Benefits of Floating Photovoltaic Technology

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Abstract— As we know, due to limited fossil fuel resources and rising energy demand, solar energy, which is a free and unlimited source of energy that is also eco-friendly and environmentally sustainable, is becoming widely attractive. But, due to land-use constraints, the cost of land and site preparation, and water evaporation and to take some environmental benefits, floating solar photovoltaic (FPV) systems have become an increasingly viable application of photovoltaic (PV) in Solar Energy field. This research paper reveal the advantages of FPV technology in the areas of energy, food, water and economic, such as enhanced efficiency of the panels, reduced usage of land and improved water quality, which will be the beneficial in the future. These benefits above are supported by practical and theoretical research data. Based on the categorization of benefits according to the practical and theoretical data, we are figuring out in which areas need further research.

Keywords— Benefits of Floating Solar Power Plant, Floating Solar Photovoltaic (FPV), Floating Solar Power Plant, Renewable Energy, Hybrid Floating Solar Photovoltaic

I. INTRODUCTION

Land use competition for buildings, industry, food production, power generation, transportation, fuel production, and ecosystem products and services increases as populations grow, resulting in increased demand for housing, food, and energy [1]. By 2050, global energy demand is expected to rise by 25–50 percent, with Asia, South America, and Africa leading the way [2]. Increases in energy demand are expected to put additional strain on existing land resources. Renewable energy projects, on average, have a larger land footprint than fossil fuel installations. Fossil-fuel and nuclear generation projects often require new land, but renewable energy projects can typically reuse the same area. Land competition is particularly fierce in land-scarce countries. Alternative power production solutions with low or no land-use restrictions could help reduce the energy–land nexus's burden. Therefore, innovative technology and policy approaches which make the best use of land resources are needed.

Water plays a wide range of roles, including irrigation, drinking water, sanitation, power generation, recreation, ecosystems, and industrial uses, in addition to its relevance to global ecosystems. In 2014, global water consumption was expected to be 10% for power generation and primary energy production, 7.5 percent for industrial, 15% for municipal usage (such as drinking water and recreation), and 68 percent for agricultural use [3,4]. Due to increase in population, global water consumption for power generation, food production, and industrial and domestic use is expected to rise by 20–30% over the next 30 years, raising questions about the sustainability of these resources as a result of competing demands [3]. Water is also subject to the effects of climate change, which affect freshwater availability, evaporation, and water quality. Thermoelectric and hydroelectric power plants, which need a reliable supply of water, continue to control the world's power supply. Due to the effects of climate change on water availability and quality, these power generation systems may become stalled infrastructure, resulting in reduced electrical capacity and blackouts. Therefore, increased use of renewable energy, energy-efficiency improvements, and widespread adoption of water-saving technologies in power production could help mitigate these concerns and balance the effects on water use for other purposes.

Floating solar photovoltaic (FPV) systems have emerged as a potential technical option for meeting future energy demands while alleviating some of the strains on land and water resources that have been highlighted. As a result, this PV deployment option has attracted the attentions of power industry players in land-constrained countries. FPV systems, both stand-alone and hybridized, are a type of PV system in which panels are installed on water rather than on land or on a rooftop. Lower infrastructure cost of installation by reusing existing transmission system and better power quality of PV, greatly reduced dependence on surface water for generating electricity, particularly during dry spells and other water shortage periods, and diminished erosion from reduced wave action in reservoirs all seem to be potential benefits of

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integrating FPV systems with hydropower plants. Lee et al. [5] estimated global technical potential for FPV-hydropower hybrids range to be 4251 to 10,616 TWh (enough to meet 29–72 percent of additional power generation needs by 2040).

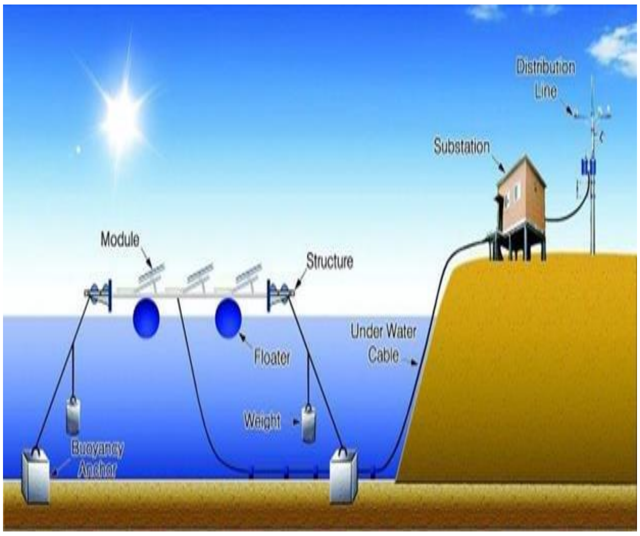

Figure 1: Floating Solar Power Plant Outline

II. STANDALONE (S) AND HYBRIDIZED (H) FPV BENEFITS

Benefits from stand-alone (S) and hybridized (H) FPV are classified into the following categories:

A. Energy:

- Improves the efficiency of the panel (for both S and H)
- Reduces the amount of shading (for both S and H)
- Increases the density of panel packing (for both S and H)
- Enhances the quality of power (for only H)

B. Land or Food:

- Repurposes land that would otherwise be unusable (for both S and H)
- Reduces the amount of land used (for both S and H)
- Increases energy sources in areas where there is a high demand for energy or where there are a lot of people (for both S and H)

C. Water:

- Decrease the temperature of the water (for both S and H)
- Reduces the creation of waves (for both S and H)
- Evaporation is reduced (for both S and H)
- During a drought, it produces electricity (for only H)
- Algae growth is reduced, and water quality is improved (for both S and H)

D. Economic:

- It makes use of existing power transmission lines (for both S and H)
- Enhances the quality of power (for only H)
- Site preparation is less time consuming (for both S and H)
- Prolongs the life of the system (for both S and H)
- It makes installation easier (for both S and H)

III. RESEARCH PROCEDURES (METHODOLOGY)

The research is developed on a broad literature review that looked for practical data on the benefits of FPV systems, both stand-alone and hybridized FPV. A thorough literature search was done to find latest research on FPV benefits, as shown in Figure 2. This included finding FPV research that was related to the benefits. When finding done, we narrowed our study to evaluating current, publically available articles to assist construct a list of claimed benefits and find additional information sources. After, construct list of benefits that have been claimed, we looked through the sources to see if they were based on theoretical data, practical field data, or other data. The benefits were then classified as follows:

1. Papers that offered practical field data from current FPV installations were practically validated benefits.
2. Where modelling study supported the statement of a benefit but there was no practical field data, it was theoretically validated benefits.
3. Where the mention of a benefit was backed by self-citing data sources or no data or citation, it was unclear or understudied benefits.

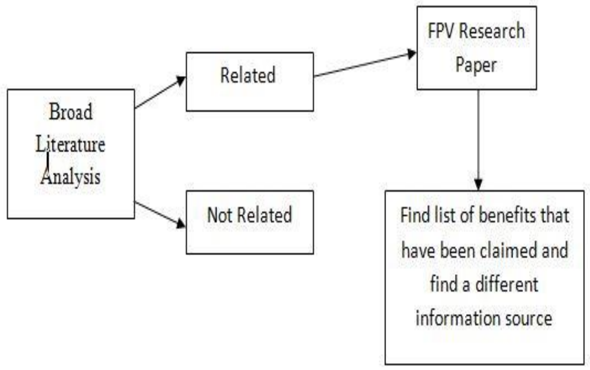

Figure 2: Find list of benefits that have been claimed

IV. HOW FPV TECHNOLOGY IS BENEFICIAL

A. Benefits related to Site-Specific Power Generation:

When compared to a land-based PV system, the most commonly recorded and practically proven benefit is greater panel efficiency, which leads to increased power generation. A 5–11% boost in power generation has been observed in California (US), Italy, Spain, and other regions with pontoon systems that enable air circulation behind the panel [6,7-9,10]. This increase in panel efficiency is directly related to the panel's lower operating temperature, which is a well-reported benefit of installing the PV system on a body of water. Because of the water and air movement beneath the PV panels on the pontoons, the operating temperature is lower. Depending on the pontoon design and climatic zone, the levels of panel efficiency vary [11,7].

B. Benefits related to Land

Reduced land consumption is one of the well-documented benefits of FPV systems. FPV systems can support larger PV installation in places with land constraints or high land costs. In this field of study, quantitative analysis is still developing; however, Cagle et al. [12] published an practical study at four sites in the United States that suggested three criteria to analyze the land and water usage efficiency of FPV systems: the land sparing ratio, water surface usage efficiency, and water surface transformation are all important factors to consider. Despite the higher cost of the floatation system, in many circumstances, the lower cost of land acquisition and preparation results in a significant cost benefit for the FPV system, translating to up to 26% lower development costs than ground-mounted PV. Also, Liber et al. [17], in way of comparison to land-based PV systems, a primary theoretical analysis of the trade-offs between land use savings and power generating efficiency in FPV systems was conducted. The study shows that FPV systems have a greater PV panel packing density, allowing for more PV capacity to be deployed for a given surface area; nevertheless, land-based PV systems may have a little higher power generation efficiency due to factors like as ideal tilt angles.

C. Benefits related to Water

One of the most prominent benefits claims is reduced evaporation. Santafé et al. [13] to quantify evaporation savings and power generation, a 300 kW FPV system test bed was put over an irrigation water reservoir covering 4490 m^2, and 5000 m^3 of water was saved per year due to reduced evaporation. Hoffacker et al. [18] used the Santafé research's water savings-to-panel ratio to predict that FPV systems may save 0.12 km^3 of water per year in a study in California's Central Valley. Some other study by Taboada et al. [14] examined the evaporation ability of two similar preheated copper mining ponds, one with high-density polyethylene pontoons with PV covering 95% of the water area and another one with the water surface left uncovered. Measurements over an 8-month period revealed that the FPV covered pond saved 90% more water than the uncovered pond. Zhang et al. [19] used a solar simulator, an organic PV cell, and a water-filled glass container to conduct a bench-top evaporation test and discovered a 24–35 percent reduction in evaporation when compared to an identical uncovered container of water. Various theoretical modelling studies have been undertaken to highlight the evaporation reduction potential of FPV systems, despite the lack of practical evidence to back this statement. Most of these evaporation experiments, according to the Liber et al. [17], use at least one of the following approaches: (1) using conventional evaporation pan techniques, (2) predicting particular evaporative savings for FPV systems using general evaporative models, (3) Employing suspended shade cloth covers as a replacement for FPV system coverage, (4) erecting a small floating shade structure. The author suggested adopting site-specific evaporation models to estimate potential evaporation savings, due to some deficiencies in these methodologies' ability to measure actual evaporation from FPV installations. One of the main advantages of FPV systems is that they reduce evaporation and hence enhance water availability for other purposes.

Improved water quality and reduced algal growth are two further water-related benefits. Yet, just one theoretical research of FPV systems' potential ecological effects has been published. Haas et al. [15] study by simulating total chlorophyll-a levels as a proxy for biomass (algal) formation, the impact of FPV modules on the water quality of a hydroelectric reservoir was found, algal bloom was reduced when FPV modules covered 40–60 percent of the reservoir.

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We were unable to validate any reports about water quality impacts except for this modelling study. We discovered no practical data from FPV installations to support the claim that FPV reduces algal growth or improves water quality, just as we found with the evaporation reduction potential.

D. Benefits related to FPV-Hydropower Hybrid

Combining FPV systems with a hydropower reservoir is a new application that could provide various additional benefits. These include power system optimization benefits like higher usage of existing transmission infrastructure, less curtailment, enhanced electricity "quality," and environmental benefits. Several modelling studies have provided a good argument for these benefits if the hybrid systems are planned and performed correctly, despite the lack of publicly available practical data from FPV-hydropower hybrid systems to justify these claims. The PV-hydropower hybrid system at Longyangxia Dam in China—which is not an FPV system but combines hydropower generating with a neighboring land-based PV power plant—demonstrates some of these benefits well [20,21]. Moreover, Liu et al. [16] modeled an FPV-hydropower hybrid system; the findings suggest that this hybrid system could save land, reduce evaporation, and improve generation without impacting system stability. The addition of FPV to existing hydroelectric infrastructure in regions such as the desert southwest of the United States and several nations in Southeast Asia could benefit save water resources by reducing evaporation and diversifying generating, easing stress on limited water resources.

E. Benefits related to Economic

The FPV setup can be built on land and then dragged into the water. As a result, labour costs can be lowered. In Japan, a couple of FPV systems on the Nishihira (1.7 MWp) and Higashihira (1.2 MWp) lakes was built, installed, and turned on in a year [22,23]. Concrete use is decreased or eliminated depending on transformer location and anchoring techniques. The cost-effectiveness of an FPV system is determined by a number of factors, such as the rate of panel and pontoon degradation. Plastic degrades under UV radiation and mechanical stress, but this may typically be minimised with the additions like UV absorbers. The FPV flotation structure is normally covered by a supplementary warranty for FPV systems. The pontoons are commonly guaranteed for 10 to 25 years by companies offering FPV floatation structuress [24,25].

V. CATEGORIZATION OF BENEFITS IN BRIEF

A. Energy:

Practically Supported:

- Increases the density of panel packing (for both S and H)
- Improves the efficiency of the panel (only for S)
- Reduces the amount of shading (for both S and H)

Theoretically Supported:

- Enhances the quality of power (for only H)
- Improves the efficiency of the panel (only for H)

Unclear or Understudied: there are no benefits (which are above mentioned) are unclear or understudied

B. Land or Food:

Practically Supported:

- Repurposes land that would otherwise be unusable (only for S)
- Reduces the amount of land used (only for S)

Theoretically Supported:

- Increases energy sources in areas where there is a high demand for energy or where there are a lot of people (for both S and H)
- Reduces the amount of land used(only for H)

Unclear or understudied: there are no benefits (which are above mentioned) are unclear or understudied

C. Water:

Practically Supported: there are no benefits which are practically supported

Theoretically Supported:

- Algae growth is reduced, and water quality is improved (only for S)
- Evaporation is reduced (for both S and H)

Unclear or Understudied:

- Decrease the temperature of the water (for both S and H)
- Algae growth is reduced, and water quality is improved (only for H)
- During a drought, it produces electricity (for only H)
- Reduces the creation of waves (for both S and H)

D. Economic:

Practically Supported:

- Site preparation is less time consuming (for both S and H)

- It makes installation easier (for both S and H)

Theoretically Supported:

- Enhances the quality of power (for only H)
- It makes use of existing power transmission lines (for both S and H)

Unclear or Understudied: Prolongs the life of the system (for both S and H)

VI. RESULTS

Overall, our research shows that the majority of FPV systems' power generation and cost-related benefits are supported by practical data; nevertheless, more research and empirical evidence are needed to confirm certain water- and land-related benefits.

VII. CONCLUSIONS

In land-scarce and water-scarce areas, FPV systems are a promising new solar technology application with various potential benefits. We identified and condensed the practically supported and unsupported benefits of FPV systems in this study using a literature review. When the above research deficiencies are fulfilled, it will be easier to justify the use of FPV systems, minimize the risk of constructing FPV projects, and attract lower-cost funding and greater investment in this new PV application.

The benefits like evaporative cooling lowers the operational temperature of the panels, FPV panels can provide 5–11 percent more power than comparable-located land-based PV. FPV systems require less land. Some other benefits like reduced evaporation, reduced algal growth and hydropower-FPV hybrids' power system benefits, such as increased power quality, reduced curtailment, and the utilisation of existing infrastructure, are also discussed. Due to these benefits, these systems are being expanded in many countries.

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