BỘ CÔNG THƯƠNG

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Ngành: Kỹ thuật Năng lượng

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THE MINISTRY OF INDUSTRY AND TRADE

ELECTRIC POWER UNIVERSITY

VAN NGUYEN NGOC

A RESEARCH ON OPTIMAL SOLUTIONS FOR CONTROL AND OPERATION OF PHOTOVOLTAIC INTEGRATED CHARGING STATIONS IN VIETNAM

Field: Energy engineering

Code: Pilot

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The dissertation is available in:

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INTRODUCTION

1. Motivation for research

1.1 COP26 and PDP VIII – the commitments of Vietnam to sustainable development

At the COP26 conference, Vietnam has committed to bring net emissions to zero by 2050. Besides, the Power Development Plan VIII (PDP VIII) sets a target of 50% of buildings and houses using rooftop PV power for self-consumption by 2030.

The commitments at COP26 and the PDP VIII demonstrate the determination toward sustainable development. Follow the orientation, this research is proposed to study solutions to promote the development of both RESs and EVs in the context of Vietnam.

1.2 The transition to electric two-wheeler mobility

In Vietnam, the transition from traditional motorcycles to E2Ws might be the result of current high rate of motorbike adoption, socio-economic conditions, and limited transport infrastructure.

However, the growth of E2Ws has been projected to result in an accelerated burden on the grid. Thus, research on solutions addressing this issue should be considered.

1.3 Rooftop solar power development in Vietnam and its impacts

Vietnam is considered a place with special potential for developing solar power. However, high PV penetration could affect the operation and security of the grid. In order to increase the grid hosting capacity, the utility could introduce mitigation techniques or adopt grid optimization solutions. Besides, the power grid needs to be upgraded and flexibly managed to better accommodate the RESs.

Another method to promote PV usage without affecting the distribution grid operation is to encourage self-consumption. With

50% of buildings utilizing rooftop solar power for self-consumption by 2030, it would be a challenge that needs solutions to reach.

1.4 PV-integrated charging stations – A solution for both E2W and rooftop solar development

Generally, in Vietnam, there are two concerning factors. Firstly, it is the emergence of charging loads which are not planned for the current infrastructure. Secondly, it is the popularity of RESs which possess stochastic and intermittent nature and are encouraged to self-consume.

PV-integrated charging stations might be an effective solution since the solution could meet the need of EV charging and encourage self-generation self-consumption. Thus, it can help mitigate unwanted impacts of charging load and RESs on the grid.

2. Research goals, scope, and research questions

Goals:

- This work aims at coordinating hundreds of E2Ws charging considering both V2G and non-V2G.
- The proposed solutions in this work aim at load leveling, valley filling and peak shaving.
- Uncertainties such as charging behaviors are considered.
- The proposed solutions in this work should consider the high number of vehicles in the charging stations.

Scope:

- This work focuses on charging/discharging Li-ion batteries. Batteries should be consistent with popular E2Ws in Vietnam. Batteries are considered ideal energy storage systems.
- The desired SOC and expected departure time of vehicles are assumed to be available to the scheduler.
- Residential voltage level of 220 V should be considered.

- Hundreds of E2Ws charging should be taken into account.
- This work does not address issues: island mode operation, optimal power dispatch, optimal sizing.
- PV power and non-EV load forecast are assumed to be available and sufficiently accurate. This work does not consider the shading effect, the uncertainty of weather conditions or forecast inaccuracy.

Questions:

- It is necessary to develop smart and flexible charging solutions.
- Charging algorithms need to meet the charging requirements while reducing impacts on the grid and other loads.
- The algorithms should also be tailored to facilitate ancillary services or grid support.
- The solutions should consider the high number of E2Ws.
- Uncertainties such as charging behaviors should be considered.

3. Research methodology

The dissertation is carried out based on the following research methods: Synthesis research; Modeling and simulation; Empirical testing; Expert consultation.

4. Research contributions

In this work, a research on the scheduling algorithms for E2W charging stations is conducted. The main contributions of this work can be expressed in the following points:

- This work provides solutions to meet new load demand and encourages rooftop PV power development while mitigating adverse impacts of EVs and PV on the distribution grid. Thus, reducing the need to upgrade/reinforce the grid.

- This work proposes and verifies two scheduling algorithms in terms of improving load profile, filling the valleys, and shedding peak loads.
- An empirical test bench has been successfully set up for evaluating the real-time responses of E2W charging station following long-term charging plan from the scheduler.

The dissertation consists of five chapters. Chapter 1 reviews the architectures and control algorithms for EV charging stations. In Chapter 2, a mathematical model and a simulation model of the station are developed. Chapter 3 proposes a power allocation algorithm aiming at load leveling. An optimal algorithm based on receding horizon framework is proposed and verified in Chapter 4. Finally, a test bench is established in Chapter 5 to verify real-time responses of E2W charging.

CHAPTER I: OVERVIEW OF EV CHARGING STATIONS – ARCHITECTURES AND CONTROL ALGORITHMS

1.1 Charging station architecture and proposal for E2W CSs.

Generally, charging a group of EVs can be implemented by centralized, decentralized, or hierarchical architectures (Figure 1.1).

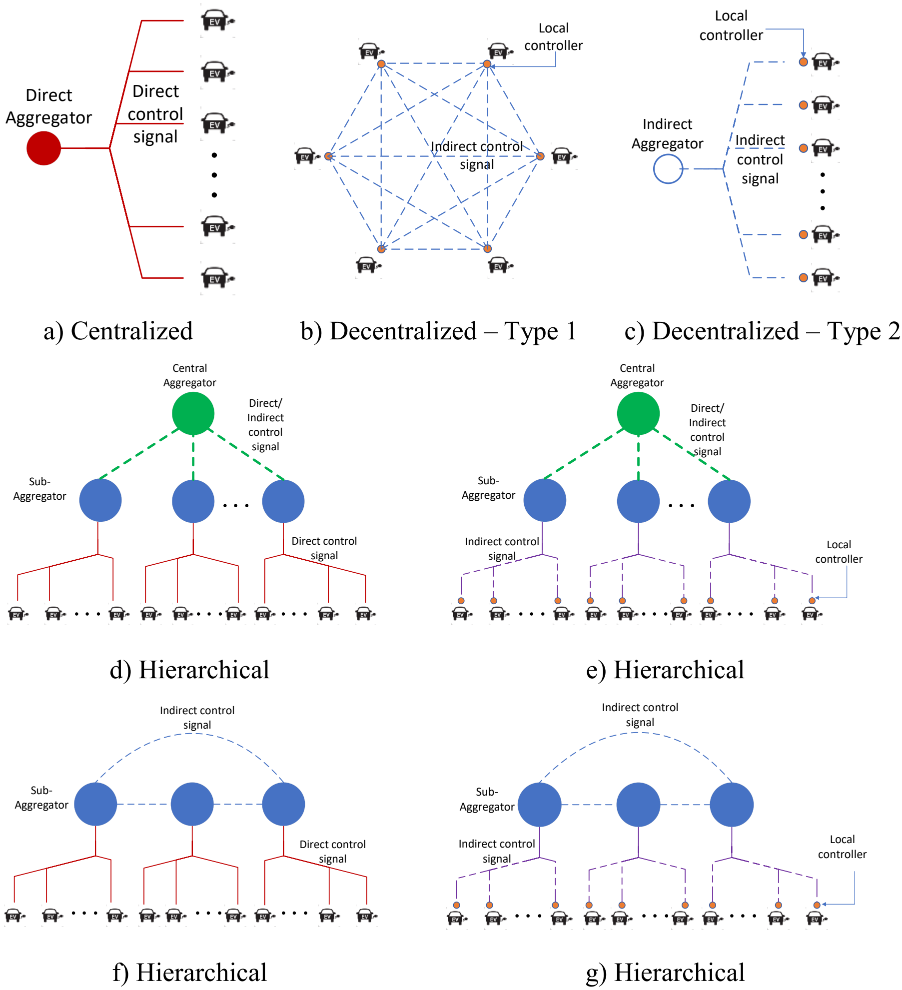


Figure 1.1 Charging station architecture.

In the decentralized architecture, the charging coordination of EVs is often achieved through signal broadcasting (such as price signals). However, this approach may not be effective for E2Ws as the price signal may not be effective since the energy and power consumption of E2Ws are usually much lower than electric cars. Therefore, when considering hundreds of E2W charging in a parking lot, it is necessary to have a centralized controller to manage E2W charging. The vehicle owner should only be responsible to a certain extent.

To increase the scalability, hierarchical architecture can be potential. Accordingly, each E2W group should be managed by a centralized controller to calculate and determine charging plan for a certain number of vehicles it manages. These sub-controllers can form a network or be managed by a central controller.

In the scope of this work, a charging station serving dozens/hundreds of E2Ws is researched. The station follows centralized architecture. On a larger scale, hierarchical architecture should be adopted.

1.2 EV charging station control algorithms

Most studies consider EV charging problem as a constrained OP, with charging rates and durations being seen as decision variables. The OP includes various constraints imposed by the grid operator, aggregator, vehicle, and vehicle owner.

Charging station control problems can be classified in terms of technical and economic aspects as in Table 1.1.

Table 1.1 Classification of charging station problems

A) Technical aspects	B) Economic aspects
1. Load regulation 2. Maximizing operational efficiency 3. Ancillary service provision 4. Other objectives:	1. Minimizing cost of electricity generation 2. Maximizing grid operator revenue

- Minimizing charging loss - Minimizing battery degradation - Ensuring charging fairness - Maximizing convenience for vehicle owners …	3. Maximizing revenue of EV aggregator 4. Minimizing charging cost

Regarding load leveling algorithms, an approach for load leveling is to minimize the load variance with the objective function as in (1.1)

$$\min_{P_t^i} \sum_{t=1}^{M} \left(D_t^S + \sum_{i=1}^{N} P_t^i \right)^2 \quad (1.1)$$

Where: D_t^S is non-EV load; P_t^i denotes the charging power of EV_i at timeslot t; M is the total number of timeslots of Δ_T.

Another approach is to affect the charging behavior through electricity pricing. After receiving price signals, each vehicle would then try to minimize charging costs by scheduling to charge at low-price times, thereby filling low-load periods.

1.3 Summary

Regarding E2W charging, a decentralized architecture based on price signal broadcasting may not be effective. It is much more practical if E2W charging stations use a central controller to coordinate charging. To reduce the computational burden in the case of hundreds/thousands of vehicles charging, the station might be divided into multiple sub-stations managed by sub-controllers.

Regarding algorithms for E2W charging stations, current research is still quite limited. However, algorithms for electric car charging stations can also serve as a reference for E2W charging stations to some extent. Besides, algorithms for E2W charging stations should consider characteristics of E2W charging such as high number of vehicles, modest battery capacity and small charging power compared to electric cars.

CHAPTER II: MODELING OF PV-INTEGRATED ELECTRIC-TWOWHEELER CHARGING STATIONS

2.1 Chapter objectives

Both real-time and long-term models of a PV-integrated E2W charging station are considered in this chapter, allowing to investigate real-time responses and integrate long-term scheduling algorithms.

2.2 Charging station block diagram

Figure 2.1 depicts an EV charging station connected to the grid, a PV system, and conventional loads.

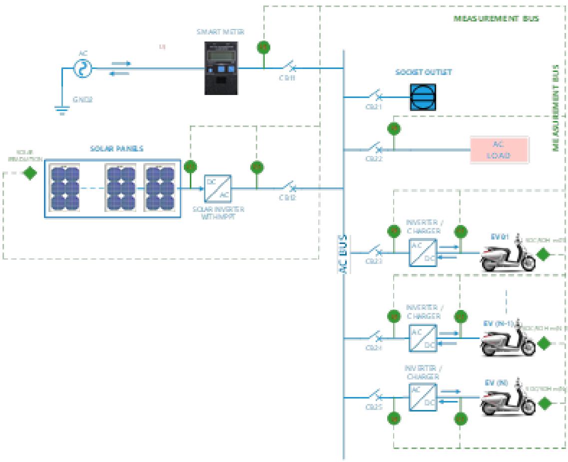


Figure 2.1 Charging station block diagram.

2.3 Realtime model

This model is suitable for investigating the charging/discharging response of E2Ws in real-time. The model consists of:

- PV model; Battery model; DC-DC boost converter; Grid-tie inverter; Bi-directional charger/discharger.

2.4 Long-term model

This model is suitable for scheduling over multiple periods.

The charging station can be described by:

$$C_S(t+1) = C_S(t) + P_S(t).T_h \quad (2.1)$$

$$E_S(t) = D_S(t) + P_S(t) \quad (2.2)$$

The constraints include:

- Power constraints:

$$Charging: P_S(t) \leq min\left\{\sum_{i=1}^{N} P_{cmax_i}, \sum_{i=1}^{N} P_{bmax_i}\right\} \quad (2.3)$$

$$Discharging: P_S(t) \geq max\left\{\sum_{i=1}^{N} P_{cmin_i}, \sum_{i=1}^{N} P_{bmin_i}\right\} \quad (2.4)$$

- Constraints on the supply capacity:

$$Charging: P_S(t) \leq P_{feedermax} - D_S(t) = P_{amax} \quad (2.18)$$

$$Discharging: P_S(t) \geq -P_{feedermax} + D_S(t) = -P_{amax} \quad (2.19)$$

- Constraints on the energy requirements:

$$R_S = \sum_{i=1}^{N} Required\ Energy\ of\ EVi$$

$$= \sum_{i=1}^{N} A_i\left(FSOC_{EV_i} - ISOC_{EV_i}\right) = \sum_{i=1}^{N}\left(\int_{t_0}^{t_m} P_t^i dt\right) \quad (2.20)$$

2.5 Summary

In this chapter, a PV integrated E2W charging station in real-time and long-term operational mode is modeled.

The real-time model can be used to study the real-time operation of the charging station while the long-term model can be utilized as the framework for integrating optimal charging algorithms in the next chapters.

CHAPTER III: CHARGING POWER ALLOCATION ALGORITHM FOR E2W CHARGING STATIONS

3.1 Chapter objectives

The objective of this chapter is to propose and develop a smart charging strategy for E2W charging stations comprising of a PV system, the distribution grid, and conventional loads. The proposed algorithm aims to improve the aggregated load profile.

With the grouping approach and three stages of power allocation, solving the constrained OP multiple times to find each E2W charging profile is eliminated, thereby reducing computational demand when scheduling hundreds of E2Ws.

3.2 Input data requirements

In order to verify the performance of a charging scheduling algorithm, certain input data needs to be provided. The data includes:

3.2.1 Electric bike and electric motorcycle specifications

3.2.2 Charging behaviors

3.2.3 Conventional load profile

3.2.4 Solar power output profile

3.3 Charging power allocation algorithm for E2Ws

With the aim of improving total load profile, this study proposes a charging power allocation algorithm that satisfies the energy needs of the E2Ws, charging constraints, and shapes the total load to match a predefined profile. The proposed algorithm consists of three stages:

- Stage 1: find the total charging pattern of the station.
- Stage 2: find group charging patterns.
- Stage 3: find individual charging patterns.

All three stages must satisfy constraints on energy requirements, charging/discharging power limits, depth of discharge (DOD) etc.

3.3.1 Mathematical formulation of the algorithm

The average power of total load during a working day:

$$\mu_{ave}^{S} = \frac{1}{M}\sum_{t=1}^{M} D_t^S + \sum_{i=1}^{N} \frac{A_i\left(FSOC_{EV_i} - ISOC_{EV_i}\right)}{M.\Delta_T} \qquad (3.2)$$

The variance of the total load can be calculated by:

$$Load\ Variance = \frac{1}{M}\sum_{t=1}^{M}\left(D_t^S + \sum_{i=1}^{N} P_t^i - \mu_{ave}^S\right)^2 \geq 0 \qquad (3.1)$$

Thus, an ideal charging reference vector could be defined as:

$$\boldsymbol{a} = \left[\left(\mu_{ave}^S - D_1^S\right)\left(\mu_{ave}^S - D_2^S\right) \cdots \left(\mu_{ave}^S - D_M^S\right)\right]^T \qquad (3.2)$$

After stage 1, the final charging reference vector is as in (3.5):

$$\boldsymbol{w} = \left[P_1^S\ P_2^S\ \cdots\ P_M^S\right]^T \qquad (3.3)$$

In the next stage, the charging reference vector is allocated to E2W groups. The charging reference matrix is defined as:

$$W = \begin{bmatrix} P_1^{G_1} & P_1^{G_2} & \dots & P_1^{G_K} \\ P_2^{G_1} & P_2^{G_2} & \cdots & P_2^{G_K} \\ \vdots & \vdots & \ddots & \vdots \\ P_M^{G_1} & P_M^{G_2} & \cdots & P_M^{G_K} \end{bmatrix} \qquad (3.4)$$

In the next stage, the charging reference matrix is then exploited to determine individual charging patterns. For simplicity, stage 3 estimates the charging power for each vehicle as in (3.12).

$$\left[P_1^{i,j}\ P_2^{i,j} \dots P_M^{i,j}\right]^T = \frac{1}{N_j}\left[P_1^{G_j}\ P_2^{G_j} \dots P_M^{G_j}\right]^T \qquad (3.5)$$

After preliminarily assigning as in (3.12), a correction process should be performed to meet the constraints and identify final individual profiles.

3.3.2 Algorithm flowchart

The flowchart of the algorithm is depicted in Figures 3.5; 3.6 and 3.7.

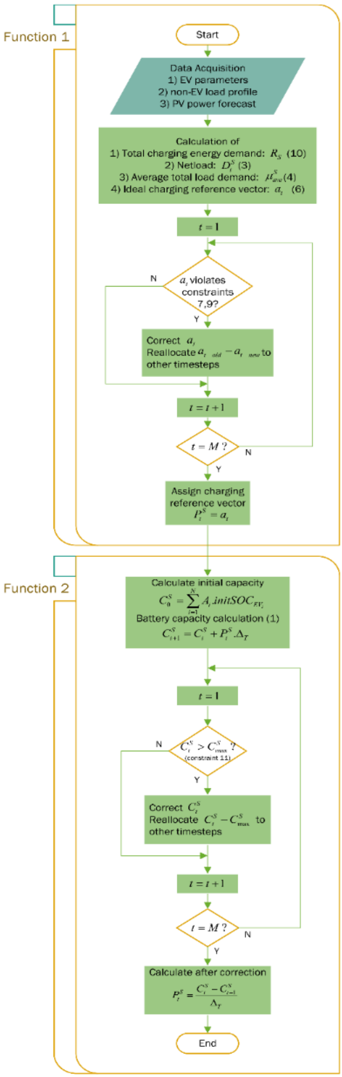


Figure 3.5 Flowchart of stage 1 algorithm

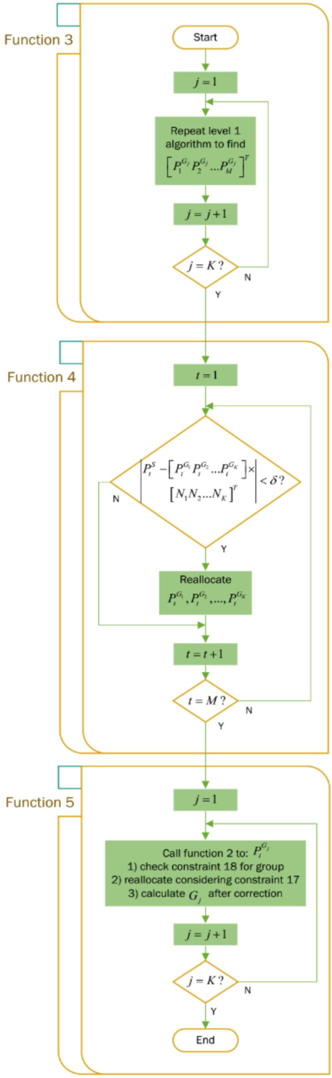


Figure 3.6 Flowchart of stage 2 algorithm

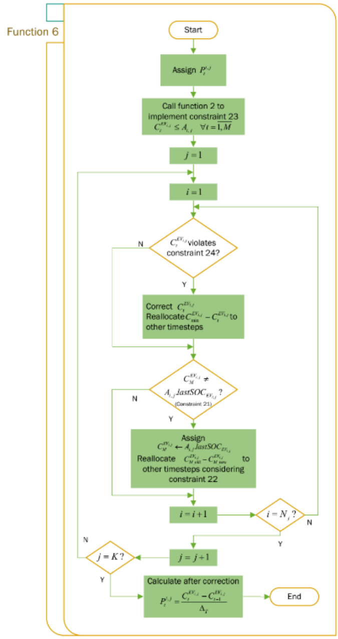


Figure 3.7 Flowchart of stage 3 algorithm

3.3.3 Case study

A charging station is built at Electric Power University (EPU), servicing 150-170 E2Ws. Vehicles are available during working hours from 7:00 to 17:00. The initial SOC, non-EV load and PV power are shown in Figures 3.8, 3.9, respectively.

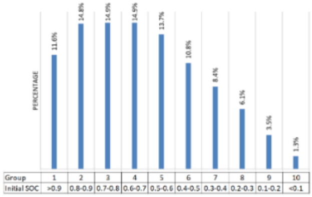


Figure 3.1 Initial SOC distribution

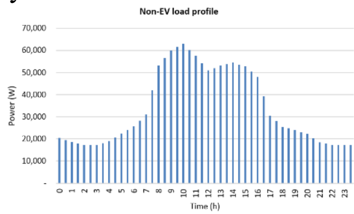


Figure 3.9 Non-EV load profile.

3.3.3.4 Simulation results

In the case study, four operation scenarios are simulated.

- Scenario 1: Charging loads do not participate in the microgrid.
- Scenario 2: Max rate charging or uncontrolled charging scheme.
- Scenario 3: Average charging scheme
- Scenario 4: Smart charging.

The simulation results are as follows:

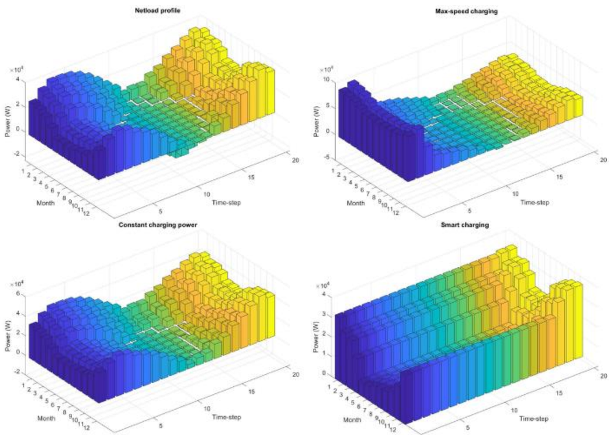


Figure 3.2 Total load profile after stage 1 implementation

Figure 3.11 shows the total load profile. Total charging power profile per vehicle in case of smart charging is shown as in Figure 3.13.

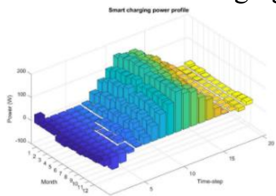


Figure 3.3 Smart charging power profile.

The charging power profiles of each group in January and in June are shown in Figure 3.14 and Figure 3.15. The charging profiles of vehicles in group 9 and group 1 are illustrated in Figure 3.16, 3.17, respectively. Figure 3.18, 3.19 indicate charging profiles and battery capacity variation of a typical E2W in group 1 and group 9.

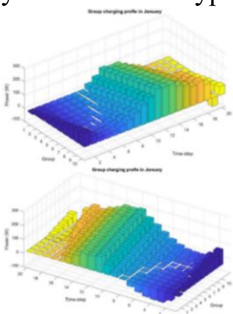


Figure 3.4 Group charging power profile in January.

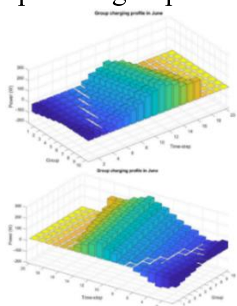


Figure 3.5 Group charging power profile in June.

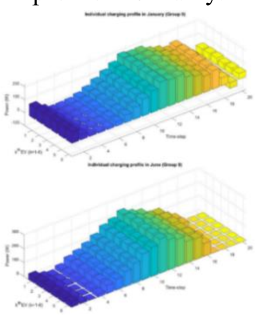


Figure 3.6 Individual charging pattern for group 9

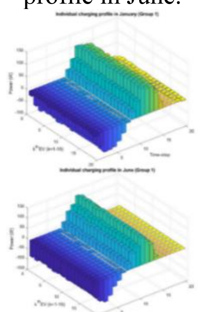


Figure 3.7 Individual charging pattern for group 1

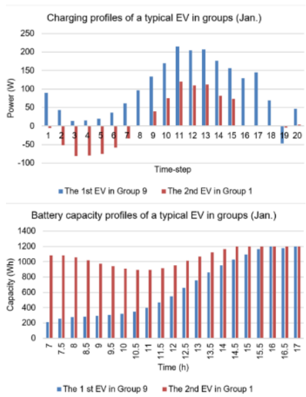


Figure 3.8 Profiles of a typical E2W in groups in January

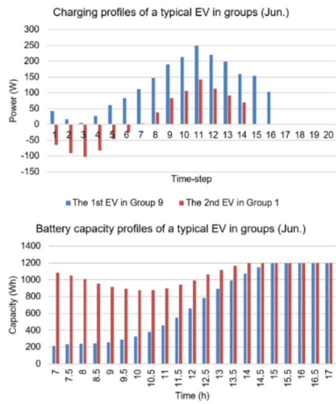


Figure 3.9 Profiles of a typical E2W in groups in June

3.4 Summary

In Chapter 3, a power allocation algorithm is proposed and simulated. The algorithm includes three stages of allocation. This approach helps to reduce computational complexity and computational time in solving OPs, especially when the number of E2Ws in a charging station is often much higher than those in electric car charging stations, leading to higher number of optimal variables.

The total load profile is designed aiming at load leveling, peak clipping and valley filling. However, because the total load profile can be pre-computed for various objectives, the proposed idea can completely adapt for many different optimization purposes.

The simulation results show that, by applying the proposed algorithm, the total load profile is significantly improved, dramatically narrowing the load fluctuation, filling the valley load as well as reducing peak load.

CHAPTER IV: OPTIMAL CHARGING ALGORITHM BASED ON RECEDING HORIZON FRAMEWORK

4.1 Chapter objectives

This chapter develops a real-time scheduling algorithm in which the vehicles are dynamically grouped and scheduled. The proposed algorithm has the following characteristics:

1) Dynamic grouping; 2) Optimizing at group level; 3) Real-time performance; 4) Handling dynamics and uncertainties.

4.2 Mathematical formulation

4.2.1 Objective function

For the purpose of load leveling, the objective function is as in (4.3):

$$\min F_{obj} = \frac{1}{M}\sum_{t=1}^{M}\left(D_t^S + \sum_{i=1}^{N} P_t^i - \mu_{ave}^S\right)^2 \quad (4.1)$$

Considering EV_i, if x_t is the charging power of EV_i at timeslot t, then the objective function is:

$$\min \sum_{t=t_a}^{t_d}\left(\mathrm{x}_t - \underbrace{(\mu_{ave}^S + P_t^{PV} - P_t^{nonEV})}_{a_t}\right)^2 \quad (4.2)$$

Subject to:

$$\sum_{t=t_a}^{t_d} x_t \Delta_T = A_i\left(FSOC_{EV_i} - ISOC_{EV_i}\right) \quad (4.3)$$

$$A_i \times ISOC_{EV_i} + \sum_{t=t_a}^{k} \mathrm{x}_t \Delta_T \le A_i,\ \forall k = \overline{t_a, t_d} \quad (4.4)$$

$$A_i \times ISOC_{EV_i} + \sum_{t=t_a}^{k} \mathrm{x}_t \Delta_T \ge A_i\left(1 - DOD_{max}^{EV_i}\right) \quad (4.5)$$

$$max\{P_{min}^{C_i}, P_{min}^{B_i}\} \le \mathrm{x}_t \le min\{P_{max}^{C_i}, P_{max}^{B_i}\} \quad (4.6)$$

Where: t_a, t_d are the arrival/ departure timeslot of EV_i, and

$$\mu_{ave} = \frac{1}{(t_d - t_a + 1)}\sum_{t=t_a}^{t_d}(P_t^{Base} - P_t^{PV} + x_t)$$
$$= \frac{1}{(t_d - t_a + 1)}\left(\sum_{t=t_a}^{t_d}(P_t^{nonEV} - P_t^{PV}) + \frac{A_i\left(FSOC_{EV_i} - ISOC_{EV_i}\right)}{\Delta_T}\right) \quad (4.7)$$

4.2.2 Quadratic Programming with MATLAB

4.2.3 Receding horizon framework

This study leverages receding horizon framework for real-time scheduling. An E2W can be characterized by a vector of parameters:

$$EV = [EV_{ID}, t_a, t_d, ISOC, FSOC, A] \quad (4.8)$$

These vectors are acquired and pushed into an “existing EV table” which is updated at the current timeslot.

4.2.4 Algorithm flowchart

The flowchart is shown in Figure 4.3.

4.3 Case study and simulation results

This section examines a university charging station, an office charging station, an apartment charging station, and a charging station for a factory.

Each case study includes scenarios:

- Scenario 1: No charging load participation
- Scenario 2: Uncontrolled charging
- Scenario 3: Average charging
- Scenario 4.1 - Smart charging – non-V2G.
- Scenario 4.2 – Smart charging – V2G

4.3.1 Charging station at university

4.3.1.1 Charging station for university staff

4.3.1.2 Charging station for students

The station can accommodate up to 225 vehicles. The simulation results are as follows:

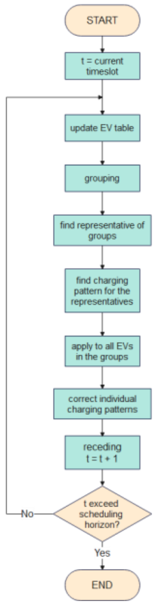
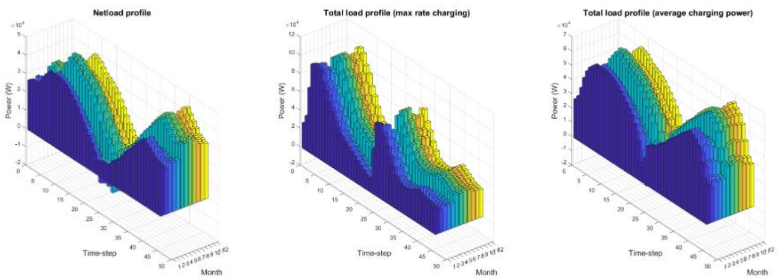


Figure 4.1 Flowchart of the algorithm



a) Neload profile

b) Total load profile - max rate charging

c) Total load profile - average rate charging

Figure 4.2 Total load profile in scenarios 1, 2, 3

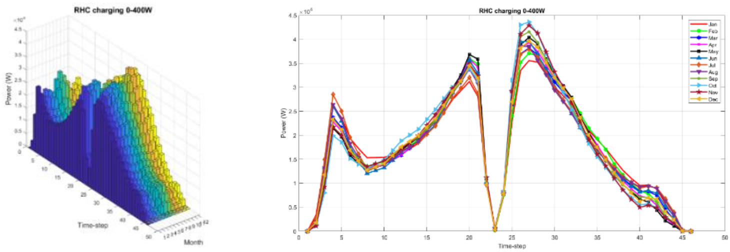


Figure 4.3 Charging profile – RH algorithm scenario 4.1

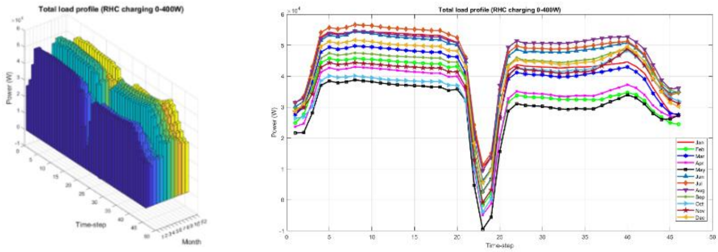


Figure 4.4 Total load profile – RH algorithm scenario 4.1

The valley time occurs between two studying periods when morning shift ends, and afternoon shift does not start (Figure 4.17).

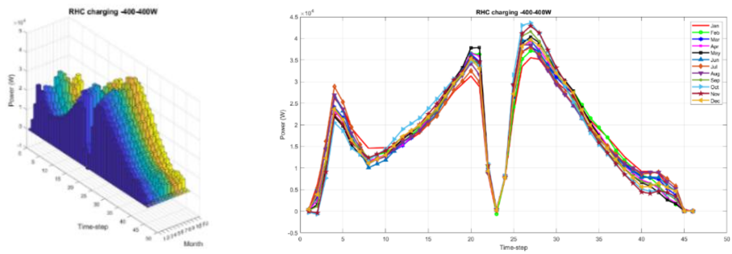


Figure 4.5 Charging profile – RH algorithm scenario 4.2

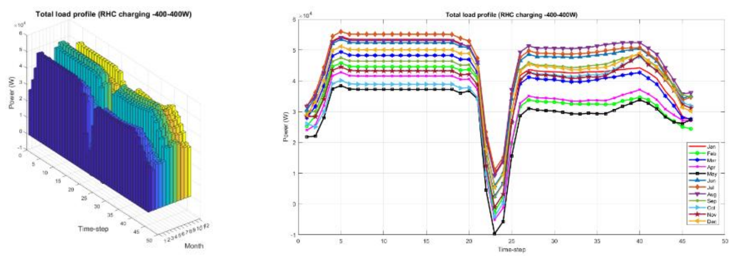


Figure 4.6 Total load profile – RH algorithm scenario 4.2

When participating in V2G, E2Ws discharge energy during peak hours and charge during off-peak hours (Figure 4.19).

4.3.2 Office charging station

4.3.3 Apartment charging station

The station can accommodate 500 E2Ws. The low load periods typically occur during the late night and early morning.

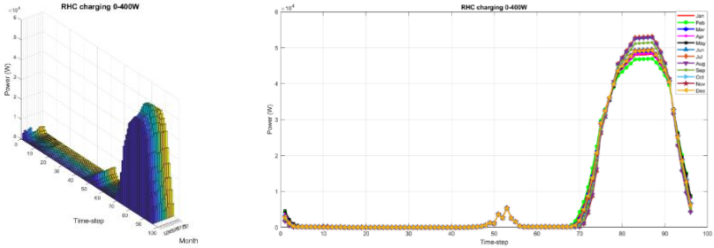


Figure 4.7 Charging profile – RH algorithm scenario 4.1

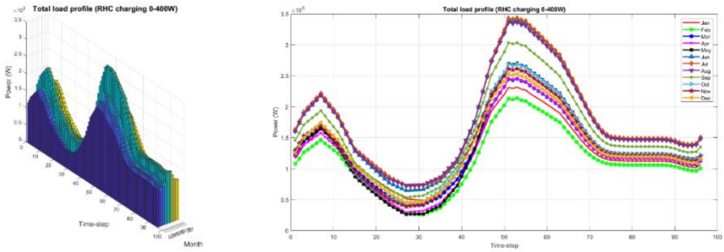


Figure 4.8 Total load profile – RH algorithm scenario 4.1

Figures 4.32, 4.33, 4.34, 4.35 illustrate the charging load and total load in scenarios 4.1 and 4.2.

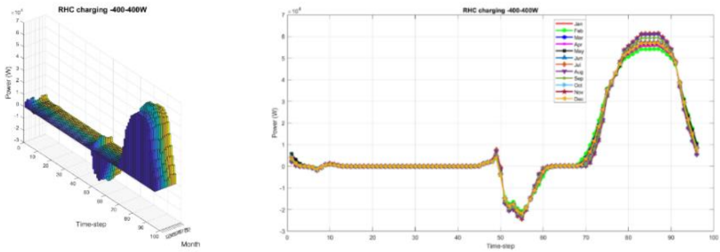


Figure 4.9 Charging profile – RH algorithm scenario 4.2

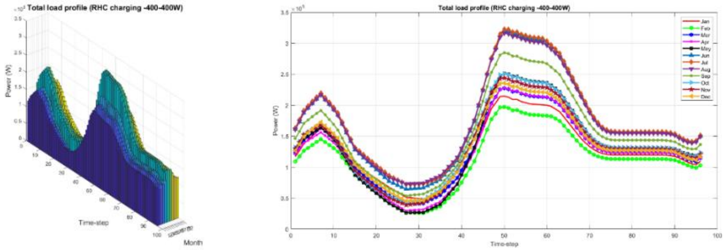
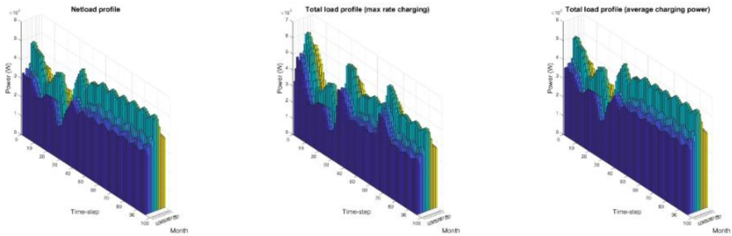


Figure 4.10 Total load profile – RH algorithm scenario 4.2

4.3.4 Factory charging station

The factory operates in three consecutive working shifts. The station can accommodate 500 EVs per shift.



a) Neload profile

b) Total load profile - max rate

c) Total load profile - average rate

Figure 4.11 Total load profile in scenarios 1, 2, 3

In the average charging, peaks occur during the transition period. Under the max rate charging, the negative impact can be realized at the arrival time of the three shifts when the aggregated charging power is highly concentrated (Figure 4.39).

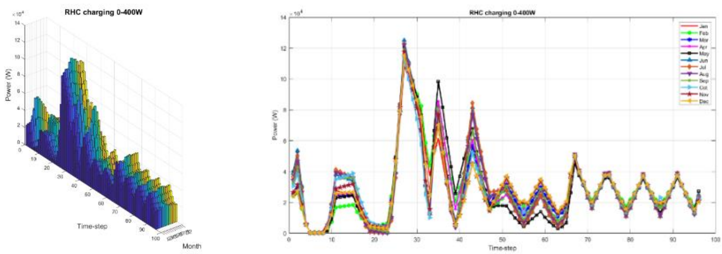


Figure 4.12 Charging profile – RH algorithm scenario 4.1

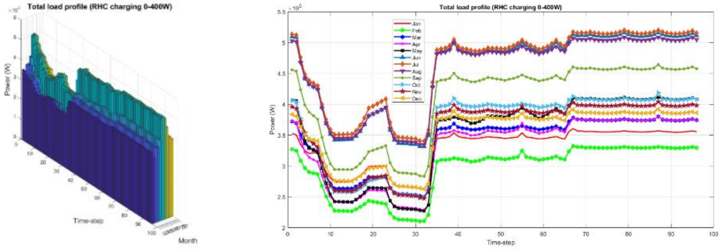


Figure 4.13 Total load profile – RH algorithm scenario 4.1

In scenario 4.1, the total load profile appears relatively flat (Figure 4.41).

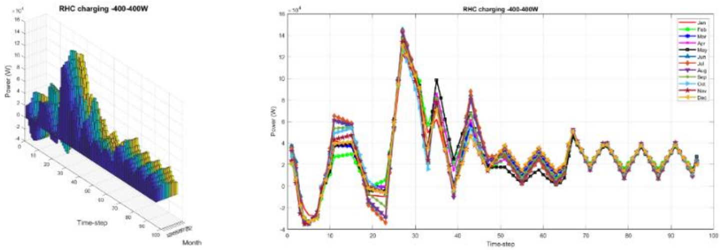


Figure 4.14 Charging profile – RH algorithm scenario 4.2

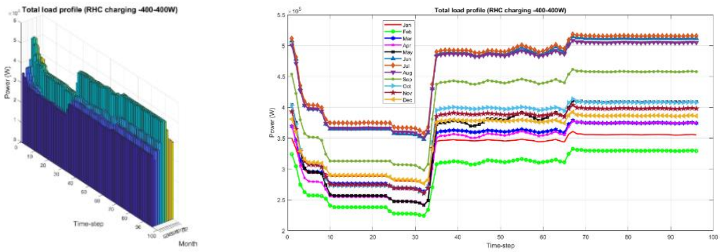


Figure 4.15 Total load profile – RH algorithm scenario 4.2

In scenario 4.2, E2Ws can discharge energy during peaks and charging during low-demand periods (Figure 4.42, 4.43).

4.4 Summary

The proposed algorithm in this chapter inherits the advantages of the group-based approach and, at the same time, leverages the RH framework and mathematical optimization tools to solve the real-time optimal charging problem. RH framework adoption enables the algorithm to handle uncertainties in charging behavior.

Research results under various case studies have revealed interesting conclusions. Both V2G and non-V2G schemes can fill the valley and perform load leveling effectively compared to other scenarios such as uncontrolled charging and average charging scheme. Furthermore, in the case of shift operation, attention should be paid during the shift transition or during the gap between shifts.

CHAPTER V: REALTIME RESPONSES OF E2W CHARGING AND PRACTICAL VERIFICATION

5.1 Chapter objectives

This chapter aims at establishing a testing workbench to implement observation, measurement, and validation of the charging/discharging responses in the charging station.

5.2 Real-time charging/discharging simulation

Simulation results show that at any time, a power balance is maintained. Furthermore, high or low charging/discharging power determines the charging rate/steep slope of the SOC curve over time.

5.3 Testing workbench setup

5.3.1 The technical scope of the test bench

In the experimental model, the range of charging/discharging power is from 0-400 W, and the batteries are 12.8 V, 30 Ah. The battery type is LiFePO4, allowing continuous discharge current up to 30 A.

Because charging is primarily performed during the CC stage, tests are conducted to observe charging responses within the CC stage.

5.3.2 Test bench design and operation

Testing design and setup are as Figure 5.8 and Figure 5.14.

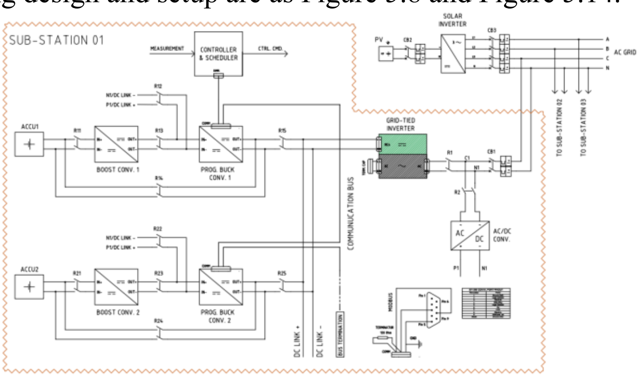
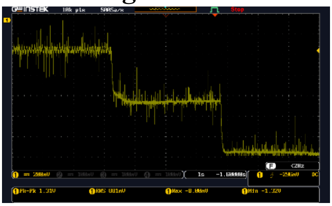


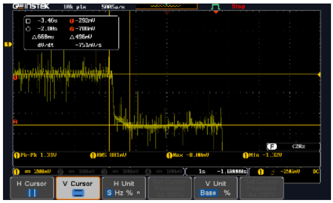
Figure 5.8 Testing workbench design

Figure 5.1 Test bench set up.

5.3 Testing results



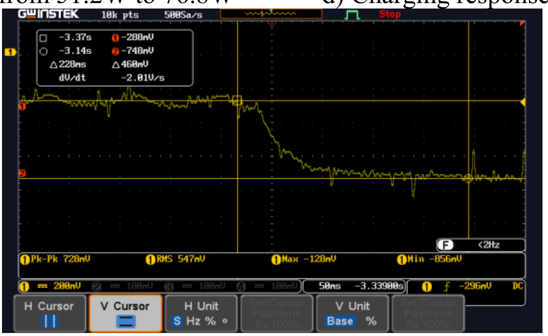
a) Three charging commands



b) Power changes from 19.2W to 51.2W

c) Power changes from 51.2W to 76.8W

d) Charging response transition 1

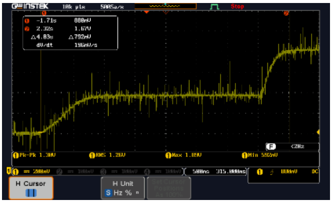


e) Charging response transition 2

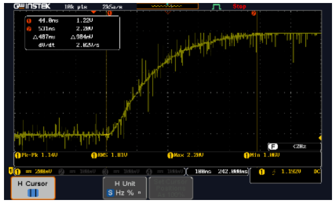
Figure 5.2 Real-time charging response

Figure 5.15 shows the charging response of a battery when charging power changes from 19.2 W to 51.2 W and 76.8 W. Battery can quickly adapt to the change in charging command.

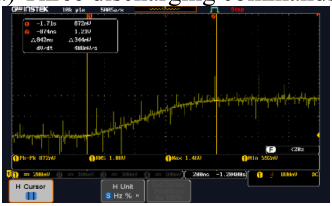
Figure 5.16 depicts the discharging response when three discharging commands are sent to the converter.



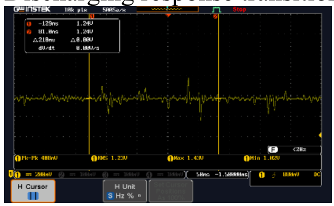
a) Three discharging commands



b) Discharging response transition 1



c) Discharging response transition 2



d) Discharging current

Figure 5.3 Real-time discharging response

The charging and discharging current at steady state do not flat (Figure 5.16d) because of output ripple of the converter.

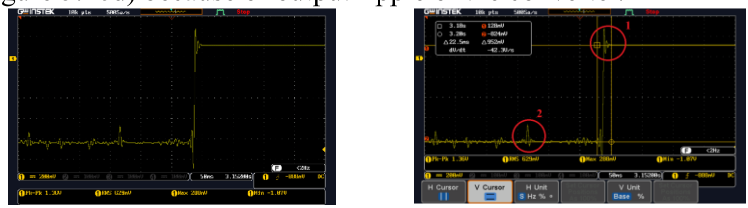


Figure 5.4 Real-time charge to discharge response.

Figure 5.17 illustrates charging current response when the battery changes from charging to discharging. The figure reveals that the transition in the charging current finishes after about 22.5 ms and the battery current experiences an overshoot. However, this overshoot is negligible compared to the variation of battery current in the steady state (positions 1 and 2).

CONCLUSIONS

The main research outcomes can briefly be summarized as follows:

1) Centralized architecture is suitable for E2W charging stations.
2) Real-time and long-term models are considered in the study.
3) Two scheduling algorithms are proposed and verified. The algorithms can accommodate high numbers of E2Ws and handling dynamics and uncertainties.
4) Research results show that attention should be paid to charging stations depending on specific locations.
5) In the study, a testing workbench has been set up for empirical verification.

Quantitatively, this work has addressed the following issues: 1) it has clarified the need for PV-integrated E2W charging stations as well as operational solutions of charging stations to promote sustainable development in the transportation and energy sectors in Vietnam, 2) proposed scheduling algorithms with objective of load leveling, valley filling, and peak shaving, 3) The thesis has empirically assessed the real-time responses of E2W charging following long-term charging schedules. The experimental measurements have demonstrated that long-term charging plans are feasible in practical implementation.

As an extension of this thesis, several tasks for future work are possible and listed below:

1) Exploring additional uncertainties: technical specifications variations; the accuracy of forecasted PV power generation and non-EV loads; charging requirements of vehicle users.
2) Addressing other issues such as: island mode operation, optimal power dispatch; optimal PV sizing.
3) Further quantitatively evaluating computational time of the proposed algorithms with a certain hardware infrastructure.
4) Further investigating converter design, component sizing, MPPT algorithm for small-scale rooftop PV systems.
5) Further developing the test bench and conducting experiments under various scenarios.

LIST OF PUBLICATIONS

[1] Ngoc Van Nguyen and Huu Duc Nguyen (2022). A validation of real-time responses following to long-term charging schedule of PV-integrated electric two-wheeler charging stations. *Journal of Science and Technology - HaUI*, **58(5)**, 15–21.

[2] Ngoc Van Nguyen, Khac Nhan Dam, Huu Duc Nguyen (2022). Research on the architectures and control algorithms for electric vehicle charging stations and electric two-wheeler charging stations in the context of Vietnam. *Journal of Science and Technology - HaUI*, **58(4)**, 55–64.

[3] Huu D.N. and Ngoc V.N. (2022). A Three-Stage of Charging Power Allocation for Electric Two-Wheeler Charging Stations. *IEEE Access*, **10**, 61080–61093.

[4] Ngoc Van Nguyen, Huu Duc Nguyen (2022). PV-Integrated Electric Two-wheeler Charging Stations: A Solution towards Green Cities. *TNU Journal of Science and Technology*, **227(3)**, 25–32.

[5] Heckmann W., Duc N.H., Granford Ruiz D. et al. (2022). Smart Energy Buildings: PV Integration and Grid Sensitivity for the Case of Vietnam. *Proceedings of the 11th Int. Conf. on Smart Cities and Green ICT Systems*, SCITEPRESS, 117–124.

[6] Huu D.N. and Ngoc V.N. (2021). A Two-Level Desired Load Profile Tracking Algorithm for Electric Two-Wheeler Charging Stations. *Eng Technol Appl Sci Res*, **11(6)**, 7814–7823.

[7] Huu D.N. and Ngoc V.N. (2021). Analysis Study of Current Transportation Status in Vietnam's Urban Traffic and the Transition to Electric Two-Wheelers Mobility. *Sustainability*, **13(10)**, 5577.

[8] Huu D.N. and Ngoc V.N. (2021). A Research on the Trend of Transport Electrification in Vietnam and the Feasibility of PV-Integrated Charging Station for Electric Two-wheelers at Electric Power University. *2021 11th Int. Conf. on Power, Energy and Electrical Engineering (CPEEE)*, Shiga, Japan, IEEE, 255–260.

[9] Ngoc Van Nguyen and Huu Duc Nguyen (2020). Technical and Economical Assessment of PV Based Charging Stations for Electric Bicycles at Electric Power University. *EPU Journal of Science and Technology for Energy*, **25**, 36–42.

[10] Ngoc Van Nguyen and Huu Duc Nguyen (2020). A research on the trend of transport electrification in Vietnam and techno-economic assessments of PV-integrated charging stations for electric two-wheelers in E.TOWN2 building – Ho Chi Minh city. *Journal of Science and Technology - HaUI*, **56(5)**, 8–15.