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A Review of Hybrid Floating Solar Plant Designs

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Abstract: The demand for power will have doubled by the year 2050. Solar energy currently meets a small percentage of the world's demand, despite its enormous potential as an eco-friendly method for producing electricity. Utilizing land resources sustainably is one of the challenges. As an alternative, floating PV (FPV) plants on bodies of water, such as a dam, reservoir, canal, etc., are gaining popularity worldwide. This project aims to design a hybrid floating solar system that can produce renewable energy in light of the above. Among the hybrid technologies addressed are FPV & hydro systems, FPV & pumped hydro, FPV & wave energy converter, FPV & solar tree, FPV & tracking, FPV & conventional power, and FPV & hydrogen. The review also summarises the main benefits and drawbacks of hybrid floating solar PV (FPV) systems. The hybrid FPV technologies with hydro and solar energy input were some of the most promising ones for producing power efficiently. The important ideas in this paper advance understanding and could serve as a catalyst for the creation of environmentally friendly, sustainable hybrid floating installations.

Keywords: Hybrid, solar, FPV, renewable energy, operational context.

I. INTRODUCTION

The need for energy, agricultural land, and housing has risen dramatically as a result of the world's expanding population. It will soon be necessary to switch to renewable energy sources because non-renewable resources like petroleum and coal are exhausting. Most places on earth have at least one commercially viable renewable energy source (wind, sun, hydroelectric, geothermal), and some have many sources. The most plentiful and inexhaustible energy source on Earth is generally acknowledged to be solar energy [1]. In order to install solar energy on a wide scale, a lot of land must be used [2]. The overall impact of traditional PV deployments is greater because of project-related operations such deforestation, bird fatalities, degradation, discharge, and micro - climate change [3]. An average field PV power plant uses 0.6–0.8 MWp/ha of land [4]. Nevertheless, solar plants are challenging to build, particularly in thickly urbanized nations [5], due to the restricted land availability and associated expenses. It is not a fully sustainable use of land resources to build solar power facilities on farmland and wastelands. Due to their negative temperature coefficient, PV panels perform better at converting sunlight into electricity as the temperature drops [6]. To take use of the solar module's negative thermal coefficient, floating solar PV (FPV), a unique application, mounts solar arrays above water bodies [7]. Due to the many advantages of FPV, water may start to have a more prominent role in solar installation [8].

Opportunities for boosting solar producing capacity are made possible by FPV and aviation systems, particularly in landlocked nations with competing land uses [9]. It might end up being more affordable than investing in pricey land for the installation of PV. In addition to other countries, FPV installations have been made in the USA, China, Japan, India, Korea, Singapore, Brazil, Norway and the United Kingdom. In regions with inadequate grid infrastructure, such as Sub-Saharan Africa and some developing regions of Asia, floating solar might be especially advantageous [10]. The need to cool solar PV plants is one of the biggest obstacles, though, as panel heat lowers electrical performance [11]. The floating photovoltaic (FPV) system functions under the premise of operating the plant with water serving as a cooling medium while producing electricity from vast water surfaces [12]. Installing solar panels on water is about 15% more expensive than installing them on land [15]. The FPV sector will likely experience rapid deployment as a result of falling floating building costs and increased growth in developing nations [16]. The literature [17] also provided a number of insights into the commercial design of FPVs. The natural water-cooling effect, which can partially boost module efficacy and extend module lives [18], makes up for the higher costs of floating solar. When compared to conventional PV systems that were tested in two different temperature zones, the energy gain from cooling Floating PV systems was found to be between 3% and 6% [19].The best places for FPV installation are those that have an abundance of water bodies, including as canals, lakes, dams, reservoirs, and lagoons, as well as an appropriate climate [20,21]. Nevertheless, sea salt buildup on PV systems decreases power output and efficiency [22]. The food, water, and energy nexus problem is examined in relation to the usage of a floating solar system in aquaculture [23]. There are several FPV system design options that can increase efficacy and cost-effectiveness [24]. A technologically possible and economically viable photovoltaic floating cover system with a method to completely cover the reservoir to avoid evaporation losses is offered as an alternative solution for the agriculture industry [25].

A unique system for using FPV modules to produce electricity and solar energy to heat water for water ponds has been examined by the mining industry [26]. FPV technology is substantially more efficient than land-based technology since it offers a number of co-benefits [27]. When compared to other conditions, FPV module temperatures are typically 5 to 10 degrees Celsius cooler, which increases efficiency by 12% [28]. A creative solution that allowed the FPV's azimuth angle to be changed while keeping its tilt constant increased power output by 28.68% compared to a conventional floating PV system [29].

II. WATER ENVIRONMENTS AND SOLAR PV

Figure 1 presents a classification of solar photovoltaic systems used in waterbodies.

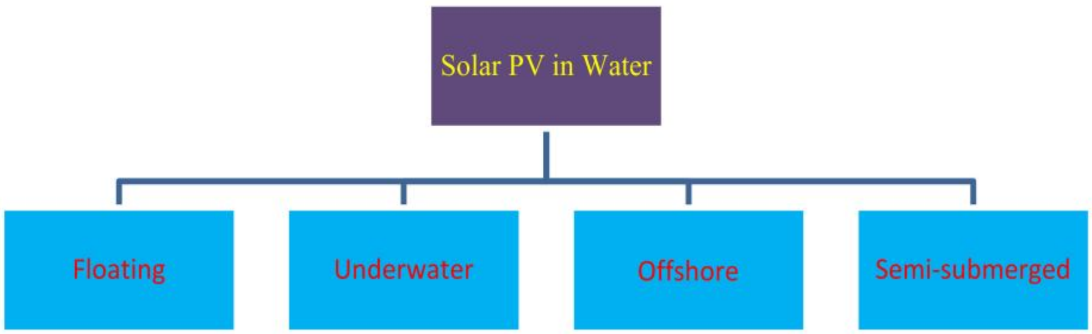

Figure 1. PV classification in an aquatic environment.

A. *Floating Photovoltaic (FPV)*

Solar panels are commonly positioned over natural or artificial bodies of water (FPV) rather than on terrestrial systems (35,36). FPV systems can be categorised into three main categories according to their supporting structures: Tracking arrays can be installed with or without pontoons, fixed tilt arrays need stiff pontoons, while flexible arrays need no pontoons at all because of their light weight. The implementation scale of FPV can also be broken down into three categories: small scale (a few kW), medium scale (kW to MW), and large scale (MW to GW) [37]. Based on the designs of their supporting structures, FPV systems can be divided into three categories: fixed floating PV systems [38], floating-tracking PV systems [39], and cooled FPV systems [40]. Fixed floating PV systems produce more electricity but have higher net capital costs than floating-tracking PV systems [41].

B. *Underwater or Submerged or Semi-Submerged*

A method for cleaning panels, lowering reflection losses, and increasing efficiency through the elimination of thermal drift is the use of PV modules in both deep and moderate water [42]. This system is capable of powering aquatic equipment, swimming pools, and ornamental fountains and pools [42]. The submerged photovoltaic solution works well in low latitude regions where the ambient temperature and illumination levels are consistently high throughout the year (i.e., lower than 30 degrees Celsius with an inclination angle of less than 20 degrees Celsius) [43]. On a modest scale, thin-film panels were used to design and test semi-submerged systems with both flexible and stiff architectures [44,45].

C. *Offshore or Marine Environment*

Approximately 50% of the global population and 75% of the world's main cities are situated near the coast. Using a floating photovoltaic (FPV) system to collect solar energy on open water is the concept of offshore PV power generating [46]. Offshore circumstances, with their rough waves created by heavy winds, require a different kind of FPV design than what is utilised on regular lakes [47]. Offshore photovoltaics are a great option for load centres since they cut down on the requirement for long-distance power transfer from other places [48,49]. This has the potential to serve as a bridge between manufacturing and consumer demand. Due to the increased relative humidity and wind speeds, the temperature at the floating installation was much lower than the surrounding sea water [33].

The design and choice of materials for the offshore system are measured against the heights of waves caused by the wind. Saltwater degradation, the requirement for an appropriate grounding mechanism, and wave intensities are among the primary technical hurdles of the offshore PV system.

III. HYBRID FPV SYSTEM

A. *Oversight on Hybridization*

Multiple energy sources, such as conventional and renewable power plants, can be harnessed simultaneously in a "hybrid energy" system. Hybrid renewable energy systems (HRES) are connected inside the same system to boost system performance and energy supply balance. Floating solar, when coupled with other variable renewables, can boost the device's energy density to the point that it can compete with fossil fuels.

Here are a few of the primary advantages of a hybrid system:

1) Improved system dependability is achieved through interconnection with the grid (through overhead lines, transformers, etc).
2) Adding a new component increases the stability and efficiency of the whole system;
3) Water resources and solar energy are mutually compensatory when used in a hybrid system [50].

B. *Classification of HFPV*

Figure 2 illustrates the classification of the HFPV.

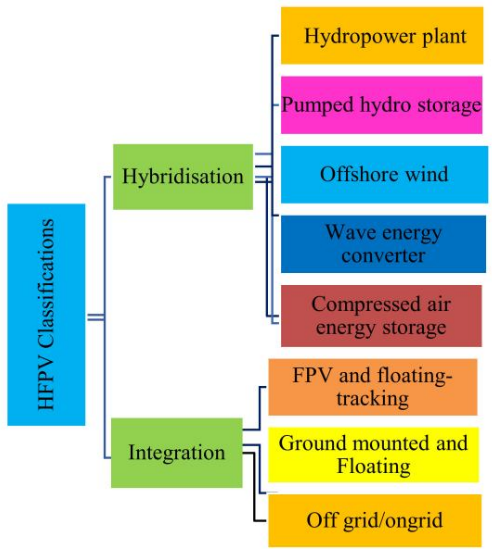

Figure 2: HFPV Classification (Modified from [50]).

IV. AN OVERVIEW OF DIFFERENT HFPV SYSTEM LAYOUTS

A. *Floating Photovoltaic & Wind*

The use of wind and solar power is expanding rapidly. However, hybrid wind and floating solar farms have not been tried. The wind farm and FPV of this offshore sustainable energy farm would provide more power per sea area. In contrast to wind energy, solar energy production ought to be constant across the research region [64]. Since deep-water power plants do not boost solar electricity production, offshore PV farms have an advantage over offshore wind farms in this regard. Due to the considerable space between the turbines and the available or anticipated cable capacity to connect the wind park to the land-based grid, floating PV may be effective in offshore wind parks [65]. Hydropower plant colocation boosts output and flattens the generation curve. While PV systems eventually have the ability to make up for the hydro energy deficit, a floating solar panel located close to a reservoir's dam can alter hydropower production to account for unsteady generation [67]. There are numerous applications for HFPV. Around reservoirs, electrical transmission lines are connected to wind turbines [68]. The generation of hydro and FPV energy can be balanced by wind turbines.

B. *Floating Photovoltaic & Hydro & Wind*

A large part of the electricity in the world may be produced via floating solar power systems and hydroelectric dams. A nation with many dammed hydropower plants should use HFPV. In the event that the floating photovoltaic panel is close to hydropower plants, developers may employ transmission cables. For coastal places, floating solar, energy storage, and hydroelectric are suggested [66]. Maximum demand is met by fluctuating floating solar resources and battery energy storage [66].

Generation is increased and the generation curve is smoothed when hydropower plants are collocated with other power sources. As time goes on, PV systems can make up for the loss in hydro energy, and a floating solar system along a reservoir's dam can alter hydropower generation to compensate for unsteady generation [67]. HFPV has many uses. Wind turbines are connected to electrical transmission lines around reservoirs [68]. Wind turbines can balance hydro and FPV energy generation. Figure 3 shows a floating PV-hydro-wind system.

An example of a suitable location would be the Australia, Central America, the Persian Gulf, Northern Mexico, Sahara, etc. all of which are typically arid regions with a lower but still present presence of hydropower facilities. The importance of hydropower in the region [69]. The best places to use solar and hydropower are in Asia. Rivers in Vietnam, Malaysia, Japan, and Indonesia, canals in Japan, tidal flows in Korea and China, aqueducts in China are only some of the places where this phenomenon has been observed.

Hydropower is best in rainy seasons, but solar systems work best in dry seasons. Thus, the two technologies can cooperate. Dry seasons are milder. The rafts can support the system on dry banks until the water level rises. This is a smart way to utilise the open surface space of reservoirs, the loss of which may have had serious financial consequences in the form of displaced homes and commercial property.

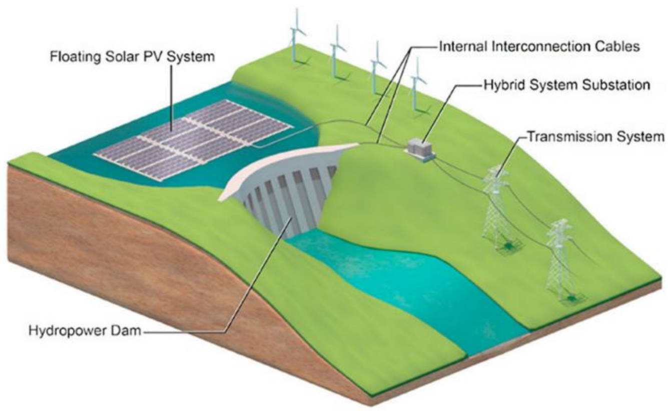

Figure 3. A plan for a floating PV-hydropower hybrid system [68]. (reprinted with permission from Elsevier).

C. Floating Solar PV with Pumped Hydro Energy Storage (FPV & PHES)

PHES was invented in the twentieth century, with most projects completed between the 1960s and 1980s. A PHES system requires a water source and two reservoirs of varying heights. PHES operations are highly flexible and feasible [69]. Solar power pumps reservoir water to generate hydroelectric power when demand is low [69]. These dams could generate power at a lower capacity. The reservoir's water will store energy efficiently. Solar energy could be stored in a hybrid system using pumped-storage hydropower. The FPV system, the PHS subsystem's upper and lower reservoirs, both buses' power electronics converters, and the load demand are all connected through the AC bus [70]. While the microgrid draws electricity directly from the FPV panels during peak solar irradiance, the reservoir stores water for later use [71]. Like a battery, the reservoir stores the water that is conserved or accumulated when PV panels are used.

Since there are no physical limits on the size of dams or water reservoirs, this kind of energy storage is very efficient. Based on the reservoir's position and intended usage, a higher coverage ratio may result in more electricity and water conservation [72]. The effectiveness of "PHES" is constrained by reservoir capacity, underscoring the need of batteries as well as other energy storage systems. Not all population hubs are serviced in proportion to their supply (demand). In addition to being able to power irrigation systems, solar panels on farms can be used to store energy [71].

D. Floating & Micro hydrokinetic Turbines

Solar panels on the top of the float absorb solar energy, and micro-hydrokinetic rotors on the bottom of the float absorb hydropower. Low-lying photovoltaic arrays that float in tidal flows, canals, rivers, and aqueducts are a possibility. Energy production is unaffected by clouds, rainfall, or even the arrival of darkness [73]. The power output of the hydroelectric and solar elements is increased by this unique combination. Additionally, the floating platform acts as a reliable, efficient, and cost-effective base for the operation and upkeep of the hydrokinetic turbine set. Finally, the units are silent and have a minimal visual impact since they leave no footprints on the surface or in the water. The design is suitable towards the floating solar idea setting despite the fact that technology was originally designed for installations on canal tops [73].

E. Storage of Energy from Floating Photovoltaic and Wind Systems

The system's fundamental premise is that the DC coming from the Floating PV arrays and/or wind turbines is transformed by an inverter and then sent to the load bus via the cables bus. The system controller continuously regulates the load and outcome from the PV and/or wind turbines [74]. A transformer transmits the energy that can instantaneously satisfy a fraction of the demand and feeds it into the distribution network to meet the load. If there is ever a requirement for more electricity than the PV arrays and/or wind turbines can produce, energy is imported through a connection to the main grid. On the contrary side, this electricity is deemed excess and is transferred to the main grid if these systems ever provide any electricity that is greater than the load. The combined renewable power is complemented with imported electricity.

F. Solar Tree and Floating Solar Tracking

The researchers [50] presented an unusual method for monitoring floating systems in Italy that was inspired by nature. This inexpensive method [77] uses an underwater concrete anchoring to secure a floating island to the mooring line. A tracking mechanism for the sun's motion powers the underwater propellers that ensure rotation.

G. Hydrogen Energy Storage on a Floating Solar Island

Solar, wind, and wave energy are combined with an OTEC plant to produce power on floating solar energy platforms. Those floating structures are designed to resist challenging conditions including high waves and heavy winds. The system incorporates a number of technologies, including as battery storage, wind farms, and floating solar. As an alternative storage option, the gadget will also use an electrolyser to make green hydrogen [80]. There is a lot of promise for marine green hydrogen generation using coupled wind and floating solar. These facilities enable hydrogen refuelling for ships. The solar island at sea might offer a viable substitute for the shipping industry.

H. FPV& Aquaculture Hybrid System

Due to its role in the global food supply, aquaculture is the industry with the greatest economic potential. FPV model is combined with aquaculture to realise the concept of aquavoltaics [23]. By enhancing the output of aquatic species, combined offshore floating platforms increase economic opportunities. Energy from the FPV system can be utilised to support off-grid aquaculture. Aquavoltaics aims to utilise water effectively by using it to produce food and energy [23]. Nevertheless, there are a number of difficulties with such a system that the science community is not completely aware of, including bacterial growth, FPV relationship with marine ecosystems, and regulatory and political obstacles.

V. HYBRID FLOATING PHOTOVOLTAIC: PROSPECTIVE, CURRENT TRENDS, AND PERFORMANCE ELEMENTS

A. Prospective

Numerous reservoirs and dams provide for the transportation of commodities and services on streams and rivers as well as the provision of drinking water and flood control. Hydropower has been crucial to the global power grid since centralised power distribution networks. Hydroelectric plants were first built in the late 1800s. The majority energy is provided by hydropower for power system stability, entertainment, and flood management.

Because the turbine cannot utilise the water vapour to produce electricity, hydropower facilities lose water when reservoirs evaporate. Hydropower devastates upstream and downstream habitat [68].

Hydropower plants, which generate energy from falling water, are everywhere. Figure 14 shows hydropower capacity by country. In 2019, the installed hydropower capacity was 1308 gigatonnes (GW), and the hydropower generation was 4306 gigatonne-hours (TWh). Hydro pumped storage plants account for 138.7 GW, while run-of-the-river facilities account for 328 GW [69]. 53% of operational renewable energy sources worldwide are hydropower, with 24% being wind and 18% being solar.

According to a World Bank research, there is a 400 GW global potential for floating solar power plants on artificial reservoirs. Floating solar panels can be put on existing hydropower reactors in 379,068 freshwater reservoirs worldwide, according to the National Renewable Energy Laboratory (NREL). Large hydropower plants with reservoirs can have their electrical output capacity replicated by covering 1-35% of the reservoir with floating photovoltaic cells. Even with 10% covering, there will be a significant boost in energy production, which in some situations might even be greater than the real hydropower output. Equatorial regions have higher solar energy yields than high latitudes, hence this figure is higher there. The potential for combining Floating PV and Hydro Power plants is particularly attractive because of the enormous hydro capacity.

B. Current Trends in Some Countries

Co-located possibilities make up the majority of existing commercial hydropower reservoir projects. Only a few modest projects with hybrid operations are now in use. On the other hand, numerous larger-scale initiatives are being looked into or proposed globally.

C. Industrial Participants

To supply a sizeable amount of the current world electricity needs, some technological developers are leveraging the momentum of a floating solar plant by combining it with other offshore power systems [85]. Additionally, a number of firms are aiming to take advantage of the increasing popularity of floating solar with HPP worldwide. HFPV may replace conventional floating solar PV in the future if development teams are successful in creating cost-effective hybrid ideas.

D. Performance Elements of Hybrid Floating PV

The whole present value of a project, which includes all anticipated costs and returns through year one, is known as the net present value (NPV). The rate of return on the NPV cashflows produced by investments is known as the internal rate of return, or IRR. The quantity of energy supplied by FPV systems compared to the maximum output of the module is known as energy yield (EY). By dividing the entire project's total cost by the volume of power generated, the LCOE of a sustainable energy project is determined. When comparing competing technologies at varying operating scales, capital requirements, and operating periods, the LCOE is a measure that is employed [87]. The LCOE can be utilized to contrast various HFPV substitutes. a reliable sign of the cost-effectiveness of a certain generation and storage mix. The CF, a crucial performance evaluation parameter, shows the proportion between the actual energy generated by a system (E) and the maximum energy the system is capable of producing at any given time. The ability to reduce greenhouse gas (GHG) emissions is used as an indication when comparing the proposed technology's ability to reduce CO2 emissions to that of traditional energy production. Solar systems are anticipated to improve people' quality of life and open up employment prospects [88,89]. The influence of combined components in generating a common value is not taken into consideration by the aforementioned indicators, it should be emphasised.

VI. POSITIVE EFFECTS AND RESTRICTIONS OF HYBRID FPV

A hybrid FPV may provide the following benefits in addition to generation, especially when combined with existing hydropower.

A. Positive Effects of HFPV

1) It promotes wise use of the land. The land can be utilized for other things because the floating PV energy plants are positioned on water [86]. For solar power plants, no new land or farming or forest conversion is necessary [90]. It protects the land's original uses, including agriculture, forestry, cattle, and environment [91]. Large land tracts are frequently needed for utility-scale solar PV, but developing nations with limited land may have to give land usage for agriculture, forestry, or other purposes priority [92]. By co-locating solar PV systems on artificial water bodies like reservoirs, FPV may be able to reduce the strain on land use from competing land uses and scale up renewable energy sources [65].
2) Farmland and forest preservation: The biggest benefit of hybrid FPVs is that they don't require any agricultural or green space. They discuss the energy-water-land nexus problem. A minimum amount of land is utilised. The quantity of land required is decreased by installing PV modules on already-existing water infrastructure (dams, oceans, etc.) [93].
3) Increased energy effectiveness. Due to its cooling impact and decreased water evaporation during hydropower generation, energy efficiency is increased by 11-16% when compared to land-based solar systems [86]. Water cooling below the panels boosts system performance [66].
4) Increased transmission line and grid access utilisation rates: Installing hybrid FPV involves less procedures and a power grid because hydro plants are frequently available and have already connected to the grid network [94]. For instance, a hybrid system might reduce transmission costs by linking to a shared substation [95]. Hydropower facilities are situated close to demand centres and utilise current energy transmission systems . The hydroelectric plant's road connectivity already lowers development and transportation expenses.
5) Employs an environmentally friendly system. Natural fish farms may thrive on the platform in the future. They promote fish breeding, increase aquatic plants, and reduce algae and microorganism levels.
6) Lower capital expenditure (CAPEX): HFPV has a reduced CAPEX because the grid infrastructure is already in place, but it is still dependent on the site's individual characteristics. Co-locating with hydropower reduces the advantages to the electricity system and capital expenses because interconnection costs are lower.

7) Decreased Emissions of co2. Compared to traditional FPV, hybrid floating solar farms have a larger potential to reduce carbon emissions. With regard to Emissions of co2 per power generated, the HFPV system is advantageous, especially in tropical areas.
8) Improvements to the current infrastructure. The outdated infrastructure of the plant has the potential to be modernised and enhanced for performance [93]. Additionally, by sharing a grid connection, HFPV and HPP could save money on grid integration.

B. Restrictions and Challenges of HFPV

1) Technology cost: Specialized equipment, which could be more expensive than standard land-based installations, is needed for hybrid floating solar installations. The prices of floating solar cells are high because to the strict module requirements, although they are anticipated to decrease as technology develops [106].
2) Considerable water level fluctuation: Hydro dams in hot, tropical locations face a major technical risk from water level variations of up to 10 feet.
3) Negative consequences of wind, wave, current, and snow include the possibility of microcracks in the solar cells due to the continual bob of the ground below. Snow, wind, waves, and currents all have an adverse effect on the long-term performance and stability of HFPV systems [40].
4) Coverage limitation: The amount of water that can be covered by the system is constrained. Typically, 1–10% of the area is covered to lessen the impact on the environment and installation constraints on the richly biodiverse coastal zone [108]. The amount of space needed for recreational and leisure activities makes coverage difficult.
5) Seasonal changes in the weather: The main disadvantage of hydropower-based hybrid FPVs is that they are geographically limited. The monsoon season has a significant impact on the growth of the majority of hydro plants, which are employed as peaking plants [109]. At certain periods of the year, some reservoirs may be too dry or otherwise unfit to support hybrid floating PV.
6) Insufficient experience and knowledge: The lack of information about hybrid FPV systems now available will hinder real - time decision-making. There is little prior knowledge about HFPV or HPP systems. Because this is a one-of-a-kind innovation, more specialised installation knowledge is required.
7) Inconsistent and hostile installation policies: The absence of rules and regulations in the HFPV system is its biggest drawback.

VII. CONCLUSION AND FUTURE PROJECTIONS

This paper looked into several hybrid floating PV systems that may be used with existing FPVs. Nonetheless, basic principles for hybrid FPV systems are being developed here, which is still in its early stages.

Floating Photovoltaic & Wind, Floating Photovoltaic & Hydro & Wind, Floating Solar PV with Pumped Hydro Energy Storage (FPV & PHES), Floating & Micro hydrokinetic Turbines, Solar Tree and Floating Solar Tracking & conventional plant are among these technologies. This article also discussed the major motivations, prospects, and advantages of HFPV technology.

Here are some important principal findings:

1) In terms of improving the technological and commercial viability of FPV installations, hybrid FPV systems might be more advantageous than floating PV systems. In general, a hybrid solar-floating system will be a more effective way to generate electricity than a traditional floating system.
2) Island nations offer a huge implementation potential for hybrid floating photovoltaic systems, particularly in hydroelectric plants, to meet their energy needs.
3) The HFPV potential of the planet is vast. Hybrid FPV is an ecologically friendly technological approach that aims to address the water-energy confluence while simultaneously offering a low-carbon pathway for the production of electricity. The world might get closer to decarbonization if the HFPV's global potential is fully realised.
4) Less established technologies, like hybrid FPV, will need more pilot studies and innovative approaches in the future to achieve scalability, reduced costs, energy output, and a high investment return. This will make it easier to weigh the benefits and drawbacks of various floating hybrid solutions and decide how to adopt them in the future.

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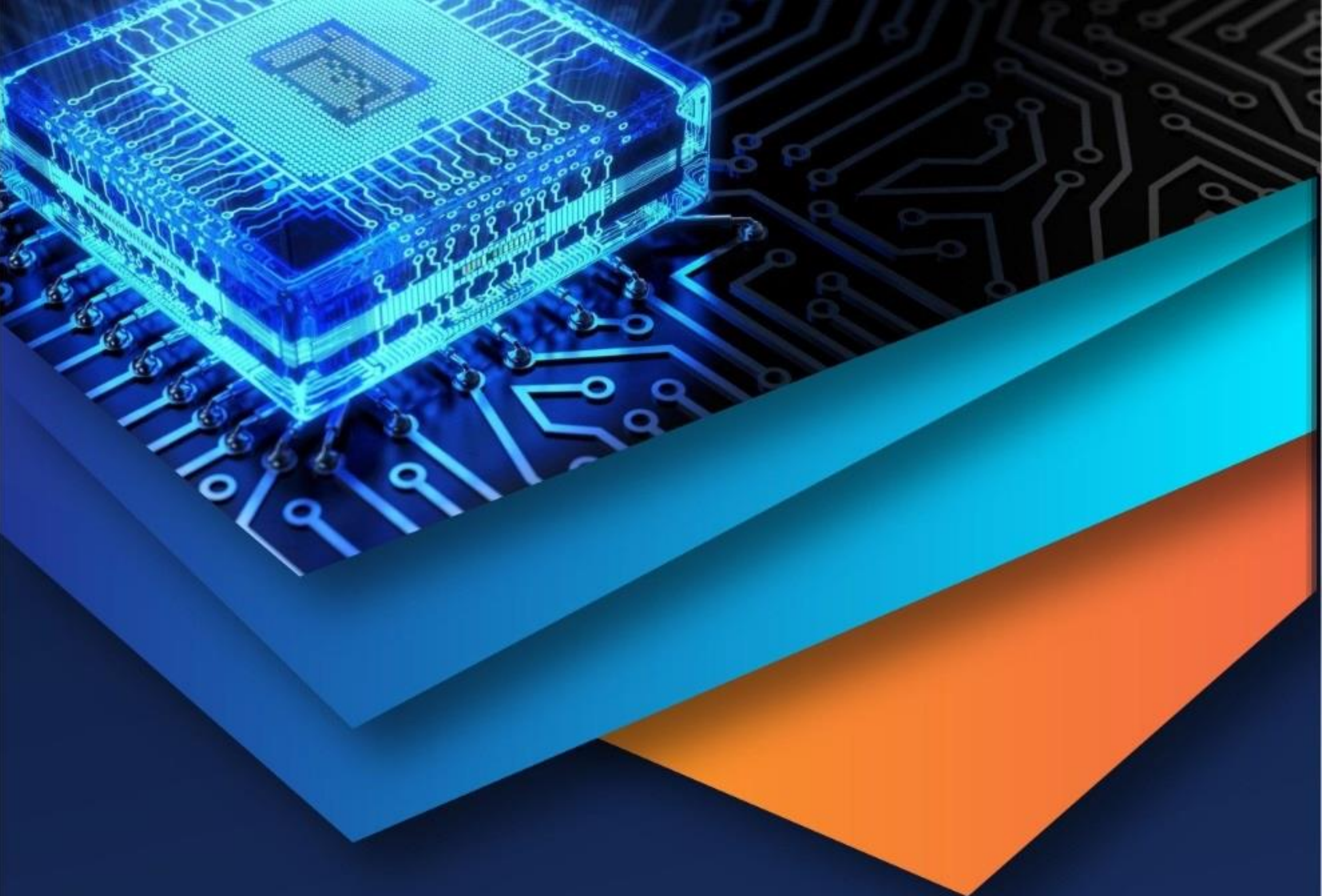

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