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Management of Hybrid Hydropower and Floating Solar Systems at Num Ngum 1 in Lao PDR

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Abstract— The integration of a hybrid hydro-floating solar power (HPP-FPV) system is covered in this study with the goal of improving energy management and producing more electricity. The production capacity of the hybrid system is almost twice as high as that of the original HPP system, demonstrating its potential for higher energy generation. Because it forecasts weather and modifies electricity generation accordingly. The analysis highlights how crucial it is to make sure that the hybrid system's electricity generation doesn't go beyond the current power grid's maximum transmission capacity. This is essential to preserving the consistency and caliber of the power that is provided. The research's overall goal of increasing the output of renewable energy through creative system integration and practical management techniques is captured in the abstract.

Keywords— Floating photovoltaic, Hydropower plant, Hybrid hydro-floating solar power system (FPV-HPP) Management, Energy Management System (EMS), System advisor model (SAM)

I. INTRODUCTION

The paper presents a comprehensive approach to managing the hybrid hydropower and floating solar power (HPP-FPV) system at the Nam Ngum 1 Hydropower Plant [1]. The methods employed are designed to enhance energy production efficiency and ensure stable power supply [2, 3]. Num Ngum 1 hydropower plant is a Hydropower electric generating plant of EDL-Generation Public Company (EDL-GEN) in Lao PDR. The HPP's ability to store potential energy in water during off-peak times and release it during high demand is highlighted as a critical feature for optimizing energy dispatch from both sources [4]. A combination of floating solar photovoltaic (FPV) systems with hydropower (HPP) aims to enhance energy generation efficiency and stability, especially during varying demand periods [5, 6]. The FPV system can generate power during the day, while the HPP can provide energy during nighttime or low solar periods [7]. Energy Management System (EMS) to optimize the operation of the hybrid system [8]. The EMS is responsible for monitoring and adjusting energy production based on real-time data, ensuring that the energy supply meets demand effectively [9].

II. METHODOLOGY

Managing a hybrid Hydropower Plant (HPP) combined with Floating Solar Photovoltaic (FPV) systems involves integrating two distinct renewable energy sources with unique operational characteristics [6]. The core theory of management for such hybrid systems revolves around optimizing energy production, balancing power output, and ensuring stable, efficient operations [10].

The principle behind hybrid HPP-FPV systems is that the two energy sources complement each other. When solar energy is unavailable (at night or during cloudy weather), hydropower can step in to meet electricity demand [11]. Conversely, during sunny periods, the solar component helps reduce the reliance on hydropower, conserving water resources for future use, this research has defined 2-3 management systems as follows:

A. *System Integration and Design*

This research selects the floating solar power generation system at Sirindhorn Dam Reservoir as an example of infrastructure design and generation system management [12]. Integrating the floating solar power generation system with the existing hydropower infrastructure [13]. This involves connecting the two systems to a 115 kV switchyard, allowing for efficient energy management and distribution, as shown in Fig. 1 [10].

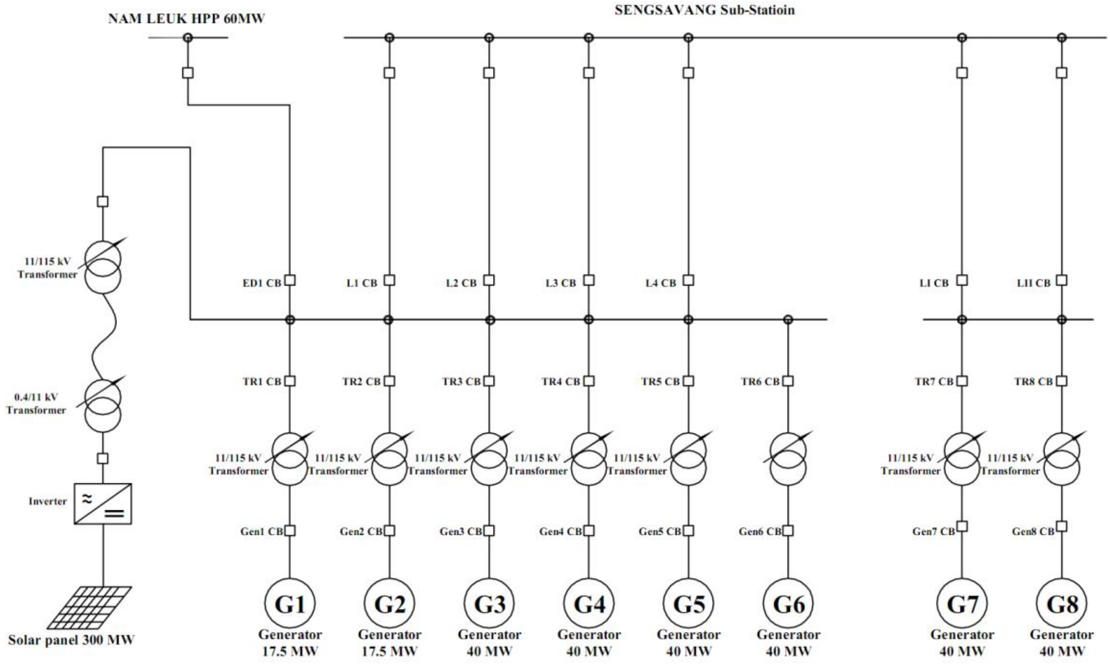

Fig. 1 Single line diagram of NNG1 hybrid HPP-FPV system

Fig. 1, the FPV 300 MW system installed on the surface of the NNG1 reservoir will be connected to the high-voltage switchyard system of the original powerhouse (units 1-6). Therefore, the maximum power generation capacity of the hybrid HPP-FPV system must be less than or equal to the maximum power generation capacity of the generators units 1-6, or less than or equal to the Pmax value of the transmission system connected to the Nam Ngum 1 Power Plant.

An Energy Management System (EMS) is a system used to monitor, control, and optimize the performance of energy generation, storage, and consumption within a facility or across multiple sites [9]. EMS is commonly used in various sectors, including industrial, commercial, and residential settings, as well as in energy production and distribution systems [8]. Which has the following important space functions:

1) Monitoring: The EMS continuously collects real-time data on energy production and supply. Such data includes the electrical parameters produced by the hydro-solar power plant system, weather conditions, and other relevant parameters. The system also processes and analyses the collected data to identify patterns, inefficient performance, and identify adjustment points in the control process. Furthermore, the EMS excels in forecasting energy output using predictive analytics based on solar radiation, water availability, and weather trends. Planning for energy supply and reservoir level control can both benefit from this. Weather forecasting is the heart of the hybrid HPP-FPV system control. Since EMS needs to be planned at least 1 hour in advance, the system must predict the conditions in advance so that the EMS can prepare to increase or decrease the production volume according to the situation and ensure the quality of the energy distributed to the transmission system [8].

2) Control: EMS can automatically adjust the energy consumption process based on preset parameters or real-time data. For example, it can reduce energy consumption during peak hours or shift loads to off-peak hours. The system can manage demand by controlling or reducing the energy load according to grid signals, helping to balance supply and demand [9]. The system sets FPV as the primary source and HPP as the backup. EMS will look at the power received from the FPV system as the main source of energy and compare it to the load or grid demand. If they are in the same range, EMS will let FPV generate power only. But whenever the grid load increases or the solar power decreases, EMS will tell HPP to start the generator to help the FPV system with the power demand (predicted). The HPP system will increase or decrease the production amount depending on the amount of energy lost from the FPV compared to the load value. It is shown that when the intensity of the sun's radiation is weak, the EMS will command the HPP to increase the load and when the sun goes down, the HPP will operate at full load, as shown in Fig. 2. EMS optimizes energy usage to reduce waste and enhance efficiency. By optimizing energy usage, EMS helps reduce energy costs. It can also identify opportunities for cost savings, such as shifting energy use to times when electricity is cheaper. EMS can manage the integration of renewable energy sources like solar panels or wind turbines into the energy mix, ensuring optimal usage of these resources [11].

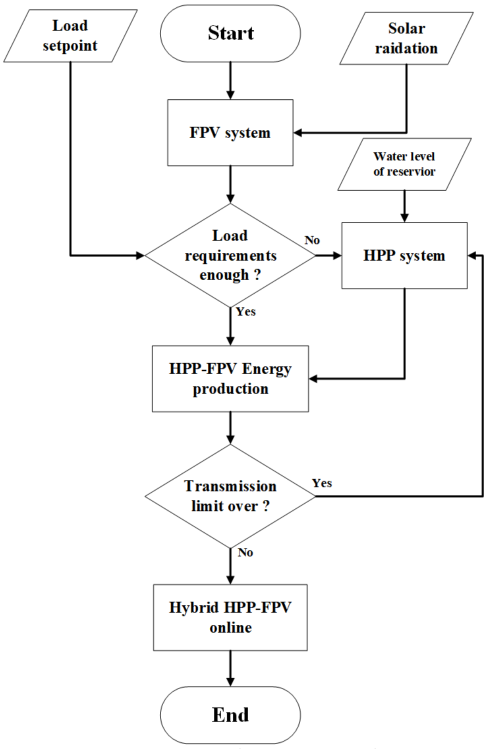

Fig. 2 Control processing flow schematic for the EMS

3) Reporting: EMS can generate reports that provide insights into energy usage patterns, efficiency levels, and areas where energy consumption can be reduced. The system can help organizations comply with regulatory requirements by maintaining detailed records of energy usage and demonstrating adherence to energy efficiency standards [9, 14].

4) Energy Storage Management: In systems that include energy storage (e.g., batteries), EMS manages the charging and discharging processes to maximize efficiency and ensure that stored energy is available when needed. EMS can interact with the grid to either draw power during low-demand periods or feed excess power back to the grid [14].

5) User Interface: Most EMS platforms provide a user-friendly dashboard that displays key metrics, alerts, and controls. This allows facility managers or operators to make informed decisions and take corrective actions quickly. Modern EMS systems often include remote access capabilities, allowing users to monitor and control energy systems from anywhere via the internet [8].

B. Operation management

1) Maximum Production Calculated: When developing a hybrid hydropower plant with floating solar PV (HPP-FPV) system, defining the production scope involves determining the capacity, energy output, operational objectives, and integration of both the hydropower and solar PV systems [3]. The calculation of the maximum power generation of the hybrid system is equal to the existing installed capacity of the hydropower plant [5] plus the power generation of the PV system as Eq.1 [6] obtained from the simulation results of the SAM software are shown in Table 1 [2, 15].

TABLE 1
SPECIFICATION AND SIMULATION RESULT OF THE HYBRID FPV-HPP AT NNG 1

Specifications			
Existing capacity (MW)	195	**Rated inverter size (MW)**	230.77
Quantity of transmission line (Circuit)	5	**Inverter efficiency (%)**	96
Conductor current-carrying (A)	600	**Array type**	Fixed open rack
Voltage of transmission system (kV)	115	**Array tilt**	20°
System Nameplate Capacity (MWdc)	300	**Array azimuth**	180°
Surface coverage (m²)	1,578,947	**Total system losses (%)**	14.08
Scale of reservoir area (%)	0.43	**Annual energy in year (kWh/year)**	421,641,825

Then the maximum power of the hybrid system can be calculated as follows:

$$P_{HYBRID} = P_{HPP} + P_{FPV} \qquad (1)$$

- Then the maximum power of the hybrid system: $P_{HYBRID} = 195 + 230 = 425$ MW.

From the total electricity generation figures calculated above, the electricity generation of the hybrid system is almost twice that of the original HPP system. Therefore, to ensure that the quality of the electricity to be exported is stable, we must consider it together with the existing power transmission system [5], which means that the electricity generation of the HPP-FPV hybrid system must not exceed the maximum transmission capacity of the 115 kV transmission system to which each dam is connected [12]. Therefore, the transmission capacity limit of the power transmission line must be calculated using the basic electricity formula for finding the energy in the power system, as shown in Eq.2 [16].

$$P_{LINE} = U \times I \times \sqrt{3} \times n \qquad (2)$$

Where:

- P_{LINE}: Capacity of transmission line (W)
- I: Conductor current-carrying (A)
- U: Voltage of transmission system (V)
- N: Quantity of transmission line

From the initial collected real data, it was found that the Nam Ngum 1 Hydroelectric Dam consists of 2 power plants: The old power plant, which began construction in 1968, has had additional generators installed periodically. As of 2021, the old power plant has installed 6 generators and consists of a 115 kV high-voltage transmission system connected to the SENGSAVANG substation, 4 circuits, and 1 circuit connected to the Num Luek hydropower plant. The expansion project, which began construction in 2014 and was completed in 2018, includes two 40MW generators and two 115kV transmission circuits connected to the SENGSAVANG substation.

Then, the maximum load limit of the power transmission system can be calculated by selecting the part to be connected to the HPP-FPV hybrid system. In particular, the Nam Ngum 1 power plant, which in this research was selected to be connected to the switchyard system of the old power plant with 5 circuits.

$P_{LINE} = 119.51 \times 5 = 597.54$ MW.

The results obtained from the above calculation can confirm that the transmission system of both power plants can also support the production capacity of the FPV system designed effectively.

To verify that the calculated maximum power of the HPP-FPV hybrid system is reliable and can be used for future production planning, the energy production data within 1 year was used by randomly selecting the maximum daily power generation of the solar system obtained from the simulation in the SAM software and integrating it with the installed capacity of each power plant [7]. The FPV system at the NNG1 reservoir was able to produce the most in early March, equivalent to 222.63 MW. The results were found to be close to the calculated values, with values in Table I, and the daily production capacity changes can be shown in Fig. 3.

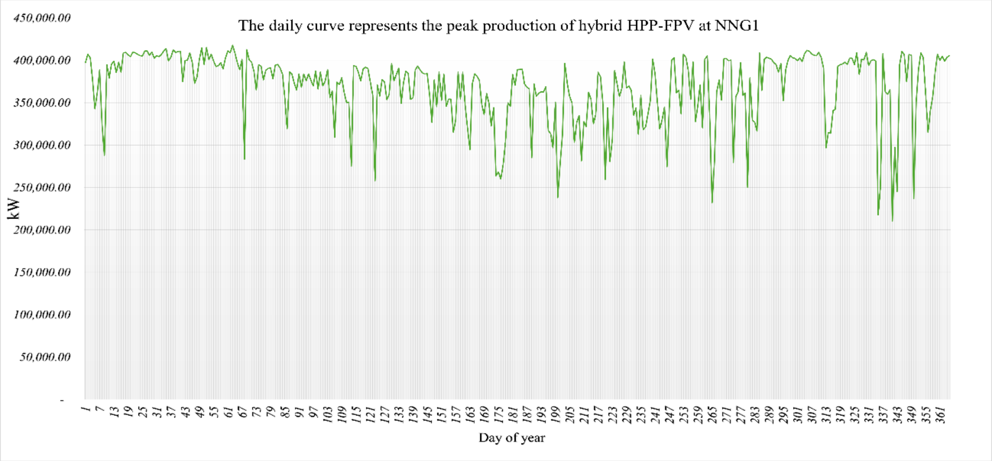

Fig. 3 Daily energy generation curve of hybrid HPP-FPV at NNG1

2) Energy production estimates: Estimating the energy production of a hybrid HPP-FPV system requires a comprehensive approach that accounts for the unique characteristics of both hydropower and floating solar PV components [10]. By systematically calculating the potential energy output of each system and considering factors like capacity factors, environmental conditions, and system efficiencies, a more accurate and reliable estimate can be achieved. This estimation is crucial for planning, optimizing operations, and ensuring the financial viability of the hybrid energy project. The energy yield of the hybrid system (E_{HYBRID}) will be equal to the actual hydropower yield of the production data plus the solar power yield from the Schoffer SAM simulation according to Eq. 3[15].

$$E_{HYBRID}= E_{HPP}+E_{FPV} \qquad (3)$$

Where:

- E_{HPP}: Energy produced by HPP systems (kWh)
- E_{HPP}: Energy produced by FPV systems (kWh)

From the actual production results of NNG1 HPP in 2023, are shown in Table 2 and Fig. 4, from April to September, which is the rainy season in Laos, NNG1 1 HPP has reduced its production capacity so that the Run-off-Rever power plant can produce electricity at full capacity. because NNG1 HPP is the largest reservoir system in the Lao PDR, which can store billions of cubic meters of water.

TABLE 2
ANNUAL ENERGY YIELD OF NNG1 HYBRID HPP-FPV (300 MW OF FPV)

Month	**E_{HPP} (kWh)**	**E_{FPV} (kWh)**	**E_{hybrid} (kWh)**
Jan	110,347,804	40,822,000	151,169,804
Feb	122,332,158	39,722,800	162,054,958
Mar	147,051,075	40,822,400	187,873,475
Apr	110,405,465	36,479,600	146,885,065
May	78,187,490	35,964,500	114,151,990
Jun	47,261,820	28,520,300	75,782,120
Jul	62,183,073	29,911,500	92,094,573
Aug	33,221,303	30,462,400	63,683,703
Sep	82,246,775	30,892,200	113,138,975
Oct	158,929,190	34,445,900	193,375,090
Nov	143,859,731	39,114,900	182,974,631
Dec	168,539,562	34,483,400	203,022,962
Year	1,264,565,446	421,641,900	1,686,2207346

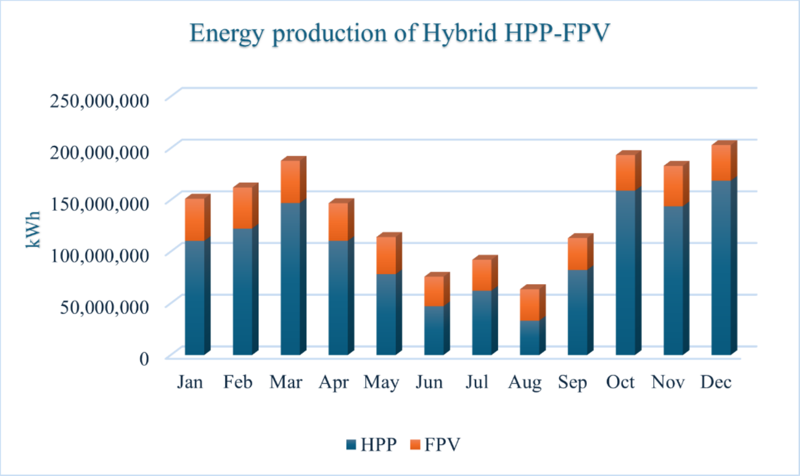

Fig. 4 The monthly energy production bar graph for NNG1's HPP-FPV system

3) Water management:

3.1) Rearranging for HPP generation: To maintain the efficiency of the hydropower plant's power generation system to remain stable and not affect the structure of the FPV system [13]. Therefore, it is necessary to reorganize the production system for the HPP system. By giving priority to FPV first by giving priority to FPV first, as mentioned in the control system topic. The HPP-FPV system should be designed to manage peak loads effectively [7]. During the day, the FPV system can provide power directly from solar energy, while the hydropower component can be used during nighttime or low solar periods.as shown in Fig. 5. The HPP can store potential energy in water during periods of low electricity demand (off-peak times) and release it during high demand. This helps to optimize energy dispatch from both sources. During the day, the HPP will be able to store the potential energy in the water during periods of low electricity demand (off-peak time) and can run the generator whenever the transmission system has an increased load [7]. This Planning will help to increase the efficiency in producing energy from both sources with certainty and high stability.

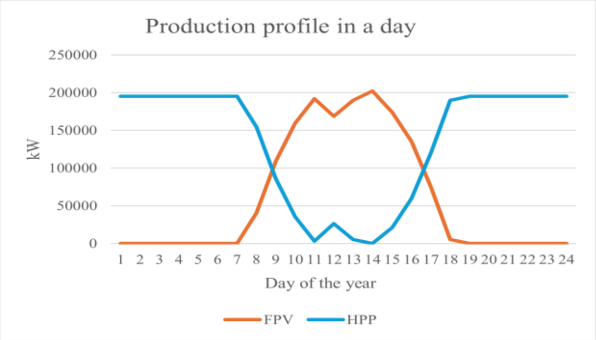

Fig. 5 Energy profile of hybrid HPP-FPV at NNG1 (in PV 300 MW scenario)

3.2) *Reexamine the water variable's scope*: The structural elements of a floating solar PV system are designed to ensure its stability, durability, and efficiency in a challenging aquatic environment. Each component, from the floating platforms to the electrical infrastructure, is carefully chosen and engineered to optimize performance while minimizing maintenance and environmental impact [11]. The selection of the FPV location in each dam is an important factor. Before starting construction, a diving team must be organized to thoroughly survey the underwater area and then the scope and area of the FPV system structure can be determined. Basically, the FPV area must be within the water surface area at the lowest water level of the rule curve of each HPP. The management of water management in the production of HPP electricity will need to adjust the rule curve a little by adjusting the minimum water level up to about 1-2 meters to avoid affecting the structure of the FPV system, as shown in Fig. 6 [13].

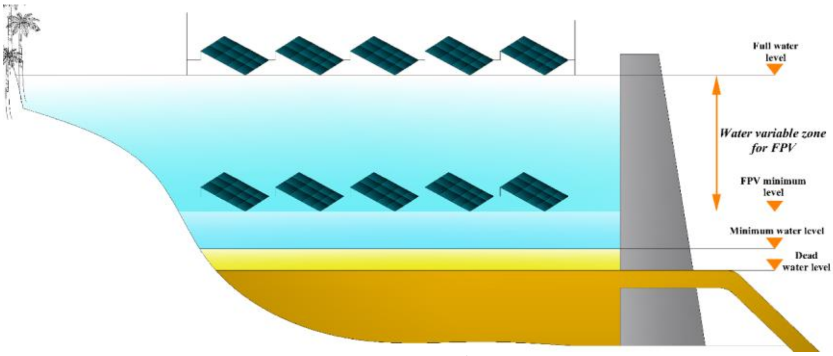

Fig. 6 Water variable zone of hybrid HPP-FPV

Therefore, in the dry season, NNG1 HPP will run the generator to produce electricity at full capacity to keep the water level in the reservoir before the rainy season, which must be at least 10 meters below the full water level of the reservoir and have distance from lowest level 3-4 maters. From the water level data in last year, NNG 1 Power Plant managed water lower than the normal water level control criteria, but still far from the minimum water level as shown in Fig. 7. Therefore, water management at NNG 1 Dam can follow the original rule curve.

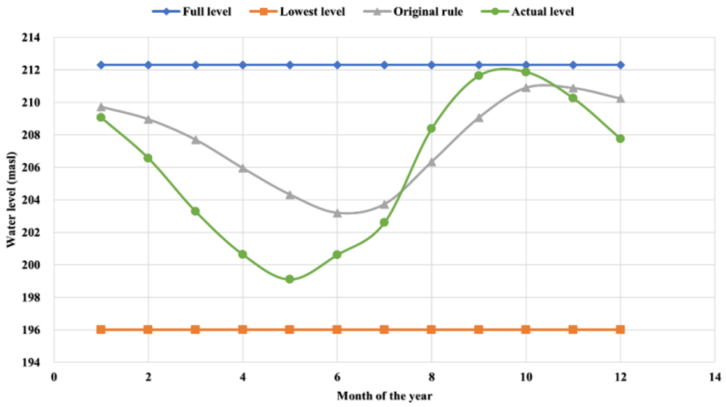

Figure 7: Water management curve of NNG1 HPP

III. CONCLUSIONS

The integration of the HPP-FPV hybrid system significantly enhances electricity generation, nearly doubling the output compared to the original HPP system. The maximum production capacity of the FPV system at the NNG1 reservoir reached 222.63 MW. The power transmission system's capacity must be carefully managed to ensure that the hybrid system's electricity generation does not exceed the maximum transmission capacity of the existing 115 kV system. The hybrid system significantly enhances energy generation, with the total electricity output being nearly double that of the original HPP system. This demonstrates the viability of integrating FPV technology with existing hydropower infrastructure [4]. The Energy Management System (EMS) plays a crucial role in adjusting production levels based on solar radiation and load demands. It ensures that the FPV system serves as the primary energy source while the HPP acts as a backup, optimizing energy distribution and maintaining grid stability. The integration of energy production data from both systems supports the accuracy of these estimates. The paper emphasizes the need to consider the existing power transmission system's capacity to ensure that the hybrid system's output does not exceed the maximum limits, thereby maintaining the quality of electricity supplied to the grid. Overall, the findings advocate for the adoption of hybrid systems in energy management to enhance efficiency and sustainability in power generation.

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