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Integrating Floating Solar PV with Hydroelectric Power Plant: Analysis of Ghazi Barotha Reservoir in Pakistan

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Abstract

Renewable energy is built as the future of energy value chain. In particular, solar energy is being utilized at a faster pace than ever. The problem sometimes occurs that large scale Floating Solar PV (FSPV) plants have to be developed, away from the population which adds to the cost of transmission and distribution. Floating Solar PV plants have recently gained traction as a suitable alternative of ground based large scale PV installation. FSPV, not only utilizes the water as real estate, but it has a number of other advantages. For example, FSPV could utilize the existing transmission and distribution infrastructure that is the part of hydroelectric power plant anyways. In this paper, we analyze hydro-FSPV combination on a small dam in Pakistan. Our results show that FSPV could complement the existing hydroelectric production and could provide electricity in conjunction with the existing generators of the hydroelectric plant. Furthermore, we also discuss options of integrating FSPV with the existing electrical infrastructure of Ghazi Barotha Dam.

Keywords: Floating Solar PV; FSPV; Hydro-FSPV; Hydroelectric production; Electrical infrastructure; Ghazi Barotha Dam

1. Introduction

Rapid technological advancements have taken place in the field of renewable energy systems. Dependency on fossil fuels for energy production, critical issues of global warming and greenhouse gas emissions have eventuated in the vast usage of renewable energy sources. The technological innovations and enhancements to harvest energy from renewable resources like solar, wind and water are the core factors that defines the future of renewable energy

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systems[1]. The growing economy like Pakistan is tremendously dependent on the carbon-based fuels for energy production. The current economy of Pakistan like many any other countries is carbon locked-in and is quite vulnerable to energy prices. Fossil fuel and hydroelectric power plants are the main source of energy production in Pakistan. According to the Asian Development Bank report [2], the total greenhouse gases emissions will be doubled by 2020 in Pakistan and due to its environmental vulnerability, Pakistan is one of the countries that is most affected by global warming and climate shifts in the region.

1.1. Renewable Energy Potential in Pakistan

The urgency of reducing large scale carbon emissions in an eco-friendly and sustainable way, has made the deployment of renewable energy systems and technologies in Pakistan, quite imperative. Pakistan has millions of MWs of renewable energy source potential [3, 4]. Of all the renewable energy resources, solar energy has the highest potential i.e. 2900 GW, wind energy and hydro power has the potential of 346 GW and 100 GW respectively[5].

There are major hydroelectric power plants in operation at Tarbela (3,478 MW), Ghazi Barotha (1,450 MW) Mangla (1,000 MW) and others that accounts for 30% of Pakistan's total electricity generation[6]. Pakistan has also made recent advancements in solar energy utilization by installing its first large scale solar power plant, Quaid-e-Azam Solar Power Park, which will have a maximum generation of 1000 MW[7].

1.2. Floating Solar PV system

The installation of Solar and Hydro power plants on such a limited spatial scale despite having such enormous power production potential across the country is twofold. Firstly, the hydroelectric power potential of Pakistan lies in the north of the country, however the main energy requirement is in the central region. Therefore, it requires huge investments to install transmission lines for energy delivery. Secondly, the central region is although rich in the solar energy but at the same time is the important food basket for the country. Large utility scale power plants are not desirable since they could erode the fertile agriculture land. In this situation, integration of solar energy system and hydro power plant at a same site for the utilization of optimal energy mix is quite a viable option. Implementation of solar PV system on water bodies is a logical alternative for harnessing solar energy and is generally known as "Floating Solar PV" (FSPV) system[8]. Floating Solar PV plants are economically viable, have lower operating temperature, conservation of water beneath by reducing water evaporation [9, 10]

Pakistan has several large water reservoirs such as Tarbela, Mangla, Ghazi Barotha and others[11]. Deployment of FSPV system on these water bodies can produce large amount of electrical energy. The installation of FSPV plants on the reservoir of dams has benefits as existing infrastructure can be utilized. In this paper, we analyze the FSPV installation on Ghazi Barotha Dam to access the feasibility of installing large scale FSPV on water. This paper is divided into two sections. In the first Section, Pakistan's solar energy and peak demand profile, floating Solar PV potential and its installation in Pakistan is discussed. In the second section, we analyze the implementation and integration technologies of a Floating Solar PV plant on Ghazi Barotha Dam, followed by the discussion on the strengths of installing FSPV plant.

2. Pakistan's Solar Energy and Peak Demand Profile

With rapid increase in population and rate of urbanization, Pakistan is facing severe electricity crisis as their energy mismatch in consumption and generation is increasing. Previously our strategy was focused on installing more power plants to reduce the gap but these power plants have environment related issues. Renewable energy sources are sustainable and environmental friendly, energy sources that can combat the energy gap between the supply and demand. Renewable energy sources particularly solar, which has a large potential, can play a vital role in overcoming the energy shortfall, reducing harmful carbon emissions and providing sustainable energy supplies[12].

Apart from its great potential for energy production, solar energy profile of Pakistan is largely concomitant with the country's load demand curve. There appears to be a one major peak in the load demand curve of Pakistan that coincidentally matches with the solar energy profile. The matching profiles of load peak demand and solar energy is the key aspect that encourages the integration of solar energy systems with the national grid to meet the peak load demands in an eco-friendly and sustainable way. In other words, solar generated electrical energy can be used to meet the peak demand of Pakistan.

3. Floating Solar PV Installation on Dam Reservoirs

The reservoirs of dam are used to reduce the spatiotemporal variability of natural water supply. They regulate the water flow and acts as a reliable source of water for a wide variety of applications. Reservoirs have a long life span and their large water resources and surface infrastructure usually remain unexplored[13]. Water reservoirs usually have optimal conditions for the installation of floating Solar PV like stable water inflow and outflow, optimal temperature, absence of shading, water availability for cleaning of panels. The purpose of this floating PV project is to utilize the existing electrical infrastructure of hydroelectric power plant thereby minimizing the additional cost of transmission related to any power system. Integrating the FSPV plant with the existing hydroelectric power plant, is therefore, more economical and technically quite effective. Also FSPV can help in the conservation of water reserves, reducing electrical stress on power system, reducing water evaporation, maximizing utilization of existing infrastructure.

4. Analysis

4.1. Ghazi Barotha Dam

The hydel power from Ghazi Barotha Dam is a major contributor towards country's total generation with a maximum contribution of 1450 MW at peak demand. It is located near the town of Ghazi where Indus River is diverted as it runs through a 100-meter-wide and 9-meter-deep channel which is completely concrete and spreads over a long range of about 52 kilometers down to the village of Barotha. The power complex other than auxiliaries comprises of a power house with five 290 MW generators. The Dam has two heads with a storage capacity sufficient for daily requirement of 4 hours peak demand. On average three out of five generating units operate for normal load conditions, and according to WAPDA records, on average individual unit produces around 150 MW[14].

4.2. FSPV on Ghazi Barotha Dam

Introducing a Floating Solar PV plant in a huge hydroelectric dam reservoir can be a revolutionary step in the field of renewable energy systems. Floating Solar PV, having a reasonable power generation potential, if implemented on Ghazi Barotha dam reservoir, can play a vital role in sufficing the peak load demand encountered by Ghazi Barotha hydroelectric power plant.

The Dam has two heads with a storage capacity sufficient for daily requirement of 4 hours peak demand. On average three out of five generating units operate for normal load conditions, and according to WAPDA records[14], on average individual unit produces around 150 MW. The storage capacity of hydroelectric reservoir is utilized when demand is at peak and according to daily load curves we have two peaks in 24 hours a day. First peak is around 10:00 - 15:00 and the second is 19:00 - 22:00, in some cases we cannot provide our peak demand because the storage has already been used in the previous peak hours, a solution of the problem of not having stored capacity for peak demand is to add one more generating unit connected to a floating photovoltaic power source of 200 MW (which is the estimated output of Ghazi Barotha Dam reservoir I & II, covering 20% of the total area) installed on the Dam reservoir, during day we could meet our peak demand with FSPV and night peak with hydro power. Moreover, no new infrastructure is required in terms of transmission line. The same transmission line can be used for the peak demand. Adding a 200 MW at this site will solve our problem of peak demand in morning and such solar plant could save the additional costs associated with installing solar power plant any place else i.e. transmission and distribution costs. It is assumed that the base load demand is always catered by the power from the hydroelectric plant. Floating Solar PV plant becomes a peak demand source during daytime.

4.3. Ground elevations, Area estimates and Power Generation Potential

FSPV plant requires some water body to be installed upon and unlike land area when a water body is used, we need to see the ground/sea-bed beneath that water body, similarly the ground elevation and the depth of water is also being taken care of. For our implementation, we have analyzed reservoirs of Ghazi Barotha Dam, the two reservoirs have potential of 200 MW at 20% covered area as proposed in a research study. We need to explore this figure of 200

MW keeping the ground elevation data in mind. When the reservoir storage is being used and water is being removed from the reservoir, there is a danger of panel hitting the ground and damaging equipment. We also need to know the locations and areas beneath the reservoirs where we can install the FSPV without the danger of damaging the panels when water is removed. Using Google Earth, we access the ground elevations of both reservoirs, Fig. 1 and Fig. 2 shows the area highlighted in white where we have sufficient depth and can install the solar panels without any consequences when water is removed from the reservoir.

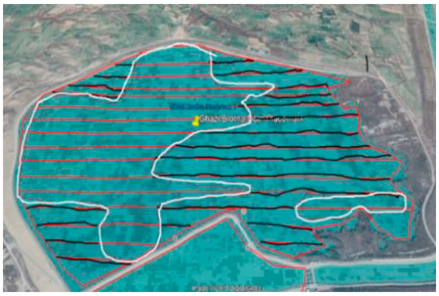

Fig 1. Reservoir 1

Fig 2. Reservoir 2

The above both images show that we cannot fully install floating solar panels in these reservoirs and comparatively less area is available for FSPV installation. To our benefit as previously explained we only need to cover 20% area to get 200 MW power out of these reservoirs, therefore, we use a best path technique in which we select a longest path and widest path in the highlighted region and try to find their potential. For this best path technique, we determine the length of the longest path and an approximate width of that path. Once we have dimensions, we can calculate how many solar modules of 10 kW can be installed in this area, similar is the case for the widest path. Using this best path technique, we determine the best path potential for both reservoirs and the combined output power of best path of both reservoirs comes out to be 280 MW, which is more than our proposed 200 MW (20% area covering). Keeping these ground elevations in view, we are still able to extract 200 MW of electricity during daytime as we plan to store water during day and use its potential energy at night time.

4.4. Implementation

4.4.1. Limitations

One of the recently installed solar power park in Pakistan, named after the founder of the country, Quaid-e-Azam Solar Power Plant (QASPP), planned to produce 1000 MW of electricity, lies in the same province and has given us the motivation and a solar model suitable for our geographical location. In a land based solar power plant, we have excess of land and our layout and orientations are in such a way that each module connected to the 500 kW inverter has optimal cable length and almost same/radial cable with respect to the inverter. A floating solar power plant has some limitations which does not allow the usual land like placement/orientation methodology. For a water body (assume a long channel of canal), we have a longitudinal direction and we can only install panels in one direction. This single direction implementation/extension creates long cables especially for the first panel in the array to the inverter (which is after the last panel) questioning about line losses of these long cable lengths.

4.4.2. Implementation & Orientation

We assume a generic solar panel of 260 W with dimensions of 5.4 ft. × 3.25 ft., we join/extend these solar panels in such a way that we create a module up to 10 kW (along length 5.4 x 40 = 230 approx. with some extra space for axis tilt) with dimensions of 230 ft. × 3.25 ft. This 10kW module is used in configuration, implementation and integration of FSPV. The orientation selected to layout these modules is along the length of channel in such a way that for a channel of length 3450 ft., we place 3450/230 i.e. 15 arrays of these modules in a single row and taking width into account we can have multiple rows. Multiple rows and columns of 10 kW modules are arranged best achieve our solar output. The problem related to cable length mentioned in the previous section is minimized by keeping small modules up to 500 kW i.e. 50 modules of 10 kW each under the dimension of 11,500 ft. x 3.25 ft. (3.5 km at maximum) which is quite acceptable.

4.4.3. Pre-Grid Interconnection

We use a 10 kW solar module to design the equipment for this FSPV to transmit power. 50 of 10 kW solar modules produce 500 kWp, feeding it through a DC cabinet and a 500 kW inverter, converting this DC input into low voltage AC power. Two of such PV power generating units passed through inverters will combine the low voltage AC output from the inverters to 33 kV through a 1 MVA double split winding step-up transformer as shown in Fig 3. Instead of trying to combine the entire 200MW output of the plant, we use 4 modules of 50 MW each. There are multiple techniques for collecting circuits, however we have considered only one which is to transmit 50 MW by 5 collecting circuits with each circuit having a capacity of 10 MW. This approach requires lesser number of circuits hence less initial cost but in case of any fault on a single circuit 20% of the system will be affected decreasing the reliability compared to the system with more circuits with less capacity.

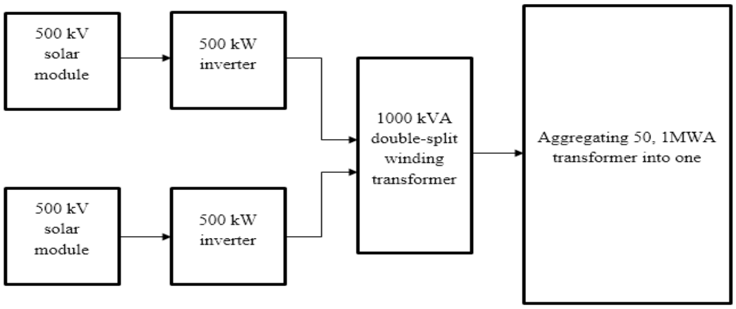

Fig 3. DC to Inverter and 1MVA transformer

Before we can integrate our setup with a National Grid (500 kV Grid Station Ghazi Barotha), we need to consider one more point, if we use 5 circuits of 10 MW capacity for a 50 MW module and 4 of these modules are required for implementation, this implies that a total of 20 circuits (10 MW capacity each), are coming our way. We cannot simply take 20 circuits with us and integrate them with a National Grid, at most we can take 2 of them. To resolve this problem, we have introduced a 33kV Bus Bar. All the circuits terminate on this bus bar instead of a single bus for 20 circuits, we can use 2 buses for 10 circuits each. Now that every circuit is giving its output on a single bus, we can now simply connect a required step-up transformer for the integration with the National Grid.

4.4.4. Integration

Integration of this FSPV is vital as our goal is to maximally utilize existing infrastructure to avoid any extra cost associated with transmission and distribution of power. There are various methods to transmit power but keeping our primary goal in mind to minimize the cost, we use a transmission at 500 kV. This method is quite cost effective as the existing hydro-electric power plant dispatch its power to nearest 500 kV Grid Station, the same is the destination of FSPV power which requires nothing more than a conductor to transmit the power to 500kV grid station.

To connect FSPV to 500 kV system, we have used the 33kV low voltage output from 33kV Bus Bar to a transformer rated 33/500 kV, thus the output of the entire FSPV system comes out on a circuit of 500 kV. The Ghazi Barotha Grid Station is the nearest 500 kV Grid Station, which lies near the Ghazi Barotha Dam. It manages hydro power also FSPV power gets connected to the same grid station. We can transmit power to the grid station either at 33kV (directly from bus bar) or 500kV (step-up). For simplicity, we transmit our power from our FSPV to the grid station at 33 kV and install a transformer rated 33/500 kV inside grid station. This 500 kV transformer is then connected to the main bus bar of 500 kV G/S Ghazi Barotha. Currently, Ghazi Barotha grid station has 5 transformers (one for each generating unit), our scheme will add another transformer to the system. Once the transformer is installed and the connection is established the FSPV power with minimum investment is now ready to be utilized.

5. Conclusions

The step of driving the focus from the conventional sources towards 'Green Energy' has effectively revolutionized the growing economy of Pakistan and has created awareness among the individuals to devise technological methods for the maximum utility of renewable resources. The trend to move towards Solar PV technology for the generation of electricity and considerable installation scale of utility scale and rooftop solar PV systems have opened new paths of utilization of Solar energy. Floating Solar PV is one of the outcomes of these evolutionary paths in Solar PV technology. Floating Solar PV have significant advantages over the land based Solar PV systems particularly when used on a dam reservoir. The conservation of water resources, the integration and implementation of floating solar PV on existing infrastructure of a hydroelectric dam, and its large potential and capability to meet the peak load demand are main advantages of the technology. Analysis on the techniques of integration and implementation of a 200 MW potential floating Solar PV has been undertaken for Ghazi Barotha dam of Pakistan. The analysis have shown the importance of the FSPV plant for meeting the peak load requirements during the availability of solar energy. Due to its high efficiency and lower operating temperature, there are large positive impacts of the FSPV plant on the electrical infrastructure of growing economy. The implementation of innovative technologies like Floating Solar PV plant, as it seems, is a reasonable step towards the attainment of 100 % renewable energy production goal in Pakistan by 2050.

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