Divecha Centre for Climate Change

DIVECHA CENTRE FOR CLIMATE CHANGE

Indian Institute of Science

Renewable Energy Systems Reports

A case study of 3-MW scale grid-connected solar photovoltaic power plant at Kolar, Karnataka

Performance assessment & recommendations

H. Mitavachan, Anandhi Gokhale and J. Srinivasan

REPORT IISc-DCCC 11 RE 1 AUGUST 2011

The Divecha Centre for Climate Change was established at the Indian Institute of Science in January 2009 with a generous financial contribution from Arjun and Diana Divecha and the Grantham Foundation for the Protection of the Environment.

The primary goal of this Centre is to understand climate variability and climate change and its impact on the environment. The Centre has undertaken outreach activities to create awareness among people and policy makers about climate change and its consequences. This has been done through workshops, lectures and quiz contests. An annual invited public lecture called the 'Jeremy Grantham Lecture on Climate Change' has been organized. The Centre has identified technologies to mitigate climate change in collaboration with entrepreneurs and different engineering departments in the Indian Institute of Science. The Centre is also working with Grantham Institute for Climate Change at Imperial College, London, on the impact of climate change on water.

Divecha Centre for
Climate Change

DIVECHA CENTRE
FOR CLIMATE CHANGE

Indian Institute of Science

Renewable Energy Systems Reports

A case study of 3-MW scale grid-connected solar photovoltaic power plant at Kolar, Karnataka

Performance assessment & recommendations

H. Mitavachan, Anandhi Gokhale
and J. Srinivasan

REPORT IISc-DCCC 11 RE 1 AUGUST 2011

Executive Summary

Karnataka Power Corporation Limited (KPCL) has established 3 MW_{peak} capacity grid-connected solar photovoltaic power plant near Yalesandra village in Kolar district of Karnataka, which is the first of its scale in India. After the site preparations were completed the first segment was installed in 4 months, followed by the second and third segments in the next two months. The plant was fully commissioned on 27 December 2009. The Yalesandra plant is one among 20 such Mega-watt size solar power plants in India, *as on 31st July 2011. India has an ambitious plan to build large grid-connected solar power plants, with a cumulative installed capacity of 20,000 MWp by 2020, under the National Solar Mission. Hence, it is essential to document the performance of the first large-scale grid-connected solar power plant installed in Karnataka. In this report we discuss the performance of the photovoltaic solar power plant in Kolar during 2010.

The Yalesandra power plant is located at a latitude of 12^0 53' and a longitude of 78^0 09'. The overall area occupied by photovoltaic modules is 10.3 acres. The plant has 3 segments with each segment having an installed capacity of 1 MW_p. Each segment has 4 inverters with a capacity of 250 kW each. There are 13,368 modules (557 arrays with 24 modules per array) that contain mono-crystalline Silicon solar cells. The solar photovoltaic modules are connected such that a voltage of 415 volts is generated at the output of each inverter. This is stepped up to 11 kV by a step-up transformer and connected to the existing 11 kV grid.

The total electrical energy generated by the Yaleasandra plant during 2010 was 3.34 million kWh and 3.30 million units were sold to the grid. Although the performance of the photovoltaic modules was good, there were teething troubles associated with the inverters, which was the main reason for reduced energy generation. The impact of temperature variation of modules on their performance was studied both on daily and yearly basis. It is observed that the efficiency of the plant is more sensitive to temperature than the solar insolation. Daily datasets of five minute average data have been used for in-depth analysis. Some of the maintenance and technical related problems faced by the plant operators have also been discussed.

** Check MNRE website (http://www.mnre.gov.in/solar-conclave2010.htm) for more details on grid-connected solar power plants in India*

Contents

1. Introduction

Karnataka's power sector has three main utilities namely; Karnataka Power Corporation Ltd. (KPCL) - the Public Sector generation utility, the Karnataka Power Transmission Corporation Ltd. (KPTCL) - the Public Sector transmission utility, and its regional distribution utilities - Electricity Supply Companies (ESCOMs). KPCL is the main power generator in the state with an installed capacity of 5975.91 MW of hydel, thermal, solar and wind energy, with an additional 9500 MW in the pipeline.

Till 1985, the state's entire capacity had been hydroelectric, but with 2328 MW of coal based thermal power stations (and a few diesel and wind-based plants), the hydro share of capacity has dropped to about 61%. Further, only about 75% of the hydro capacity is available for utilization; the remaining 25% comprises (a) “non-firm” capacity (i.e. a part of the water stored in some hydro-reservoirs is also meant for irrigation), (b) unforeseen outages (necessitating a spinning reserve), and (c) maintenance protection reserve. Also, in years of poor rainfall, the contribution of hydel plants to annual electricity generation decreases further [1]. One of the main reasons for the power crisis in 2008-09 was the failure of the monsoon, which reduced the reservoir levels in the major hydel reservoirs (viz., Linganamakki, Supa and Mani) by 26% compared to 2007-08 and this led to a reduction of 29.51% (2261 MU) in hydro generation [2]. All of these are leading to an increased dependence on thermal plants, whose GHG emissions are high and pollute the environment more compared to hydro and other renewable energy sources. So, to reduce the dependence on fossil fuels and increase the share of renewable energy sources, KPCL has started investing in wind and solar energy technologies.

In early 2009, KPCL started the ‘Arunodaya’ scheme to demonstrate, popularize and increase the usage of solar energy for electricity generation. Under this scheme, KPCL came up with a proposal for installing the country's first 3MW$_p$ scale photovoltaic solar power plant near Yalesandra village in Kolar district of Karnataka. The intent of the project was to provide power to the farmers to enable pumping and using of the groundwater for irrigation. There are around 450-500 10-HP pumps in about 14 surrounding villages and farmers were unable to use these at full capacity because of inconsistent power supply. The Kolar plant was fully completed and commissioned on 27 December 2009 (see Figure1). Later, two more plants with the same capacity were constructed in Belgaum and Raichur (see Table1 and Figure2).

India has an ambitious plan to build large grid-connected solar power plants, with a cumulative installed capacity of 20,000 MW$_P$ by 2020, under the National Solar Mission. Hence, it is essential to document the performance of the first large-scale grid-connected solar power plant installed in Karnataka. This report contains the analysis of the performance of the photovoltaic solar power plant in Kolar during 2010.

Figure 1 : Photovoltaic Solar Power Plant at Yalesandra, Kolar, Karnataka

Table 1 : Mega Watt scale Solar PV Plants in Karnataka State (all are under KPCL)

Place	Cost per Mega Watt (Approximate figures)	Total Nominal Capacity (MW)	Contractor
Yalesandra Kolar	Rs. 20 crore	3	Titan Energy Systems Ltd.
Itnal, Chikkodi Belgaum	Rs. 20 crore	3	Photon Energy Systems Ltd.
Yapaldinni Raichur	Rs. 14.5 crore	3	BHEL (yet to be commissioned)
Shivanasamudra Mandya	-	5	-

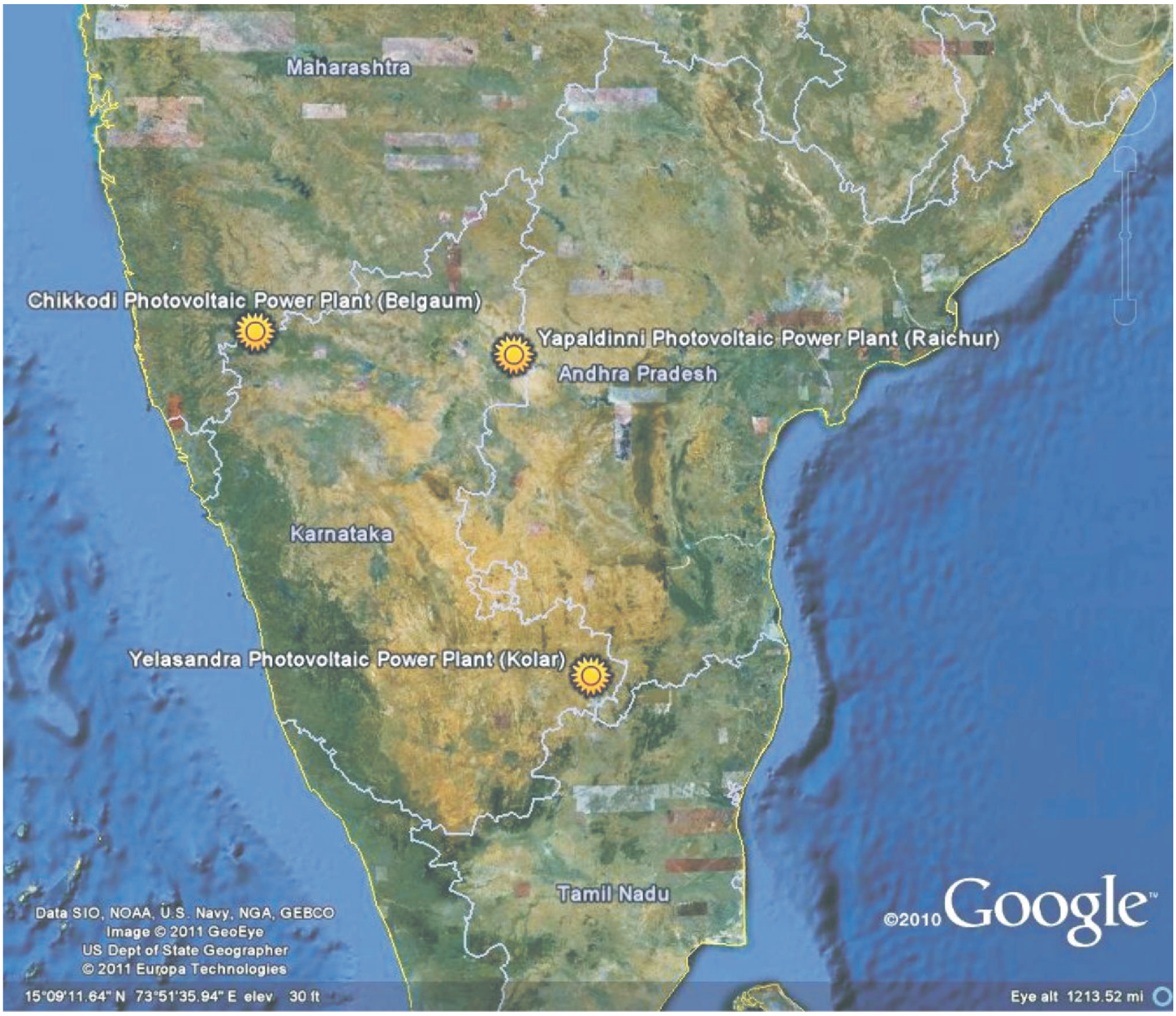

Figure 2 : Karnataka map showing the locations of all the three 3MW Solar PV Power Plants

2. Site details

The Yalesandra plant installation site has a steep slope with a level difference of about 15 m and there are rock outcrops in the site. The structures for the Power Plant comprises Solar Arrays, PCUs, control room, substation and other ancillary structures. The general information regarding the climatic conditions of Kolar district and description of the Plant are given in the Tables 2 and 3.

Table 2 : General Climatic conditions of Kolar district [3]

Height above sea level	882 m
Ambient Air Temperature	Maximum: 40°C Minimum: 18°C
Relative Humidity	Maximum: 99.1% (during monsoon) Minimum: 18.3%
Rainfall	Annual average: 1549 mm Period: 4 months

Table 3 : General description of Yalesandra PV Plant

Place of Installation	Near Yalesandra Village, Kolar, Karnataka, India
Latitude & Longitude of the place	12° 53' & 78° 09'
Allotted Land Area	15 acres (10.3 acres effectively used)
Nominal Capacity of the PV Plant	3 MW
Date of Commission	27th December 2009
Owner	Karnataka Power Corporation Limited (KPCL)
Installed by (Contractor)	Titan Energy Systems Ltd., Secunderabad
Modules	Titan S6-60 series
SCADA for diagnosing and monitoring	Yes
PCU (Inverters)	250 kW (12 Nos)
HT Transformer and switchgear for evacuation	1.25 MVA for each MW

2.1 Technical details

Segments

The 3 MW Plant is divided into three independent segments of one MW each. Each segment is equipped with four Inverters of 250 kW each and grouped together to form one LT panel. Depending on the mix of 225 & 240 Wp modules, 45 to 46 PV Arrays are connected in parallel to each single Inverter, and each array consists of 24 modules connected in series. The power generated from 3 MW_p PV Plant at 0.415 kV is stepped up to 11 kV with the help of three step-up transformers and connected to existing 11 kV lines. The simple block diagram of the Plant is shown in Figure 3.

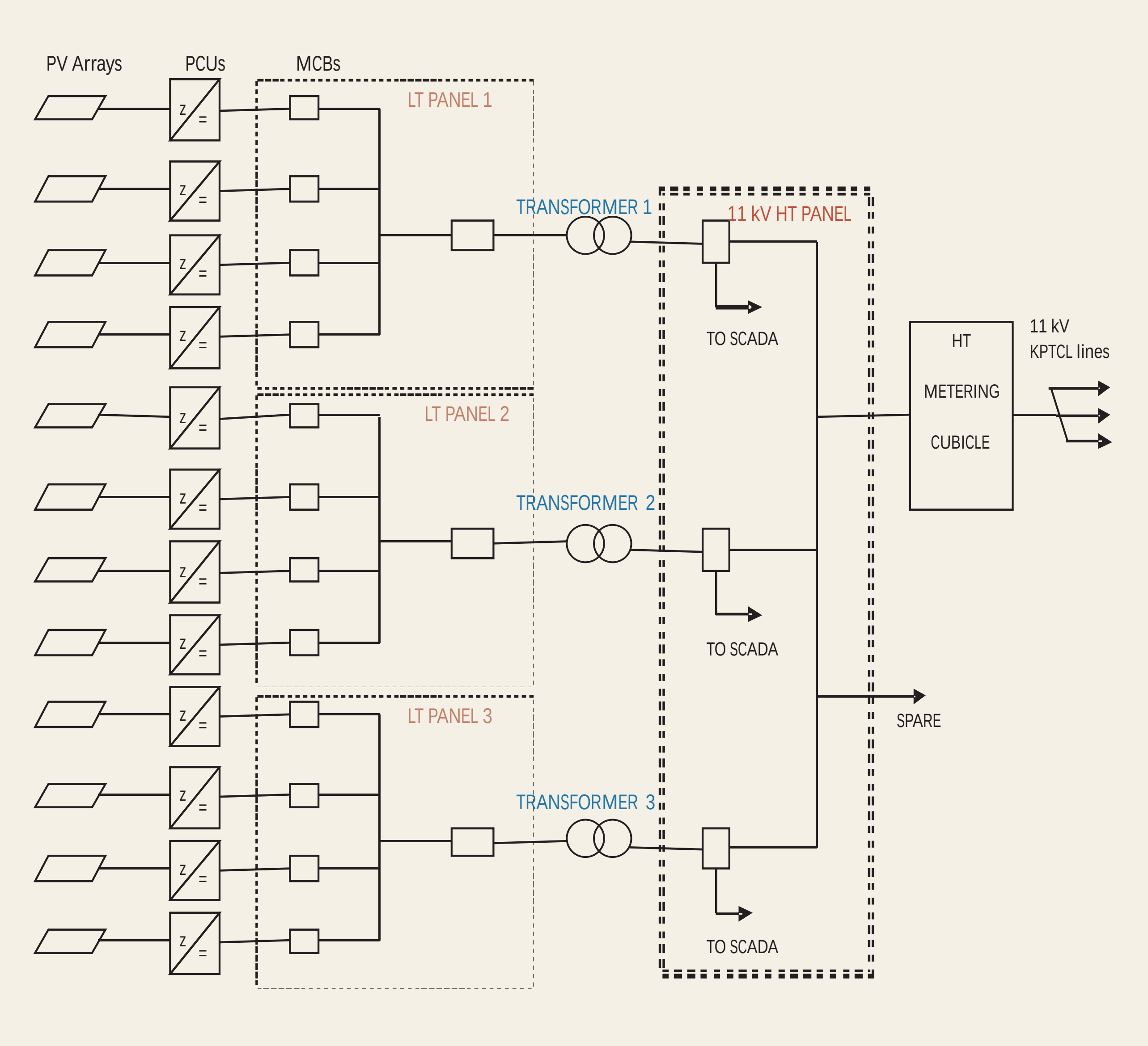

Figure 3 : Simple block diagram of the PV Plant

Tables 4 and 5 give the general technical details and the module specifications of the Plant.

Table 4 : Technical data of Solar PV

Two type of S6-60 series modules are used	225 W_p & 240 W_p
Total number of modules	13,368 [10,152 - 225 W_p; 3216 – 240 W_p]
Solar Cell material	Mono-Crystalline Silicon
1 Array	24 Modules
No. of Arrays per Inverter(250 kW)	45-46 (Total 557 Arrays with 12 Inverters)
Arrays per MW	1st MW – 181 2nd & 3rd MW – 188 per MW
Total Solar Cells area	5.4 acre
Inclination of Modules	15 degree

Table 5 : Module Specifications [4]

Type	**S6-60 series**	
Maximum Power, Pmp (W)	225	240
Maximum Power Voltage (Vmp)	28.63 V	29.62 V
Maximum Power Current (Imp)	7.93 A	8.12 A
Open Circuit Voltage (Voc)	37.50 V	37.62 V
Short Circuit Current (Isc)	8.52 A	8.55 A
Module dimensions (mm)	1657 x 987 x 42	
Number, type and arrangement of cells	60, Mono-Crystalline, 6 x 10 Matrix	
Cell Size	156 x 156 (mm)	
NOCT– Nominal Operating Cell Temp (°C)	45	
Weight (Kg)	19	
Glass Type and Thickness	3.2mm Thick, Low iron, Tempered	

Power Conditioning Units (PCUs)

All the twelve PCUs are identical and are supplied by the single manufacturer BONFIGLIOLI (VECTRON, RPS 450 type). The MPPT device is in-built in the control system which allows operating at constant voltage. The efficiency of the PCUs is around 96% at nominal load. The rated capacity of the PCU is 250 kW.

Transformers

The full load rating of the Transformers is 1.25 MVA. All the three oil - cooled Transformers are supplied by the manufacturer Pan Electro Technic Enterprises Pvt. Ltd. The efficiency is 98.91% at rated voltage and 99.3% at maximum flux density.

Mounting structure

Type	6 x 4 Module Array (24 modules per Structure)
Material	Mild Steel
Overall dimensions (mm)	6780x 6030
Coating	Galvanized
Wind rating	160 km per hour
Tilt angle	15^0
Foundation	PCC
Fixing type	Nut Bolts

Timelines

Foundation was laid on 9th January 2009 and the site handed over to TITAN on 28th May 2009. 1MW_p was completed on 30th September 2009, 2 MW_p on 12th November and 3 MW_p on 27th December 2009.

2.2 Cost details

The total cost of installing the Power Plant including the maintenance charges for first three years is approximately Rs. 60 crores.

The detailed Cost breakup of 3 MW Kolar PV plant is given in Table 6.

Table 6 : Cost breakup of 3 MWp Yalesandra PV power plant [3] [5]

Item	Cost (in Rupees)
SPV Arrays totaling to 3 MWp	43,50,00,000
PCUs	5,40,00,000
Mounting structures	3,00,00,000
Cables & Hardware	50,00,000
Junction box & distribution boxes	9,00,000
Lightning Arrester, Earthing kit	12,00,000
PVC pipes & accessories	3,00,000
Spares for 3 years	5,00,000
SCADA system	20,00,000
Taxes, CST/KVAT, etc.	1,05,78,000
Design, engineering, quality surveillance, testing, transportation, insurance coverage, etc.	1,80,99,400
Total Supply of Equipments (for 3 MW)	**55,75,77,400**
Erection & Commissioning	**2,98,00,000**
10 kW additional solar PV system with Battery support	31,00,000

Note: Miscellaneous expenses have not been taken into account

2.3 Plant Maintenance & Operation

In addition to 3 MW_p, one more 10 kW PV plant has been installed on the rooftop of office building to take care of domestic lighting and cooling loads of the Plant, including the load of exhaust fans. At present, the plant is maintained by 13 workers which includes 2 technical persons who look after data collection and monitoring.

Three bore - wells have been installed at the site with pump-set capacities of 2 HP, 5 HP and 10 HP. The 2 HP pump set is used regularly to meet the water requirements of the Plant. The other two pump sets remain idle most of the time.

Cleaning of PV Modules:

Generally, the modules are cleaned by spraying water with the help of extendable hosepipes. Occasionally, wipers are used to remove the accumulated dirt and bird droppings, say once in a month. On an average, each module is cleaned once in a week on rotational basis.

3. Performance analysis

The total Energy produced by 3 MW_p Plant during the year 2010 was 3,347,480 units. Out of this, 3,303,200 units were sold to the grid. Figure 4 shows the contribution of all the three Segments in the total power generation during 2010. Since Segment-3 was not performing satisfactorily for a few months, which is evident from the figure, we will restrict our analysis to the first two Segments only.

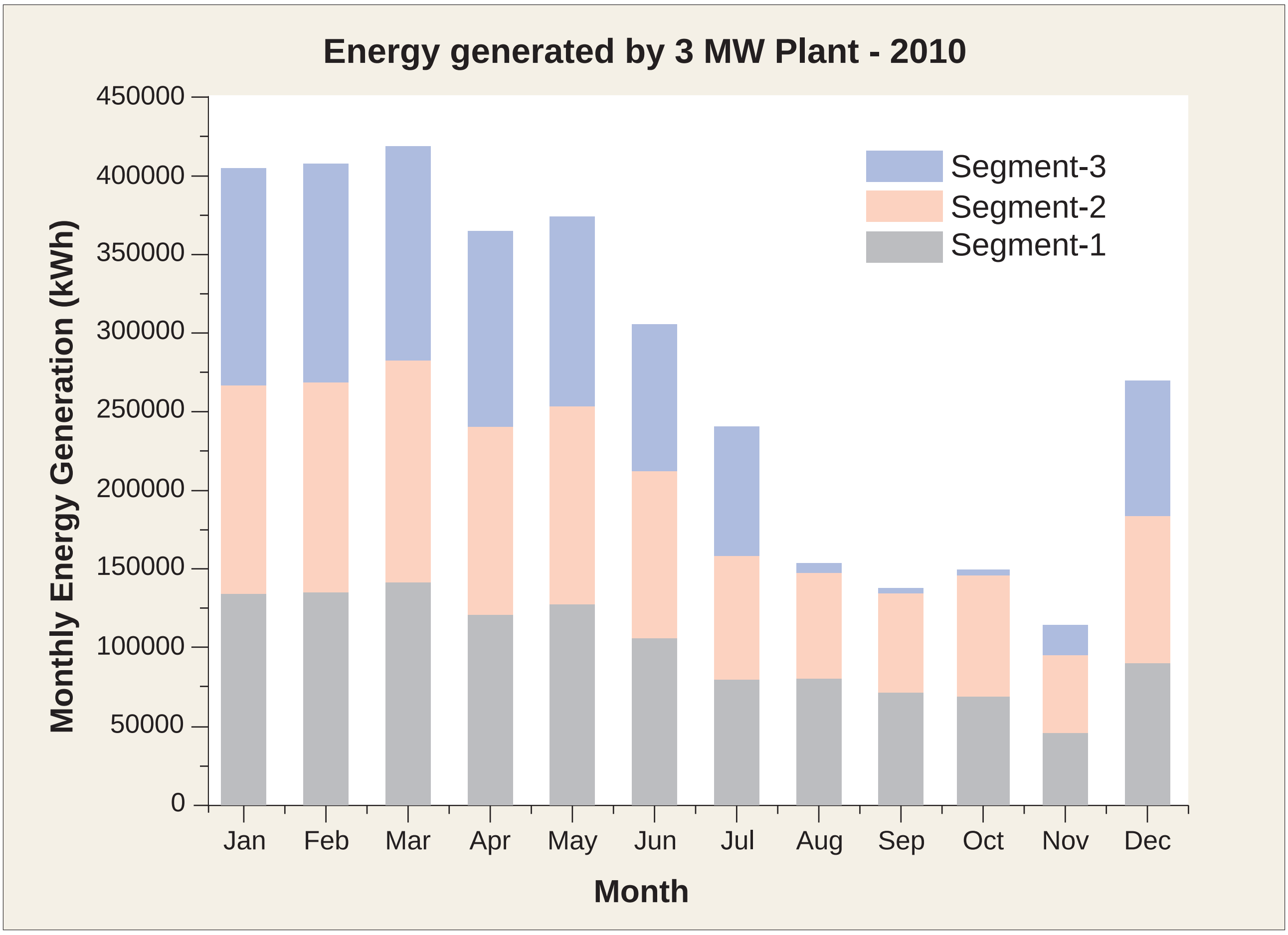

Figure 4 : Contribution of all the three segments in the total power generation during 2010

3.1 Segment-1 and Segment-2

The performance of the first two segments and their cumulative production over the year 2010 is shown in Figures 5 and 6 respectively. The total cumulative Energy generated by both the Segments together for the year 2010 was 2,429,219.6 kWh with mean output of 6655.4 kWh per day. The capacity factor for this 2 MW plant was around 14.52% at the generation end (impact of grid-off times and maintenance down times are not included).

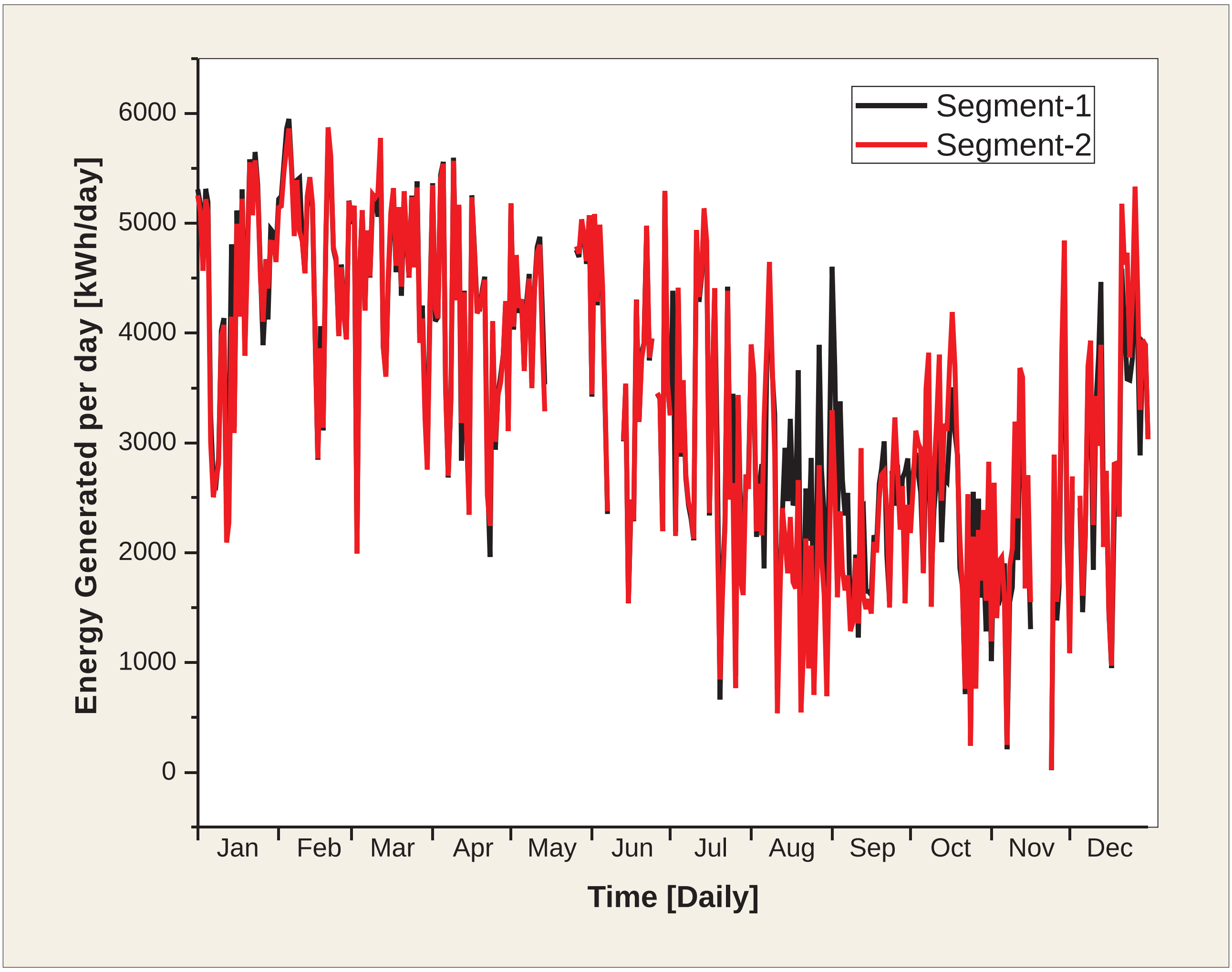

Figure 5 : Daily Performance of Segment 1 & 2 during 2010

The highest power generation achieved was 11812.4 kWh on 5th February 2010, with the recorded insolation, average module temperature and Plant efficiency of 6663 Wh/sqm/day, 42°C and 12.24% respectively.

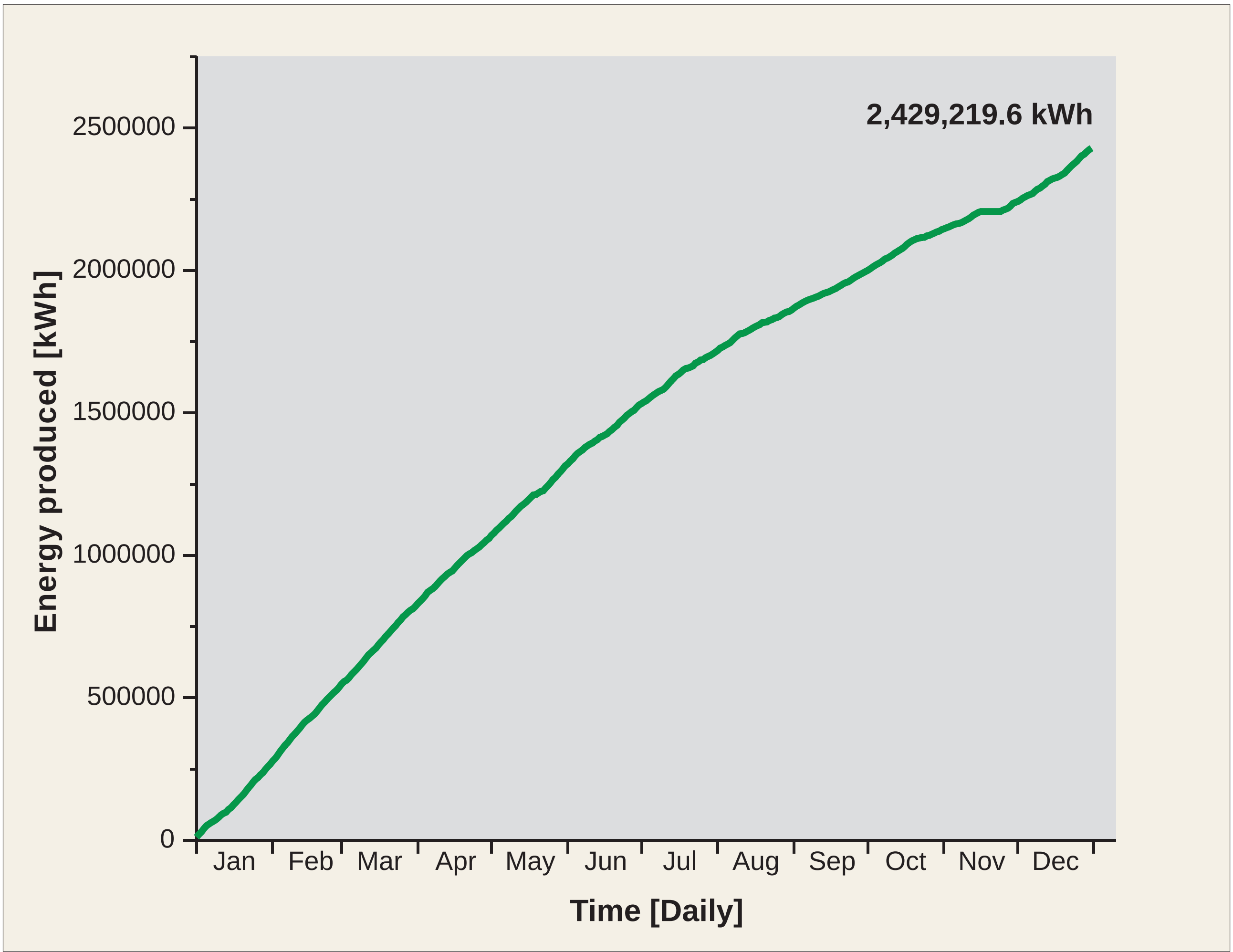

Figure 6 : Cumulative Energy Produced by Segment 1 & 2 for the year 2010

The decline in energy generation during August to November period in Figure 7 was mainly due to the improper functioning of four Inverters (two in Segment-1 and the other two in Segment-2), and partially because of higher plant downtime and more number of cloudy days during that period (see Figures 8 and 9). The declination can be seen more clearly in Fig. 11 which shows the variation of daily efficiency for the 2 MW plant during the year 2010.

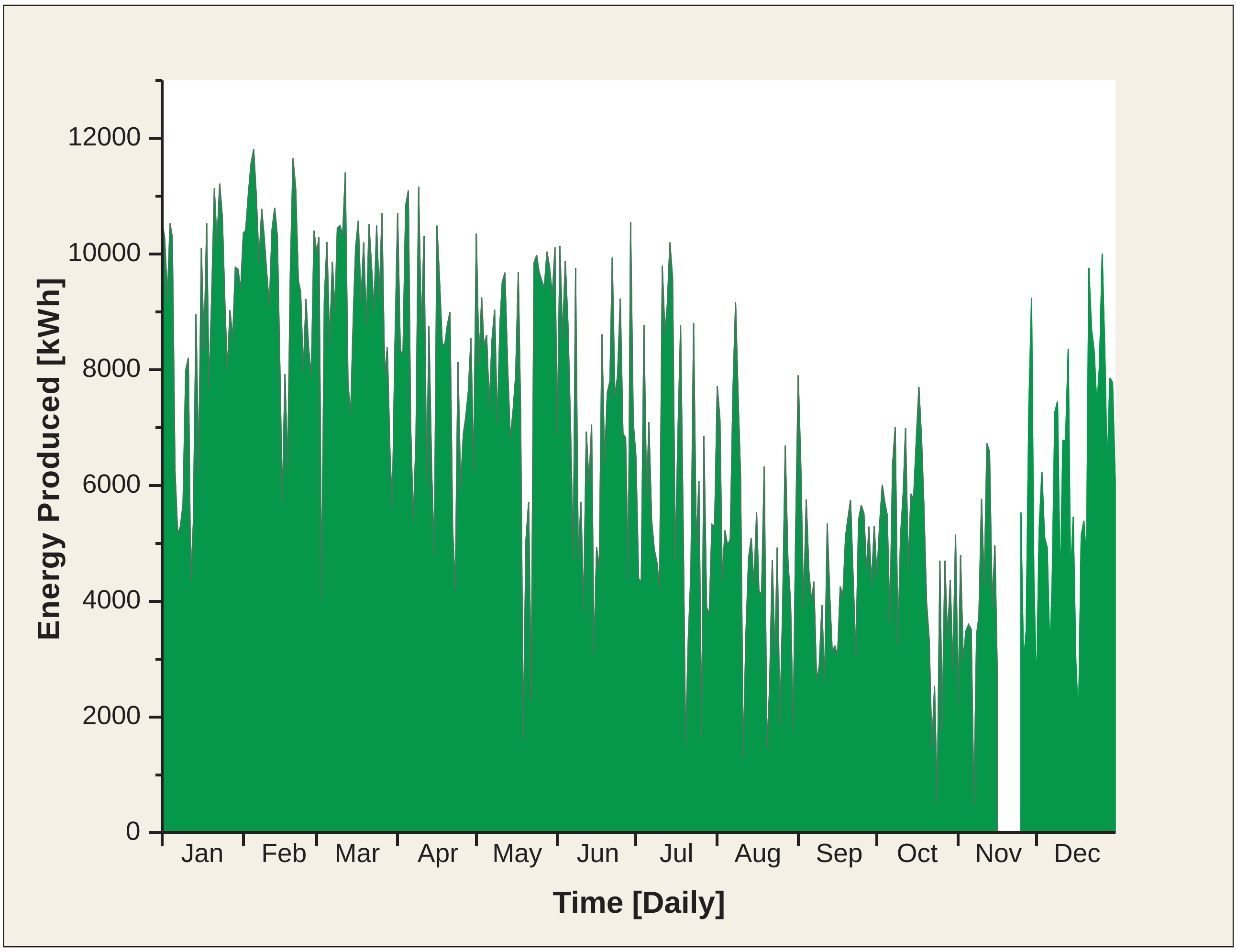

Figure 7: Daily energy production of 2MW Plant [Seg.1 & 2]

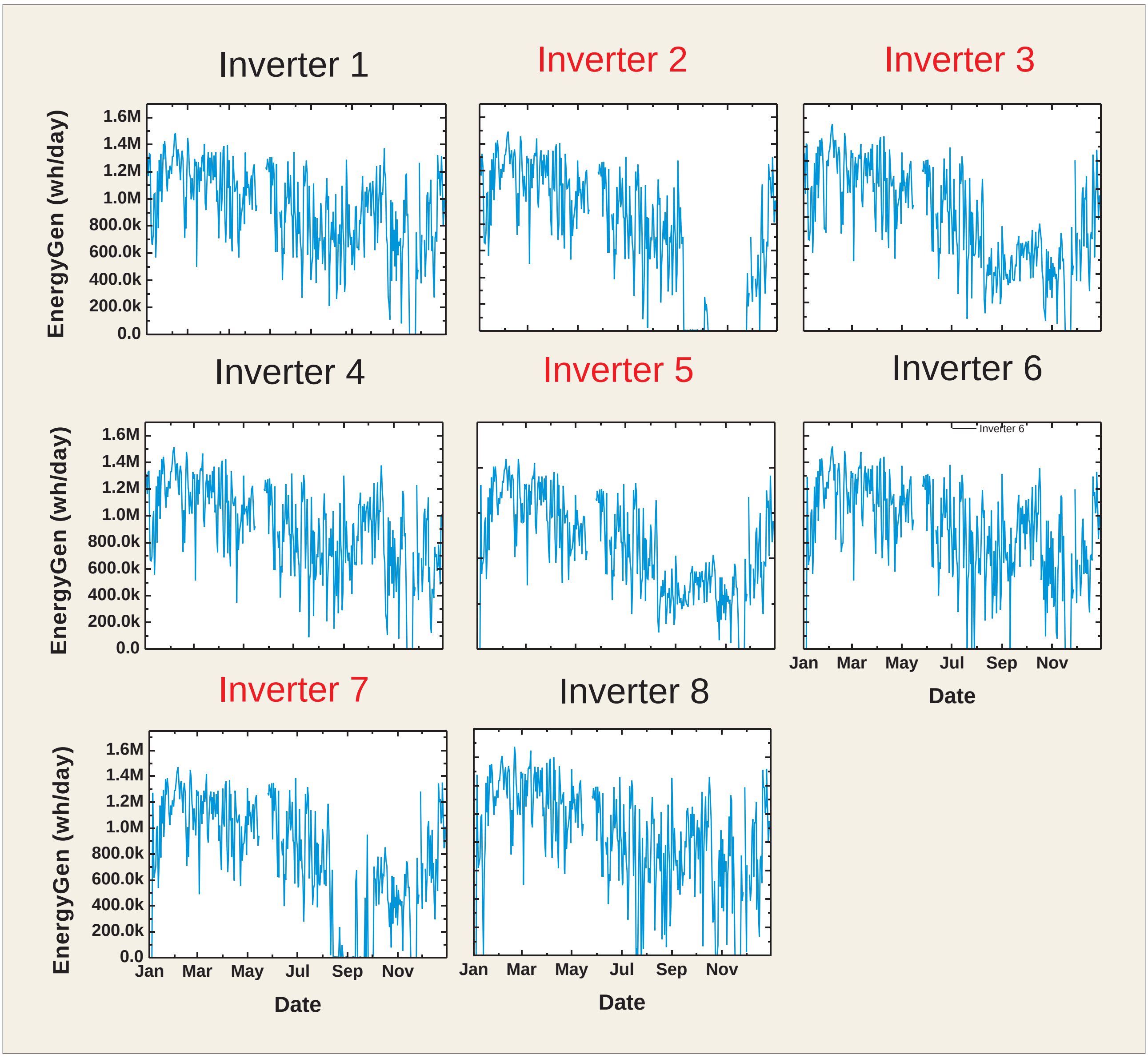

Figure 8: Daily performance of all the 8 inverters

Figure 8 shows the daily performance of all the inverters, first four come under Segment-1 and the next four under Segment-2. It can be seen that the Inverters 2, 3, 5 and 7 (which are shown in red) were malfunctioning during the period August to November, as compared with the remaining four inverters.

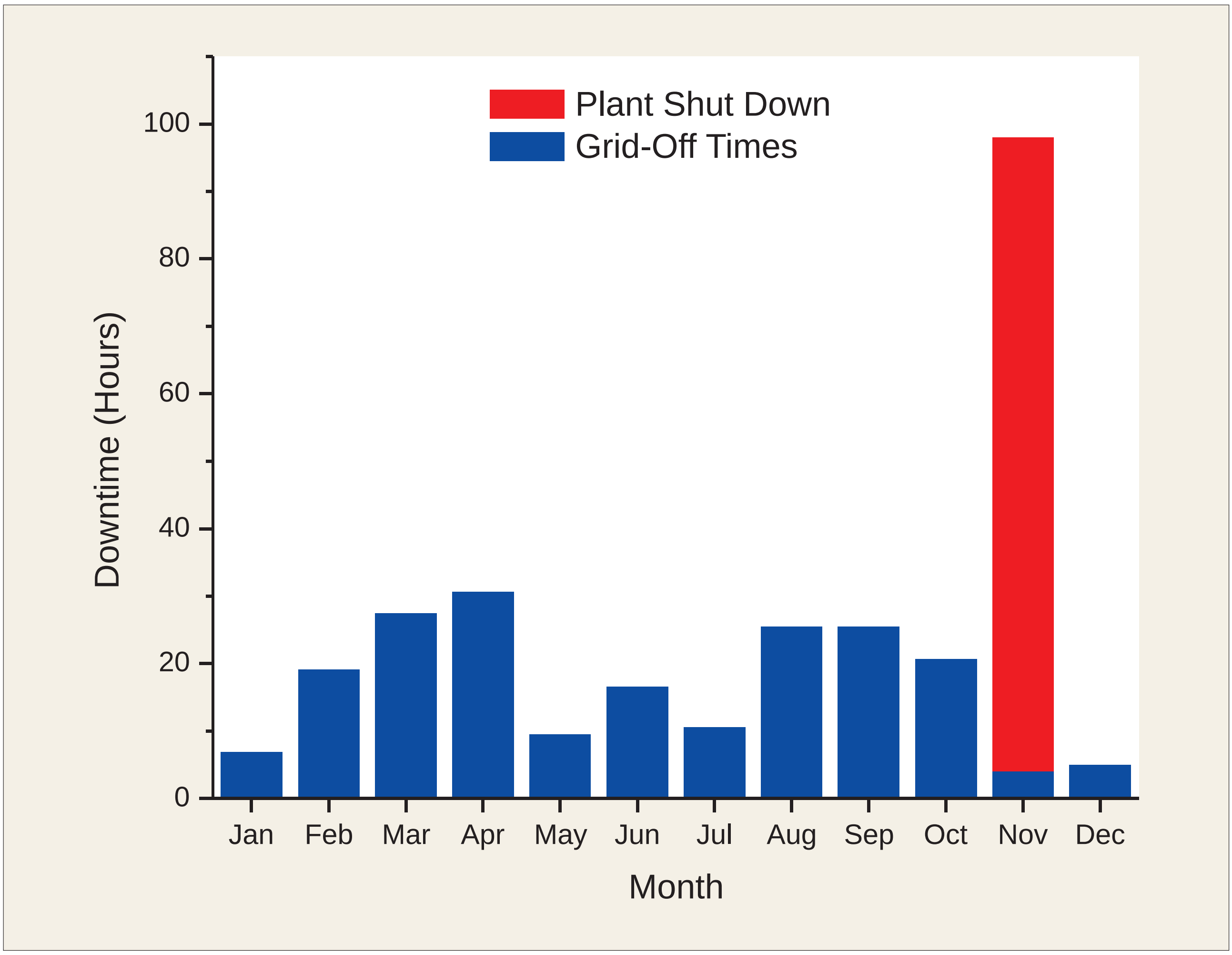

Figure 9: Monthly Plant down-time in hours-2010

Grid-off times: Figure 9 shows the cumulative monthly grid-off times during the year 2010. Out of the 357 days of the Plant's operation, there were 75 days on which the grid was off for less than an hour and 57 days with grid-offs more than one hour. Totally the grid was off for about 201.4 hours. Also, it was observed that the grid-offs occurred mainly during the peak hours (11.30 am – 2 pm), that is, when the availability of solar insolation is maximal.

The Plant was shut down for 8 days during November for repairing the faulty cables and Inverters.

Solar Insolation

The Plant is equipped with a Pyranometer installed at an angle of 15°, equal to the inclination of the Modules. The Solar Insolation recorded at the site is shown in Figure 10. The Insolation data is not available for about 44 days, especially from mid May to mid June, due to some problem in the Pyranometer. The highest recorded daily insolation was 7199 Wh/sqm on 2nd March 2010. The yearly average insolation on the panels was about 4789 Wh/sqm/day.

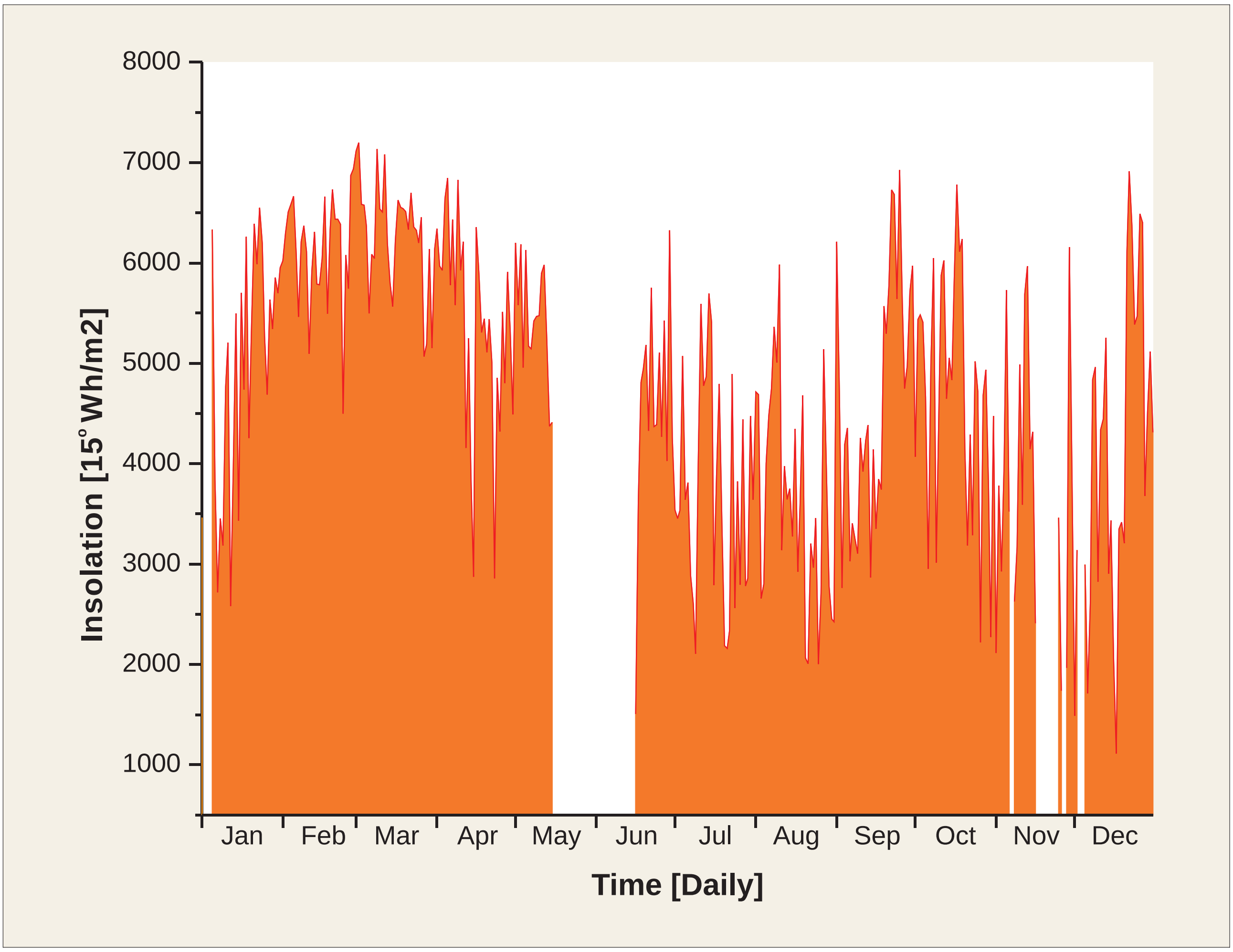

Figure 10: Daily Solar Insolation at the site - 2010 [@15°. inclination]

Efficiency

The 2-MW plant efficiency is the combined efficiencies of segments 1 and 2 after the dc-ac conversion by inverters to 415 Volts and just before stepping up to 11 kV ac. So, this should not to be confused with the overall plant efficiency.

Figure 11 shows the efficiency of the 2 MW plant, that is combined efficiency of segments 1 & 2, over the study period. The highest efficiency achieved was 13.41% on 24th July 2010. The total energy generated on that day was 4975.8 kWh with solar insolation of 2561 Wh/sqm and an average module temperature of 28.63^{0}C. The daily efficiency of the 2MW plant ranged from 5% to 13.41% depending on the performance of arrays, inverters, average module temperature and the solar insolation. The yearly average daily efficiency of the plant was about 10.14%, considering the days which have grid-offs for less than half an hour or no grid-offs. The abnormal drop in the efficiency during the last few months was mainly due to inverter related problems.

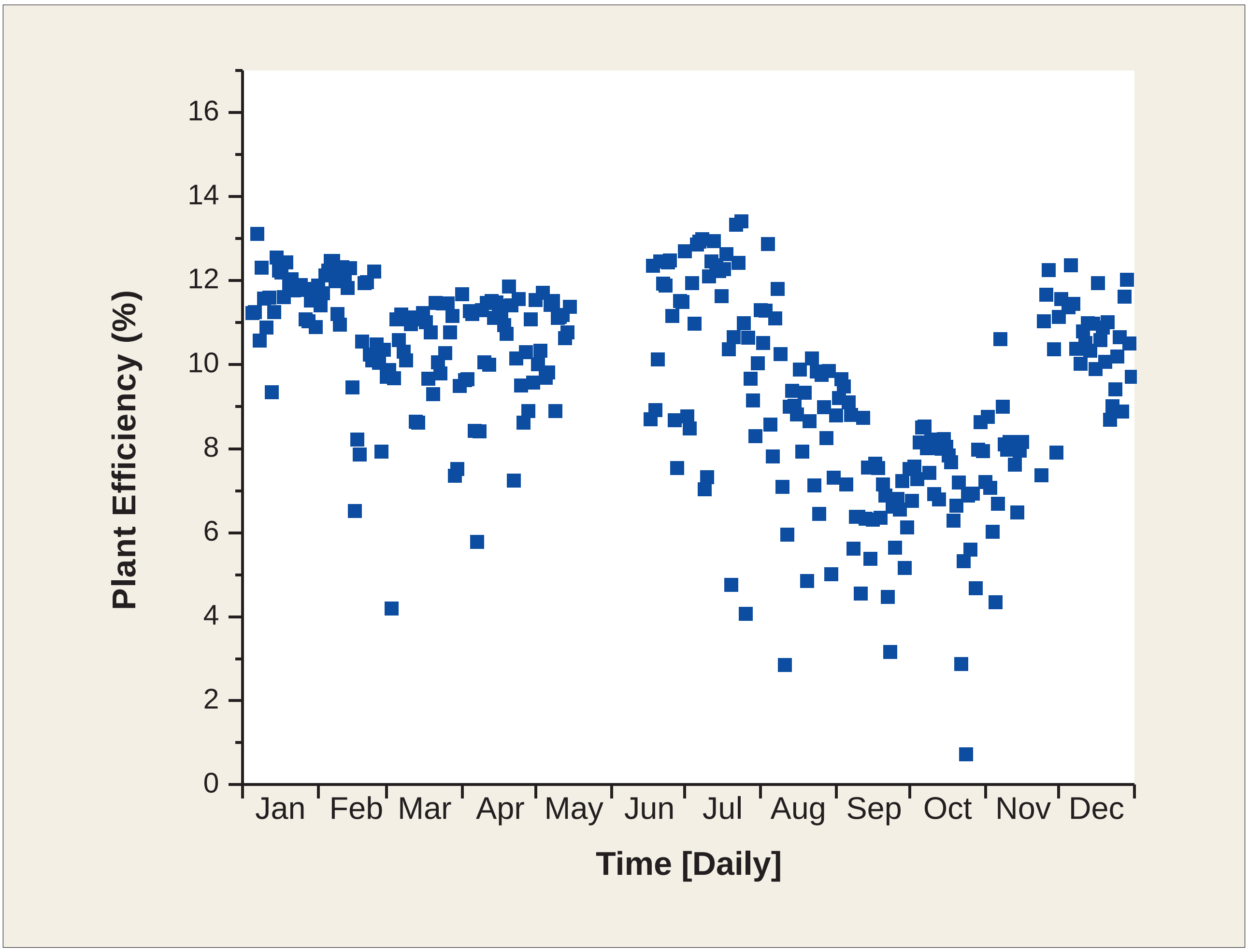

Figure 11: Daily Efficiency of 2 MW Plant [Seg.1&2]

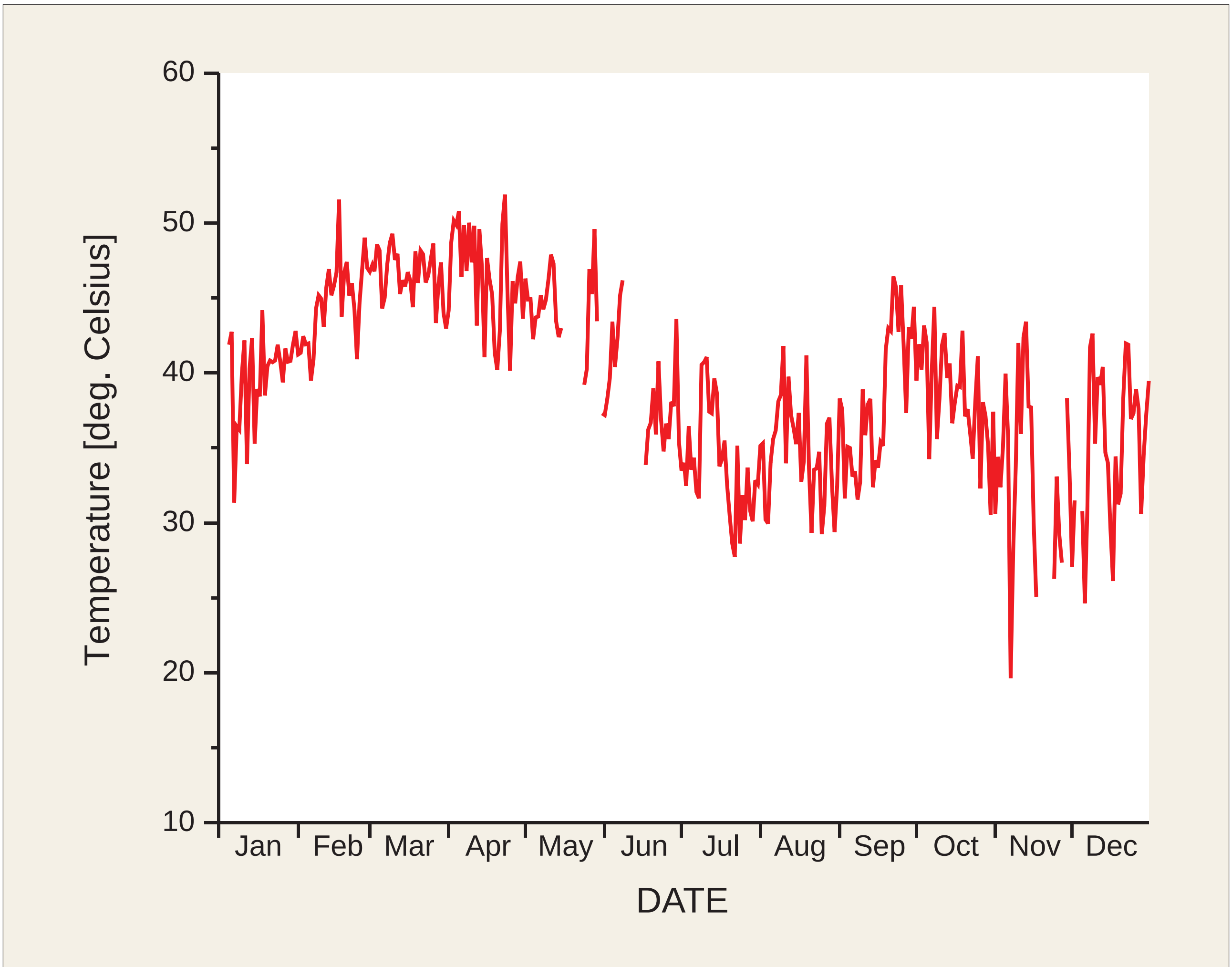

Figure 12: Daily average temperature of PV modules (During day time) – 2010

3.2 PV Modules Temperature

Figure 12 shows the daily average temperature of PV modules for the year 2010. It ranged from a minimum of 24.65^{0}C (on 6th Dec) to a maximum of 51.9^{0}C (on 23rd April).

Figure 13 shows the combined plots of plant efficiency, daily average modules temperature and daily solar insolation with reference to time scale. It appears from the figure that the efficiency is more sensitive to modules temperature than the insolation. Although the solar insolation level is more in March compared to January, the efficiency during March is low. This may be due to increase in the daily average temperature of PV modules during that month, as seen from the Figure. But this is not very clear because of too much noise in the data. To reduce the noise and explore the issue further, we decided to analyze a single inverter which had performed well during the study period.

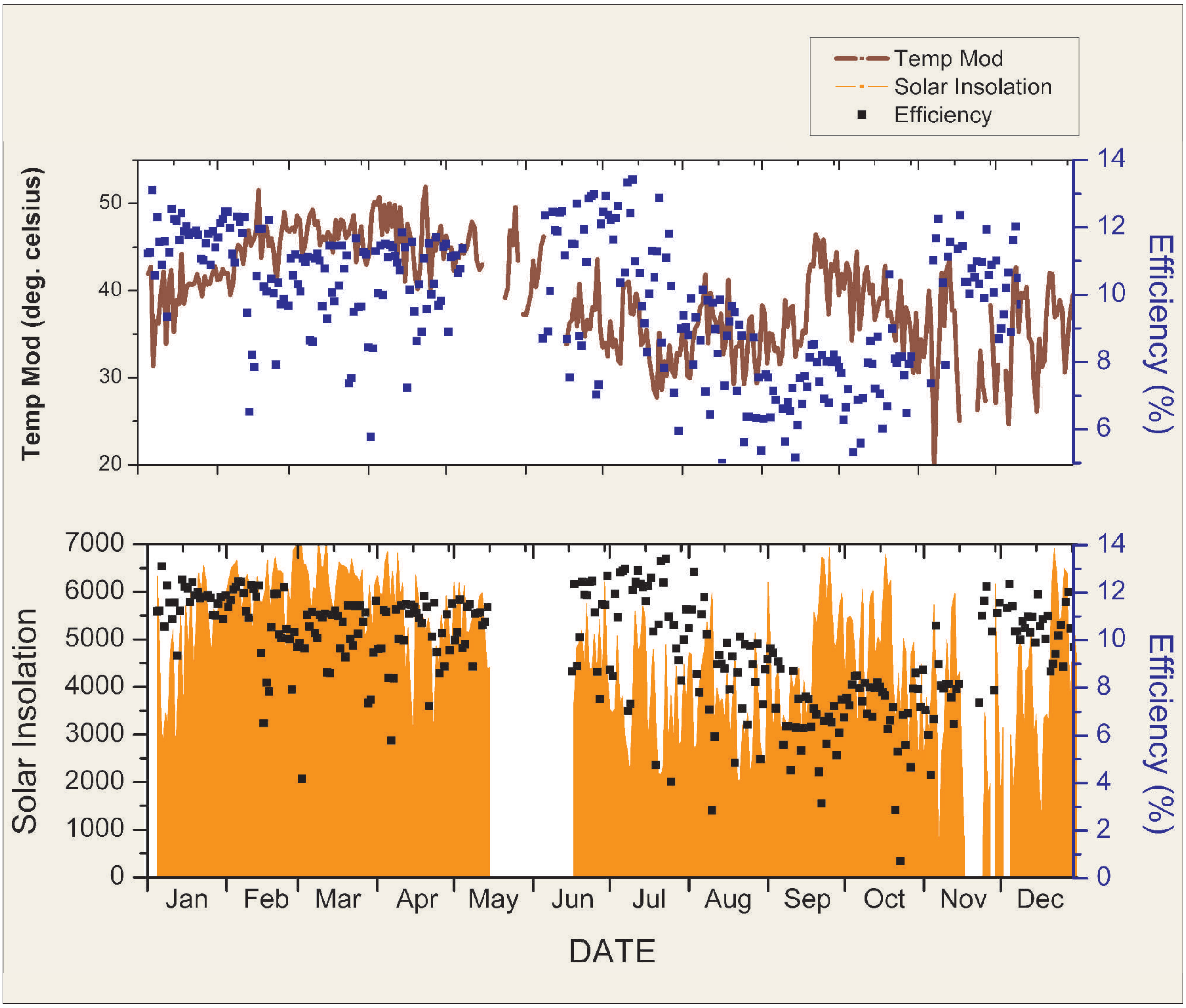

Figure 13: Daily variation of average modules temperature, insolation (in Wh) and efficiency of the 2MW Plant

3.3 Performance of Inverter-1

As the performance of Inverter-1 is good compared to other Inverters (see Figure 8), we chose this Inverter for more in-depth study. Figure 14 shows the plot of daily energy generation by Inverter-1 versus the incident solar insolation on that day for the year 2010. The energy generation increases linearly with the increase in solar insolation.

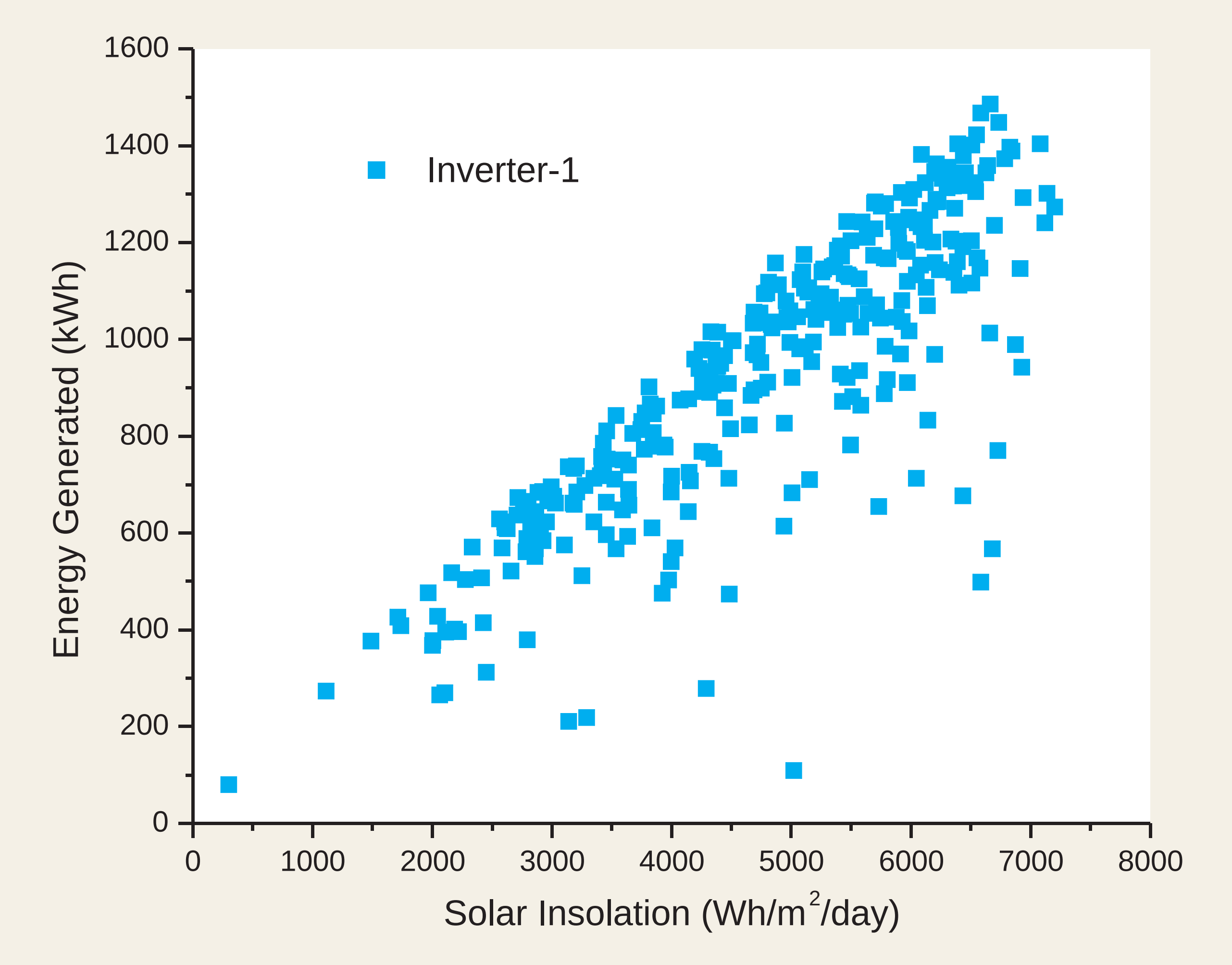

Figure 14: Annual plot of daily energy generated by Inverter-1 versus solar insolation

3.3.1 Effect of temperature on efficiency

Figure 15 shows the variation in energy generation of solar modules with insolation and the effect of module temperature on their efficiency. The plots are made using the 5 minutes average values from 10 am to 3 pm on 21st January, 2010.

Even though the energy generation shows direct dependency on the incident solar insolation [see Figure 15(A)] and reaches the maximum during peak insolation hours, the efficiency of the modules decreases and reaches the minimum during peak hours. This is mainly because of increase in the temperature of modules, which negatively impacts the efficiency more during that time [see Figure 15(B)]. Figure 16 shows the variation in efficiency of the modules with variation in temperature of modules, along with color mapped values for average solar irradiance. The efficiency of the modules decreases from 14.5% at 30°C to 11.5% at 55°C. It is also clear from the Figure that the temperature of modules increases with the increase in solar insolation and reaches the maximum during peak insolation hours, leading to reduced conversion efficiency. Thus, the Plant's capacity to produce maximum power is retarded during peak insolation hours, when the availability of incident solar radiation is highest, because of increase in modules temperature.

Figure 17 shows the annual plot of daily efficiency of modules in Inverter-1 versus daily averaged module temperature (binned values) for the year 2010. Due to lots of noise below 20°C, the temperature values were binned between 20°C and 55°C. Then the efficiency values were binned between 10% and 15% choosing only the maximum points. The plot shows linear decrease in the daily efficiency of modules from 14.5% to 11.5% with increase in the daily averaged modules temperature from 25 °C to 50°C.

3.3.2 Performance of Inverter-1 on good days – Daily plots

Figure 18 shows the daily performance plots of Inverter-1 on 24th March, 11th May, 18th June, 24th July and 20th September. The plots on the left side show the variation of energy generation with solar insolation and the right side plots show the variation in efficiency of Inverter-1 with modules temperature. The values of solar insolation, modules temperature and efficiency are averaged for every 5 minute interval. The energy generation values are the cumulative figures generated for the same time period.

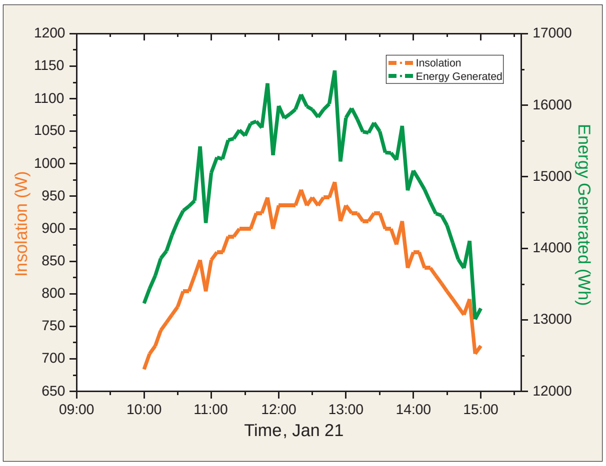

Figure A: Insolation and Energy Generation (of Invereter-1)

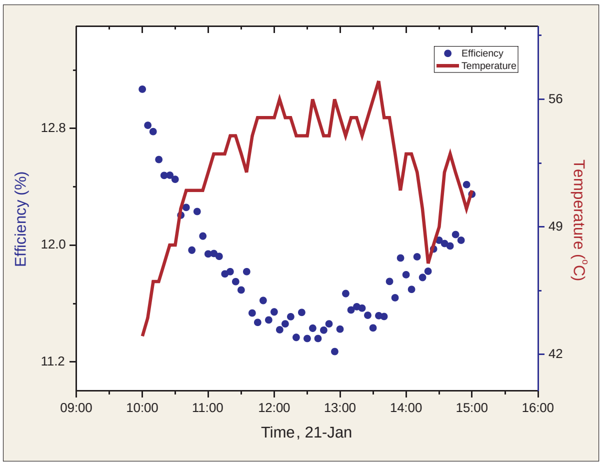

Figure B: Efficiency and Temperature of Modules (of Invereter -1)

Figure15: Plots of insolation, energy generation, efficiency & temperature of Inverter-1 modules on January 21

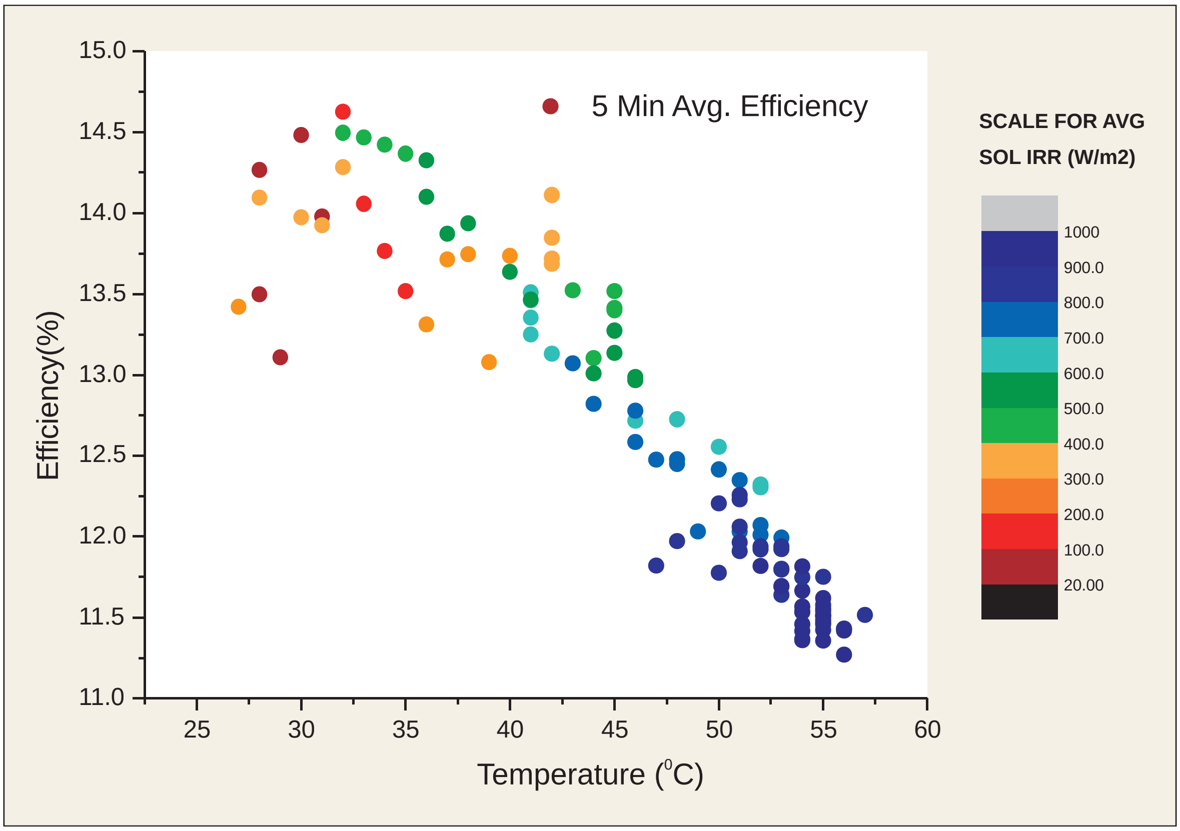

Figure 16: Efficiency v/s Temperature of modules of Inverter-1 (5 min average values) on January 21, 2010 (Color scale : Average Solar Irradiance)

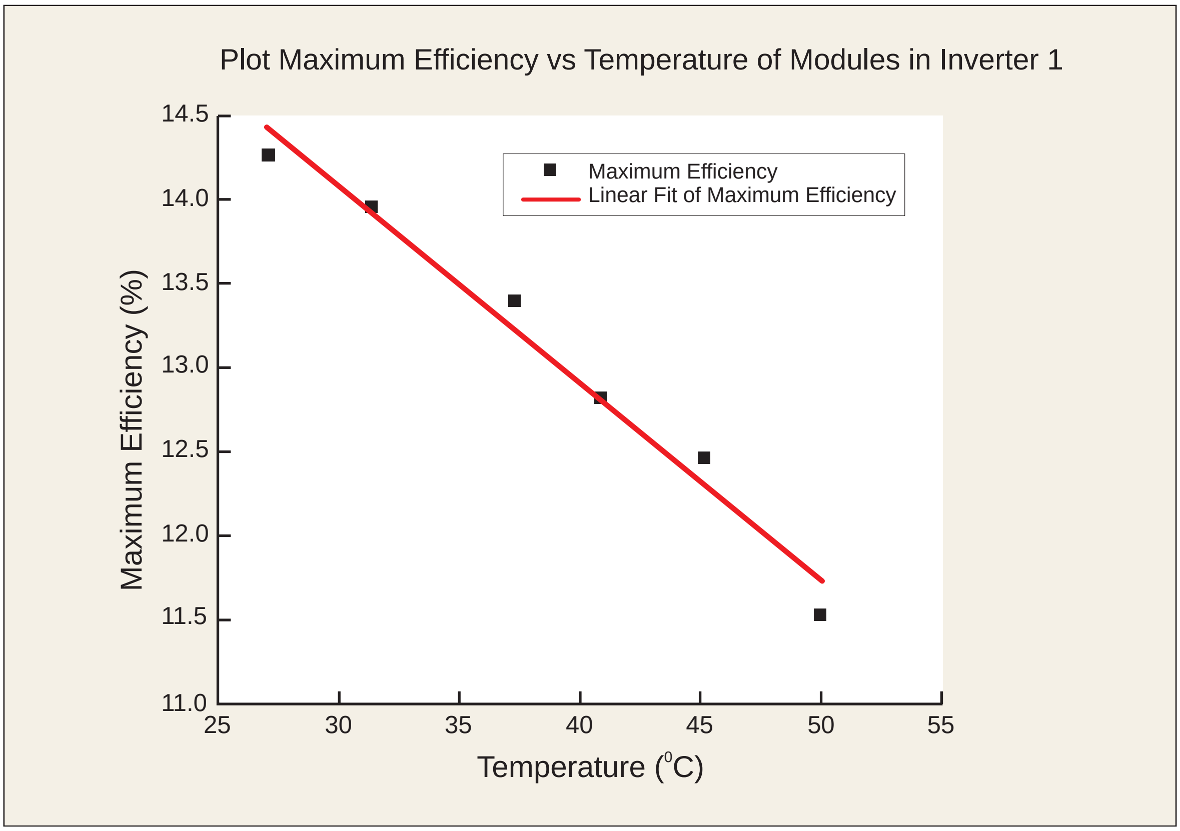

Figure 17: Plot of daily maximum efficiency versus temperature of modules in Inverter-1 for 2010

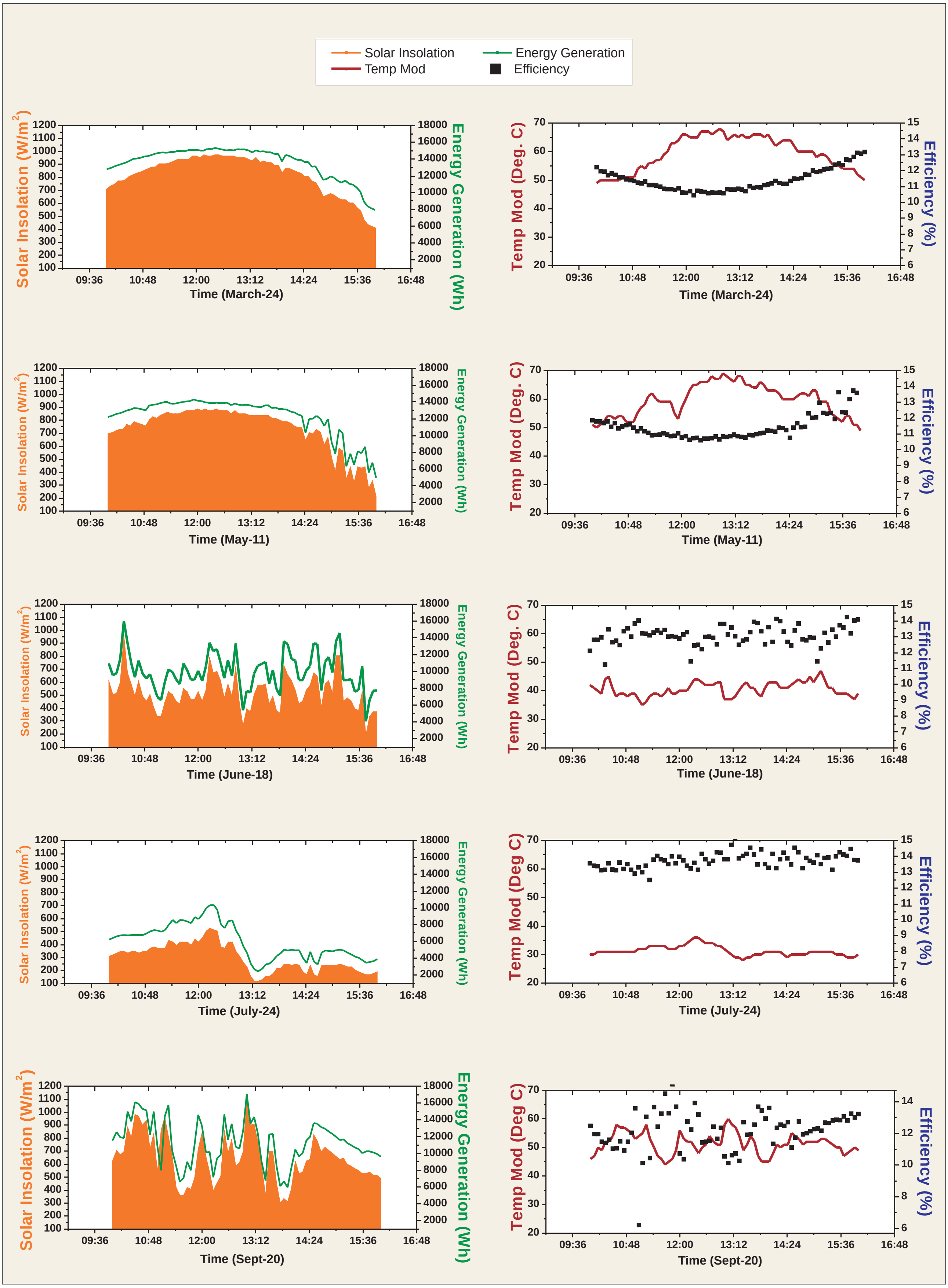

Figure 18: (Left) Daily plots showing variation of energy generation with insolation; (Right) Daily plots showing variation of efficiency with modules temperature

4. Technical and maintenance related problems

Some of the major technical & maintenance related problems faced by the plant operators are as follows:

- The power of the PV plant cannot be fed to the grid if the power supply from the grid stops. Due to this, the power from the PV Plant is not available when it is needed most and the capacity of the Plant to work effectively has been retarded.
- There is no tracking mechanism to locate the modules if they fail. If a module fails, it is very tiresome to identify it because no sensors have been installed for this purpose. The only solution presently available is to wait till the peak time to identify the Inverter (from which the output is lower). Then the Inverter has to be isolated and all the 45-46 arrays connected to this inverter should be checked. Once the faulty array is located, all the connected modules need to be checked to identify the faulty one.
- Presently the modules are cleaned by spraying water. But the dust accumulated on the modules turns into paste form once the modules are water sprayed, making it difficult to remove. Also, the height of the modules mounting structures (see Figure 19) makes it impossible to remove the dirt completely with wipers while standing on the ground. This has led inevitably, to the option of cleaning the modules by climbing on top of them (and then using wipers!). This will weaken the strength of solar modules as well as mounting structures in the long run and also affect the power production. Hence, it is felt that there is a need to address this issue by developing alternate method/ technology for cleaning the PV modules.
- Recently, some of the modules have shown change in color (see Figure 20). It is yet to be ascertained whether this color change in the modules has any negative impact on their performance.

Figure 19: Photo of PV Plant showing the modules mounting structures inclined at 15^0.

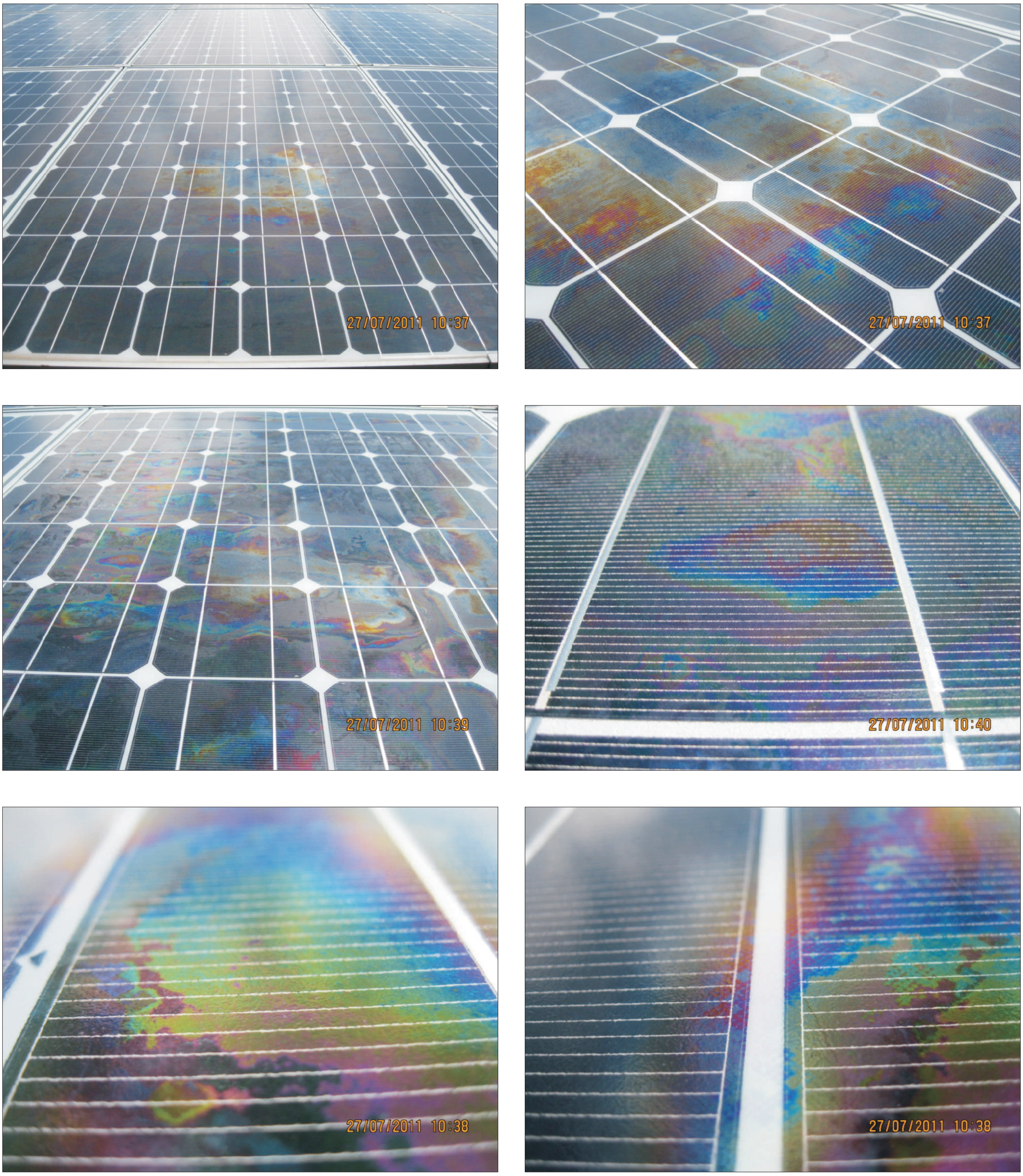

Figure 20: Visual color change of the photovoltaic modules

5. Conclusion

The performance of the 3 MW_p Yalesandra solar photovoltaic power plant has been analyzed for the year 2010. The total electrical energy generated by the Yalesandra power plant during 2010 was 3.34 million kWh and 3.30 million units were sold to the grid. Based on the performance of the first two segments we estimate the mean output to be 6655 kWh per day. This is lower than expected for a solar power plant and is on account of teething trouble associated with inverters and the grid-encountered in the first year of the operation of the plant. It was found that failure in inverters were the most frequent incidents. This is mostly caused by lack of experience in the initial production stage and some unexplained inverter failures might be caused by disturbance from the grid and other interconnected issues [6].

The impact of temperature variation (of modules) on the performance of photovoltaic mono-crystalline silicon modules was studied both on daily and yearly basis (daily average values). It is observed that the efficiency of modules is more sensitive to temperature than the solar insolation. The normal daily trend is that the efficiency of Plant is high during morning hours but low during the middle of the day and again starts increasing from late afternoon. The daily efficiency of modules varied from 14.5% to 11.5% with the variation in the daily averaged modules temperature from 25°C to 50°C. Hence, cooling of the solar modules may be desirable to increase the efficiency. There is a need to evaluate if the additional energy required for cooling the solar modules will be less than the additional energy generated due to higher efficiency.

The daily plots showing the variation of efficiency with modules temperature and the variation of energy generation with solar insolation have been plotted for five different days of the year. Also, some of the present maintenance and technical problems faced by plant operators, including the color change in PV modules and cleaning issues, have been discussed.

It is also suggested that more measuring instruments such as Pyrheliometer, Rain Gauge, Thermocouple (Thermometer) for measuring ambient temperature, to be installed in the plant and the existing instruments to be calibrated for greater accuracy. This will enable further technical analysis of India’s first 3MW scale plant and help KPCL in their future solar power plant projects.

6. References

1. Antonette D'Sa and K. V. Narasimha Murthy, Karnataka's Power Sector & Suggested Ways Forward, International Energy Initiative, discussion paper, 2002.

2. K. Jairaj, Energy scenario in Karnataka, power point presentation, Energy Department, Government of Karnataka.

3. Solar PV Power Plants, contract agreement for supply of equipments, CE(EI&TA)/SPV, KPCL and Titan Energy Systems Ltd., Secunderabad.

4. Operation manual, Titan Energy Systems Ltd., Secunderabad.

5. Contract agreement for Erection, testing and commissioning of 3 MW Solar PV power plant, KPCL and Titan Energy Systems Ltd., Secunderabad.

6. Mohamed A. Eltawil and Zhengming Zhao, Grid-connected photovoltaic power systems: Technical and potential problems - A review, Renewable and Sustainable Energy Reviews, 14, 2010, 112–129.

7. Acknowledgements

We wish to thank Mr. B. R. Nagaraju, Ex-Chief Engineer, RE Projects, Karnataka Power Corporation Ltd. (KPCL) for participating in the project by giving authorization to collect and use data for this research. We thank Mr. A. V. V. Reddy, Executive Engineer, in-charge of Kolar PV Plant for giving us the performance data of the plant. We also appreciate his spending valuable time with us and sharing his concerns about the plant during our field visits. We also thank Mr. D. C. Krishnamurthy, Executive Engineer, Electrical Division, KPCL for helping us in getting the data and other information related to the plant.

We also acknowledge Mr. M. K. Nagaraj and the office staff at Divecha Centre for Climate Change, for their kind support during the course of this project.

Satellite image of the 3-MW scale grid-connected solar photovoltaic power plant at Kolar, Karnataka

REPORT IISc-DCCC 11 RE 1
AUGUST 2011

DIVECHA CENTRE FOR CLIMATE CHANGE
INDIAN INSTITUTE OF SCIENCE
Bangalore