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Floating Solar Photovoltaic Systems: A Case of Estimated Capacity Calculation at Tehri Dam Reservoir and its Contribution Towards Sustainable Energy

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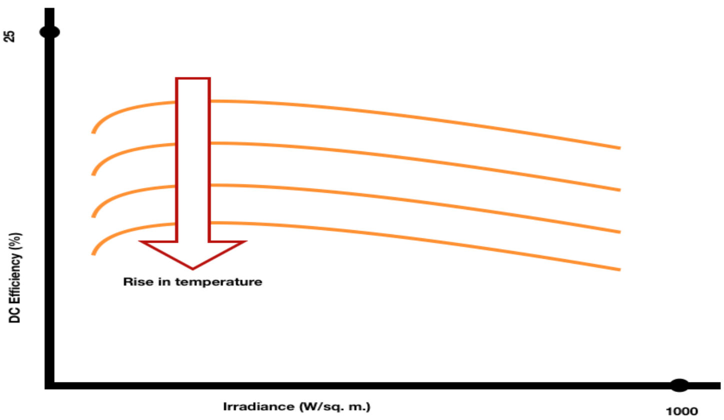
Abstract: Floating photovoltaic systems or FPV systems are gaining a rapid pace of popularity in the world as well as in India. With the cost of land taking a steep rise and an ever increasing population of the country, we need to resort to proper utilization of land and continuously look for alternatives. Floating PV plant can be installed on a fresh water body (natural or artificial) such as a lake, pond, reservoir etc. This paper will discuss the FPV Technology in brief and in length the feasibility of a FPV plant to create a solar hydro hybrid with the 2000 MW Tehri Hydroelectric Dam. Lack of waste land gives an advantage towards floating PV plant for sustainable energy production. The feasibility and capacity analysis check is an original idea of the paper. A 2000 MW Floating PV plant in Tehri Reservoir will increase the installed capacity of Tehri Hydro Dam by 100%. This PV plant will produce 3125 GWh of energy annually while generating/saving Rs 1575 crores/year. It will also help us save 75700 million liters of water as a result of reduced evaporation, while also reducing CO_2 emissions by 2.935 million tonnes annually. It is expected that the research work carried out in this paper will be beneficial to the energy sector towards creation of more hybrid plants and contribute to sustainable energy production.

Keywords: Floating PV plant; Reduce CO_2 emissions; reduce water evaporation; sustainable energy production; solar energy; hybrid power plants.

I. INTRODUCTION

Solar energy is one of the carbon-neutral technologies and is a way of sustainable energy production but the hindrance in installation large solar plants is the low energy density of the solar energy, which asks for large land requirements. India is a population of 135 crores and the amount of waste land in India is very less. Therefore, more productive use of land is the need of the hour.



Large hydropower plants have huge reservoirs built to cater them with the water they require for the generation of electricity. Floating PV plants can be installed on these large reservoirs to create a solar hydro hybrid power plant. The already built hydro power plants are well connected to the grid and thus the installation of the PV panels will require fewer infrastructures. Open reservoirs face a huge amount of evaporation losses and installation of PV plant reduces the evaporation of water by 30% [1], providing more water to the hydro power plant and thus increasing the capacity of it as

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well. The floating panels can gain 7 – 14 % [2] more energy than land-based panels due to moderation effect of the water. The merging of solar and hydro can increase the total capacity of the plant by 50- 100%. A general graph of efficiency of panel Vs Irradiance is given below [3].This paper will briefly discuss the basics of the floating PV system and then proceed to the feasibility and capacity analysis for the installation of a Floating PV plant to merge it with the already existing 2000 MW Tehri Hydroelectric Dam owned by THDC India Limited. The amount of CO_2 emissions reduced will also be calculated as well as the savings and revenue generated by the installation of this plant.

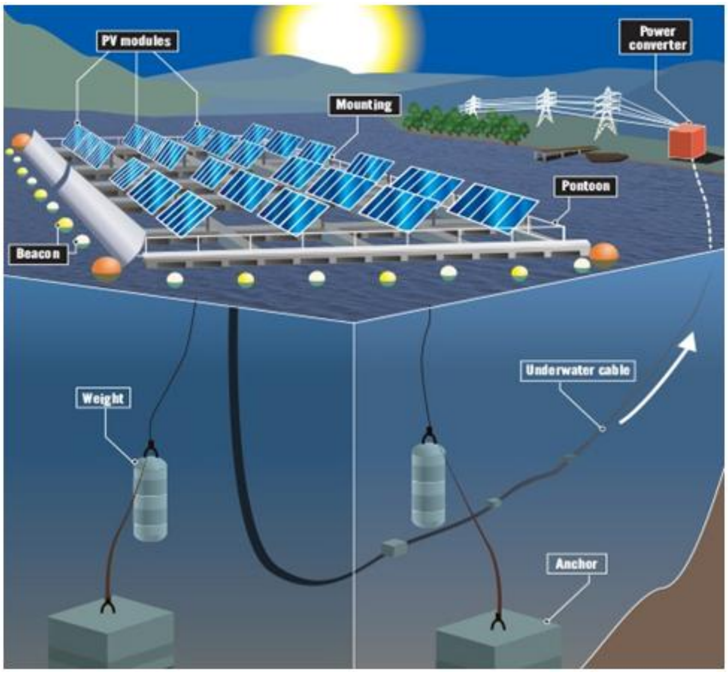
II. COMPONENT OF FPV

According to Waree Engineers Limited, the components of floating PV plant are [4]:

a) **Floating structure**: Also known as Pontoon, the floating structure is a sturdy structure which easily holds the solar panel. It also has enough buoyancy to stay afloat on water while supporting the heavy load.

b) **Mooring system**: The floating structure is held securely with a permanent structure known as mooring. This halts the free movement of the floating structure in water. The floating structure can be fixed with reference to a point on bottom of waterway eliminating the need to connect to the floating structure to the shore. This can be done with help of anchor mooring.

c) **Under water Cabling**: This form as an important link between the grid and the solar panels. Due to its usage under water, the cabling may be designed to be shock and/or leakage proof. A typical technical diagram of floating PV system is shown in the figure below: [5]



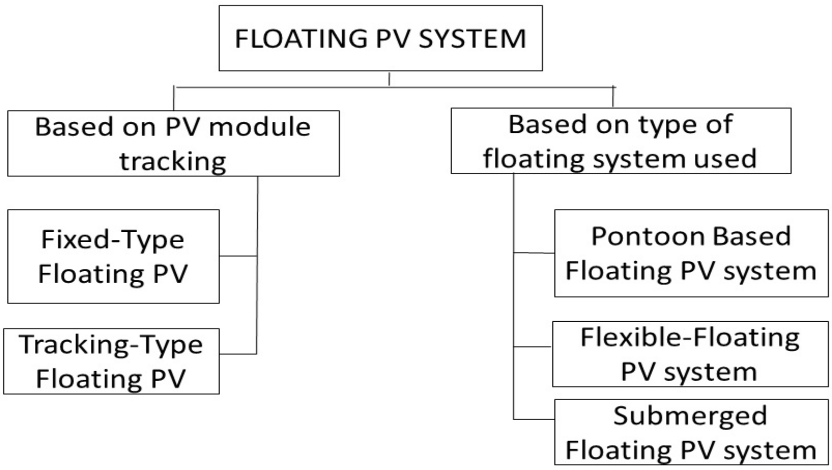


Fig: Categories of Floating PV System [9]

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III. FEASIBILITY OF INSTALLING FLOATING PV PLANT ON RESERVOIR OF TEHRI DAM HYDROELECTRIC PLANT

The Tehri Dam is the highest dam in India and one of the highest in the world. It is a multi-purpose rock and earth-fill embankment dam on the Bhagirathi River near Tehri in Uttarakhand, India. Tehri Dam is a 260.5 m (855 ft) high rock and earth-fill embankment dam. Its length is 575 m (1,886 ft), crest width 20 m (66 ft), and base width 1,128 m (3,701 ft). The dam creates a reservoir of 4.0 cubic kilometers (3,200,000 acre·ft) with a surface area of 52 km^2 (20 sq mi). The installed hydrocapacity is 1,000 MW along with an additional 1,000 MW of pumped storage hydroelectricity.

NOTE: In this paper the area available for installation will be assumed to be 50% of the total surface area of the reservoir i.e. 26km^2. The feasibility and capacity calculations will be based on 20km^2 of solar panel installation and rest 6 km^2 is deemed unusable for the sake for installation uses. In this paper care for the environment and the organisms are taken care of and that's the reason only half of the reservoir is used for the installation of solar plant while the remaining half can be used for fishing, tourism or other recreational activities. The Tehri Reservoir is a fresh water reservoir with calm waters and thus proves to be an excellent site for the installation of the installation of the floating PV plant.

Fig: Tehri Dam Reservoir [7]

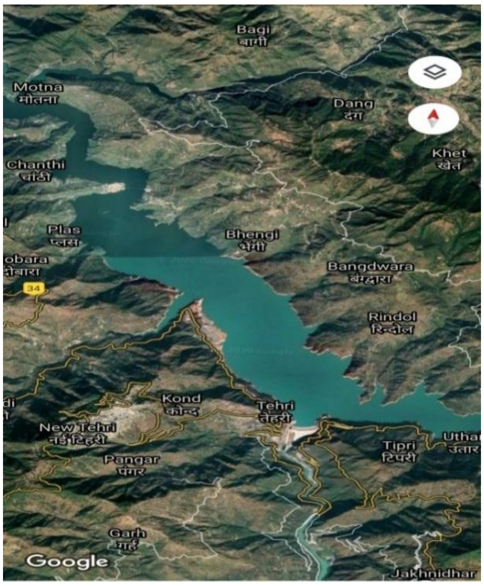

Fig: Satellite View of Tehri Reservoir [8]

IV. CAPACITY CALCULATION

Assumptions used while calculating capacity:

1. The power developed by solar power is taken as 100 Watts/sqmtr. because in the area of 20 km^2, not only solar panels but supporting structures and walking bays will also be present . [10]
2. 1000 gallons/m^2/year would be saved due to reduction in evaporation. [11]
3. 0.932 tonnes of CO_2 emission reduction per megawatt – hour of energy produced from a solar PV plant [12]

Note: Assumption number 1 is very conservative. Actual number may be much higher due to increasing efficiency in the PV Technology. Following all the assumptions on a surface area of 20km^2 surface area gives us a rated plant capacity of - 2000 MW (The total hydro power capacity of Tehri Dam is 2000MW). This will lead to a 100% increase of the power generation capacity of the present in a much cleaner, green, carbon neutral and sustainable manner.

V. SITE SOLAR IRRADIANCE DATA.

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The coordinates of the Tehri Lake is Latitude: 30.3929° N Longitude: 78.4780° E

The Solar irradiance data of any area is given by

i. Direct normal irradiation[13]
ii. Global horizontal irradiation[14]
iii. Photovoltaic power potential [15]. For the simulation it was assumed that cumulative losses due to dirt and soiling, inter row shading, mismatch, inverters, cables , transformers to be 7.5% as calculated by "Global Solar Map by Solargis"

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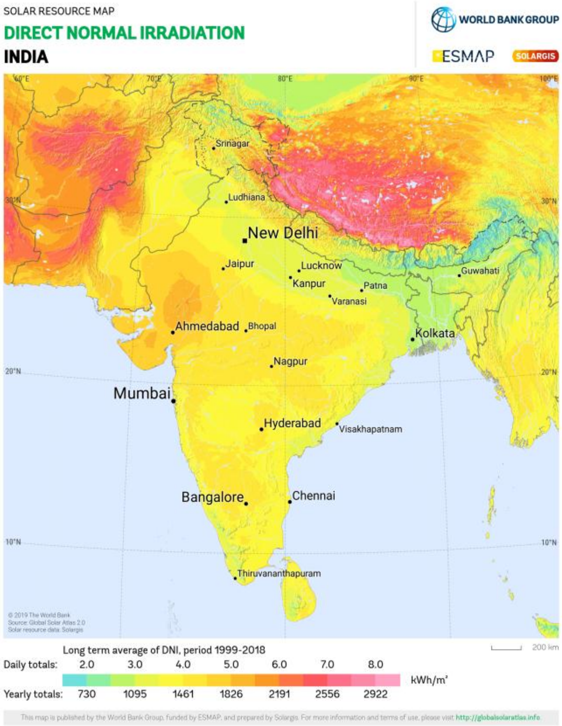

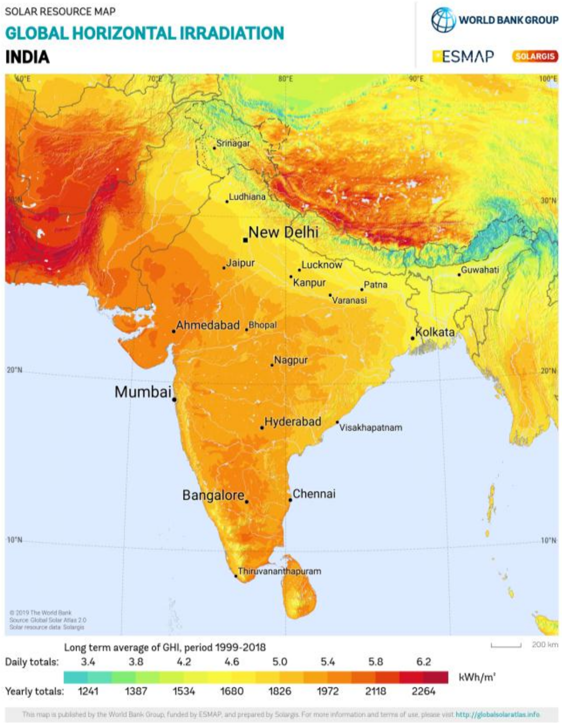

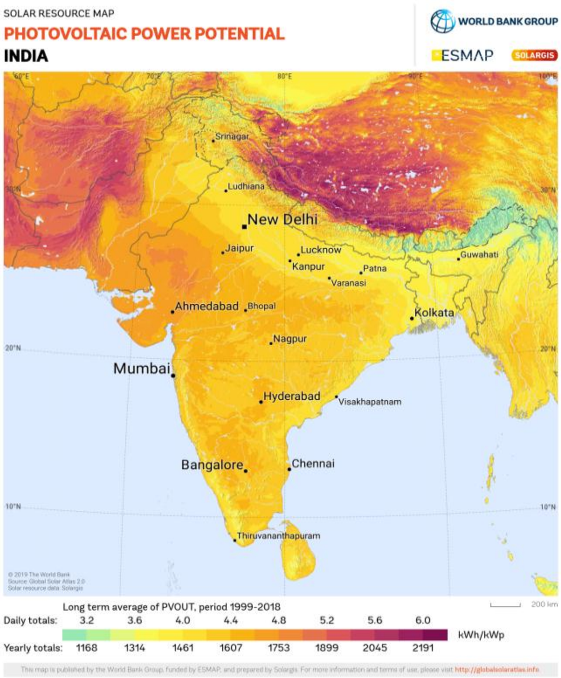

SITE TECHNICAL PARAMETERS(yearly data)[17]

Specific photovoltaic power output	1575 kWh/kWp
Direct Normal Irradiation	1389 kWh/m^2
Global Horizontal Irradiation	1704 kWh/m^2
Diffuse Horizontal Irradiation	743 kWh/m^2
Global Tilted Irradiation at Optimum Angle	1900 kWh/m^2
Optimum tilt of PV module	31^0
Terrain elevation	790 m
Air Temperature	22.3 ^{0}C

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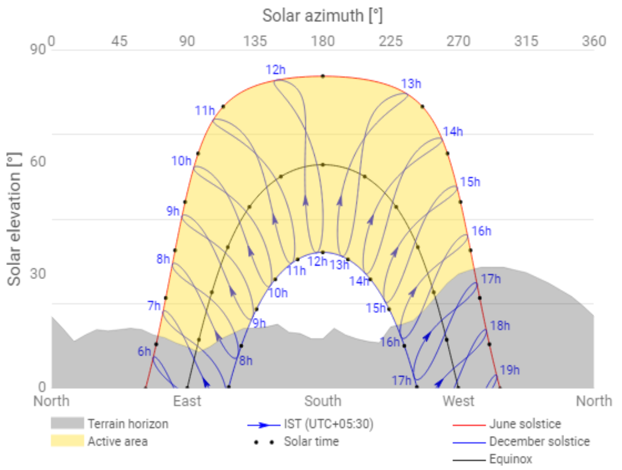
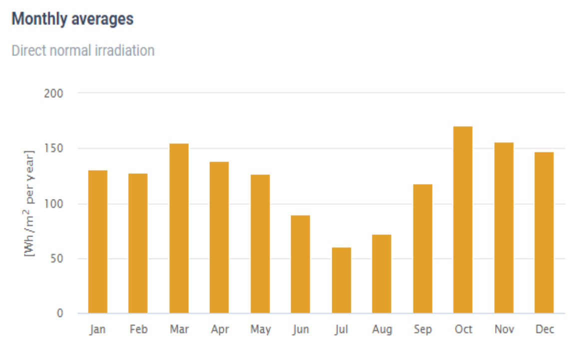
Horizon and Sunpath



Monthly Average DNI

Month	Direct Normal Irradiation(kWh/m2)
Jan	130.7
Feb	128
Mar	154.9
Apr	138.2
May	127.1
June	90.2
July	60.8
Aug	72.2
Sept	118
Oct	170.9
Nov	155.9
Dec	147.4



Average hourly profles

Direct normal irradiation [Wh/m^2]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6												
6 - 7			59	164	185	125	50	56	118	82		
7 - 8		172	360	343	307	204	98	128	268	449	247	
8 - 9	360	449	496	465	415	287	153	198	382	588	606	441
9 - 10	565	541	582	545	492	344	199	263	461	680	697	676
10 - 11	614	594	629	586	523	367	229	286	486	729	746	729
11 - 12	643	626	642	585	515	367	255	304	502	737	755	748
12 - 13	638	624	638	561	498	367	270	320	517	727	734	731
13 - 14	609	590	624	524	465	345	263	307	500	680	686	686
14 - 15	549	529	525	460	392	304	226	268	434	590	596	609
15 - 16	238	446	443	375	306	244	181	197	264	250	129	134
16 - 17						51	38					
17 - 18												
18 - 19												
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4215	4571	4997	4607	4099	3005	1962	2328	3932	5513	5197	4753

VI. RESULTS

For a specific photovoltaic power output of 1575 kWh/kWp, the plant proposed in this paper is of 2000MW. **This will lead to an annual production of 3.15*10^9 kWh/year valuing Rs. 1575 crores at a rate of Rs. 5 per kWh in Uttarakhand**. Therefore we can save Rs. 1575 crores annually, if same amount of electricity is purchased from the grid. The following tables and figures will show the energy generated each month as well as the monthly savings for a given month.

Month	AC Energy (GWh)	Monthly Savings (Rs Crores)
Jan	275.31	137.655
Feb	269.64	134.82
Mar	326.34	163.17
Apr	291.37	145.68
May	267.75	133.875
June	189.945	94.97
July	127.89	63.94
Aug	152.145	76.07
Sept	248.535	124.26
Oct	360.04	180.02
Nov	328.7	164.35
Dec	310.78	155.38

Water Saving Calculations: 1000 gallons/m^2/year would be saved due to reduction in evaporation. This leads to an annual saving of 75700 million liters of water as a result of reduced evaporation. This huge extra amount of water can be used for extra hydro generation as well as for drinking, irrigation & industrial purposes as well. CO_2 emission reduction calculations: We assumed that 0.932 tonnes of CO_2 emission reduction per megawatt – hour of energy produced from a

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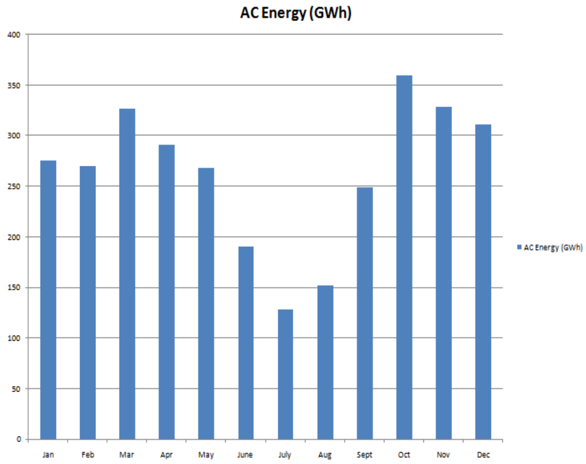
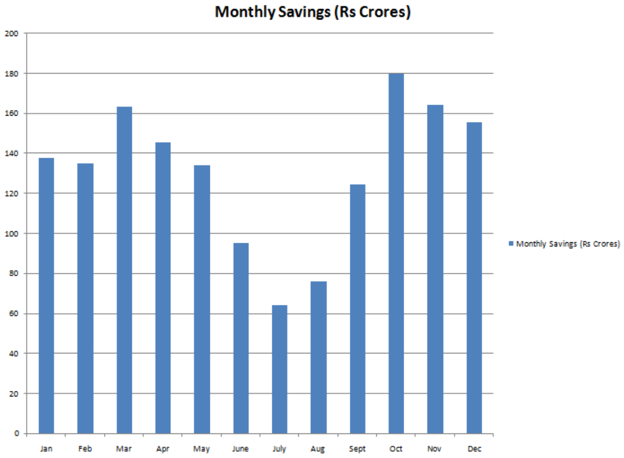
solar PV plant. Therefore, the proposed 2000 MW solar PV Plant will help reduce 2.935 million tons of CO_2 emissions annually.





VII. EVAPORATION RESULT ON ALGAE GROWTH

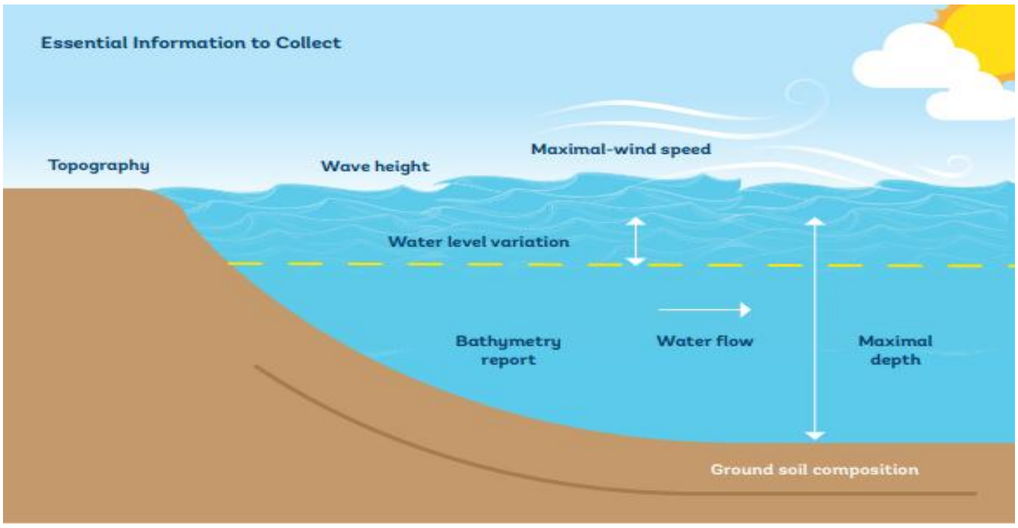
A floating PV Plant covers only a certain percentage of the water surface and thus the distribution of sunlight and oxygen continue in the water body by the means of its natural convection cycles as found by REC Group [18]. There are also spaces between the panels due to various support structures which helps reduce the effect of large scale shading to minimum. Also FPV system may cause benefits to the ecosystem by reducing chances of algae bloom which does not let sunlight penetrate deep into the water body and reduce its biological oxygen demand

VIII. ESTIMATED COSTS AND RATE OF RECOVERY

Recent developments in the Floating PV Technology have reduced its cost significantly. According to the "Economic Times" [19], in the tender of 70MW Kayamkulam Phase II , developers have quoted as low as Rs 35 per watt. At this rate, the cost of the plant proposed in this paper will be Rs.7000 crores. The estimated revenue per year is Rs 1575 crores. Taking a five percent inflation rate, the money invested will be recovered in 5-6 years. With almost zero investment later on, it will give us excellent profits while generating energy in a green and sustainable way.

IX. SPECIAL ANCHORING AND MOORING SYSTEM FOR VARIABLE WATER LEVEL IN TEHRI RESERVOIR

For designing a proper anchoring and mooring system various water characteristics are required as shown in the figure below [20]



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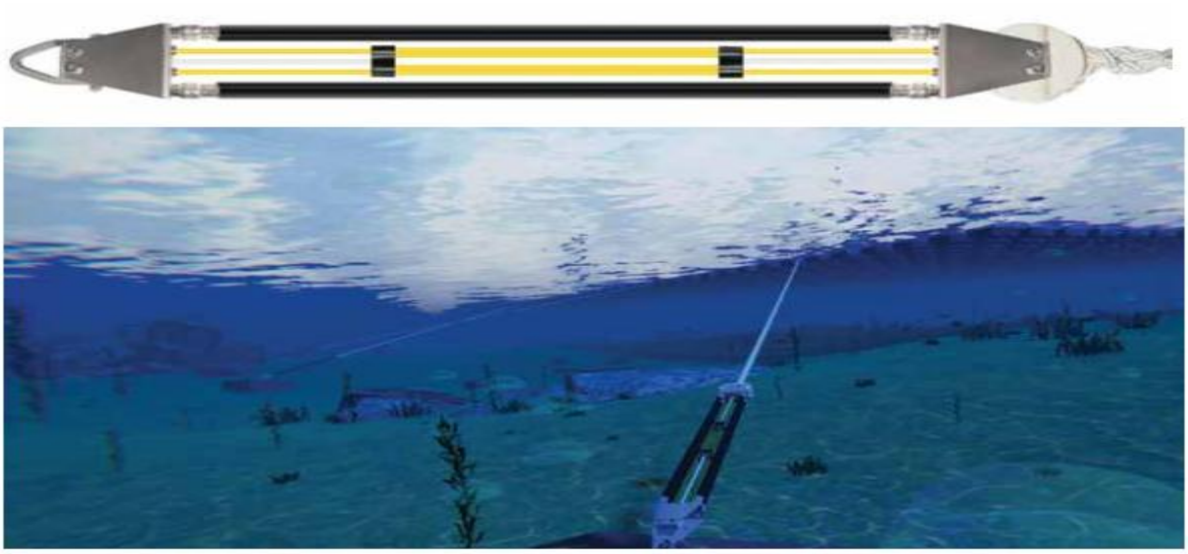
In large reservoirs like the Tehri Reservoir, water variations are apparent. Due to the large surface area of the reservoir, reduction of water level is there due to extensive evaporation and due to other mainstream uses such as hydroelectricity generation and for irrigation purposes. For such sensitive water variation sites the mooring and anchoring systems will have to be designed for such extreme variation making it require more complex mooring systems.

Mooring can be done in the following three ways :[21]
1. Bank anchoring: for shallow water
2. Bottom anchoring : for medium levels of water. It is the most common anchoring process.
3. Piles: In this method , the piles are drilled onto the bed of the reservoir and then the floating resin platforms are moored to these piles. The main advantage of this system is its capability in deep reservoirs and to withstand high levels of water variations(as is the case of Tehri Reservoir). This system despite its advantages , is costlier than the other two anchoring methods and requires heavy machinery and extensive civil work.

The shading which will occur through the solar PV Plant will also help to check extensive evaporation of water which will lead to a more stable water level in dry summer season, which will also partially solve the purpose.
According to the World Bank's publication "FLOATING SOLAR HANDBOOK FOR PRACTITIONERS"[22] , it discusses at length the design systems to accommodate large variations in water level. It states in the handbook that the mooring lines should be long enough to accommodate water level changes as well as restrict lateral movement due to waves. For high water level variations inelastic mooring lines are also not recommended as they are not flexible and cause damage to the mooring points.

There are two solutions to this problem as recommended by World Bank :
1. Use auxiliary buoys and dead weights.
2. Use of more advanced elastic mooring lines with Adjustable lengths. For example the Swedish Company "Seaflex" provides a rubber based elastic mooring system that elongates and retracts in a slow and smooth movement.[23] Such technology can prove to be vital in water varying reservoirs such as the one proposed in this paper.



[23] Seaflex rubber based elastic mooring system

X. CONCLUSION

Floating PV is a great utilization of water body space and gives us an opportunity for a secondary income when coupled with hydro power plants but in a much greener and sustainable way. It increases the grid interaction without taking any extra valuable land space. Further research is required for concentration towers, concentration mirrors in the floating PV Technology which will increase the capacity of the solar power per unit area. A 2 axis or 3- axis tracking system will also increase the efficiency of flat plate collector system. The proposed 2000 MW floating PV Plant in the paper will increase the installed capacity of Tehri Hydro Dam by 100%. This PV plant will produce 3125 GWh of energy annually while generating/saving Rs 1575 crores/year. It will also help us save 75700 million liters of water as a result of reduced evaporation, while also reducing CO_2 emissions by 2.935 million tonnes annually.

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