Uninterrupted Green Power using Floating Solar PV with Pumped Hydro Energy Storage & Hydroelectric in India

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Abstract

The 100 GW Solar capacity by 2022 is a target which is being aggressively pursued by India. However, the intermittent nature of Solar PV makes it essential that adequate energy storage capacity is created to ensure uninterrupted power for consumers from renewable sources. Pumped Hydro Energy Storage (PHES) is a dominant form of energy storage being used since long by utilities. This paper aims at combining FSPV with PHES & Hydroelectric to try & create a model for a source of Uninterrupted Green Power. It attempts to estimate the potential of this model in large reservoirs in India. It also discusses the advantages, challenges & environmental impact related to the concept. It estimates that Uninterrupted Green Power Supply of 13GW round the year can be obtained from the mentioned reservoirs using FSPV+PHES & Hydroelectric. The reduction in evaporation loss is expected to be 1692 MCM per year in these reservoirs. This involves installation of around 60 GWp of FSPV & 30GW of PHES capacity.
Keywords: Floating Solar PV, Pumped Hydro Energy Storage, Hydroelectric, Uninterrupted Green Power

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I. INTRODUCTION

The 100 GW Solar capacity by 2022 is a target which is being aggressively pursued by India. However, the intermittent nature of Solar PV makes it essential that adequate energy storage capacity is created to ensure Uninterrupted Green Power for consumers. Pumped Hydro Energy Storage (PHES) is a dominant form of energy storage being used since long by utilities. India is blessed with enormous water resources & large reservoirs. Many PHES installations & hydroelectric plants already exist. There is good potential for Floating Solar PV (FSPV) on these reservoirs. In case FSPV is used with PHES & hydroelectric in the existing reservoirs, it can result in a source of Uninterrupted Green Power for the utilities. This paper aims to research, estimate & analyse the potential in India for this model in the present & future.

II. OBJECTIVE

The main objective of this paper is to establish a basis for treating FSPV used with PHES & existing hydroelectric capacity as a source of Uninterrupted Green Power in India throughout the year to overcome the intermittent nature of FSPV. The basic technology for both FSPV & PHES is well established & functioning successfully in many countries. But a combination of the same with hydroelectric to meet the requirement of Uninterrupted Green Power for the Indian consumer is the need of the hour. The quantification of the concept for large reservoirs in India to get an idea of the scale of its potential is demonstrated. An analysis of its advantages, challenges & environmental impact is also attempted.

III. METHODOLOGY

The existing technology for FSPV was studied using reference available. The output of the ground mounted Solar PV power plants in India (e.g. Gujarat sites taken as ref.) has been considered for arriving at the power profile for FSPV, as there is no history of FSPV plants operating in India. This is a conservative approach as the output of FSPV is expected to be higher than ground mounted. It is to be noted that the output figures of Gujarat Solar PV sites are also available online in real time.

The performance of PHES & Hydroelectric is well documented & established in India over the years. The output profile for the same has been taken from the relevant references quoted.

The advantages, challenges & environmental aspects have been enumerated using references available on present FSPV installations & research undertaken (e.g. the effect of shading). The standards in the US have also been used as reference to the environmental aspects.

The figures on reservoir surface area have been taken from relevant Govt. of India publications quoted. The calculations for the output for FSPV with PHES & Hydroelectric illustrated are for demonstration of the concept & to quantify the scale of the potential. The actual capacity & output for each site may depend on grid requirement, evacuation, type of modules, tracking, insolation, weather patterns & local conditions.

IV. BACKGROUND & LITERATURE SURVEY

A. On FSPV & Solar PV performance

The following literature supports the concept of FSPV. It elaborates the performance, advantages, challenges & environmental impact of FSPV & used as ref. in relevant sections here.

'Variability of Photovoltaic Power in the State of Gujarat Using High Resolution Solar Data Technical Report-(9), discusses the variation in Solar PV Generation in Gujarat, India. This is indicative of the power profile expected in FSPV in India & used as a ref. here. The paper 'A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact' (12), discusses the performance of typical FSPV plant in relation to environmental factors. This paper compares and analyzes the empirical data of the floating PV system, which K -water has installed, with that of the existing overland PV and has verified that the generating efficiency of floating PV system is superior by 11% and more. The paper 'A study on major design elements of tracking-type floating photovoltaic systems' (13) discusses the Tracking feature in FSPV. In general, it is known that on the ground, the power generation of a dual-axis tracking-type is 30% greater than a fixed-type. Though not covered here, tracking in FSPV is a point for future development for improved output. The paper - 'A Case Study on Suitable Area and Resource for Development of Floating Photovoltaic System(14) discusses issues related to site selection for FSPV. In this paper, property survey, on-site survey, and photovoltaic resource survey were conducted with the case of 100 kW tracking-type floating photovoltaic system in Hapcheon Dam. Water depth (data and actual measurement), solar distribution, shade analysis (analysis of Solar Pathfinder), effect of floodgate opening during flood (flow modeling), and system connection were reviewed, as well as connectivity with power system. In addition, altitude of the sun at the installation point was surveyed for each season and hour to select optimal tilt angle and separation distance for photovoltaic arrays. The points raised may be useful in site selection in reservoirs. The paper - Installation and Safety Evaluation of Tracking-type Floating PV Generation Structure (15) discusses the results of investigations pertaining to the design, fabrication, and installation of tracking-type floating PV energy generation structure system. The points are to be considered for installation, maintenance & safety aspects of FSPV.

B. On Energy Storage including PHES

The following literature enforces the case of PHES being a good choice for GW level energy storage & its value to complement FSPV.

The presentation 'Grid Integration of Renewables(1) discusses the status of various sources of power generation in India, variation in demand & generation as well as possible integration of renewables with the grid. It also touches upon PHES in India. The variation in Hydroelectric indicated is used here as ref. The report 'Grid Energy Storage (2) discusses the status of grid energy storage in the US. It also compares the development of various energy storage technologies. It indicates that a) Pumped hydroelectric energy storage is a large, mature, and commercial utility-scale technology currently used at many locations in the United States and around the world. b) New capabilities of pumped hydro, through the use of variable speed pumping, is opening up the potential for the provision of additional services that may be used to assist in the integration of variable generation sources. c) Projects may be practically sized up to 4,000 MW and operate at about 76%–85% efficiency, depending on design. d) Pumped hydro plants have long lives, on the order of 50-60 years. e)As a general rule, a reservoir one kilometer in diameter, 25 meters deep, and having an average head of 200 meters would hold enough water to generate 10,000 MWh. These inferences are used here as ref. The presentation 'IndustRE project -Is industrial demand response complementary or competitive to pumped hydro storage?'(3) discusses the demand response with respect to variable speed PHES. It indicates that demand response has similar characteristics with decentralised storage solutions. A large part of the demand response potential can be activated today without any infrastructure requirements and without geographical limitations. The paper 'Developing Cost-Effective, Flexible, Reliable GWh-scale Energy Storage – An eStorage Project Update' (4), discusses the status of energy storage including PHES in Europe. It indicates that one plant alone will not provide the necessary storage flexibility to reach the EU's 2050 goal & many more plants are needed. The article 'Pumped Storage Hydro Power Plant' (5) discusses the status of large PHES in India. It indicates that PHES can help in grid stability, reliable supply & quality power in India. The presentation 'Evaluating The Energetic And Carbon Performance Of Flexible Power Grid Resources—A Net Energy Analysis' (10) discusses the Flexible Power Grid Sources including comparative lifecycle CO_2 emissions per MWh of various storage technologies with PHES having the lowest figures. The paper Feasibility Study of a Hydro PV Hybrid System Operating at a Dam for Water Supply in Southern Brazil (32) discusses the pre-feasibility study conducted on the subject with Homer software . It indicates that the hydroelectric plant with a capacity of 227 kW can operate together with 60 kW of PV modules. This combination will result (in one of the configurations considered) at an initial cost of USD$1715.83 per kW installed and a cost of energy of USD$ 0.059/kWh.

It is apparent from above references that significant work has been done on various aspects of PHES & FSPV. However, this paper aims at combining FSPV with PHES & Hydroelectric in existing major reservoirs in India to try & develop a model for Uninterrupted Green Power Source. It attempts to estimate the potential of this model in large reservoirs in India. It also discusses the advantages, challenges & environmental impact related to the concept.

V. BASIS OF ESTIMATE POWER PROFILE IN RESERVOIRS USING FSPV+ PHES & HYDROELECTRIC (1,5,6,8,9,12,13,16,17,18,27,32,33,35,36,38,39)

Based on the experience in existing installations, a conservative estimate of 40 MWp capacity FSPV can be taken per sq. km of reservoir surface area covered. (e.g. ref.18 - Kyocera using 74 MWp per sq. Km, a much higher value)

The coverage of 20 % of total reservoir surface area can be considered with negligible impact on environment. The saving in water due to reduction in evaporation losses is taken as 1.125 MCM per year per sq. km. of covered area (27) – a minimum reduction in evaporation loss of 50%, Ref. 16 – the evaporation loss in reservoirs in India being 2.25 million cubic meters (MCM) per sq. Km per year.)

A typical model for contribution by various sources in a day is shown in Table 1. The power profile for a typical day will be as given in figure 1 below for Oct. to June. (9) – the NREL report on variability of Solar PV output in Gujarat is taken as a reference) A peak generation of 65% of installed capacity of FSPV of 3GW has been taken based on annual average observed.

PHES output indicated is with 80% efficiency. The Hydroelectric output is taken with average annual output of 30% of installed capacity.

The typical energy export profile will be as per fig.2. We observe from the profile that the possible combination for uninterrupted power exported to grid throughout the year is approx. 17% of the installed FSPV MWp capacity plus 33% of existing Hydro Power MW capacity for installations in India. The PHES capacity needed is nearly 50% of FSPV capacity. Though adequate here for estimating the potential, this combination will have to be worked out in detail for each site based on local conditions ,historical data, future plans & other factors.

VI. ASSESSMENT OF POWER PROFILE IN RESERVOIRS USING FSPV+ PHES (1,5,6,8,9,16,17,18,39)

The assessment of output for FSPV with PHES & Hydroelectric for a typical reservoir in India is as follows -

A. *Sardar Sarovar, Gujarat*

Total reservoir surface area K = 375.33 km^2
Present hydroelectric generation capacity A = 1450 MW
Proposed area coverage for FSPV- R = K X 0.2 = 375.33X 0.20 = 75.06 km^2
Proposed FSPV rating B = 75.06 X40 = 3002.4 MWp
PHES capacity needed = B X 0.5 = 3002.4 X 0.5 = 1501.2 MW
24X7 Power exported to grid throughout the year = (A X 0.33) + (B X 0.17) = 1000 MW
Reduction in evaporation water loss per year = R X 1.125 = 75.06 X 1.125 = 84.44 MCM

Table – 1
Typical hourly power profile for a day - Sardar Sarovar - Oct. to June

Time	*FSPV Generation MW*	*FSPV to Grid MW*	*FSPV to PHES MW*	*PHES to Grid MW*	*Hydro to grid MW*	*Total Export to grid MW*
5:00 AM	0	0	0	500	500	1000
6:00 AM	0	0	0	500	500	1000
7:00 AM	0	0	0	500	500	1000
8:00 AM	300.24	0	300.24	500	500	1000
9:00 AM	600.48	500	100.48	0	500	1000
10:00AM	1501.2	500	1001.2	0	500	1000
11:00AM	1801.44	500	1301.44	0	500	1000
12:00PM	1981.584	500	1481.584	0	500	1000
1:00 PM	1891.512	500	1391.512	0	500	1000
2:00 PM	1831.464	500	1331.464	0	500	1000
3:00 PM	1801.44	500	1301.44	0	500	1000
4:00 PM	1351.08	500	851.08	0	500	1000
5:00 PM	750.6	500	250.6	0	500	1000
6:00 PM	0	0	0	500	500	1000
7:00 PM	0	0	0	500	500	1000
8:00 PM	0	0	0	500	500	1000
9:00 PM	0	0	0	500	500	1000
Time	*FSPV Generation MW*	*FSPV to Grid MW*	*FSPV to PHES MW*	*PHES to Grid MW*	*Hydro to grid MW*	*Total Export to grid MW*
10:00PM	0	0	0	500	500	1000
11:00PM	0	0	0	500	500	1000
12:00AM	0	0	0	500	500	1000
1:00 AM	0	0	0	500	500	1000
2:00 AM	0	0	0	500	500	1000
3:00 AM	0	0	0	500	500	1000

4:00 AM	*0*	*0*	*0*	*500*	*500*	*1000*

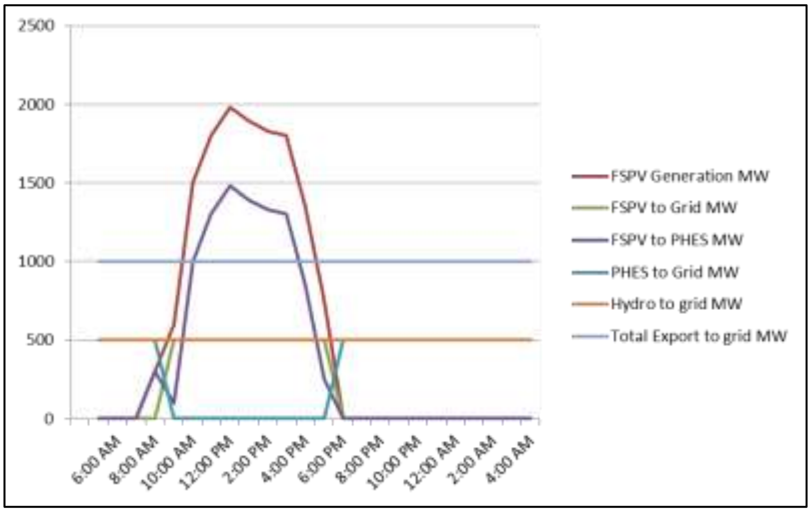

Fig. 1: Typical hourly power profile for a day - Sardar Sarovar - Oct. to June

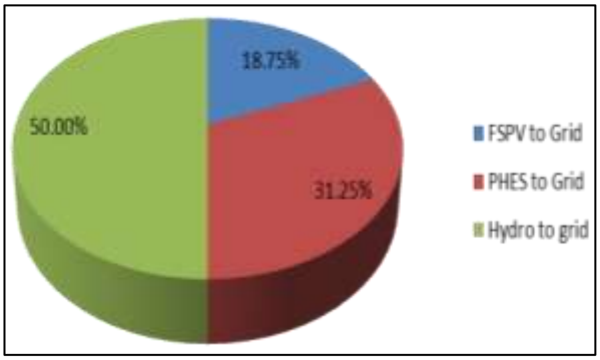

Fig. 2: Typical energy export profile for Sardar Sarovar - Oct. to June

VII. RESULTS

In line with the example given above, the results for various reservoirs are summarised in Table 2 below

Table – 2
Potential for Floating Solar PV with Pumped Hydro Energy Storage & Hydroelectric in Large Reservoirs in India as a Source of Uninterrupted Green Power

Reservoir Name	*Reservoir Surface Area Sq. Km.*	*Hydro electric MW*	*FSPV Area Cover Sq. Km.*	*FSPV capacity MWp*	*PHES capacity needed MW*	*Uninterr-upted Green Power exported to grid MW*	*Reduction in evap.water loss per year Million Cubic Meter (MCM)*
Sardar Sarovar	*375.33*	*1450*	*75.06*	*3002.4*	*1501.2*	*1000*	*84.44*
Nagarjun Sagar	*284.90*	*815.6*	*56.98*	*2279.2*	*1139.6*	*656*	*64.10*
Srisailam	*616.42*	*1670*	*123.28*	*4931.2*	*2465.6*	*1390*	*138.69*
Sriramsagar	*450.82*	*36*	*90.16*	*3606.56*	*1803.28*	*613*	*101.43*
Pong	*260*	*396*	*52*	*2080*	*1040*	*484*	*58.50*
Tungabhadra	*378.13*	*127*	*75.62*	*3025.04*	*1512.52*	*514*	*85.07*
Linganamakki	*316.65*	*55*	*63.33*	*2533.2*	*1266.6*	*430*	*71.24*
Almatty	*754.25*	*290*	*150.85*	*6034*	*3017*	*1121*	*169.70*
Gandhisagar	*723*	*320*	*144.6*	*5784*	*2892*	*1088*	*162.67*
Indirasagar	*913*	*1000*	*182.6*	*7304*	*3652*	*1571*	*205.42*
Koyna	*891*	*1960*	*178.2*	*7128*	*3564*	*1858*	*200.47*
Paithan	*350*	*12*	*70*	*2800*	*1400*	*476*	*78.75*
Rihand	*466*	*300*	*93.2*	*3728*	*1864*	*732*	*104.85*
Hirakud	*743*	*307*	*148.6*	*5944*	*2972*	*1111*	*167.17*
Total	*7522.5*	*8738.6*	*1504.4*	*60179.6*	*30089.8*	*13044*	*1692.54*

Uninterrupted Green Power supply of 13GW can be obtained round the year from the above mentioned reservoirs using FSPV+PHES & Hydroelectric. The reduction in evaporation loss can be 1692.54 MCM per year in these reservoirs. This involves installation of around 60 GWp of FSPV & 30GW of PHES capacity.

VIII. ADVANTAGES (2,3,4,5,10,11,17,18,19,20,21,22,30,31,34,36,37,38)

The advantages of FSPV+ PHES with Hydroelectric in India can be listed as follows.

1) It saves the utilisation of precious land resource of minimum 4 acres per MWp needed for ground mounted Solar PV.
2) It converts the intermittent nature of Solar PV power plant output to Uninterrupted Green Power Supply.
3) The output of Solar PV modules improves due to better cooling on reservoir water surface environment.
4) It reduces evaporation water loss in a significant way. For India, which faces a water deficit, this may be a bigger benefit than the power output, as the demand for water increases in future.
5) The existing infrastructure for power evacuation in hydroelectric power plants can be augmented & used.
6) Mass manufacturing mounting platforms made of potable water grade HDPE can make the FSPV more economical than ground mounted Solar PV.
7) FSPV faces an environment in reservoir which has less dust compared to ground mounted Solar PV. Also cleaning of modules is easier with sprinklers. This improves the output.
8) All materials can be recycled
9) FSPV has lower environmental impact as excavation work involved ground mounted plants is avoided.
10) FSPV reduces erosion of reservoir embankments by reducing waves.
11) FSPV can be adapted to any electrical configuration.
12) FSPV is scalable from low to high power generation.
13) In terms of installation speed, FSPV is faster than a rooftop or ground mounted installation.
14) No special tools or heavy equipment is needed for FSPV installation.
15) FSPV can support distributed generation & micro-grids, using local water bodies.

IX. CHALLENGES (2,3,4,5,10,11,14,15,17,18,19,20,21,22)

The challenges for FSPV+ PHES with Hydroelectric in India can be listed as follows –

1) The environmental impact due to shading caused by FSPV needs to be assessed & minimised
2) Proper anchoring will be needed to minimise impact of wind on FSPV.
3) Scheduling for export of power to grid will be needed to accommodate variations in sunshine & rain periods.
4) Water birds be attracted to the project by virtue of its being on water & nests & droppings may cause problems.
5) There may be a risk of power loss in PV modules due to micro cracks caused by vibrations due to wind, waves and external forces.
6) FSPV may be hampered by factors that affect installation and maintenance: depth of water (water level fluctuation), frozen region, inflow of floating matters, accessibility, interference by dam facilities (water intake tower, waste-way), etc.
7) FSPV may face legal restrictions such as water source protection area ,Environment Preservation Act, Protection of Wild Fauna and Flora Act, fishing prohibition area, marine leisure activity

X. POSSIBLE IMPLEMENTATION OPTIONS FOR FUTURE

We may consider the following as some of the options for implementation of the concept in India –

1) The FSPV plants can be undertaken using the process of bidding being currently used for Ground Mounted Solar PV e.g. Feed in tariff , reverse bidding , viability gap funding etc.
2) The PHES may have to be considered as key asset in National Energy Security Framework with few or no known alternatives for GW level energy storage. It is best for it to be financed & owned by the Public Sector.
3) A cess with say 25 yrs spread can be considered for Uninterrupted Green Power. PHES is localised & stationary. It does not face many of the environmental issues of the Hydroelectric Plants related to the river.
4) The Hydroelectric plants existing need to be upgraded to the extent possible, though additional capacity is not an essential requirement.

XI. ENVIRONMENTAL IMPACT (23,24,25,26,28,29,35)

As the supports for FSPV are made with potable water grade HDPE, the effect on environment is mainly due to shading. The shading reduces the sunlight reaching the water & prevents growth of algae. Algae are desirable as they use sunlight (through photosynthesis) to produce carbohydrates and are eaten by grazers such as protozoa and zooplankton (little animals like water fleas and rotifers). The zooplankton is, in turn, grazed upon by fish, which are eaten by bigger fish, and on up the food chain. A productive lake produces large fish and good fishing for humans as well as supporting food and habitat for wildlife and waterfowl. However, nutrient-rich lakes or ponds may support rapid growth of blue-green algae (algae blooms). Blue-green algae with cyanobacteria forming surface scums up to several inches thick. Cyanobacteria are of greater concern as some species can produce potent toxins. Even if blue-green blooms are not toxic, they are unsightly and when they decompose often produce bad odours (methane). Shading caused by FSPV may help reduce blue green algae as well as methane release.The reduction in temperature of water due to shading helps in improving the concentration of dissolved oxygen in water which is desirable for aquatic life.

XII. CONCLUSION

Uninterrupted Green Power Supply of 13GW round the year can be obtained from the above mentioned reservoirs using FSPV+PHES & Hydroelectric. The reduction in evaporation loss is expected to be 1692 MCM per year in these reservoirs. This involves installation of around 60 GWp of FSPV & 30GW of PHES capacity. If coverage of 30% reservoir area is done in place of 20% considered here & other reservoirs are also utilised, a 50 GW Uninterrupted Green Power Supply round the year can be aimed at in India using FSPV + PHES with Hydroelectric. Also a reduction in evaporation loss of 5000 MCM per year can be anticipated. It is likely that with growing demand for water, reduction in evaporation loss is considered a benefit as important as the power output in future.

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