




Mono-crystalline and Poly-crystalline Solar Cell Power Management in Hybrid Off-grid System to increase Agriculture Productions

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Abstract. Indonesia prioritizes agricultural development for food security, facing challenges like land conversion and drought due to climate change. Indonesia faces agricultural challenges like drought; hybrid Solar Power Plants (SPP) using mono/poly-crystalline cells offer renewable irrigation solutions. The IoT integration enables remote monitoring for efficiency. Systems leverage sunlight (up to 33°C in rice fields), supporting modern agriculture sustainability with PLN backup. Research develops 500W hybrid SPP for food production, enhancing agricultural productivity and reducing carbon emissions. This research develops hybrid SPP systems combining mono-crystalline and poly-crystalline solar cells with PLN back-up for modern agriculture applications. Analysis of 160Wp mono-crystalline and 100Wp poly-crystalline cells shows tilt angle significantly affects output power (Pout). At 105° tilt (10:20 AM), mono-crystalline Pout=138.81W; poly-crystalline Pout=101.32W. At 90° tilt (12:00 AM), mono-crystalline Pout=181.38W; poly-crystalline Pout=108.78W. Fill Factors (FF) range 86-92% (105° tilt) and 94-97% (90° tilt). Optimizing tilt angles enhances energy output. Hybrid SPP systems can support sustainable energy in underdeveloped areas for successful implementation in modern agriculture.

Keywords: Hybrid Off-Grid System, Solar Power Plants (SPP), Agriculture Productions, Mono-Crystalline and Poly-Crystalline Solar Cell

1 Introduction

Indonesia is an agricultural country, serving as a primary source of livelihood for the majority of its population. As one of the countries highly committed to enhancing food security, Indonesia considers development in the agricultural sector a top priority, viewing it as a strategic component of national development. Law No. 7 of 1996 on food stipulates that achieving food security is a shared responsibility of the government and the community [1].

However, attaining this goal is challenging. Agricultural land extensification alone is insufficient because substantial land has been converted to other uses. Additionally, climate change, marked by prolonged dry seasons, has led to drought affecting many agricultural areas, particularly rice fields. According to data from the West Java

Department of Agriculture and Food Crops (DIPERTA), 73,906 hectares of rice fields across 22 districts/cities in the province were affected by drought as recorded. For instance, Indramayu district was severely impacted, with 24,195 hectares experiencing drought; 8,897 hectares of which suffered crop failure, consequently reducing food productivity. To mitigate drought, farmers resort to irrigating fields using generator-powered pumps to draw water from nearby rivers. This solution, however, is costly, involving equipment rental and fuel expenses, compounded by the difficulty of locating rivers with sufficient water during extended dry spells [2].

In this context, a solar cell system utilizing solar energy, which can be converted into electrical power, is considered an appropriate solution to address the issue of drought in rice fields during the hot dry season. This is attributable to the fact that sunlight in rice field areas can reach temperatures of up to 33°C, rendering it highly effective for conversion into electrical energy via solar cells. Contemporary developments indicate that, beyond lighting applications, solar cell systems for agricultural purposes are increasingly being integrated with Internet of Things (IoT) technology.

A solar cell power system by using solar energy that can be converted into electrical power is considered the appropriate solution to overcome the problem of drought in rice fields during the hot dry season. This is because sunlight in the rice field area can reach 33°C, making it highly effective to convert into electrical energy through solar cell. Current developments in [3], in addition to lighting, solar cell for agricultural systems are equipped with Internet of Things (IoT) technology as a remote control system in building an agricultural production. Based on the background above, this research focuses on Solar Power Plants (SPP) for support a modern agriculture system applications. Initially, research activities concentrate on literature review and the development of a 500 Watt hybrid SPP system with plans to expand into more complex for food productions, especially rice. One advantage of the hybrid system is its elimination of the need for a backup battery. This is attributable to the system's capability to automatically switch to PLN (state electricity company) power supply when the battery is depleted, and conversely revert to solar power when available.

2 Literature Review

2.1 Hybrid off-grid solar cell power management system

The focal activities of this research endeavor are centered on the development of a solar cell hybrid off-grid system, leveraging both mono-crystalline and poly-crystalline technologies, specifically tailored for areas that are inaccessible or difficult to reach by conventional PLN (state electricity company) electrical grids [4]. The electrical energy generated within this hybrid off-grid system is derived entirely from the conversion of solar irradiance into electrical voltage, a process that traditionally necessitates the incorporation of substantial backup battery storage to ensure continuity of power supply. Given the inherent limitations and costs associated with extensive battery deployment, this research is purposefully directed towards the development of a heterogeneous solar cell configuration. Such a configuration is envisaged to exhibit

enhanced versatility and efficiency, rendering it optimally suited to diverse agriculture system applications.

Mono-crystalline and poly-crystalline solar cells have different characteristics in terms of efficiency, cost and durability. Hybrid power plant (HPP) system combine the advantages and disadvantages of each other. When coupled with a PLN supply, they can provide sustainable electricity, ensuring the continued performance of the solar power plants (SPP) system, which can increase agricultural production finally.

Furthermore, the application of such solar technologies in agriculture could contribute significantly to sustainable farming methodologies, reducing dependence on fossil fuel-based energy sources and mitigating associated carbon emissions. The development of efficient heterogeneous solar panels could thus play a pivotal role in advancing renewable energy adoption within the agricultural sector, fostering increased productivity while aligning with broader environmental stewardship objectives.

The Solar Power Plants (SPP) System is a generating system that uses solar energy through cells to be converted into electrical energy. SPP systems are categorized into three primary types: off-grid (also known as communal or stand-alone systems), on-grid systems which are connected to the PLN (state electricity company) network, and hybrid SPP systems that are connected to the PLN grid and incorporate energy reserves from batteries or other generating systems [5]. The construction of an SPP system necessitates several key components, including solar cells, a Battery Control Unit (BCU), accumulators, inverters, control systems, and loads (comprising both DC and AC loads). These components can be tailored to meet the specific requirements of the proposed system, aiming to minimize losses from both electrical and economic perspectives. A critically important component is the solar cell, which is capable of converting solar energy into electrical energy via a photovoltaic system. The photovoltaic effect refers to the phenomenon wherein an electrical voltage is generated due to the contact of two electrodes connected to a solid or liquid system when exposed to light energy [6].

Generally, there are two primary types of materials utilized in the fabrication of solar cells, namely Crystalline Silicon and Thin Film, as [7]. Crystalline Silicon represents the first generation of solar cell technology and is widely adopted within the industry and by consumers globally. The Crystalline type is the first generation of solar cell and widely used by the community. In comparison, crystalline silicon has two main types of panels, namely Mono-crystalline Silicon (m-Si) and Poly-crystalline Silicon (p-Si), with different characteristics. Mono-crystalline is more expensive, accounting for an average efficiency of 19%, while poly-crystalline is 18%. Additionally, the absorb color affects the performance. This is because poly-crystalline with blue cell absorb lower heat than dark cells in mono-crystalline. However, excessive heat received by mono-crystalline can reduce the performance and efficiency of the panel (Dobrzanski et al, 2013) [8].

In the use of photovoltaic, the amount of output power generated from the process of converting sunlight into electricity is determined by several environmental conditions where a photovoltaic is placed. These include intensity of sunlight, temperature, direction of sunlight, and spectrum of sunlight. Environmental conditions that are al-

ways changing and disturbances from external factors also cause fluctuation in photovoltaic output power. To prevent damage and decreased performance of photovoltaic, there is a need to introduce a monitoring tool that provides notifications when performance is reduced, allowing for timely intervention. Therefore, SPP research has started to implement a remote monitoring system by using the internet network better known as IoT based system.

In [9, 10] this system can monitor the use of current, voltage, and power in real-time through the Blynk application, which is already available on the Android Play Store system.

2.2 Electrical Power Generated in Mono-crystalline and Poly-crystalline Solar Cell

A solar cell is an electrical device that converts light energy into electricity through the photovoltaic effect. The predominant material utilized in the fabrication of solar cells is silicon, owing to its abundant availability and suitable electronic properties. The performance of a solar cell is intricately tied to its current-voltage (I-V) characteristics, which delineate the intensity of the electric current generated under varying irradiance conditions. Photovoltaic solar cells are capable of generating electricity solely when they receive photon energy from sunlight, underscoring their dependence on solar irradiation.

The fundamental parameters of solar cells, derived from the I-V Curve and corroborated through mathematical formulations, exhibit consistency, thereby validating the precision of the measurements. In [8], mono-crystalline silicon solar cells are typically manufactured employing the Czochralski process. This method involves the growth of single-crystal ingots, from which wafers are subsequently cut. However, single-crystal wafer cells are associated with higher costs, attributable to the slicing process from cylindrical ingots, which often results in considerable wastage of pure silicon without fully utilizing the square module area efficiently.

In contrast, poly-crystalline silicon is produced through the casting of square ingots, wherein large blocks of molten silicon undergo controlled cooling and solidification processes. Poly-crystalline silicon cells present a more economical manufacturing alternative compared to single-crystal silicon cells, albeit typically exhibiting lower efficiencies. The trade-off between cost and efficiency is a critical consideration in the selection and deployment of solar cell technologies for various applications.

The distinctions between mono-crystalline and poly-crystalline silicon solar cells extend to aspects of material properties, production economics, and performance metrics, influencing their suitability for diverse photovoltaic system installations. Ongoing research endeavors aim to enhance the efficiency, reduce the costs, and improve the sustainability of solar cell technologies, thereby augmenting the viability of solar energy as a prominent renewable energy source globally.

Table 1. Properties of mono-crystalline and poly-crystalline solar cell.

No	Specification of Properties	Mono-crystalline	Poly-crystalline
1	Rated Maximum Power (Pmax)	160 Wp	100 Wp
2	Tolerance	3%	3%
3	Cell Efficiency	22-27 %	16,93 %
4	Voltage at Pmax (Vmp)	17,8 V	17.8V
5	Current at Pmax (Imp)	8,43 A	5.62A
6	Open-Circuit Voltage (Voc)	21,8 V	21.8V
7	Short-Circuit Current (Isc)	9,08 A	6.05A
8	Normal Operating Cell Temp	47C#39C	-4'C to +85'C
9	Maximum System Voltage	1000 VDC	1000 VDC
10	Series Fuse Rating (A)	12 A	12 A
11	Number of bypass diode	1	2
12	Solar Cells	Mono-crystall	36 cell in series
13	Dimension	1480x680x35mm	1020x670x30mm

Mono-crystalline and poly-crystalline solar cells essentially have four performances electrical power data sheet parameters at the maximum power point (MPP): short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), current at maximum power point (I_{mpp}), and voltage at maximum power point (V_{mpp}). The temperature coefficient is also required because changes in temperature will affect the performance of the solar cell. The analysis concluded that measuring the current-voltage characteristics allows for characterizing the fundamental properties of solar cells. Furthermore, these measurements can provide important information about the quality the prepared metal contacts. Among these values, the most important parameters are J_{sc} (mA/cm^2), V_{oc} (V), maximum power (mW/cm^2), and fill factor (FF) (%).

Photovoltaic conversion efficiency or fill factor (FF) is defined as the ratio of the maximum electrical power output to the total incident radiation power, as shown in the following equation.

$$FF = \frac{V_{MPP} \times I_{MPP}}{V_{OC} \times I_{SC}} \quad (1)$$

The FF parameter is generally better in mono-crystalline solar cells compared to poly-crystalline solar cells. Cells with a high fill factor have low equivalent series resistance and high equivalent shunt resistance, so less of the current generated by the cell is dissipated in internal losses. By analyzing the dark characteristics of solar cells, we can infer that the better the diode characteristics, the better the efficiency of the solar cell under illumination.

Research on the dark characteristics of photovoltaic cells can help determine the method for analyzing module efficiency parameters (η)

$$\eta = \frac{I_{sc} \times V_{oc} \times FF}{J \times S} \quad (2)$$

The following parameters are defined for solar cells: I_{sc} (short-circuit current), I_{mpp} (current at the maximum power point), V_{mpp} (voltage at the maximum power point), V_{oc} (open-circuit voltage), FF (fill factor), P_{max} (maximum power), η (efficiency), S (area of the solar cell), and E (irradiance). For monocrystalline and polycrystalline solar cells, the state conditions that affect efficiency include I_{sc} , I_{mpp} , V_{mpp} , V_{oc} , and P_{max} .

3 Method

Hybrid Power Plants (HPP) systems represent a synergistic integration of renewable energy sources, such as solar cells, with conventional energy systems, aiming to enhance the efficiency, effectiveness, and reliability of power supply to meet requisite electrical demands. The fundamental configurations of HPP systems are categorized into three primary architectures: series, parallel, and switched hybrid systems, each possessing distinct operational characteristics tailored to specific application needs.

The purpose of HPP is to make the power plant more efficient, effective, and reliable to supply the needed electricity. The basic configuration of HPP system is grouped into three, namely series, parallel, and switched hybrid system. To ensure operational reliability, each component is equipped with a charge controller, generator, and inverter, with potential to serve peak loads.

Series Hybrid System supplies DC power to the solar cell power battery. Parallel Hybrid System, the generator and storage or battery bank supply the load in parallel. This system uses a bidirectional inverter (BDI) that converts DC power sources to AC and vice versa (rectifier), serving as a charger. And Switched Hybrid System, the generator and inverter operate as AC sources, while the generator and renewable energy sources charge the battery. The load is directly supplied by the generator, thereby increasing total efficiency. Excess power from the generator can be used to charge the battery load. To ensure operational reliability, each component in an HPP system is equipped with advanced control mechanisms. Charge controllers regulate the flow of energy to and from the battery bank, preventing overcharging or deep discharging. The potential of HPP systems to serve peak loads makes them an attractive solution for areas with high energy demands.

Research methodology focuses on designing and implementing a 500 Watt hybrid off-grid Solar Power Plant (SPP) system to assist with lighting, utilizing a combination of solar energy and PLN (Indonesian state electricity company) as backup. The system operates by charging batteries from solar cells and supplying energy to loads from the battery when full. When the battery is low, the system automatically switches to PLN electricity. The design includes two solar cells (mono-crystalline and poly-crystalline) arranged in parallel to optimize energy conversion efficiency and reduce electricity

costs. The system aims to provide a more economical and efficient solution for energy needs.

The design of this SPP system consists of 2 solar cells arranged in parallel to obtain a large current so that it can accelerate the charging of the battery. The solar cells used are one unit mono-crystalline solar cells and one unit poly-crystalline solar cells with the aim of obtaining optimal energy conversion efficiency.

The deployment includes one mono-crystalline solar cell unit and one poly-crystalline solar cell unit, selected to attain optimal energy conversion efficiencies. Figure 1 illustrates a block diagram of the hybrid SPP system incorporating PLN electricity as a backup provision. The SPP is equipped with a 12 A Solar Charge Controller (SCC), a 12 V 1000 Watt inverter, a 12 V 100 Ah battery, and an integrated control system. The Solar Charge Controller (SCC) constitutes an electronic apparatus tasked with regulating direct current charging to the battery and discharge from the battery to the load, managing excess voltage from solar cells. Mitigating excess voltage and inappropriate charging regimes is critical to preserving battery lifespan. The research has been conducted using study literature method as shown in Figure 1.

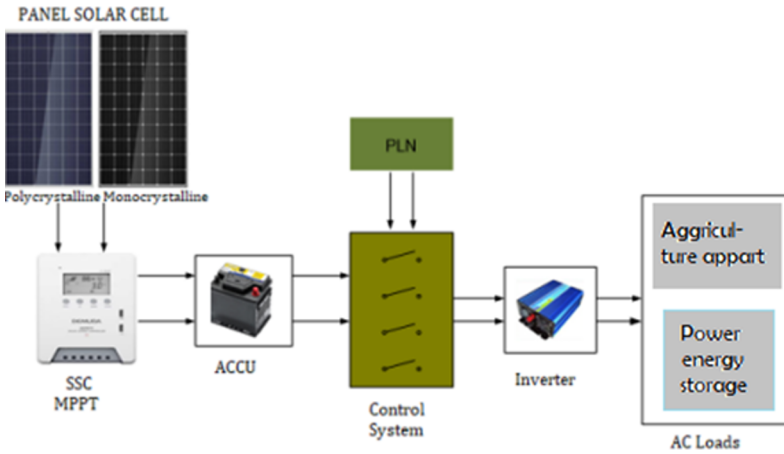


Fig. 1. Block diagram of hybrid SPP system combine PLN supported.

In Fig. 2, the design of SPP system consists of four solar cells arranged in parallel to obtain a large current, thereby accelerating the charging of the battery. A total of one unit mono-crystalline and one unit poly-crystalline solar cells are used to obtain optimal energy conversion efficiency.

4 Results and Discussion

Indonesia's average solar radiation intensity is approximately 4.8 kWh/m^2 . However, implementing Solar Power Plants (SPP) in Indonesia faces challenges like high costs, reliance on imported modules, and module efficiencies ranging from 16% to 20%. Using mono-crystalline and poly-crystalline solar cells can benefit advanced agriculture. Thus, planning must consider factors like load, module number/type, location, and battery capacity.

This research develops an SPP system for lighting, smart irrigation, and smart farming, supporting modern agriculture. It explores hybrid SPP systems combining solar energy with PLN (state electricity company) backup for reliable energy. The study highlights selecting suitable solar cell types and designing systems to minimize losses, plus monitoring for performance and damage prevention.

The SPP system can benefit underdeveloped areas and support sustainable energy. Analyzing 160Wp mono-crystalline and 100Wp poly-crystalline solar cells shows: - At 105° tilt (10:20 AM): Mono-crystalline $V_{oc}=20.10\text{V}$, $I_{sc}=8.75\text{A}$, $P_{out}=138.81\text{W}$; Poly-crystalline $V_{oc}=18.81\text{V}$, $I_{sc}=5.82\text{A}$, $P_{out}=101.32\text{W}$. - At 90° tilt (12:00 PM): Mono-crystalline $V_{oc}=21.10\text{V}$, $I_{sc}=9.01\text{A}$, $P_{out}=181.38\text{W}$; Poly-crystalline $V_{oc}=20.58\text{V}$, $I_{sc}=5.63\text{A}$, $P_{out}=108.78\text{W}$. - Fill Factor (FF): 86.28-92.2% (105° tilt, 10:20 AM); 94.4-96.8% (90° tilt, 12:00 PM).

Tilting modules toward the sun increases output power (P_{out}) and potentially improves FF and efficiency (η). Optimal design enhances SPP performance. Hybrid SPP systems can aid sustainable energy development in underdeveloped areas. Careful planning considering load, modules, location, and battery capacity is essential for success

5 Conclusions

The performance of solar power generation systems is significantly influenced by the design characteristics of solar modules. An analysis of 160Wp mono-crystalline and 100Wp poly-crystalline solar cells reveals that the tilt angle of solar modules plays a crucial role in determining output power.

At a 105° tilt angle (10:20 AM), mono-crystalline solar cells showed an average open-circuit voltage (V_{oc}) of 20.10 V and average short-circuit current (I_{sc}) of 8.75 A, yielding an output power (P_{out}) of 138.81 W; poly-crystalline cells had $V_{oc}=18.81\text{V}$, $I_{sc}=5.82\text{A}$, $P_{out}=101.32\text{W}$. At a 90° tilt angle (12:00 PM), mono-crystalline cells had $V_{oc}=21.10\text{V}$, $I_{sc}=9.01\text{A}$, $P_{out}=181.38\text{W}$; poly-crystalline cells had $V_{oc}=20.58\text{V}$, $I_{sc}=5.63\text{A}$, $P_{out}=108.78\text{W}$.

The fill factor (FF) was $>86\%$ (105° tilt, 10:20 AM) and $>94\%$ (90° tilt, 12:00 PM). While solar cell efficiency (η) isn't explicitly stated, data suggests tilting modules toward the sun can increase output power and potentially improve FF and η . Optimizing solar module tilt angles can maximize energy output and enhance overall system performance. This research demonstrates the feasibility and benefits of hybrid Solar Power

Plant (SPP) systems for modern agriculture, supporting sustainable energy development and agricultural productivity.

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