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Original Research Article

Simple Photovoltaic Electric Vehicles Charging Management System Considering Sun Availability Time

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ABSTRACT

Solar electric vehicle charging can substantially reduce carbon emissions compared to conventional utility grid-based electric vehicle charging. In the future, the need for the use of electric vehicle charging will continue to increase so that an energy charging management system that is simple and has ubiquitous components is needed. This paper presented a simple charging management system. The current solution is full of complexity with various algorithms, deep learning and machine learning solutions, and artificial intelligence, which can lead to errors for which no known solution exists. The main novelty in the proposed strategy is to compare the components used to get a simple but reliable system. The component that will compare is Raspberry Pi and ESP32. The ESP32 can offset the advantages of the Raspberry Pi with the help of Blynk, so for a simple and cheaper but reliable system, the ESP32 system is better for an energy charging management system.

KEYWORDS

Charging station, Esp32, Pv-ev management system, Raspberry pi, Solar energy, Blynk.

INTRODUCTION

Since the beginning of the industrial era, the electricity and transportation sectors have become the two most significant sources of greenhouse gas (GHG) emissions, one of the leading causes of global warming [1]. This is because both sectors have been relying on fossil fuels [2]. The transition to more sustainable energy and low-emission transportation systems has been promoted globally in recent years [3]. This has led to significant growth in adopting renewable energy sources and transportation of electricity in recent decades [4].

The increase in carbon emissions from fuel oil has given rise to research policies for developing Electric Vehicles (EVs) worldwide [5], which are marked by the growing market of electric vehicles [6]. In realizing the transformation, one strategy is to develop the electric vehicle industry ecosystem [7]. Globally, the use of electric vehicles has increased rapidly, reaching a world market share of 2.6% in 2019 [8]. Vehicle electrification with relatively low carbon intensity is a future trend in reducing global warming [9]. However, the electric vehicle

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fleet increase has led to a rise in electricity and charging infrastructure demand [10]. Charging using conventional electricity, which is dominated by fossil generators, causes environmentally friendly electric vehicles to become less meaningful [11]. Therefore, it needs to harmonize with electricity sources from renewable energy, such as solar energy [12].

In recent years, many kinds of energy management issues have been studied in electric vehicles. Various algorithms, deep learning and machine learning solutions, and artificial intelligence solutions have been proposed for Energy management systems (EMS) [13], [14]. Electric Vehicle-Intelligent Energy Management and Charging Scheduling System (EV-EMSS) for charging station and management system [15], [16]. The proposed system provides convenient energy management services by using battery control units and communication with charging stations for charging decisions. Then, dynamic energy management of an electric vehicle charging station using photovoltaic power [17], this station consists of a PV and energy storage system (ESS) with real-time coordination between the PV power station. The grid and the ESS for enhancing the station working as a standalone system as long as possible and satisfying the EVs requirement. However, the current solution is full of complexity with various algorithms, deep learning and machine learning solutions, and artificial intelligence, which can lead to errors for which no known solution exists.

The use of electric vehicles will increase over time. This will align with the need for charging the electric vehicle itself. With the current conditions that still use many complex systems with various algorithms, it will undoubtedly cause many problems in the future. Therefore, a charging management system is needed that is simple, cheap, and uses ubiquitous components for convenience for consumers. Such a system will minimize errors from large complex systems. A simple and cheap system will require easier maintenance at a smaller cost than a complex system.

Among renewable energy sources, solar energy sources are the most widely developed and reliable alternative [18]. The condition of Indonesia, located in the tropics, has a vast potential for solar energy, around an average of 4.8 kWh/m2/day or equivalent to 112,000 GWp, so it is feasible to be used as an alternative source of electrical energy [19]. Solar energy sources have become a priority energy source to develop to achieve the target of new and renewable energy (EBT) of 23% in 2025 and 31% in 2050, as stated in Government Regulation No. 79 of 2014 concerning the national energy policy [20]. In addition, integrating renewable energy-based scattered generators in load centres can reduce power losses and increase the voltage of the electricity network [21].

There are two approaches to charging electric vehicles using solar power: on-grid PV and standalone PV [22]. On-grid PV charging has the advantage that during insufficient sunlight, charging using a grid [23]. It is also flexible because solar power can be exported to the grid if no electric vehicles are charged. On the other hand, standalone PV is more advantageous for remote areas where utility supplies are unavailable or too expensive [24], [25].

For this reason, this research proposes a simple photovoltaic electric vehicle charging management system considering sun availability time. The coordination management system designed will maximize the use of solar generators; excess energy will be stored in batteries for later use when energy from the sun is unavailable, and grid electricity as a backup power source. The main novelty in the proposed strategy is to compare the components used in making EMS to get a simple but reliable system. Raspberry Pi and ESP32 are cheap and widely circulated components on the market that can manage EMS. In this paper, we will compare Raspberry Pi and ESP32 to get a simpler and cheaper system while still prioritizing its function in the energy management system.METHODS

The coordination management system designed will maximize the use of solar generators; excess energy will be stored in batteries for later use when energy from the sun is unavailable,

and fossil generators as a backup power source. Intermittent constraints from solar plants will be overcome by adjusting the pattern of solar power generation, batteries, and grid electricity. The operations coordination management system will regulate the operation pattern based on the availability of intermittent generator energy and the remaining storage capacity of the battery state of charge (SoC). The process of data acquisition, data processing, and data communication will use digital technology and information systems that support the advanced monitoring infrastructure (AMI). The charging status of electric vehicles can be monitored and controlled centrally on the web using the internet.

The system created uses 2 different components and will compare, namely the Raspberry Pi and ESP32. The working principle of these two systems will be the same, the only difference being the use between Raspberry Pi and ESP32. For the Raspberry Pi system, the monitoring and control system for charging solar electric cars will develop using dual servers, namely a local server and a web hosting service provider as an internet-connected server. For the ESP32 system, the monitoring and control system for the charging station will develop using Blynk apps. The results of the design and development of the PV, battery, and Grid operation management system for online electric vehicle charging expect to be implemented at electric vehicle charging stations to increase national energy security, increase local technology content and reduce greenhouse gas (GHG) emissions.

The coordination and battery charging management system uses a PZem sensor circuit for Alternating current (AC) parameter measurement; the Direct current (DC) sensor module will be integrated using the Raspberry Pi and ESP32. Then an analysis of the energy balance scheme is carried out to obtain optimal operation in charging electric vehicles, increase reliability, significant savings, and analysis of the length of time for the return on investment costs. The design of the electric vehicle charging system consists of 6 relay units to regulate the start/stop charging and transfer of sources from PV to the grid, as shown in Figure 1 for the Raspberry Pi system and Figure 2 for ESP32.

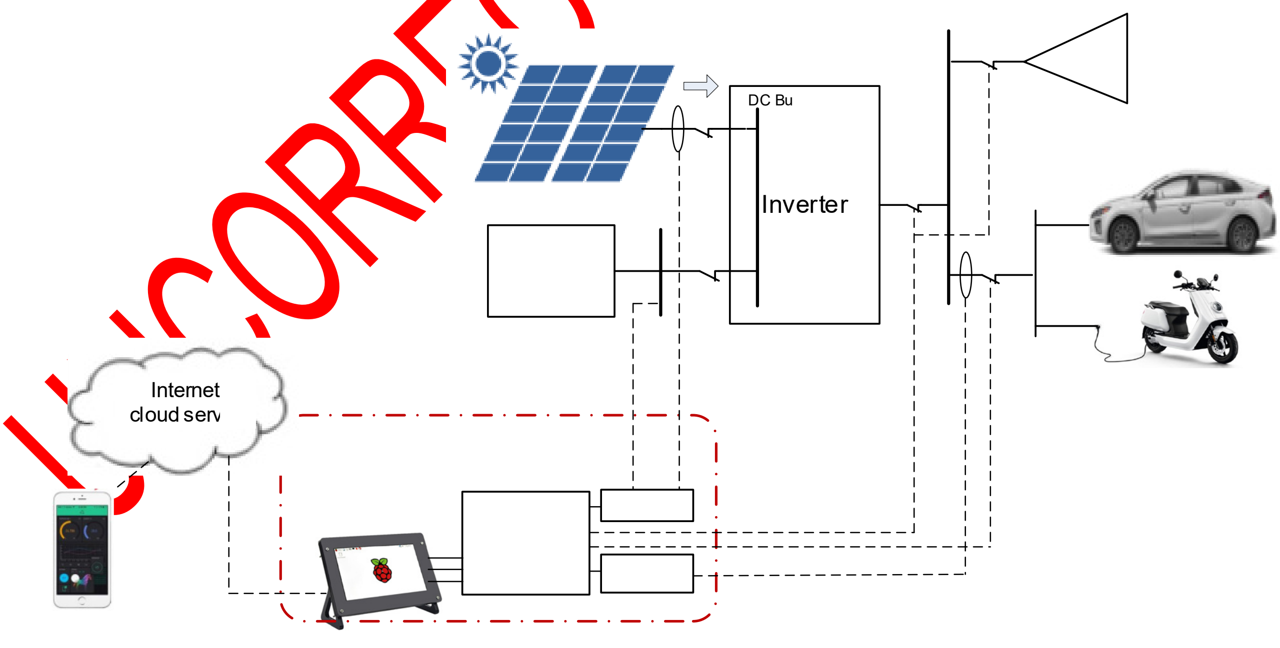

Figure 1. PV-EV charging management system using Raspberry Pi

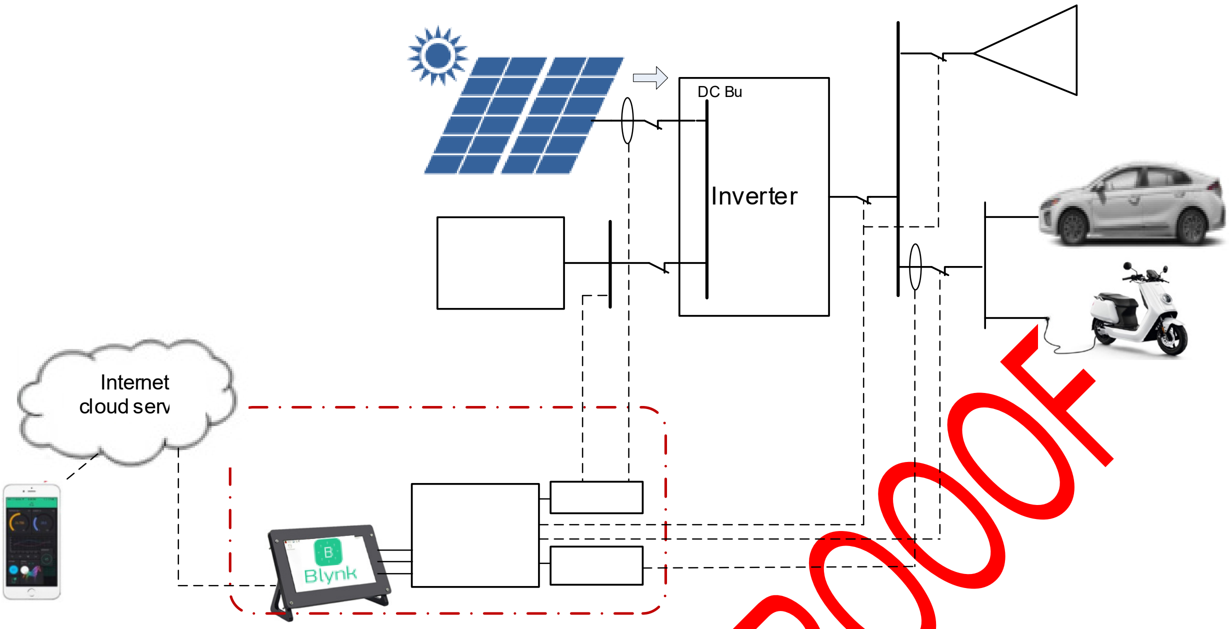

Figure 2. PV-EV charging management system using ESP32

The system consists of several sensors that will send parameters to the Raspberry Pi / ESP32 to receive data from sensors as data and as decision-makers during the energy harvesting process and supply transfer to the charging station. The sensors used in this charging station are divided into two types. The first is the AC sensor (PZem 004T), which can identify the charging station's voltage, current, power, and energy during the charging process. The PZem sensor will also supply a data logger for the charging station system, which will also send many data to the server that has been prepared. The second is a DC sensor (ACS712 30A (I_{dc} in Figure 1 and Figure 2) and a voltage sensor (V_{dc} in Figure 1 and Figure 2)). This sensor is used to obtain PV system parameters as the main supply in this study. The second function of the sensor in the DC section will also affect the supply transfer system from the PV rooftop to the grid, which will be used as a backup when the availability of sunlight decreases until it does not exist at all (rain or goes late into the night). The function of the relay on the charging station is to break or connect the load with the supply and transfer the supply so that the load can continue served without a momentary disconnection.

RESULT AND DISCUSSION

Simple photovoltaic electric vehicles charging management system considering sun availability time using Raspberry Pi / ESP32, as shown in Figure 3. Each system will use Pzem to read charging current, power, and energy values. Then a DC sensor (ACS712 30A and a voltage sensor) read the PV output current and battery voltage, which will use as a reference for the charging management system. Relays regulate the transfer of PV, battery, and grid energy. In addition, the relay is used to start/stop charging.

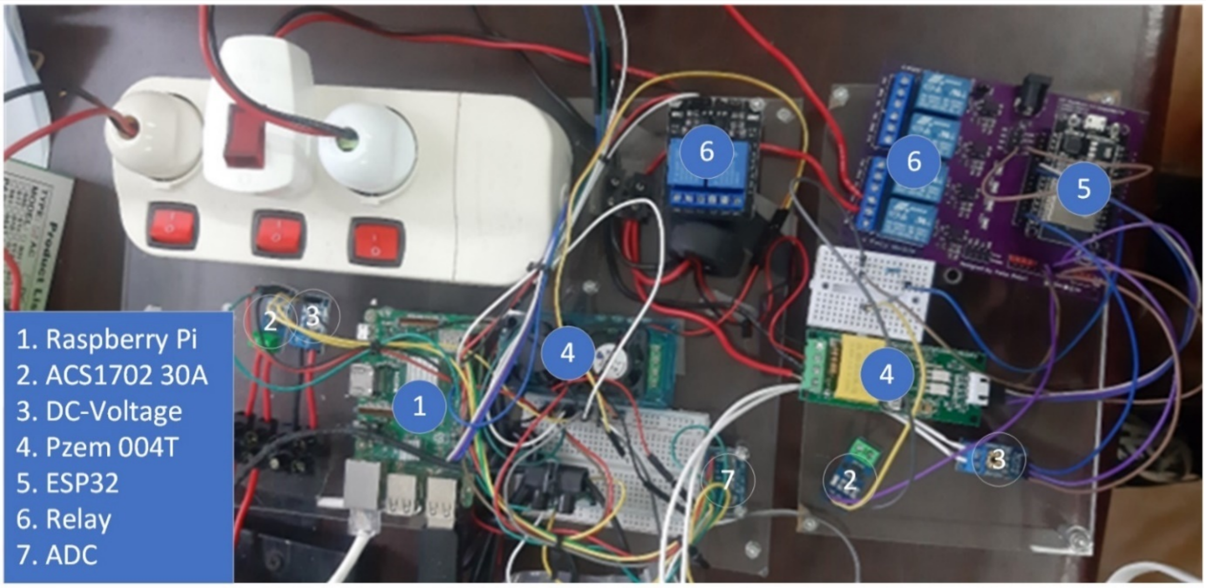

Figure 3. Charging management system using Raspberry Pi / ESP32

Raspberry Pi and ESP32 are systems that each work with the same principle. In this study will compare the work between Raspberry Pi and ESP32. The difference between using the Raspberry Pi and the ESP32 system is shown in Table 1.

Table 1. Comparison between Raspberry Pi and ESP32 system

No	Parameter	Raspberry Pi	ESP32
1	Function	Complex	Simple
2	Database	Yes	No
3	Analog pin	No	Yes
4	Program language	Python	C
5	Cost	Expensive	Cheap
6	Monitoring	Dual-web server	Blynk
7	Time	Based on time server	Need to set up first

Based on its function, the Raspberry Pi is more complex than the simple ESP32. The Raspberry Pi has the advantage of being like a computer in general. It can do everything a computer or laptop with the Linux operating system can do, like making programs in various languages to building servers. For advanced usage, the Raspberry Pi has almost no limitations making it possible to develop applications. While ESP32 is simpler, ESP32 works like a microcontroller in general but has the advantage of having Wi-Fi, so it supports the creation of Internet of Things systems. Then, because raspberry pi can build a server, it has a database, while ESP32 does not have storage for the database, so it requires another platform. Raspberry Pi has the disadvantage of not having an analogue pin, while ESP32 has an ADC pin to read analog signals. The analogue pin is used to receive the analogue output from the sensor. For Raspberry Pi to be able to read analog signals, an additional component is needed, namely the ADC module. The programming used on the Raspberry Pi is Python, while on ESP32, it uses C++. When compared between Python and C++, the code in the Python programming language is shorter than in C++. Python is a dynamically writable programming language, whereas C++

is statically writable only. In terms of cost, the Raspberry Pi is much more expensive when compared to the ESP32, which can cost up to 30 times as much.

Regarding monitoring, the Raspberry Pi system uses a dual-web server, while the ESP32 system uses Blynk. With the advantages of the Raspberry Pi, it is possible to create a server so that monitoring and control of the system can use a dual-web server to connect to the internet. The web server has the advantage of being freely developed as desired. However, the use of web servers has become more complicated and advanced. In comparison, the ESP32 system uses Blynk for monitoring and control. Because ESP32 cannot create its server, a platform is needed to support this, namely Blynk. Blynk is an IoT valuable platform for monitoring and controlling systems displayed on the web and mobile phones. Using Blynk is easy because users only take advantage of the tools that have been provided and adapt them to their needs. However, it has drawbacks if the required tools are not available. The Raspberry Pi has the advantage of setting a time that can be set automatically based on the time on the server. Meanwhile, the time on ESP32 needs to be set up first when inputting the program. This is because the Raspberry Pi has a built-in timer.

Electric vehicles ' real-time monitoring and charging status can be monitored and controlled centrally on a web-based basis using the internet network with a display for the Raspberry Pi system, as shown in Figure 4. Real-time monitoring and control charging for the ESP32 system on Blynk are shown in Figure 5. Compared to the appearance of the web server and Blynk, the appearance of the web server is more attractive because it can be developed freely, rather than Blynk, which only utilizes existing tools.

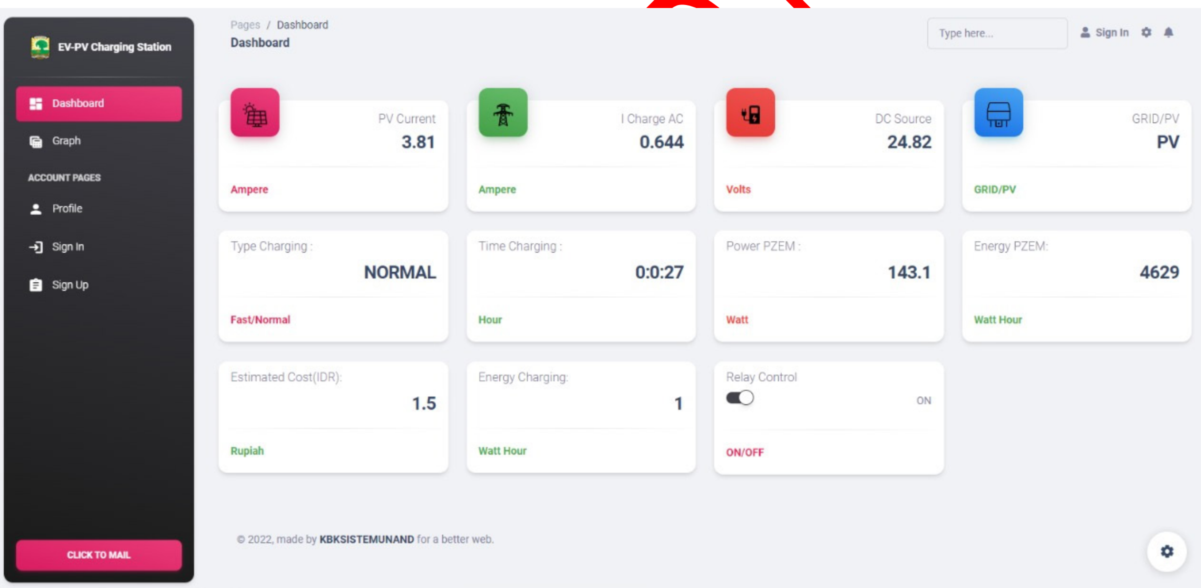

Figure 4. Charging Station Web Desain (Raspberry Pi system)

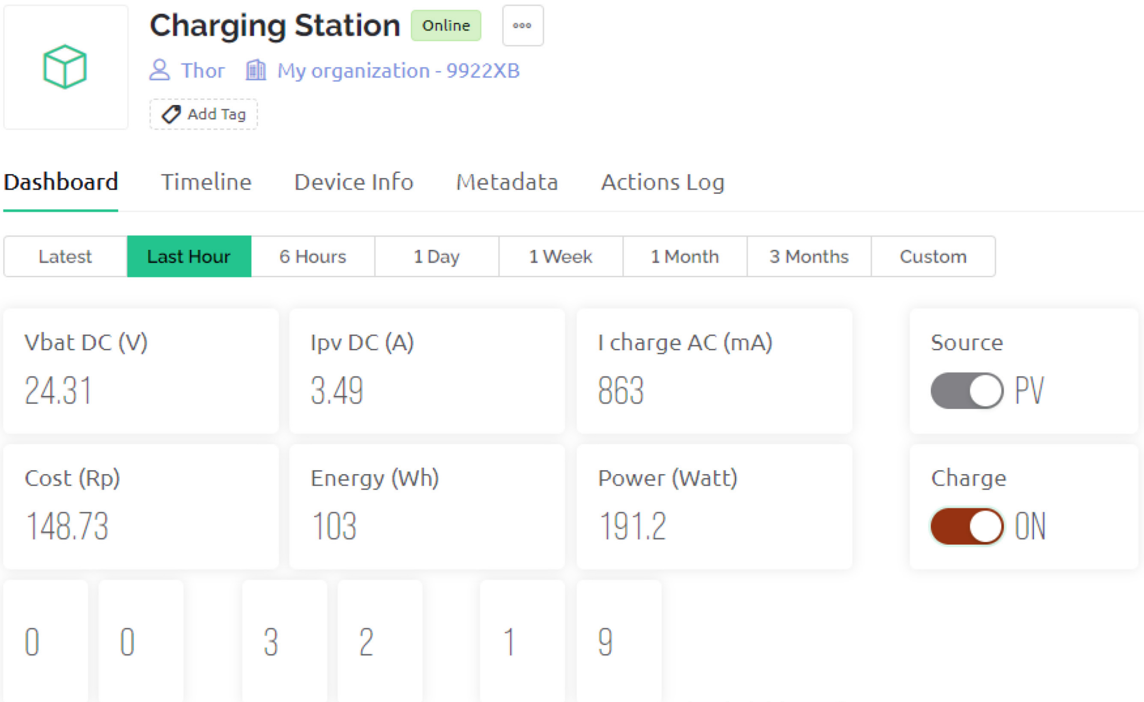

Figure 5. Charging station on blynk (ESP32 system)

Meanwhile, the infographic display of the reading results are shown in Figure 6

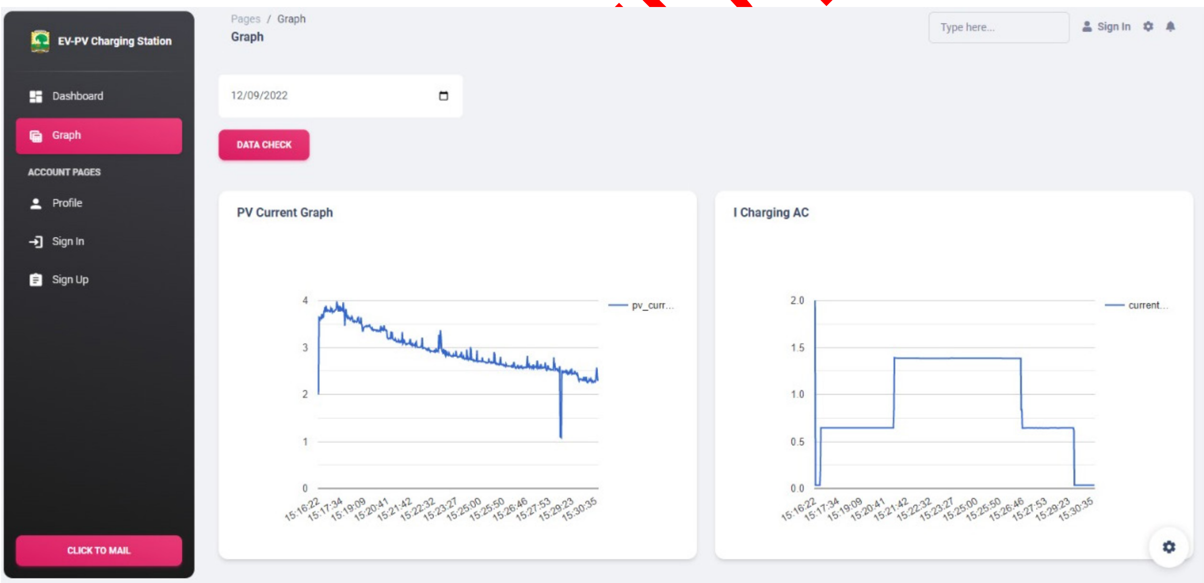

Figure 6. Infographic display of reading results

The web-based PV-EV charging management system requires an accurate transducer to deliver correct data to the database. This study takes a standard digital mustimeter Fluke for sensor calibration and sensor accuracy measurement. The test results are shown in Table 2.

Table 2. Sensor accuracy of web-based PV-EV charging management system

Component	Sensor	Mustimeters	Difference	Average
	25,55	25,61	0,23	
VDC Battery	25,08	25,09	0,04	
(Voltage Sensor)	24,85	24,86	0,04	0,08
	24,55	24,56	0,04	

	24,41	24,42	0,04	
I DC PV (ACS712 Sensor)	4,28	4,28	0,00	0,05
	4,26	4,27	0,23	
	4,29	4,29	0,00	
	4,29	4,29	0,00	
	4,29	4,29	0,00	
PZEM AC Volt (PZEM Sensor)	223	222,5	0,225	0,35
	222,2	221,5	0,316	
	221,9	220,9	0,453	
	220,8	219,3	0,684	
	218	217,8	0,092	
PZEM AC Current (PZEM Sensor)	0,32	0,28	0,04	0,05
	0,64	0,59	0,05	
	0,96	0,92	0,04	
	1,39	1,34	0,05	
	1,54	1,49	0,05	

In the graph shown in Figure 7, the condition of the PV output has little effect on the battery voltage. However, these conditions do not make the battery voltage that looks much reduced. This is because the PV can still supply the load side to charge the battery while serving loads ranging from 0.7 A to 1.4 A. Data retrieval takes when the sky is hot and tends to be consistent, as seen on the PV output graph. The decrease in the PV output graph is not too significant, t; the reduction is directly proportional to the sunlight time between 12.00 and 15.00 WIB. Shading is also a factor in the lack of maximum sun absorption by solar panels because the location of the solar panels is slightly blocked by trees when the sun is on the west side of the panel. For testing, will used 2 250 Wp polycrystalline solar panels located on the rooftop of the Electrical Engineering Department Building for the inverter and battery located in the research room on the 2nd floor.

The results of the battery voltage reading, as shown in Figure 7, are used as a consideration for the source to switch to the grid if the capacity (SoC) of the battery has reached the 20% limit. During the day, this PV output will be a parameter for supply transfer between PV and Grid.

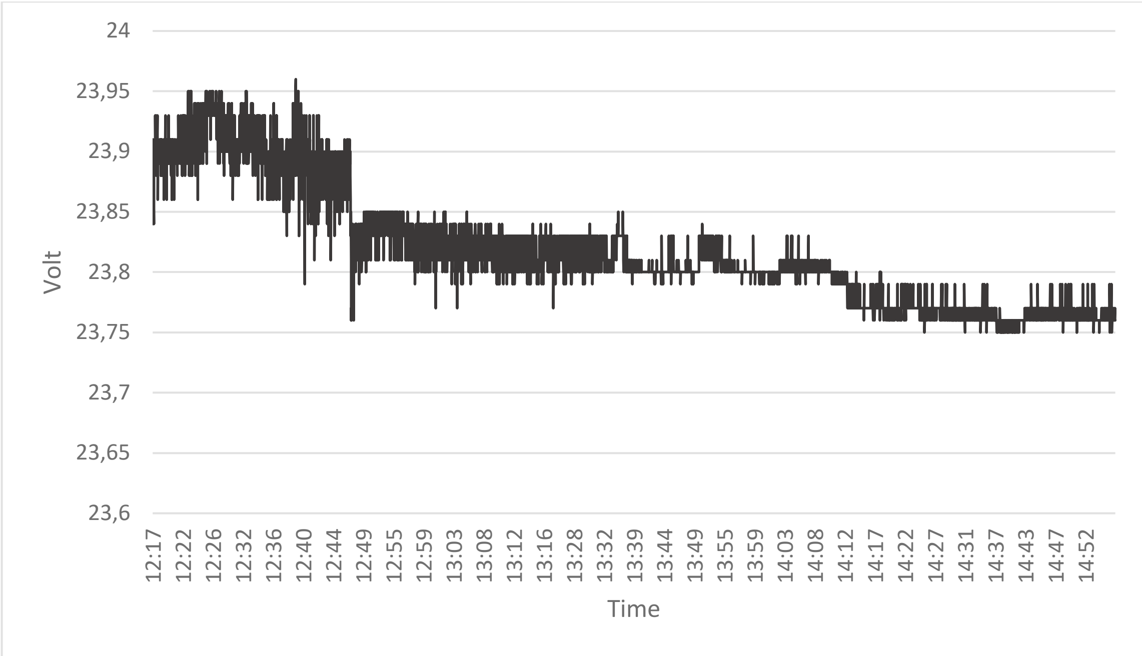

Figure 7. Results of monitoring battery voltage

Based on the graph shown in Figure 8, the PV output current fluctuates from 12.17 to 13.02 due to weather changes affecting sunlight absorption on the solar panels. Starting from 13.07 until the afternoon, the decrease in the intensity of the sun looks normal. During the day, the supply transfer between PV and the Grid will influence by the results of battery voltage measurements and the output current of PV panels. While at night, only the battery voltage will be a parameter of the supply switching.

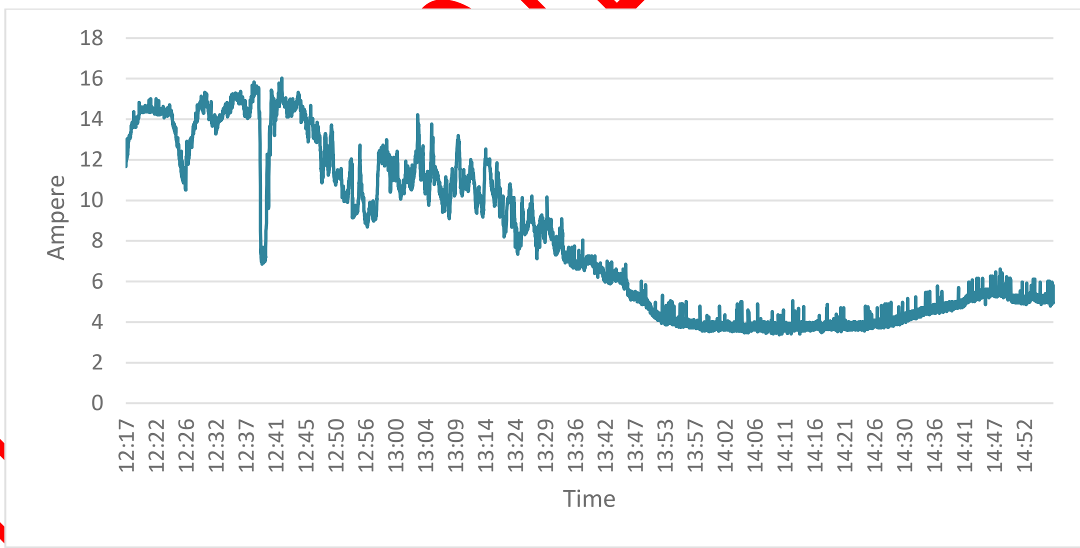

Figure 8. The output current of the PV panel

Figure 9 show that battery voltage measurements under transition process. When the battery capacity runs out, this system will transition to supply electric vehicle charging from the PV battery to the grid. Then it will resume charging from the PV-Battery when it is available again. In this graph, it is shown that the battery voltage condition increases when there is a transition when PV is actively supplying energy (Condition 1) and PV stops supplying energy (Condition 0).

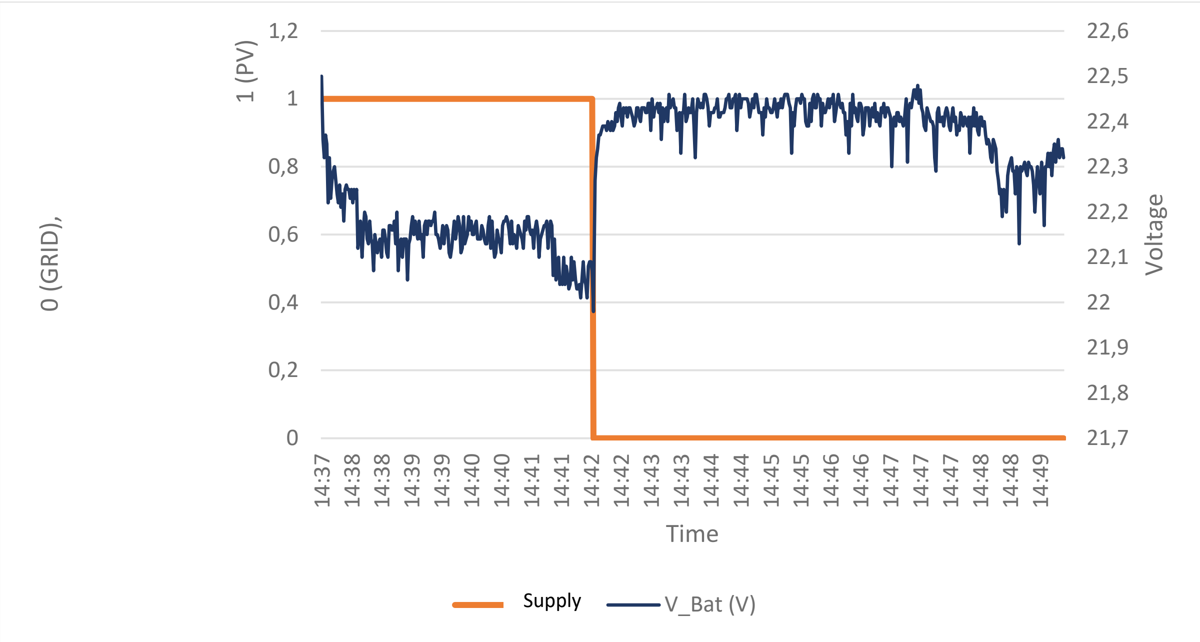

Figure 9. Battery voltage measurement under transition process

The results of the energy reading test and the estimated cost are shown in Figure 10 Both have shown a linear reading value, meaning that every increase in electrical energy absorbed by electric vehicles is proportional to the costs that must pay. This graph shows that the cost of energy use when charging will continue to increase along with the length of time and the amount of energy used. The purpose of this graph is to show the function of an electric vehicle charging station which displays the costs of charging an electric vehicle, with this linear reading shows that the system works as it should.

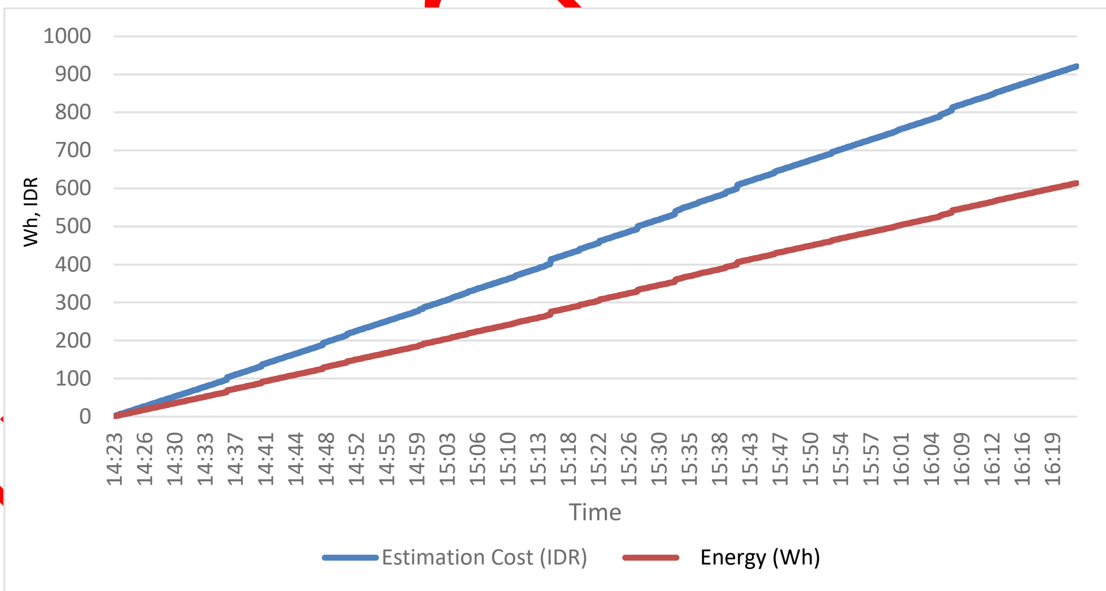

Figure 10. Energy reading test results and cost estimation

Based on the system testing, the Raspberry Pi and ESP32 systems can adequately run the PV-EV charging management system based on sun availability. With each advantage and disadvantage, the Raspberry Pi and ESP32 can run PV-EV charging as desired. The ESP32 can offset the advantages of the Raspberry Pi with the help of Blynk. The ESP32 system is better than the Raspberry Pi system for energy charging management for a simple and cheaper but reliable system.

CONCLUSION

The web-based Blynk user interface application has been designed for a real-time monitoring system of PV current, battery charge, electric vehicle charging current, and its infographic display. The estimated charging cost is obtained from reading the energy absorbed during the charging process multiplied by the electricity tariff; the results can be displayed on the web page. The charging process using a 2-channel relay and its functional test have been added. The method of transferring to the grid has been built using a 4-channel relay module. Transfer charging resources from PV to Grid and test the transition system from PV to Grid based on the SoC of the battery and the availability of sunlight. During the day, the supply transfer between PV and Grid will influence by the results of battery voltage measurements and the output current of PV panels. While at night, only the battery voltage will be a parameter of supply switching.

After comparing the system with Raspberry Pi and the system with ESP32, based on its function, the Raspberry Pi is more complex than the simple ESP32. Then, because raspberry pi can build a server, it has a database, while ESP32 does not have storage for the database, so it requires another platform namely Blynk. Raspberry Pi has the disadvantage of not having an analogue pin that must added ADC modul to read analogue signals, while ESP32 has an ADC pin to read analog signals. In terms of cost, the Raspberry Pi is much more expensive when compared to the ESP32, which can cost up to 30 times as much. Based on the finding and research objectives to get a simpler and cheaper system while still prioritizing its function in the energy management system, the ESP32 system, is better than the Raspberry Pi system.

A simple and much cheaper system will reach a wider range of researchers to continue developing energy management systems. With many contributing to this research, it will accelerate the goal of getting a reliable, simple and inexpensive system to be used commercially and accelerating the use of electric vehicles will be achieved faster.

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REFERENCES

1. IPCC Working Group III, “Climate change 2014 : mitigation of climate change,” 2014.
2. N. Kumar, T. Kumar, S. Nema, and T. Thakur, “A comprehensive planning framework for electric vehicles fast charging station assisted by solar and battery based on Queueing theory and non-dominated sorting genetic algorithm-II in a co-ordinated transportation and power network,” *J Energy Storage*, vol. 49, p. 104180, May 2022, https://doi.org/10.1016/J.EST.2022.104180.
3. V. Heinisch, L. Göransson, R. Erlandsson, H. Hodel, F. Johnsson, and M. Odenberger, “Smart electric vehicle charging strategies for sectoral coupling in a city energy system,” *Appl Energy*, vol. 288, p. 116640, Apr. 2021, https://doi.org/10.1016/J.APENERGY.2021.116640.
4. D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, “The role of renewable energy in the global energy transformation,” *Energy Strategy Reviews*, vol. 24, pp. 38–50, Apr. 2019, https://doi.org/10.1016/J.ESR.2019.01.006.
5. C. Zimm, “Improving the understanding of electric vehicle technology and policy diffusion across countries,” *Transp Policy (Oxf)*, vol. 105, pp. 54–66, May 2021, https://doi.org/10.1016/J.TRANPOL.2020.12.012.
6. P. Sharma, “Analyzing the Role of Renewables in Energy Security by Deploying Renewable Energy Security Index,” *Journal of Sustainable Development of Energy,*

Water and Environment Systems, vol. 11, no. 4, 2023, https://doi.org/10.13044/j.sdewes.d11.0463.
7. A. I. Karameros, A. Chassiakos, and S. Karatzas, "Design and Evaluation of a Micro-Grid Energy Management Scheme Focusing on the Integration of Electric Vehicles," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 11, no. 1, Mar. 2023, https://doi.org/10.13044/j.sdewes.d9.0413.
8. IEA, "Global EV Outlook 2020," Paris, 2020.
9. H. Attia, M. Mohsen, B. Qadoor, M. Al Shamsi, O. Abdulsalam, and Z. Rahman, "New design and implementation of a solar car of the American university of Ras Al Khaimah: Electrical vision," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 8, no. 3, pp. 452–463, Sep. 2020, https://doi.org/10.13044/j.sdewes.d7.0281.
10. A. Kiani, B. Fani, and G. Shahgholian, "A multi-agent solution to multi-thread protection of DG-dominated distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 130, p. 106921, Sep. 2021, https://doi.org/10.1016/J.IJEPES.2021.106921.
11. H. Matalata, S. Syafii, and M. I. Hamid, "Evaluation of Future Battery Electric Vehicles as an Environmentally Friendly Transportation Means: A Review," *Andalasian International Journal of Applied Science, Engineering and Technology*, vol. 3, no. 01, pp. 32–43, May 2023, https://doi.org/10.25077/aijaset.v3i01.67.
12. A. Halimatussadiah *et al.*, "The Impact of Fiscal Incentives on the Feasibility of Solar Photovoltaic and Wind Electricity Generation Projects: The Case of Indonesia," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 11, no. 1, Mar. 2023, https://doi.org/10.13044/j.sdewes.d10.0425.
13. A. Alsharif, C. W. Tan, R. Ayop, A. Dobi, and K. Y. Lau, "A comprehensive review of energy management strategy in Vehicle-to-Grid technology integrated with renewable energy sources," *Sustainable Energy Technologies and Assessments*, vol. 47, p. 101439, Oct. 2021, https://doi.org/10.1016/J.SETA.2021.101439.
14. R. Zahedi, M. hasan Ghodusinejad, A. Aslani, and C. Hachem-Vermette, "Modelling community-scale renewable energy and electric vehicle management for cold-climate regions using machine learning," *Energy Strategy Reviews*, vol. 43, p. 100930, Sep. 2022, https://doi.org/10.1016/J.ESR.2022.100930.
15. K. N. Qureshi, A. Alhudhaif, and G. Jeon, "Electric-vehicle energy management and charging scheduling system in sustainable cities and society," *Sustain Cities Soc*, vol. 71, p. 102990, Aug. 2021, https://doi.org/10.1016/J.SCS.2021.102990.
16. S. Karatzas, P. Farmakis, A. Chassiakos, T. Farmakis, Z. Christoforou, and G. Liappi, "Development of a Multi Criteria Model for Assisting Electric Vehicle User Charging Decisions," *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 11, no. 2, Jun. 2023, https://doi.org/10.13044/j.sdewes.d10.0439.
17. K. Kouka, A. Masmoudi, A. Abdelkafi, and L. Krichen, "Dynamic energy management of an electric vehicle charging station using photovoltaic power," *Sustainable Energy, Grids and Networks*, vol. 24, p. 100402, Dec. 2020, https://doi.org/10.1016/J.SEGAN.2020.100402.
18. C. K. Nayak, K. Kasturi, and M. R. Nayak, "Economical management of microgrid for optimal participation in electricity market," *J Energy Storage*, vol. 21, pp. 657–664, Feb. 2019, https://doi.org/10.1016/J.EST.2018.12.027.
19. Syafii, Zaini, D. Juliandri, and Wati, "Design and Economic Analysis of Grid-Connected Photovoltaic on Electrical Engineering Building in Universitas Andalas," *International Journal of Engineering and Technology*, vol. 10, no. 4, pp. 1093–1101, Aug. 2018, https://doi.org/10.21817/ijet/2018/v10i4/181004029.

20. ESDM, *Peraturan Pemerintah Republik Indonesia No. 79 Tahun 2014, Tentang: Kebijakan Energi Nasional*. 2014.
21. Syafii and K. M. Nor, "Unbalanced active distribution analysis with renewable distributed energy resources," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 13, no. 1, pp. 21–31, 2015, https://doi.org/10.12928/TELKOMNIKA.v13i1.960.
22. A. R. Bhatti, Z. Salam, M. J. B. A. Aziz, K. P. Yee, and R. H. Ashique, "Electric vehicles charging using photovoltaic: Status and technological review," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 34–47, Feb. 2016, https://doi.org/10.1016/J.RSER.2015.09.091.
23. A. A. S. Mohamed, A. El-Sayed, H. Metwally, and S. I. Selem, "Grid integration of a PV system supporting an EV charging station using Salp Swarm Optimization," *Solar Energy*, vol. 205, pp. 170–182, Jul. 2020, https://doi.org/10.1016/J.SOLENER.2020.05.013.
24. R. Ghotge, A. van Wijk, and Z. Lukszo, "Off-grid solar charging of electric vehicles at long-term parking locations," *Energy*, vol. 227, p. 120356, Jul. 2021, https://doi.org/10.1016/J.ENERGY.2021.120356.
25. D. Hao *et al.*, "Solar energy harvesting technologies for PV self-powered applications: A comprehensive review," *Renew Energy*, vol. 188, pp. 678–697, Apr. 2022, https://doi.org/10.1016/J.RENENE.2022.02.066.