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IMPLEMENTATION OF AN OFF-GRID HYBRID SOLAR PV–GRID SYSTEM FOR ELECTRIC VEHICLE CHARGING AT THE UNESA KETINTANG CAMPUS

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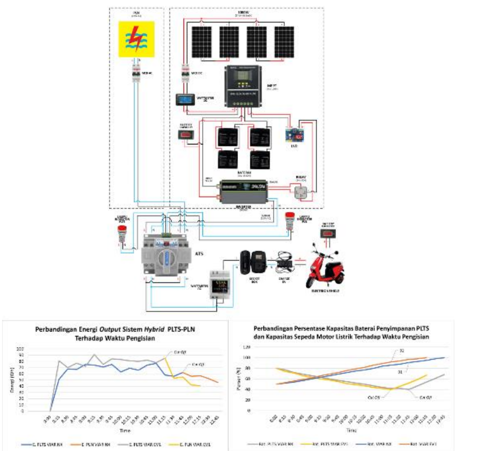

Abstract
The transition to clean energy is a strategic step in reducing carbon emissions, including through the development of electric vehicle charging infrastructure based on renewable energy. This study aims to implement of an off-grid hybrid solar PV-Grid system for charging electric vehicles at the UNESA Ketintang campus. The research method used an experimental approach carried out directly in the field. The results show that the system is capable of charging the Viar NX electric motorcycle (1.338 kWh) within 4 hours and 45 minutes, where 41% of the energy is supplied by the solar PV system and 9% by the Grid. Meanwhile, the Viar EV1 (1.605 kWh) requires 4 hours and 15 minutes of charging time, with 42% of the energy provided by the solar PV system and 8% from the Grid. Overall, the integration of this hybrid system has empirically demonstrated its ability to improve the reliability and continuity of the electric vehicle charging process.
Keywords: Renewable Energy, Off-Grid, Hybrid Solar PV, Grid, Electric Vehicles.

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1. Introduction

The global transition toward clean and sustainable energy has become a major focus in efforts to reduce environmental impacts caused by climate change and global warming. Data from NASA indicate that the average global temperature in 2023 shows a significant increase in global warming since the 19th century [1]. With the adoption of the Paris Agreement in 2015, countries have committed to limiting the rise in global temperatures in order to prevent the harmful impacts of climate change [2]. This transition toward cleaner and more sustainable energy is crucial for maintaining the balance of fragile ecosystems and protecting biodiversity [3]. One of the key sectors contributing to this global transition is the transportation sector through the adoption of electric vehicles (EV). Electric vehicles play an important role in reducing carbon emissions and dependence on fossil fuels [4]. The use of electric vehicles not only helps reduce air pollution but also supports the development of renewable energy technologies such as solar PV [5].

The adoption of electric vehicles in Indonesia has increased rapidly in recent years. This growth is supported by various government initiatives as well as increasing public awareness of the importance of reducing carbon emissions to create a cleaner and pollution-free environment [6]. The Indonesian government has implemented several proactive policies, including tax incentives, purchase subsidies, and import duty exemptions for electric vehicle components [7]. In addition, the government supports the expansion of electric vehicles by accelerating the development of Electric Vehicle Charging Stations (EVCS). The government targets the construction of thousands of EV charging stations in various strategic locations across Indonesia, including urban centers and areas with high potential for electric vehicle adoption [8]. However, the development of EVCS can become problematic if the electricity supply is generated from fossil fuel power plants, as this would only shift pollution from urban areas to fossil fuel power plants located outside the cities [9]. The integration of renewable energy particularly Solar Photovoltaic (PV) systems, has become a potential solution for the operation of EVCS [10]. This initiative aligns with the government's vision to accelerate Indonesia's transition toward sustainable and environmentally friendly energy [11].

Solar PV systems used as an energy source for EVCS can generally be classified into two categories, namely on-grid systems and off-grid systems [12]. On-grid systems are directly connected to the national electricity grid, allowing energy to be distributed directly to support electricity demand [13]. However, the dependence of on-grid systems on the main grid makes them less flexible. In contrast, off-grid systems operate independently without connection to the main grid, utilizing batteries as energy storage media [14]. Technical challenges in off-grid systems arise when weather variability affects the availability of solar energy. Therefore, a hybrid system that combines solar PV with National grid electricity as a backup is required to ensure the continuity of energy supply.

Sureshbabu *et al*. (2022) in the journal *Electrical Systems in Transportation (IET)*, investigated the design and analysis of a solar-powered EVCS in a campus environment [15]. The results showed that the solar PV system can provide a stable power supply for EV charging with backup support from the main energy source. This study highlights the importance of hybrid system integration to maintain power continuity during periods of low solar irradiation.

Singh *at al*. (2024) in the journal *Springer Lecture Notes on Flexible Electronics for Electric Vehicles*, examined the testing of a 3.2 kW solar-powered EVCS in India [16]. The results showed that variations in solar radiation intensity significantly affect charging time and overall system performance. To overcome this issue, a hybrid system supported by the electrical grid is required to ensure power stability during the EV charging process.

Khazali *et al.* (2024) in the journal *Energies*, developed a hybrid energy storage system model based on a microgrid to support EVCS operations [17]. The system utilizes a combination of solar energy and battery storage to maintain efficiency and continuity of energy supply. The results indicate that the use of a hybrid system can improve reliability, extend battery lifespan, and reduce power losses in the charging system.

This study aims to implement an off-grid hybrid solar PV system with national electricity grid as a backup for electric vehicle charging. The research focuses on developing a system design that can operate independently while remaining sustainable, as well as analyzing the system performance in supporting electric vehicle charging requirements. The results of this study are expected to provide a significant contribution to the development of renewable energy-based EV charging stations, particularly in university environments as pioneers in the transition toward sustainable clean energy.

2. Method

2.1. Material

The main materials used in this research include the components of an off-grid hybrid Solar PV, and the test subjects are electric vehicles. The following are the main components of an off-grid hybrid Solar PV-Grid system:

1. Solar Panels

Solar panels are modules that convert solar radiation into DC electrical energy, which is the system's primary source. The modules used in the system are 250 WP monocrystalline solar panels from ST SOLAR. Monocrystalline solar panels were chosen for their high efficiency and high temperature resistance [18].

Figure 1. Solar Panel Monocrystalline ST SOLAR 250 WP

Table 1. Solar Panel Specification

Spefikasi	Keterangan
Type	Monocrystalline
Rated Maximum Power (Pmax)	250W
Voltage at Pmax (Vmp)	18.6V
Current at Pmax (Imp)	13.45A
Open Circuit Voltage (Voc)	22.25V
Short Circuit Current (Isc)	14.39A
Weight	14Kg
Dimension	1530 × 760 × 35 mm

The solar panels used are monocrystalline from ST SOLAR with a power of 250 Wp. Four solar panels are connected in series and one in parallel, producing a power capacity of 37.2V 26.9A.

2. Sollar Charger Controller (SCC)

The SCC used in this system is a 100A MPPT. The SCC regulates and optimizes the flow of energy from the solar panels to the battery and load, as well as protecting the system from overcharging, over-discharging, and voltage instability. The following are the specifications of the SCC used.

Figure 2. Solar Charge Controller (SCC) MPPT SY48100A

Table 2. Solar Charge Controller (SCC) Specification

Specification	Information
Type	MPPT SY48100A
Battery Voltage (PV)	12V (15-25V), 24V (30-50V), 36V (45-75V), 48V (60-100V)
Maximum Power (PV)	12V (1200W), 24V (2400W), 36V (3600W), 48V (4800W)
Material	Plastik
Dimension	190 x 180 mm

3. Battery

The battery used in this system is a 12V 22.3Ah VRLA (Valve Regulated Lead Acid) battery from Nagoya. The battery functions to store the electrical energy generated by the solar panels.

Figure 3. Battery Nagoya VRLA NFP12220

Table 3. Battery Specification

Specification	Information
Type	Nagoya NFP12220 VRLA
Power Capacity	12V 22.3Ah
Charge voltage	14.60 – 14.80V
Charge time	8 – 12 jam
Max. initial current	Less than 5.0A
Min. initial current	More than 2.5A

This system uses four batteries connected two in series and one in parallel, producing a power capacity of 24V 44.6A.

4. Inverter

The inverter converts DC electricity from the battery into AC electricity as the output of the solar PV. The inverter used in this system is the Taffware Power Inverter Pure Sine Wave (PSW) 2000W 24V.

Figure 4. Taffware Power Inverter NBQ2000W

Table 4. Inverter Specification

Specification	Information
Wave Form	Pure Sine Wave
Voltase Input	DC 24 V
Voltase Output	AC 220 V
Kontinu Power	1000 W
Surge Power	2000 W
Frekuensi	50 HZ
Material	Aluminium
Dimension	289 x 103 x 60 mm

5. Low Voltage Disconnect (LVD)

The LVD used in this system is the XH-M609. The LVD protects the battery from damage by cutting off the power supply when the battery voltage drops below a safe limit [19].

Figure 5. Low Voltage Disconnect (LVD)

Table 5. Low Voltage Disconnect (LVD) Specification

Specification	Information
Type	XH-M609
Power supply voltage	12V – 36V battery
Control precision	0.1 V
Power consumption	Less than 1.5 W

6. Automatic Transfer Switch (ATS)

The ATS automatically switches the energy source from the Solar PV to Grid and vice versa [20]. The ATS in this system uses the ATS 63A.

Figure 6. Automatic Transfer Switch (ATS)

Table 6. Automatic Transfer Switch (ATS) Specification

Specification	Information
Type	ATS 2P 63A TOMZN
Rated Current Ie A	63A
Rated voltage Ue	220V (2P)
Rated frequency	50/60Hz

2.2 Method

This research was applied using an experimental approach with a field case study design that aims to implement and directly evaluate the operational performance of the off-grid electricity system of the hybrid Solar PV-Grid. Where Solar PV is the main energy source and Grid as a backup, which results in an integrated generator configuration that is able to provide a continuous energy supply for the charging needs of electric vehicles. The experiment was carried out under controlled conditions in the Electric Vehicle Laboratory, Building A7, Faculty of Engineering, Surabaya State University (UNESA) Ketintang Campus. The population of this treatment subject includes two-wheeled electric vehicles, with the experimental sample being an electric motorcycle model Viar NX which has a battery capacity of 1.338 kWh and the model Viar EV1 with a capacity of 1.605 kWh.

The implementation of an Off-grid hybrid Solar PV-Grid system, is carried out through the integration of Solar PV, Solar Charge Controller (SCC), batteries for energy storage, an inverter for power conversion, and an Automatic Transfer Switch (ATS) for switching energy sources. The system is designed to prioritize Solar PV energy as the primary source, using Grid only as a backup source when the Solar PV energy is insufficient. This implementation aims to ensure the stable and continuous charging process for electric motorcycles, despite fluctuating solar irradiance.

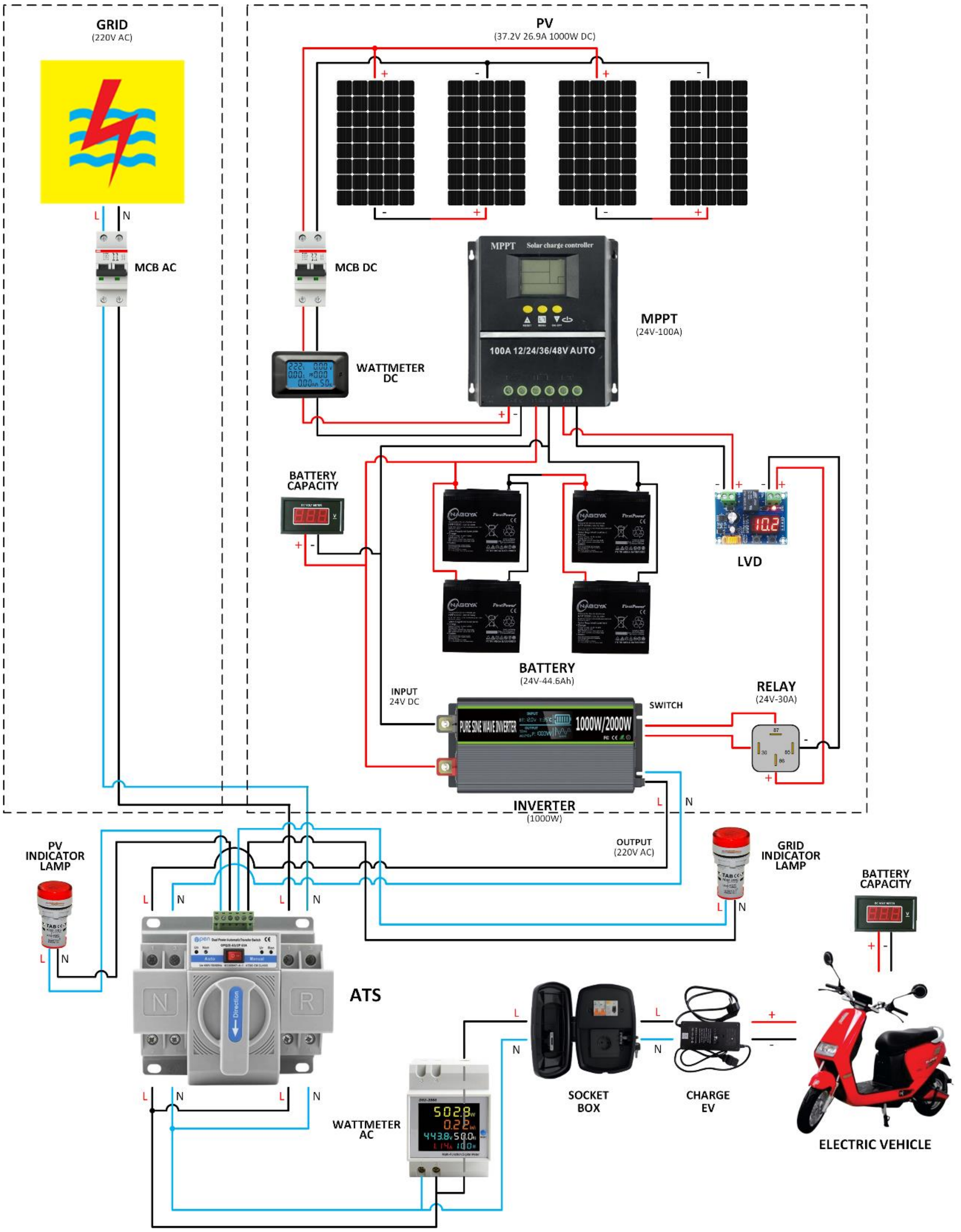

Figure 7. Wiring Diagram of PLN Hybrid Off-Grid Solar Power System for Charging Electric Vehicles

Initially, solar energy is captured by the solar panels and converted into Direct Current (DC) electricity. This DC energy is channeled to the SCC, which regulates the voltage and current to meet the battery's charging limits. The SCC also protects the battery from overcharging and over-discharging. The regulated energy is then stored in the system's battery as the primary energy source for charging electric vehicles. The amount of stored energy is determined by solar intensity, solar panel capacity, and SCC efficiency.

The energy from the battery is then converted to 220 V AC current by the inverter. This AC current serves as the primary source for charging the Viar NX and Viar EV1 electric motorcycles. The inverter ensures a stable output waveform even if the battery voltage fluctuates during charging. This allows electric vehicles to be charged without interruption.

Meanwhile, national electricity grid serves as a backup source through an ATS (Anti-Clock Switching System). When the solar PV system's battery SoC drops to 40% (cut-off), the LVD will cut-off the power supply to protect the battery from overdischarge. The ATS automatically switches the power source from the solar

PV system to grid, allowing the electric motorcycle to continue charging. This switch prevents charging failures and ensures that energy needs are met. Once the battery returns to a normal SoC of 80%, the LVD will actively flow electricity from the battery to the inverter, where the ATS will switch the system back to Solar PV system mode.

The overall system implementation demonstrates that this hybrid design is capable of combining the reliability of solar energy with the stability of grid supply. In operation, the system successfully provides sustainable energy for charging electric motorcycles, prioritizing renewable energy while maintaining operational continuity through grid support. The integration of hybrid solar PV-Grid system through the ATS has proven effective in reducing the risk of running out of power, improving operational feasibility, and making motorcycle charging more efficient and safe.

2.3 Experimental Procedure

The testing procedure in this study aims to evaluate the operational performance of hybrid Solar PV-Grid system for charging electric vehicles. The testing was conducted using the following steps:

1. Preparation Stage

   The following are the things researchers need to prepare before conducting the research:

   a. Designing an electrical system diagram, including the connections between the solar panels, SCC, battery, inverter, ATS, and national electricity grid.
   b. Selecting the capacity of key components, such as the solar panels, battery capacity, inverter capacity, and SCC rating, based on the load's power requirements.
   c. Calculating power requirements, referring to the charger and battery specifications for the Viar NX and Viar EV1 electric vehicles.

2. Implementation Stage

   The following points must be considered during the research:

   a. Preparing research tools and instruments by ensuring all components of the solar power plant system are functioning optimally.
   b. Calibrating research measuring instruments.
   c. Operating the Solar PV storage battery with a Depth of Discharge (DoD) of 40% from an initial State of Charge (SoC) of 80%.
   d. Data collection was conducted every 15 minutes, starting at 8:00 a.m. WIB (Western Indonesian Time) until the electric vehicle was fully charged.
   e. When the electric vehicle started charging, measure and record the percentage capacity of the solar PV storage battery and the electric vehicle battery using a Battery Capacity Voltage Meter.
   f. Record the voltage (V), current (A), power (W), and energy (Wh) on a DC Digital Multi-function Meter.
   g. Record the inverter output power and load power consumption on a Din Rail AC Multi-Meter.
   h. Measure sunlight intensity (irradiance) using a lux meter to determine the solar PV input power.
   i. Use a stopwatch to determine the charging time of the electric vehicle.

3. Data Analysis Stage

   Data analysis involves analyzing all the data obtained. The data collected includes:

   a. Processing test data.
   b. Evaluating the system's operational performance by examining power supply stability, charging time, and system response during power source transfers (Solar PV to Grid).
   c. Comparison of system performance under two different electric vehicle load conditions (Viar NX and EV1).
   d. Analysis of system operational performance based on test results.

3. Result and Discussion

The operational performance of the off-grid hybrid solar PV system, supported by electricity grid as backup, was analyzed based on the system's ability to supply stable energy during the electric vehicle charging process. The analysis was conducted by considering the percentage capacity of the Solar PV storage battery, the hybrid system output, and the percentage capacity of the electric motorcycle during testing.

Measurement results show that the Solar PV acts as the primary energy source, while Grid only activates when energy from the Solar PV and storage battery is insufficient. This demonstrates that the hybrid system is working as designed, maximizing solar energy and minimizing Grid usage.

1. Average Results of VIAR NX Testing

Tabel 1. VIAR NX Solar PV Data

Time	Light Intensity (W/m^2)	DC			Energy (kWh)	Battery Capacity PV (%)
		Voltage (V)	Current (I)	Power (W)		
08.00	281	23.6	6.68	157	0	80
09.00	477	22.9	11.1	256	0.167	66
10.00	535	24.7	11.6	287	0.221	55
11.00	602	24.8	13	323	0.233	44
12.00	707	25.6	14.8	379	0.265	47
12.45	850	25.2	18.1	456	0.260	68

Tabel 2. VIAR NX Hybrid Charging System Output Data

Time	Source	AC			Energy (kWh)	Battery Capacity EV (%)
		Voltage (V)	Current (I)	Power (W)		
08.00	PLTS	221.3	2	256	0	50
09.00	PLTS	211	2.4	300	0.261	60
10.00	PLTS	188.6	2.3	252	0.283	72
11.00	PLTS	222.4	3.4	308	0.286	84
12.00	PLN	224.6	1.7	224	0.232	93
12.45	PLN	222.1	1.4	184	0.155	100

2. Average Results of VIAR EV1 Testing

Tabel 3. VIAR EV1 Solar PV Data

Time	Light Intensity (W/m^2)	DC			Energy (kWh)	Battery Capacity PV (%)
		Voltage (V)	Current (I)	Power (W)		
08.00	426	23.4	6.6	155	0	80
09.00	439	22.5	10.4	236	0.179	63
10.00	525	23.1	12.1	282	0.252	51
11.00	735	20.7	19	395	0.286	42
12.00	821	26.9	16.4	441	0.309	59
12.15	879	27.2	17.3	471	0.092	67

Tabel 4. VIAR EV1 Hybrid Charging System Output Data

Time	Source	AC			Energy (kWh)	Battery Capacity EV (%)
		Voltage (V)	Current (I)	Power (W)		
08.00	PLTS	224.5	2.2	320	0	50
09.00	PLTS	211.3	2.3	288	0.300	62
10.00	PLTS	231.2	2.4	332	0.333	76
11.00	PLTS	191.5	2.8	312	0.321	89
12.00	PLN	229	1.2	168	0.235	98
12.15	PLN	229.8	1.2	164	0.041	100

Information:

I (Current) : Symbol for electric current intensity, measured in amperes (A).

V (Voltage) : Symbol for electric potential difference, measured in volts (V).

W (Watt) : Symbol for electric power (P).

3. Ratio of the Output Energy of the PV-Grid Hybrid System Against Charging Time

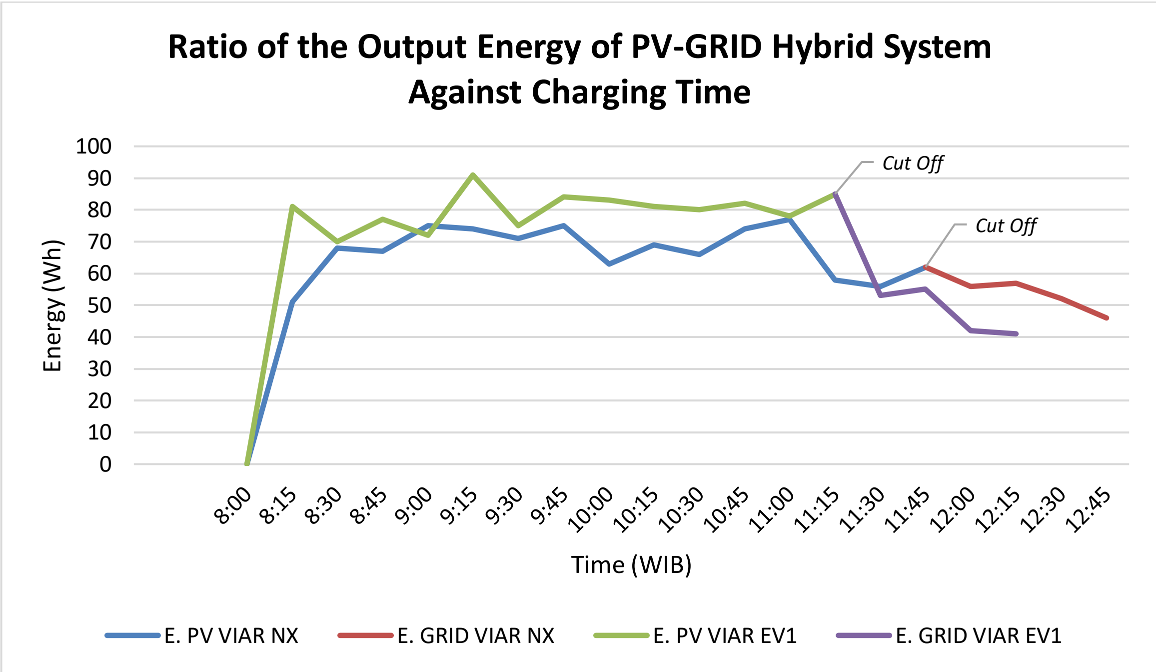

Figure 8. Ratio of the Output Energy of the PV-Grid Hybrid System Against Charging Time

Figure 8 shows the average dynamic fluctuations in the output energy (Wh) distribution of the hybrid Solar PV-Grid system during the charging cycle for two electric motorcycle load variants, namely the VIAR NX and VIAR EV1. During the initial charging phase, initiated at 8:00 a.m., the control system operates with the Solar PV as its primary energy source. The Solar PV output energy curve displays a fluctuating characteristic of the solar irradiation intensity received by the solar panels. During this phase, the VIAR EV1 load observed a higher energy absorption rate from the Solar PV, reaching a peak of 91 Wh at 9:15 a.m., compared to the VIAR NX load, which fluctuated with a peak of 77 Wh at 11:00 a.m.

The complementary mechanisms of he hybrid system are clearly visualized through the power transition phenomenon, or cut-off point. This point is a manifestation of the controller system intervention that automatically disconnects the power supply from the Solar PV and switches it to Grid when the Solar PV storage battery has reached the lower threshold of State of Charge (SoC). For the VIAR EV1 charging process, the cut-off intervention was identified at 11:15, where the Grid network immediately took over the power supply from the 85 Wh point. After this transition, the Grid energy output curve shows a downward trend along with the increasing internal resistance of the electric motorcycle battery capacity which begins to approach full capacity, until finally the charging process stops at 12:15. An identical transition pattern is observed in the VIAR NX load, with the cut-off point occurring later at 11:45 at the energy level of 62 Wh, followed by the energy supply from Grid which gradually decreases until it reaches full charge at 12:45. Where the total energy output of the hybrid system when charging VIAR NX is 1.217 kWh with energy contributions from Solar PV 1.006 kWh and Grid 0.211 kWh. While when charging VIAR EV1 it is 1.230 kWh with energy contributions from Solar PV 1.039 kWh and Grid 0.191 kWh.

4. Ratio of the Percentage Capacity of PV Storage Batteries and Electric Motorcycle Batteries Against Charging Time

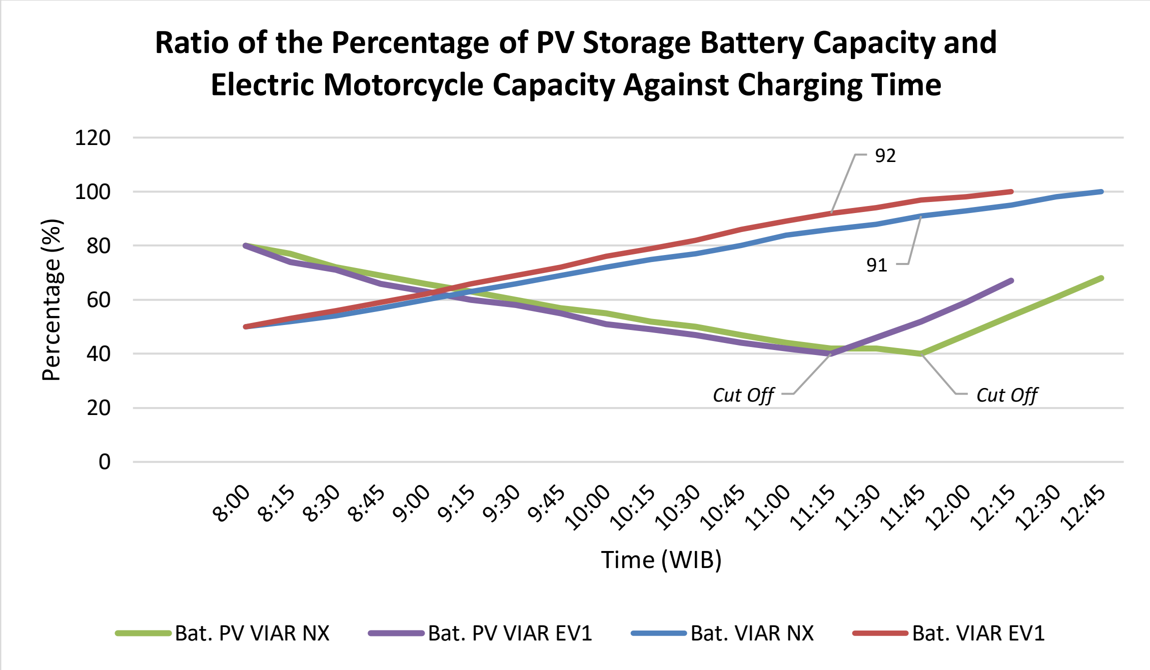

Figure 9. Ratio Chart of the Percentage Capacity of PV Storage Batteries and Electric Motorcycle Batteries Against Charging Time

Figure 9 shows the average results of the dynamics of changes in State of Charge (SoC) or the percentage of battery capacity temporally during the charging cycle, both on the solar PV storage battery side and on the load side (VIAR NX and VIAR EV1 electric motorcycle batteries). This energy equilibration process was initiated simultaneously at 08.00 with the initial condition of the Solar PV battery SoC parameter at 80%, while both electric vehicle batteries were at 50% equivalence. Over time, a relatively linear capacity degradation curve was observed in the Solar PV battery (discharging phase), which had an inverse correlation with the capacity accumulation curve in the electric motorcycle battery (charging phase). The power absorption rate at the VIAR EV1 load showed a slightly steeper gradient profile than the VIAR NX. This impacted the Solar PV battery protection system (BMS), which triggered a premature cut-off at 11:15 a.m. when the storage battery's SoC reached the 40% Depth of Discharge (DoD) tolerance threshold. The VIAR EV1 battery capacity was observed to reach 92% at 11:30 a.m., and was continued by Grid power supply until it reached full charge (100%) at 12:15 p.m.

Conversely, the VIAR NX charging process operated at a more moderate accumulation rate. The cut-off from the Solar PV system due to the SoC dropping to 40% was only triggered at 11:45 a.m., coinciding with the motorcycle's battery capacity reaching 91%. The VIAR NX charging process was continued by Grid power supply until it reached full charge (100%) at 12:45 p.m. Another important phenomenon recorded in the graph is the post-cut-off point in each charging cycle; The solar PV battery percentage curve immediately transitioned to a positive trend, or capacity escalation. This post-cut-off curve increase indicates that the solar PV storage system has automatically isolated itself from load intervention (electric vehicles) and is entering a capacity recovery phase (recharging phase) independently using energy generated by solar panels.

Overall, the operational performance of the off-grid hybrid Solar PV-Grid system can be categorized as good, stable, and according to design. This is because the solar PV source can meet most of the energy needs during sunny weather, while Grid only serves as a backup source. These results align with research by [15] and [17], which states that hybrid systems can increase electrical energy availability while reducing dependence on conventional energy.

4. Conclusion

In this study, the implementation of the off-grid hybrid Solar PV-Grid system has been successfully realized through the integration of solar panel components, Solar Charge Controller (SCC), battery, inverter, Low

Voltage Disconnect (LVD) and Automatic Transfer Switch (ATS). The results show that the system is capable of charging the Viar NX electric motorcycle (1.338 kWh) within 4 hours and 45 minutes, where 41% of the energy is supplied by the solar PV system and 9% by the Grid. Meanwhile, the Viar EV1 (1.605 kWh) requires 4 hours and 15 minutes of charging time, with 42% of the energy provided by the solar PV system and 8% from the Grid. Overall, the integration of this hybrid system has been empirically proven to be able to improve the reliability and continuity of the electric vehicle charging process. For future study, several aspects can be considered to improve the performance and value of the system implementation. First, the implementation of an Internet of Things (IoT)-based monitoring system can be developed to enable real-time monitoring of solar power plant performance, allowing for more accurate and sustainable analysis of operational data. Second, the development of a direct current (DC) charging system can also be a focus of further research, considering that this method has the potential to increase charging efficiency and shorten the charging time of electric vehicles compared to alternating current (AC)-based systems.

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