INTEK: Jurnal Penelitian
Vol. 12, No. 1, pp. 58-64, April 2025

Integration of On-Grid Solar Photovoltaic Systems for Electric Motorcycle Battery Swap Stations

Muhammad Ruswandi Djalal[1,*,a], Nur Rahmah[1,b], A.M. Shiddiq Yunus[1,c], Hilmah Marjan Basir[1,d], Andi Muhammad Fachrezy[1,e], Putri Ratu Matajang[1,f] and Ahmed Abu-Siada[2,g]
[1]Department of Mechanical Engineering, Politeknik Negeri Ujung Pandang, Makassar, Indonesia
[2]Department of Electrical Engineering, Curtin University, Perth, Australia
[*,a]wandi@poliupg.ac.id (Corresponding Author), [b]nurrahmah@poliupg.ac.id, [c]shiddiq@poliupg.ac.id, [d]hilmahmb@gmail.com, [e]fachrezyandi@gmail.com, [f]putriratumatajang@gmail.com, [g]a.abuSiada@curtin.edu.au

Abstract—**This study presents a design and feasibility analysis of an on-grid Solar Power System (SPS) integrated with an electric motorcycle battery swapping station at PT Indomarco Prismatama Tbk Makassar. The aim is to develop a renewable energy based swapping facility and assess its technical, economic, and environmental performance. PVSyst simulations were conducted to validate the numerical calculations. Novelty of this work lies in the first implementation model that integrates an on-grid SPS with a commercial battery swapping station for electric motorcycles in Makassar. While previous studies have focused on conventional charging stations or standalone photovoltaic systems, this study introduces a grid assisted solar powered swapping concept that reduces charging time, increases reliability, and minimizes the need for large storage capacity. A combined feasibility approach is used by integrating numerical economic analysis with PVSyst simulations. The 4.8 kWp SPS consists of twelve 400 Wp monocrystalline panels, a 5-kW inverter, and a 12-slot battery swap cabinet. Annual energy production was estimated at 7,884 kWh from numerical calculations and 7,670 kWh from PVSyst simulations. Economic results indicate strong feasibility with a Net Present Value of IDR 104,891,580, an Internal Rate of Return of 14.79 percent, a Profitability Index of 3.0, and a Discounted Payback Period of 8 years and 1 month. The system can also reduce about 6.56 tons of carbon dioxide emissions annually. These results confirm that the on-grid SPS based battery swapping station is technically feasible, economically viable, and environmentally beneficial.**

Keywords—On-Grid, SPS, Swap Battery, Electric Vehicle, PVsyst

I. Introduction

The development of electric vehicles (EVs) has become a major focus in the global transition toward clean energy [1]. Amid the climate crisis and the high consumption of fossil fuels, the use of EVs offers a strategic solution for reducing carbon emissions and decreasing dependence on fossil energy [2]. Indonesia, as a country with a continuously increasing number of motor vehicles, has begun to promote the adoption of electric motorcycles as part of its national energy policy toward achieving net zero emissions [3]. However, the adoption of EVs, particularly electric motorcycles, faces several real challenges in practice. One of the main obstacles is the limited availability of an efficient and widely distributed charging station infrastructure [4, 5]. Conventional charging requires a relatively long time, which becomes a significant constraint for daily motorcycle users who rely on speed and time efficiency [6].

To address these challenges, battery swapping technology has emerged as an innovative alternative capable of overcoming the limitations of charging time. Battery swapping allows users to replace an empty battery with a fully charged one within minutes. Combining this system with a grid connected solar power system (SPS) will create an environmentally friendly and energy efficient infrastructure while supporting the development of renewable energy in the urban transportation sector [7, 8].

Several scholars have explored the development of supporting facilities for electric transportation. For instance, a grid-connected photovoltaic system designed to supply power to an electric motorcycle charging station has been successfully implemented at Udayana University [9]. In a different context but within a similar topic, the study in developed a more self sustaining concept by designing a battery charging facility for electric motorcycles that operates entirely independently of the main electrical grid at a technological university in Thailand [10]. Recent developments in this field are demonstrated by Mphephu and colleagues through their innovation of a hybrid system that combines SPS with the conventional electrical grid for electric bicycle applications [11]. Meanwhile, Nandini and her research team proposed a solution based on advanced optimization techniques to integrate EVs charging

DOI: https://doi.org/10.31963/intek.v12i1.5917

stations with SPS sources and energy storage units [12]. This approach has proven effective in reducing dependence on the main electrical grid while improving power supply quality by minimizing voltage fluctuations in the distribution system through the implementation of intelligent algorithms for managing battery charging and discharging.

Based on these research findings, it can be concluded that charging infrastructure for EVs that utilizes renewable energy sources, whether in grid connected, stand alone, or hybrid configurations, has reached a sufficient level of maturity in terms of both technical performance and economic feasibility. However, it should be noted that the existing studies remain limited to the concept of conventional charging stations and have not yet explored battery swapping systems, which offer faster processes and higher operational efficiency, particularly for meeting the intensive mobility needs of urban areas and industrial zones.

Based on these research findings, it can be observed that most studies remain focused on conventional charging station concepts, whether grid connected, stand alone, or hybrid. To date, no research has specifically examined the integration of a battery swapping station with an on-grid SPS within a commercial company environment in Makassar. An on-grid SPS offers several advantages, including the ability to supply electricity directly to loads while simultaneously exporting surplus energy to the utility grid, thereby improving supply efficiency and reducing the need for large energy storage capacity [13, 14]. In addition, an on-grid SPS provides higher operational reliability because it can combine solar generation with grid power when energy production decreases due to fluctuations in solar irradiation. These advantages make an on-grid SPS a feasible and economical option for integrating renewable energy infrastructure in high activity zones such as commercial areas [15, 16]. Therefore, this presents a new research opportunity with the potential to make significant contributions to the development of renewable energy based electric vehicle infrastructure in urban areas of Eastern Indonesia.

This study proposes the integration of an electric motorcycle battery swapping station with a grid connected SPS in an urban context in Makassar, along with an analysis of its technical and economic feasibility. This approach offers a new contribution in the form of a hybrid energy system design, the optimization of solar energy utilization for transportation needs, and simulations of actual usage based on local demand profiles. This research is expected to serve as an implementable reference for the development of EVs infrastructure in Eastern Indonesia, which currently lags behind major cities in Java and Bali in terms of supporting facilities for EVs.

II. Research Methods

The design study of the on-grid SPS is conducted at the office of PT Indomarco Prismatama Tbk, located at Jl. Kima 10 No. 5 – A5A, Daya, Tamalanrea District, Makassar City. The site has geographical coordinates of latitude −5.11° (S), longitude 119.50° (E), and an altitude of 12 meters. The detailed location can be identified through the following reference.

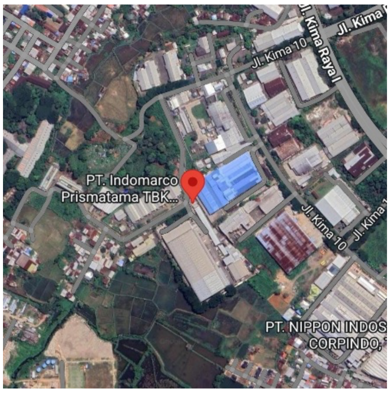

Figure 1. Location Map of PT. Indomarco Prismatama Tbk

A. *SPS Planning*

The SPS to be designed utilizes rooftop mounted solar panels in the parking area as the primary electricity source to meet the charging demand of electric motorcycle batteries. The electrical energy generated by the solar panels is converted through an inverter, distributed via a switchboard, and monitored using a data logger before being supplied to the battery swapping station.

As a backup source, the system is connected to the PLN utility grid, which functions as a reserve supply when solar energy is insufficient, such as during nighttime or periods of low solar irradiance. An automatic switching system manages the transition between the SPS and the grid seamlessly to ensure continuous electricity supply.

Battery charging is carried out centrally through a Battery Swapping Station that complies with the electric motorcycle manufacturer's standards. This swapping station is equipped with a visual indicator system:

- Green: Battery fully charged
- Red: Battery charging in progress

DOI: https://doi.org/10.31963/intek.v12i1.5917

- No light: No battery is being charged
- Auto cut off feature: Automatically disconnects the power supply when the battery reaches full capacity

The advantages of this centralized system include:

- Continuous availability of fully charged backup batteries
- Improved employee mobility due to faster battery replacement processes
- Reduced operational time
- High system reliability supported by dual energy sources (SPS as the primary source and the PLN grid as the backup)

With optimal integration of the solar power system as the main energy source and the PLN grid as the backup, this system ensures efficient, reliable, and sustainable operational continuity.

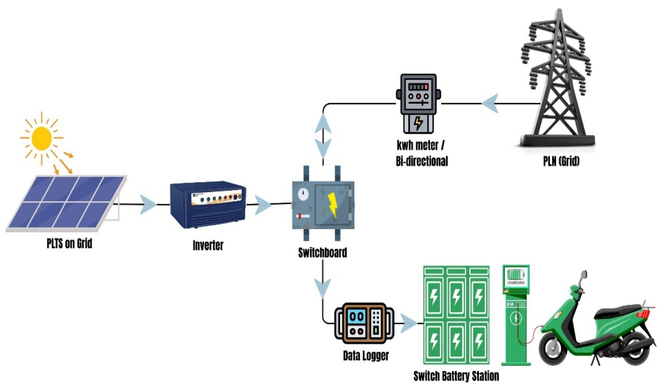

Figure 2. On-grid SPS Design Scheme

B. Location Profile

The location of PT. Indomarco Prismatama Tbk in Makassar has excellent solar energy potential for the installation of an on-grid PV system. Based on meteorological data from 2016 to 2021, the average annual solar radiation reaches 5.47 kWh/m² per day, which is considered ideal for solar power generation. Throughout the year, solar intensity remains consistent with an annual variability of only 6.2%. The period from August to October records the highest radiation levels, ranging from 6.28 to 6.50 kWh/m² per day, while February has the lowest value at 4.55 kWh/m² per day. Environmental conditions are also supportive, with an average temperature of 27.1°C that is sufficiently moderate for maintaining panel efficiency, and wind speeds of 1.2 m/s that help with natural cooling. With stable irradiation profiles and favorable climatic factors, this location is highly suitable for the installation of a PV system capable of delivering significant energy savings.

C. Analysis Method

1. Technical Analysis

After the SPS system design is completed, a technical analysis is carried out to evaluate the amount of electrical energy that can be generated and to calculate the overall system performance. The technical analysis includes several key aspects, namely the installation site, building orientation, solar irradiation data, load data, determination of the number of panels, panel configuration, daily energy production, solar panel efficiency, and inverter capacity selection. The results of this technical analysis are then compared with the simulation results generated using PVSyst software to ensure design accuracy and to verify the system's performance more comprehensively.

2. Economic Analysis

The economic analysis includes calculating the capital cost of the on-grid SPS based on current market component prices. The investment feasibility is evaluated using several financial parameters, including the Net Present Value (NPV), Profitability Index (PI), Discounted Payback Period (DPP), and Internal Rate of Return (IRR). NPV represents the difference between the present value of cash inflows and cash outflows over a specified time period. Equation (1) presents the calculation of NPV.

$$NPV = \sum_{n=1}^{n} \frac{NCFt}{(1+i)^n} - C \quad (1)$$

NCF_t refers to the net cash flow from year 1 to year n (IDR), *n* is the investment lifetime (years), *i* is the interest rate (%), and *C* is the initial investment cost (IDR). The decision-making criteria for determining whether an investment proposal is feasible are as follows: the investment is considered feasible if the NPV is positive (>0), and it is considered not feasible if the NPV is negative (<0).

The Profitability Index (PI) is defined as the ratio between the present value of future cash flows and the initial investment. The PI of the system is calculated using Equation (2):

$$PI = \sum_{t=1}^{n} \frac{NCF_t(1+i)^{-n}}{C} \quad (2)$$

NCF_t refers to the net cash flow from year 1 to year *n* (IDR), *n* is the investment lifetime (years), and *C* is the initial investment cost (IDR). The decision criteria for determining whether an investment proposal is feasible are as follows: the investment is considered feasible if the

DOI: https://doi.org/10.31963/intek.v12i1.5917

PI is greater than 1 (>1), and it is considered not feasible if the PI is less than 1 (<1).

The DPP refers to the length of time required to recover the total capital or initial investment. The calculation of this payback period can be performed using two approaches: by projecting the number of years in which the accumulated Net Present Value of Net Cash Flow (NVNCF) equals the initial investment, or by applying a specific mathematical formula. By following these two approaches, the DPP can be expressed mathematically using Equation (3):

$$DPP = n + \frac{C - NVNCF_n}{PV_{n+1}} \qquad (3)$$

$NVNCF_n$ is the accumulated Net Present Value of Net Cash Flow up to year *n,* and PV_{n+1} is the present value of the cash flow in year *n+1*. The term PV_{n+1} represents the present value of the net benefit for a one-year period. In this context, the net cash flow is calculated from the revenue generated by electricity sales after deducting all discounted annual operation and maintenance (O&M) costs. Based on investment feasibility criteria, a project is considered feasible if the DPP is shorter than the project lifetime (*n*). The financial attractiveness of a project increases as the gap between the DPP and *n* becomes larger, indicating a faster capital recovery period.

The IRR is the interest rate (in percent) that makes the present value of all cash inflows equal to the initial investment value. In practice, when two different NPV values are known, the IRR can be calculated using a linear interpolation approach. This calculation method is expressed in Equation (4).

$$IRR = I_r + \frac{NPVr}{NPV_r - NPV_t}(I_t - I_r) \qquad (4)$$

IRR is the Internal Rate of Return (%), NPV_r is the Net Present Value calculated at the lower interest rate (IDR), and NPV_t is the Net Present Value calculated at the higher interest rate (IDR). I_r represents the lower interest rate (%), and I_t represents the higher interest rate (%). In this method, NPV_r must be positive ($NPV_r > 0$), while NPV_t must be negative ($NPV_t < 0$).

III. Results and Discussion

A. Design Results

Figure 3 shows the building planned as the installation site for the battery swap cabinet. The location was selected to allow direct monitoring by industrial security personnel or through CCTV. Figure 4 presents the orientation of the building, which supports the layout and positioning of the system components. The planned configuration of the solar panels is shown in Figure 5, followed by the PV module placement plan illustrated in Figure 6. Finally, Figure 7 depicts the planned position of each system component, including the battery swap cabinet, which is intended to be installed on the second floor of the parking area. The building itself has a total area of 1,080 m² and a height of 6.75 m.

Figure 3. PT. Indomarco Prismatama Tbk Parking Building

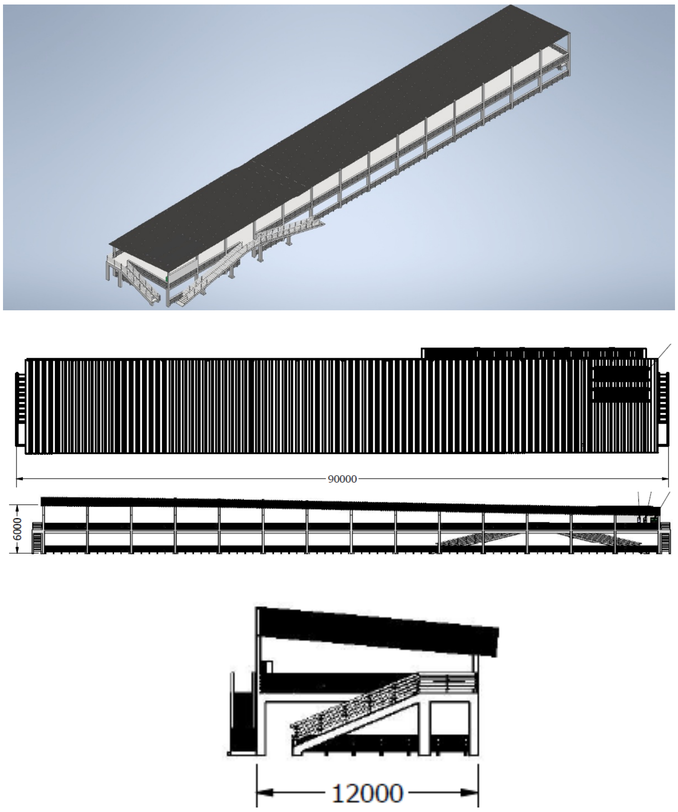

Figure 4. Orientation of PT. Indomarco Prismatama Tbk Parking Building

DOI: https://doi.org/10.31963/intek.v12i1.5917

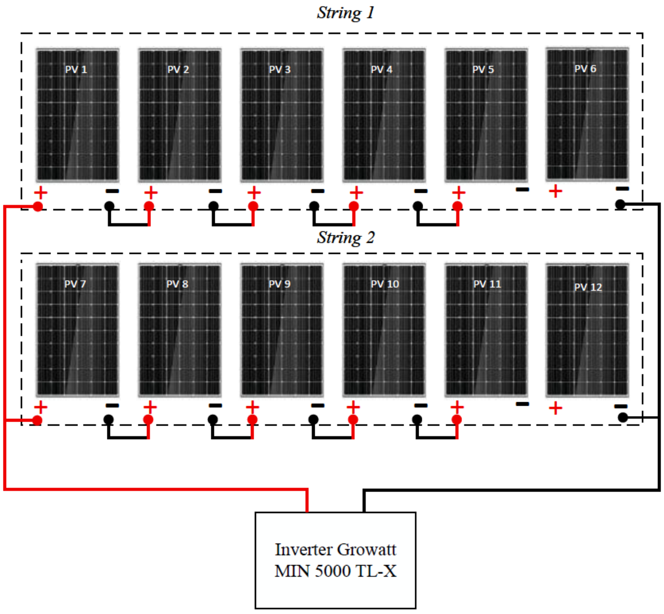

Figure 5. Solar Panel Configuration Planning

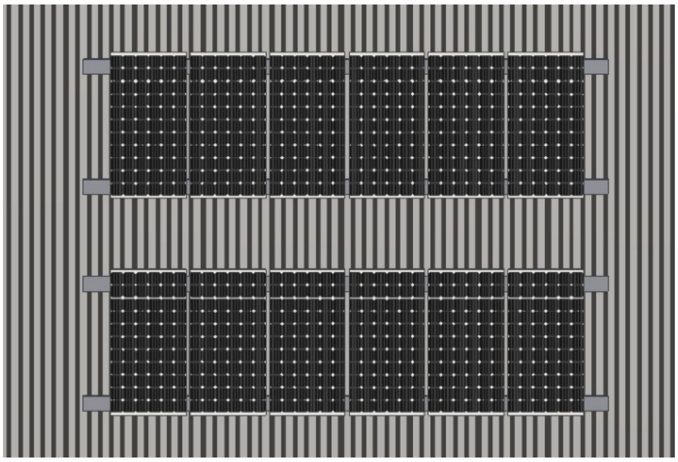

Figure 6. PV Module Placement Plan

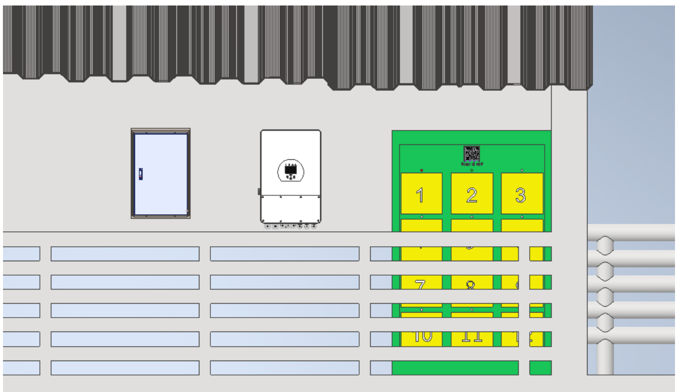

Figure 7. Component Placement Position Plan

B. Numerical Calculation Method

The results of the study show that the SPS system has a capacity of 4.8 kWp, utilizing twelve 400 Wp monocrystalline solar panels configured in 2 parallel strings of 6 series panels, one 5 kW inverter unit, and a 12-slot battery swap cabinet. The annual energy production reaches 7,884 kWh. The economic analysis yields a positive NPV of up to IDR 104,891,580, an IRR of 14.79%, a PI of 3.0, and a discounted payback period of 8 years and 1 month.

C. PVSyst Simulation Method

The economic analysis of the SPS system using PVSyst simulations provides a comprehensive overview of its financial feasibility. The total initial investment required is IDR 61,577,000, with a specific cost of IDR 12,829 per Wp. Assuming a project lifetime of 20 years and a discount rate of 8.5% per year, and applying a feed-in tariff of IDR 2,500 per kWh guaranteed for 20 years, the system yields an NPV of IDR 28,031,815.45, an IRR of 14.32%, an ROI of 45.5%, a payback period of 9.9 years, and an LCOE of IDR 1,148 per kWh. The cumulative cash flow analysis indicates that the investment begins generating positive returns in the 10th year and continues to increase significantly until the end of the project. The initial investment costs for the battery swap station designed at PT Indomarco Prismatama Tbk are determined in consultation with the client and will include the procurement of the battery swap cabinet, the costs of the primary and supporting components of the SPS, as well as shipping and installation expenses.

To validate the numerical calculations performed in the design of this on-grid SPS, a simulation was also carried out using specialized software, namely PVSyst. This simulation enables a more comprehensive analysis by taking into account a wider range of detailed technical and environmental parameters, such as performance ratio, solar fraction, and various losses that may occur under real operating conditions. Table 1 below presents a comparison summarizing the differences between the manual numerical calculations and the PVSyst simulation results for several key parameters.

DOI: https://doi.org/10.31963/intek.v12i1.5917

Table 1. Initial Investment Cost Details

No	Components	Qty	Unit Price (IDR)	Total Price (IDR)
Main Components				
1	SGB Volta Cabinet	1	7,500,000	7,500,000
2	400 Wp Solar Panel	12	643,000	7,716,000
3	5 kW Inverter	1	13,200,000	13,200,000
Supporting Components				
4	4x4 angle iron	48	65,000	3,120,000
5	Mounting bracket PV	24	35,000	840,000
6	End clamp kit mounting	48	12,000	576,000
7	Midle clamp kit mounting	24	15,000	360,000
8	Nut bolt	200	5,000	1,000,000
9	Cable NYY 1x1.5 mm²	50	15,000	750,000
10	Cable NYY 1x4 mm²	50	25,000	1,250,000
11	Cable NYY 1x6 mm²	30	35,000	1,050,000
12	Cable NYCY 1x35 mm²	20	75,000	1,500,000
13	Connector MC4	8	40,000	320,000
14	MCB DC 50 A	2	250,000	500,000
15	MCB AC 50 A	1	150,000	150,000
16	MCB AC 300 A	1	600,000	600,000
17	SPD DC 500 V	1	450,000	450,000
18	Combiner box DC	1	850,000	850,000
19	Grounding system	1	750,000	750,000
20	Cable tray	25	45,000	1,125,000
21	Conduit PVC	30	25,000	750,000
22	AC surge protector	1	350,000	350,000
23	Monitoring system	1	1,500,000	1,500,000
24	DC fuse 15A	2	85,000	170,000
25	Tools & accessories	1	1,200,000	1,200,000
System Installation				
26	Installation costs	–	10,000,000	10,000,000
27	Transportation	–	2,500,000	2,500,000
28	Permitting and documentation costs	–	1,500,000	1,500,000
Total Initial Investment Amount				61,577,000

The implementation of an SPS system integrated with a centralized battery charging cabinet for electric motorcycles at PT Indomarco Prismatama Tbk not only provides positive economic and technical impacts but also contributes significantly to environmental sustainability and operational efficiency. Based on the PVSyst simulation, the 4.8 kWp SPS is capable of producing kWh of electrical energy per year. Using Indonesia's CO_2 grid emission factor of 734 g/kWh, this system has the potential to reduce carbon emissions by approximately 6.56 tons of CO_2 per year, or the equivalent of 197.0 tons of CO_2 over a 30-year system lifetime. This reduction represents a tangible contribution by the company in supporting national energy transition initiatives and reducing the industrial carbon footprint.

Table 2. Comparison of Manual Calculation Results and Using the Pvsyst Application

Parameter	Numerical Calculation	*PVSyst*
Annual Energy Production	7,884 kWh/year	7,669.94 kWh/year
Cost of Energy (COE/LCOE)	IDR 1,080/kWh	IDR 1,148/kWh
Life Cycle Cost (LCC)	IDR 80,604,238	-
Net Present Value (NPV)	IDR 104,891,580	IDR 28,031,815
Payback Period	8.1 years	9.9 years
Internal Rate of Return (IRR)	14.79%	14.32%
PV Capacity	4.57 kWp	4.80 kWp
Number of Solar Panels	12 panels / 400 Wp	12 panels / 400 Wp
Performance Ratio (PR)	Not counted	82.68%
Solar Fraction	Not counted	48.95%
Initial Investment Cost	IDR 61,577,000	IDR 61,577,000

Controlled and optimized charging in a dedicated battery cabinet, compared to non-standardized conventional charging, can significantly reduce early battery degradation. Studies indicate that uncontrolled charging of lithium batteries can accelerate capacity loss by up to 30%. With a centralized system that maintains a charging efficiency of 92%, battery lifespan can be substantially extended, which in turn reduces the frequency of battery replacement and the volume of battery waste generated.

IV. Conclusion

The electric motorcycle battery swap station system has been successfully designed by integrating an on-grid Solar Power System (SPS) consisting of 14 DAH-400 (400 Wp) solar panels arranged in 2 parallel strings of 6 series panels each, equipped with a Growatt MIN 5000TL-X 5 kW inverter and a 12-slot battery cabinet. This 4.8 kWp SPS is designed to meet a daily energy demand of 17.5 kWh, and PVSyst simulations indicate an annual energy production of 6,387.5 kWh with a Performance Ratio (PR) of 82.68%.

From a technical perspective, the system is considered feasible as it fully satisfies the energy requirements (solar fraction), with an optimized configuration for an average solar irradiation of 5.47

DOI: https://doi.org/10.31963/intek.v12i1.5917

kWh/m²/day in Makassar, resulting in efficient and stable operation. Economic analysis indicates that the investment is profitable, with a Net Present Value (NPV) of IDR 104,891,580, a Profitability Index (PI) of 3.0, a Discounted Payback Period (DPP) of 8 years and 1 month, and an Internal Rate of Return (IRR) of 14.79%, all exceeding standard benchmarks (NPV>0, PI>1, DPP<20 years, IRR>8.5%). In addition, the Levelized Cost of Energy (LCOE) is IDR 1,080/kWh, which is lower than conventional electricity tariffs over the long term.

The system also delivers positive environmental benefits, with a potential carbon emission reduction of 6.56 tons of CO_2 per year, or approximately 197 tons over 30 years of operation. The use of a standardized battery swap system further extends battery lifespan, reducing potential electronic waste while improving operational efficiency.

References

[1] A. S. Okoh and M. C. Onuoha, "Immediate and future challenges of using electric vehicles for promoting energy efficiency in Africa's clean energy transition," *Global Environmental Change,* vol. 84, p. 102789, 2024.

[2] A. M. Al-Ghaili, H. Kasim, H. Aris, and N. M. Al-Hada, "Can electric vehicles be an alternative for traditional fossil-fuel cars with the help of renewable energy sources towards energy sustainability achievement?," *Energy Informatics,* vol. 5, no. Suppl 4, p. 60, 2022.

[3] A. Soemanto, E. Mohi, and Y. Gunawan, "The role of oil fuels on the energy transition toward net zero emissions in indonesia: a policy review," 2023.

[4] A. Mohammed, O. Saif, M. Abo-Adma, A. Fahmy, and R. Elazab, "Strategies and sustainability in fast charging station deployment for electric vehicles," *Scientific reports,* vol. 14, no. 1, p. 283, 2024.

[5] L. Bitencourt, B. Dias, T. Soares, B. Borba, J. Quirós-Tortós, and V. Costa, "Understanding business models for the adoption of electric vehicles and charging stations: Challenges and opportunities in Brazil," *IEEE Access,* vol. 11, pp. 63149-63166, 2023.

[6] T. Eccarius and C.-C. Lu, "Powered two-wheelers for sustainable mobility: A review of consumer adoption of electric motorcycles," *International journal of sustainable transportation,* vol. 14, no. 3, pp. 215-231, 2020.

[7] M. Marhatang, M. R. Djalal, A. Pangkung, and S. Sonong, "Development of automatic transfer switch design in hybrid solar power system," in *AIP Conference Proceedings*, 2024, vol. 3140, no. 1: AIP Publishing.

[8] S. Suwasti, Y. Klistafani, and M. R. Djalal, "Application of water tube filling pump in hybrid system of solar energy and PLN," *Przegląd Elektrotechniczny,* vol. 7, 2024.

[9] I. W. Adiyasa, M. A. H. B. Rasid, I. W. Warsita, Z. Arifin, A. D. Dwipayana, and R. P. Suteja, "Identification of computation of solar and wind energy potential for off-grid electric motorcycle battery charging stations," in *2023 International Conference on Smart-Green Technology in Electrical and Information Systems (ICSGTEIS)*, 2023: IEEE, pp. 208-213.

[10] A. Siriwattanapong and C. Chantharasenawong, "Electric motorcycle charging station powered by solar energy," *IOP Conference Series: Materials Science and Engineering,* vol. 297, p. 012060, 01/01 2018, doi: 10.1088/1757-899X/297/1/012060.

[11] F. Mphephu, I. Ayoade, and O. Longe, "Design and implementation of a hybrid solar-grid-powered electric bicycle," *E3S Web of Conferences,* vol. 636, p. 04003, 06/30 2025, doi: 10.1051/e3sconf/202563604003.

[12] K. Nandini, N. Jayalakshmi, and V. K. Jadoun, "Energy management system for PV integrated utility grid with electric vehicle as storage system," in *2022 2nd International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC)*, 2022: IEEE, pp. 1-6.

[13] Z. Serat, S. A. Z. Fatemi, and S. Shirzad, "Design and economic analysis of on-grid solar rooftop PV system using PVsyst software," *Archives of Advanced Engineering Science,* vol. 1, no. 1, pp. 63-76, 2023.

[14] A. Alnoosani, M. Oreijah, M. Alhazmi, Y. Samkari, and H. Faqeha, "Design of 100mw solar PV on-grid connected power plant using (pvsyst) in Umm Al-Qura University," *International Journal of Science and Research (IJSR),* vol. 8, no. 11, pp. 356-363, 2019.

[15] S. Ergun, A. Dik, R. Boukhanouf, and S. Omer, "Large-scale renewable energy integration: tackling technical obstacles and exploring energy storage innovations," *Sustainability,* vol. 17, no. 3, p. 1311, 2025. [Online]. Available: https://www.mdpi.com/2071-1050/17/3/1311.

[16] M. Morey, D. Gupta, M. M. Garg, and A. Kumar, "A comprehensive review of grid-connected solar photovoltaic system: Architecture, control, and ancillary services," *Renewable Energy Focus,* vol. 45, 05/01 2023, doi: 10.1016/j.ref.2023.04.009.

DOI: https://doi.org/10.31963/intek.v12i1.5917