Challenge, Design, and Solution of Offshore Solar Power Generation – Project Case of First Offshore Green Platform in Indonesia

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***Abstract*—The remote offshore location with extreme environmental conditions poses significant challenges in generating energy. This undoubtedly affects all aspects, especially construction and costs, of building a power plant. Solar Power Plants have become a popular solution for meeting clean and sustainable energy needs especially for remote area. This paper discusses the challenges, design, and solutions for solar power generation development installed on manned offshore platform, focusing on the implementation of an 8 kWp solar power plant on the Heli Deck in the green offshore AVSA Area, Indonesia which owned by Pertamina Hulu Energi ONWJ. The research findings reveal that one of the solutions for construction challenges is utilizing ballast as a strong support for a sturdy foundation for the Photovoltaic panel support to counter the extreme environmental condition at offshore area. Moreover, this offshore solar power generation development offers additional advantages, such as reducing operations cost for fuel diesel engine and maintenance, and ensuring reliable 7 x 24 hours power continuity. The construction of the 8 kWp AVSA Offshore Solar Power Generation received the Museum of Indonesia Record Award as the first manned offshore platform which fully operated using solar power generation and also Indonesia Subroto Award in the energy sector for the category of special innovation project.**

Keywords— offshore solar power, green offshore platform, offshore renewable energy, support design.

I. INTRODUCTION

Development of renewable energy is currently advancing and has become a primary focus in efforts to reduce dependence on fossil fuels. As a country located on the equator with abundant and consistent solar radiation, Indonesia has a solar power generation potential of 207.8 GWp [1]. Recognizing this potential, the government through the Ministry of Energy and Mineral Resources (ESDM), has set a target of achieving a 23% contribution from renewable energy sources to the national energy mix by 2025, with a projected total investment cost of 13.197 million USD [2].

As a concrete commitment to Indonesia, PT. Pertamina Hulu Energi is realizing the construction of the first Offshore Solar Power Plant (PLTS) in Indonesia, located in the Avsa Zone, with a capacity of 8 KWp. Being the first Offshore PLTS project in Indonesia, this project undoubtedly faces significant challenges due to its offshore location.

Therefore, the objective of this research paper is to identify the challenges in developing an offshore PLTS and to implement the construction in a tangible manner as a solution to address and overcome these challenges. The paper also provides an analysis of the design and maintenance of the PLTS, which differs from onshore solar power plants, ensuring that the PLTS AVSA operates effectively and sustainably. In terms of design as an alternative for offshore PLTS development, ballast is utilized as a support and strong PV panel framework to address challenges in construction and extreme environmental conditions.

II. OFF-GRID SOLAR POWER PLANT

The Off-Grid Solar Power Plant (PLTS) provides isolated communities without access to the national power grid (PLN) with a novel and environmentally friendly method of generating electricity [3]. The accessibility and mobilization issues these locations face greatly raise the investment costs related to building conventional power plants or expanding the power grid infrastructure [4]. The limited transportation options available to reach these remote regions further increase the operational and maintenance costs of such conventional systems.

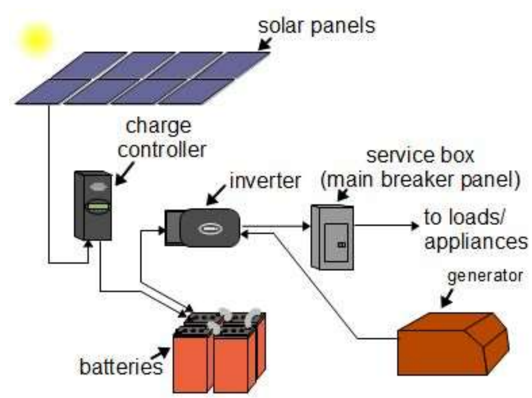

Fig. 1. Off-grid Solar Power Plants [5]

The Off-Grid PLTS, on the other hand, exclusively uses solar energy as its main source of energy, making it an eco-friendly and emission-free alternative. This technology effectively turns the abundant solar energy into electrical energy by utilizing it, so addressing the urgent need for a dependable power supply in remote areas, especially offshore locations.

The Off-Grid PLTS is built with cost-effective and user-friendly maintenance and operation in mind. Long-term dependability and stability are guaranteed by the system's capacity to function without interruption for up to 10 years without replacing any equipment. Due to its longer lifespan and overall economic viability, the Off-Grid PLTS is a desirable choice for generating sustainable energy in rural locations [4].

The choice of the Off-Grid PLTS system is made after giving serious attention to a number of variables. First, the lack of adequate sea transit choices creates considerable logistical difficulties, necessitating the installation of a self-sufficient energy generation system that can function without the use of outside resources. In addition, the offshore locations' distinctive geographic features, which are in the middle of the ocean, necessitate the development of specialized system designs in order to endure the severe marine environment and maximize solar energy absorption. The Off-Grid PLTS is additionally intended to be a standalone power generation solution, obviating the requirement for labor-intensive integration with other power plants and easing the installation procedure. The system's modular design enables simple extension and scalability, guaranteeing its capacity to react to shifting energy demands in remote places.

Another significant benefit of the Off-Grid PLTS is that it relies on copious solar radiation as a reliable and sustainable energy source, especially in offshore regions. The efficiency of solar energy absorption and conversion is maximized when sunlight is not impeded by obstructions like trees, buildings, or residential constructions. This produces a steady and dependable source of power [8]. The Off-Grid PLTS promotes a cleaner and greener energy future by reducing carbon emissions connected with traditional power generation technologies and minimizing their negative environmental effects through the use of solar energy.

Furthermore, the Off-Grid PLTS liberates remote areas from their dependence on oil fuel, eliminating the uncertainties and vulnerabilities associated with fluctuating oil prices and supply. This energy independence contributes to the long-term sustainability of the remote communities, ensuring a consistent and affordable power supply for their essential needs.

III. Methodology

In this paper, the methodology is crucial for the successful implementation of the Solar Power Plant, ensuring that the system is appropriately sized, optimized for performance, and cost-effective for the desired application. The entire research methodology is shown in the flow chart schematic in Figure 2 below.

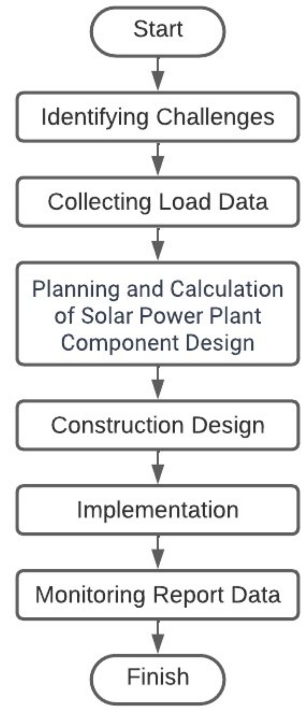

Fig. 2. Methodology of Research

IV. Design

A. Installation Location

Pertamina Hulu Energi will construct a Solar Power Plant (PLTS) with a total capacity of 8 kWp, to be installed on the Heli Deck in the green offshore AVSA area. AVSA is one of the facilities owned by PHE ONWJ that is currently inactive. However, security measures are still implemented to prevent theft and monitor the ZULU gas fuel facilities provided by Zelda. Presently, AVSA relies on electrical supply from Zelda, but any issues with Zelda would result in disruptions to the power supply for AVSA. Therefore, to enhance the reliability of the power supply, the installation of a solar power generation system in AVSA is proposed. The electricity generated will be utilized for lighting to ensure continuous visibility in the AVSA area and to prevent vessels from colliding with this green offshore area.

B. Electrical System Design

In designing the construction of a Solar Power Plant (PLTS), it is important to ensure the existence of the load that will be supplied. Since AVSA is already inactive, the load to be supplied will only consist of household loads. The following are the loads to be supplied by the PLTS that will be built, along with their power requirements and duration of usage.

TABLE I. LOAD LIST AVSA

Equipment	Load Duration (hours/day)	Power (Watt)
Refrigerator	24	440
Freezer	24	220
Lamps	13	440
Radio	24	110
TV	10	220
Rice Cooker	0.5	440
Electrical Stove	1.5	880
Ketel	0.5	880
Total	-	**3630**

Based on the calculation of the total load present in AVSA, it is possible to determine the required number of components from the Solar Power Plant (PLTS) to generate the required power and supply it to the load for a period of 24 hours. The calculation is as follows.

- Photovoltaic Array

Based on Electrical Load List calculation, total daily load is 129.22 Ah/day. So, by incorporating a 20% daily load tolerance in the design, the designed daily load amount.

Design daily load = daily load x design factor
= 129.22 x 120%
= 155.06 Ah/day

The derating factor of PV modules is the combination of different loss parameters that reduce the PV output power.

Photovoltaic Derating Factor (DF)

$$DF = 0.93 \times 0.95 \times 0.95 \times 0.95 \times 0.95 = 0.76$$

The current generated by the PV system to supply the load should be in accordance with the load calculation. Therefore, the system requires a current flow to supply the load.

Design Required Array Current (Iarr)

$$I_{arr} = \frac{155.06}{4} = 38.766\ A$$

So, we can calculate the current that each PV module should generate to supply the load.

PV Current per Module

$$= I_{mp} \times DF$$
$$= \big(5.4 - (10\% \times 5.4)\big) \times 0.76$$
$$= 3.6936\ A$$

The values of voltage and current that should be generated by the PV module being used are already known, allowing us to determine the number of PV modules that need to be connected in parallel and series.

No of Parallel PV Module Required

$$= \frac{I_{arr}}{PV\ Current} = \frac{38.766}{3.6936} = 11\ Modules$$

No of Series PV Module Required

$$= \frac{Nominal\ Voltage}{PV\ Voltage} = \frac{24}{20.1} = 2\ Modules$$

Total Number of PV Module Required

$$= 11 \times 2$$
$$= 22\ Modules$$

Therefore, the number of PV modules shall be installed on AVSA Platform is 22 modules.

- Charge Controller Device (CCD)

Each CCD will include 1 (one) Master Control Unit (MCU) and 1 (one) Slave Unit (SU). Each unit can be utilized for 3 (three) PV array and each PV array will arrange by 4 (four) PV Modules (2x2 module). By design, the daily load calculation is 155.06 Ah/day, with the load being used continuously for 24 hours per day. Therefore, a current flow to the load per hour.

Load current per hour

$$= \frac{Design\ Daily\ Loads}{Hours\ of\ a\ day}$$
$$= \frac{155.06\ Ah/day}{24\ h/day}$$
$$= 6.461\ A$$

The daily average insolation is 4 hours for a day, so we can determine that the battery discharge time in a day = 24 hours – 4 hours = 20 hours. Therefore, we can know that total daily battery discharge current per hour to supply the load.

Total daily battery discharge

$$= Design\ Daily\ Loads \times \frac{Discharge\ Time}{Total\ Time}$$
$$= 155.06 \times \frac{20}{24}$$
$$= 129.22\ Ah$$

To recharge the battery during an insolation of 4 hours for a day and total daily battery discharge is 129.22 Ah, we need calculate the minimum current required.

Total recharge current required

$$= \frac{Total\ Daily\ Battery\ Discharge}{Daily\ Average\ Insolation}$$
$$= \frac{129.22}{4}$$
$$= 32.305\ A$$

So, by adding the current supplied to the load per hours with the current supplied for recharging the battery, we will obtain the total current that needs to be transmitted by CCD.

Total required current

$$= Load\ current\ per\ hour + Total\ recharge\ current$$
$$= 6.461 + 32.305$$
$$= 38.766\ A$$

With the tolerance by design is 25%, we can calculate the minimum output current must be transmitted by CCD to the system is 48.4575 A(consist of 1 Master Unit and 1 Slave Unit).

- Inverter

The inverter of battery and solar power generation have similar function with battery charger as stated in IEEE946. Based on IEEE946, IEEE Recommended Practice for the design of DC auxiliary power systems for generating stations, Charger rating is calculated as follows.

Calculation for Charger Size

$$= \left(\frac{AHR \times R}{T} + L\right) \times \frac{1}{K1} \times \frac{1}{K2}$$
$$= \left(\frac{154.4 \times 1.15}{8} + 0\right) \times \frac{1}{0.965} \times \frac{1}{1}$$
$$= 23\ A\ (Calculated)$$

So, we can calculate the charger capacity for the nominal AC voltage of 220 VAC.

Inverter/Charger Capacity

$$= Nominal\ AC\ Voltage \times Charger\ Size$$
$$= 220 \times 23$$
$$= 5060\ VA$$
$$\approx 6\ kVA$$

Therefore, the selected 24 VDC / 220 VAC 1 phase Inverter rating is 23 A or 6 kVA for minimum.

- Battery

The parameters value for Battery sizing are such as Battery cell type VRLA, cell voltage required for satisfactory charging is 2.35 Vpc with maximum voltage input +10% of 24 VDC, so we can calculate the required number of cells.

Required number of cells

$$= \frac{Maximum\ Sytem\ Voltage\ Input}{Cell\ Voltage\ Required\ for\ Satisfactory\ Charging}$$
$$= \frac{24 + (10\% \times 24)}{2.35}$$
$$= 11.23404\ Cells$$
$$= 12\ Cells\ (Chosen)$$

To generate 24 VDC with a voltage variation ± 10% of nominal utilization voltage therefore the required numbers of cells are 12 cells in series configuration.

In this case, the calculation yields a required cell size of 177.67 Ah. So, The total requirement of battery capacity to accommodate the load on NUI platform are **1 x 177.67 Ah**.

C. Construction Design

During the construction phase of this solar power plant (PLTS), a strong support structure is required to permanently hold the solar panels. The following are the requirements and design for the panel support needed for the PLTS AVSA project.

TABLE II. MATERIAL REQUIREMENTS

No.	Item	Quantity
1	Rail Support	36 rod @ 2100 mm
2	End Clamp	120 set
3	L Clamp	60 set
4	Jointing Panel	30 set
5	Ballast	32 ea @ 300 mm x 300 mm x 300 mm
6	Nut and Bolt Elbow	100 set

TABLE III. TOOLS FABRICATION REQUIREMENTS

No.	Item	Quantity
1	Cement Bucket	6 ea
2	Hoe	2 ea
3	Dustpan	2 ea
4	Plastering Trowel	2 ea
5	Cement Spoon	2 ea
6	Cutting Steel	1 ea
7	Machine Driil	1 set
8	Screwdriver	1 set
9	Pliers	1 set
10	Pass Wrench	1 set

The design of the PV support panel and ballast used as support for the construction of PLTS AVSA is as follows :

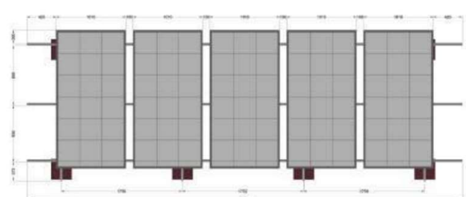

Fig. 3. Top View Support PV Panel

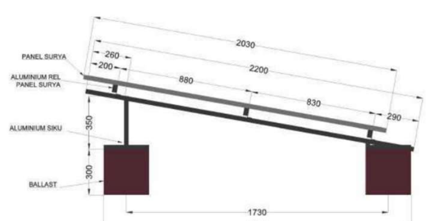

Fig. 4. Side View Support PV Panel

The building of offshore PLTS differs in terms of the construction techniques employed from the building of onshore solar power plants, such as those on rooftops or buildings. The foundation holding the solar panels needs to be extremely durable in offshore areas due to the harsh weather and strong winds. Each leg of the support panel is supported by a ballast system in the PLTS AVSA building method. The PLTS AVSA's ballast design is seen here.

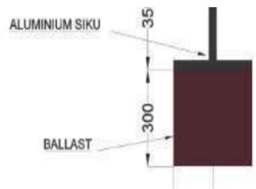

Fig. 5. Ballast For Support Panel PLTS AVSA

A cube-shaped structure with dimensions of 300 mm x 300 mm x 300 mm was utilized as the ballast during the building of PLTS AVSA. This ballast serves as both support and weight for the PV panel support. By doing this, it is made sure that the PV panel support system is strong and wind-resistant. When the ballast is put, a cement mixture is applied around the margins of the ballast to support its construction and provide a precise fit with the PLTS construction area.

Construction materials are used to create the ballast, which is then molded to the required dimensions (300 mm x 300 mm x 300 mm). A total of 32 ballasts were utilized in the building of PLTS AVSA, with 8 ballasts per PV panel rack. The following picture shows how the ballasts supporting the PV panel support are arranged.

V. Design Implementation

A. Challenges

The building of offshore solar power plants (PLTS) faces difficulties in the technical aspects of designing and constructing structures that can withstand harsh offshore conditions, such as storms with high rainfall intensity, high sea waves, strong winds, and corrosion from seawater [7]. In order to combat unfavorable weather circumstances with severe wind gusts, ballast is utilized in the building of this PLTS AVSA. severe materials are also needed for the PLTS's supporting structures, notably aluminum for the PV support panels. Clamps are also used during construction to guarantee a strong, permanently standing structure.

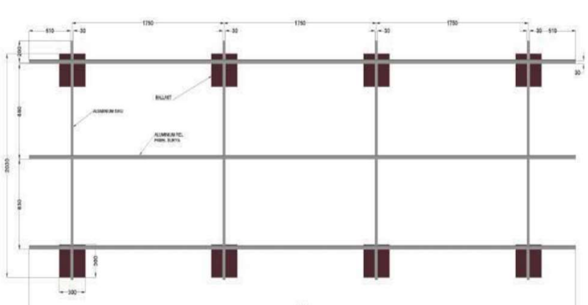

Fig. 6. Ballast Formation For Support Panel

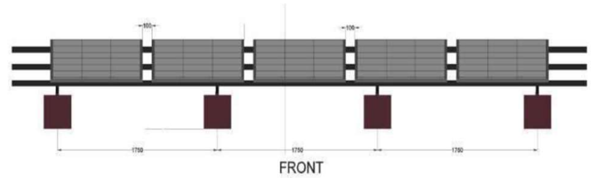

Fig. 7. Front View Formation Ballast

Economically speaking, the development of offshore solar power plants (PLTS) entails substantial upfront investment expenditures, including costs associated with installation and maintenance in remote areas [6]. To make sure that offshore PLTS projects are financially viable and sustainable, other issues including the accessibility of supporting infrastructure and long-term operational costs must be taken into account. However, by employing more effective installation methods, using inexpensive materials that are still sturdy and corrosion-resistant, and applying automated and integrated maintenance techniques, these difficulties can be overcome. These steps can reduce maintenance costs over time, increasing the viability of offshore PLTS operations.

Regulatory and permitting considerations must also be made when developing offshore PLTS. For the growth of offshore PLTS projects, the government and pertinent organizations must have clear and current regulatory frameworks. The pace and accessibility of investments in offshore PLTS may also be impacted by the difficult regulatory process and the length of time needed to acquire the proper permissions. These difficulties can be overcome by carrying out the goals listed in this paper's objectives as well as more research and development on offshore PLTS building. In this manner, the government can fully support Indonesia's use of renewable energy.

Despite the challenges, there are several technical advantages to offshore PLTS. The offshore location, being far from land, eliminates obstacles to solar radiation such as trees, buildings, and housing, making the construction of PLTS flexible in selecting locations with potential for solar energy development. Some offshore locations near the equator receive higher solar radiation intensity, leading to increased and more stable electricity production.

B. Implementation

In this paper, the designed PLTS was implemented by Pertamina Hulu Energi with a total capacity of 8 kWp, and it was installed on the Heli Deck in the green offshore AVSA area. The following is the implementation of the PLTS construction carried out by Pertamina Hulu Energi.

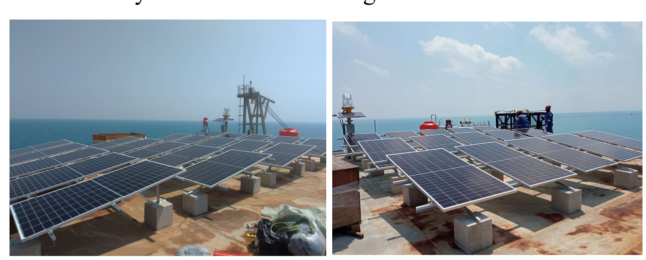

Fig. 8. Design Implementation of PLTS AVSA

The implementation of the design in the PLTS AVSA project has been successfully carried out. Basically, the installation of offshore PLTS is almost the same as onshore, but in actual implementation, the role of ballast as a support for PV panel is crucial in facing construction challenges. Furthermore, for monitoring the operation and performance of the PLTS AVSA, remote monitoring is utilized using an integrated cloud application connected to an Off-Grid Solar Inverter with a capacity of 5000VA. This remote monitoring method is effective and efficient, addressing the challenge of high operational costs.

Monitoring the performance of the PLTS system is crucial to ensure optimal operation and gain a better understanding of the potential of renewable energy harnessed offshore. The following are data insights regarding the monitoring of the AVSA PLTS and performance analysis based on the collected data.

The table above is the power absorption data by load through the inverter for each month from 2021 to 2023. This data is obtained remotely using an online application that is integrated with the cloud, which stores data from the inverter.

In the monitoring data shown in the table and graph above, it can be seen that in November 2021 there is no absorbed power data. This is due to technical constraints on the communication devices used. The technical issue occurred when the communication card connected to the data cloud lost connection, causing an interruption in monitoring data for that month. Card replacement takes time to ship to AVSA location, causing monitoring data for November 2021 to be missing.

However, it should be noted that even though there is no monitoring data, PLTS AVSA continues to operate and generate electricity in that month and year. This is also a consideration in terms of the importance of addressing and mitigating communication problems before undertaking any future offshore solar projects.

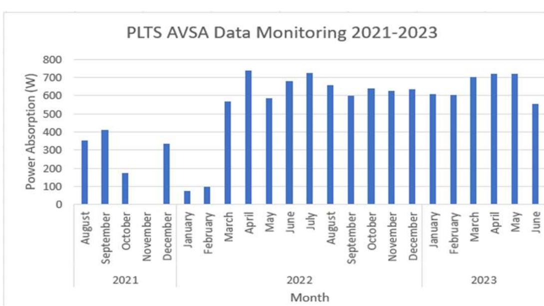

Fig. 9. Graphic Monitoring Data 2021-2023

Furthermore, from August 2021 to February 2022, the power absorbed is relatively low. This is because it is still in the trial phase of the project, where usage may not have reached maximum capacity. From March 2022 to June 2023, the chart shows a stable trend without significant fluctuations, indicating the effective utilization of energy by PV mini-grid to support the required operations.

Based on monitoring data generated from 2021 to 2023, it can be concluded that PLTS AVSA is functioning well from an operational perspective. This is shown by the stable energy production and absorption every month.

VI. Conclusion

The increasing demand for energy, coupled with the decline of fossil fuel resources, drives the search for alternative energy sources. This research focuses on analyzing the potential of Offshore Solar Power Plants (PLTS) as a source of electrical energy. The research methodology involves numerical calculations, virtual design, and real-world implementation.

The study also addresses the challenges faced during the construction of Offshore PLTS and proposes potential solutions for future developments. The research specifically focuses on the construction of an 8 kWp PLTS in the Heli Deck Offshore Area of AVSA. Building and implementing Offshore PLTS offer a promising pathway for generating electrical energy with several advantages, such as reducing operations cost for fuel diesel engine and maintenance, reliable 7 x 24 hours power continuity. Moreover, the development of the 8 kWp AVSA Offshore Solar Power Generation received the Museum of Indonesia Record Award as the first manned offshore platform which fully operated using solar power generation and also Indonesia Subroto Award in the energy sector for the category of special innovation project.

Acknowledgment

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