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One-year 60 kWp photovoltaic system energy performance at CINVESTAV, Mexico City

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Abstract

Since June 2012, the Research Center of the National Polytechnic Institute (CINVESTAV), located at Mexico City has installed 60 kilowatt-peak (kWp) photovoltaic (PV) system. PV system energy performances are reported together with the measured solar irradiation, PV module temperature and wind velocity. The grid-connected PV system consists of 240 PV modules of 250 Wp each, which are connected to 5 inverters to convert three phase 240 VAC. The injected energy to the grid, is used mainly for the building illuminations. We report the general PV system electric performances as a function of the seasonal solar irradiation and whether variations. The produced average energy during June 2012, was about 250 kWh/day, with a minimum and maximum of 100 and 350 kWh/day, respectively. In the same month, the PV module average operating temperature was between 55 to 62°C. The best energy produced month was February 2013 with 310 kWh as daily-based average.

Keywords: PV System; Grid-connected; Solar Radiation; PV module; Temperature dependences.

1. Introduction

Photovoltaic (PV) systems are used to convert sunlight directly into electricity. They are safe, reliable and low-maintenance source of solar-electricity without on-site pollution or emissions. PV systems are easy to install on most of the sites. Internationally, utility grid-connected PV systems represent the majority of the present installations, growing annually at a rate of over 30% in the last 10 years. Now, although in 2010 the 85% of the new installed capacities were in off-grid applications in Mexico, the number of grid-connected system started to grow after 2007, with the Nation-wide PV grid connection permission and also due to the recent PV module cost reductions. Furthermore, the increased environmental awareness of some homeowners and corporations, the demand of PV systems has substantially increased without governmental financial or tax incentive supports.

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The installed 60kw PV system is grid-connected, however, we consider that the total generated electricity is internally consumed in our building needs, and won´t be "injected" to the electric utility to supply energy.

The present job, monitor and evaluates the generated electricity from the PV system taking in consideration the local weather conditions. The module temperature, wind velocity and the solar irradiations are the main parameters for PV system performances. We are confident that our system generates the proper amount of energy. Even though, if the output energy from the system, for example, is not at least 80% of the theoretically predicted, we have to analyze, detect and repair the system malfunctioning components or connections. No one can totally guarantee how much electricity will generate the solar PV system, because it depends mostly on the local weather conditions. However, it should be possible to predict and to guarantee the minimum amount of energy to be generated based on a reliable solar irradiation data.

2. System description

One of the main photovoltaic (PV) system components is the PV module, which is composed of a number of interconnected solar cells. PV modules are connected together into panels and arrays to meet higher energy needs. The PV array is connected to an inverter that converts the Direct Current (DC) generated by the PV array into Alternating Current (AC) compatible with the electricity supplied from the grid. AC output from the inverter is connected to the electric grid.

The 60 kWp PV system (see Fig. 1), consists of 240 single-crystalline silicon-based PV modules with 250 Watt-peak (Wp) each.

Fig. 1. Part of 60 kWp system PV module array. Each PV module consists of 250 Wp power unit, and total of 240 modules connected to 5 inverters. (Chiquihuite´s mountain can be seen at the North direction at the back; 2730 meters high over sea-level)

The PV module S60MC-250 has the dimension of 1640mm × 991mm × 40mm, weight of 20.5 Kg are assembled by Solartec, a Mexican Company. PV module specifications are described in Appendix 1.
The PV arrays were installed on the roof of the Institution´s main building and fixed on an aluminum framed structures oriented 30° East-faced from the geographical South (see Fig.1). The system is located at 19° 30' 38'' North-latitude, 99° 07' 50'' West-longitude, and the modules were installed at the latitude´s inclination of 20°. The total PV module arrays are subdivided in 5 sectors. Each array is composed by a string of 48 PV modules which are connected 12 in series and 4 of this in parallel. Each of the five arrays is connected to the inverter Fronius model IG Plus V11-4-3 DELTA with the capacity of 11.4 kW. The inverter converts from DC to three-phase 240 VAC. The injected energy is consumed mainly by building internal office needs as illuminations. The inverter´s complete specifications are given in Appendix 2.

2.1 System monitoring

Without accurate and reliable data monitoring, evaluating and maintaining optimal system performance, is just a guessing game. Data monitoring is one of the requirements for utility scale PV systems, where it is used to track performance and comply with regulatory reporting status, and increasingly used in commercial applications. Without accurate data monitoring, the actual system performances cannot reliably be compared to the calculated power generation. Effective data monitoring not only helps to identify system performance troubles, but it also helps to resolve them [1].

There are two main pieces to solar performance monitoring; accurate data collection and consistent data upload. A data logger, also called a data acquisition unit, is an electronic analog-to-digital processing device that resides in the physical layer. This device records data over time and has internal memory for data storage. Some data loggers can also function as signal converters to internet gateways. Web-based interface to display, analyze and report data collected at the project site. The Fronius inverter integrates all of the logged data and processes it automatically.

In the other hand, a weather sensors measure the environmental conditions in which the PV system operates. Examples of weather sensors include pyranometers to measure global horizontal sunlight irradiance in a precise way. A reference solar cell mounted in the same plane as the PV array, also provides irradiance data. Thermocouples fixed on the back of one of the PV modules, provides cell temperature data and anemometer measures wind speed. In certain PV systems a stepwise or gradually progressing decline in performance ratio can indicate other issues, such as blown string or sub-array combiner box fuses, broken modules or inverter failures. Recently, the power induced degradations (PID) has intensely been studied by the PV community mostly for mega-sized PV systems. It seems these troubles are provoked by a given natural reverse potential induction in a series connected PV modules [2].

3. PV system performance and discussion

3.1 General performance

The PV system has been monitored from June 1, 2012 to May 31, 2013, and the measured data were logged and recorded every 5 minutes. Fig.2. shows the generated PV power in a daily basis data during 365 days. In the figure shows numerical average daily generated power for the corresponding month in kWh. The daily generated average energy during the complete year was 266.71 kWh, with the total generated energy of 97,244.2 kWh. As can see, February 2013 was the highest energy generated month with 310.09 kWh as a daily average. June 2012 was the minimum energy generated month with 243.38 kWh, which is similar value to July 2012.

Now, as for the evaluated local solar irradiation by mean of pyranometer (global horizontal), the yearly average peak-hour and its standard deviation are 1825 +/- 219 peak-hours, based on fourteen consecutive years [3].

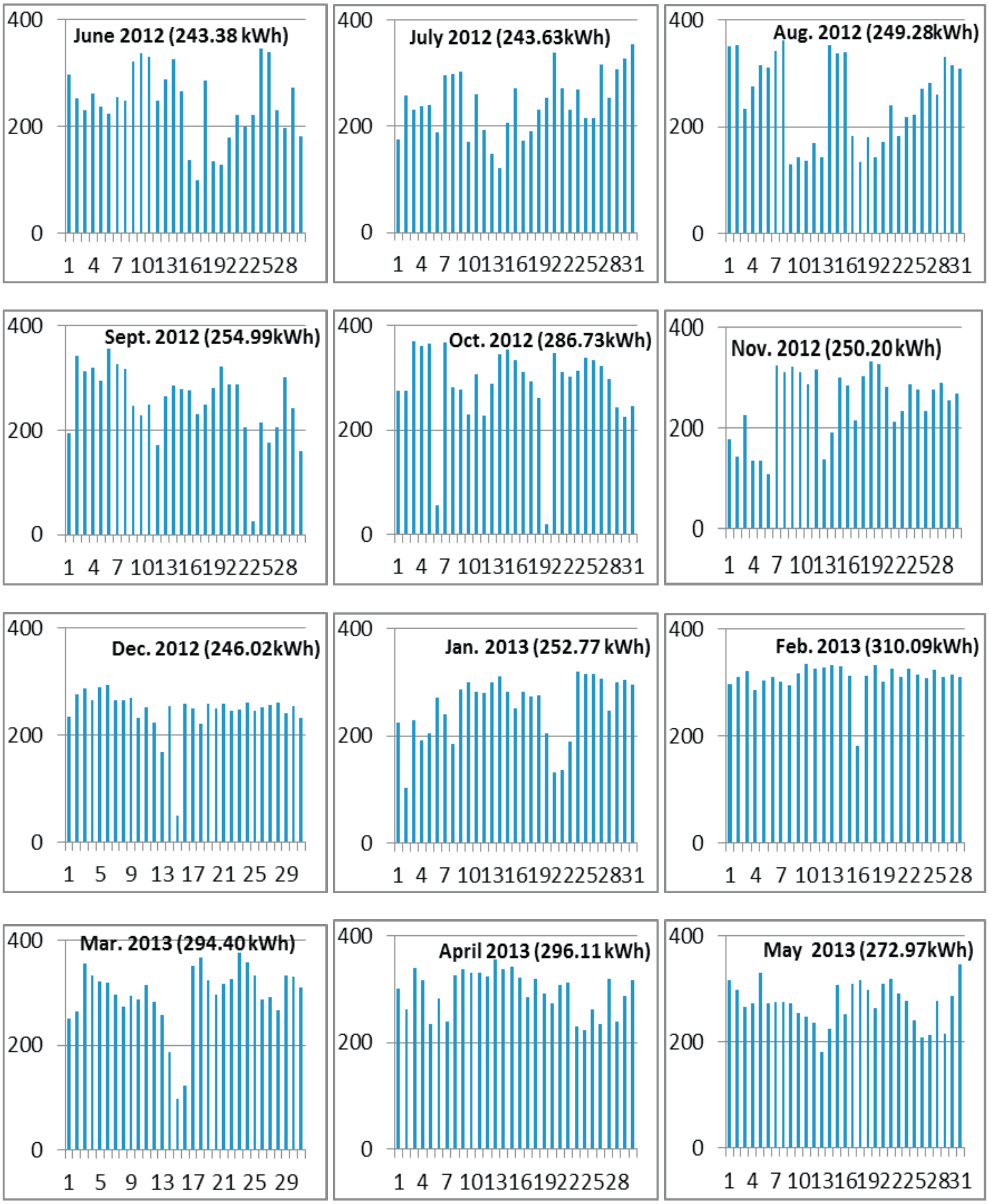

Fig.2. Generated electric energy by 60 kWp PV System. The vertical scale indicates energy in kWh and the horizontal are days of the month. The daily average was 266.71 kWh for the one-year period, and the annual generated total energy was 97,244.2kWh.

If we consider this solar irradiation data, the total solar irradiation may have varied from 1606 to 2044 peak-hour depending of the year, which corresponds to power production of 60.55 kW(or 100.9 % of 60 kW) to 47.55 kW (or 79.3 % of 60 kW) as PV system array efficiency. Let consider 1825 peak-hour as the average solar irradiance for the present. And using the system generated energy of 97,244 kWh, results PV system efficiency of 88.8 % or about 53.3 kWp real average capacity. Because this solar irradiation data has been taken from a global horizontal, it is not representative for our system which was installed at the latitude inclination. However, we may realize an idea to know probable or closer system efficiency. Now, the PV module conversion efficiency is 15.37 % at standard test conditions as Appendix 1, but in a reality, the array efficiency under operating conditions is typically in the order of 13.0 % to 14.4 %. This is mostly due to the effects of temperature coefficient on PV modules (see Fig. 6, PV module operating temperatures). Supposing an inverter average efficiencies of 90% (it can attain 96% under optimal conditions as Appendix 2), this leads to a yearly average system total efficiency of at least 11.7%, and translates into an average yearly output of 1620 kWh per installed kWp of PV module.

3.2 Specific day performances

Fig. 3, 4, 5 and 6, shows the measured average generated energy; the average solar irradiation; monthly based average generated energy and registered maximum and minimum PV module temperatures in the month, respectively. Comparisons from Fig. 3 and Fig. 4, the generated power fits well as solar irradiance. However some months as June may not fix the similar profile as irradiation. In Fig. 4 the irradiation of June (19.09 MJ/m^2) is greater than that of July (17.37 MJ/m^2), even though, the corresponding generated energy has resulted as same for the mentioned months at the Fig. 3. This

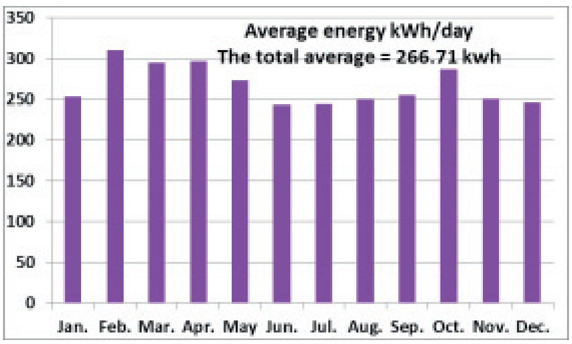

Fig. 3 Average daily produced energy in the month.

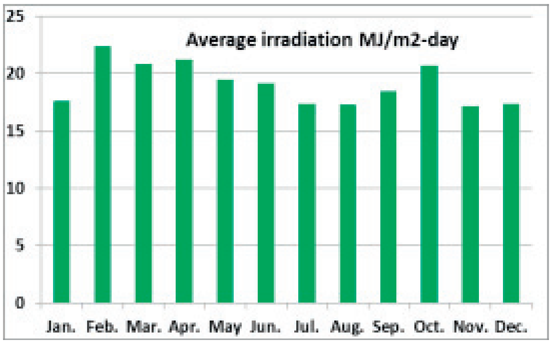

Fig.4 Average solar irradiation for each month

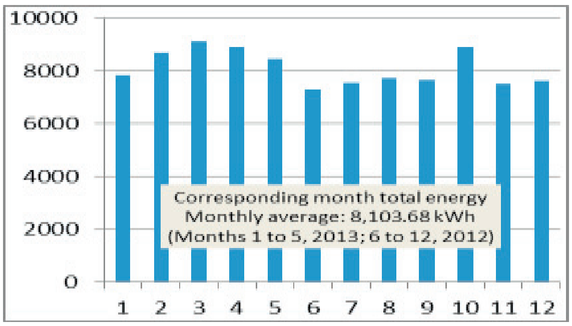

Fig.5 Total generated energy in monthly basis.

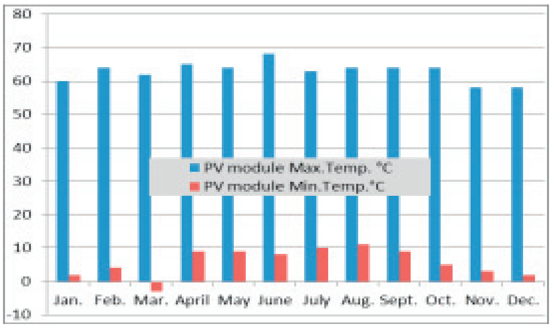

Fig. 6. Maximum and minimum PV module temperatures.

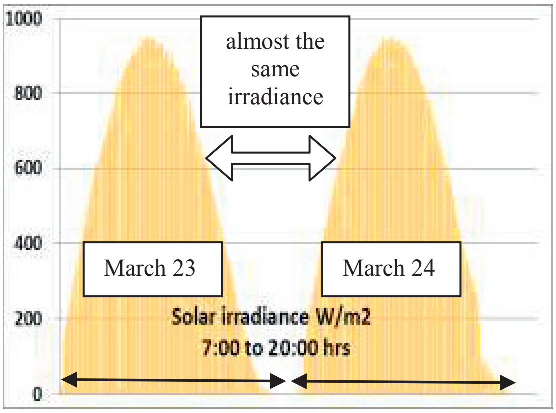

Fig. 7. Solar irradiance during March 23 and 24, 2013.

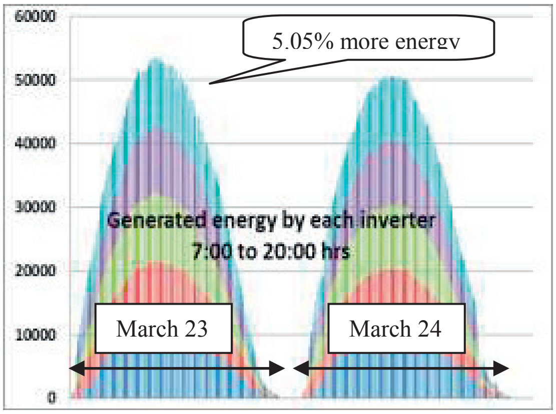

Fig. 8. Generated energy for the same March 23 and 24, 2013.

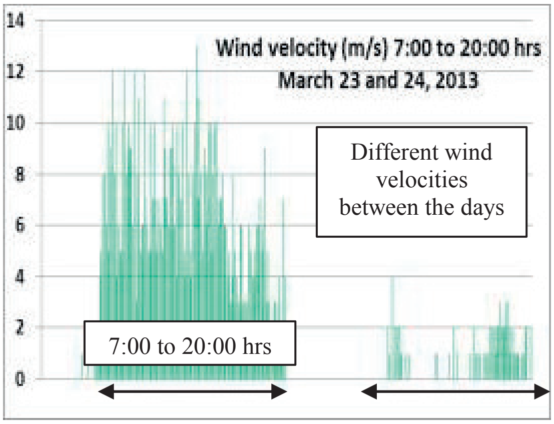

Fig. 9. Detected wind velocity during March 23 and 24, 2013.

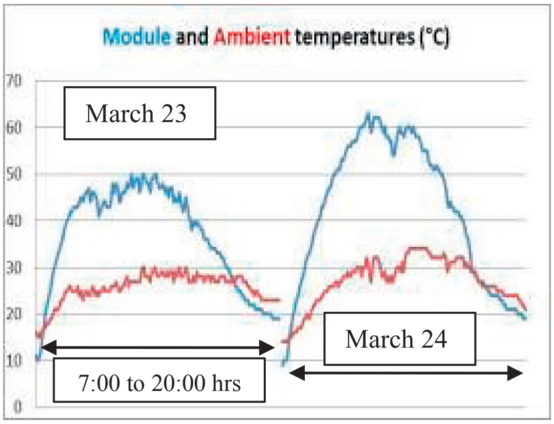

Fig. 10. Measured PV module temperature for March 23 and 24.

difference may have caused by one of the PV array string connector interruption during some days in the month, which has reduced the generated energy in one of the inverter, but we are now analyzing this situation. Fig. 5 refers to the total produced energy during the month. March due to its 31 days, the accumulated energy was 9,126.47 kWh, while February only with 28 days, was 8,682.75 kWh. Fig. 6 shows the detected maximum and minimum PV module temperatures during the month. It has detected a minimum temperature of minus 3 degrees in March. The maximum temperatures are in the range of 58 to 68 °C, while the minimum´s are between -3 to 11°C. (see Appendix 3, Mexico City´s North weather)

Fig.7. shows the measured irradiance during March 23 and 24, 2013. The corresponding solar irradiance was measured by using a reference crystalline solar cell which was installed as sensor in the same PV array. This sensor has installed at the same angle inclination as the PV modules at 20°. The detected solar irradiance differences between these days are 1.86%. March 23th had a bit more irradiance than a day 24th. This difference may come due to the quicker solar irradiation loss at the sunset time. (see Fig. 7 right-side irradiance) However, as can see in Fig. 8, the total generated energy in March 23th is 5.05 % higher than that of day 24th. In the same Fig. 8, it is possible to identify the energy gains for each of the inverters along a day. In order to explain these differences, it has made some more analysis. Fig. 9 shows wind velocity data during these days from 7:00 am to 8:00 pm. While March 23th, has had wind during

almost all the day with an average of 6.11 m/s, the day 24th, had only 0.48 m/s. As can see in the Fig. 9, sometimes the detected wind velocity achieved 12 m/s during the day 23th, but almost no wind in the day 24th. Comparing PV module temperatures as is shown in Fig. 10, it differs in almost 10 °C between the compared days. Also ambient temperature of both days is shown in the same Fig. 10. We conclude that, this PV module temperature differences provoked in the amount of the generated energy, in spite of almost the same solar irradiations.

3.3 An electric energy feeding troubles

The PV array electric circuit has not been stable as was determined in the electric cable sector for the inverter connection. As has been mentioned previously and mentioned during the explanation of the Fig. 4, solar irradiance versus produced energy at fig. 3, we have detected failures as part of PV array DC feeding interruption. The cause of this incidence was probably due to the static induced electricity, which makes burn out the circuit protective fuse interrupting the electricity to the inverter. When this trouble happens, we lose part of the generated energy. Sometimes only 75% of the PV array´s string energy achieves to one of the inverter. It means only three-quarter of the array string feeds the inverter. It is necessary to calculate proper fuse capacity to reduce this interruption risk. Fortunately in the case of some module or string failure can effectively detect malfunction of power performance for the given string site.

Another clear PV system operation loss or interruption has been provoked by electric utility when they interrupt the grid energy for its maintenances. The AC power interruption and due to anti island configuration, it was interrupted for several times in some of the weekends. The low energy or interrupted days were in September 24th, October 6th and 20th, as well as December 15th which can see in Fig.2. We will have to review PV system anti islanding actuator in order to reestablish as soon as possible after the grid energy establishment.

3.4 PV module array shadowing

In the other hand, PV modules are extremely sensitive to shadowing. Solar cells within a PV module and PV module itself within the array are often connected in series. When the cells or/and modules are forming a long chain and the amount of current flowing through the chain is limited by the weakest link, i.e. the shaded cell or module. The shaded cell or module will act as a electric resistor. For example, if one of the PV modules in an array of 12 series connected modules is completely shaded, it can reduce the output power of the entire array-series. In addition, given that the module will be acting as a resistor stopping the current flow, it will heat up to the point where it can become damaged. Fortunately, we have diode pass to avoid greater damages.

Therefore, when evaluating different geographical locations to install PV array, a closer shading analysis needs to be considered that identify when and where shading will occur. In our case, the two installed PV arrays are relatively near each other, and in a winter period, when the sun is with a lower altitude in the sky, one of the array modules provoke shadows to the next during a couple of hours in the morning. This happened due to our limited roof area. It means, one of string is completely shadowed which is connected to inverter number one, and the connected inverter does not produce energy during early morning. However, fortunately the calculated energy loose during the affected season of October to March, is less than 1.67 % of the total. This shadowing loss comparison has been made based using inverter number five as reference.

4. Conclusion

We have measured during one-year the 60 kWp grid-connected photovoltaic system at north of Mexico City. PV system was monitored and analyzed through the year and was determined its performance. The PV systems works properly at more than an 88 % of efficiency and PV modules at more than a 84.5 %. The system absolute efficiency is about 11.7 %. The generated energy's seasonal variations were analyzed and interpreted. One of the major parameter influencing system electric performance is the PV module operating temperature. Some of the system troubles and shadowing effects were briefly reviewed.

Acknowledgements

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Appendix 1. PV Module specification [4]

250 W +/- 3%, N° of Cells (60), Operating Temperature: -40 to + 90°C
Maximum System Voltage: 600 VDC
Fuse rating: 15A, Fire Rating: Class C
Dimension: 1640mm × 991mm × 40mm.
Weight: 20.5 Kg
Efficiency=15.38%

PV Module Model S60MC-250	STC	NOCT
Open Circuit Voltage (V)	37.92	35.10
Optimum Operating Voltage (V)	30.96	28.50
Short Circuit Current (Amp)	8.62	6.95
Optimum Operating Current (Amp)	8.07	6.36
Maximum Power (W)	250	181.6
Module Efficiency (%)		15.37
Voltage: Temperature Coefficient (%/°C)		-0.346
Power: Temperature Coefficient (%/°C)		-0.47

Appendix 2. Inverter specification [5]

Fronius model IG Plus V 11.4-3 DELTA
The Fronius IG Plus inverter line from 3.0 to 11.4 kW is field programmable to 208, 240 or 277 volts
Recommended PV-Power (kWp) 9.70 - 13.10 kW
Nominal input current: 31.4 A
Max. usable input current: 53.3 A
Nominal output power (PAC nom) 11,400 W
Nominal AC output voltage 208 V / 240 V, our case: 211 - 264 V (-12 / +10 %)
Number of phases: 3
Admissible conductor size (AC) No. 14-4 AWG
Max. continuous utility back feed current 0 A
Nominal output frequency 60 Hz, Operating range 59.3 - 60.5 Hz
Total harmonic distortion < 3 %
Maximum CEC Efficiency 96.0 %
Power factor 1 (at nominal output power)
Consumption during operation 20 W
Consumption in standby (night) < 1.5 W
Power stack weight 84 Ibs. (38 kg)

Appendix 3. Temperature in north Mexico City [6]

Although we have measured this time (2013) a lowest photovoltaic module temperature of minus 3 degrees C, as below, the recorded low temperature was minus one degree C in the past. In this sense, we will have to analyce if PV module may affect provoking lower temperature. (from Fig.3)

Climate data for Gustavo A. Madero (1951-2010)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C	37.0	31.0	38.5	35.0	36.5	35.0	30.0	29.5	30.0	30.5	31.0	29.0	38.5
Average high °C	22.7	24.4	27.0	27.9	27.7	25.9	24.4	24.5	23.9	23.8	23.3	22.2	24.8
Daily mean °C	13.4	14.8	17.2	18.8	19.4	19.1	18.1	18.1	17.8	16.6	15.0	13.5	16.8
Average low °C	4.1	5.3	7.5	9.6	11.1	12.2	11.7	11.7	11.6	9.5	6.8	4.9	8.8
Record low °C	−7.5	−5.0	−1.0	−1.0	0.9	5.5	6.0	7.0	0.0	−5.0	−6.5	−6.0	−7.5
Precipitation mm	8.9	6.8	10.2	23.6	48.6	104.9	121.2	118.5	98.0	48.8	13.4	5.3	608.2
Avg. precipitation days (≥ 0.1 mm)	1.8	1.8	2.6	6.1	10.0	14.9	18.0	17.5	14.0	7.6	2.9	1.6	98.8

Source: Servicio Meteorológico National. Retrieved October 29, 2012.