Integration of P.V. floating with hydroelectric power plants

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Abstract

Man made water reservoirs have been constructed throughout history for various uses such as hydropower generation, energy storage, flood control, fishing, irrigation, etc. as we continually embrace sustainable development goals, the demand for cheap, clean energy is increasing. Investing in renewable sources such as solar, wind, and thermal power is vital in achieving SDG 7 by 2030.

Hydropower generation represents an enormous share of renewable electricity generation globally. Most of these reservoirs are from river run off, and the rest hydro-pumped storage controlled to different degrees. Floating solar photovoltaic (FPV) is an emanating and feasible use of photovoltaics where the systems are directly placed on waterbodies. Despite its increased market interest and reduced price over the years, the potential adopters of this technology remain concerned about the benefits offered and the merits of incorporating it in hybrid systems.

To support decision making, this paper aims to review the associated importance of a hybrid FPV-Hydropower system operation. Hybrid systems of floating solar systems and hydropower plants hold untapped potential to increase significantly renewable electricity generation across the globe. Due to connection to a standard grid, the operation of a hydropower plant is flexible, thus facilitating a "virtual battery" which consists of meeting the demand for electricity with solar energy during high peak hours while balancing the grid with hydropower during low peak hours, thus providing a zero impact area for FPV power plant deployment.

Keywords: Hydropower, Floating solar, FPV, Hybrid, Photovoltaics,

1. Introduction

1.1 Overview of research topic

Energy is a basic necessity in the modern-day way of life. Kenya, a developing country, has encountered challenges over and over in maintaining a constant supply of energy to its ever-growing population and economy. The current demand for energy exceeds the available resources. Thus, as we gear towards a sustainable world, renewable energy sources can be used as an alternative to non-renewable ones such as fossil fuels. Renewable energy shares the advantages of being pollution-free, clean, and endless non-exhaustible (Pimnapat Iemsomboona, 2012). Presently, clean energy plays a huge role in planning and energy security due to increased demand for clean energy sources and advances in a low carbon footprint. Solar energy production has increased rapidly in recent years, and its cost decreased. It's highly anticipated that solar will be the most competitive renewable energy in the coming years. However, it has been coupled with challenges such as long-distance transmission, large capacity power accommodation and low quality power. Hydropower, on the other hand, is another renewable energy source whose output can be instantly adjusted and is flexible in storage and discharge. (Zhenchen Deng, 2019). Floating solar panels also referred to as floatovoltaics became popular initially in Japan as an answer to the land constraints they were facing. The hydropower industry has realized the significance of retrofitting photovoltaics on the abundant water surfaces of reservoirs. Installed capacity globally had reached nearly 600MW by 2018 (International hydropower association, 2018). In a hybrid system, combining a hydropower plant with floatovoltaics or pumped storage ensures solar energy is produced during daytime while the reservoir stores energy to be used during peak demand periods. This ensures continuous production of reliable clean energy which is essential in achieving a sustainable energy future. Advantages of using floating photovoltaics:

- When floating photovoltaics and hydropower reservoirs are integrated, they utilize existing transmission infrastructure. These include connection to the power grid of the transformers thus saving additional infrastructure costs.
- Taking advantage of unused water surfaces for energy generation provides areas of potential zero impact and avoid land use competition.
- The cooling provided by water Increases the P.V. panels' efficiency.

- The shading provided by the floating photovoltaics reduce evaporation to preserve water for hydropower output or other water uses.
- Reduction on algal growth as a result of the shading provided by P.V. panels which in turn improve water quality.

The combined use of floating photovoltaics and hydropower presents numerous advantages. However, a feature yet to be fully investigated is the potential of the hydropower plant to act as a virtual battery of the floating photovoltaics. (Javier Farfan, 2018). Connecting the national grid to renewable sources of energy can cause problems in handling the dynamics of those kind of variations. A reliable, continuous supply of power is hard to achieve without energy storage. With an energy storage system being used, energy being produced in surplus can be stored. This is when demand has been exceeded by the power generation and released when there is a net load thus providing quick back up for intermittent renewable sources of energy. This has an advantage of increasing dependability and flexibility of the system thereby reducing the variations offered by renewable sources.

Pumped hydropower storage was developed in the 20th century with majority of these projects undertaken between the 1960s and 1980s. This was mainly steered by energy security concerns and the oil crisis in the 1970s.Interest in the pumped hydropower storage has since been renewed and a number of countries led by China have increased their capacity. They have increased their production to up to 15,000MW since 2010 (Mathis Rogner, 2018). Global capacity as of 2017 stood at 161,000MW as shown in figure 1 below.

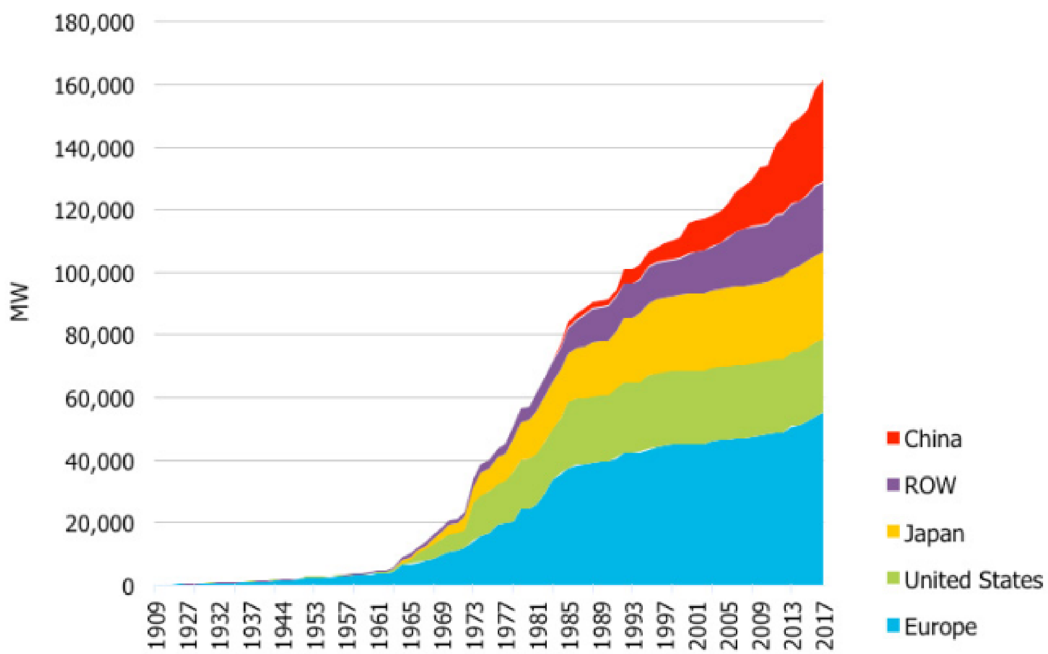

Figure 1.1: Total installed capacity additions to 2017 broken down by country and region. Source: IHA's hydropower database

An overdesigned hybrid system satisfies the demand due to its huge size. However, it is a costly venture. On the other hand, a small undersized hybrid system might be cost-efficient but not capable of meeting the demand. The optimal hybrid energy system's optimal sizes are achieved by several mathematical models and system components simulation until the best possible solution is achieved (Mariana Simão, 2020).

1.2 Objectives

To highlight the attributes of hybrid pumped hydropower systems. This includes operational and technological innovation that contributes to power system flexibility.

To stir discussions amongst policymakers and major stakeholders in the energy sector about the increased importance of hybrid FPV-hydropower stations on clean energy transition. Traditional streams of revenue continue becoming more unpredictable and markets being volatile. These hybrid systems secure long term revenue and attract financing in particularly liberalized energy markets (Mariana Simão, 2020).

2. Methodology

2.1 Characterization

A hybrid power system that is integrated eliminates the demerits that exist in the individual energy power generation methods. Therefore, as engineers design hybrid power systems, the major goals are to minimize cost of producing power, purchasing costs of energy from the grid, reduction of emissions by use of clean and safe energy thus increasing the adaptability and reliability of the system generating power. To increase the levels of renewable energy, these hybrid systems are the most reliable and constitute a feasible option that is reliable considering these components are optimally sized.

Pumped hydropower systems provide the ability of energy storage on a large scale, thus improving the daily capacity factor of the system generating power. Energy is stored in the form of potential energy in a pumped hydropower system in a lower reservoir. The water is pumped to a higher reservoir to be used in turning the turbines, thus satisfying the energy demand. During off-peak hours, this particular system uses low cost electric power to power the pumps used to elevate water from the lower reservoir to the higher one. (Mariana Simão, 2020)

The electricity storage for the dam is calculated as shown in the equations below:

$$E = \eta * \rho * g * h * \dot{\text{O}}.\text{T}$$

$$T = \frac{\varphi}{\theta}$$

Where;

E-Maximum electricity storage capacity of the reservoir (Wh)
η -Efficiency of turbine + generator (assumed 90% for hydropower)
ρ -Density of water (kg/m3) Water flow (m^3/s)
$\dot{\text{O}}$ -Gravity constant (rounded to 9.81 m/s^2)
h-Head of the dam (m)
T-Time (hours)
φ -Volume capacity of the reservoir (m^3)
θ -Yearly average discharge ratio of the reservoir (m^3/s)

Using the global annual irradiation profiles, a simulation of the irradiation maps for optimally fixed-tilted P.V. systems was calculated location-wise for the FPV energy production. The surface of the reservoirs was assumed to be only a quarter-way covered. This was to protect the floating photovoltaics from the effects of the shifting water levels. Other influencing factors such as cooling and albedo effects on the water surface were neglected. The results were simulated according to the 145 regions described geographically (Mariana Simão, 2020).

3. Discussion

The photovoltaic system is a system that is renewable. Its uses P.V. modules that convert sunlight to electricity. Generation of this electricity can either be used directly or stored. It can also be fed back to the grid line or used as a renewable source. This source of energy is clean and reliable and can suit a wide range of applications.

Given the methods and assumptions previously stated, the figure below shows the obtained findings. It shows the potential installation capacity while the other figure represents the prospective electricity generation by the floating photovoltaics on the reservoirs that produce hydropower (Either as a primary or secondary purpose of the reservoir). The main basis of integrating floating photovoltaics with existing hydropower stations is their low cost. This is because of the already-available infrastructure such as the grid connectivity. Globally, 4400GWp of Floating photovoltaics capacity installed could estimatedly produce 6270 TWh just by covering 25% of the reservoirs surface area. This energy can be used virtually as a battery. Locations with the greatest potential for this virtual battery include Siberia, Eastern Europe, Parts of South and North America and Central Africa. Regions such as the Persian Gulf and the northern parts of Africa hold the least potential due to lack of available water. In Africa we have the largest controllable water reservoir. This is the boundary territory which is integrated between Kenya and Uganda which, when combined with efficient solar irradiation conditions, holds the most potential of combining Hydropower with FPV.

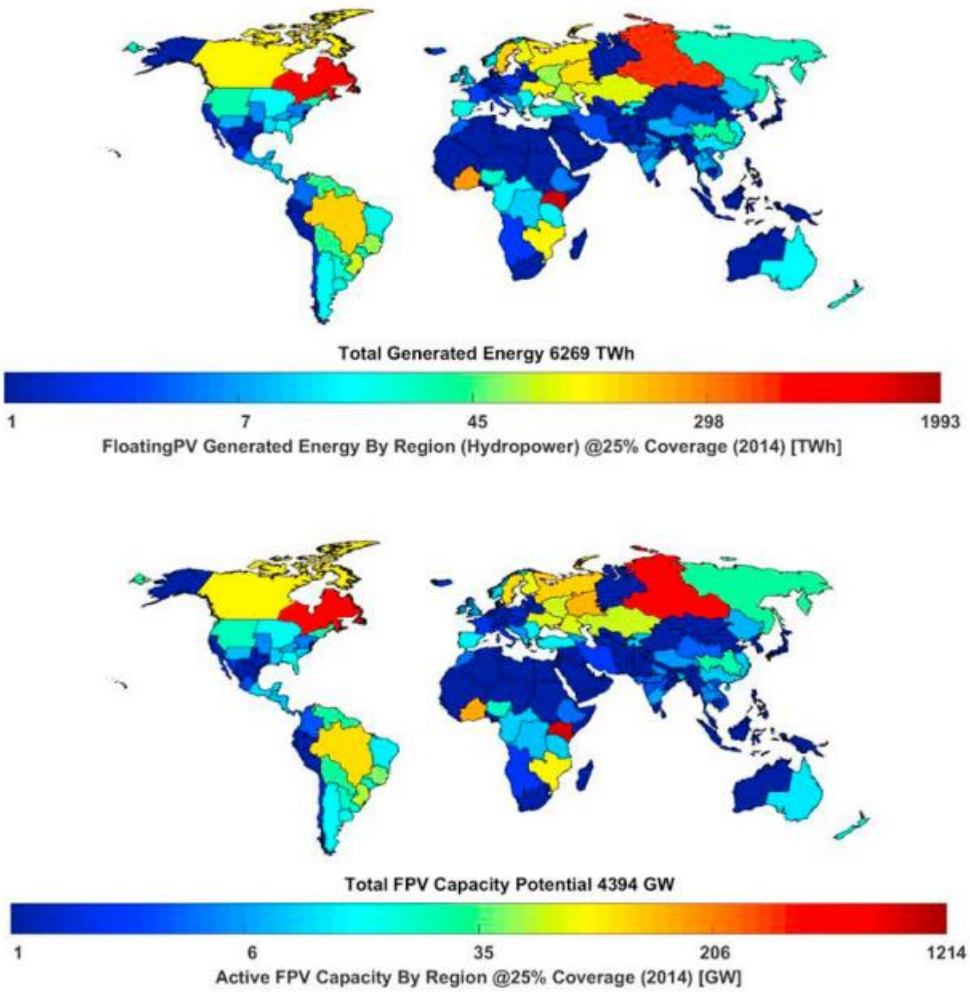

Figure 3.1: Potential electricity generated per year from (top) and potential capacity of (bottom) FPV covering 25% of the water surface of hydropower reservoirs. *(Mariana Simão, 2020)*

Bloomberg estimates by the year 2020 the global energy demand would be 300GWh (BNEF-Bloomberg New Energy Finance, 2017). This is roughly six times the levels being produced in 2016. By 2050, for the world to be totally dependent on renewable sources of energy the storage demand would be $15{,}100TWh_{cl}$ and thereof $10{,}100TWH_{CL}$ of utility scale batteries. (Mariana Simão, 2020).

4. Conclusion

The advantages of a hybrid system are significant. Floating photovoltaics, apart from satisfying the load demand globally for energy storage, has benefits that exceed further. The operations of hydropower plants and floating photovoltaics complement each other in good measure.FPV can significantly provide more electricity 6270 TWh than hydropower generated from the reservoirs (2510TWh). This is at a coverage rate of 25% whilst balancing the FPV intermittent operation. The water available through prevention of evaporation that is estimated at 6.3% can be used to potentially increase generation of hydropower electricity by the same ratio. This under the underlying conditions present about (142.5TWh) assuming 90% efficiency in hydropower. Depending on the additional uses of the reservoir and its location, higher ratios could be considered thus increasing capacity, electricity generation and the rate at which the water is conserved. Then reservoir surfaces are covered at about 50%, This could increase the amount of electricity generated by the FPV outstripping the hydropower generation by factors. However, environmental and social issues may increase as the surface coverage increases.

Alternative energy storage technologies and batteries still have a major role to play. The hybrid FPV-hydropower configuration is disadvantaged by their geographical restricted to certain regions. These systems are also affected strongly by weather patterns and seasons. The virtual battery functionality provided by the hydropower reservoir is restricted to the size of the reservoirs capacity.

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