3
Overview of Photovoltaic Plants and Data Description

3.1 INTRODUCTION

In this study rooftop grid connected to large-scale solar photovoltaic power plants are discussed. 58 kW C-Si and 43 kW A-Si grid connected solar photovoltaic power plants at Indian Institute of Technology (IIT) Jodhpur and 5 MW Gujarat Power Corporation Limited (GPCL) Charanka, Gujarat photovoltaic power plants are taken for further study.

3.2 SITE DESCRIPTION FOR INDIAN INSTITUTE OF JODHPUR GRID CONNECTED ROOFTOP SOLAR PHOTOVOLTAIC POWER PLANT

The PV solar power plant described in this project has been installed on the roof of academic block I and II, 43 kW grid-connected Amorphous PV system installed at block- I and 58 kW grid-connected Crystalline PV installed at block- II in Indian Institute of Technology Jodhpur, Rajasthan, located in Jodhpur, the second largest city in the Indian state of Rajasthan at coordinates 26°17'N 73°01'E which is 335 kilometers west of the state capital, Jaipur and 200 kilometers from the city of Ajmer is shown in Figure 3.1-3.2.

3.2.1 58 kW C-Si based solar PV system description

Figure 3.1 Academic block ii building, located at "IIT, jodhpur" Jodhpur

The PV system has a nominal peak power of 58 kWp and installed on the roofs of the academic block II building. The overall surface area is 724.16 m^2. The schematic diagram of plant is shown in Figure 3.3.

Figure 3.2 C-Si Based 58 kW Rooftop Grid Tied Solar Photovoltaic System

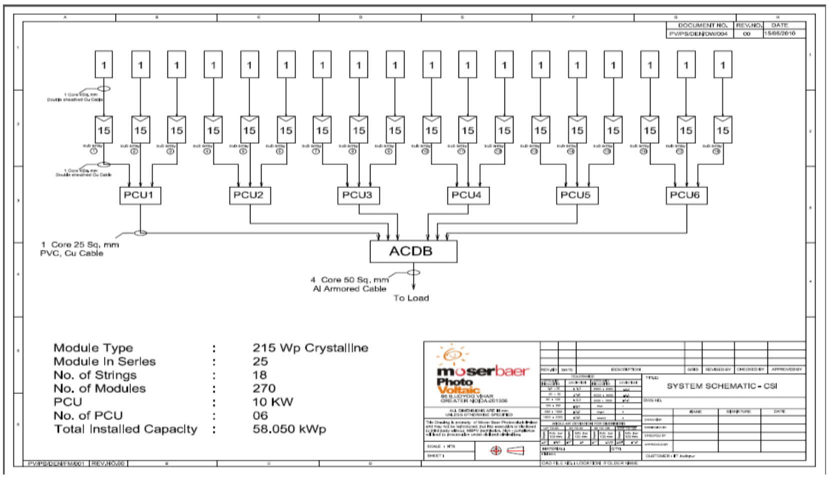


Figure 3.3 Schematic Diagram of C-Si SPV Plant

(a) System Specification

In this plant six power conditioning unit (PCU) of 10kW$_p$ are used. Each power conditioning unit provide 230 V AC, 50 Ht, set of three PCU's are synchronized using power balancing cable to convert single phase output of individual PCU to three phase 415V AC, 50 Hz.

The main features of the PV system and module specifications are summarized in Table 3.1:

Table 3.1 58 kW C-Si Based Solar PV System

1.	Total no. of modules	270
2.	No. of inverter	6
3.	Inverter rating	1000W
4.	No of modules/ string	15
5.	No. of strings/ Inverter	3
6.	DC voltage(DC)/ inverter	546V
7.	DC voltage (at P_{max})/ Inverter	438.5V
8.	DC current (I_{sc})/ Inverter	24.51A
9.	DC current (at P_{max})/ Inverter	22.23A
10.	Inverter AC Voltage	230V

(b) PV Module Specification

The generated power from panels goes through a DC distribution network to a grid – interactive inverter. It converts the DC power into 230V at 50 Hz AC for single phase operation or 415V at 50 Hz AC for three phase operations, as per requirement. In this solar PV plant 270 Nos. of 215W_p C-Si module and 15 modules are configured in series to form a string, and such 18 string will be installed for a system capacity of 58kW C-Si rooftop based solar Power Plant. Module specification are given in Table 3.2.

Table 3.2 C-Si Module Specification

S. No.	Product Type	MBPV CAAP Max Series
1.	Maximum power(P_{mpp})	216.53W
2.	Voltage at Maximum Power(V_{mp})	29.23V
3.	Current at Maximum Power(I_{mp})	7.41A
4.	Open Circuit Voltage($_{Voc}$)	36.40V
5.	Short Circuit Current($_{Isc}$)	8.17 A
6.	Fuse Rating	10.00A
7.	Weight	19.5kg
8.	Dimension	1661x991x40(mm)
9.	NOCT	47+-2
10.	Operating Temp	-40 to+85
11.	Cell type	Multi-Crystalline
12.	Cell Dimension	156x156(mm)
13.	No of Cells	60
14.	Temperature Coeff. of Pmax(%/K)	-0.43
15.	Temperature Coeff. of V_{oc}(%/K)	-0.344
16.	Temperature Coeff. of I_{sc}(%/K)	0.11

3.2.2 43 kW A-Si based solar PV system description

The PV system has a nominal peak power of 43 kWp and installed on the roofs of the academic block I building. The overall surface area is 652.34 m^2. It consists of 114 modules for a total of 38 arrays each array consist of 3 module, which is connected to the inverter, each inverter has six arrays in which modules are connected in series and arrays are connected in parallel. Total numbers of inverters are six. The installed PV plant and its schematic diagram are shown in Figure 3.4-3.6.

Figure 3.4 Academic Block I Building, located at "IIT, Jodhpur" Jodhpur

Figure 3.5 A-Si Based 43 kW Rooftop Grid Tied Solar Photo Voltaic System

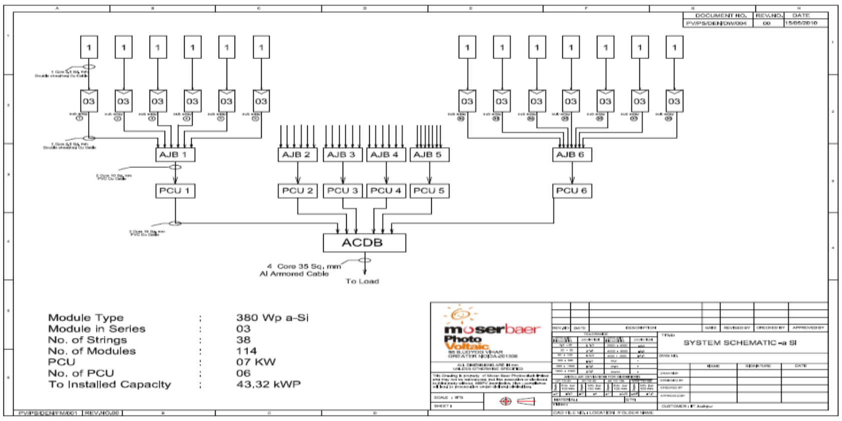


Figure 3.6 Schematic Diagram of A-Si SPV Plant.

(a) System Specification

In this plant, power conditioning unit (PCU) provide 230 V AC, 50 Hz, set of three PCU's are synchronized using power balancing cable to convert single phase output of individual PCU to three phase 415V AC, 50 Hz. The main features of the PV system are summarized in the Table 3.3.

Table 3.3 43 kW A-Si Based Solar PV Systems

1.	Total no. of modules	114
2.	No. of inverter	6
3.	Inverter rating	7000W
4.	No of modules/ string	38
5.	No. of strings/ Inverter	7
6.	DC voltage(DC)/ inverter	560V
7.	DC voltage (at P_{max})/ Inverter	340V
8.	DC current (I_{sc})/ Inverter	23A
9.	DC current (at P_{max})/ Inverter	22A
10.	Inverter AC Voltage	230V

(b) PV Module Specification

In this solar PV plant 114 Nos. of 380W_P A-Si module and 3 modules are configured in series to form a string, and such 38 strings are installed for a system capacity of 43 kW C-Si rooftop based solar Power Plant. Module specification are given in Table 3.4.

TABLE 3.4 A-Si Based Module Specification

	Product Type	MBPV CAAP Max Series
1.	Maximum power(P_{mpp})	380W
2.	Voltage at Maximum Power(Vmp)	143.4V
3.	Current at Maximum Power(Imp)	2.65A
4.	Open Circuit Voltage(Voc)	187.8V
5.	Short Circuit Current(Isc)	3.27 A
6.	Fuse Rating	10.00A
7.	Maximum System voltage	1000V
8.	Weight	19.5kg
9.	Dimension	2.5m * 2.2m
10.	NOCT	47+-2
11.	Operating Temp	-40 to+85
12.	Cell type	Amorphous Silicon
13.	Cell Dimension	156x156(mm)
14.	No of Cells	60
15.	Temperature Coeff. of Pmax(%/K)	-0.41
16.	Temperature Coeff. of Voc(%/K)	-0.334
17.	Temperature Coeff. of Isc(%/K)	0.9

3.2.3. Data Description

The power generation data used in this work is measured on the basis of the Indian Power Sector norms. A time slot of 15 minutes is considered for scheduling. The data is recorded at above mentioned site, where day length is in range of 9-11 hours in a day. Moreover, location is coming under clear sky condition. Each measurement is recorded under 15 minute interval. The Sunny sensor web box is mounted on PV mounting frame shown in Figure 3.7.

Figure 3.7 Sunny sensor box

Measured variables and its relationship with Respect to Power Generation

The power generation of PV plant highly influenced by above parameters. Figure 3.8 show the relationship of solar radiation, ambient temperature, module temperature and wind velocity with solar power generation.

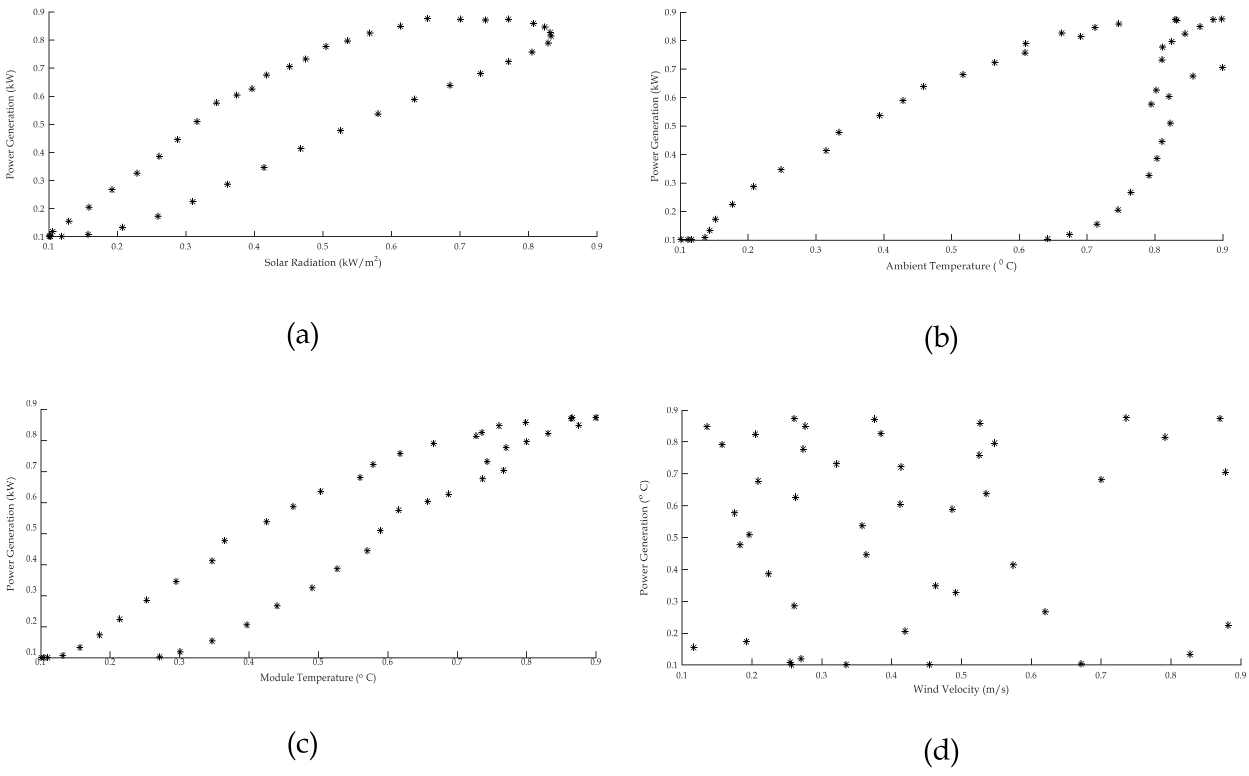


Figure 3.8: Relationship between the input parameters and solar power generation (a) Solar Radiation (kW/m^2); (b) Ambient Temperature(°C); (c) Module temperarture (°C); (d)Wind velocity

Figure 3.9 shows such scatter matrices for the measured data. It shows a pair wise correlation between the each independent variables and power generation. In this figure the wind variation during the day is intermittent and random and has bad correlation with power generation.

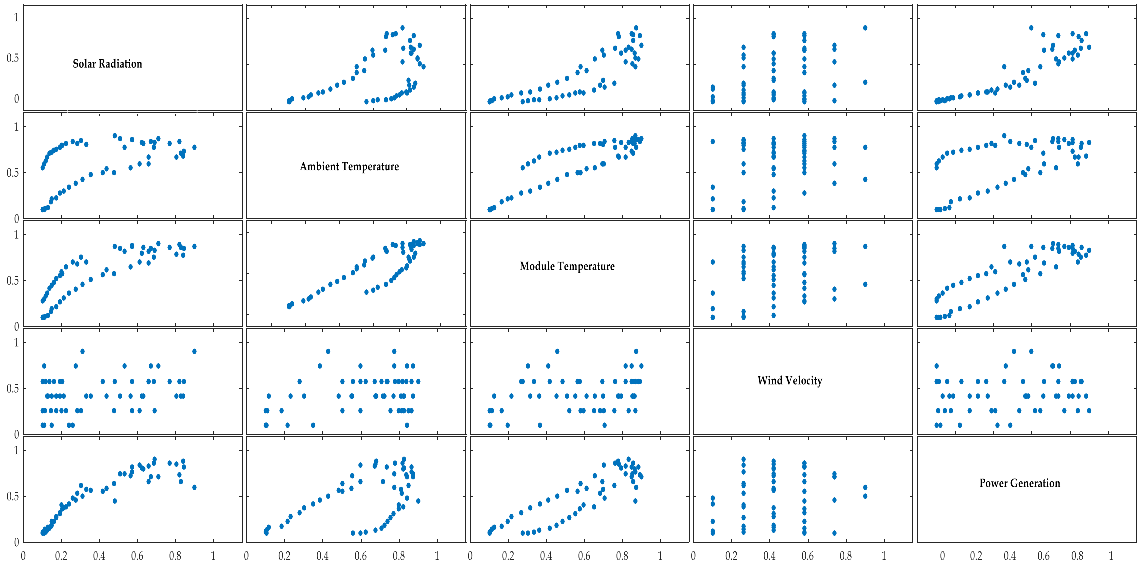


Figure 3.9 Scatter plot matrices for measured data

3.3 SITE DESCRIPTION FOR GUJARAT POWER CORPORATION LIMITED GRID CONNECTED SPV PLANT

Gujarat has extreme climatic conditions characterized by very hot and dry summers and cold and chilly winters. Hence the performance of the solar power plant varies not only with solar radiation but also temperatures in each season. Figure 3.10-3.12 shows 5 MW grid-connected Multi-crystalline photovoltaic power plant and its layout and satellite view of solar power plant. It is developed in approx. 2,024 hectares of government wasteland and has the capacity to generate 7750 MWh/year of electricity in favorable conditions. The GPCL has used the state-of-the-art technology considering the local conditions. The project is fully commissioned and operational. The plant is located at a Latitude 23^{0}54'20.24" N and Longitude 71^{0}11'54.29"E [GPCL, 2012].

Figure 3.10: Aerial view of MW Gujarat power Corporation limited solar photovoltaic power plant

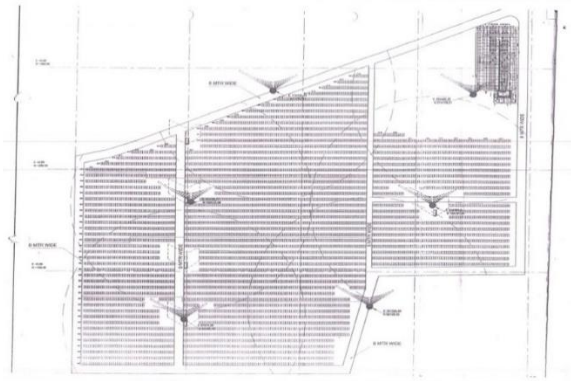


Figure 3.11 Complete layout of 5 MW GPCL SPV plant [GPCL, 2012]

Figure 3.12 Satellite view of 5 MG GPCL SPV plant [GPCL, 2012]

3.3.1 System Description

Solar PV array is made of high-efficiency poly/multi-crystalline -Si SPV Modules. The plant consists of 21,277 no. of 235W_p poly/multi crystalline-Si from "C-Sun" Solar. Details of solar photovoltaic panels are shown in Table 3.4 [CSUN, 2013]. The basic function of power conditioning unit is to convert DC electricity generated by solar modules into AC electricity which is then fed into the grid. The plant comprises of 5 power conditioning units and 5 Inverters of 1000 MVA inverter from "Bonfiglioli" in Figure 3.13.

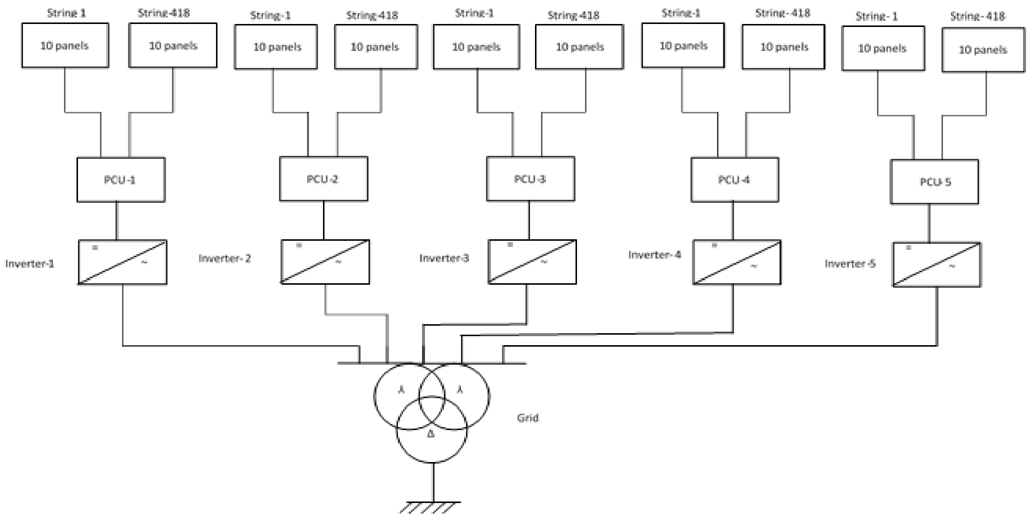


Figure 3.13 Schematic block diagram of the considered PV plant (5 MW GPCL solar PV plant)

Table 3.5: C-Sun 235 Wp Solar panel specification

Particulars	Specifications
Power (W)	235
Tolerance	3%
Max. Power Voltage (V_{mp})	29.5
Max. Power Current (A)	7.97
Open Circuit Voltage (V_{oc})	38.8
Short Circuit Current (I_{sc})	8.59
Temperature Coefficient of Power (%/OC)	-0.408%/k
Maximum system voltage (V_{dc})	1000
Length (mm)	1640
Width (mm)	990
Height (mm)	50
Weight (kgs)	19.8
Max. Power Current (A)	7.97
Open Circuit Voltage (V_{oc})	38.8

3.3.2 Online data acquisition system

In this solar power plant, data acquisition using ground-based measurement approach for measuring the solar resource parameters and meteorological data describe in Table 3.5. Solar photovoltaic plant generation is online monitored at the both DC and AC side using data acquisition system controlled by sunny sensor web box. The RS232/RS485 peripheral interface is used for data communication and stored in the computer system using supervisory control and data acquisition (SCADA). Converted DC power is directly fed into 11 kV grid of GPCL via a 415V/11 kV transformer [GPCL, 2012]. The schematic diagram of the solar power plant and surface plot of collected measured parameters are shown in Figure 3.14 and Figure 3.15 respectively.

Table 3.6: Measured Data

S. No.	Data	Resolution	Available Period	Source
1	GHI	Daily Averaged	1 Year:2014	5 MW GPCL SPV plant
2	Tilt GHI	Daily Averaged	1 Year:2014	5 MW GPCL SPV plant
3	Max Amb. Temp	Daily Averaged	1 Year :2014	5 MW GPCL SPV plant
4	Module Temp.	Daily Averaged	1 Year:2014	5 MW GPCL SPV plant
5	Sun Availability	Daily Averaged	1 Year:2014	5 MW GPCL SPV plant
6	Solar Power Generation	Daily Averaged	1 Year :2014	5 MW GPCL SPV plant

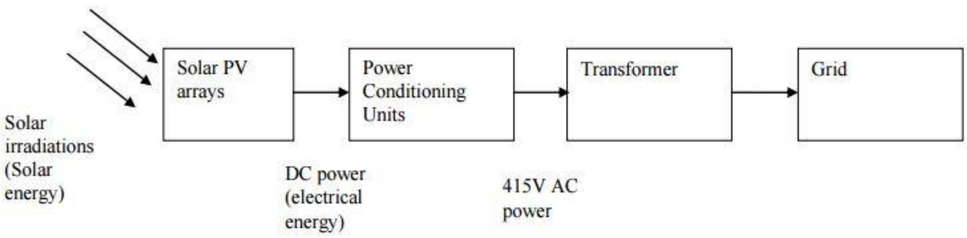
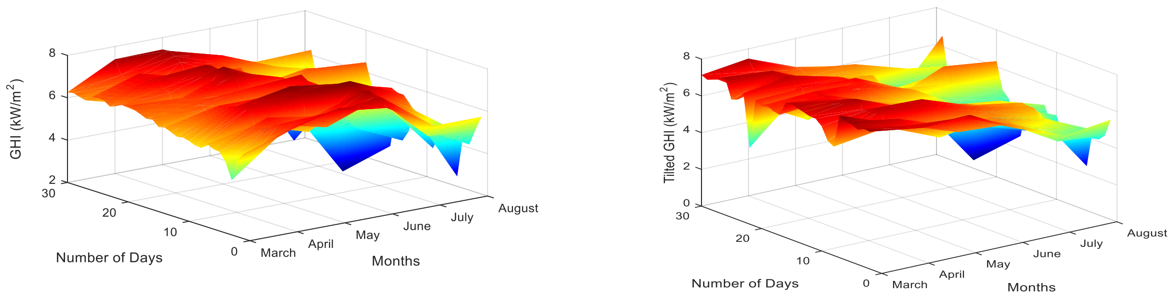
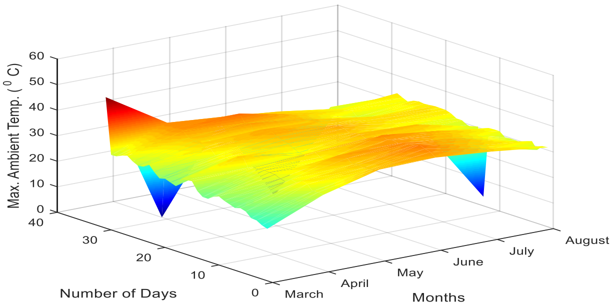


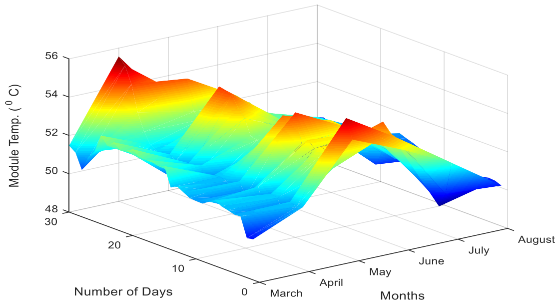
Figure 3.14: Schematic diagram of 5 MW GPCL SPV power plant.



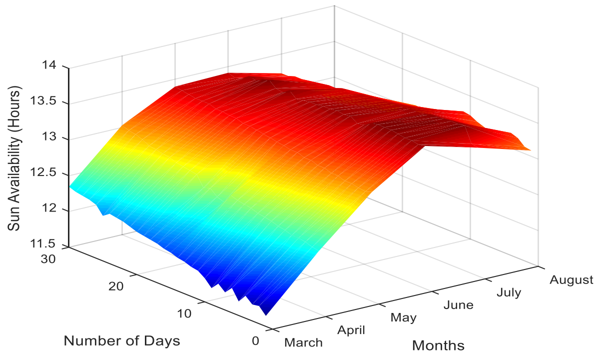
(a) **(b)**



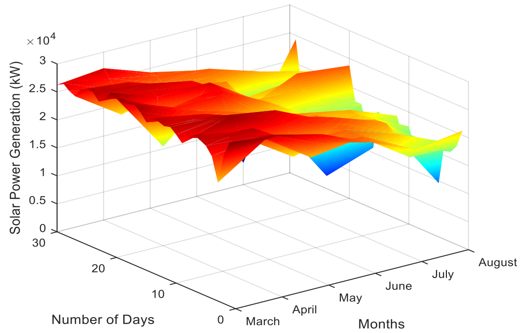
(c)



(d)



(e)



(f)

Figure 3.15: (a) Daily averaged GHI (b) Averaged GTI (c) Max. Ambient temperature (d) Module Temperature (e) Sun Availability and (f) Solar power plant generation

3.3.3 Data Description

As seen in the previous section, the global horizontal irradiation (GHI) and ambient conditions influence on the power generation of PV plant. However, daily ambient conditions have a stochastic behavior and because of this reason solar power generation from 5 MW PV plant can also be stochastic. The PV generation depends on GHI, GTI, ambient temperature, Module temperature and Sun availability. The strength of association between the generated power of PV power plant and a global horizontal and Tilted irradiation are shown in Figure 3.16(a-b) and impact of ambient and module temperature on PV power generation presented in figure 3.16 (c-d). Figure 3.16 (e) presents the relationship between recorded sun availability and PV power output. Figure 3.17 presented Scatterplot for a set of data variables (GHI, GTI, Ambient Temp., Module Temp. and Sun availability). the scatter plot matrix shows all the pairwise scatter plots of the variables on a single view with multiple scatterplots in a plotmatrix.

The performance of solar power plant is also directly affected by ambient conditions. So global horizontal irradiance, global titled irradiance, max. ambient temperature, max, module temperature and sun availability (Sun window: duration of sunshine in a day) are considered as predictors for solar power generation. Monitoring and measurement of data is an essential part of solar power forecasting. So in this section ground-based daily averaged measurement are considered as a final data set.

Measured parameters and its relationship with Respect to Power Generation

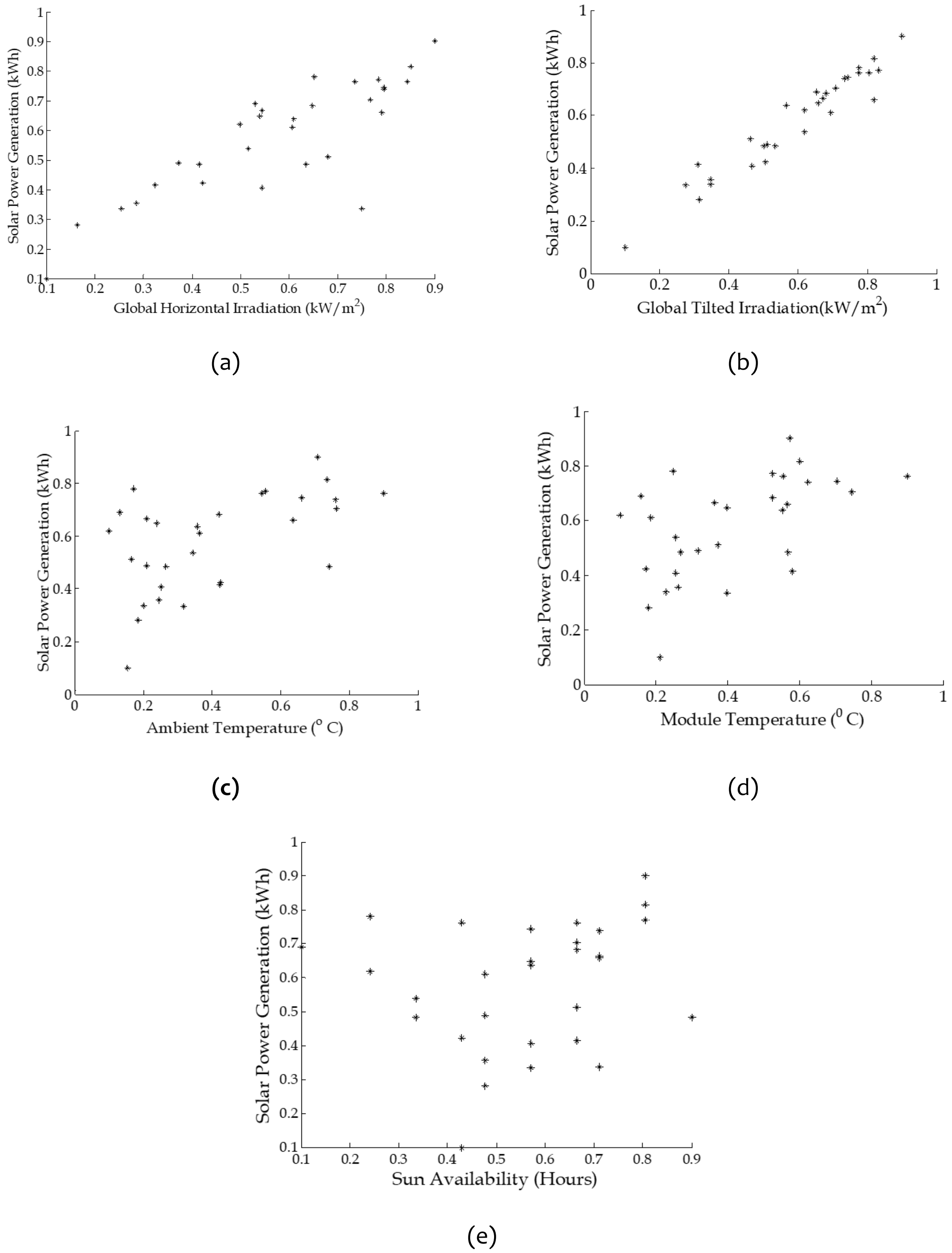


Figure 3.16: Relationship between the input parameters and solar power generation (a) global horizontal irradiation; (b) global tilted irradiation; (c) and Max. Ambient Temperature; (d) Max. Module temperature; (e) sun availability

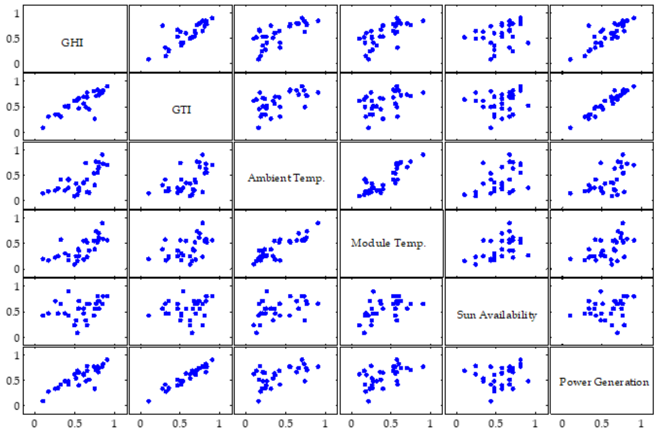


Figure 3.17 Plotmatix for input parameters

3.4 PRE-PROCESSING OF DATA

The available data is from photovoltaic power plants may have different sampling frequencies over a year and may need normalization and appropriate averaging. Different type of parameters measured from SCADA systems and weather monitoring stations are used to collect data. Collected data is in the raw form. There are some data redundancy and uncertainty issues in the data. So we need a preprocessing of the data to develop forecasting models. Data pre-processing is playing an important role in forecasting problem.

Data normalization is most important and fundamental data pre-processing step for learning from data before feeding to the forecasting model. Normalization is a must because of different ranges of the input parameters. With the help of normalization process, data ranges are fit in to the small specified ranges. The data attributes are scaled so as to fall within a small specified range, such as -1.0 to 1.0, 0.0 to 1.0 . Normalization methods transform the old attribute data in to the new attribute data set [Han and Kamber, 2006]. It can be useful to speed up the computing time in forecasting and avoid the data scalability issue. There are few conventional normalization methods like Z-score, decimal scaling and Minimum and Maximum as given below [Mustaffa and Yusof, 2011]:

- ***Z-Score Normalization***: Consider any data set $D = \{v_1 \dots, v_n\}$. In this process, the actual values are transformed in to the normalized values in to an average of zero and a standard deviation of one. An actual input value, v_i, of any vector is normalized as input value v_i'.

$$v_i' = \frac{v_i - \overline{D}}{\sigma_D}$$

$$\overline{D} = \frac{1}{n}\sum_{i=1}^{n} v_i$$

$$\sigma_D = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \overline{D})^2}$$

Where,

v_i' =Z-Score normalized value
v_i= Actual value
$\overline{D}$ = Mean of the data set
σ_D = Standard deviation of data set

- ***Decimal Scaling Normalization :*** In this method, Actual data is normalized to change the decimal point of values of data set D. as shown below. The normalized value is given by :

$$v_i' = \frac{v_i}{10^j}$$

j= smallest integer $Max\ (|v^i|) < 1$, for all $i = 1, \dots, n$.

- ***Min-Max Normalization:*** Actual data if transformed in the old minimum and maximum range in to the specific minimum to maximum value of data set D.

$$v_i^{"} = \frac{v^i - min_D}{max_D - min_D}\left(new_{max_D} - new_{min_D}\right) + new_{min_D}$$

min_D = Minimum value of actual data set
max_D = Maximum value of actual data set
new_{min_D} = Minimum value of specific normalization range
new_{max_D} = Maximum value of specific normalization range

Min-max Normalization out-performs Z-Score and decimal scaling normalization [Shalabi and Shaaban, 2006]. In this work, min-max normalization method is used for data preprocessing so we consider a small specified range in between 0.1 as min. and 0.9 as max. to avoid convergence problems using Eq. (3.1).

If

$$X = Column\ Vector\ of\ particular\ parameter(Actual\ data)$$
$$X_{max} = \max(X)$$
$$X_{min} = \min(X)$$
$$Coefficient = 0.8/(X_{max} - X_{min})$$
$$Y = 0.1 + (X - X_{min}) * \left(\frac{0.8}{X_{max} - X_{min}}\right). \quad (3.1)$$

3.5 SUMMARY

In summary, this chapter has covered the detailed description of both the plants with a description of its location, architecture, details of PV modules, inverters, and plant level power evacuation details. Online data monitoring systems for both the plants are also described in this chapter. Online data acquisition system gives power plant output and a pyranometer measures global horizontal irradiance at plant level. The factors affecting the solar power generation are solar irradiance, ambient temperature, module temperature, wind velocity and sun availability. In this chapter, the relationship between selected input parameters and output parameter is shown in above plots. It is clear that global horizontal irradiance is highly correlated with the solar power generation among all the input parameters considered.

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