Site Inspection Report

500 kWp Floating PV System, Banasurasagar Dam, Wayanad

by TeamSustain

About Us

***TeamSustain* Limited** is one of the world's leading Clean and Green technology solution providers. TeamSustain has completed thousands of projects since inception in 1994 in the field of Energy Efficiency, Energy Management, Solar PV, Solar Thermal, Waste to Energy, Small Wind, Sustainable Tourism, Solar/Electric Boating & Transportation Solutions, Sustainable Rural Electrification, Micro Hydro, etc. Our projects are spread across South Asian regions, USA, Middle East and African countries.

We are one of the few companies in the world to possess the expertise, knowledge and capabilities to provide solutions in all the domains of ***Clean and Green Energy technologies***. Several of our projects have made first-time contributions to various sectors including, tourism, commercial and residential properties & community development projects.

We have consistently won many Awards and Accolades. We have been nominated for the largest number of times for the prestigious InterSolar Awards and we have won the InterSolar Awards for the year 2014 and 2016.

With a highly skilled and committed in-house Audit team, we have successfully executed path breaking Energy Efficiency projects and offered many project consultancy services:

⇒ HVAC and Lighting System Audit for CMC, Vellore.
⇒ Efficiency Audit of Cement Factory for Ras AL-Khaimah Cement Factory, UAE.
⇒ Energy Efficiency Audit, Optimization and System Design for Spice Village Resort in Thekkady
⇒ Eco Efficiency Audit for Christian Institute of Health Sciences & Research (CIHSR), Dimapur, Nagaland
⇒ Energy Efficiency Audit for Cochin Yacht Club
⇒ Concept note on Transforming Chandigarh into an Eco City by 2020
⇒ Eco Audit of the Swiss Hotel Dubai, UAE
⇒ Eco - Efficiency Audit for Soneva Fushi, Maldives
⇒ Consultants for Design and Engineering of 25 KW Solar Power Plant in Andaman and 100 KW Solar Power Plant in Lakshadweep Island in 1999
⇒ Consultants for Design and Engineering of 20 KW Solar Power Plant by Central Electrochemical Research Institute (CECRI) (A Constituent Laboratory of CSIR Ministry of Science & Technology) in Karaikudi, Kerala & Tamil Nadu.
⇒ Design & Engineering Consultants for the World's largest Solar Telecom initiative in UP, Bihar, Jharkhand & Leh totaling 60 MW of Solar PV Deployment. The project was funded by IFC, OPIC and other leading PE companies.
⇒ MOU with UB Engineering Ltd. - a flagship company of the UB Group, to jointly execute EPC projects in Solar PV with TeamSustain providing the Domain Expertise – Design & Engineering.
⇒ Consultants to major solar equipment manufactures in India and abroad (EMMVEE Solar India, Anu Solar, India & • GETWATT, S.Korea, OUTBACK, USA) for designing solar power solutions.

Introduction & Objective

Site Name	:	500 kWp Floating Solar Farm
Site Name & Address	:	Banasura Sagra Dam, Wayanad Kerala
Date of Visits	:	23rd December 2017
Energy Auditors	:	Prof. Chem Nayar, TSL Sujith Rajan, TSL Naijo Dominic, TSL
Visit Hosted by	:	Mr. Ravindran, Designation & Company

A team of three Engineers from TSL made their visit to the site on 23rd December 2017 and carried out the Site Inspection.

The major objectives of the visit:

- To inspect the Floating PV system
- To do quality check of the installation
- To check the scope for remote monitoring and monthly report generation

Project Introduction

Project Location – Banasura Sagar Dam, Kerala

Banasura Sagar Dam, which impounds the Karamanathodu tributary of the Kabini River, is part of the Indian Banasurasagar Project consisting of a dam and a canal project started in 1979. The goal of the project is to support the Kakkayam Hydroelectric power project and satisfy the demand for irrigation and drinking water in a region known to have water shortages in seasonal dry periods.

Location : Wayanad,Kerala

Latitude : 11.67°N

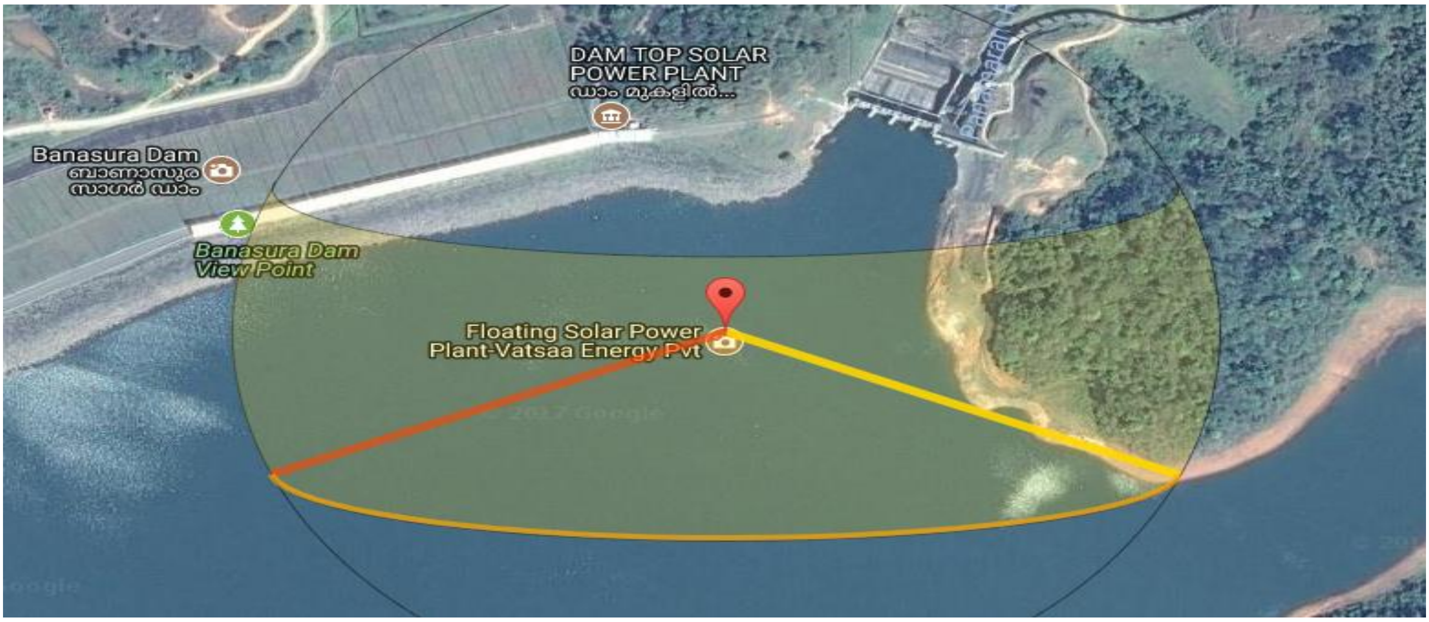
Longitude : 75.96°E

Altitude : 2423 Ft

Climatic Data

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature
	°C	%	$kWh/m^2/d$	kPa	m/s	°C
January	26	58.80%	5.83	98.3	3.8	27
February	26.3	62.40%	6.49	98.2	3	28.2
March	26.8	67.40%	6.92	98.1	3.4	29.6
April	26.5	77.00%	6.73	98	3.5	29.2
May	26.5	79.10%	5.85	97.9	4.2	28.7
June	25.8	81.90%	4.19	97.9	6.5	27.1
July	25.1	83.10%	4.26	98	6.2	26
August	24.8	83.40%	4.9	98.1	6	25.8
September	25	81.60%	5.56	98.1	4.5	26.5
October	25.3	80.10%	5.08	98.1	3.2	26.9
November	25.9	69.90%	5.12	98.2	3.5	27
December	26.2	60.20%	5.44	98.3	4.5	26.8
Annual	**25.9**	**73.70%**	**5.53**	**98.1**	**4.4**	**27.4**

The climatic data for the location from the NASA website is shown above.



Sun Trajectory at the site

Technical Specification

The 500 kWp Grid Interactive Floating Solar Power Plant in the Banasura Sagar dam, Wayanad is the first of its kind in India. The project is designed for Kerala State Electricity Board (KSEB) and the solar photovoltaic array is installed on 18 floating platforms made of Ferro cement floaters with hollow insides which are able to adapt to varying reservoir water levels by means of an innovative anchoring system. Floating solar farm floats on 6,000 square metres of water surface of the reservoir.

Each floating platforms has 114 numbers of solar panels and a 33kW solar string inverter – which converts the direct current (DC) generated by the solar panels into high quality three phase alternating current (AC).

A prefabricated steel enclosure housing HT Switchgear, 500kVA Transformer, LT Switchgear and associated equipment to form a composite compartmentalized Unitised Sub-Station was also installed on one of the floats.

There is Supervisory Control and Data Acquisition (SCADA) system to control and monitor power generation and the power produced will be transmitted to the 11-kV line of the KSEB.

Solar Panel – Radiant Solar RS260P – 60

Maximum Peak Power, Pmax	W	260
Maximum Peak Voltage, Vmp	V	31.60
Maximum Peak Current, Imp	A	8.23
Open Circuit Voltage, Voc	V	37.73
Short Circuit Current, Isc	A	8.96
Maximum System Voltage	V	1000

String Inverter – ABB -PRO – 33.0 – TL – OUTD

Absolute Maximum DC Input voltage, Vmax_abs	V	1100
Startup DC input Voltage, Vstart	V	610
Operating DC Input Voltage Range, Vdc_min to Vdc_max	V	580 to 950
Rated DC input Voltage, Vdcr	V	580
Rated DC input Power, Pdcr	W	33700
Number of MPPT	-	1
MPPT Input DC Voltage Range, Vmppt_min to Vmppt_max at Pacr	V	580 to 850
Maximum DC Input Current, Idc_max/for each MPPT,Imppt_max	A	58
Maximum Input Short Circuit Current, Idc_max	A	80

Observations

PV Array Stringing

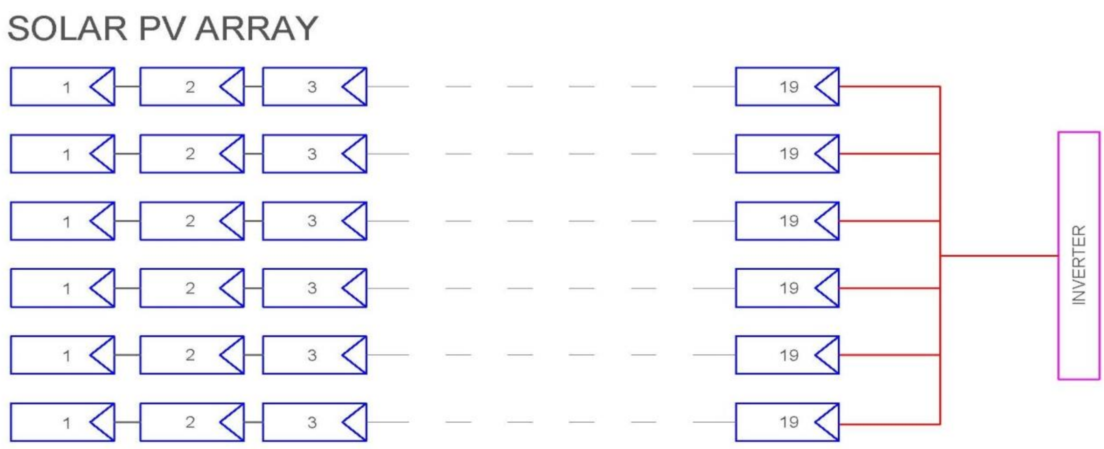
The PV Array Stringing was done based on the initial design with ABB TRIO 27.6-TL solar string inverter. Later the inverter was changed to ABB-PRO-33.0-TL, but the initial stringing was not changed.

Radiant Solar RS260P - 60

Electrical Characteristics (STC)	240Wp	245Wp	250Wp	260Wp
Max Peak Power, Pmax (W)	240	245	250	260
Max Peak Voltage, Vmp (V)	30.96	31.32	31.56	31.60
Max Peak Current, Imp (A)	7.77	7.82	7.92	8.23
Open Circuit Voltage, Voc (V)	37.20	37.34	37.68	37.73
Short Circuit Current, Isc (A)	8.47	8.51	8.63	8.96

ABB -PRO - 33.0 - TL - OUTD

Type designation	33 kW
	PRO-33.0-TL-OUTD
Input side	
Absolute maximum DC input voltage ($V_{max,abs}$)	1100 V [4]
Startup DC input voltage (V_{start})	610 V
Operating DC input voltage range (V_{dcmin}...V_{dcmax})	580 to 950 V
Rated DC input voltage (V_{dcr})	580 V
Rated DC input power (P_{dcr})	33 700 W
Number of independent MPPT	1
MPPT input DC voltage range ($V_{MPPTmin}$...$V_{MPPTmax}$) at P_{acr}	580 to 850 V
Maximum DC input current (I_{dcmax})/for each MPPT ($I_{MPPTmax}$)	58 A
Maximum input short circuit current for each MPPT	80 A



Out of **1938** number of 260Wp PV panels, 114 PV panels are placed in each floating platforms.**19** PV panels are connected in series and **6** such combinations are **parallel**ed together and connected to the inverter MPPT.

Voltage

Vdc = Voc x Number of panels in series

Vdc = 37.73 x 19

Vdc = **716.87V** < 1000V (Vdc_max)

Vmppt = Vmp x Number of panels in series

Vmppt = 31.60 x 19

Vmppt = **600.40V** < 610V (Vstart)

Current

Idc = Isc x Number of panels in parallel

Idc = 8.96 x 6

Idc = **53.76A** < 80A (Isc_max)

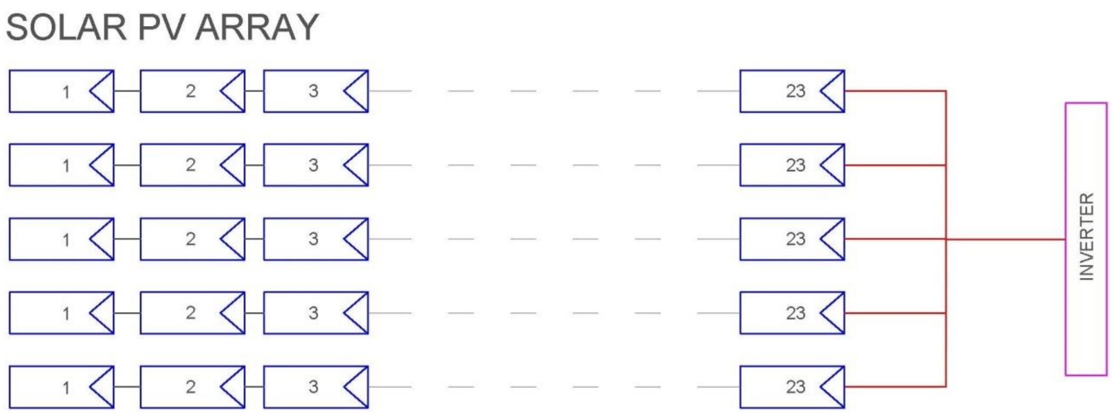
Imppt = Vmp x Number of panels in parallel

Imppt = 8.23 x 6

Imppt = **49.38A** < 58A (Imppt_max)

Even though the Vmppt Voltage of the string inverter is within the MPPT input DC voltage range, it is less than the start voltage of the inverter which will result in decrease in the energy yield.

So changing the stringing is adequate. Currently planning is on-going for increasing the number of panels to **23** numbers **per strings** and **5** such combinations in **parallel**. Total number of PV panels will be increased to **1955** numbers.



Voltage

Vdc = Voc x Number of panels in series

Vdc = 37.73 x 23

Vdc = **867.79V** < 1000V (Vdc_max)

Vmppt = Vmp x Number of panels in series

Vmppt = 31.60 x 23

Vmppt = **726.80V** > 610V (Vstart)

Current

Idc = Isc x Number of panels in parallel

Idc = 8.96 x 5

Idc = **44.8A** < 80A (Isc_max)

Imppt = Vmp x Number of panels in parallel

Imppt = 8.23 x 5

Imppt = **41.15A** < 58A (Imppt_max)

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Grid-Connected System: Simulation parameters

Project :	**Grid-Connected Project at Banasura Sagar Dam**			
Geographical Site		**Banasura Sagar Dam**	**Country**	**India**
Situation	Latitude	11.4°N	Longitude	75.6°E
Time defined as	Legal Time	Time zone UT+6	Altitude	735 m
	Albedo	0.20		
Meteo data :	Banasura Sagar Dam, Synthetic Hourly data			

Simulation variant :	**New simulation variant**			
	Simulation date	05/01/18 10h30		

Simulation parameters

Collector Plane Orientation	Tilt	10°	Azimuth	0°
51 Sheds	Pitch	4.00 m	Collector width	3.00 m
Inactive band	Top	0.00 m	Bottom	0.00 m
Shading limit angle	Gamma	26.48 °	Occupation Ratio	75.0 %
Horizon	Free Horizon			
Near Shadings	Mutual shadings of sheds			

PV Array Characteristics

PV module Si-poly	Model	**RS260P-60**		
	Manufacturer	Radiant Solar		
Number of PV modules	In series	23 modules	In parallel	85 strings
Total number of PV modules	Nb. modules	1955	Unit Nom. Power	260 Wp
Array global power	Nominal (STC)	**508 kWp**	At operating cond.	459 kWp (50°C)
Array operating characteristics (50°C)	U mpp	648 V	I mpp	708 A
Total area	Module area	**3174 m²**		
Inverter	Model	**PRO-33.0-TL-OUTD**		
	Manufacturer	ABB		
Characteristics	Operating Voltage	580-850 V	Unit Nom. Power	33.0 kW AC
Inverter pack	Number of Inverter	17 units	Total Power	561.0 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	15 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

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Grid-Connected System: Main results

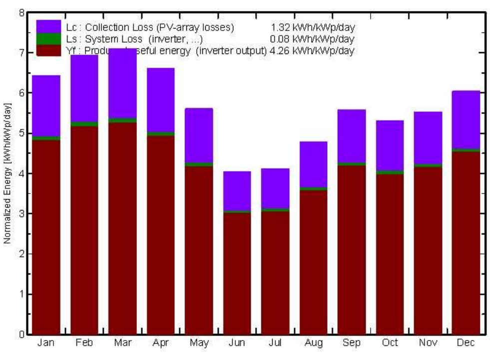
Project : **Grid-Connected Project at Banasura Sagar Dam**

Simulation variant : **New simulation variant**

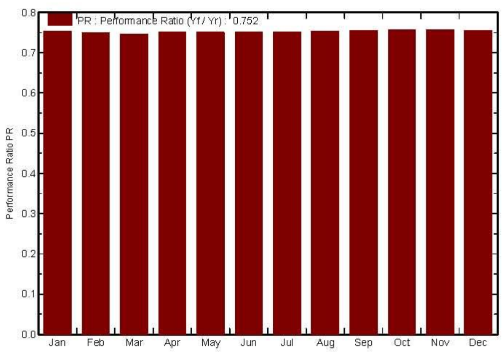
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	10°	azimuth	0°
PV modules	Model	RS260P-60	Pnom	260 Wp
PV Array	Nb. of modules	1955	Pnom total	**508 kWp**
Inverter	Model	PRO-33.0-TL-OUTD	Pnom	33.0 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	**561 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**790 MWh/year**	Specific prod.	1554 kWh/kWp/year
	Performance Ratio PR	75.2 %		

Normalized productions (per installed kWp): Nominal power 508 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	%	%
January	180.7	26.03	199.4	192.4	77.75	76.31	12.28	12.06
February	181.7	26.31	194.2	187.9	75.34	73.95	12.22	12.00
March	214.5	26.80	219.9	213.0	84.95	83.38	12.17	11.94
April	201.9	26.49	198.0	190.9	76.93	75.50	12.24	12.01
May	181.3	26.49	173.7	166.5	67.51	66.23	12.24	12.01
June	125.7	25.80	121.3	115.3	47.23	46.25	12.27	12.01
July	132.1	25.09	127.3	121.4	49.61	48.57	12.28	12.02
August	151.9	24.83	148.2	141.7	57.88	56.73	12.30	12.06
September	166.8	24.99	167.3	160.9	65.47	64.22	12.33	12.10
October	157.5	25.29	164.2	158.0	64.34	63.10	12.34	12.11
November	153.6	25.91	165.8	159.5	64.92	63.71	12.34	12.11
December	168.6	26.20	187.1	180.1	73.11	71.76	12.31	12.08
Year	2016.4	25.85	2066.4	1987.7	805.04	789.72	12.27	12.04

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

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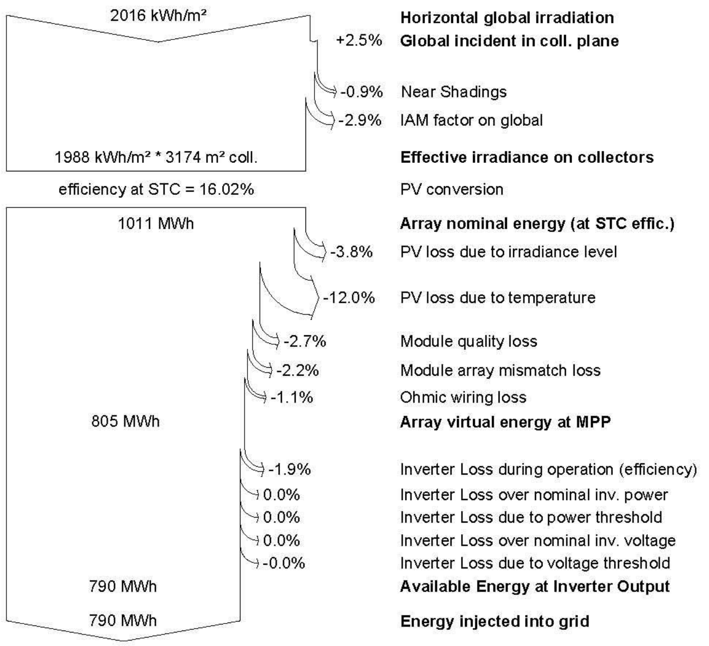
Grid-Connected System: Loss diagram

Project : **Grid-Connected Project at Banasura Sagar Dam**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Sheds disposition, tilt	10°	azimuth	0°
PV modules	Model	RS260P-60	Pnom	260 Wp
PV Array	Nb. of modules	1955	Pnom total	**508 kWp**
Inverter	Model	PRO-33.0-TL-OUTD	Pnom	33.0 kW ac
Inverter pack	Nb. of units	17.0	Pnom total	**561 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Upkeep and Maintenance

Dust and bird droppings were noticed in almost all part of the PV array. Provision for frequent cleaning is required to keep the PV array clean and thereby ensuring maximum energy yield.

Earthing

Water earthing : Supports are provided around the floating platforms to which the earthing plate is attached. The earthing plate is placed in that portion of the floating platforms which is submerged in water.

Affecting Factors to be considered

- coefficient of parallel connection
- corrosion of electrodes
- seasonal variation

Armour earthing : During occurrence of earth faults, the metallic sheaths are expected to carry a substantial proportion of the total fault current. For safety and reliable operation, the shields and metallic sheaths of power cables must be grounded. Armour earthing is done at the site which is good for the system safety.

KSEB has recommended for separate copper rod earthing to the land which could have been eliminated by the use of 4 or 5 core cable, dedicating one of the core for earthing.

Lightning Arrester

Since the floating PV installation is in an open area (dam) there are chances for lightning strikes. “Lightning rods” are static discharge devices that are placed above buildings and solar-electric arrays, and connected to ground. They are meant to prevent the build-up of static charge and eventual ionization of the surrounding atmosphere. They can help prevent a strike, and can provide a path for very high current to ground if a strike does occur. So it is advisable to install lightning arresters over the transformer room and north side of the installation.

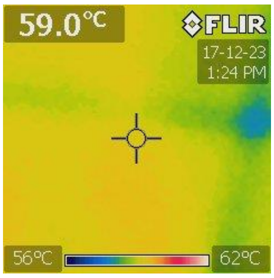
Operating Temperature

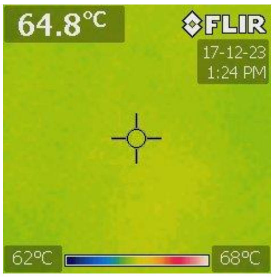
The PV Array is placed over two areas as mentioned below

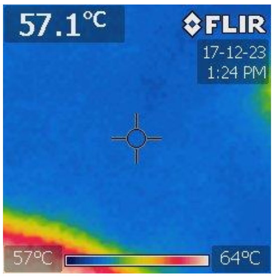
1. Ferro-cement Platform
2. Water Body

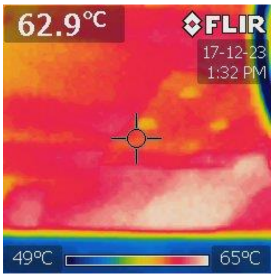
Ferro-cement Platform

Water Body









During development stage of the project, it was expected that floating solar panels generate higher output due to lower ambient temperature existing on the surface of the water body, but on contrary there wasn’t much difference in the temperature between PV array over water body and Ferro-cement platform.

The total energy radiated from a body is directly proportional to the surface area of the body according to Stefan–Boltzmann law. Even though the panel is placed over the water body, there is Ferro-cement platform surface in depth and in length adjacent to the water body. The radiation from this surface almost nullifies the cooling effect caused by the water body. That is why temperature difference is minimal between the panels placed above water body and that above the Ferro-cement platform. The high operating temperature will decrease the annual energy yield as the crystalline panels have high temperature coefficient. Providing additional fibre like material puffing may reduce the heat radiations from the Ferro-cement platform.

Installation

The cable routing and terminations are fine and neat at the site. Cable protection is provided by means of PVC conduit and flexible corrugated conduit hose.

The roofing for the inverter will protect it from direct rain and sunlight. The AC combiner box is well designed and neatly installed. A current transformer (CT) is provided for earth leakage detection which will increase the safety of the entire system.

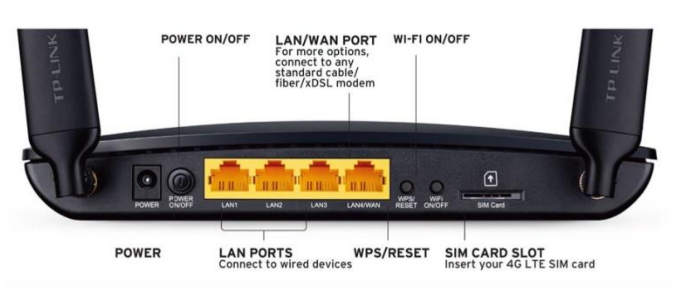
The structure mountings are good and the PV panels are arranged neatly above the structure. The provision for keeping the armoured cable is a future proof design, considering the seasonal water level changes.

Online Remote Monitoring

The online monitoring provides real-time analytics which maximises the solar plant yield.

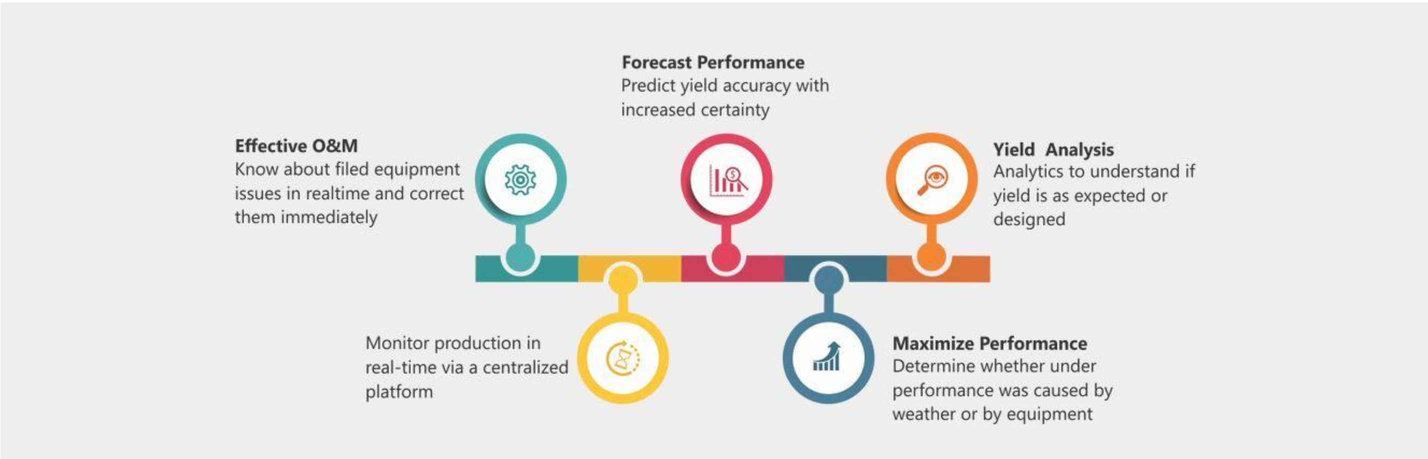
Presently, online remote monitoring system is contracted to Machine Pulse. But the risk in third party tie-up is that we have to rely on them for information as the data are being sent to their cloud.

Whereas depending on the manufacturer communication system will ensure reliability. ABB do have online remote monitoring facility but there is need for LAN connection for data transfer for the same. Since it is a floating installation there is difficulty in getting a wired LAN connection to the installation. This difficulty can be overcome by the usage of modem with the provision for sim card insertion. “Archer MR200” from TP-LINK is an option.



Suggestions

- To setup a proper performance evaluation system
- To establish preventive and reactive maintenance procedures based on regular performance evaluation
- To setup hotline (24/7) technical support facility for the onsite team.
- To carryout regular trainings and troubleshooting workshops for the onsite team.
- To carryout periodic system health check-ups
    - Solar panel : Solar panel deterioration, hotspots, micro-cracks, EVA backsheath degradation, PID degradation etc
    - Inverter : Efficiency testing of inverter, leakage current detection analysis etc



Executive Summary

Sl.No	Observations	Remarks
1	PV Array Stringing	The string voltage less than the start voltage which is set to change by changing the stringing
2	Upkeep and Maintenance	Provision for frequent cleaning is required for ensuring maximum energy yield.
3	Earthing	Need for separate copper rod earthing to the land which could have been eliminated by the use of 4 or 5 core cable, dedicating one of the core for earthing.
4	Lightning Arrester	Install lightning arresters over the transformer room and north side of the installation
5	Operating Temperature	There is not much difference in the temperature between PV array over water body and Ferro-cement platform
6	Installation	Cable routing, termination and protection is ok at the site. The roofing for the inverter will protect it from direct rain and sunlight. The AC combiner box is well designed and neatly installed. Current transformer (CT) provided for earth leakage detection will increase the safety of the entire system. The structure and the PV panels are arrangement is fine. The provision for keeping the armoured cable is a future proof design.
7	Online Remote Monitoring	To setup a proper performance evaluation system To establish preventive and reactive maintenance procedures based on regular performance evaluation To setup hotline (24/7) technical support facility for the onsite team. To carryout regular trainings and troubleshooting workshops for the onsite team. To carryout periodic system health check-ups