6

Performance Analysis of 58 kW Multicrystelline-Silicon and 43 kW Amorphous-Silicon Grid-Connected Rooftop Solar PV Systems

The performance of a grid-connected PV system depends on PV technology used, inverter efficiency, overall system lose and weather parameters such as global irradiance, ambient temperature and soiling loses. The proper analysis of PV power plant is one of the most crucial requirements for the development of technology, proper distribution and maintenance to optimize the design and predict the energy injected into the grid for a given PV power plant. This chapter presents analysis and comparison of performance of two grid-connected photovoltaic plants which are situated at the same location but based on different module technologies. The monitored plants are 43 kW grid-connected amorphous-silicon system and 58 kW multicrystelline-silicon grid-connected PV system. The performance indices used for study of systems are performance ratio, specific yield, reference yield, capture loss, system loss, system efficiency, PVUSA rating and performance indicator based on ratio of ac power at PTC to dc power at STC. Three years monitored data from July 2011 to July 2014, since the commission of the plant, are used for the analysis purpose. Major operation and maintenance issues that have occurred during this period are also discussed.

6.1 INTRODUCTION

Demand of renewable energy in India is increasing continuously due to less generation of power than demand, cost effectiveness, availability of energy with negligible emissions of air pollutant and greenhouse gases. Among several renewable sources of energy off-grid and grid-connected Solar photovoltaic (SPV) technology is highly preferred technology in western India due to abundant availability of solar resource, it requires less maintenance and is capable of generating outputs from few micro watts to megawatts which can fulfil the demand of remote areas where electricity supply from the grid is uneconomical to meet the user demand [Bijarniya *et al.*, 2016]. As a tropical country, India experiences around 300 sunny days per year thus leading to a huge solar potential. Considering the growing demand of energy and to exploit the solar potential, the government of India, under Jawaharlal Nehru National Solar Mission (JNNSM) has set a target of generating 100 GW of electricity by year 2022 using the solar source. Out of this, 40 GW target is reserved to be achieved from solar rooftop systems only because of the drastically reduced cost in last few years, consumer awareness and lucrative offers under the JNNSM scheme from Ministry of New and Renewable Energy (MNRE), govt of India. As a result in many rural and urban areas, rooftop solar systems are being installed with great pace and hence share of renewable energy in installed capacity has been significantly increased from total share of 5 % in 2007 to over 12 % in 2012 [Joshi and Pindoriya, 2012]. The power generated through solar PV is utilized for own use and the surplus power is fed to the grid. Installation of SPV system on the surface is not always feasible because it requires large area of land availability. Hence, spare rooftop area can be utilized successfully for installing SPV system. Once the SPV systems are installed, then it becomes necessary to have the information on its operational performance, reliability, loses, and effects of component ageing [Mondol *et al.*, 2006; Kymakis *et al.*, 2009; Villalva *et al.*, 2009]. Furthermore, knowledge about operational and maintenance issues, cost of produced energy, and pay back period is also necessary [Kazem *et al.*, 2014; Armstrong and Hurley, 2010]. Information in the aforementioned areas is useful for the system integrators, manufactures, utilities and end-users in order to improve the SPV system components, maintenance and the overall system design. Comparative performance of the SPV system based on mono-crystalline and poly-crystalline technology using performance indices-final yield, reference yield, system efficiency, performance ratio, and capacity factor presented in [Komoni *et al.*, 2014; Scolari *et al.*, 2017]. Tripathi et.al. in [Tripathi *et al.*, 2014], have presented performance comparison of the SPV plants based on Amorphous-silicon and Multicrystalline-silicon using performance indices of final yield and performance ratio. In [Decker and Jahn, 1997], performance of small grid-connected PV systems for residential uses have been studied using final yield and performance ratio. Performance analysis of 190kW solar PV plant installed at Khatkar-Kalan, India, is carried out using various metrics in [Sharma and Chandel, 2013]. The final yield, reference yield and performance ratio, annual average performance ratio, capacity factor and system efficiency, average annual measured energy yield of the plant is found to be 1.45 to 2.84 kWh/kWp-day, 2.29 to 3.53 kWh/kWp-day and 55-83 %, 74 %, 9.27 % and 8.3 % and 812.76 respectively. Performance analysis of a 3 MW grid-connected SPV plant located in Karnataka State, India is done and presented for the year 2011 [Padmavathi and Daniel, 2013]. The annual average reference yield, final yield are found to be 5.36[kWh/(kWp-day)] and 3.73 [kWh/(kWp-day)] respectively whereas performance ratio was found to be less than 0.6 corresponding to high inverter failure losses 818 MWh and 0.7 corresponding to inverter failure loss 409 MWh. Performance evaluation of a rooftop grid-connected photovoltaic (PV) system installed in Tangier, Morocco is presented in [Attari *et al.*, 2016]. The plant supplied the grid with 6411.3 kWh, final yield ranged from 1.96 to 6.42 kWh/kWp, the performance ratio ranged from 58 % to 98 % and the annual capacity factor was found to be 14.84 %.

In this chapter, we present performance analysis of a 43 *kW* amorphous-silicon thin-film and 58 *kW* multi-crystalline based grid-connected PV system installed at the roof-top of Indian Institute of Technology Jodhpur, India, academic campus. The monitoring data including climate data (solar irradiance, module temperature, and ambient temperature) and system electrical data recorded during three years July 2011-July 2014, have been used in the analysis. The chosen time scale is mainly monthly and in few cases yearly. The performance is evaluated based on net/total yield, final/specific yield, performance ratio, and modified PVUSA rating based performance ratio of ac power produced at PTC (PVUSA test conditions) to dc power at STC (standard test conditions). Lastly, issues encountered in the plant operation and components fault during three years are also reported.

The rest of the chapter is organized as follows. In Section 6.2 , brief system technical description of both the systems is given. Section 6.3, discusses indices used to analyze the system performance with respect to energy production, solar resource and different loses. Major operational issues encountered in previous years are also reported. Obtained results and discussion are presented in Section 6.4 and finally conclusions are drawn in Section 6.5.

6.2 SYSTEM DESCRIPTION

6.2.1 Technical description of 58 kW multicrystalline-silicon grid-connected roof-top system

The 58 *kW* grid-connected roof-top system under study was installed on the roof of the Block-II, Indian Institute of Technology Jodhpur transit campus, in March 2011. The representative schematic of the actual system is shown in Figure 6.1. The system technical specifications are given in Table 6.1. The PV array consists of MOSER BAER's multi-crystalline silicon module fixed to the roof using metal mounting structure at an optimum fixed tilt angle. The module technical specifications are given in Table 6.2. The grid-connected single phase SMA SUNNY BOY are used in plant. The output of six inverters are collected at an AC distribution box (ACDB) and is connected to form a three-phase system. The plant is connected to the public utility grid via three-phase energy meter at 415 V level. The system also uses SUNNY SENSOR BOX and SUNNY WEB BOX for the measurement and monitoring of the climate and electrical parameters of the system.

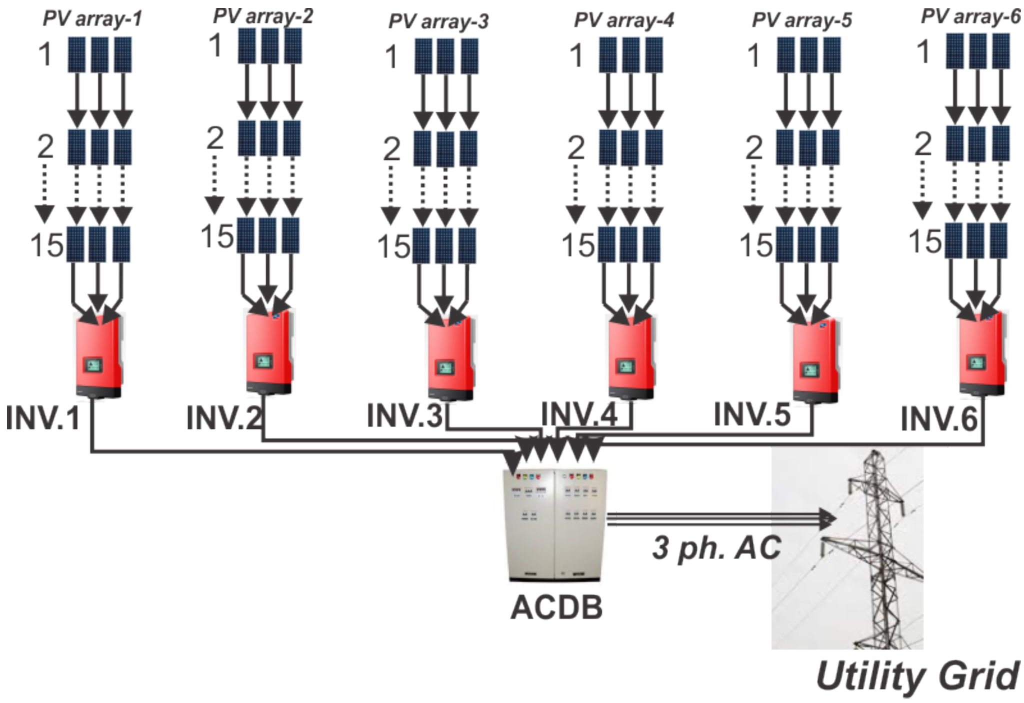

Figure 6.1 : 58 *kW grid-connected multicrystalline-silicon roof-top PV system*

Table 6.1 : Module Specifications of 58 kW PV system

Sr. No.	Parameter	Value
1	Model	Max series MBPV CAAP
2	Maximum Power P_{mpp}	215 W
3	Voltage at Maximum power V_m	29.23 V
4	Current at maximum power I_m	7.41 A
5	Open Circuit voltage V_{oc}	36.4 V
6	Short circuit current I_{sc}	8.17 A
7	NOCT	$47 \pm 2\ ^oC$
8	Operating Temp.	$-40\ to + 85\ ^oC$
9	Temp. coeff. of P_{mpp}	$-0.43\ \%/C$
10	Temp. coeff. of V_{oc}	$-0.344\ \%/C$
11	Temp. coeff. of I_{sc}	$0.11\ \%/C$

6.2.2 Technical description of 43 kW grid-connected amorphous PV system

The 43 kW grid-connected Amorphous PV system under study was installed on the roof of the Block-I, Indian Institute of Technology Jodhpur transit campus, in May 2011. The representative schematic of the system is shown in Figure 6.2. The PV array consist of MOSER BAER thin-film Amorphous-Silicon module fixed to the roof of the building using metal mounting structure at an optimum fixed tilt angle. The module technical specifications are given in Table 6.3. The overall system technical specifications are given in Table 6.4. The grid-connected single phase SMA SUNNY BOY inverters are used in plant. As shown in Figure 6.1, one strings contains three

Table 6.2 : Plant Specifications of 58 kW PV system

Sr. No.	Parameter	Value
1	Rated power at STC	58 *kW*
2	Number of modules	270
3	Number of inverters (SMA 10000 *TL*)	6
4	Number of modules/string	15
5	Number of strings	18
6	Number of strings/inverter	3
7	Plant output	3 ph.415*V AC*

modules and six or seven strings form an array. The first four arrays contains 6 strings each and last two arrays contains seven strings each. The output of six arrays is collected at array junction box (AJB) from where it is connected to the inverters. The output of the inverters are collected at an AC distribution box (ACDB) and connected to form a three-phase system. The plant is connected to the public utility grid via three-phase energy meter at 415 V level. The system also uses SUNNY SENSOR BOX and SUNNY WEB BOX for the measurement and monitoring of climate and electrical parameters of the systems.

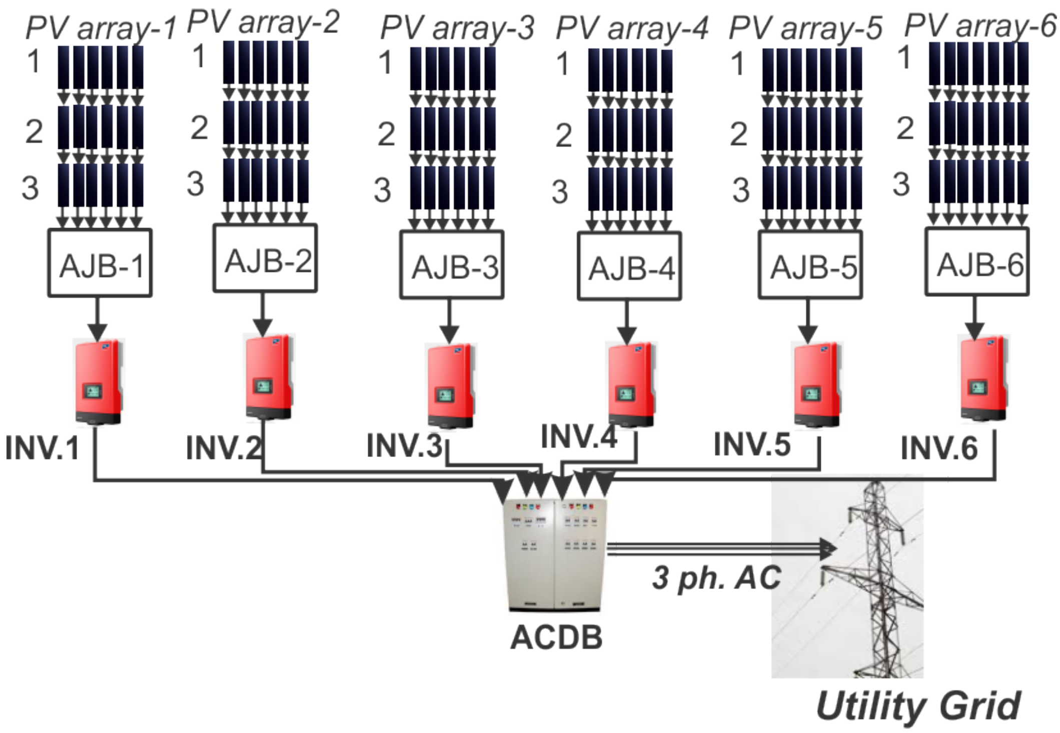

Figure 6.2 : 43 *kW grid-connected amorphous-silicon thin-film roof-top PV system*

6.3 PERFORMANCE CHARACTERIZATION

The performance of grid-connected SPV systems depends on many factor such as local climate, inverter efficiency, overall system loses, and PV technology used. The performance analysis is essential mainly to estimate energy produced by the PV generator, the output of the inverter and energy injected into the grid. The commonly used performance indices to determine the operational performance of the grid-connected SPV systems are plant capacity factor, yield factor/final yield/specific yield, reference yield, performance ratio, and PVUSA rating

Table 6.3 : Module Specifications of 43 kW PV system

Sr. No.	Parameter	Value
1	Model	Power Series FS $BIN380$
2	Maximum Power P_{mpp}	380 W
3	Voltage at Maximum power V_m	143.4 V
4	Current at maximum power I_m	2.65 A
5	Open Circuit voltage V_{oc}	187.8 V
6	Short circuit current I_{sc}	3.27 A
7	NOCT	$47 \pm 2\ ^oC$
8	Operating Temp.	$-40\ to + 85\ ^oC$
9	Temp. coeff. of P_{mpp}	$-0.2\ \%/\ ^oC$
10	Temp. coeff. of V_{oc}	$-0.34\ \%/\ ^oC$
11	Temp. coeff. of I_{sc}	$0.09\ \%/\ ^oC$

Table 6.4 : Plant Specifications of 43 kW PV system

Sr. No.	Parameter	Value
1	Rated power at STC	43.3 kW
2	Number of modules	114
3	Number of inverters (SMA 7000 HV)	6
4	Number of modules/string	3
5	Number of strings	38
6	Number of strings/inverter	6/7
7	Plant output	Three-phase 415V AC

& performance ratio based on PVUSA rating [Marion *et al.*, 2005; Pietruszko *et al.*, 2009; Jahn and Nasse, 2003, 2004]. These performance indices are used for analysis of these power plants because it is based on normalized analysis and offer a convenient way to compare performance of the plants of different sizes, technology, and locations [Komoni *et al.*, 2014; Tripathi *et al.*, 2014].

Normally, the starting point in the system performance analysis of the PV systems is its rated d.c power at standard test conditions (STC) i.e. irradiance of 1000 W/m^2, AMI=1.5 and cell temperature of 25 ^oC. Next step is to determine actual ac power produced once system is put into the field conditions which is given by

$$P_{ac} = P_{dc,STC} \times conversion\ efficiency \tag{6.1}$$

where, $P_{dc,STC}$ is the name plate power rating of the system at STC and conversion efficiency includes the effect of the inverter efficiency, dirt accumulation at the module surface, module mismatch and effect of variation in ambient conditions from STC.

In this chapter, we use frequently utilized indices to estimate the performance of the grid-connected PV systems which dictates overall system performance related to energy production, solar resource and different conversion loses. In what follows, the performance parameters-Total Yield, specific yield, performance ratio (PR), and PVUSA rating are briefly described. In the subsequent subsection, major operation and maintenance issues are also reported.

6.3.1 Total yield

The total yield of the system is defined as net or total energy produced by the plant in kWh in a given time e.g. a day, a month or a year. Total yield is defined as the amount of net or total energy output (kWh) from the plant in a given time. It is the energy that is injected into the grid [Sharma and Chandel, 2013].

6.3.2 Final yield/specific yield/yield factor

Final PV yield or specific yield or yield factor is the ratio of net energy output E of the system to nameplate dc power P_o of the installed PV array at STC (1000 w/m^2,25^0C). Y_f is the number of hours that the PV array would need to operate at its rated power to provide the same energy and its unit is hours. The Y_f is a normalized parameter which represents the energy produced with respect to the system size. Hence it is used to compare the energy produced by PV systems of different sizes [Marion *et al.*, 2005; Al-Otaibi *et al.*, 2015; Ayompe *et al.*, 2011].

$$FinalYield,\ Y_f = \frac{E}{P_o}\ \ (hours) \tag{6.2}$$

6.3.3 Performance ratio (PR)

Performance ratio is the ratio of actual energy fed to the grid and theoretical or nominal plant output [Kumar and Sudhakar, 2015; Attari *et al.*, 2016]. Nominal output is the energy that the system could have produced at DC rated power for the number of peak sun hours per day. PR is a dimensionless quantity and it indicates the overall effect of loses on the rated output that are caused by PV module temperature, inverter inefficiency, soiling or component failure. The Pr value of a SPV plant is more in winter than summer loses cause by PV module temperature. The plant PR is one of the frequently used indicator which can be used to compare plants installed at different locations. .

$$PR = \frac{Actual\ plat\ output\ (kWh)}{Calculated,\ nominal\ plant\ output(kWh)} \tag{6.3}$$

Where nominal plant output can be calculated using following relation

$$Nominalplantoutput = Incidentsolarirradiationatthemodulessurfaceoftheplant(kWh) \times EfficiencyofthePVmodules$$

PR can be determined on daily, monthly or yearly basis. It indicates the proportion of the energy available for export to the grid after deducting thermal loses and conduction loses. The performance ratio tells the plant owners that how energy efficient and reliable their plant is. The determination and monitoring of PR at regular intervals can lead towards the possible faults and other issues in case abnormal deviation is observed in the PR value. There are number of factors which influence the PR such as temperature, irradiance, soiling of module or sensors, module and inverter efficiency, solar technology, and recording period.

6.3.4 PVUSA rating

In order to account for the change in the power produced due to higher cell temperature, PVUSA rating system is used to calculate the ac power produced under PVUSA test conditions (PTC). The PTC test conditions are defined as irradiance of 1000 W/m^2, ambient temperature of 20 ^oC and wind speed of 1 m/sec. The power produced at PTC, $P_{ac,PTC}$ is good indicator of the actual power delivered at full sun ($1000\ W/m^2$) irradiance as compared to name plate rating $P_{dc,STC}$. The difference between $P_{dc,STC}$ and $P_{ac,PTC}$ is a good indication of the system loses associated with dc to ac conversion. The reduction in the PVUSA rating with time reflects permanent loss in the system performance [Marion *et al.*, 2005; Gilbert, 2004].

In order to determine $P_{ac,PTC}$, first step is to calculate cell temperature T_{cell} using following relation.

$$T_{cell} = T_a + (\frac{NOCT - T_a}{0.8})G \tag{6.4}$$

Where G is full sun solar irradiance. Now to obtain $P_{ac,PTC}$ following relations are used.

$$P_{dc,PTC} = P_{dc,STC}[1 + k_{mpp}(T_{cell} - 25)] \tag{6.5}$$

$$P_{ac,PTC} = P_{dc,PTC} \times \eta_d \times \eta_m \times \eta_i \quad (6.6)$$

Where, NOCT is the normal operating cell temperature, k_{mpp} is temperature coefficient of the maximum power, η_d is the efficiency factor due to dirt accumulation on the module surface, η_m is the efficiency factor due to module mismatch and η_i is the module efficiency.

In the presented work, authors use ratio of $P_{ac,PTC}$ to $P_{dc,STC}$ to estimate the the system loses associated with dc to ac conversion. Modified PTC conditions based on actual monthly mean module temperature rather than one obtained using fixed ambient temperature of 20 ^oC is considered in the study. Specified values of the k_{mpp} and η_i are used while the realistic values are assumed for η_d and η_m.

6.3.5 Operation and maintenance issues with 58 kW multicrystalline-silicon PV system

Despite the best efforts extended to maintain the system in efficient working conditions, following minor problems were encountered during last three years of plant service.

1. Burnt connection points at ACDB: This is the major event that occurred twice in the last three years and caused partial loss of production. The connection points of the three inverters burned at the MCB's in the ACDB because of loose connections.

2. Tripping of inverters: The issue of the tripping of the particular group (three) of inverters encountered trppings couple of times.

3. Communication faults: There were some occurrences when motoring system of the plant reported communication fault and for that duration of the fault, the monitoring data could not be transmitted to the data acquisition system. But as such there was no loss of data as data also gets stored in the memory card present in the SUNNY WEBOX.

4. Non-availability of the grid supply: Although such occurrences were very limited and of course unavoidable in nature, but system remained idle whenever there was no availability of the grid supply.

6.3.6 Operation and maintenance issues with 43kW amorphous PV system

Despite the best efforts extended to maintain the system in efficient working conditions, following minor problems were encountered during last three years of plant service.

1. Module crack: Full size amorphous-silicon modules which comes without any supporting frame were used in the plant. It was challenging task to install such a huge and heavy modules (100 kgs) at the roof-top of a building. It was observed that in few months 2-3 modules developed cracks which normally started from the edges and traveled through the entire module within a short time leading to the hot-spots. At present the number of such modules have reached 12. Although, the thorough study of these cracks is yet to be done but thermal and mechanical stresses may be possible reasons for it. Figure 6.3, shows images of the some cracks.

2. Communication faults: There were some occurrences when motoring system of the plant reported communication fault and for that duration of the fault, the monitoring data could not be transmitted to the data acquisition system. But as such there was no loss of data as data also gets stored in the memory card present in the SUNNY WEBOX.

3. Non-availability of the grid supply: Although such occurrences were very limited and of course unavoidable in nature, but system remained idle whenever there was no availability of the grid supply.

Figure 6.3 : *Cracks developed in the PV system modules*

4. Dust storm: Due to local climate conditions, dust storm frequency is quite high in Jodhpur as compared to other parts of the country. In such conditions regular cleaning of the modules becomes very much essential and failure in maintaining clean modules may result in partial loss of plant output.

5. Output loss due to higher cell temperature: Summers in Jodhpur are relative hotter, sometimes ambient temperature touches 48 ^{o}C and it remains in the range of $40 - 45$ ^{o}C for 2-3 months. In such condition cell temperature also gets high and even higher (sometimes reaches$>$ 65 ^{o}C) for mostly glass made amorphous-silicon made modules which increases temperature dependent loses in the system.

6.4 RESULTS AND DISCUSSIONS

6.4.1 58 kW multicrystalline-silicon PV System

This section describes the evaluated performance of the 58 kW roof-top PV system under study based on the performance indicator discussed in the previous Section. Figures. 6.4-6.9 show the evaluated plant performance using system monitoring data recorded during July 2011-July 2014. Plot shown in Figure 6.4 gives monthly total energy produced by the plant which indicates monthly change in the reading of the meter used to record the plant output. Monthly plant specific yield and performance ratios are shown in Figures 6.5 and 6.6. The specified module efficiency of 13.6 % mentioned in the product manual has been used in the calculation of nominal plant output to determine the performance ratio. The abnormal dips in the plots shown in the Figures. 6.4-6.6 during March to May in the year 2012-13 and 2013-14, is due to the reduced plant output attributed to fault and sustained tripping of a group of inverters.

The performance indicator based on PVUSA rating which accounts for the loses associated with higher cell temperature is shown in Figure 6.7. The values of η_d, η_m, and η_i considered in the calculation of $P_{ac,PTC}$ are 0.94, 0.97,0.95 respectively. The effect of dusty atmosphere particularly in summer due to dust storms, is accounted for by considering relatively lower value of η_d. The ratio plotted indicates that the effective plant capacity in terms of ac output is reduced by this factor due to higher cell temperature. The field value of the solar irradiance has to be further accounted for to get the actual ac power produced from the plant.

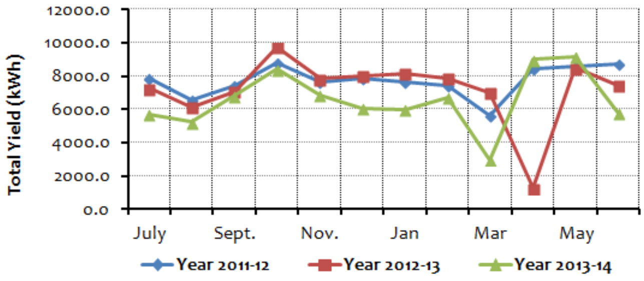

Figure 6.4 : *Monthly Total Yield*

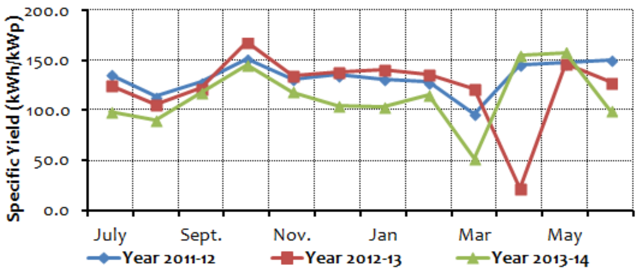

Figure 6.5 : *Monthly specific yield*

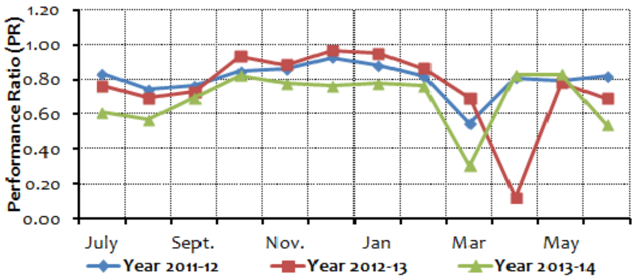

Figure 6.6 : *Monthly Performance ratios*

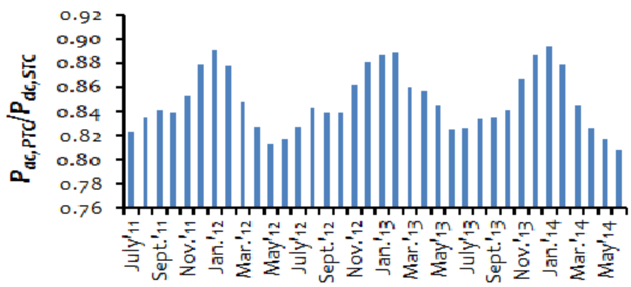

Figure 6.7 : *Performance indicator based on* $P_{ac,PTC}$

Figure 6.8, shows monthly variation of the mean values of solar irradiance, ambient temperature and module temperature. It can be seen that due to some error in the sensor associated with ambient temperature, it could not be recorded for initial few months.

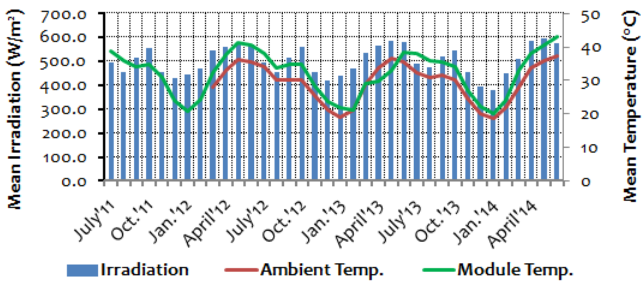

Figure 6.8 : *Monthly mean values of the solar irradiation, ambient temperature an module temperature*

Energy produced by the individual inverters over three years is plotted in Figure 6.9. From this plot we can easily identify the inverter which encountered faults (burnt terminals) and tripping. Finally, year-wise total yield by the plant is shown in Figure 6.10.

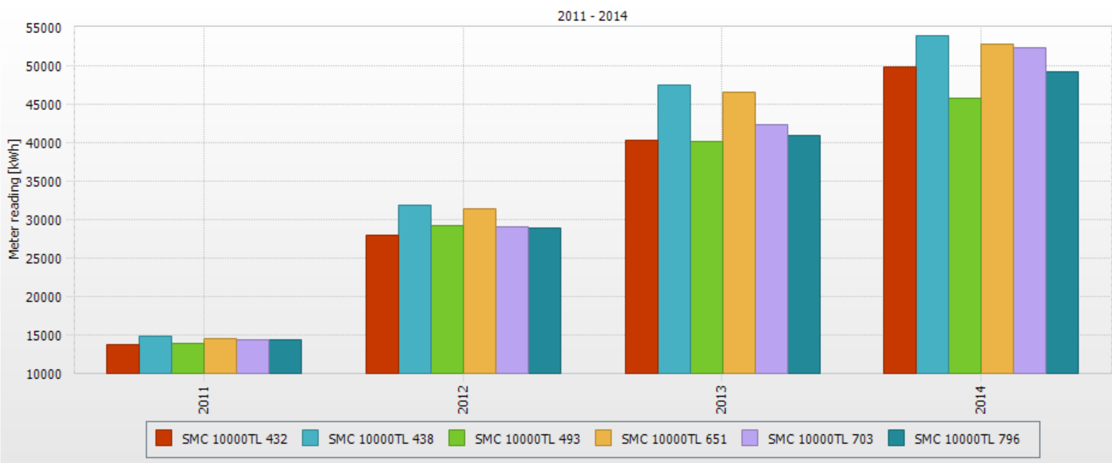

Figure 6.9 : *Year-wise energy produced by six inverters*

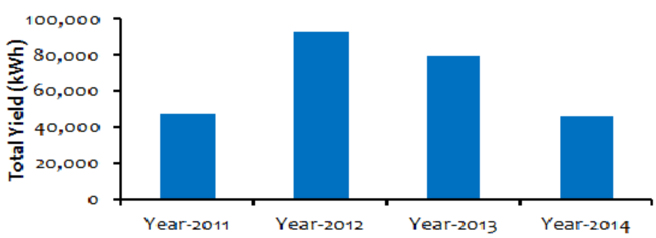

Figure 6.10 : *Year-wise total yield in kWh*

6.4.2 43 kW grid-connected amorphous-silicon PV system

The results of the performance analysis of the 43 kW roof-top PV system are presented in this Section. Initially the rated capacity of the plant was 43.3 kW but later on during in Jan. 2013, 12 modules were separated out from the plant for other research related activities, leaving system capacity of 38.76 kW. Wherever required the value of rated capacity is used accordingly. Figures 6.11-6.17 show the evaluated plant performance using system monitoring data recorded during July 2011-July 2014. Plot shown in Figures 6.11 gives monthly total energy produced by the plant which indicates monthly change in the reading of the meter used to record the plant output. Monthly plant specific yield and performance ratios are shown in Figures 6.12 and 6.13 respectively. The specified module efficiency of 6.6 % mentioned in the product manual has been used in the calculation of nominal plant output to determine the performance ratio. The performance ratio lies in the range of $0.52 - 0.81$.

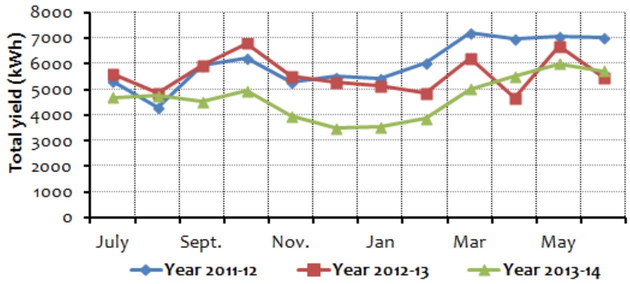

Figure 6.11 : *Monthly Total Yield*

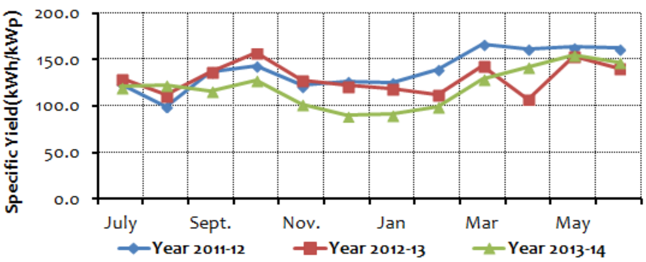

Figure 6.12 : *Monthly specific yield*

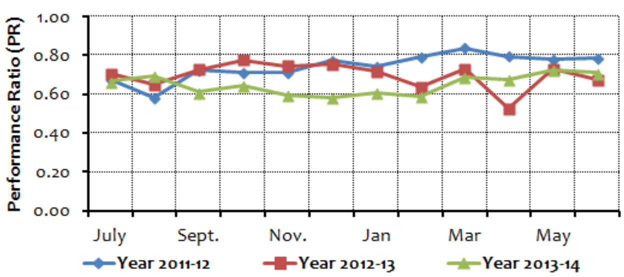

Figure 6.13 : *Monthly Performance ratio*

The performance indicator based on PVUSA rating which accounts for the loses associated with higher cell temperature is shown in Figure 6.14. The values of η_d, η_m, and η_i considered in the calculation of $P_{ac,PTC}$ are 0.94, 0.97,0.95 respectively. The effect of dusty atmosphere particularly in summer due to dust storms, is accounted for by considering relatively lower value of η_d. The ratio plotted indicates that the effective plant capacity in terms of ac output reduces by this factor due to higher cell temperature. The field value of the solar irradiance has to be further accounted for to get the actual ac power produced from the plant. It can be seen form the plot that this performance ratio lies in the range of $0.83 - 0.88$ indicating $12 - 17$ % loses in dc to ac conversion at $1000W/m^2$ solar irradiance, which include loses associated with soiling of module surface, module mismatch and inverter efficiency.

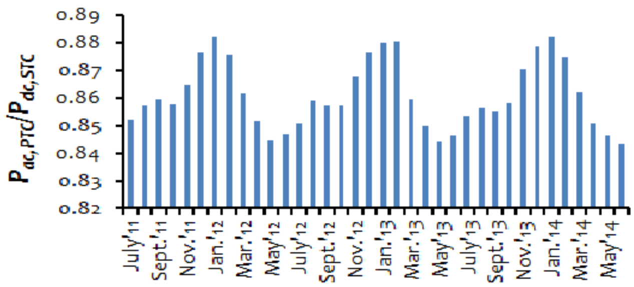

Figure 6.14 : *Performance indicator based on* $P_{ac,STC}$

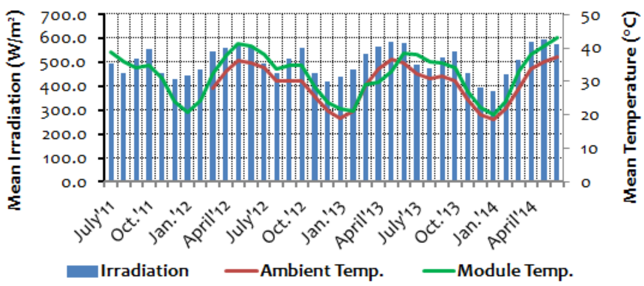

Figure 6.15 : *Monthly average values of the solar irradiation, ambient temperature and module temperature*

Figure 6.15, shows monthly variation of the mean values of solar irradiance, ambient temperature and module temperature. It can be seen that due to some error in the sensor associated with ambient temperature, it could not be recorded for initial few months.

Energy produced by the individual inverters over three years is plotted in Figure 6.16. It can be seen that there difference in individual inverter output energy that further increases during year 2013 and 2014. This is firstly due to the one string/inverter more in two of the inverters and secondly due to removed strings from two other inverters. Finally, year-wise total yield by the plant is shown in Figure 6.17.

6.5 CONCLUSIONS

The chapter presents operating performance analysis of the 58 kW multicrystalline-silicon and 43 kW amorphous-silicon grid-connected roof-top PV system using widely used performance indices such as total yield, specific yield and performance ratio. Evaluated normalized performance indicators e.g. specific yield and performance ratio can conveniently be used to

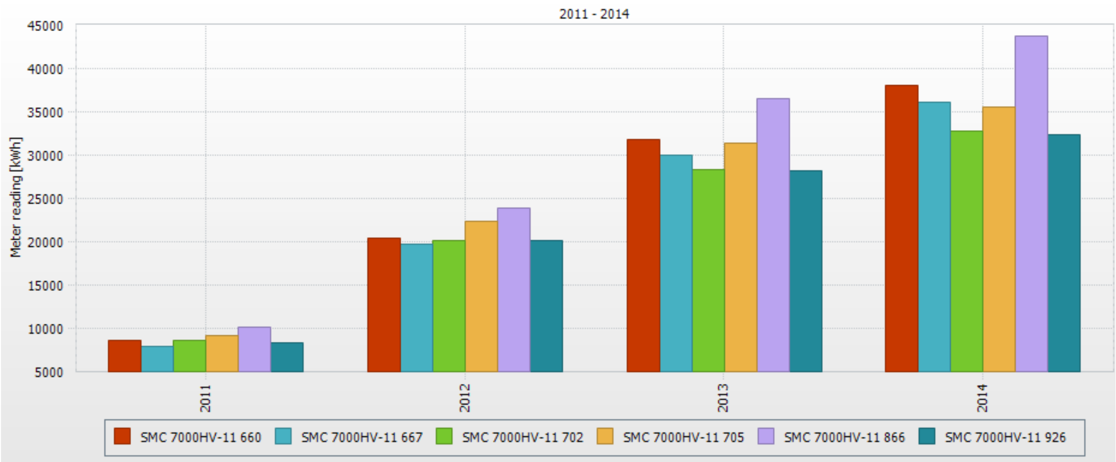

Figure 6.16 : *Year-wise energy produced by six inverters*

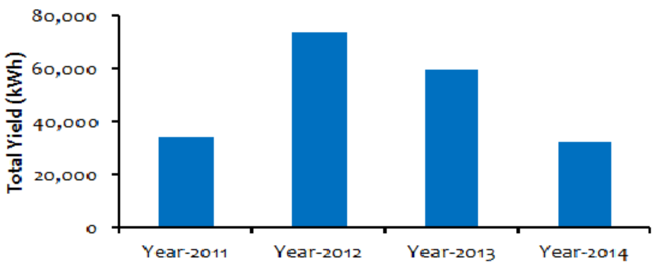

Figure 6.17 : *Year-wise total yield in kWh*

compare the plant performance with the plants of different size and locations. Modified PVUSA based performance indicator is proposed which takes into account actual measured module temperature for calculating $P_{ac,PTC}$ from $P_{dc,STC}$. The plant performance ratio was found in the range of $0.16 - 0.98$ and $0.52 - 0.81$ for 58 kW and 43 kW plant respectively. The extremely low values of PR are attributed to the system faults in the form of burnt connections and tripping of a group of inverters. The amorphous-silicon thin-film modules are very delicate and require careful handling during installation and cleaning etc. Cracks in some of the modules have been observed leading to partial to full loss of module generation capacity. Other operation and maintenance issues of importance have also been discussed.

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