

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