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Design and Performance Analysis of Integrated Floating PV System for Retrofitting the Kun Chaung Hydropower Plant

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Abstract – This paper presents the design and performance analysis of a 30 MW floating solar photovoltaic (FPV) system integrated with the Kun Chaung Hydropower Plant in Myanmar. The study involves a systematic approach covering site data collection and assessment, PV system design and array configuration, floating platform and mooring/anchoring design, electrical system design, shading analysis, and energy yield estimation and integration. Analytical calculations based on site-specific solar and environmental data were performed to determine system performance. Results show that the integrated FPV–hydropower system achieves an annual energy generation of 687 GWh, compared to 300 GWh from FPV alone. The hybrid configuration enhances power generation by reducing water evaporation and improving hydropower efficiency. The findings confirm that FPV–hydro integration offers a reliable, sustainable, and land-efficient solution for renewable energy expansion in Myanmar.

Keywords: Floating Solar Photovoltaic, Kun Chaung Dam, Renewable Energy, FPV–Hydro Integration

I. INTRODUCTION

The global transition toward sustainable and renewable energy has intensified interest in hybrid power generation systems that combine multiple renewable resources to improve efficiency and reliability [1, 2]. Among various hybrid concepts, the integration of floating solar photovoltaic (FPV) systems with existing hydropower reservoirs has gained increasing attention as a viable and eco-friendly solution [3, 4]. This approach enables effective utilization of existing infrastructure, optimizes energy production, and minimizes environmental and land-use impacts compared to conventional ground-mounted PV systems [5]. Floating PV systems also offer improved module efficiency due to the cooling effect of water and reduced dust accumulation, leading to higher overall energy yield [6, 7].

The combination of hydropower and solar energy is particularly advantageous because of their complementary operating patterns [8]. Solar generation peaks during the daytime, while hydropower can be regulated to compensate for the variability of solar output. Such a hybrid hydro-PV configuration provides smoother power generation, enhances grid stability, and reduces seasonal dependence on reservoir inflow [9, 10]. Moreover, the shared use of electrical, civil, and transmission infrastructure lowers capital costs and shortens project implementation time, making FPV retrofits a practical approach for expanding renewable energy capacity [11, 12].

Myanmar, with its significant hydropower potential and high solar irradiance, presents favorable conditions for hydro-PV hybridization [13, 14]. The Kun Chaung Hydropower Plant, located in the Bago Region, features a large reservoir area suitable for floating solar installation [15]. Retrofitting this plant with a floating PV system can increase total renewable generation, reduce seasonal power shortages, and improve water-resource management efficiency [16]. The site's tropical climate also provides an opportunity to evaluate the thermal and electrical performance of floating PV under high-temperature conditions [17].

This study aims to design and analyze the performance of an integrated floating PV system retrofitted to the Kun Chaung Hydropower Plant. The work includes system sizing, layout configuration, and simulation using local meteorological and hydrological data [18, 19]. Key performance indicators such as energy yield, efficiency, and temperature response are evaluated, and comparisons are made with equivalent ground-mounted systems [20]. The results are expected to highlight the technical feasibility and performance advantages of FPV–hydropower integration, providing valuable insights for future renewable energy development in Myanmar and similar regions [21, 22].

II. LITERATURE REVIEW

The increasing demand for renewable energy has driven global research and development toward sustainable and efficient power generation systems. Among recent innovations, floating photovoltaic (FPV) technology, solar arrays installed on buoyant platforms over water bodies, has emerged as a practical solution to land-use limitations and environmental challenges [2, 24, 27]. Studies have shown that FPV installations on reservoirs, lakes, and dams not only optimize unused surface areas but also improve module efficiency through the cooling effect of water [20, 25, 27]. Countries such as Japan, China, South Korea, and Singapore have successfully implemented large-scale FPV projects, demonstrating the viability of this approach in diverse climatic conditions [2, 23]. The technology offers additional benefits, including reduced land acquisition costs, lower dust accumulation, and decreased water evaporation rates [3, 5, 8].

Integrating FPV with existing hydropower systems enhances both energy production and operational flexibility. Hydropower and solar energy are naturally complementary, solar generation peaks during daylight hours, while hydropower output can be regulated to balance the fluctuations in solar supply [5, 10, 26]. Research indicates that such hybrid systems improve the stability of power generation and grid reliability by allowing flexible dispatch between PV and hydro resources [13, 26]. The shared use of existing transmission, access roads, and substation infrastructure also lowers the overall investment cost and minimizes environmental impact [5, 17]. Case studies in Asia and Europe confirm that floating PV–hydropower hybridization increases total renewable generation capacity and reduces seasonal water stress by enabling reservoir operators to conserve water during high solar periods [17, 26].

A comparison between floating and ground-mounted PV systems reveals several distinct operational characteristics. FPV systems generally exhibit lower operating temperatures, resulting in higher efficiency and slower degradation rates compared to conventional ground-based installations [16, 20]. The proximity of panels to the water surface provides continuous convective cooling, which helps maintain optimal performance even under high ambient temperatures [6, 20]. Mousazadeh et al. [20] observed a significant improvement in the energy yield of FPV systems due to water-based cooling, while Ghosh [2] reported that FPV installations can achieve 10–15% higher efficiency than similar ground-mounted systems. However, FPV systems also face technical challenges such as mechanical stress from waves and wind loads, the need for reliable mooring systems, and tilt-angle limitations due to buoyancy constraints [22, 27]. Despite these factors, research consistently confirms that FPV offers superior energy performance and reduced land dependency in hot and humid environments [2, 7, 20].

Simulation and modeling tools are essential for designing and analyzing FPV and hybrid renewable systems. MATLAB/Simulink provides flexibility for dynamic modeling and grid-integration studies, enabling co-simulation of PV inverters and hydropower control mechanisms [5, 10]. Similarly, Metronome datasets are often used to simulate solar resource profiles, assess techno-economic feasibility, and optimize system configurations [15, 19, 23].

Studies highlight the importance of accurate solar radiation modeling, optimal tilt-angle selection, and temperature correction factors to ensure reliable performance estimation [9, 15, 16, 22].

Despite rapid advancements, several research gaps remain. Long-term operational data for FPV installations in tropical regions are limited, and performance models often rely on assumptions derived from temperate climates [2, 17]. Furthermore, the coordination between hydropower and FPV operations, especially in reservoir management and real-time grid support, requires more detailed dynamic simulation and control strategies [5, 13, 26].

Environmental and ecological assessments of large FPV installations, including their effects on aquatic life and water quality, are still underexplored [25, 27]. Standardized guidelines for mechanical design, anchoring, and electrical protection are also needed to enhance reliability and scalability [21, 25]. Considering these gaps, the present study focuses on the design and performance analysis of an integrated floating PV system retrofitted to the Kun Chaung Hydropower Plant in Myanmar. The Kun Chaung reservoir, with its large surface area and stable water level, presents a favorable site for FPV deployment

[17]. This study employs MATLAB/Simulink tools for system design, performance evaluation, and grid-integration analysis, using local meteorological data from Metronome and NASA-based datasets [19]. The objective is to quantify the technical feasibility, performance improvement, and operational synergy of hydro–FPV hybrid system, providing a reference for future renewable energy development and hybrid retrofits in tropical regions such as Myanmar.

III. CASE STUDY

Fig. 1 Installed PV System Area on Kun Chaung Dam

Geographically, the Kun Chaung Hydropower Plant is located on a tributary of the Sit Taung River, about 9 miles southwest of Phyu City in Myanmar's Bago Region, at approximately 18°29′ N latitude and 96°26′ E longitude [17]. The reservoir formed by the dam covers a total surface area of around 10.03×10^6 m^2, offering ample space for the installation of floating photovoltaic (FPV) modules. The proposed FPV layout across the reservoir, as illustrated in Figure 1, highlights the spatial suitability of the site for large-scale deployment. By harnessing the abundant solar potential of the Kun Chaung reservoir, the project supports Myanmar's shift toward a sustainable and resilient hybrid energy system, while also contributing to improved water resource utilization and ecosystem conservation.

IV. METHODOLOGY

This study focuses on the design, modeling, and performance analysis of a floating photovoltaic (FPV) system integrated with the Kun Chaung Hydropower Plant in Myanmar. The methodology integrates site assessment, system configuration, simulation modeling, and performance evaluation to determine the technical feasibility and potential energy yield of the proposed hybrid hydro–solar system. The design process involves 30 MW floating PV plant retrofitted onto the existing hydropower reservoir, combining hydrological, structural, and electrical engineering aspects to ensure safe and reliable operation under local environmental conditions. The methodology is structured into the following main stages:

- Site data collection and assessment
- PV system design and array configuration
- Floating platform and mooring/anchoring design
- Electrical system design
- Shading analysis
- Energy yield estimation and integration

A. Site data collection and assessment

The Kun Chaung Dam, located at 18°29′ N and 96°26′ E near Phyu City, Myanmar, presents favorable climatic and hydrological conditions for the deployment of a floating photovoltaic (FPV) system. The reservoir, with a gross capacity of 1467.84 Mm^3 and 15.24 m seasonal water-level variation, provides a stable platform for floating installations while avoiding competition with agricultural or terrestrial land use [17]. Long-term solar radiation data show an average annual insolation of 5.02 $kWh/m^2/day$, peaking at 6.6 $kWh/m^2/day$ in April, confirming high solar potential comparable to other tropical FPV sites [19, 27]. The annual mean temperature of 25.1°C and the average wind speed of 3.07 m/s contribute to stable operation and effective cooling of PV modules over the water surface [20]. According to Duffie and Beckman [6], such irradiance and temperature conditions support high conversion efficiency when modules are optimally tilted near the site latitude [9, 15]. The earth-fill dam structure also constrains anchoring methods; thus, non-penetrating deadweight concrete anchors are adopted to maintain stability under fluctuating water levels and wind loads [2]. This hydrological and climatic assessment confirms that the Kun Chaung reservoir provides an ideal environment for 30 MW floating PV system, supporting hybrid operation with the existing hydropower plant to enhance renewable generation reliability and energy security in Myanmar [5, 17, 26].

B. PV system design and array configuration

The proposed floating photovoltaic (FPV) system is designed for a total installed capacity of 30 MW, distributed across thirty (30) PV arrays of 1 MW each.

Each array is configured using LONGi LR5-72HBD 550 W monocrystalline modules, selected for their high efficiency, low temperature coefficient, mechanical robustness, and proven suitability for large-scale floating applications [2, 6, 27]. The key electrical and physical parameters of the selected module are summarized in Table 1, ensuring optimal energy yield, operational reliability, and long-term durability under tropical conditions.

Table 1. PV Module Parameters

No	Parameters	Rating
1	Module Power	550 W
2	Voltage at Maximum power	41.95 V
3	Current at maximum power	13.12 A
4	Short-circuit current (I_{sc})	13.99 A
5	Open-circuit voltage (V_{oc})	49.8 V
6	Cells per module	144 cells
7	Dimension	2278*1134*35mm
8	Weight	27.5 kg

$$V_{Dc\ Link} = 2\sqrt{2}V_{rms} = 2\sqrt{2} * 400 \sim 1150\ V \quad (1)$$

$$\text{Numbers of Modules } (N_m) = \frac{\text{String Voltage } (V_{\text{string}})}{\text{Voltage at Maximum Power Point } (V_{\text{mpp}})}$$

$$\cong 28\ Modules\ per\ String$$

$$\text{Number of strings in an array } (N_{\text{string}}) = \frac{1 \times 10^6}{15.4 \times 10^3} = 64.5 \sim 65 = 65\ strings$$

$$N_{\text{array}} = \frac{P_{\text{total array}}}{P_{\text{array}}} \quad (2)$$

The total plant capacity is 30 MW. Each PV inverter is rated at 1 MW per array. The total number of arrays is calculated using Equation (2), resulting in 30 arrays.

The total number of modules for the system is given by,

$$N_{T,Sys} = N_m \times N_{\text{string}} \times N_{\text{array}} \quad (3)$$

$$N_{T,Sys} = 28 \times 65 \times 30 = 54600 \text{ modules}$$

C. Floating Platform and Mooring/Anchoring Design

The proposed 30 MW floating photovoltaic (FPV) system is configured as five independent islands of 6 MW each, deployed on the Kun Chaung reservoir. Each island consists of modular high-density polyethylene (HDPE) pontoons interlocked to form buoyant rafts that support aluminum or galvanized-steel mounting frames tilted at 21°. The platform uses standard 500 × 500 × 400 mm pontoons, each providing approximately 95 kg of buoyant capacity. Modular Floating Dock Cube parameters is presented in Table 2. Considering a total design load of about 43 kg per PV module—including panel weight, mounting hardware, and a 25 % safety factor—two pontoons are assigned per module to ensure sufficient freeboard and stability against wind and wave action. The resulting freeboard of about 0.31 m provides excellent resistance to small waves and personnel loads. Additional pontoons are incorporated for walkways, perimeter stiffeners, and inverter platforms, bringing the total to roughly 4,550 floats per MW or 136,500 units for the entire plant. The modular configuration allows flexible assembly, simple maintenance access, and good adaptability to seasonal water-level variations of the reservoir.

In this design, each floating island is held in place only by reinforced-concrete dead-weight anchors resting on the reservoir bed. No screw or pile anchors are used. The anchors are placed around the edges and some inside points of the floating platform, at about one anchor for every 250–300 m² of area. This means around 24 anchors for each 1 MW block, about 145 for a 6 MW island, and roughly 725 for the full 30 MW system. To allow for the 15.24 m change in water level during the year, taut mooring lines are used. Each anchor is connected to the platform with a short steel chain (3–5 m) joined to a strong polyester rope, fixed at an angle of 30–45° to the water surface. The ropes are long enough to stretch as the water level changes, usually 28–30 m in total length. The concrete anchors weigh about 3.5–8 tons each, depending on soil strength and wind load, with heavier ones placed at the corners facing the wind. The anchors have built-in steel lifting hooks and galvanized fittings for easy handling and long life. After every monsoon, the system is checked to ensure that the lines remain tight, undamaged, and the anchors in place. This dead-weight anchoring method is simple, reliable, and cost-effective, while providing good stability and safety for the floating solar platforms.

Table 2. Modular Floating Dock Cube Parameters

Parameter	Value / Notes
Product Name	Modular Floating Dock Cube
Model	KS500
Size	500 × 500 × 400 mm
Material	HDPE
Weight	~7 kg (single cube)
Load Capacity	350 kg/sq m

D. Electrical System Design

For the 1 MW floating solar PV system consisting of 28 modules in series and 65 strings, the array operates at approximately V_{mp} = 1,174.6 V with a total MPP current ≈ 852.8 A (I_{sc}_total ≈ 909.4 A; Voc ≈ 1,394.4 V). The array is divided into five combiner boxes, each receiving 13 strings (13 × 13.12 A = 170.6 A per box). Because of the floating environment—high humidity, limited cooling, and UV exposure—tinned-copper conductors with XLPE or EPR insulation rated for ≥ 1.5 kV DC and marine-grade sheathing are required. Each combiner box output uses a single 185 mm² copper cable per polarity, which can safely carry up to 360 A under floating PV derating. From the five combiners to the inverter, the parallel configuration (5 × 185 mm² per polarity) provides an overall ampacity margin for 850 A total current, limits voltage drops below 1.5 %, and ensures reliability under site-specific conditions.

Table 3. DC cable Parameters

Item	Description	Value / Specification
Combiner boxes	5	
Voltage at MPP	1,174.6 V	total
Cable from combiner to inverter	185 mm² Cu (tinned)	1 per polarity / per combiner
Parallel cables to inverter	5 × 185 mm² per polarity	For 1 MW
Cable insulation	XLPE / EPR, 1.5 kV DC	UV + marine grade
Fuse rating	20 A DC per string	PV-rated
Combiner isolator rating	≥ 250 A, ≥ 1.5 kV DC	DC type
SPD	Type 2 DC, ≥ 1.5 kV rating	per combiner

For the 30 MW floating PV system, each 1 MW inverter (SG1100UD-20) outputs AC at 660 V line-to-line with a maximum power of 1320 kVA. The full-load AC current of a single inverter is approximately 1155 A. When 6 inverters are connected in parallel to feed a 0.42/33 kV transformer, the combined low-voltage current reaches about 6930 A. Directly carrying such high current in a single cable is impractical. Therefore, each inverter is connected to the LV bus via 3 × 800 mm² Cu cables, and the LV bus then connects to the transformer using either busbars or multiple parallel cables to handle the total current while minimizing voltage drop. The transformer steps up the voltage from 0.42 kV to 33 kV, where the high-voltage current (~116 A) is much smaller, allowing smaller HV cables. Proper cable sizing ensures efficiency, safety, and reliability of the PV system.

E. Shading Analysis

For the Kun Chaung 30 MW floating solar PV plant, proper spacing between rows is essential to prevent shading and ensure maximum energy yield. The row-to-row distance is calculated by,

$$D = W(\cos\propto + \sin\propto\tan\beta) \quad (4)$$

where W is the panel width and α is the tilt angle.

$$\beta = \propto_{at} + 23.5^{\circ} \quad (5)$$

Where α_{at} is the geographic latitude.

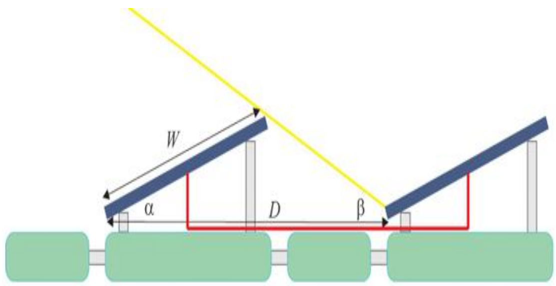

Fig. 2 Spacing between rows (D) to avoid shading [21]

The plant is located at approximately 18°29′ N latitude (α_{at} =18.48°), and the floating PV system uses a reduced tilt angle of 21° to mitigate wind effects. The solar panels have dimensions of 2.278 m × 1.134 m. Substituting these values into the formula yields a row-to-row spacing of approximately 1.42 m. This spacing ensures that each panel row receives optimal sunlight throughout the day, while accounting for the lower tilt of floating installations compared to ground-mounted systems, thereby minimizing shading losses and maximizing energy generation.

F. Energy Yield Estimation and Integrated Performance Analysis

The energy yield of the floating solar PV (FPV) and the integrated hybrid system was evaluated using irradiance and temperature data from the Kun Chaung site. The FPV system showed higher efficiency than ground-mounted PV due to its cooling effect over water. Annual analysis revealed that the FPV system produced about 300 GWh, while the integrated FPV–hydropower system reached 687 GWh, representing an approximate 129% increase in total annual energy generation. The average power rising from 44.1 MW to 64.2 MW, and average monthly energy generation increasing from 33 GWh to 57.25 GWh, an annual gain of about 300 GWh over standalone hydropower. This improvement results from the FPV's direct contribution and enhanced hydropower efficiency due to reduced evaporation. Figures 3 illustrate these gains and confirm the hybrid system's superior energy performance.

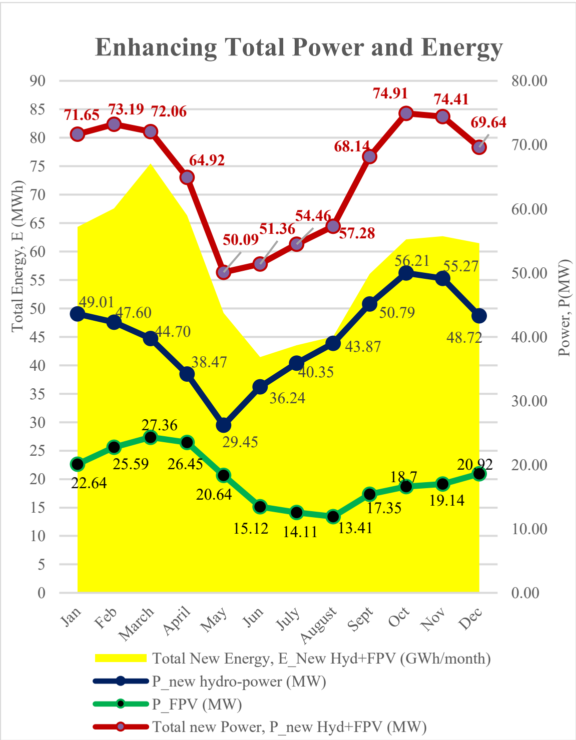

Figure 3. Enhancing Total Power and Energy Generation of Kun Chaung Power Station

V. DISCUSSION

The integration of a 30 MW floating solar photovoltaic (FPV) system with the Kun Chaung Hydropower Plant demonstrates significant technical and operational advantages. Based on calculated and simulated results, the FPV system exhibits improved performance due to its lower module temperature and natural cooling effect from the reservoir surface. The estimated annual FPV energy yield is 687 GWh when integrated with hydropower, representing a 77.3% enhancement in total renewable energy generation. The combined hybrid system also achieves a considerable increase in power output, with the average monthly generation rising from 44.1 MW (hydropower only) to 64.2 MW (integrated system). Similarly, monthly average energy generation grows from 33 GWh to 57.25 GWh, resulting in an annual gain of approximately 300 GWh, which is about 77.3% higher than the standalone hydropower output. These improvements are mainly attributed to the additional energy contribution from the FPV system and the enhanced hydropower efficiency resulting from reduced reservoir evaporation losses, which allow for more water availability for power generation.

VI. CONCLUSION

The integration of a 30 MW floating solar photovoltaic (FPV) system with the Kun Chaung Hydropower Plant shows clear technical and operational benefits. Based on calculation and simulation data, the hybrid system achieves an annual generation of 687 GWh, compared with 300 GWh from the FPV alone, representing 129% increase in total energy output and a 77.3% improvement over standalone hydropower generation. The hybrid configuration not only enhances total generation but also reduces water evaporation, helping to maintain reservoir levels and improve hydropower efficiency. This synergy between floating solar and hydropower ensures optimal use of water resources while reducing land requirements and environmental impacts. Overall, the proposed FPV–hydro integration at Kun Chaung demonstrates a sustainable and effective pathway for increasing renewable energy generation and improving the stability of Myanmar's power system.

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