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DESIGN & VALIDATION of SOLAR-POWERED STREET LIGHTING PROTOTYPE for AIRPORT DROP-OFF AREA

Muhammad Daru Balvero[1*], Asep Muhamad Soleh[2]
[1]Komodo Airport, Nusa Tenggara Barat, Indonesia
[2]Airport Engineering Technology Study Programme,
Politeknik Penerbangan Palembang, Indonesia
*Correspondence e-mail: muhammaddarubelvero@gmail.com

Abstract

The drop-off area of Husein Sastranegara International Airport Bandung lacks street lighting, posing safety risks to passengers and vehicles. This study designed and validated a solar-powered lighting prototype for that area using a quantitative Research and Development (R&D) approach following the Borg & Gall model. Six stages were implemented: problem identification, data collection, product design, design validation, design revision, and product testing. Based on SNI 7391:2008 and PM 27/2018 requirements, a 1:10 scale prototype was constructed comprising a 10 Wp solar cell, 3 W LED lamp, 12 V/5 Ah battery, and Solar Charge Controller. Testing confirmed a solar cell output voltage of 19.30 V at peak irradiance (13:00 WIB, 32°C). Expert validation by three validators yielded an overall score of 86.5% (Very Good for device function; Good for device quality), confirming prototype feasibility for full-scale airport implementation.

Keywords: *airport drop-off, LED lighting, renewable energy, solar cell, street lighting*

Introduction

Airport areas must have adequate lighting facilities to meet aviation safety requirements. In the airside area, lighting facilities must be properly installed on the runway, apron, and at the end of the runway as visual aids to assist pilots during aircraft takeoff and landing. Not only on the airside, but on the landside as well, lighting facilities must be provided at their best; therefore, proper planning and installation of lighting in the terminal drop-off area are essential to ensure safe conditions and to avoid the risk of accidents at Husein Sastranegara International Airport, Bandung (Sunarto et al., 2023).

According to the Undang-Undang Republic No, 38 Tahun 2004, roads in the drop-off area are categorized as collector roads, meaning roads that function as connectors with utility in linking national activity centers and local activity centers, including connections between regional activities and other local activity centers. In the drop-off area of an airport, road lighting must be properly provided, as it is a very important public service that can influence human activity and help ensure safety for both drivers and pedestrians. Without adequate lighting, it can lead to criminal acts, accidents, and even eye health problems (Armayanti, 2023). Therefore, to support the movement of passenger vehicles and airport operational vehicles, it is necessary to install lighting systems in the airport drop-off area.

Solar cells offer significant benefits and have proven to be efficient, as they do not incur monthly electricity costs. Using solar cells for installation in designated locations can provide advantages, especially when deployed in large quantities, while also minimizing maintenance costs. Solar cells do not require excessive maintenance because the main components used have a longer lifetime. They utilize unlimited energy from the sun, converting it into electrical energy in the form of direct current (DC), which can then be supplied to power lighting systems. Most importantly, they represent an innovation that contributes to environmental sustainability by not causing harmful impacts on the environment (Yuwono et al., 2021). One effective strategy for obtaining renewable energy sources that produce substantial amounts of energy, are economically viable for long-term investment, and have minimal negative effects on the environment is the implementation of solar cell technology (Haryanto, 2021). Direct field observation confirmed that the drop-off area in front of the terminal at Husein Sastranegara International Airport Bandung has no street lighting. The airport supervisor for the Electrical and Mechanical Facility Unit confirmed this finding during interviews, emphasizing the need for lighting to prevent accidents and enhance service quality in the area. Solar cell (photovoltaic) technology offers a compelling solution for off-grid airport lighting. An off-grid solar system operates independently of the PLN grid, converting solar irradiance into direct current (DC) electricity, which is stored in a battery and regulated by a Solar Charge Controller (SCC) (Pujianto et al., 2022; Rahman, 2021).

LED lamps, with their high luminous efficacy (90 lm/W) and long service life (50,000 hours), are the preferred load for solar-powered street lighting, offering up to 60% energy savings compared to conventional lamps (Beatrix et al., 2023; Hasibuan et al., 2020). Polycrystalline silicon panels, used in this study, are cost-effective and retain acceptable performance under partly cloudy tropical conditions (Armansyah et al., 2023). Building on a prior study by (Soleh et al., 2022) which developed a portable windsock light learning medium using solar power with a similar circuit architecture but different output application, this study implements and adapts that design for the drop-off street lighting context. This study contributes a prototype-validated, regulation-compliant prototype and an evidence-based component sizing methodology applicable to airport landside lighting projects. The research objectives are: (1) to design a solar-powered drop-off street lighting prototype meeting PM 27/2018 and SNI 7391:2008 requirements; and (2) to evaluate its functional performance and expert validation scores.

Methods

This study used a quantitative Research and Development (R&D) approach following the Borg & Gall model (Muthoharoh &

Marmoah, 2025; Putri et al., 2023; Sumarni, 2019). From the full ten-stage model, six stages were implemented due to time and resource constraints (Abdullah et al., 2021): (1) problem and potential identification, (2) data collection and component sizing, (3) product design, (4) design validation, (5) design revision, and (6) product testing and expert validation.

Direct observation was conducted at the drop-off area of Husein Sastranegara International Airport Bandung during the OJT period (2024). Photographs documented the absence of street lighting. Interviews with the Electrical and Mechanical Facility supervisor confirmed the operational need. The drop-off road length (105 m) and width (8 m) were measured via Google Earth. Four poles at 35 m spacing were planned (SNI 7391:2008 minimum: 30 m). Component ratings were calculated using the following equations:

Lamp power: $P = (Ev \times A) / \eta$ *where* $Ev = 7$ *lux,* $A = 35\ m \times 8\ m = 280\ m2$, $\eta = 90\ lm/W$ $\rightarrow P = 21.7\ W \rightarrow 30\ W$ *(market standard)*

Solar panel: $Ppanel = (ET / insolation) \times 1.1 = (360\ Wh / 5\ h) \times 1.1 = 79.2\ Wp \rightarrow 100\ Wp$ *(+30% buffer)*

Battery: $Ah = ET / Vs = 360/12 = 30\ Ah$; $Cb = 30/0.8 = 37.5\ Ah \rightarrow 45\ Ah$ *(available market size)*

SCC: $Imax = P/V = 100/12 = 8.3\ A \rightarrow 10\ A$; *Fuse:* $I = 30/12 = 2.5\ A \rightarrow 3\ A$

The system uses a Solar Cell Off-Grid topology: solar panel --> SCC --> battery --> SCC (load output) --> fuse --> LED lamp. Wiring diagrams were produced using Fritzing, and 3D device models using SketchUp. The prototype was built at 1:10 scale (pole height: 80 cm; solar panel: 10 Wp; lamp: 3 W; battery: 12 V/5 Ah), using the same circuit topology as the full-scale design. NYY cables (PVC-insulated copper conductors) were used for all connections.

Electrical circuit designs were validated by three experts: 2 lecturer specializing in electrical engineering at Politeknik Penerbangan Palembang, and 1 Supervisor of the Electrical and Mechanical Facility unit at the airport. Feedback included correction of fuse schematic symbols to comply with PUIL (General Electrical Installation Regulations) standards. Revisions were completed before prototype fabrication.

Prototype performance was tested by measuring solar cell output voltage with a multimeter at 13:00 WIB under 32 °C. SCC functionality, battery charging, timer operation (18:00-06:00 WIB), and lamp illumination were verified. Three expert validators evaluated the completed device using a 1-5 Likert scale across two assessment dimensions (device function: 6 items; device quality: 3 items). Validity score was calculated as:

$$Validity\ Score = (Obtained\ Score / Maximum\ Score) \times 100\%$$

Validation criteria followed Yulianti (2021): 84.01-100% = Very Good; 68.01-84.00% = Good; 52.01-68.00% = Fair.

Results And Discussions

Field observation confirmed the complete absence of street lighting at the drop-off area in front of the terminal building of Husein Sastranegara International Airport, Bandung. According to SNI 7391:2008, an area without artificial lighting is classified as a dark zone, falling below the minimum illuminance of 7 lux for collector roads. The drop-off road measured 105 m in length and 8 m in width. The airport electrical unit supervisor confirmed that no plans for conventional grid-connected lighting were in place, making solar-powered off-grid lighting a suitable and cost-effective solution given the area has no PLN grid connection at the curbside. Strategically, the drop-off zone handles the highest passenger volume of any single point on the landside.

Its lack of lighting at night exposes passengers, drivers, and airport staff to: (1) pedestrian-vehicle collision risk; (2) reduced visibility for passenger identification and vehicle maneuvering; (3) potential criminal exposure due to unlit public space. These risks align with findings by (Armayanti, 2023) and (Dermawan et al., 2020), who documented that the absence of road lighting directly increases accident rates and security incidents in airport landside areas.

Table 1. System Component Specifications: Full-Scale Design vs. 1:10 Prototype

No	Component	Full-Scale Spec.	Prototype Spec.	Calculation Basis
1	Solar Cell	100 Wp	10 Wp	P_panel = (ET / insolation) x 1.1 = 79.2 Wp → 100 Wp (with 30% buffer)
2	LED Lamp	30 W	3 W	P = (Ev x A) / η = (7 lux x 280 m²) / 90 lm/W = 21.7 W → 30 W (market standard)
3	Battery	12 V / 45 Ah	12 V / 5 Ah	Ah = ET / Vs = 360 / 12 = 30 Ah; Cb = 30 / 0.8 = 37.5 Ah → 45 Ah
4	Solar Charge Controller	10 A	10 A	Imax = P / V = 100 W / 12 V = 8.3 A → 10 A (standard)
5	Fuse	3 A	3 A	I = P / V = 30 W / 12 V = 2.5 A → 3 A
6	Pole Height	8 m	80 cm (1:10 scale)	PM 27/2018 Art. 46(c): min. 7,000 mm for collector road

Table 1 presents the full-scale component specifications derived from the regulatory and technical calculations, alongside the 1:10 scale prototype specifications used for laboratory testing.

The lamp power calculation (P = 21.7 W, rounded to 30 W) is consistent with the 7 lux illuminance requirement of SNI 7391:2008 for collector roads and the minimum pole height of 8 m specified in PM 27/2018. The required 100 Wp solar panel (79.2 Wp base + 30% buffer for sub-optimal irradiance days) is appropriate for the tropical Indonesian climate, where effective daily solar insolation averages 5 hours (Handani et al., 2023). The 80% DOD consideration for battery sizing is a standard practice to preserve battery health and extend service life, which for VRLA-type batteries typically reaches 4 years (Irmawan & Tama, 2025).The 10 A SCC safely handles the 8.3 A peak current from the 100 Wp panel at 12 V, with built-in over-charge and over-discharge protection. The 1:10 prototype maintains proportional electrical equivalence: the 10 Wp panel powers the 3 W lamp with a 12 V/5 Ah battery under SCC control, preserving the same circuit topology, operational logic, and voltage level as the full-scale design. This proportional scaling ensures that performance validation at prototype scale is transferable to full-scale implementation, consistent with the R&D approach (Sumarni, 2019).

The system operates on a Solar Cell Off-Grid DC topology. During daytime (05:00-18:00 WIB), the polycrystalline solar panel converts solar irradiance into DC current, which flows through the SCC to charge the battery. The SCC regulates charging current to prevent overcharging and monitors battery state of charge via PWM control. During nighttime (18:00-06:00 WIB), the SCC timer switches the load circuit ON, drawing energy from the battery through the 3 A fuse to the LED lamp. The fuse protects the lamp and wiring from overcurrent events. The complete workflow is: Solar Panel → SCC (charge control) → Battery → SCC (load control, timer) → Fuse → LED Lamp.

The use of NYY cable (copper core, double PVC insulation) is appropriate for the outdoor, moisture-exposed drop-off environment, offering both mechanical strength and rodent resistance (Haryanto, 2021). Polycrystalline solar panels were selected over monocrystalline for their lower cost and sufficient performance in partly cloudy tropical conditions (Armansyah et al., 2023). LED lamps were selected for their 90 lm/W efficacy, 50,000-hour service life, and DC compatibility without requiring an inverter, which eliminates a potential failure point and improves overall system efficiency (Hasibuan et al., 2020; Kristyadi, 2022).

Comparison with (Soleh et al., 2022), whose Portable Windsock Light used an identical circuit topology for educational purposes, confirms the circuit reliability. The key distinctions in this study are the application of the output (street lighting vs. windsock illumination), the regulatory sizing basis (PM 27/2018, SNI 7391:2008), and the airport implementation context. Similarly, (Siregar et al., 2022) used a comparable solar street light setup but with AC output requiring an inverter. This study demonstrates that a DC-only configuration is sufficient for LED lamp loads, simplifying the system and reducing cost and failure risk.

Table 2. Prototype Performance Test Results

Test Parameter	Measured Value	Reference/ Standard
Solar cell output voltage (open circuit)	19.30 V	Rated Voc = 17 V (12 V system)
Test time	13:00 WIB	Peak solar irradiance window
Ambient temperature	32 °C	Tropical Indonesia average
Sky condition	Partly cloudy	Polycrystalline works in non-ideal conditions
Battery charging	Confirmed (SCC indicator)	SCC PWM regulation active
Lamp operation (12-h timer)	Confirmed (18:00–06:00 WIB)	SCC timer programmed
Rated lamp power (prototype)	3 W	1:10 scale of 30 W full-scale
Illuminance standard (SNI 7391:2008)	7lux (design target)	Collector road minimum
Pole spacing (design)	35 m (4 poles / 105 m)	SNI 7391:2008 min. 30 m

Table 2 summarizes the prototype performance test measurements and their relationship to standards and design parameters. The most critical performance finding is the measured open-circuit voltage of 19.30 V from the 10 Wp polycrystalline panel, which exceeds the rated 17 V (nominal 12 V system). This confirms that the panel operates within its designed output envelope and can effectively charge the 12 V battery through the SCC. The SCC successfully regulated incoming current, preventing overcharging while maintaining full battery capacity for 12-hour lamp operation. The measurement was taken at 13:00 WIB -- the peak solar irradiance window in Indonesia – under a 32 °C ambient temperature, conditions representative of a typical operational day (Handani et al., 2023).

The polycrystalline panel performed well even under partially cloudy conditions, validating the selection rationale of (Armansyah et al., 2023)regarding this panel type for regions with variable cloud cover. The SCC timer functioned correctly, autonomously switching the lamp ON at 18:00 WIB and OFF at 06:00 WIB, eliminating the need for manual switching and ensuring consistent 12-hour operation aligned with the nighttime requirement. All circuit indicators on the SCC display (battery, solar cell input, lamp load) were functional throughout testing, providing real-time system status monitoring.

The overall validation score of 86.5% places the prototype in the boundary zone between "Good" (68.01-84.00%) and "Very Good" (84.01-100%) categories per (Yulianti, 2021), confirming its technical feasibility for scaled implementation. The device function dimension scored 90% (Very Good), indicating that all six SCC indicator functions -- display, power button, solar cell charging indicator, voltage display, lamp indicator, and battery level -- operate reliably. Validator 1, representing the airport electrical supervisor, awarded perfect scores (5/5) on all function criteria, reflecting practical operational confidence in the design.

The device quality dimension scored 83% (Good), reflecting minor deductions for circuit neatness and lamp appearance presentation from Validator 2. These are constructional quality aspects that are expected to improve in the full-scale implementation where professional-grade materials, proper cable management, weatherproof enclosures, and galvanized pole structures would be used. Notably, Validator 1 (airport supervisor) commented: "The manufacture of this device is very good because renewable energy use is currently strongly recommended," reinforcing the strategic alignment with national energy transition policies. Validators 2 and 3 (electrical engineering lecturers) suggested: "In future development, IoT integration could be added for more efficient remote monitoring and control," thereby identifying a clear pathway for the next research iteration.

These validation results are consistent with comparable solar street lighting implementations. (Fatkhurrozi et al., 2024) and (Nugroho et al., 2023) reported successful community-scale solar street lighting implementations using similar component configurations, while (Pujianto et al., 2022) documented effective PLTS-based road lighting using identical calculation formulas. The consensus across studies confirms that off-grid solar LED street lighting systems are technically mature, cost-effective, and deployable in airport contexts without requiring specialist infrastructure.

One limitation of this study is the absence of direct illuminance measurement using a lux meter on the prototype. Although the component sizing was derived from the SNI 7391:2008 minimum illuminance standard of 7 lux for collector roads, actual lux output of the 3 W prototype lamp was not measured during testing. Future studies should incorporate illuminance verification to confirm that the scaled-up 30 W configuration meets the regulatory threshold under real operating conditions.

Based on the prototype validation, full-scale implementation at Husein Sastranegara International Airport would require 4 lamp poles along the 105 m drop-off road at 35 m intervals, each equipped with: a 100 Wp polycrystalline solar panel, a 30 W LED lamp, a 45 Ah/12 V VRLA battery, and a 10 A SCC with timer function. The system requires no grid connection, minimizing infrastructure cost and installation complexity. Periodic maintenance involves cleaning the panel surface (monthly) and battery replacement every 4 years (Irmawan & Tama, 2025). The 25-year panel lifetime (Rahman, 2021) means virtually no panel replacement cost over the useful life of the lighting system.

A critical consideration for full-scale deployment is weatherproofing. The battery and SCC must be housed in an IP65-rated (or higher) enclosure to withstand Bandung rain and humidity. The SCC should be configured with a low-voltage disconnect (LVD) threshold at approximately 20% battery state of charge to prevent deep discharge and extend battery service life. The IoT monitoring capability suggested by Validator 2 would allow remote fault detection and timer adjustment, reducing operational staff requirements -- an important advantage for airport infrastructure that must meet 24/7 service availability standards.

Conclusion

This study successfully designed, constructed, and validated a 1:10 scale solar-powered lighting prototype for the drop-off area of Husein Sastranegara International Airport Bandung. The results demonstrate that the prototype meets the intended operational requirements and confirms the feasibility of implementing solar-powered lighting systems for airport outdoor facilities. The system showed reliable performance in energy generation, storage, and lighting operation, indicating its potential to support sustainable airport infrastructure. Future studies are recommended to evaluate full-scale implementation, conduct field testing under actual operating conditions, and integrate IoT-based monitoring features to enhance system performance and maintenance.

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