PV-INTEGRATED ELECTRIC TWO-WHEELER CHARGING STATIONS: A SOLUTION TOWARDS GREEN CITIES

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ABSTRACT

Currently, in Vietnam's big cities, private gasoline-powered motorcycles are the main means of transportation. The ubiquitous adoption of motorcycles on one hand can satisfy travel needs of the citizens, but on the other hand it could trigger traffic congestion, unsafe travel, and worsen air quality which directly affect the well-being of urbanites. Electric two-wheelers, which are less polluting, might emerge as a potential alternative of gasoline-powered motorcycles and might contribute to a more sustainable mobility. However, to promote the development of this means of transport, it is required a dedicated charging infrastructure. In Vietnam, with high potential of solar energy, PV-integrated charging stations can be considered as a potential solution of powering electric two-wheelers, reducing greenhouse gas emissions as well as mitigating air pollution in urbans. This paper collects, processes and analyzes latest data from the state of the art and recent research. Therefore, the article proposes a solution for electric vehicle charging stations towards a green city. The proposed and analyzed economic and technical models of the charging station are introduced and analyzed in order to meet sustaiable growth of urban areas in the context of Vietnam.

TRẠM SẠC XE ĐIỆN HAI BÁNH SỬ DỤNG ĐIỆN MẶT TRỜI: GIẢI PHÁP HƯỚNG TỚI THÀNH PHỐ XANH

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TỪ KHÓA

Trạm sạc
Xe điện hai bánh
Phát triển bền vững
Thuật toán sạc
Điện mặt trời

TÓM TẮT

Hiện nay tại các thành phố lớn của Việt Nam, các xe máy chạy bằng xăng là các phương tiện giao thông cá nhân chính. Việc sử dụng xe máy giúp đáp ứng nhu cầu đi lại của người dân, tuy nhiên nó cũng là một trong nguyên nhân chính gây ra ùn tắc giao thông, mất an toàn và đặc biệt là ảnh hưởng tiêu cực đến chất lượng không khí, qua đó làm ảnh hưởng đến chất lượng cuộc sống của cư dân đô thị. Xe điện hai bánh giúp giảm khí thải là một giải pháp tiềm năng hướng tới giao thông xanh – bền vững. Tuy nhiên vấn đề với sự phát triển của xe điện đó là phát triển hạ tầng trạm sạc xe điện tương ứng. Việt Nam là nước có tiềm năng cao về điện mặt trời, do vậy trạm sạc xe điện sử dụng điện mặt trời là một giải pháp tiềm năng giúp đóng góp vào giảm tiêu thụ nhiên liệu hóa thạch, giảm khí thải, tiếng ồn đô thị. Bài báo này tiến hành thu thập, xử lý và phân tích dữ liệu từ các nghiên cứu mới nhất liên quan. Qua đó bài báo đưa ra giải pháp trạm sạc xe điện hướng tới đô thị xanh. Các mô hình kinh tế kỹ thuật của trạm sạc được đề xuất và phân tích đáp ứng bối cảnh đô thị Việt Nam.

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1. Introduction

1.1. Current transportation status in Vietnam's urban areas

Currently, in Vietnam's major cities such as Hanoi, Ho Chi Minh City (HCMC), public transport has not yet been able to satisfy the citizens' travel demand. In Hanoi, public transport meets about 15% of people's travel needs while it is about 9% in HCMC. Urban traffic still heavily depends on private vehicles, in which gasoline-powered motorcycles take a dominant role.

According to the United Nations, HCMC has 6.2 million motorbikes, more than 600,000 cars, 2,764 buses and trucks. In addition, there are more than 1 million vehicles travelling in and out of the city everyday. The number of taxis and contract vehicles is more than 11,000 and 15,000 vehicles, respectively. In Hanoi, as of 2020, there are 6.4 million vehicles, including 5.7 million motorbikes, nearly 700,000 cars, and 1.2 million vehicles from neighbour provinces participating in Hanoi traffic [1].

The development of transport infrastructure has not kept up with urbanization process and vehicle growth [2]. Specifically, the growth of traffic infrastructure only increases by about 3% annually, land area reserved for traffic increases from 0.25-0.3% per year while the average annual growth rate of traffic is 10.2% [3]. Not only the road density has been very low, the land area for static traffic such as parking lots has been under the requirements [4].

The main means of public transportation in Hanoi are buses and taxis whose contribution to the total ridership is as low as 15% while the urban railway has recently been put into trial operation [3]. The level of connectivity and integration of transport services is still very poor. The quality of bus service is still limited. Bus operation heavily affected by mixed traffic flow and traffic congestion [5]. Some routes still do not have bus service and the distance between stations is often quite far. At rush hours, on some corridors axes, the waiting time for the bus at the stop is usually 10-15 minutes later than scheduled [6].

In HCMC, the bus system has not yet operated effectively because functional areas are poorly planned [2]. In recent years, HCMC has focused a lot on upgrading the bus system from infrastructure to policies. However, the number of bus passengers tends to decrease [7].

Generally, public transport in Hanoi and HCMC currently cannot accommodate a significant shift from private transport modes. Besides, transit services to facilitate access to the public transport have also not been considered appropriately, inevitably causing most people to choose a personal motorcycle as the preferred means of transportation.

1.2. Air pollution and the transition to electric two-wheeler mobility

In developing countries as well as in Vietnam, gasoline-powered motorcycles are prevalent, which derives from many advantages such as 1) purchase price and operating cost are consistent with low and middle income level, 2) high flexibility, suitable for short and medium distance travel, 3) modest space occupied, suitable for traveling in narrow road conditions, 4) providing low cost mobility especially when public transport is immature. However, when the number of private vehicles is too high, it also puts burden on traffic infrastructure, causing traffic congestion, noise and air pollution, which directly affects the urbanites' well-being.

Exhaust from fossil-fuel vehicles are the main contribution of urban air pollution. In Vietnam, there are more than 60,000 deaths every year related to air pollution [8]. Adverse health impacts are not only come from fine particulate matter (PM2.5, PM10) but also from other substances such as O_3, NO_2, SO_2. According to WHO, in 2016, the average concentration of fine particulate matter in Hanoi was 102.3 $\mu g/m^3$ (PM10) and 47.9 $\mu g/m^3$ (PM2.5) and in HCMC, it was 89.8 $\mu g/m^3$ for PM10 and 42 $\mu g/m^3$ for PM2.5. These figures are much higher than air quality standard recommended by WHO (20 $\mu g/m^3$ for PM10 and 10 $\mu g/m^3$ for PM2.5).

Because of serious air pollution and traffic congestion in big cities, many solutions have been considered such as applying stricter exhaust emission standards, limiting private vehicles, developing public transport and encouraging less polluting means of transort... Hanoi may limit and proceed to stop operating motorcycles in the inner districts in 2030 which requires the public transportation system and alternative means to meet at least 65% of the travel needs of the citizens. Control measures for gasoline-powered motorcycles that cannot ensure technical and environmental standards were also proposed.

In HCMC, the transportation sector accounts for 45% of total greenhouse gas (GHG) emissions. In which, motorcycles account for about 29% of NO emissions, 90% of CO, 37.7% of dust emissions, and 31% of fine particulate matter emissions [9]. In order to reduce the risk of pollution, HCMC has implemented many solutions such as a pilot project to check the emission of motorbikes, proposing to limit private vehicles, developing the public transport system both in quality and quantity, and diversifying the types of public transport. In addition, less polluting vehicles and solutions for easier access to public transport are also encouraged.

Recently, a notable transition in Vietnam's urban traffic is the introduction of electric vehicles (EVs). In the first periods, it was the appearance of electric bicycles. With notable characteristics such as low cost (about 400 USD [10]), low speed, no driver's license and vehicle registration requirements, electric bicycles were preferable choice of students and elders. However, electric bicycles were not really attractive because they were considered cannot perform as well as gasoline-powered motorcycles, especially in bad weather conditions. In addition, most of them were imported from China with relatively low quality [11].

When several major manufacturers such as Honda, Yamaha, Piaggio, Vinfast have engaged in EV market and launched their electric bicycles/electric motorcycles, electric two-wheelers (E2Ws) gradually attract public's attention. With a 6.4-hectare factory, modern production lines, capable output of 250,000 vehicles per year (up to 1 million vehicles), Vinfast has introduced many models such as Klara, Ludo, Impes, Theon, Feliz... to the market. Modern designs, good quality, diverse features (eSim, anti-theft, cruise control, operation history record, waterproof) and acceptable purchase price are factors that help E2Ws draw great attraction from public.

In 2019, the E2W market in Vietnam experienced a remarkable growth. Many high quality products are brought to the market from manufacturers such as Pega, Mbigo, Yadea, VinFast. According to Vinfast, the company currently sells an average of 10,000 electric motorcycles per month. Although there are no accurate statistics on the number of E2Ws in Vietnam, but according to the International Association of Public Transport (UITP), by 2017 Vietnam had about 0.9 million E2Ws and increased to 5 million units by 2019. According to data from the Registry Department, in 2018, there were 14 enterprises producing two-wheeled electric vehicles with an output of 46,373 units. By 2019, the number of manufacturing and assembling enterprises decreased to 11, but the output volume reached 52,938 units. The annual growth rate of E2W market is up to 30-40%.

In terms of environment aspect, recent research shows that, the total amount of CO_2 emissions due to the operation of fossil fuel motorcycles in HCMC is 11.34 million tons per year. If 30% of traditional motorbikes are replaced by E2Ws, the annual emissions will be reduced to 8.33 million tCO_2-eq/year. If completely replacing gasoline-powered motorbikes by E2Ws, the annual CO_2 emissions will be only 1.3 million tCO_2-eq/year [12]. The estimation proves the great potential of electric vehicles in reducing GHG emissions as well as improving air quality in urban areas.

With the high rate of motorbike usage in Vietnam, the transition from traditional motorcycles to E2Ws seems to be feasible. Two-wheeled electric vehicles still remain remarkable features of motorcycles in urban traffic, while providing other benefits such as no tail-pipe emission, higher energy conversion efficiency, low noise, has the potential of providing ancillary services for the power grid and potential of developing intelligent transportation systems when integrated with appropriate information infrastructure. Compared to traditional motorbikes, E2Ws also provide equivalent travel distance, similar vehicle costs and space occupied. In addition, with lower speeds, E2Ws are considered safer than motorcycles. The e-bikes also offer physical activity option, providing more health benefits to urban dwellers.

Generally, in Vietnam, immediate potentials for the electrification of road transport, notably in urban areas, may be offered by E2Ws such as e-bikes, e-scooters, and e-motorcycles. E2Ws promise to better connect people with public transport and make better use of travel space, while being more consistent with the income level of the majority as well as the existing infrastructure, reducing GHG emissions, and mitigating air and noise pollution. E2Ws are likely to be a promising alternative to gasoline-powered motorcycles, contributing to a greener and more sustainable mobility.

2. Green charging stations – Solution for E2W charging in Vietnamese cities

Although electric bicycles/electric scooters have great potential in Vietnam's urban traffic, but in order to encourage the development of this type of vehicle, it is required supporting policies, technical guidelines, environment impact assessment as well as charging infrastructure.

Studies show that any form of EV such as HEV (Hybrid EV), PHEV (Plug-in hybrid EV), PEV (Plug-in EV) has lower well-to-wheel emissions than internal combustion engine counterparts. Noteworthily, the amount of emissions depends on the proportion of clean energy supplied to the vehicle [13]. Thus, the adoption of EV only contribute significantly to the reduction of GHG emissions if EVs are charged from renewable energy sources. In Vietnam's urbans, rooftop solar power is an attractive option because of the following factors:

(1) The cost of PV module, hardware and inverter are continuously decreasing.

(2) Since PV modules can be installed on the roofs close to the charging stations or placed on/used as the roof of the carports, solar power can be accessed easily.

(3) The combination of EV charging and solar power can help both reducing the amount of PV power injected into the distribution grid and, at the same time, satisfying charging needs of EVs. Thus, it can help reducing unwanted impacts of charging load and high share of renewable energy on the grid.

(4) The batteries of EVs can be used as energy storage devices, which could contribute to optimal exploitation of solar energy.

(5) Charging cost from solar power is cheaper than from grid. Electricity is locally generated and consumed, which can be seen as a solution to anticipate the decrease of FiT [14].

(6) PV system has low operation and maintenance cost.

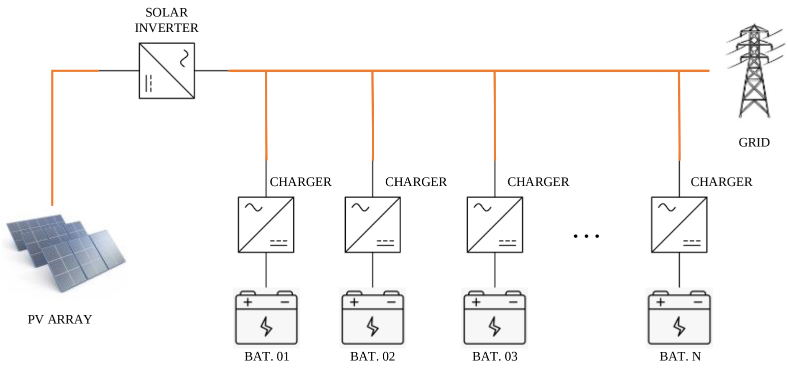

Figure 1. *Charging station block diagram*

Research [14] shows that Vietnam can be considered as a country having great potential of solar energy. Annual sunshine hours are from 1600-2600 hours and average solar irradiation is up to 5 kWh/m^2. However, because of uncertainty and intermittent nature, high penetration rate of solar power might cause negative impacts on the operation of the power grid [15]. Thus, it is recommended that solar power should local generated and local consumed instead of injecting to the grid. PV-integrated charging stations, with on-site production and consumption, can be seen as a green and sustainable solution. It can reduce GHG emissions and, at the same time, contribute to a higher usage of renewable energy while reducing the need of grid infrastructure upgradation for accommodating the development of both EVs and distributed renewable generation.

Figure 1 shows the block diagram of a PV-integrated charging station. Electricity, which is from solar power or from the grid, is supplied to the vehicles' batteries. If the amount of solar power is greater than the charging demand, the surplus electricity will be injected into the grid. In case of charging demand being greater than solar output, the grid would compensate the remaining power. If AC/DC converters are bidirectional (charge/discharge), EVs' batteries can also be used as energy storage devices which can be used for providing ancillary services.

3. Challenges of charging station control

The participation of EVs, charging stations and distributed rooftop solar systems in urban areas poses challenges of control and management so as to achieve economic and technical goals. Charging stations when combined with rooftop solar and conventional loads can form microgrids. These microgrids can be interconnected with each other and with the distribution grid, forming a smart grid with potential of flexible and optimal operation.

Charging stations which have the ability of controlling distributed renewable sources (rooftop solar), storage devices (EVs' batteries) and conventional loads, could allow operation with both grid interconnection or grid independence. Thus, it can provide flexible and optimal operation in both technical and economic terms and at the same time satisfy the requirements of many parties.

Basically, control algorithm of charging station is an optimization problem with different constraints. From a technical perspective, the objectives could be:

- Load regulation: control charging/discharging processes in order to flatten the total load profile, perform peak shaving, and valley filling. However, when considering the objective of load regulation, the control algorithm must also satisfy constraints such as: required energy constraint, constraints on charging/discharging power, overload constraints, voltage constraint at the connection point...
- Maximizing operational efficiency: the objective might be optimal use of renewable energy sources, reduce the amount of electricity consumption from grid or coordinate charging/ discharging to follow the day-ahead energy plan.
- Management and provision of ancillary services: When the charging load is involved, the charging stations can be controlled to provide ancillary services such as voltage control, frequency regulation, spinning reserve, active and reactive power compensation.
- Minimizing charging power loss or minimizing battery degradation: Several control strategies are built to minimize power loss of charging process or increase battery life.
- Ensuring charging fairness: there are diverse fairness options such as first come first serve, earliest deadline first serve, shortest job first served, or lottery policy.
- Improving the convenience of vehicle owners: the algorithms might aim to minimize the charging time while still satisfying technical constraints.

In terms of maximizing profit or cost optimization, algorithms might aim to minimize microgrid operating costs or minimize charging costs. By providing charging services to customers and/or ancillary services to the grid, charging stations can make revenue. In electricity market, charging station operators can purchase electricity at wholesale prices through long-term contracts or by participating in the day-ahead electricity market based on electricity price forecasts. To maximize revenue, some algorithms manage to design charging rates and charging strategies optimally while ensuring the rate stays at acceptable levels. Other algorithms manage to increase profits through minimizing the cost of purchasing electricity according to the TOU (time-of-use) prices.

In general, the deployment of smart and flexible EV charging stations not only allows to meet the needs of EVs development, but also has the potential of participating in the grid operation and electricity market and contribute to increasing the usage of clean energy. However, challenges relating EV charging station deployment include solution for different kinds of optimization problems, controllers as well as supporting communication infrastructure.

4. Economic and technical model of PV-integrated charging station in urbans

In order to evaluate the feasibility of PV-integrated charging station in Vietnam, we've conducted studies on the economic and technical model of E2W charging stations in two cases: at Electric Power University (EPU) and in an office building.

4.1. Charging station at university

With the assumption of serving about 100 electric bicycles of students and lecturers, in the study [16], we proposed three charging station options. Through investigating the installation area, it is possible to install PV systems with the capacity of about 150 kWp. Sunshine hours, solar irradiation, temperature... at the site are used for the study.

After conducting simulation and calculation, we get three options as in Table 1.

Table 1. *Charging station options at EPU*

Option	PV Module	Inverter	Total cost (VNĐ)
Option 1	Canadian Solar 415W, Poly Number of modules: 360 Number of modules per string: 18 Number of strings: 20 Total power: 149,400 Wp Installation area: 795.3 m^2	Sungrow SG60KU-M (66 kVA) Number of Inverters: 2	1,871,506,885
Option 2	Tamesol 360W, Mono Number of modules: 432 Number of modules per string: 18 Number of strings: 24 Total power: 155,520 Wp Installation area: 838.2 m^2	SMA Solid-Q Pro 60 (66 kVA) Number of Inverters: 2	2,661,583,000
Option 3	AE Solar 330W, Poly Number of modules: 440 Number of modules per string: 20 Number of strings: 22 Total power: 145,200 Wp Installation area: 853.8 m^2	Sofar Solar 60000TL (60 kVA) Number of Inverters: 2	2,244,180,000

Comparing investment costs, it is found that option 1 has the lowest investment cost while still meeting the technical requirements. Simulation also shows that option 1 has a payback period of only 7 years, so it is technically and economically feasible.

4.2. Charging station for office building

In case of office building, we have carried out a study on technical and economic assessment for E2W charging station at E.Town 2 building - HCMC [17]. We assumme that the charging station has a capacity of 100 kW and can serve about 65-100 vehicles. After simulation, three technical options are proposed as in Table 2.

Table 2. *Charging station options at E.Town 2 building*

Option	PV Module	Inverter	Total cost (VNĐ)
Option 1	Canadian Solar 415W, Poly Number of modules: 252 Number of modules per string: 18 Number of strings: 14 Total power: 105,000 Wp Installation area: 795.3 m^2	Sungrow SG50KLT (55 kVA) Number of Inverters: 2	1,389,361,714
Option 2	Tamesol 360W, Mono Number of modules: 252 Number of modules per string: 18 Number of strings: 14 Total power: 90,000 Wp Installation area: 838.2 m^2	ABB Trio - TM-50 (50 kVA) Number of Inverters: 2	1,596,673,540
Option 3	Jinko Solar 340W, Poly Number of modules: 252 Number of modules per string: 18 Number of strings: 14 Total power: 86,000 Wp Installation area: 853.8 m^2	Canadian Solar CSI-50KTL-GS-FL (50 kVA) Number of Inverters: 2	1,259,909,544

Comparing total cost of investment, it is found that option 1 has the average investment cost but can produce highest power output. Regarding option 1 and option 3, the output power of option 1 is 1.22 times higher than option 3 while the investment cost is only 1.1 times higher. Thus, among three options, the selection of option 1 is economically and technically reasonable. Calcuation also shows that option 1 has a payback period of only 4 years, which can prove its technical and economic efficiency.

5. Conclusions

The paper conducts research on the current status of urban traffic, traffic electrification and PV-integrated charging stations for electric bicycles/electric motorcycles in Vietnam as a solution towards green and sustainable cities. It is obvious that, compared to developed countries, in Vietnam, the transition from fossil fuel vehicles to electric vehicles has distinct characteristics. Socio-economic characteristics, income levels, current transport infrastructure, serious air pollution, along with the government's orientation of sustainable development, make two-wheeled electric vehicles as a potential choice for urban traffic.

With regard to infrastructure supporting E2Ws, the integration of PV power into charging stations can be considered as an effective solution in reducing electricity consumption from the grid, exploiting the potential of rooftop solar power and mitigating negative impacts of E2W charging as well as high share of PV power injection into the distribution grid. With the continuting development of E2W adoption and deacreasing investment cost of PV systems, PV-integrated charging stations can be seen as a economical and effective solution for air pollution in big cities as well as a contribution to sustainable development in urban areas.

The study also summarizes the technical and economic evaluations of E2W charging solution in two cases: Charging station at Electric Power University and at the E.Town 2 office building. The results show that PV-integrated charging station is technically and economically feasible to accommodate the transition to traffic electrification in Vietnam, contributing to sustainable development in both the transport sector and the energy sector.

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