Efficiency Assessment of a Hybrid Hydro–Solar Floating Energy Framework with Dynamic Ballast Regulation

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ABSTRACT

Drifting renewable power setups are more and more viewed as a practical means for local power making in streams, channels, and storage areas where ground area is scarce. Newer studies suggest that floating hydro units paired with combined solar– hydro configurations can boost the utilization of renewable power while cutting down on the need for broad ground building [1], [2]. However, shifts in water levels and stream speeds heavily affect how far down turbines are placed and the steadiness of stages in older, set-buoyancy drifting setups, causing uneven power output and lower working capability [3].To lessen these problems, changing ballast and buoyancy control methods have been looked at in big drifting power stages to improve steadiness and power recovery [4]. This paper looks over recent progress in floating hydro power advances, combined drifting solar–hydro layouts, and ballast-based steadiness handling methods, paying special attention to bettering capability through regulated turbine sinking. In contrast to studies centered on power holding or faraway tracking, this review highlights control-oriented, lab-sized models that gauge quick power creation for direct capability judging. Key research holes concerning flexible sinking control, testing proof, and smaller-scale uses are noted, along with a talk about forthcoming research paths.

Index Terms **-Floating renewable energy, dynamic ballast regulation, hybrid hydro–solar systems, floating units, turbine submersion management, immediate power assessment.**

INTRODUCTION

The growing demand for clean and spread out power selections has pushed forward studies on renewable power setups able to work in natural water settings like streams, channels, and reservoirs. Standard hydro power plants, though quite effective, demand major ground work and are not perfect for spots with low height or changing water supplies [1]. Drifting hydro power setups remove these barriers by enabling direct power taking from moving water with lessened nature impacts and simpler setting up [2].

At the same time, solar photovoltaic (PV) setups that float have gained attention because they can conserve land area and improve PV performance through the water'scooling effect [3]. Pairing floating solar PV with hydroelectric systems is thought to increase energy supply and reduce unpredictable power output [4]. Even with these advantages, floatingenergy setups remain highly sensitive to shifts in water height and movement patterns, which directly influence how deep turbines sit, where the platform rests, and how well electricity is produced overall [5].

Most existing floating arrangements employ platforms with set buoyancy that cannot adjust to shifting working environments, causing inconsistent contact between the turbine and the water and unsteady power generation. These difficulties emphasize the need for flexible setups that can control turbine depth and increase the efficiency of production as it happens.

A. Problem Statement

Presently, most floating hydropower setups, including those that combine hydro and solar power, utilize stable buoyancy platforms which cannot automatically adjust to shifting water depths and stream velocities. These unmoving arrangements impede keeping the turbine perfectly submerged, particularly during the different water conditions usually present in reservoirs and rivers [1],[2]. As the water level moves up and down, the turbine might end up not deep enough or too deep, causing uneven forces between the blades and the moving water. These uneven forces result in unpredictable turning force generation, fluctuating rotational speeds, and inconsistent electrical energy supply. Over a period, these operational problems lower the overall energy conversion rate and introduce extra physical stress on the turbine axles, supporting parts, and power generating units, potentially damaging lasting strength and dependability [2].

Although ways for changing the weight and flotation have been looked into deeply for sea-based floating power platforms to better structural steadiness and boost energy capture, their application in smaller floating hydropower or combined hydro-solar setups has not been broadly investigated [4]. Existing sea-based answers suggest that precisely adjusting the platform depth can significantly boost dependable operation; nevertheless, applying these concepts to smaller, cost-effective freshwater systems brings forth both building and evaluation difficulties.

Furthermore, a substantial portion of current studies mainly focus on technical and financial assessments, the practicality of big installations, or incorporating energy storage for long durations, instead of prioritizing performance enhancement instantly based on direct electrical result measurements [3],[4].

There remains a distinct absence of hands-on research which evaluates performance gains through tailored immersion control employing smaller scale test setups. In particular, merely a small number of explorations have systematically contrasted unchanging flotation setups against setups that allow for vertical movement under identical running parameters [1],[2]. These research efforts have yet to completely measure the boosts by way of live readings taken for voltage, amperage, and electrical force. This gap in exploration underscores the need to create control-focused sample mechanisms that test how flexible weight systems affect the steady nature of turbines and how well power generation works. Fulfilling this research need will assist in bridging the gap separating conceptual plans for floating power sources and real world applications that lead to better results.

B. Related Works

Recent progress concerning floating hydropower technologies demonstrates the capability to generate power from moving water without utilizing established dam constructions. Prototype floating hydropower facilities have been built for deployment in streams and channels, emphasizing adaptable structure, ecological soundness, and straightforward setup [1]. These installations illustrate the potential for energy generation that is spread out and renewable, particularly in shallow or remote locations where large hydroelectric endeavors prove unworkable. However, outcomes from these explorations suggest that rigid mounting arrangements might cause shifts in turbine operation because of yearly changes in water height or alterations in current velocity. Because the depth covering the turbine changes naturally with the state of the water, the electrical power frequently fluctuates, resulting in lower general system effectiveness [1],[2].

Further research concerning floating waterwheel and stream energy mechanisms highlights even more the vital necessity for steady turbine positioning to maximize how the fluid moves around it [2]. Detailed analysis implies that the way the blades connect with the water is fundamental for creating turning force and dependable power. Shifts in how deep the turbine is placed or poor alignment with the current can seriously affect both turning and the resulting voltage. Although these inquiries provide useful academic insight and planning elements, numerous deployments mentioned rely upon fixed floating mechanisms that fail to adjust to shifts in the surrounding environment. Consequently, even though the potential of the technologies is proven, improving output via proactive structural management is mostly an area not covered in smaller versions.

Besides power generation studies, floating solar photovoltaic setups draw much attention because they offer better heat performance and benefits for land utilization [3]. Research about floating solar arrays suggests that water cooling might increase panel output when contrasted with setups installed on ground areas. Furthermore, economic assessments of combined hydro-solar plants imply that adding floating PV to present hydropower stations can raise total capacity use and lessen water loss from evaporation [4]. Notwithstanding these good points, many combined systems often favor energy joining and cost effectiveness more than structural adaptability or ways to manage submergence that affect hydropower parts.

Exploration into floating power structures at sea provides further understanding about how to handle floating ability. Investigations into flexible ballast regulation have occurred to maintain platform steadiness and better energy collection under changing ocean settings [4]. These ways show that adjusting the depth and position can greatly improve dependable operation and reduce stress on machinery. Yet, these methods are usually created for very large offshore wind or ocean setups and include complex water and mechanical assemblies. Putting these into practice for smaller, cost effective freshwater floating hydropower units has seen little testing in trials.

To sum up, the reviewed documents confirm that floating hydropower and combined power setups are technically possible while also pointing out a missing piece in making performance better instantly using adaptive ballast handling. Much of the work concentrates on building practicality, looking at costs, or computer model methods, with fewer studies centered on small lab prototypes using direct electric output checks for set and variable height floating designs. This missing part stresses the need for actual tests aiming to prove adaptive submergence control is a real way to boost turbine steadiness and electric output improvement in smaller combined floating power

PROPOSED SYSTEM DESCRIPTION

The proposed mixed floating power generation approach joins solar photovoltaic power creation along with small-scale water power retrieval on one shared floating base, like one sees in Fig.

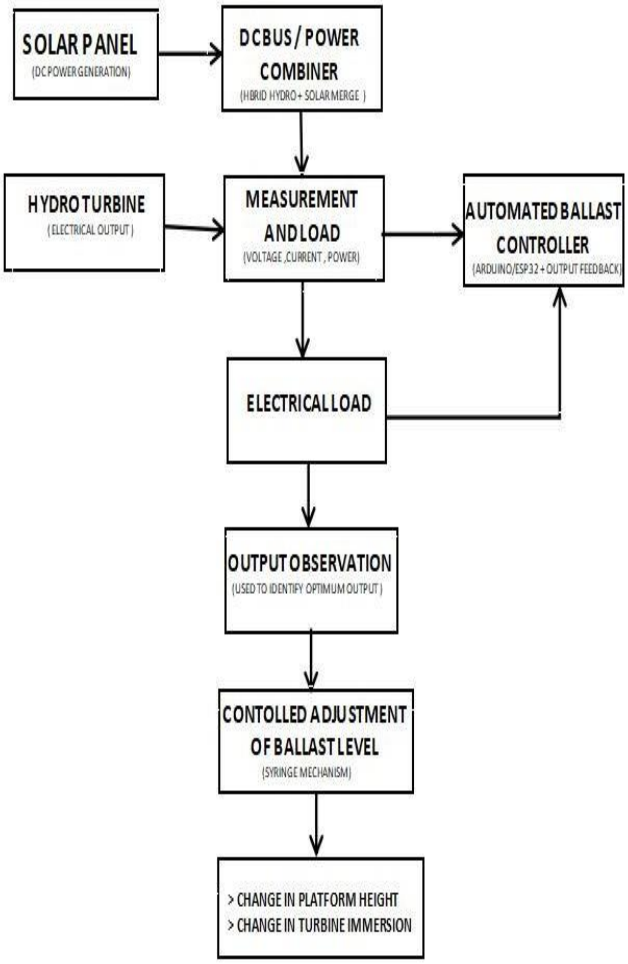

Fig.1.Hybrid Hydro–Solar Floating Energy Framework with Dynamic Ballast Control Via Automated Syringe Mechanism

1. This setup mixes the two power origins through a DC bus or power combining unit, permitting the concurrent utilization of both water and solar power sources. Comparable arrangements have been observed to boost power accessibility and make the best use of available green power, particularly in isolated and shallow water environments [3], [4].Within the arrangement detailed, the solar panel creates direct current (DC) electricity, while the water turbine converts motion energy from flowing water into electric power. Contrary to older floating water power setups that employ fixed buoyant frameworks [1], this fresh layout includes an automatic weight control method that manages how deep the turbine sits underwater. The electric outputs originating from the solar and water sources are united at the DC bus and forwarded to the monitoring and usage area, where voltage, current, and real power are continuously observed. Direct electric gauging provides an exact and useful review of how the setup performs, enabling live checks on effectiveness instead of relying only upon calculated water movement predictions [2].

A key improvement within this setup is the performance-based weight adjustment circuit. The recorded electric output acts as the principal measure for making things better. Should shifts in water levels or flow patterns cause changes in power creation, the automatic weight regulator—employing a small computer setup such as Arduino or ESP32—changes the ballast level by employing a needle-driven mechanical process. This modification influences the elevation of the floating base, thereby changing how far the turbine sinks. By keeping the best depth, the arrangement guarantees better blade contact with the water, steady turning force output, and uniform turning rate, adding to improved steadiness in the electric result [1], [2].

The ballast adjustment mechanism employed suggests a flexible buoyancy control strategy based on the stability methods observed in bigger offshore renewable structures [4]. Unlike complex deep-water setups relying on substantial hydraulic mechanisms, this suggested device employs a small and mechanically simple syringe arrangement, perfectly suited for testing in a lab setting and for minor deployments. By constantly checking electrical energy and altering buoyancy when necessary, this setup establishes a self-correcting refinement process that actively modifies the turbine's depth for peak generation.

This technique successfully addresses the shortcomings present in existing floating hydropower and combined systems, most of which rely on fixed buoyancy frameworks unable to adjust to shifts in the surrounding environment [1], [3]. Utilizing instantaneous electrical data and responsive ballast handling, the suggested structure allows for a structured comparison between floating designs that can change height and those that cannot. This evaluation based on results helps bridge theoretical floating renewable concepts with efficiency improvements verified through experimentation [2],[4].To sum up, the introduced system shows a practical, control-oriented way to improve energy consistency in combined hydro-solar floating setups. By merging direct power detection, automatic ballast changing, and combined energy incorporation into a single floating structure, it increases operational dependability and establishes a framework ready for future adaptable floating renewable use.

Objectives

The main aims of this study include:

1. To look over recent papers about floating hydropower and combined solar-hydro power setups.
2. To investigate ways for changing ballast and controlling float used in floating structures.
3. To judge how performance varies between systems that keep a set float height and ones with changing vertical positions.
4. To find topics needing more study related to immediate control, making stability better, and testing at the initial model stage.

METHODOLOGY

A complete and structured survey of existing writing was conducted to evaluate recent advances in floating hydropower systems, combined hydro- solar setups, and adjustable ballast handling methods. Articles examined by other experts were collected from trusted academic databases such as IEEE Xplore, Science Direct, and Google Scholar, which confirmed the accuracy and engineering importance of the selected texts. Research papers released between 2021 and 2024 were prioritized to emphasize the most recent advancements in offshore renewable power options. Several search terms like floating hydropower, floating solar photovoltaic systems, hybrid hydro-solar energy, adaptive ballast management, and buoyancy control mechanisms were employed to deliberately pick relevant documents [1]-[4].

The selected research papers were grouped into four primary sections for straightforward evaluation:

1. Floating hydropower systems that use physical models.
2. Methods for controlling ballast and buoyancy on floating structures.
3. Arrangements that mix floating solar and hydro power systems.

This division permitted a concentrated look at engineering approaches and pointed out common topics related to keeping stability, improving output, and putting systems together. Much attention was given to testing and physical model research instead of just theory or computer models, because hands-on proof is crucial for judging how well something works in actual settings.

Next, a structure for side-by-side comparison was created to examine important technical features mentioned in the collected material. These features covered the design of the platform, the way the turbine is put underwater, the kind of buoyancy setup (set or changeable), the control method (done by hand, partially automatic, or completely automatic), and ways to measure how well the electricity works. Particular attention was paid to keeping the turbine submerged at the correct level when water changes, because how the water moves around the device greatly impacts how much turning force is made and how steady the power output is [1], [2]. Furthermore, the research was checked based on whether the assessment of good performance used direct recordings of electrical power (looking at voltage and current) or depended on estimated figures and predictions of energy output over time [3],[4].

The methodology also concentrated upon finding limits and functional weaknesses across every research area. For example, floating hydropower models were checked for steadiness when facing varying water levels, while hybrid setups were examined for difficulties in joining structure and managing control. Methods for ballast management were considered based on how mechanically complex, how easily scaled, and how suitable they were for small bodies of fresh water. This orderly comparison allowed finding spots that lack much study, especially the slight physical testing of responsive ballast systems using actual electrical result as a measure for making performance better.

By using this organized and contrasting technique, the review builds a technical foundation for judging platforms for renewable energy that can change their height while floating. The process makes certain that understanding comes from facts shown through trials and system adjustments rather than only from cost estimates or forecasts about huge deployments. This procedure encourages the growth of test-based adaptive setups that aim to better manage how deep the turbine sits and increase current generation effectiveness in mixed floating renewable energy situations [1]- [4].

Comparative Analysis

Floating hydropower setups with fixed float height show uneven results when water levels change, causing problems like parts of the turbine being underwater, less contact between blades and water, and changing electrical output. In contrast, adaptive ballast control methods used in floating power setups show greater steadiness and boost energy gathering by making sure operating settings are best [4].

Combined setups that mix floating solar and hydro technology provide better energy use but bring difficulties regarding how parts fit together and managing them at the same time [1],[2]. A large portion of current investigation relies upon computer models or ideas, with little attention given to proving results in a controlled test setting and contrasting immediate effectiveness between set and changing floating designs.

Research Gaps Identified

From the literature that has been reviewed, the subsequent areas for deeper inquiry have been noted:

1. Limited use of adjusting ballast systems in smaller, floating power setups [4]
2. Not immediately improving how well things work based on feedback from the turbine's power output [1]
3. Not enough hands-on testing for floating bases made for managing control [2]
4. Not much focus on cheap and simple mechanical ways to change floating ability fit for local setups

CONCLUSION

This assessment carefully studied recent developments in floating hydropower systems, merged solar-hydro floating setups, and adjustable ballast control techniques intended to improve renewable energy effectiveness and increase operational dependability. The study of engineered floating hydropower models suggests their potential for localized energy generation in shallow water and river settings, offering less need for major construction and ways to install them that are kinder to the environment [1],[2]. Furthermore, floating solar photovoltaic (FPV) setups show notable improvements in how efficiently land is used and in thermal performance, due to the cooling effect water surfaces provide, which raises power output when set against typical land-mounted setups [3]. Merging hydropower with floating solar technologies further increases the total energy yield and resource utilization, especially across regions where yearly changes affect single renewable power supplies [4].

Nevertheless, in spite of these positive leaps forward, several functional difficulties persist without resolution. A key weakness noted within existing floating hydropower setups is their reliance upon fixed-buoyancy configurations, restricting their ability to maintain turbines at prime depths when water levels and current speeds fluctuate [1]. Adjustments to submergence depth directly influence fluid dynamics, the creation of turning force, and the consistency of rotation, which might result in fluctuating power output and lower overall system performance [2]. Although combined floating designs do increase the total energy yield, incorporating structures without flexible stabilizing measures might introduce increased structural strain and problems with long term durability [3],[4].

Adaptive ballast control offers a practical technical way to address these problems by enabling flexible handling of the structure's depth and the turbine's position. Studies in similar offshore power fields demonstrate that changing the lift capability can significantly enhance operational steadiness and energy gathering success if done properly [4]. However, most present work concentrates on very large or computer generated models, with relatively small hands-on checking in smaller floating renewable models centered on control [1], [2]. Furthermore, few investigations emphasize immediate electrical gauging as the primary means for improvement, a factor essential for correctly judging performance.

FUTURE SCOPE

Future investigations into floating renewable energy technologies should emphasize creating sophisticated adaptive ballast systems that integrate embedded processors capable of instantaneous sensing, decision-making, and actuation. By utilizing microcontroller-based control systems, it would be possible to maintain ongoing surveillance of electrical output metrics such as voltage, current, and power. This would allow for dynamic adjustments to ballast based on optimization goals instead of predetermined structural setups. Such processor-driven adaptive mechanisms would improve turbine immersion control, reduce output variability, and enhance overall energy conversion efficiency in response to changing hydrodynamic conditions.

Before large-scale implementation, further experimental validation in controlled lab settings is vital. Conducting tests at varying water flow rates, simulated depth differences, and disturbance conditions would yield quantitative data on platform stability, mechanical reliability, and operational longevity [2]. Additionally, expanding the experimental datasets across various hydrological conditions would aid in forming predictive control models that can ensure optimal turbine positioning in real-time [1]. Controlled experimentation is especially critical for hybrid hydro– solar floating systems, where the structural integration and load distribution need careful consideration to prevent mechanical stress and performance decline [3],[4].

Moreover, future research could investigate the possibility of incorporating remote monitoring features and advanced control algorithms to boost system autonomy. Current small-scale models focus on straightforward performance assessment and mechanical simplicity. However, integrating wireless data transfer and smart optimization methods might support predictive maintenance, malfunction detection, and performance analysis over prolonged operating times [3].

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