Research and design an electric car charging station using solar energy integrating an IoT technology monitoring system

Dinh Thi Thanh Loan[1], Doan Quang Trung[2], Mai Huu Thuan[3*]

[1]Industrial Vocational College Hanoi (HNIVC), 131 Thai Thinh, Dong Da, Hanoi, Vietnam;
[2]Center for Vietnam Young Talents, Science and Technology, 7 Xa Dan, Dong Da, Hanoi, Vietnam;
[3]Hanoi University of Science and Technology, 1 Dai Co Viet, Hai Ba Trung, Hanoi, Vietnam.
[*]Corresponding author: thuan.maihuu@hust.edu.vn
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ABSTRACT

As technology advances, the cost of renewable energy equipment decreases, which has resulted in a massive increase in solar photovoltaic installations. In this study, we designed and calculated a solar power system for a charging station for 12 electric cars that integrates an energy protection system using IOT technology. The analysis results of the independent EV-PV charging station model and the grid-connected model with storage have shown the efficiency and profitability of each model. The solar energy system utilizes an IoT-based monitoring system to enhance the capacity and quality of electricity for electric vehicle charging stations. This is achieved through a sensor network that monitors factors affecting the efficiency of solar panels, such as dust, solar radiation intensity, weather conditions, and the tilt angle of the solar panel arrays. Smart Monitoring displays the daily usage of renewable energy, helps the users to analyze energy usage, will help us in its maintenance, fault detection, and will give us a record of all the data and electricity issues.

Keywords: Electric car charging station; Solar power system; Electric car (EC); IOT technology.

1. INTRODUCTION

During the process of industrialization and modernization, the automotive industry has been identified as one of the pivotal economic sectors, playing a crucial role in a nation's economic development. In Vietnam, the automotive industry has consistently received significant attention and encouragement from the government for investment and development. Consequently, in recent years, Vietnam's automotive industry has made substantial progress, with increased domestic production and assembly and a higher localization rate. According to data from The Vietnam Automobile Manufacturers' Association (VAMA, 2022), TC Group, and VinFast, the total automobile sales in the Vietnamese market exceeded 510,000 units, marking an all-time high. Furthermore, according to the Vietnam Industry Research And Consultancy (VIRAC), in the first half of 2023, Vietnam spent 1.6 billion USD on importing nearly 70,000 vehicles of various types, a 5% increase compared to the same period in 2022 [1].

At the beginning of 2022, VinFast - the first automobile manufacturer in Vietnam - announced its plan to cease the production of gasoline vehicles and transition to electric vehicles by the end of 2022. VinFast has been developing a range of products comprising six electric car models across segments A, B, C, D, and E: (VF 5 Plus, VF 6, VF 7, VF 8, VF 9). By mid-2023, VinFast had announced the launch of the VF 3 model, a small-sized (Mini car). Currently, the VF 6, VF 7, and VF 3 models have not been officially released. The remaining models, including the VF e34, VF 8, VF 9, and VF 5 Plus, were gradually released in 2021, 2022, and 2023, with prices ranging from 458 million to 1.57 billion VND [1, 2].

Another important trend is the installation of solar power systems to power vehicles. For example, electric vehicle charging stations are increasingly being integrated with solar battery systems to reduce the load on the traditional power grid. With a solar power system providing clean energy to the charging station, electric car users can save a large amount of money on monthly recharging costs. According to estimates, the cost of charging electricity from solar energy is only 1/3 of the price of electricity from the national grid [3].

Each brand of electric car uses a different technology, so the charging standard is also different. Developing a comprehensive and synchronous EC system requires a versatile charging system, capable of supporting charging for many different EC brands. While in Vietnam, currently, only VinFast has been developing more than 150.000 ports to charge both electric motorcycles and electric cars at parking lots, bus stations, rest stops, petrol stations, commercial centers, apartment buildings/office buildings, highways, national highways, and some suitable location to serve the needs of this brand's EC users [4]. According to the Department of Industry - Ministry of Industry and Trade, the standard of plugs into the charging port varies from region to region and depends on the design of each vehicle model. For example, the US fast charging standard is CCS1/Tesla, the European charging standard is CCS2, CHAdeMO is from Japan, and GB/T is from China [5]. Therefore, developing a charging station system that can meet the demand for all types of ECs with different charging standards is also a challenge

2. PROPOSED SYSTEM

2.1. Analysis and selection of basic components

Currently, electric car manufacturers are providing a variety of solutions to fully meet the needs of customers by building charging towers with different capacity levels. The System block diagram (Fig. 1). The charging post with the largest capacity is DC 250 kW, followed by DC 60 kW, DC 30 kW, DC 11 kW, this means that the charging time will be different, the theoretical charging time will be different. Using formula (according to standards published by the manufacturer) [6] is:

$$Ah_{EV,TT} = (85\% - 25\%) \text{ x } Ah_{EV,ST} \text{ (kWh)} \quad (1)$$

In there: $Ah_{EV,TT}$ is the actual battery capacity the EV needs to consume each day (kWh). Therefore:

$$T_{P\text{-}EVcharging} = Ah_{EV,TT} / \text{P-EVcharging (minutes)} \quad (2)$$

where $T_{P\text{-}EVcharging}$ is the charging time depending on charger capacity (minutes), P-EV is the charging capacity of charging device (kW).

$$T(250 \text{ kW}) = 25.2 / 250 = 6 \text{ (minutes)}$$

$$T(60 \text{ kW}) = 25.2 / 60 = 25 \text{ (minutes)}$$

$$T(30 \text{ kW}) = 25.2 / 30 = 50 \text{ (minutes)}$$

$$T(11 \text{ kW}) = 25.2 / 11 = 137 \text{ (minutes)} = 2 \text{ (hours 17 minutes)}$$

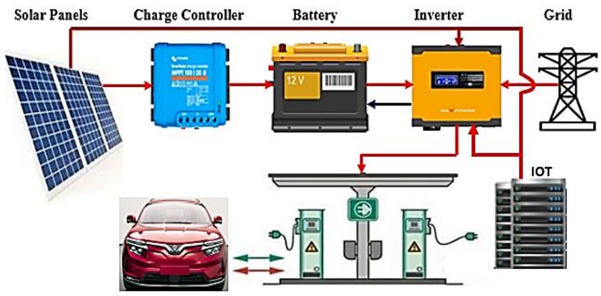

Figure 1. *EV-PV charging station system block.*

From the above calculation, it can be seen that with a 250 kW charging post, it only takes about 6 minutes to charge up to 70% of the vehicle battery capacity with a travel distance of 210 km, saving a lot of time for customers. Next, with 60 kW and 30 kW, respectively (Fig. 1), it takes less than 1 hour to charge this capacity. The longest charging time at the station with 11kW charging post, takes more than 2 hours, suitable for long rest stops, car parks at work and public offices.

From here, it can be seen that the development of charging technology is increasingly convenient and fast, creating more conveniences and experiences for customers.

- The cost of some types of solar panels (table 1)

Solar panels are an important element of a solar power system, accounting for about 60% of the total investment cost. Therefore, the choice of panels will greatly affect the efficiency of the system. Depending on the capacity, area, and investment capital choose the appropriate type of solar panels.

Table 1. *Cost of some solar panels [7].*

Brand	Capacity	Code	Price (VND)
Yamafuji Solar	450 W	Tiger Pro 72TR Monofacial	2 150 000
Risen Solar	500 W	**RSM150-8-500M**	2 172 500
Canadian Solar	500 W	Mono HalfCell CS6W-535MS	2 300 000
Jinko	550 W	Tiger Pro 72TR Monofacial	2 200 500
Blue Carbon Solar	550 W	BCT550M - 48	2 250 000

- Cost of some types of inverter (table 2)

Table 2. *Cost of some types of the inverter [8].*

Name	Basic parameters	Price (VND)
Goodwe GW50K-MT	50 kW 3 EO 380 V / **H = 97,6%**	64.581.000
Growatt MAX 50KTL3 LV	50 kW 3 EO 380 V/ **H = 98,5%**	70.000.000
Hybrid Deye SUNSG04L P3-EU	50 kW, 60 kW, 70 kW, 80 kW, 100 kW, 3 EO 380 V/ **H = 97,6 ÷ 99,2%**	46.900.000 - 90.000.000
Huawei SUN2000-100KTL-M1	100 kW 3 Pha 380 V/ **H = 99,1%**	105.000.000

- Cost of some types of storage

Maintaining a constant, stable power supply for important electrical devices in the charging station system, such as EV charging, is the purpose of energy storage (Battery/Battery). However, because the investment cost is quite high, the investment consideration is careful for this system. Today, there are many famous manufacturers of specialized solar storage, such as Tesla Powerall, Growatt, Gigawatt, GEL Largestar. Here is some information of some battery/battery manufacturers (table 3).

Table 3. *Some common storage for PV systems [9].*

Name	Code	Price (VND)
Battery VISION 12 V - 200 Ah	6FM200D-X	6.700.000
Lithium Growatt ARK 2.5L	ARK 2.5L-A1	22.000.000
Lithium Growatt AXE 5.0L	AXE 5.0L	34.500.000
Lithium SOFAR GTX5000	AMASS GTX 5000	41.000.000

Storage selection is based on solar array capacity and expected energy demand.

- Electric vehicle charger (table 4)

Classification:

Level 1 charging (120 V): Level 1 charging offers the slowest type of charge, taking about 20 hours to fully charge most vehicles.

Level 2 charging (240 V): Doubles the voltage of charging level 1, level 2 charging uses 240 volts for a moderately faster charge time. Many homes and most public charging stations have a Level 2 setup.

Level 3 charging (DC charging): DC chargers use their own power supply, with currents greater than 480 V and more than 100 A. DC fast chargers can provide 50-350 kW of electricity, and some countries in Europe can go up to 400 kW

Table 4. *Price list of solar charging ports.*

Charging	Level	Code	Specifications	Price (VND)
MEGEAR Zencar	1-2	J17722	100 - 240 V, 16 A, 3.84 kW	6,663,000
PRIMECOM DEV-10	2	J17722	220/240 V, 16 A, 3.84 kW	12,476,000
BESENERGY BS-F30-14-50	2	J17722	240 V, 32 A, 7.65 kW	13,617,000
POTAT0 EC2-2	2	J17722	100 - 240 V, 16 A, 3.84 kW	5,877,000

2.2. Solar monitoring system

- Smart solar panel power monitoring system based on IoT

+ A solar monitoring system consists of sensors placed at a separate location to monitor and track the output performance of solar panels (Use sensors: DHT22, DHT11, SHT20 or SHT30, AM2305).

+ The generated data is transferred to the IoT gateway and uploaded to the cloud for data monitoring.

+ Data uploaded to the cloud can be easily accessed by users and installers at any time through the monitoring application.

- Smart solar monitoring function:

+ The IoT-based solar monitoring system performs centralized remote monitoring and tracks real-time performance data of solar PV systems, such as performance degradation, downtime, losses , and other factors causing power generation loss.

+ Data Storage: Monitored data is stored in the system and can be retrieved at any time to determine system effectiveness.

+ Recorded data is displayed in graph form and reported daily and monthly (timely reports can be generated depending on requirements) via SMS or Email.

+ Fault detection: The monitoring system comes with an alarm function when high temperature or abnormal fuse, etc. (one can set the alarm function according to parameter and location requirements)

+ Predictive analytics: Analyzed data records and tracked the real-time gap between expected and generated energy. This allows customers to make future decisions depending on previously stored data. The IoT remote monitoring SCADA system has a market price of about 20 million VND.

2.3. PV*SOL Software

Enter data according to the corresponding steps on the PV*SOL interface: Enter project information (name, date, etc. Input data on the installation site and type of single-phase or three-phase grid; Enter the expected consumption data of the load (expected annual consumption); Enter solar array data (select panel type, array capacity, installation orientation, and tilt angle); Enter the data of the inverter system (select inverter type, select the quantity to match the solar power system); Enter storage data (if any) (select storage battery type, enter quantity); Edit the connection diagram (if any); Check the overview of the system connection diagram; Enter financial data (if any); Finally, the software will give detailed calculation results and reports.

2.4. Technical Calculation Methodology

Perform theoretical calculations by the following steps:

1/ Calculating the solar array capacity based on the number of hours of sunshine at the installation site and the expected consumption demand per day, according to the expression: kWp (P_{PV}) = expected EV demand per day (Wh) * 1,25 / number of hours of sunshine per day (kWp). (In which, 1,25 is the factor of safety). Some panels needed = Number of Wp the panels must provide / Wp number of 1 panel.

Sunshine hours are obtained from the "global solar irradiance map" data at globalsolaratlas.info. Find the location of Hanoi City and determine the intensity of solar radiation/year as 1.345 $kWh/m^2/year$, equal to 3,69 $kWh/m^2/day$) [10].

2/ Select Inverter and configure the system based on condition: $P_{inv} \geq P_{PV}/1,2$ (with 1,2 as a safe value to prevent the sudden increase in load capacity at start-up) and Satisfied parameters: 100 ÷ 500 V, 40 A/80 A, 20 ÷ 40 kW.

3/ Select storage based on expected EV demand per day. Determine the storage capacity by the formula: Capacity (Ah) = expected EV demand per day (Wh)/(the charge-discharge efficiency * DOD * V). In which, the charge-discharge efficiency is determined at 80%; DOD – depth discharge is 0,6; V is the voltage of the storage.

4/ Choose a solar charge controller that meets the conditions: I_{max} = 1,3*number of panels/string*I_{SC-PV} (A). In which, I_{SC-PV} is the short-circuit current of a solar panel.

After entering the data calculated in the above steps into the software, it will give the following results: Total solar power output/year; Storage charging capacity; Power Consumption; Grid capacity.

3. RESULTS AND DISCUSSION

3.1. Charging station design

3.1.1. Experimental measurement, and power calculation

Make measurements of 3 solar panels with capacities of 400 W, 450 W, 500 W and 550 W to determine the optimal tilt angle. Place the panels on a horizontal plane, then gradually raise the tilt angle in the North-South direction., at Hanoi area, coordinates: 21°01′42″North 105°51′12″East, Measurement time period: 11h00' ÷ 12h20' this July 25, 2023. The power results of panels at different measuring angles are in figure 2. Based on the above results, we choose a tilt angle of 12 ÷ 18 degrees for the PV system in the Hanoi area, (depending on different installation locations, there will be optimal tilt angles).

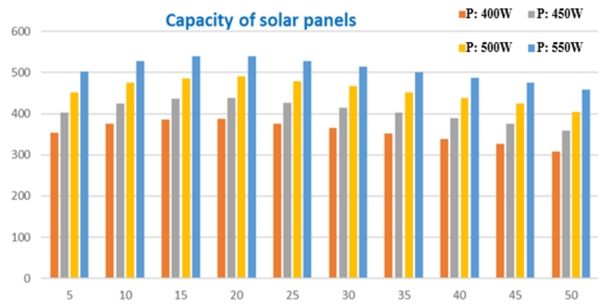

Figure 2. *Solar panel capacity chart and tilt angle.*

3.1.2. Design a charging station for an electric car

Perform calculations and design the charging station according to the calculation method in section 2.4.

+ Select car model

On the Vietnamese market today, many electric cars and electric cars (test or official) from many famous car manufacturers such as VinFast, Tesla, Nissan, KIA, BWM, Porcher have gradually appeared are listed in table 5 due to the increasingly rapid green energy transition in this market. Choose the VinFast VFe34 model with a 42 kWh battery capacity. To avoid "bottlenecks", the battery should only be discharged to the recommended level (about 20-25%). In addition, EC batteries are designed by manufacturers to charge at 85% capacity instead of 100% capacity to inhibit the charging process. So the consumption demand is about 42 * (85% - 25%) = 25,2 kWh.

Table 5. *Summary of some electric car brands [11].*

Brand	Model	Capacity	Distance	Brand	Model	Capacity	Distance
Audi	e-TRON	93 kWh	425 - 488 km	VINFAST	VFe35	82 kWh	460 - 510 km
Porsche	Taycan 4S	79,2 kWh	405 km	Tesla	Model S 75D	75 kWh	490 km
Nissan	LEAF	40 kWh	340 km	Volkswagen	e-up!	18,7 kWh	160 km
VINFAST	VFe34	42 kWh	300 km	Volkswagen	e-Golf	35,8 kWh	300 km

Currently, VinFast's charging stations install charging posts with capacities of 250 kW, 60 kW, 30 kW, and 1 kW, respectively. The corresponding estimated charging hours corresponding are: 2 hours 17 minutes (25,2/11 = 2,29 hours), 50 minutes, 25 minutes and 6 minutes.

+ Choose the type of solar panel:

Select battery Risen 500Wp (RSM150-8-500M) with parameters: Pmax: 500 (W); Operating voltage Vmp: 42,88 (V); Open circuit voltage Voc: 51,01 (V); Short circuit current Isc: 12,46 (A).

Calculating the PV system according to the steps in section 2.4, obtained the following results:

1/ In a day with a demand of 25,2 kWh, the number of Wp PV needs to provide is 25.200*1,25/3,69 = 8.537 (Wp). From the calculation results, choose the 9000 Wp system. The number of 500 W panels to use is 9.000/500 = 18 panels.

2/ With a 9,000 Wp system need an inverter system with a satisfactory capacity: Pinv ≥ 9.000/1,2 = 7.500 W, quantity selection is 1 piece Goodwe GW10K inverter with product code *GW10K-MS* (Vmppt-max-inv: 850 V; Imax-input-inv: 12,5 A; Vdcmax-inv: 1000 V) satisfy the condition.

Choice of strings number: the maximum number of panels in a string is: 850/42,88 ≈ 20 >18 panels. The array can be divided into 2 strings, each with 09 panels.

Consider the operating conditions of a string with 10 panels: 200 < Voc (10*40,5 = 405) < 850 V; Isc = 12,46 A < 12,5 A. So, a string of 09 panels works stably. Since all strings work, an inverter is suitable for the system.

3/ Capacity (Ah) = 25.200/(0,85*0,6*12) ≈ 4.118 (A). Select battery VISION 12 V - 200 Ah to store electricity. To meet the demand, we need about 21 batteries connected in parallel. Instead, choose 6 batteries ~ 1200 Ah will meet: (1.200*25.200)/4.118 = 7.343 (Wh) = 7,343 (kWh)

4/ Imax = 1,3 * 09 * 12,46 = 145,78 (A). With 2 strings, each charge controller connected to 1 string must meet the condition: Imax ≥ 145,78 /2 ≈ 72(A). So, choose MPPT 80A 12V/24V Auto solar charge controller.

+ The calculation results according to the simulation show the PV system results: PV Capacity: 9.00 kWp; PR – Chỉ số hiệu suất: 87,82%; Annual PV output: 10.999 kWh/year; Emission reduction CO_2: 5.157 kg/year; PR is 87,82%. That is, the usable received power during the day is (10.999/365)*87,82% ≈ 26,46 kWh.

3.1.3. Charging station scale for a VF8 car

- Estimate the cost of implementing the charging station

Table 6. *Cost of raw materials to make.*

Equipment	Unit price (VND)	Quantity	Price (VND)
Solar panel	2.172.500	18	39.105.000
Invecter hybrid	47.000.000	1	26.700.000
Battery	3.000.000	6	18.200.000
Charge controller	2.700.000	2	5.400.000
BESENERGY BS-F30-14-50	13,617,000	1	13,617,000
Truss frame	220.000	43,56 m^2 (2,2*1,1*18)	9.583.000
Total cost			**112.605.000**

- Survey of operating capacity

+ The power that can be consumed from the system is 26,46 kWh.

+ Charging time: 26,46/11 = 2 hours 24 minutes; 26,41/30 = 0 hour 53 minutes; 26,46/60 = 0 hour 27 minutes; và 26,46/250 = 0 hour 6 minutes.

+ Battery percent: 26,46/42 = 63% (Since the distance traveled when fully charged is 300 km, the estimated distance is about: 300*63% = 189 km).

3.2. Design and budget for solar charging station (12 ECs)

3.2.1. Estimated cost of raw materials

From the above design calculation model, we estimate the following:

The minimum number of panels required for 12 parking spaces is 12*18 = 216 panels, 500 Wp of type. The estimated one-day received power is 216*500*80%* (5 h) = 432 (kWh) (The number of rechargeable VFe34 vehicles is 432/26,46 ≈ 12 ÷16 cars). System capacity is 216 x 500 = 108 KWp, therefore we choose 02 inverter Growatt MAX KTL3-VL 60KW or 01 inverter inMitsubishi FR-F740P-110K (table 2)

If we need 60 kWh for storage, the number of 12 V–200 Ah batteries we need is 30*6/7,343 ≈ 25 (batteries). Therefore, with the above storage needs, about 25 batteries are needed for the system. Area of charging station = 1,1 *2,2*216* = 475,2 (m^2). 216 panels are divided into 6 rows, with a distance of 1 cm between rows (increasing temperature release). Each row of 36 panels is close together, so the actual charging station roof area is: 6*(2,2+0,1)*36*1,1= 546,48 m^2 (Fig 3).

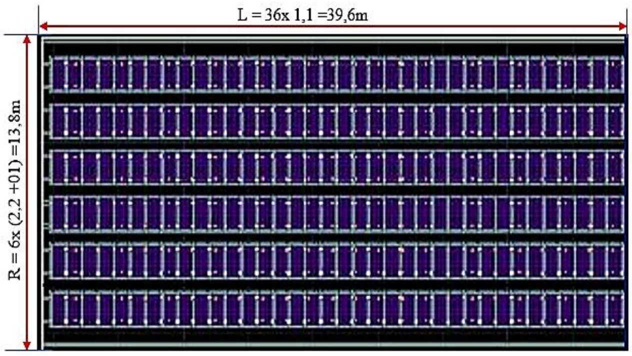

Figure 3. *Diagram of solar panels for stations for 12 cars.*

Table 7. *The estimated cost of materials for a solar charging station with storage (12 EC).*

Equipment	Unit price (VND)	Số lượng	Price (VND)
Solar panel (**Risen** Solar 500 W)	2.172.500	216	325.620.000
Inverter (Growatt MAX KTL3-VL)	64.200.000	2	128.400.000
Battery (GS N200 12 V - 200 Ah)	3.000.000	25	75.000.000
BESENERGY BS-F30-14-50	13,617,000	12	163.404.000
Solar monitoring system	20.000.000	1	20.000.000
Truss frame	220.000	546,48 m^2	120.225.000
Total cost			**823.649.000**

For an independent system, the number of batteries needed is: 108* 6/9 = 72 battery (GS N200 12 V - 200 Ah) and Total cost: 823.649.000 VND + 3.000.000 VND *(72-25) = 964.649.000 VND.

3.2.2. Estimated economic benefits from EV-PV charging stations

Project efficiency from the EV-PV charging station is determined by the profit achieved and the project payback period. The profit of the EV-PV charging station project is calculated in 2 steps [12]:

- Step 1: Calculate the profit

I = (B1-C) +...+ (B20-C). In which, B: Revenue = E*P (với E is annual PV output, and P is EVN's selling price of electricity) in 20 years; C is Investment cost, and I is profit (VND).

- Step 2: Calculate the payback period

The payback period is determined by calculating the "accumulated net cash flow each year". At the moment this value in a year is zero, and the project is payback.

Through the calculation according to the above two steps, we can determine the economic efficiency as summarized in table 8

It can be seen that the grid-tied EV-PV charging station model without storage has the earliest payback period (5 years), and the profit is quite high compared to savings with an interest rate of 7%/year analyzed above. This is followed by the grid-tied EV-PV charging station model with storage, household, and the stand-alone model, which has the highest total investment cost, whereby the profit is negligible, and the payback period is about 8,5 years. From the above analysis, it can be seen that this is also considered an effective long-term investment plan in the future. However, it should also be considered because of the large investment costs. Therefore, it is necessary to have a reasonable financial balance to get a more effective investment plan.

Comments: The EV-PV charging station is both energy efficient and has a progressive stat reduction with a payback period for an EV-PV charging station without storage for as early as a payback time is 5 years. This shows that when using a grid power system combined with solar energy, the economic benefits are very large (higher profit than bank savings). This model is more efficient than the EV-PV analysis in the publications [4, 13].

Table 8. *Summary of calculation results of EV-PV charging station project business models.*

Result	Household	Grid-tied EV-PV with storage	Grid-tied EV-PV without storage	Standalone EV-PV
Investment cost (VND)	112.605.000	823.649.000	757.649.000	964.649.000
Profit (VND)	580.942.130	3.219.672.679	3.387.172.679	1.951.521.102
Payback period (year)	4,46	6,04	5,70	6,46

4. CONCLUSIONS

1) An experimental survey on voltage, current, and capacity of some solar panels in Hanoi, shows the direction and tilt angle of the solar panel array to the South at an angle of 12 ÷ 18 degrees to obtain the radiation maximum.

2) Based on theory and using software to support the design of solar power systems PV*SOL has designed and calculated capacity for EV-PV charging stations for households (S = 43,56 m^2, P = 9 kWp, DCap = 112.605.000 VND) with an electric car brand VinFast - model VFe34 or other similar brands, after 4,46 years the capital has been paid back and the profit is 580.942.130 VNĐ until the 20^{th} year.

3) Calculated and designed EV-PV charging stations for 12 electric cars with additional investment for the models of independent EV-PV charging stations, grid-tied EV-PV charging stations with and without storage indicated. It turns out that efficiency is the profit of each model. The capital cost of raw materials is 757.649.000 VND for a grid-tied EV-PV charging station with no storage, with payback after 5,7 years. This model problem shows that the economic and energy efficiency is very large.

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TÓM TẮT

Nghiên cứu thiết kế trạm sạc xe điện sử dụng năng lượng mặt trời tích hợp hệ thống giám sát công nghệ IoT

Khi công nghệ ngày càng tiến bộ, chi phí của thiết bị năng lượng tái tạo ngày càng giảm, dẫn đến việc lắp đặt quang điện mặt trời tăng mạnh. Trong nghiên cứu này, chúng tôi thiết kế và tính toán hệ thống điện năng lượng mặt trời cho trạm sạc cho 12 ô tô điện tích hợp hệ thống giám sát năng lượng, sử dụng công nghệ IOT. Kết quả phân tích mô hình trạm sạc EV-PV độc lập và mô hình nối lưới có lưu trữ đã cho thấy hiệu quả và lợi nhuận của từng mô hình. Hệ thống năng lượng mặt trời sử dụng hệ thống giám sát công nghệ IOT giúp nâng cao công suất và chất lượng về điện cho trạm xạc ô tô điện, do có hệ thống cảm biến giám sát được các yếu tố ảnh hưởng đến hiệu suất pin mặt trời như (bụi, cường độ bức xạ mặt trời, thời tiết hay hướng nghiêng của dàn pin mặt trời).

Từ khóa: Trạm sạc ô tô điện; Hệ thống điện năng lượng mặt trời; Ô tô điện (EC); Công nghệ IoT.