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Installation and Performance Evaluation of On-grid 640 kWp Capacity Rooftop SolarPower Plant at the University Campus – a case study

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Abstract:

Dr. Y S Parmar University of Horticulture & Forestry, Nauni is the 1st university in Asia that is growing rapidly. Electricity consumption is around 2.23 million units annually contributing GHGs responsible for climate change. To reduce electricity consumption, a power developer has installed an on-grid 640 kWp capacity rooftop solar power plant at their own cost on RESCO mode at the university campus. The university has provided rooftop space free of cost for 25 years while the university will purchase electricity @ 1.90/unit. The university campus has 280-290 sunny days annually with solar radiation ranging from 3.56 to 7.53 kWh/m^2/d. Solar modules of 20 kW to 80 kW capacities were installed at 13 selected buildings. The university buildings have inclined rooftops which reduces the structural cost. About 823,340 units of solar electricity have been generated until May 2023, thereby saving Rs. 4 million annually and a reduction in CO_2 of 658,672 kg. The overall performance ratio of rooftop solar power plants comes out to be 77.95% capacity utilization factor of 20.98% and a specific yield of 5.03 kWh/kWp. The RTSVP meets the UN sustainable goals 7 and 13. The system will generate solar power on a sustainable basis for 25 years.

Keywords: Rooftop, solar, electricity, CO2 reduction, SDG 7&13

Nomenclature:

IEA	International Energy Agency
NREL	National Renewable Energy Laboratory
TW	Terra Watt
GW	Giga Watt
NEA	National Energy Administration
kWh	Kilowatt-hour
MWh	Megawatt hour
EU	European Union
PWh	Petawatt Hour
RTSP	Rooftop solar power plant
PV	Photovoltaic
GWp	Gigawatt peak

DNI	Direct Normal Irradiance
MNRE	Ministry of New & Renewable Energy
RPSSGP	Rooftop SPV and Small-Scale Generation Programme
JNNSM	Jawaharlal Nehru National Solar Mission
DISCOM	distribution company
IREDA	India Renewable Energy Development Agency
HIMURJA	HP State Energy Agency
kPa	Killo pascal
GHI	Global horizontal irradiance
MMPT	Maximum Power Point Tracker
ACDB	Alternative current distribution box
MCCB	Molded Case Circuit Breaker
MRI	Meter Reading Instrument
SECI	Solar Energy Corporation of India

Highlights

- Reduction in consumption of conventional electricity
- Cost saving for 25 years
- Sustainable energy for mitigating climate change,
- meets SDG 7 & 13
- Carbon reduction

1. Introduction:

About 800 million people, over 10% of the world's population, were without electricity till 2018, mostly in rural areas (IEA, 2019). According to an analysis by the National Renewable Energy Laboratory (NREL) in 2016, over 8 billion m^2 of rooftops are available to produce solar power with a potential of over one TW of solar power. The rooftop potential will be higher as the conversion efficiency of the solar module is improving. Residential and other small rooftops represent about 65% of the national rooftop potential, and 42% of residential rooftops are households. On average, 3.3 million houses will be constructed annually, with thepotential of nearly 30 GW of solar power (NREL, 2016). National Energy Administration (NEA) reported that rooftop solar power installations in China were 10.1 GW in 2020 (Mercom, 2021). The Chinese mainland city's RTPV area has reached 3.35 billion m^2. If urban roofs areused for solar power generation in China, the annual photovoltaic power generation capacity will be 672 billion kWh, which is about 61% of the total annual electricity consumption of thewhole society in 2020 (Zhang et al 2021). Germany has set a goal to produce rooftop solar power up to 200GW by 2030 from a present level of 59GW using all suitable roof areas. Russian solar power costs $0.070/kWh (pv-magazine, 2023). China will be the largest marketthis year with 148.9 GW, followed by the United States with 40.5 GW, India with 17.2 GW,

Brazil with 14.2 GW, Germany with 11.8 GW, Spain with 11.4 GW, and Japan with 8 GW (EMILIANO 2023). The EU's solar power cost is less than 0.02 EUR/kWh (Ram et al, 2017).

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Joshi et al (2021) identified 0.2 million km of rooftop area globally, which can generate 27 PWh annually. The cost of rooftop solar power will be in the range of $40 and $280/MWh, the lowest costs are in India ($66/MWh) and China ($68/MWh), and the highest in the United Kingdom ($251/MWh) and the United States ($238/MWh). According to an estimate, the rooftop solar power potential in the EU is 680 TWh which is 24.4% of current electricity consumption (Bodis et al 2019).

Between 2006 and 2018, the installed capacity of the RTSP increased from 2.5 GW to 213 GW which is 85 times the increase globally (IEA Renewable 2019). RTSP currently accounts for 40% of the cumulative installed capacity of solar power globally and about 25% of the total renewable capacity additions in 2018. RTSVP technology has shown a steep decline in its cost which ranged between 63 and 265 $ MW/h in 2019 (IREA, 2019).

The decentralized RTSP can meet the Sustainable Development Goals (SDG) 3,7 and 13. The problem of energy access can be mitigated by reducing installation time and the low cost of RTSP. The consumer who is the owner can generate and consume electricity as per his requirements without depending on centralized grid electricity. The solar photovoltaic technology is the fastest energy generation technology with the highest year-on-year growth rate (IEA, 2020), projectedto meet 25–49% of the global electricity requirements by 2050 while providing jobs for nearly15 million people between 2018 and 2050 (IRENA, 2019). RTSP will contribute up to 40% ofthe total solar PV-based electricity till 2050 (Joshi, et al 2021).

1.2. India's Perspective

India has 250-300 sunny days in a year. India has a solar power potential of between 4 and 7 kWh/m^2/day (Goel, 2016), the solar power potential has been estimated at 750 GWp. The solar power installed capacity was 48.556 GW as of 30 November 2021 (MNRE, Physical Progress -Achievements).

In a large part of India Direct Normal Irradiance (DNI) is more than 5 kWh/m^2/day. Highest in the state of Gujarat, Rajasthan, and the high-elevation Himalayan region. Indian states like Madhya Pradesh, Chhattisgarh, and Maharashtra receive an annual average DNI of more than 5.5 kWh/m^2/day. India is projected to achieve 40% cumulative electric power installed capacity from non-conventional energy resources by 2030. India has achieved a cumulative installed renewable energy capacity of 92.54 GW. India's RTSP installed capacity is at 3.7 GW and over 2.6 GW capacity is under installation (MNRE, Annual Report).

Indian solar photovoltaic power generation was started in the 1970s after the world oil crisis. In 2010, JNNSM was introduced as part of the National Action Plan on Climate Change (2008) with a target to install 20 GW of solar powerby 2022. Out of three phases of JNNSM i.e., Phase I (2010-12), II (2013-17), and III (2017- 22), phase - I of the mission launched on 30th December 2015 have the RPSSGP one of the components to install rooftop or ground-mounted solar power plants with a maximum capacity of 2 MW.

Rooftop Phase-II was launched in February 2019 with a target of cumulative capacity of 40GW till 2022 out of which 4GW will be installed in the residential sector, to involve DISCOM for fast deployment of RTSP.

According to the study, India's rooftop solar power potential is estimated as 1.7PWh annually

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whereas India's current electricity demand is 1.3 PWh annually. Maharashtra, with 181 TWh /year and Uttar Pradesh with 168.07 TWh/year has the highest solar rooftop potential in the country. The average cost of rooftop solar power in India is between USD 60 and USD 65/MWh, with Gujarat and Rajasthan producing RTSP at the lowest rates (livemint.com).

1.3. Rooftop Solar Photovoltaic Policy in India

1.3.1 MNRE policy

The MNRE has changed a policy in 2022 that the consumer can install an RTSPV systemfrom the company directly which may or may not be registered with MNRE/HIMURJA (Rooftop MNRE New Policy). The beneficiary will register in the national portal to install RTSP. The application will be sent to DISCOM online for technical feasibility approval. After the installation of the solar power plant, the beneficiary will apply for net metering to DISCOM.After completing all the codal formalities, the subsidy will be transferred to the beneficiary online. The MNRE will provide a subsidy of 40% for capacity up to 3 kWp, 20% for capacitybeyond 3 kWp and up to 10 kWp, and 20% for Group Housing Societies (GHS)/ Residential Welfare Associations (RWA) capacity up to 500 kWp which is limited to 10 kWp per house and total up to 500 kWp (MNRE, 2019).

1.3.2. Solar Energy Corporation of India

The SECI has given the target to install a grid-based RTSP of 97.5 MWp capacity at government buildings in selected areas of India under the CAPEX or RESCO model. (Solar Energy Corporation of India, 2019). Under this scheme, the present rooftop SPV plant has been installed under RESCO mode.

1.3.3. State policy

Himachal Pradesh is a power surplus state having a hydropower potential of about 25,000 MW, including about 2300 MW of small hydropower out of which about 10,000 MW have already been harnessed and an additional about 8000 MW are under development (HIMURJA 2016).

According to an estimate by the National Institute of Solar Energy (NISE), the state has a rooftop solar potential of 34 GW including 3% of the total wasteland of the state whereas IREDA has an estimated potential of 53 MW including 5% of wasteland. (HIMURJA)

According to H.P. Solar Power Policy (2016), consumers can install-grid connected rooftop SPV system (RTSPVS) of capacity 1kW to 5 MW using bidirectional meters. Under this policy, the solar power generated will be consumed by the consumers and surplus electricity will be exported to the grid whereas deficit will be imported from the grid. The Himachal Pradesh State Electricity Board Limited (HPSEBL) will purchase surplus power at the rate of @5/unit. A consumer can install 80% of the official electricity load approved by HPSEBL.

HIMURJA is providing an additional subsidy of Rs. 4000/kW to domestic consumers in the by the companies approved by MNRE/HIMURJA. The benchmark cost of RTSPVS for the years 2021-2022 was Rs. 45087/kW (3-10 kW) for the hilly state of HP (MNRE, 2021).

2. Installation of the rooftop solar power plant at the university campus

2.3. Location:

Dr. Y. S. Parmar University of Horticulture and Forestry is a state university located in the district of Solan, Himachal Pradesh, India. The university has the exclusive mandate of education,research, and extension in Horticulture and Forestry which is situated at latitude 30.8625118°N, longitude 77.1679151°E, and an altitude of 1275 meters (amsl). The climatic data of Nauni obtained from the Ministry of New and Renewable Energy, GOI (Solar Radiation Resource Assessment Station) installed at the Nauni campus is presented in Table 1. The university receives 280-290 sunny days annually recorded using the sunshine recorder of IMD, GOI at the Conventional MeteorologicalObservatory of IMD, GOI at the university campus (Table 1).

Table 1. Climate data of campus

Month	Air temperature (°C)	Relative humidity (%)	Daily horizontal global solar radiation (kW/m^2)	Atmospheric pressure (kPa)	Sunshine Hour (hrs)
January	8.51	47.08	3.22	878.17	5.92
February	1.01	56.46	3.90	877.29	8.34
March	14.16	43.06	5.02	876.41	6.33
April	17.21	36.10	6.12	874.10	6.70
May	23.25	36.83	6.50	872.02	7.47
June	24.49	42.66	5.94	868.68	6.10
July	23.53	54.06	4.40	867.77	2.82
August	23.40	67.69	4.51	869.29	4.10
September	21.84	56.03	5.09	872.62	5.18
October	17.57	39.92	4.99	876.88	8.59
November	13.32	39.96	3.73	878.14	7.85
December	9.40	40.23	3.21	878.40	7.83

2.4. Solar potential:

Spatial analyses show that the state receives annual average GHI of above 4.5 kWh/m^2/day. The regional availability of GHI in Himachal Pradesh is influenced by its eclectic topography, seasons as well as microclimate. The lower and middle elevation zone (<3500 m)with tropical to wet-temperate climate receives higher GHI (>5 kWh/m^2/day) for a major partof the year compared to the higher elevation zone (>3500 m) with dry-temperate to alpine climate (4 - 4.5 kWh/m^2/day). Results show that Himachal Pradesh receives an average isolation of 5.86 ± 1.02–5.99 ± 0.91 kWh/m^2/day in the warm summer months; 5.69 ± 0.65– 5.89 ± 0.65 kWh/m^2/day in the wet monsoon months; 3.73 ± 0.91–3.94 ± 0.78 kWh/m^2/day in the colder winter months.

Since the energy consumption in the university campus is more than 2.7 MWh annually costing around Rs. 14.3 million ad the same time contribution GHGs in the atmosphere. Keeping in view of this the university has planned to establish Rooftop solar power plant with zero investment.

2.5. Buildings identified

The university has an area of 545 hectares out of which 279 hectares are cultivated and 266 hectare is non-cultivated. There are many buildings constructed on the campus that are scattered due to the hilly terrain. A survey was conducted to identify the rooftop top solar power potential of the building. Based the on survey 13 buildings were identified for the installation of solar modules which are presented in the Table 2. The installation of some modules depends upon the available south-faced rooftop area of the building. The solar modules were placed directly on the roof of the building at an angle of nearly 28^0 (Figure 1).

Figure. 1: View of the buildings with solar modules

Keeping in view the solar power potential of the building, the following buildings were identified and solar modules were installed to generate solar power (Table 2). The buildings are constructed scattered due to hilly terrain and, the electricity generated from these buildings could not be joined together directly.

Table 2: Solar power capacity of selected buildings

S. No.	Name of building	Solar Power Capacity (kWp)
1	Kalyani Hostel	30
2	New Girls Hostel	20
3	Forestry Phase - II	30
4	Guest house	20
5	Forestry Phase - I	80
6	Horticulture block (1)	40
7	Horticulture block (1)	80

8	Nandini Hostel	40
9	Extension Education block	30
10	Administrative block	60
11	International hostel	60
12	Gymnasium	80
13	Keshav and Madhav hostels	70
	Total	**640**

3. Experimental details:

3.1. Solar PV modules:

The solar modules are made of Pennar and Satvik 335watts polycrystalline silicon modules. Panels made with polycrystalline cells tend to be slightly less expensive because the cells are grown in a large block of many crystals instead of individually. The crystals give polycrystalline a mosaic or shattered-glass appearance. A Total of 1918 solar modules were installed at the site. The specifications of the SPV module (SGE335-72P) installed at the university campus are given in Table 3. Power measured in standard test conditions: Irradiance of $1000 w/m^2$; AM 1.5; 25^0C Cell temperature.

Table 3: Specification of SPV module installed at the university campus

Rated peak power (P max) (0 ~+3%):	336 W
Rated voltage (Vmp):	36.94 V
Rated current (Imp):	9.08 A
Open circuit voltage (Voc) (± 5%):	45.39 V
Short circuit current (Isc) (± 5%):	9.35 A
Maximum fuse rating:	15 A
Maximum system operating voltage:	1500 V

3.2. Solar Inverters:

The inverter converts the DC power generated by the PV array into AC power for despatching to the grid (Figure 2). During DC/AC conversion, some losses occur in the cables, electronic components, and transformer. Collect data from solar inverters & MPPT strings to give accurate insights into the plant’s performance. On-Grid PV inverters from QINLONG Solis inverters (RANGES FROM- 10Kwp to 80KWp) have been used with a high switch frequency of 180v-1000 voltage MPPT Range, GPRS enabled for real-time monitoring and best in class IP66 RATING.

Figure 2: Solar inverter

3.3. Data loggers:

Track-so solar loggers have been used (Figure 3). TrackSo Solar monitors performance remotely,spot or predict failures and provide proactive maintenance of solar PV assets. TrackSo Solar is a cloud-based energy management IoT platform to track solar PV system's performance, identify anomalies and provide immediate support, giving full control over the system without actually being present there. Coupled with smart data logging hardware, TrackSo performs remote monitoring and troubleshooting for all kinds of solar systems.

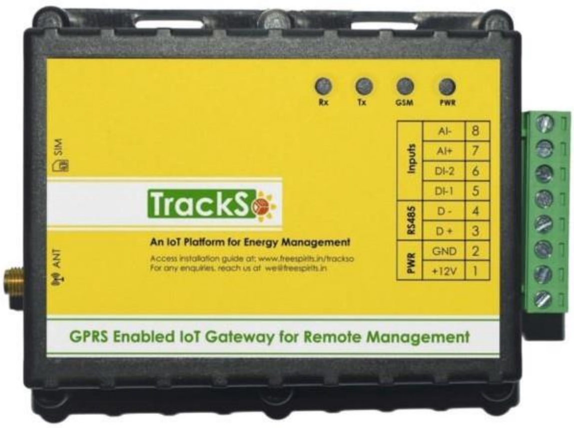

Fig. 3: Data logger

3.4. Earthing:

The earthing component is connected between the equipment body or enclosure and the earth pit which is placed under the earth's surface to discharge the electrical charge directly to the earth (Figure 4). Rod Earthing System which is similar to a pipe earthing system has been used. A copper rod with galvanized steel pipe is placed upright in the ground physically with a chemical compound to enhance earthing. Double earthing has been provided with the solar plant. The two points on earth provide two parallel paths for the earth's fault current. The two parallel paths are connected to two separate earth points. Thus, the equivalent resistance of the two parallel paths gets reduced and it offers a low resistance path to the fault current.

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Fig.4: Double earthing

3.5. Alternative current distribution box:

This is a panel that receives the AC power generated by the solar inverter and receives AC power at different points using the distribution board (Figure 5). ACDB system also includes a surge protection device that prevents inverter or damage due to heavy voltage of electricity. The device is well recommended by MCCB, which immediately breaks the circuit and prevents high voltage power through distribution cables. ACDB can vary depending on the strength of the load or inverter.

Figure 5: AC distribution box

3.6. Power generation meter and net meter:

A power generation meter has been installed at each building to record the generation of solar power as per the mandate of DISCOM (Figure 6). This meter is mandatory for a building with 20kW of RTSP plant. One Net meter (bidirectional) and check meter have been installed near the substation to record solar power generated from all the buildings at one point (High tension power supply) and one net meter and check meter have been installed for low tension power supply (Figure 7). The Himachal Pradesh Electricity Regulatory Commission notified the regulation, 2015 regarding Rooftop Solar PV Grid Interactive System based on Net Metering. According to this the consumer shall install and maintain a solar meter of 0.2s class accuracy with the facility of wireless equipment or Meter Reading instrument (MRI). Check meter is mandatory for Rooftop Solar systems having a capacity of more than 20 kW. The solar plant developer and consumer will jointly take the meter reading which will be deducted from the electricity bill issued by DISCOM. The consumer will pay Rs.1.899/kWh. The solar power tariff is decided by the Solar Energy Corporation of India Limited (SECI) – a Government of India Enterprise. The developer will get a 70% subsidy from the SECI.

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The RESCO model is a zero-investment model for consumers in which the consumer pays only for the electricity generated, while the solar plant developer is responsible for the installation, operation, and maintenance of the plant. The university has signed MOU with the developer under RESCO mode for the installation, operation and maintenance of 640 kWp for which the university will provide rooftop space free of cost and will purchase electricity at the rate of Rs.1.899/kWh.

Figure 6: Power Generation meter

Figure 7: Net Meter (High Tension)

3.7. Weather sensors required for the plant

The amount of electrical energy that PV systems can produce depends on the amount of solar radiation available in the area and ambient temperature. For this, two sensors have been provided with solar panels. One is the temperature sensor and the other is the solar radiation sensor as shown in Figure 8 & Figure 9.

Figure.8: Ambient temperature sensor

Figure.9: Solar radiation sensor

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5.0 Energy saved:

The university experiences 280-290 sunny days annually. The estimated rooftop solar power generation from 640 kWp capacity power plant will be about 729,600 kWh annually which will save around Rs. 2,152,320 (14.98%). The month-wise electricity consumption and bill during the year 2021 when university was closed due to COVID-19 and the year 2022 when the plant was in operation and university was fully occupied are given in Table 3. It revealed that the minimum electricity consumption was during June in 2021 and September in 2022. The maximum consumption of electricity was during February in both years. The study revealed that the electricity bill was almost same for the years on annual basis which was due to the generation of solar power. Around 0.6 million units were generated during the year 2022. As the electricity tariff increases by DISCOM, the saving will also increase as the cost of solar power will remain the same for 25 years. The government provides electricity at subsidised rates which are likely to increase in near future. The plant is fully owned by the developer, the university only provided south-facing rooftop space. The performance indicators of the rooftop solar power plant installed at the university campus provided by the system aregiven in Table 4.

Table 4: The month-wise electricity bill of the university campus (Personal communication)

Month	Amount	Consumption	Amount	Consumption
	2021		**2022**	
January	1262870	239500	1222859	226455
February	1398642	265580	1525894	294380
March	1151252	215460	1323539	252580
April	1050864	196140	914137	168010
May	823530	149180	785778	141320
June	702506	124180	897889	164450
July	723660	128550	939816	173100
August	812445	146890	959737	177210
September	847977	154230	733535	130070
October	864050	157550	799831	148730
November	1222859	226455	845323	147090
December	1222859	226455	1162248	225840
Total	**12083514**	**2230170**	**12110586**	**2249235**

6.0. Performance evaluation of rooftop solar power plant

TrackSo, a SaaS product by free spirits green labs, is an IoT-based energy management platform to track performance, spot or predict failures and provide proactive maintenance of

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assets, giving full control remotely. Coupled with smart IoT gateways, one can connect, visualize and analyse all assets. The performance parameters have been analysed on 12th June 2023 because during this day all the data loggers are well connected to record data from all the locations. The monkeys regularly break down the wires and we are not in position to record the data.

6.1. Performance evaluation parameters

The 'Performance Ratio' (PR) means the ratio of plant versus installed plant capacity at any instance concerning the radiation measured is calculated as

$$PR = \frac{Measured\ output\ in\ kW}{Installed\ capacity\ in\ kW\ x\ Measured\ radiation\ intensity\ in\ kW/m2}\ x\ 100$$

The building-wise different performance parameters are summarised in Table 5

Table 5: Building wise performance ratio evaluation

S. No.	Name of building	Inverter capacity (kW)	Total DC load (kWp)	Load on ACDB wise (kW)	Active Load/Power (kW)	Irradiance (W/m^2)	PR (%)
1	New Girls Hostel	20	20.100	20.100	15.00	930	80.24
2	Auditorium	80	82.745	82.745	47.63	750	76.75
3	College of Horticulture	Inv-1:40 Inv-2:40 Inv-3:40	40.200 40.200 40.200	40.200 40.200 40.200	20.05 21.45 20.89	635 679 671	78.54 78.60 77.44
4	Gymnasium	80	69.345	69.345	32.50	625	74.99
5	International Hostel	Inv-1:30 Inv-2:30	26.800 26.800	26.800 26.800	13.11 14.57	630 718	77.65 75.72
6	Hostels: Keshav Madhav	 Inv-1:40 Inv-2:30	 39.530 30.820	 39.530 30.820	 18.05 15.30	 630 625	 72.48 79.43
7	Administrative block	Inv-1:30 Inv-1:30	31.490 31.825	31.490 31.825	22.42 22.50	890 895	80.00 78.99
8	Guesthouse	20	20.100	20.100	15.60	940	82.57

Table 5 revealed that the performance ratio (82.57%) is highest in the university guesthouse whereas, the lowest (72.48%) is in the Keshav hostel. The 2 MWp PV plant's average performance ratio (PR) was 73.3 obtained by Ajith et al (2021) installed at the Kuzhalmannam site, Palakkad district, Kerala. Saxena et al (2021) in their feasibility study found the PR of 70% to 80% in 100kWp SPV for various locations in India. Performance ratio of 1kW rooftop solar PV power plant over the whole year estimated to be 0.706 (Sourabh et.

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al./ ICCIP-2019). Although the maximum solar irradiation (940W/m^2) wasat Guesthouse and New Girl's hostel (930W/m^2). The overall performance ratio of the plant inthe campus was highest (86.52%) at 9:30AM (Figure 10).

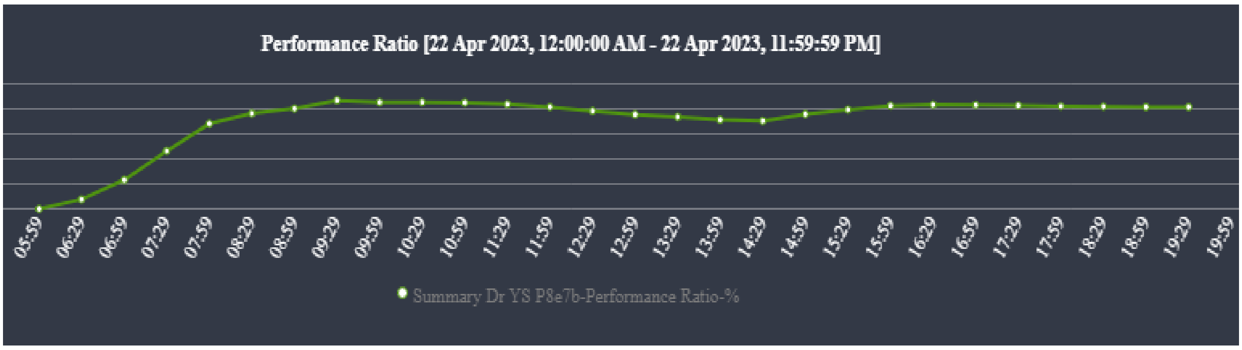

Figure 10: Overall performance ration of the RTSVP in the campus

6.2. Capacity Utilisation Factor (CUF): Capacity Utilization Factor shall mean ratio of total kWh (units) of power generated by Solar Plant in a year and Contracted capacity in kW multiplied with Number of hours in the same Year.

The CUF is calculated as

Actual energy from the plant (kwh) / (Plant Capacity (kwp) x 24 x 365)

According to the reports from Ministry of New & Renewable Energy, Govt of India in 2013, the average capacity utilization factor of solar PV plants in India is in the range of 15-19%. The highest CUF of the plant in the campus was found to be 20.98% on 12th June 2023 2023 (Figure 11). The CUF on 12th June is higher because of length of day is maximum during June.

Figure 11: CUF of the RTSVP in the campus

6.3. Specific yield (kWh/kWp)

Specific yield (or simply "yield") refers to how much energy (kWh) is produced for every kWp of module capacity over the course of a typical or actual year. The overall highest specific yield of the plant in the campus was found to be 5.03 kWh/kWp on 12th June 2023 (Figure 12). Medianand maximum yields obtained by this system for the best insolation (June 2021) were 6.64 kWh/kWp and 7.88 kWh/kWp respectively (Gulkowski 2022).

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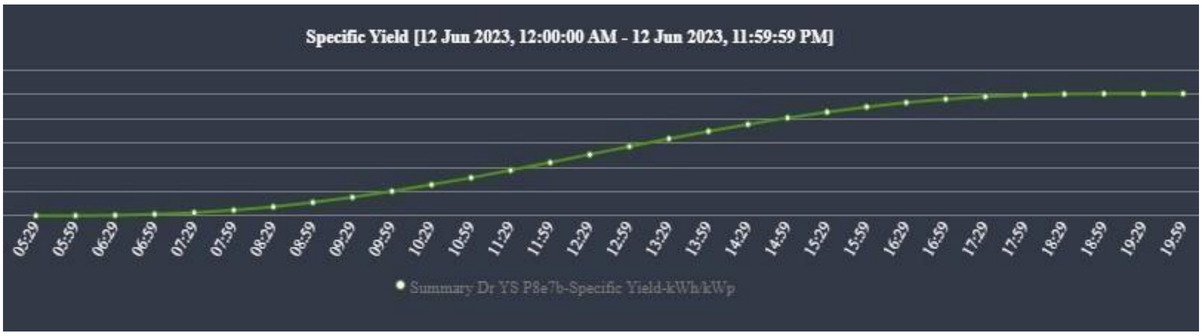

Figure 12: Specific yield of the RTSVP in the campus

6.4. Active power output

Active Power Output means the active power during a Demand Period (kW) or multiples thereof, obtained by dividing the Active Energy produced in kWh or multiples thereof during that period by the time interval of the said demand in hours. The overall highest active power output of the plant in the campus was found to be 422.70 KW at 12:30 Noon on 12th June 2023 (Figure 13).

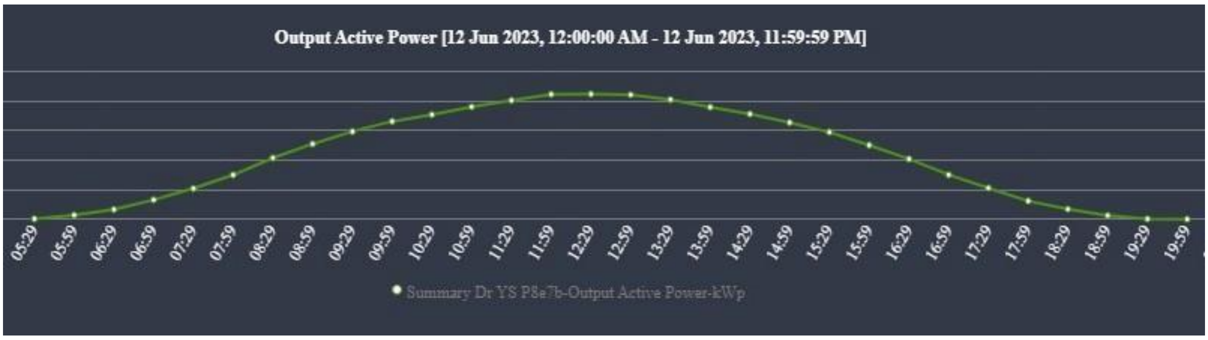

Figure 13: Overall active power output of the RTSVP in the campus

6.5. Solar Power Generation

The building wise solar power generated from rooftop SPV plant during January to December 2022 is presented in Table 6 which reveals that around 0.58 million units have been generated in first complete year. Latest Joint Meter reading (JMR) taken for last 33 days is 76,122 kWh which is 2.3kWh/day. According to EAI, rooftop solar power plant of one kW capacity produces 4.5 kWh/day in plain areas of India. The low power generation was due to the abnormal rainfall observed in the state during April 2023. The normal sun shine hour at university campus is 7.4 however, during April 2023 the monthly average of 6.6 sun shine hours were recorded which are less than the normal of 7.4.

Table 6: Building wise power generation

S. No.	Name of building	Solar Power Capacity (kWp)	Power generation (kWh)
1	Kalyani Hostel	30	37, 473
2	Nandini Hostel	40	52, 928
3	Horticulture block - 1	40	36, 586

4	Horticulture block - 2	80	48, 556
5	Forestry block - 1	80	58, 876
6	Forestry block - 2	30	31, 004
7	Guesthouse	20	28, 738
8	Extension Education	30	33, 546
9	International hostel	60	38, 714
10	Gymnasium	80	54, 212
11	Keshav and Madhav hostels	70	63, 964
12	New Girls Hostel	15	26, 369
13	Administrative block	60	69, 280
	Total	**640**	**580, 246**

About 823,340 units have been generated until May 2023, thereby saving Rs.4 million annually. The overall performance ratio of rooftop solar power plants comes out to be 77.95%. On a typical day 12th June 2023, the generated solar power was3,234 kWh with capacity utilization factor of 20.98% i.e., 5.03 kWh/day which is above the EIA projection of 4.5 kWh/day.

6.0 Environmental benefit:

A rooftop solar power plant of 1 kW capacity generates 1200 units annually in India. The emission of CO_2 equivalent from 1 kWh grid-connected electricity is 820 g (Central Electricity Authority, India). Based on these assumptions 1 kW grid-connected capacity rooftop solar power plant will save 924 kg CO_2 equivalent annually (cleantechnica.com). The 640 kWp RTSP plant installed at the university campus saved 591.36 tons of CO_2 annually. The solar power of 823,340 units generated during 2022 reduces CO_2 by 675.138 kg.

7.0Conclusions:

The rooftop solar power plant of 640 kWp capacity installed at the university campus on RESCO mode. The plant has generated 823,340 units till May 2023 at the same time it reduced the emission of CO_2 by 675.138 kg. The saving in electricity bills will further increase when the electricity tariff will increase in near future but the cost of solar power will remain the same (Rs. 1.899/unit) for 25 years. Thus, reducing the emission of GHGs mitigating climate change and meets the UN sustainable goals 7 & 13. The performance ratio of the plant comes out to be more than 86% and CUF of 20.98% was obtained. The specific yield was more than 5.03 kWh/kWp. After the successful implementation of this plant the RTSPV was further installed at Mushroom Centre, Solan, Central Potato Research Institute, Shimla and Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. Thus, RTSPV can be installed throughout Himalayan region as inclined rooftop is available easily thereby reducing the cost of structure required for the installation of solar module. The system will generate solar power on a sustainable basis for 25 years. The state is moving towards carbon neutral.

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