



HAL
open science

Predictive smart charging of plug-in electric vehicles for parking fleet scenario with modular converters

Reza Razi, Majid Mehrasa, Khaled Hajar, Mehrdad Gholami, Ahmad Hably, Seddik Bacha, Antoine Labbone

► To cite this version:

Reza Razi, Majid Mehrasa, Khaled Hajar, Mehrdad Gholami, Ahmad Hably, et al.. Predictive smart charging of plug-in electric vehicles for parking fleet scenario with modular converters. CIRED Porto Workshop 2022 E-mobility and power distribution systems, Jun 2022, Porto, Portugal. 10.1049/icp.2022.0831 . hal-03658903

HAL Id: hal-03658903

<https://hal.science/hal-03658903>

Submitted on 4 May 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Predictive smart charging of plug-in electric vehicles for parking fleet scenario with modular converters

Reza RAZI¹
reza.razi@grenoble-inp.fr

Majid MEHRASA¹
majid.mehrasa@grenoble-inp.fr

Khaled HAJAR¹
khaled.hajar@grenoble-inp.fr

Mehrdad GHOLAMI^{1,2}
mehrdad.gholami@grenoble-inp.fr

Ahmad HABLY¹
ahmad.hably@grenoble-inp.fr

Seddik BACHA¹
seddick.bacha@grenoble-inp.fr

Antoine LABONNE¹
antoine.labonne@grenoble-inp.fr

¹ Univ. Grenoble Alpes, CNRS, Grenoble INP*, GIPSA-Lab, G2ELAB, 38000 Grenoble, France

² Faculty of engineering, University of Kurdistan, Sanandaj, Iran

* Institute of Engineering Univ. Grenoble Alpes

ABSTRACT

In recent years, smart charging of electric vehicles has been considered in various scenarios for all parties involved. However, the issue of smart charging is less explored in the parking lot scenario than in other ones, where the number of vehicles is typically greater than the number of charging points. In addition, the charging period is temporary, and modular converters are used to reduce costs in this scenario. In this paper, a modified algorithm is presented to connect each vehicle to the suitable and pursue the desired goals. The effectiveness of the proposed method is evaluated through simulation.

INTRODUCTION

Nowadays, the environmental problems associated with traditional vehicles with fossil fuels are clear enough to everyone. In this regard, electric vehicles (EVs), as a new generation and replacement of old vehicles, also have challenges [1]–[3]. One of the main concerns related to these vehicles is the significant rise in energy demand [4]. In fact, a similar pattern of users' behavior, the design of ultra-fast chargers, and the significant growth of plug-in electric vehicles (PEVs) will impose heavy pressure on power distribution networks. In other words, PEVs increase the energy density of the load profile at certain times, especially around early morning and early evening. Therefore, this is a fact that the lack of energy demand management of PEVs will become a serious challenge in the near future.

From the point of view of the economy and electrical sciences, this congestion leads to higher prices, reduced efficiency, and increased investment costs. Therefore, in an ideal plan, all parties involved in the issue are trying to resolve it through cooperation. In this regard, smart charging of PEVs has become a hot trend in recent years [5], [6]. In other words, various methods control the output power of PEV as a flexible element to optimize the desired

objective functions. In a simple view, PEV can be charged when the price or load is low or can be discharged in the opposite situation when the price is high. In general, there are two main control methods for smart charging of PEVs including the rule-based method [7]–[9] and optimization method [10]–[13]. It can be claimed that in recent research, optimization algorithms have received more attention due to the better results, which have been improved in real-time with the help of the second method [14]. Also, researchers try to employ model predictive control (MPC) to deal with uncertainties in the desired structure.

In one of our recent works in [15], user-friendly smart charging was proposed by considering the charging cost and battery health, in such a way that the user plays a key role in choosing the desired charging scenario for PEV. In another work in [16], a Mamdani-based fuzzy strategy was developed to manage the output power of PEVs. In addition, a simple technique was presented in [17] to limit the number of discharge cycles for the bidirectional smart charging scenario. However, the main algorithm was only used for one vehicle in residential or workplace applications. Therefore, in most of past literature, less attention has been paid to energy management of parking lot scenarios where the number of charging points (CPs) is usually less than the number of PEVs and the parking time is temporary.

In this paper, a user-friendly predictive algorithm for smart charging of PEVs in the parking lot application is presented, which is based on the following salient features:

- ✓ Developing a novel algorithm to assign each PEV to the appropriate CP
- ✓ Compatibility with modular converters
- ✓ Independent of the number of PEVs with plug-and-play capability
- ✓ Minimizing the charging cost by maintaining the priority of PEVs and satisfying the restrictions
- ✓ Interacting with the user and providing possible results related to the cost and state of health (SOH)

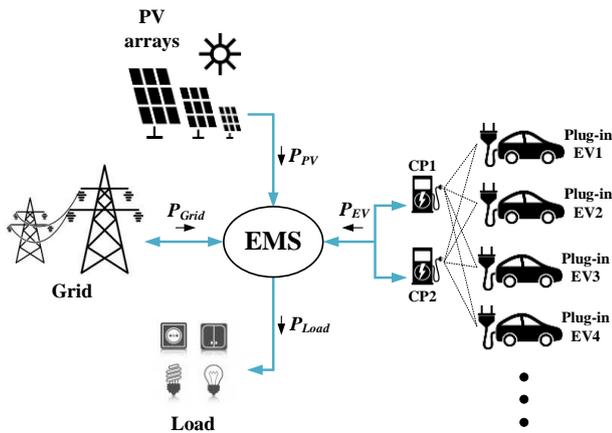


Fig. 1. Typical structure of parking lot charging station.

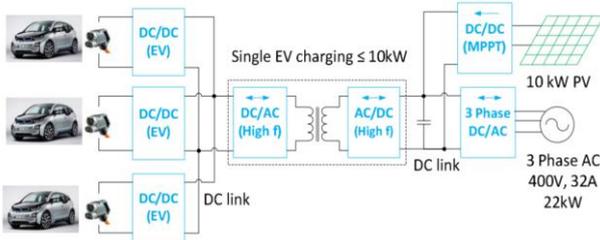


Fig. 2. Modular converter topology for connecting multiple PEVs to a single EV-PV charger [18].

In the rest of the paper, a typical structure of a parking lot charging station is described in the next section. After that, the proposed algorithm will present. Finally, the simulation results will be shown to verify the effectiveness of the proposed algorithm.

PARKING CHARGING STATION STRUCTURE

In this section, it is better to start with a general structure of the electrical elements in the parking lot charging station. A Typical structure of parking lot charging station is shown in Fig. 1. As it can be seen in this structure, there are several CPs, a utility grid, local loads, and photovoltaic (PV) arrays. In smart charging algorithms, an energy management system (EMS) unit communicates with all the elements. Power directions for different components show positive directions of their power flow.

The main application of this structure is in shopping malls, city centers, government offices, hospitals, restaurants, airports and universities. In this regard, many PEVs will come to the desired parking lot, which the number of PEVs may be more than the capacity of CPs. Usually the parking time and energy demand of vehicles in this application is limited. The number of each PEV only indicates the priority of arrival of that vehicle. Also, each PEV can be connected to an arbitrary CP where it is not possible to change that after specifying. Chandra Mouli *et al.* [18] tried to connect several vehicles to a single CP simultaneously by presenting a modular converter topology. The desired topology is shown in Fig. 2. In fact,

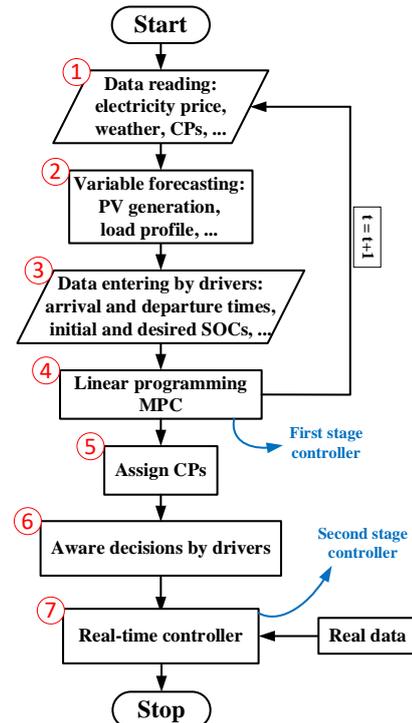


Fig. 3. Flowchart of the proposed smart charging algorithm.

due to the high energy density of CPs and reduced investment costs, this topology was very successful. It is assumed that in this structure, there are two CPs, which can charge three PEVs simultaneously while maintaining the maximum power of CP ($P_{\max-CP} = 10 \text{ kW}$). However, energy optimization between different elements and CPs in the presence of this topology requires a predictive algorithm to assign each vehicle to the appropriate CP. At the same time, the number of PEVs may still be more than the input of modular converters. In this case, the proposed algorithm should be able to reserve and supply energy related to vehicles in the charging queue, which will be presented in the next section.

PROPOSED SMART CHARGING ALGORITHM

As mentioned earlier, the main idea of this paper is inspired by the previous work of the authors in [15], which could not be generalized for parking lot scenarios. In this regard, the proposed smart charging algorithm is improved and its flowchart is presented in Fig. 3.

Initially, data such as electricity price, weather conditions, and the number of CPs is obtained in the first step. Then, the desired information is estimated in the second step or is received directly from the user in the third step. In fact, the PV generation power and load profile should be estimated and arrival time, departure time, the initial state of charge (SOC), and final SOC can be received. Although obtaining some information from the driver may not be very accurate, it greatly reduces uncertainty. After that, as it can be seen, the algorithm uses two scheduling methods, including predictive linear optimization in the fourth step and a real-time scheme in the seventh step. In parallel with

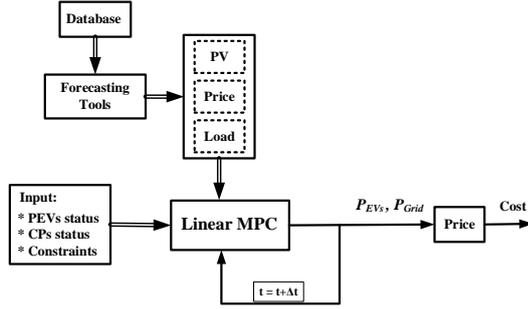


Fig. 4. Block diagram of linear MPC.

the optimization in the fourth step, the appropriate CP is assigned to each vehicle in the fifth step. Then in step six, the user or driver will select one of the possible scenarios. Finally, the real-time controller is used to compensate for errors caused by uncertainties. However, in this paper, the seventh step is ignored because there is no real-time implementation. The following is a more complete description of linear optimization and the algorithm for assigning PEVs to CPs.

Here, unlike the previous work, all PEVs are controlled based on a single optimization controller. The proposed optimization is employed in the form of MPC, which its details are shown in Fig. 4. In fact, for each 5-minute time step, the problem is optimized over a 20-hour time horizon. The total objective function of the linear programming MPC reduces the cost of energy exchanged with the grid by observing the priority of charging of vehicles and considering the efficiency of batteries, as follow:

$$\min C_{tot} \left(\sum_{i=1, \dots, n} P_{EV,i} \right) = \sum_t C_{grid}(t) \times \underbrace{P_{grid}(t) \times \Delta t}_{\Delta E_{grid}(t)} - \sum_{i=1, \dots, n} \lambda_{energy,i} \times E_{EV}(i, t_0 + \Delta t) + \sum_{i=1, \dots, n} \sum_t \lambda_{battery,i} \times C_{grid}(t) \times P_{EV,i}(t) \quad (1)$$

where n , i , C_{grid} , Δt , E_{EV} , λ_{energy} and $\lambda_{battery}$ represent the total number of PEVs, the index of each PEV, the electricity price, optimization time step, the PEV battery energy, charging priority coefficient and battery efficiency coefficient, respectively. As it is clear, the second term of the objective function is related to the priority of charging. In fact, a PEV has a higher energy coefficient when it arrives to the charging station earlier. This factor is defined in this work as follow:

$$\lambda_{energy,i} = (n - i + 1) \times 100E - 09; \quad i = 1, \dots, n \quad (2)$$

Besides, the third term avoids useless charging and discharging of batteries due to the loss of energy as follow:

$$\lambda_{battery,i} = \begin{cases} 1 & ; P_{EV,i} \geq 0 \\ 0.9 & ; P_{EV,i} < 0 \end{cases}; \quad i = 1, \dots, n \quad (3)$$

Also, the power balance equation is:

$$P_{PV} + P_{Grid} + \sum_{i=1, \dots, n} P_{EV,i} = P_{Load} \quad (4)$$

On the other hand, the proposed scheme for assigning PEVs to CPs is working as shown in Fig. 5.

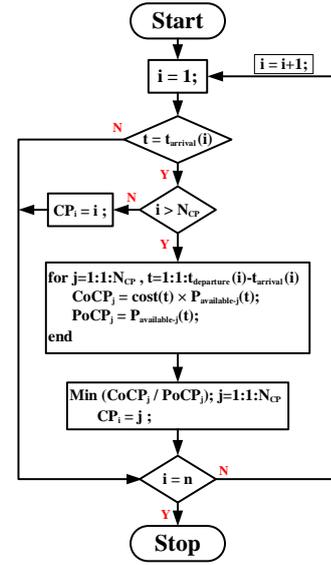


Fig. 5. Proposed flowchart of the CPs assigning (Fifth step).

As it can be seen, this algorithm is repeated for all n vehicles to find their proper CP. The algorithm is activated only once for each vehicle when the EV enters the charging station ($t = t_{arrival}(i)$). If the vehicle number i be equal to or less than the number of the CPs (N_{CP}), the vehicle is connected to the corresponding CP ($CP_i = i$). In this way, one-to-one correspondence is created between the EVs and the CPs, and the maximum dispersion is respected.

Otherwise, when the EV number is more than the number of CPs, there is a different procedure for selecting the CP. In this regard, for all CPs and for the time period between the arrival and departure times of the desired vehicle ($t_{departure}(i) - t_{arrival}(i)$), the available power of CP ($PoCP_j$) and its cost ($CoCP_j$) are calculated. This variable represents the remaining power capacity of the CP, which is equal to the maximum power minus the power of previous vehicles connected to that CP.

$$PoCP_j = P_{available-j} = P_{CP-j}^{max} - \sum_{i \in j} P_{EV-i} \quad (5)$$

In the next step, the cost-to-power ratio ($CoCP_j / PoCP_j$) of each CP is obtained such that the CP with the lowest value is selected as the appropriate CP of the vehicle. In fact, the algorithm considers the CP with more capacity and lower price for EVs. When each EV is added to a appropriate CP, the following constraint is activated:

$$P_{EV-new} + \sum_{i \in j} P_{EV-i} \leq P_{CP-j}^{max} \quad (6)$$

At the end, this procedure is repeated for the next EV. As a result, the power of vehicles, grid power, and associated CPs will be obtained.

SIMULATION RESULTS

In this section, the simulation results of various cases in the presence of proposed method will be analyzed. It is assumed that the grid power limitation is 30 kW. In this regard, the results for a parking lot with two CPs are shown

TABLE I
 PEVS SPECIFICATION

	Arrival time	Departure time	Initial SOC	Final SOC	SOC min/max	Nominal energy	Power max/min
PEV1: Renault Zoe	08:00	12:30	20%	65%	20%, 90%	44.1 kWh	±10 kW
PEV2: Peugeot e-208	10:45	13:00	45%	70%	20%, 90%	50 kWh	±7.4 kW
PEV3: Tesla Model 3	10:00	15:00	30%	60%	20%, 90%	50 kWh	±10 kW
PEV4: Tesla Model 3	10:30	14:00	40%	75%	20%, 90%	50 kWh	±10 kW

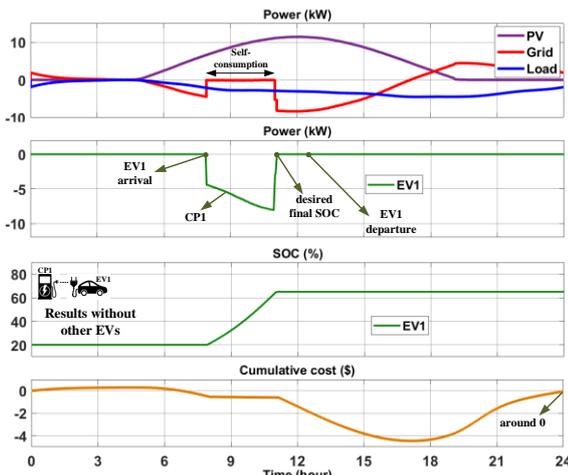


Fig. 6. Simulation results for a single PEV and two CPs.

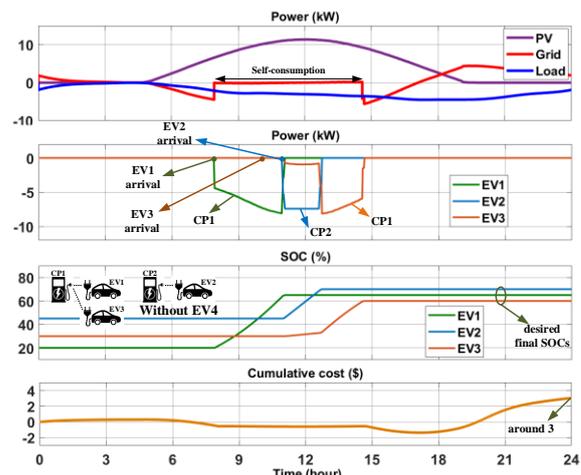


Fig. 8. Simulation results for three PEVs and two CPs.

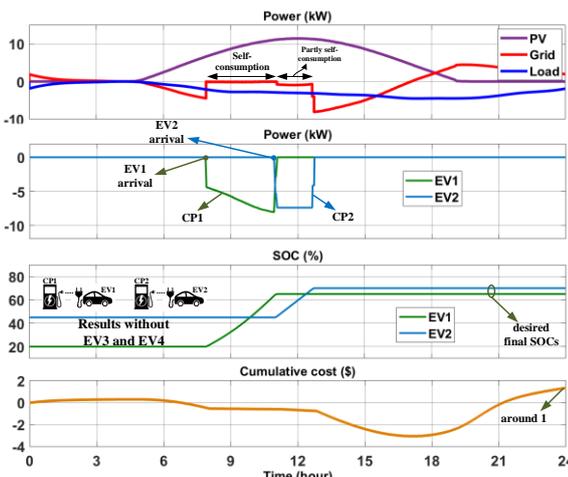


Fig. 7. Simulation results for two PEVs and two CPs.

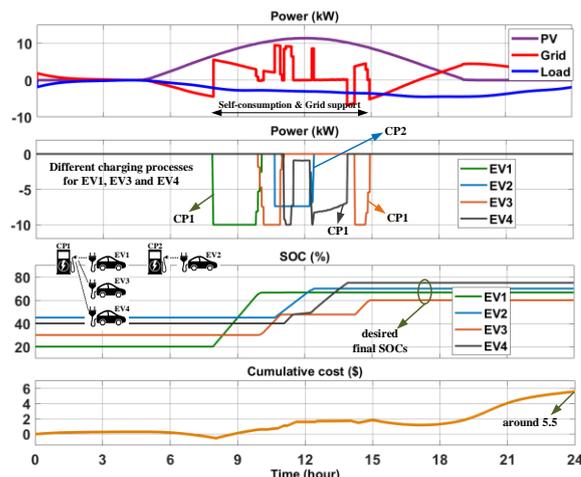


Fig. 9. Simulation results for four PEVs and two CPs.

in Figs. 6-9 based on the provided information in Table 1. Here, due to the short parking time and constant electricity price, the unidirectional scenario is only considered such that the PEV will act as a flexible load.

In the first case study, the first EV arrives at the parking lot at 8 am. The simulation results are shown in Fig. 6, which includes the power of different elements, charge status and cumulative cost. As it can be seen, EV1 is immediately connected to the first CP and it is charged with solar energy to reach the final SOC. It should be noted that during this period, the energy exchanged with the grid is null.

As shown in Fig. 7, in the second case study, the EV2 is connected to the CP2. Although the CPs of the first and second EVs are different, EV2 is charged after the first vehicle to use the renewable energy produced inside the

parking lot. Here, due to being at the PV power peak, the EV2 is charged with maximum power and at a constant rate.

Then, in the third case, the simulation results with the addition of the third vehicle are shown in Fig. 8. It should be noted that EV3 arrives at the parking lot earlier than EV2, but the second car has reserved CP2 by announcing earlier. Therefore, according to the proposed algorithm, EV3 is connected to CP1. In this case, as in previous simulations, no energy is received from the grid to charge EVs.

Finally, the simulation results in the presence of four vehicles are shown in Fig. 9. In this case, there is not enough photovoltaic energy to charge all the cars. Therefore, the grid utility needs to be involved in the charging process of EVs. Here, due to the provided data

and limitations, the fourth EV is also connected to the CP1, such that the changes in the output power of other EVs are also evident.

Therefore, as expected, with the addition of other vehicles, the system constraints, especially the capacity of the CPs, are activated and the optimal conditions change.

Conclusion

Smart charging of EVs in the parking lots in the presence of modular converters can have technical and economic benefits for the driver, station owner and network operator. For this purpose, in this paper, a modified predictive intelligent charging algorithm was presented that determines the ideal charging point and charging process of different vehicles. In this regard, in the proposed objective function, several goals were pursued, including minimizing the cost of energy exchanged with the grid, prioritizing for charging of EVs and considering battery efficiency. In addition, to assign the suitable charging point, the available power at all charging points and electricity cost were used. Finally, it was verified with the help of simulation results that the proposed algorithm has the flexibility to operate in the desired application.

Acknowledgments

This work has been supported by the aVEnir project of the PIA operated by ADEME.

REFERENCES

- [1] I. Husain *et al.*, “Electric Drive Technology Trends, Challenges, and Opportunities for Future Electric Vehicles,” *Proc. IEEE*, vol. 109, no. 6, pp. 1039–1059, Jun. 2021.
- [2] R. Fachrizal, M. Shepero, D. van der Meer, J. Munkhammar, and J. Widén, “Smart charging of electric vehicles considering photovoltaic power production and electricity consumption: A review,” *eTransportation*, vol. 4, p. 100056, May 2020.
- [3] B. Al-Hanahi, I. Ahmad, D. Habibi, and M. A. S. Masoum, “Charging Infrastructure for Commercial Electric Vehicles: Challenges and Future Works,” *IEEE Access*, vol. 9, pp. 121476–121492, 2021.
- [4] International Renewable Energy Agency, “Electric-Vehicle Smart Charging Innovation Landscape Brief,” 2019.
- [5] A. Ovalle, A. Hably, and S. Bacha, *Grid Optimal Integration of Electric Vehicles: Examples with Matlab Implementation*, vol. 137. Cham: Springer International Publishing, 2018.
- [6] K. Hajar, B. Guo, A. Hably, and S. Bacha, “Smart charging impact on electric vehicles in presence of photovoltaics” *2021 22nd IEEE International Conference on Industrial Technology (ICIT)*, 2021, pp. 643–648.
- [7] H. Turker, S. Bacha, and A. Hably, “Rule-based charging of plug-in electric vehicles (PEVs): Impacts on the aging rate of low-voltage transformers,” *IEEE Trans. Power Deliv.*, vol. 29, no. 3, pp. 1012–1019, 2014.
- [8] X. Li and S. A. Evangelou, “Torque-Leveling Threshold-Changing Rule-Based Control for Parallel Hybrid Electric Vehicles,” *IEEE Trans. Veh. Technol.*, vol. 68, no. 7, pp. 6509–6523, Jul. 2019.
- [9] S. Zhou, Z. Chen, D. Huang, and T. Lin, “Model Prediction and Rule Based Energy Management Strategy for a Plug-in Hybrid Electric Vehicle With Hybrid Energy Storage System,” *IEEE Trans. Power Electron.*, vol. 36, no. 5, pp. 5926–5940, May 2021.
- [10] H. Turker and S. Bacha, “Optimal Minimization of Plug-In Electric Vehicle Charging Cost With Vehicle-to-Home and Vehicle-to-Grid Concepts,” *IEEE Trans. Veh. Technol.*, vol. 67, no. 11, pp. 10281–10292, 2018.
- [11] C. S. Ioakimidis, D. Thomas, P. Rycerski, and K. N. Genikomsakis, “Peak shaving and valley filling of power consumption profile in non-residential buildings using an electric vehicle parking lot,” *Energy*, vol. 148, pp. 148–158, 2018.
- [12] D. Van Der Meer, G. R. C. Mouli, G. M. E. Mouli, L. R. Elizondo, and P. Bauer, “Energy Management System with PV Power Forecast to Optimally Charge EVs at the Workplace,” *IEEE Trans. Ind. Informatics*, vol. 14, no. 1, pp. 311–320, 2018.
- [13] J. F. Franco, M. J. Rider, and R. Romero, “A Mixed-Integer Linear Programming Model for the Electric Vehicle Charging Coordination Problem in Unbalanced Electrical Distribution Systems,” *IEEE Trans. Smart Grid*, vol. 6, no. 5, pp. 2200–2210, Sep. 2015.
- [14] Y. Guo, J. Xiong, S. Xu, and W. Su, “Two-Stage Economic Operation of Microgrid-Like Electric Vehicle Parking Deck,” *IEEE Trans. Smart Grid*, vol. 7, no. 3, pp. 1703–1712, 2016.
- [15] R. Razi, K. Hajar, A. Hably, and S. Bacha, “A user-friendly smart charging algorithm based on energy-awareness for different PEV parking scenarios,” in *2021 29th Mediterranean Conference on Control and Automation (MED)*, Jun. 2021, pp. 392–397.
- [16] M. Mehraza, R. Razi, K. Hajar, A. Labonne, A. Hably, and S. Bacha, “Power Management of a Smart Vehicle-to-Grid (V2G) System Using Fuzzy Logic Approach,” in *IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society*, Oct. 2021, vol. 2021-October, pp. 1–6.
- [17] R. Razi, K. Hajar, M. Mehraza, A. Labonne, A. Hably, and S. Bacha, “Limiting discharge cycles numbers for plug-in electric vehicles in bidirectional smart charging algorithm,” in *IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society*, Oct. 2021, vol. 2021-October, pp. 1–6.
- [18] G. R. C. Mouli, P. Bauer, and M. Zeman, “Comparison of system architecture and converter topology for a solar powered electric vehicle charging station,” in *2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia)*, Jun. 2015, pp. 1908–1915.