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Potential Analysis of Hybrid Floating Solar Photovoltaic Systems with Hydropower Electricity Generation in Lao PDR

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Laos' economy is primarily based on the agriculture sector, which drives the country's economic growth. However, the hydropower sector is experiencing the highest emerging growth, with significant export potential to neighboring countries. With a maximum potential of 18 GW of hydropower, Laos aims to provide the nation and the region with sustainable and clean energy. This research aims to investigate the possibilities of floating photovoltaic (FPV) systems in Laos, particularly at the Nam Ngum 1 (NNG1) and Huay Lamphan Gnai (HLG) dams. Its goal is to increase the efficiency and sustainability of electric energy production by combining FPV systems with hydropower plants (HPP). The research demonstrates the feasibility of installing FPV systems on the selected dams, which would lead to cost savings and increased overall efficiency. By integrating FPV systems with hydropower, the paper contributes to enhancing the renewable energy mix in Laos and the region, supporting the country's goal of providing sustainable and clean energy. The findings of the research provide valuable insights for policymakers, energy planners, and stakeholders in the energy sector to consider the benefits of hybrid systems for future energy projects in Laos and similar regions.

1. Introduction

Energy is crucial for socio-economic development, and renewable energy sources are seen as a solution to mitigate climate change and its adverse effects from natural disasters. ASEAN has set a target of achieving a 23 % share of renewable energy in the total primary energy supply by 2025. In Southeast Asia, the pattern of solar irradiation is advantageous due to the region's geography. To meet renewable energy (RE) goals, it is essential for solar energy technologies to continue advancing. Additionally, there is a global shift away from carbon-reliant energy systems toward carbon-free alternatives. Therefore, ASEAN nations aim to develop decentralized, carbon-free electricity using solar power (Surendra et al., 2022).

From water usage statistics to produce electricity by EDL-Gen previously, there have been some years when the amount of water in the reservoir has been insufficient to meet demand, especially in the dry season. Many power plants must run the generator to generate electricity at the lowest water level, which must be turned off to wait for the water level in the reservoir to increase, this may take several days or might need to be held off until the rainy season. As a result, electricity production does not go as planned. In addition, some power plants must run generators to produce electricity at water usage rates less than 60 % of the required efficiency to support the load of electricity consumers in regional areas, which is not good for generator systems, especially turbine systems (Nishi et al., 2020).

A hydroelectric power system is a method of producing electricity by harnessing the energy of moving water. Production efficiency is determined by the ratio of the reservoir's water level, when the water level drops, production capacity will decrease as well (Bragalli et al., 2023).

Solar PV systems use solar energy as the main factor in generating electricity. The efficiency of producing energy is determined by the amount of solar irradiance. The installation of ground-based photovoltaic systems is challenging and has a big influence on the environment. Some of the challenges include site acquisition, compensation, evacuation zones, and environmentally destructive land invasion. The heat dissipation of the soil also affects the efficiency of solar panels, which inevitably results in a loss of production capacity (El Hammoumi et al., 2022).

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Currently, a system for generating electricity from solar energy has been developed to be installed on the surface of the water called “floating solar photovoltaic (FPV)” (Pouran et al., 2022). FPV systems can be put anywhere that is convenient, particularly near the reservoirs of different power dams.

Therefore, when both systems are installed collectively, it will be a "hybrid" electricity generation system between a solar photovoltaic system and a hydropower generation system. This can help increase production capacity or save water. When separating the production time into two periods, use FPV during the day and HPP at night (Piancó et al., 2022).

The main objective of this research is to find ways to increase the efficiency of electricity production for hydroelectric power plants in Laos that focus on finding clean alternative energy sources to help save water, especially during the dry season. In addition, this article also analyzes the environmental benefits that would follow from integrated power generation.

Among the hydropower plants managed by EDL-Gen are six large reservoirs, each with a full water level covering at least 500 hectares and a water surface area of at least 68,000 m^2 (EDL-GEN, 2024). Upon completion of the installations, it will be possible to conserve the water used in electricity production. This research utilizes simulations involving the Nam Ngum 1 (NNG1) Hydroelectric Dam and the Huay Lamphan Gnai (HLG) Hydroelectric Dam as case studies. The location of each site is shown in Figure 1.

Figure 1: Location on map of NNG1 and HLG

2. Methodology

2.1 Capacity calculations

In the initial stage, the researcher will define the potential analysis of both reservoirs into three scenarios based on the water surface area: 1 %, 5 %, and 10 %, and determine the extent of the capacity to build the floating solar PV systems using the formula provided in Eq(1). The calculation results with basic information are shown in Table 1.

$$P_{FPV}=\frac{(A_{RES} \text{ x } \%C_{RES})}{A_{1MWp}} \text{ x } 1MWp \qquad (1)$$

Where P_{FPV} is the capacity of potentials for each reservoir under different scenarios (kWdc), A_{RES} is reservoir area (m^2), %C_{RES} is percentage of reservoir covered (m^2), and A_{1MWp} is area occupied for 1 MWp installation (4,663.2 m^2) (Pouran et al., 2022).

Table 1: Basic information about the selected site and the calculation results of each scenario for both reservoirs

Basic information and calculated information			Site name	
			NNG1	HLG
Exiting capacity (MW)			275	88
Total area of water surface at full level (km²)			370	6.82
Scenarios	1 % of total area	Surface coverage (m²)	3,700,000	68,200
		DC Capacity (kWdc)	793,450	14,630
	5 % of total area	Surface coverage (m²)	18,500,000	341,000
		DC Capacity (kWdc)	3,967,230	81,120
	10 % of total area	Surface coverage (m²)	37,000,000	682,000
		DC Capacity (kWdc)	7,934,470	146,250

2.2 Sizing Design of FPV

This research uses the System Advisor Model (SAM) program version 2023.12.17 to assist in the design of the system. which is provided by the National Renewable Energy Laboratory (NREL). SAM supports the simulation and optimization of various renewable energy systems, including photovoltaic (PV), concentrated solar power (CSP), wind power, and more.

Prior to the creation of the simulation. It is important to visit and collect actual data at the two hydropower plants. Precise location information is provided so that the program can pull weather data from NREL, a database used to calculate solar intensity and other weather factors directly affecting the potential of the solar cell system that will be installed.

The installed capacity of the photovoltaic system is then determined using the water surface area values for each scenario calculated in Table 1 as a basis. Other parameters are determined based on the value of the underlying software.

2.3 Ability to reduce the amount of water used to produce electricity of HPP analysis

The simulation used in this research uses NNG 1 and HLG hydroelectric dams as case studies.

From design data and production statistics from the past several years. The rate of water use in the electricity production of the two power dams can be calculated in Eq(2) (Haas et al., 2020).

$$W_r = \frac{Q_t}{E_{hpp}} \quad (2)$$

Where W_r is the rate of consumption of water (m^3/kWh), Q_t is the actual amount of water passing through the turbine (m^3), and E_{hpp} is the actual annual energy in the hydropower plant (kWh/y).

In 2022, NNG1 hydropower plant has actual annual energy in the year of 1,055,608,087 kWh, and the actual amount of water passing through the turbine is 10,970,667,221 m^3, so the rate of consumption of water equals 10.4 m^3/kWh. HLG hydropower plant has an actual annual energy in the year of 478,040,000 kWh, and the actual amount of water passing through the turbine is 380,712,331 m^3, so the rate of consumption of water equals 0.8 m^3/kWh.

The amount of water lost during the generation of energy from both hydroelectric dams may therefore be calculated using Eq(3) (Haas et al., 2020).

$$Q_s = E_{FPV} \text{ x } W_r \quad (3)$$

Where Q_s is the amount of water that has dropped (m^3) and E_{FPV} is the FPV system's yearly electricity generation (kWh/y).

2.4 Greenhouse gas reduction analysis

Among the greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases). These gases cause climate change and global warming by trapping heat in the earth's atmosphere (Oertel et al., 2016). The quantity of greenhouse gases created when the same amount of power produced by a renewable energy system is produced using a fossil fuel energy system is referred to as the reduction of GHG emissions. It is calculated by the following, Eq(4) (Sapthanakorn and Salakij, 2021).

$$G_t = E_{FPV} \times G \times (1 - \beta_L) \tag{4}$$

G_t is amount of GHG reduced annually ($kgCO_2/y$), E_{FPV} is annual electricity production from the FPV system (kWh/y), G is standard value of GHG emissions for each country ($kgCO_2/kWh$), β_L is average loss rate of the power transmission and distribution. In this paper, the GHG value land-based on Thailand power development plan (PDP2018) rev. 1 (Sapthanakorn and Salakij, 2021), which G = 0.44 ($kgCO_2/kWh$) and the average loss rate from 2023 to 2024 of the power transmission and distribution in Lao PDR is 0.068.

3. Results and Discussion

3.1 Simulation results

Simulations conducted using the PVWatts function in the SAM program indicate the feasibility of installing floating solar systems on the surfaces of the NNG1 Dam and HLG Dam. The simulation results provide comprehensive answers to the research questions, especially regarding the installed capacity for each scenario and the basic cost of installation. These are reliable indicators for making construction investment decisions. The simulation results in Table 2 clearly show that installing a solar power generation system on the NNG1 Reservoir has very high potential, Just 1 % of the total reservoir area can install more than 700 MW of floating solar power systems, But if we use 10 % of the reservoir area to install solar panels We will have a capacity of more than 7,000 MW, The efficiency is equivalent to the total capacity of existing hydroelectric power plants in Laos. As for installing the system on the surface of the HLG reservoir, it will be smaller according to the surface area of the water; 1 % of the water surface area at the full water level of the basin can be used to install solar panels not exceeding 13 MW.The goals of the research are to determine the potential of each dam and to manage the hydroelectric power generation system in conjunction with floating solar power generation.

Table 2: Simulation results for each scenario

System and financial parameters			Project name	
			NNG1	HLG
Simulation of each scenario	1 % of total area	System Nameplate Capacity (kWdc)	703,000	12,958
		Capital cost (USD)	816,183,000	15,044,238
		Fixed operating cost (USD)	11,655,739	214,843
	5 % of total area	System Nameplate Capacity (kWdc)	3,515,000	64,790
		Capital cost (USD)	4,080,915,000	75,221,190
		Fixed operating cost (USD)	58,278,699	1,074,218
	10 % of total area	System Nameplate Capacity (kWdc)	7,030,000	129,580
		Capital cost (USD)	8,161,830,000	150,442,380
		Fixed operating cost (USD)	116,557,399	2,148,436

Consequently, it has been decided that the size of the FPV system's installation will not exceed that of the existing power plant. This approach will help reduce the cost of installing the FPV system, particularly the cost of constructing the electrical transmission system, and will improve the efficiency of the dam. The FPV design simulations for the two dams, along with their current installed capacities, are described in Tables 3 and 4.

Table 3: Monthly data of solar irradiance and AC energy

Month	Daily average solar irradiance ($kWh/m^2/d$)		AC Energy in Year (kWh/y)	
	NNG1	HLG	NNG1	HLG
Jan	5.9	5.69	40,821,983	11,767,806
Feb	6.51	6.11	39,722,784	11,092,146
Mar	6.05	5.05	40,822,428	10,175,337
Apr	5.73	4.98	36,479,591	9,688,744
May	5.44	4.68	35,964,493	9398,332
Jun	4.43	4.25	28,520,269	8,383,027
Jul	4.39	3.57	29,911,528	7387,605
Aug	4.52	3.5	30,462,351	7,210,351
Sep	4.76	4.33	30,892,216	8,623,810
Oct	5.14	5.52	34,445,860	11,171,559
Nov	5.94	5.39	39,114,905	10,866,609
Dec	4.91	5.01	34,483,385	10,512,581
Year	5.31	4.84	421,641,825	116,268,913

Table 4: Simulation results under the existing capacity

Result value from SAM simulation	Project name	
	NNG1	HLG
Existing capacity (MW)	270	88
System Nameplate Capacity (kWdc)	300,000	90,000
Surface coverage (m²)	1,578,947	473,684
Capital cost (USD)	348,300,000	10,449,000
Fixed operating cost (USD)	4,973,999	1,492,199
LCOE (cents/kWh)	8.76	9.53

The amount of solar radiation obtained from the simulation is displayed in Figure 2a and 2b. The area of NNG1 reservoir receives more sunlight than the area HLG reservoir; The intensity of sunlight is most effective from January to May, and during Laos' rainy season, which runs from June to September, there will be prolonged periods of cloudy and rainy weather. As a result, the amount of solar radiation is low.

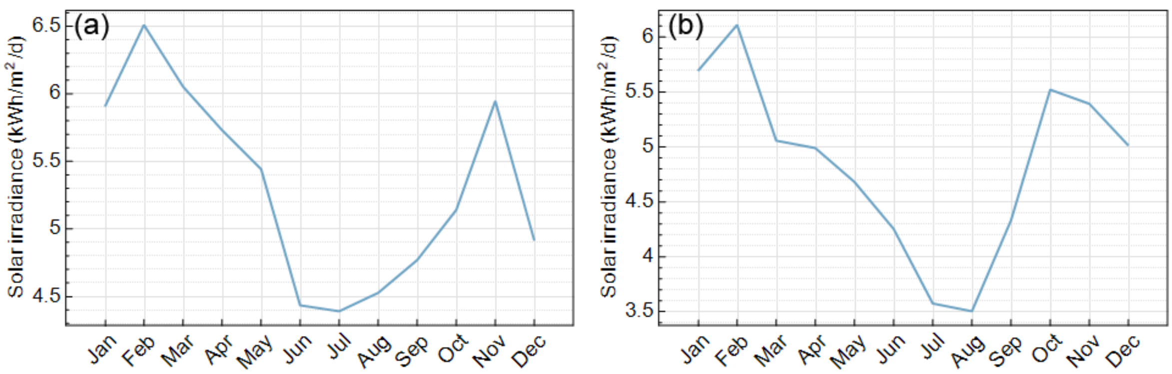

Figure 2: Monthly average of solar radiation for the (a) NNG1 region and (b) HLG region

The bar graphs of the average amount of energy the system can produce in a year are shown in Figures 3a and 3b for both locations, demonstrating that the largest electricity generation occurs from October to December and from January to May for FPV systems. This will frequently decrease from June to September.

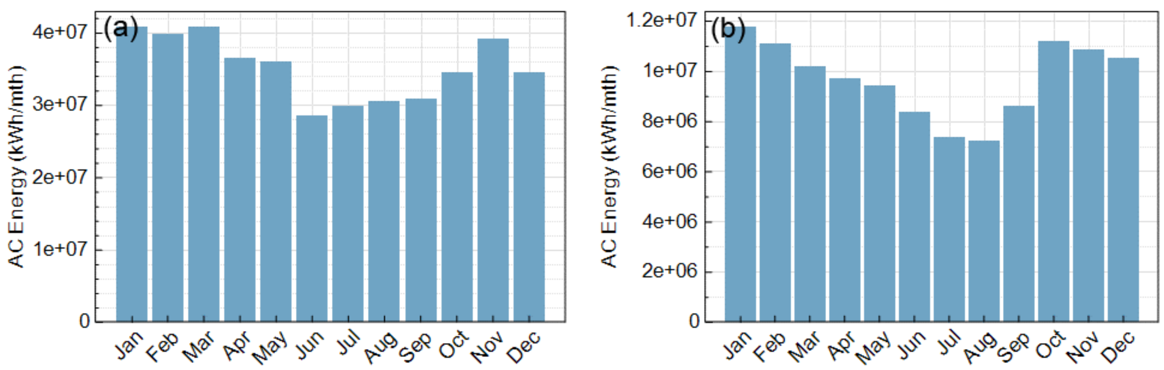

Figure 3: Monthly AC energy average in a year of the FPV at (a) NNG1 reservoir and (b) HLG reservoir

3.2 Ability to reduce the amount of water used to produce electricity and greenhouse gases (GHG)

From the data on production values in one year of the floating solar photovoltaic system under existing capacity. that is simulated through the SAM program, it is possible to calculate the amount of water saved from hydropower generation and reduced greenhouse gas emissions from a hybrid FPV with HPP. by using Eqs. (3) and (4) as follows in Table 5.

Table 5: GHG reduction and water energy savings calculations' outcomes

Project name	Capacity (MW)	Annual electricity generation (kWh/y)	GHG (t CO_2/y)	Amount of water saved (m^3)
NNG1	300	421,641,825	172.91	438.51×10^7
HLG	90	116,268,913	47.68	9.3×10^7

4. Conclusion

The integration of floating solar technology over reservoirs not only enhances energy generation efficiency but also contributes to environmental sustainability by utilizing clean and renewable energy sources. Insightful information for future energy planning and decision-making is provided by the findings, which highlight the significance of clean energy sources like solar and hydropower for socioeconomic growth in Laos and the larger Asian region. Overall, the findings provide valuable insights for future energy planning and decision-making. It emphasizes the importance of using clean energy sources for economic and social development in Laos and the wider Asian region. In particular, the area in front of the NNG 1 HPP reservoir has high potential for installing an FPV system. Simulation results clearly show that only 1% of the water surface area can be installed, producing more than 700 MW of electricity.

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