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# Performance Analysis and Comparison of Different Photovoltaic Modules Technologies under Different Climatic Conditions in Casablanca

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## Abstract

The main goal of this work is to study the performance of silicon-based photovoltaic modules of different technologies (Monocrystalline (c-si), Polycrystalline (p-si) and Amorphous (a-si)) installed on rooftop of the Ben m'sik faculty at Hassan II university, Casablanca, Morocco (Latitude 33°36"N, Longitude 7°36"W). This study is based on daily measurements under various climatic conditions (clear, cloudy and rainy). In order to improve the performance evaluation, the real-time measurements were taken for every five minutes of different climatic parameters (solar irradiation, ambient temperature, module temperature, wind speed and direction) and electrical parameters (power, current and voltage). In fact, we studied the PV array efficiency, the inverter efficiency and the system efficiency. In addition, we performed an evaluation to the PV array, reference and final yields and the performance ratio (PR). The results show maximum values for module efficiency, final efficiency and system efficiency on a clear day for all three technologies due to high irradiation. The maximum values of PR are 72.10%, 91.53% and 86.20%, are obtained on a cloudy day, this is due to the low temperature and the high wind speed. Minimum values of PR, module efficiency, reference efficiency and final efficiency on a rainy day are due to the low sun exposure and the rain which affect the generated energy and stability of PV systems.

**Keywords:** PV performance; PV array efficiency; PR inverter efficiency

## Introduction

The cost increase of conventional energy, the limitation of its resources, the uncertainty on energy supply and global warming have caused renewed interest in installations using solar energy, especially in areas with favourable climatic conditions. Currently, photovoltaic systems are becoming among the most popular renewable energy resources and have numerous applications in various fields. Indeed, the photovoltaic industry has achieved durative development at an annual average rate of 42% since 2009 [1]. In 2015 the total cumulative installations amounted to 242 GWp [2]. Morocco adopts an energy policy to use solar energy, the aim is to reach 6 GW of installed capacity from renewable energy resources by 2020 [3].

The performance of photovoltaic systems is affected by climatic conditions. It is directly affected by solar irradiation and indirectly by operating temperature, which depends on many factors such as ambient temperature, wind speed and direction. The prediction of the performance of these systems is therefore important in several related aspects such as system sizing and control. In addition, this performance data is important for system planning and financing, as well as energy market analysis, especially when these systems are injected into the grid.

Several research projects have been carried out in different parts of the world on the performance and characteristics of the grid connected photovoltaic systems, for example Elkholy, found that low solar irradiation has a significant impact on the energy quality of the Photovoltaic system output [4]. Dabou, presented a study on the effects of climatic conditions on the performance of the grid connected photovoltaic system. The results show that these performances are affected on a cloudy and sandy day due to successive and rapid change of clouds and exposure to sand which affect the generated energy and stability of the photovoltaic system [5], while there are no studies that include experimental results on PV performance in the Casablanca region and the interaction of these PV with the environment in this region, this paper presents an experimental study with a critical analysis of different PV modules based on silicon for 3 days under variable climatic conditions (clear, cloudy and rainy), the experimental analysis was carried out in order to evaluate the real performance of the selected technologies under real conditions in Casablanca.

In fact, the performance of photovoltaic systems depends on the continuous and unpredictable change of several variables, such as solar irradiation, ambient temperature and wind speed. Therefore, the presence of a meteorological station is essential.

## Materials

### PV array

Our 6 kWp photovoltaic installation (Figure 1) is facing equator, tiletd by 30° and devised into 3 mini-installations using three silicon technologies, of nearly 2 kWp for each one. Each mini-installation is connected to a Sunny Boy inverter. Both polycrystalline and monocrystalline contain 8 "Solar World" modules of 255 watts each, while the amorphous contains 12 "Next Power" modules of 155 watts each. The details PV modules specifications are presented in Table 1.

### Inverters

In our installation, we used string inverter architecture (Figure

**Figure 1:** View of 6 kWp PV installed in Casablanca.

| Performance under STC condition | SW 255 MONO | SW 255 POLY | NT-155 Amorphous |
|---|---|---|---|
| Maximum power (Pmax) | 255 Wp | 255 Wp | 155 Wp |
| Open circuit voltage (Voc) | 37.8 V | 38 V | 85.5 V |
| Maximum power point voltage (Vmpp) | 31.4 V | 30.9 V | 65.2 V |
| Short circuit current (Isc) | 8.66 A | 8.88 A | 2.56 A |
| Maximum power point current (Impp) | 8.15 A | 8.32 A | 2.38 A |

**Table 1:** PV modules electrical characteristics.

2), in this architecture an inverter is placed at the end of each chain which aims to increase the number of DC/DC converter which leads to the possibility of extracting the maximum power [6]. The main specifications of the inverter are showing in Table 2.

## Weather station

In order to collect the meteorological data, we installed one of the 20 stations developed in the PROPRE.MA project [7], funded by Research Institute in Solar Energy and New Energies (IRESEN). This station measures the horizontal and 30° tilted solar irradiations, ambient temperature, PV modules temperature and the wind speed and its direction (Figure 3).

The solar sensor used in our metrology system is a polycrystalline silicon module, this solar "Sun Plus 20" is suitable for industrial and professional uses. An anemometer was used to measure the running speed and wind direction. For the measurement of ambient and module temperatures we used four temperature sensors PT100 module, for room temperature the sensor is in direct contact with air, but protected from sun and rain. Its shelter is well ventilated but provides enough against rain. For module temperature, sensors are equipped with a specially insulated attachment system of a better contact with the back of the modules.

The monitoring of the different measurements assured by four PC DUINO (is a mini PC or single board computer platform that runs PC like OS such as Ubuntu and Android ICS). The recorded parameters provide information about the power levels, DC/AC currents and voltages as well as the metrological parameters. The data is recorded with five minutes time step and saved on daily files.
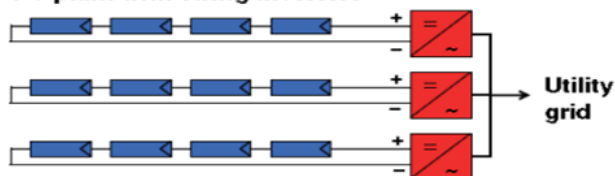


**Figure 2:** Inverter architecture.

| Inverter | Specification |
|---|---|
| Maximum DC power | 2600 W |
| Maximum DC voltage | 700 V |
| PV - voltage range at MPPT | 175 V-560 V |
| Maximum DC current | 15 A |
| Maximum AC power | 2500 VA |
| Nominal AC power | 2500 W |
| Nominal AC voltage | 230 V/60 Hz |
| Nominal AC current | 14.2 A |
| Maximum efficiency - Euro efficiency | 96.3%-95.3% |

**Table 2:** Sunny Boy 2500 HF inverter specifications.



**Figure 3:** View of weather station.

## Methodology

The conversion efficiency value of PV modules is very low. Since their available power depends on environmental conditions such as solar irradiance, temperature and other weather conditions. Performance assessment of PV modules becomes important. In order to investigate the energy performance of the PV modules, some indicators proposed by IEC 61724, NREL and SMA etc., can be used [8]. In this context, AC power, DC power, solar irradiance and surface area are used to calculate the performance of modules.

The instantaneous PV array efficiency ($\eta_{PV}$) is important parameter. The power conversion efficiency for one square meter surface area depends on size of PV modules, DC power ($P_{DC}$) and solar irradiance as given in equation 1 [9].

$$\eta_{PV} = \left(\frac{P_{DC}}{G * A}\right) * 100\% \qquad (1)$$

Where;

G is instantaneous solar irradiance (W/m²) and A the area of PV array (m²).

The efficiency of the solar inverters can be calculated based on the value of electrical DC power delivered to the inverters from PV generator ($P_{DC}$) and the AC power obtained from inverters ($P_{AC}$). The instantaneous inverters efficiency ($\eta_{inv}$) is defined as the ratio of output to input power as given in equation (2) [10]:

$$\eta_{inv} = \left( \frac{P_{AC}}{P_{DC}} \right) * 100\% \tag{2}$$

The instantaneous system efficiency:

$$\eta_{syst} = \left( \frac{P_{AC}}{G * A} \right) * 100\% \tag{3}$$

The reference yield ($Y_R$) is the reference time in hour and it is calculated as given in equation 4 [11]:

$$Y_R = \left( \frac{G_t}{G_{STC}} \right) \tag{4}$$

Where;

$G_T$ is the total solar irradiance (kWh/m²) and $G_{STC}$ is the irradiance under standard test condition (1 kW/m²).

The PV array yield ($Y_A$) is the time which PV module operates under STC. This time can be calculated as given in equation 5 [12]:

$$Y_A = \left( \frac{E_{DC}}{P_{PV.rat}} \right) \tag{5}$$

Where;

$E_{DC}$: DC energy output (daily) of PV array (kWh).

$P_{PV.rat}$: PV rated power ($kW_p$).

The final yield ($Y_F$) is defined as the energy output divided to the nameplate power of the photovoltaic generator in STC, the $Y_F$ as given in equation 6 [13]:

$$Y_F = \left( \frac{E_{AC}}{P_{PV.rat}} \right) \tag{6}$$

Where;

$E_{AC}$: AC energy output (daily of inverter (KWh).

The performance ratio is an important performance evaluation of PV systems and it means to a measure of the quality of a PV plant that is independent on environmental parameters. Furthermore, it is stated as percent and describes the relationship between actual and theoretical energy outputs of the PV plant as formulated in equation 7 [14]:

$$PR = \left( \frac{Y_F}{Y_R} \right) \tag{7}$$

The array capture losses ($L_C$) are due to the solar PV array losses and are given by equation 8 [15]:

$$L_C = Y_R - Y_A \tag{8}$$

The system losses ($L_S$) are as result of the inverter losses and are given by equation 9 [15]:

$$L_C = Y_R - Y_A \tag{9}$$

## Results and Discussion

### Solar irradiation and DC/AC power measurements

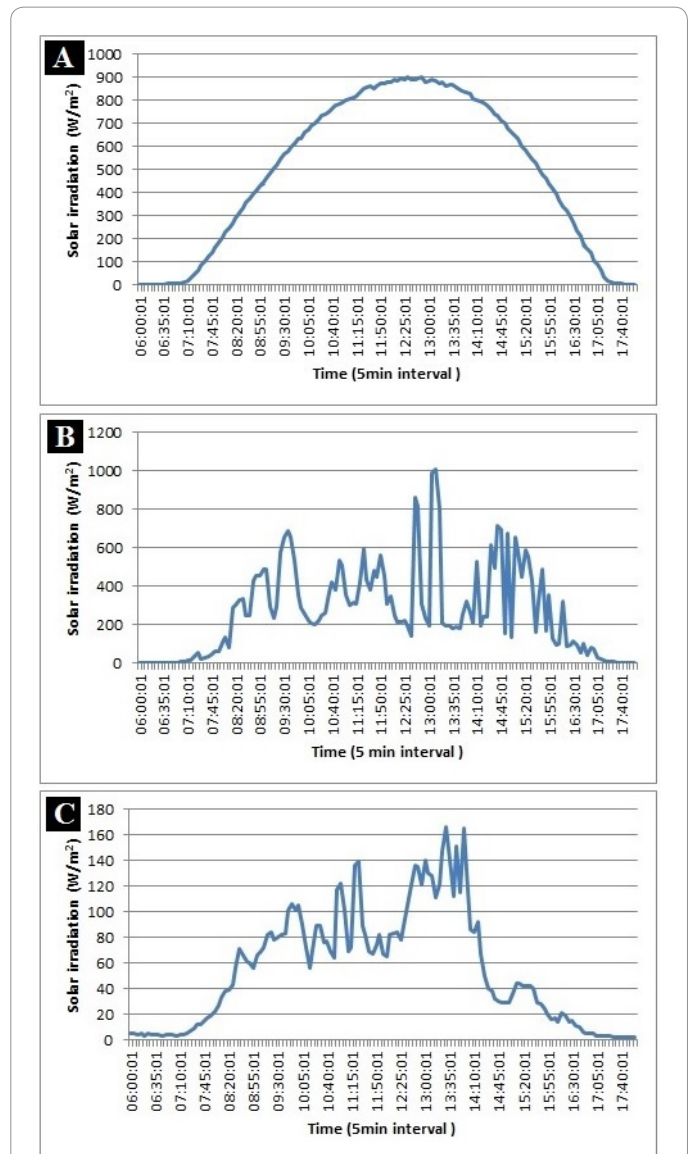Figures 4 and 5 shows the variation of solar irradiation, ambient

**Figure 4:** Solar irradiation in different days (clear (A), cloudy (B) and rainy (C)).
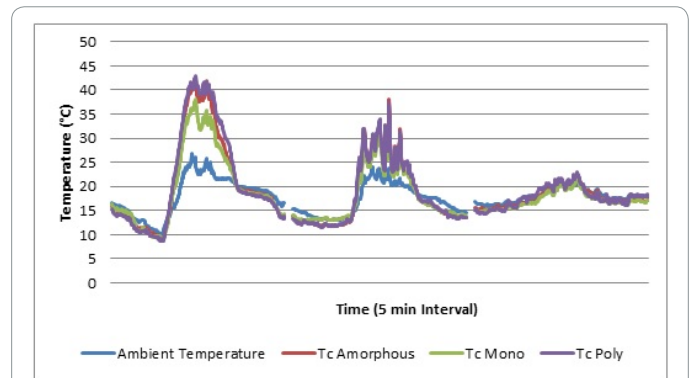
**Figure 5:** Ambient temperature and modules temperature in different days (clear, cloudy and rainy).

temperature and module temperatures during the three days (clear, cloudy and rainy). The clear day is characterized by a maximum

irradiation during the noon, this leads to an increase of the ambient temperature and the temperature of the modules. During the other two days we observed that the solar irradiation has an irregular shape and the wind speed is greater in comparison with the clear day, which explains the small difference between the ambient temperature and the temperatures of the modules. This means that the modules cool down fairly quickly with the help of wind speed, these results are coherent with the results reported in Al-Otaibi et al. [16].

The Figures 6 and 7 show the DC powers of the photovoltaic modules and the AC active powers of the inverters. During the clear day the powers are higher and similar to solar irradiations compared to a cloudy and a rainy day where the fluctuations of solar irradiation conducted fluctuations of the system's powers. At relatively high temperatures (clear day noon) the p-si generates more power than the c-si, but at low temperatures (rainy day) le c-si generates more power than the p-si. During the three days, the a-ci generated less power than c-si and p-si, but during the cloudy day which characterized by low irradiation and relatively low temperatures, the a-si become more efficient, this is due to the better performance under diffused irradiation.

The efficiencies of the modules and the photovoltaic systems are shown in Figures 8 and 9. For the three days, it is clear that the efficiencies of the modules and the systems vary inversely with respect to temperature fluctuation for the modules c-si and p-si, in contrast, for the a-si the temperature variation has practically no effect on the module and system efficiency. In the rainy day there is a disconnection of the p-si inverter, which means that there is no sufficient DC power to generate the AC power, this is in good agreement with the results reported in Dabou [5].

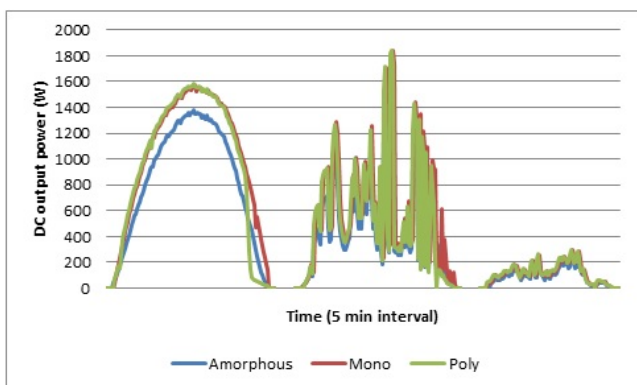Figure 10 shows the variation of the efficiencies of the inverters



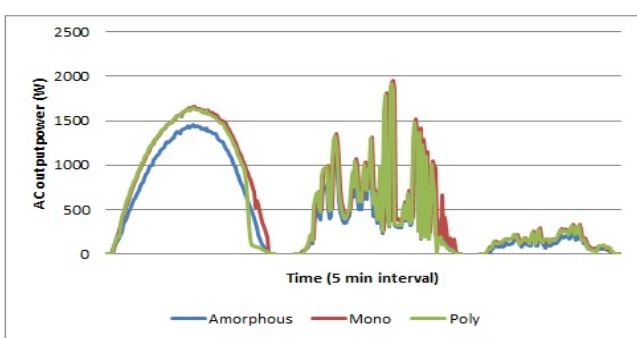**Figure 6:** DC output power in different days (clear, cloudy and rainy).



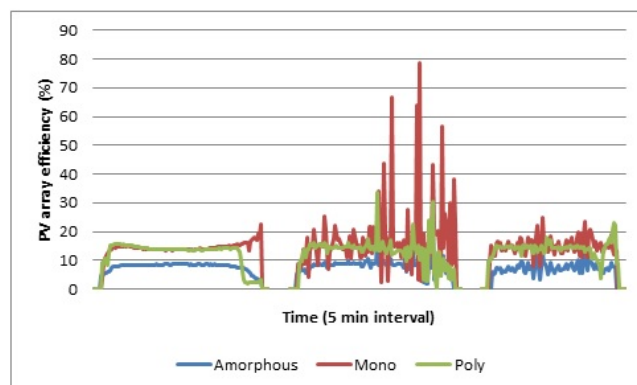**Figure 7:** AC output power in different days (clear, cloudy and rainy).



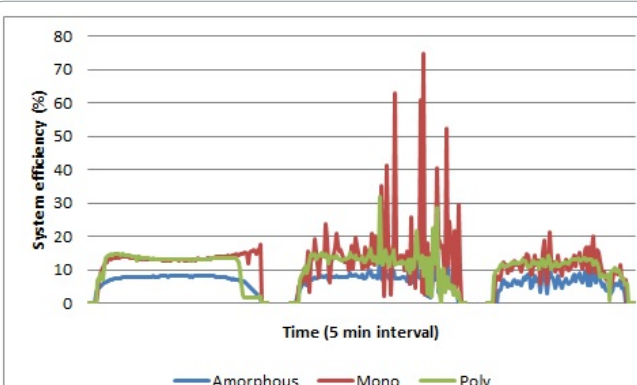**Figure 8:** Daily variation of PV array efficiency in different days (clear, cloudy and rainy).



**Figure 9:** Daily variation of system efficiency in different days (clear, cloudy and rainy).
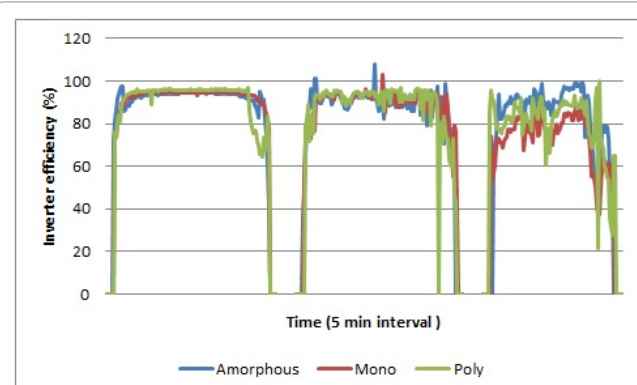


**Figure 10:** Daily variation of inverters efficiency in different days (clear, cloudy and rainy).

corresponding to each technology. During the clear day, there is a stability of the efficiencies of the inverters around 95%. As for the cloudy and rainy day, the efficiencies of the inverters have an irregular shape and some peaks. This variation is normal because of the rapid changing of the solar irradiation which is caused by the clouds and the rain. In the rainy day there is a significant decrease in the efficiency of the c-si and p-si inverters which is caused by the low input voltage supplying the inverters that were out of the maximum efficiency range of inverters [17].

| Day | Solar irradiation (KWh/m²) | Ambient temperature (°C) | Wind speed (m/s) |
|---|---|---|---|
| Clear day 16/11/2016 | 5.85 | 23.95 | 2.7 |
| Cloudy day 19/11/2016 | 3.19 | 21.48 | 4.06 |
| Rainy day 02/11/2016 | 0.63 | 18.02 | 5.2 |

**Table 3:** Daily solar irradiation, average of ambient temperature and wind speed.

| Day | Technologies | PV array efficency (%) | Inverter efficency (%) | System efficency (%) |
|---|---|---|---|---|
| Clear day 6/11/2016 | Amorphous | 8.09 | 93.50 | 7.56 |
| | Mono | 14.01 | 94.14 | 13.19 |
| | Poly | 13.15 | 95.29 | 12.53 |
| Cloudy day19/11/2016 | Amorphous | 8.21 | 92.12 | 7.57 |
| | Mono | 14.56 | 92.64 | 13.49 |
| | Poly | 13.55 | 93.56 | 12.68 |
| Rainy day 02/11/2016 | Amorphous | 6.50 | 90.21 | 5.87 |
| | Mono | 13.22 | 77.62 | 10.26 |
| | Poly | 12.72 | 83.33 | 10.60 |

**Table 4:** Daily PV array efficiency, inverters efficiency and system efficiency in different days for each technology.

| | Technologies | Reference yield (KWh/KWp/Day) | Array yield (KWh/KWp/Day) | Final yield (KWh/KWp/Day) | Capture losses (h/Day) | System losses (h/Day) | Performance ratio (%) |
|---|---|---|---|---|---|---|---|
| Clear day 16-11-2016 | Amorphous | 5.85 | 4.50 | 4.21 | 1.35 | 0.24 | 71.96 |
| | Mono | 5.85 | 5.55 | 5.22 | 0.30 | 0.32 | 89.31 |
| | Poly | 5.85 | 5.20 | 4.95 | 0.65 | 0.15 | 84.61 |
| Cloudy day 19-11-2016 | Amorphous | 3.20 | 2.50 | 2.30 | 0.69 | 0.20 | 72.10 |
| | Mono | 3.20 | 3.15 | 2.92 | 0.04 | 0.23 | 91.53 |
| | Poly | 3.20 | 2.95 | 2.75 | 0.24 | 0.20 | 86.20 |
| Rainy day 02-11-2016 | Amorphous | 0.63 | 0.54 | 0.39 | 0.09 | 0.15 | 62.90 |
| | Mono | 0.63 | 0.62 | 0.49 | 0.005 | 0.13 | 77.77 |
| | Poly | 0.63 | 0.59 | 0.50 | 0.04 | 0.09 | 79.36 |

**Table 5:** Daily reference yield, array yield, final yield, capture losses, system losses and performance ratio in different days for each technology.

Table 3 sums the solar radiation, ambient temperature and the wind speed during the three days. The efficiencies of the modules, the inverters and the systems are showing in Table 4. In Tables 1 and 2 we observed that the clear day is characterized by an intense solar irradiation and a mean temperature close to the standard condition temperature (STC) which influences the performances of the photovoltaic module. The results show that the efficiency of the module and that of the system are maximal in the cloudy day for the three technologies due to the low temperature and the high wind speed which affects the module temperature [18].

During the rainy day the efficiencies are minimal for the three technologies due to the low solar irradiation and the rain [19].

### Performances of the PV systems

The reference, the module and the final yields, as well as the capture losses, the systems losses and the performance ratio are shown in Table 5. The results show that maximal values of the module, reference and the final yields for the three technologies are registered during the clear day. The yields of c-si are a bit greater than those of p-ci due to the different coefficients of temperature and power. The a-si has more important capture and system losses in comparison with those of c-si and p-si, this result can be explain to the a-si's greater temperature coefficient. Also the PR varies with solar irradiation [20] and the PR is maximal for the three technologies in the cloudy day owing the fact that the decreasing in losses which is caused by the decrease of module temperature.
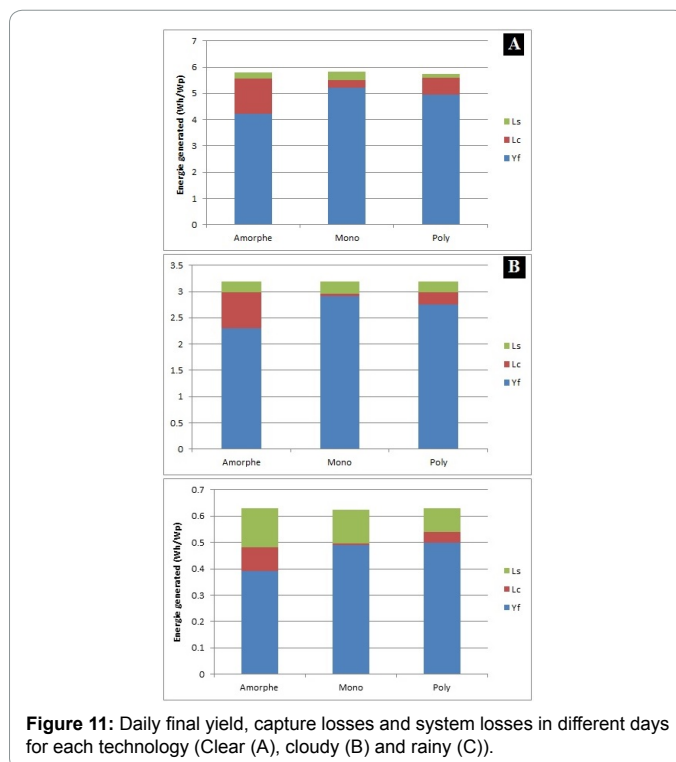


**Figure 11:** Daily final yield, capture losses and system losses in different days for each technology (Clear (A), cloudy (B) and rainy (C)).

Figure 11 (clear (A), cloudy (B) and rainy (C)) shows the final yields, the losses of the captures and the losses of systems for the three technologies during the three days. On the clear day, the three technologies have generated a great amount of energy in comparison with the two other days. The losses of the system for the three technologies in both the cloudy and rainy day increase with decreasing of the inverter efficiency. Also the capture losses of a-ci during the three days have the most important values. In fact, two factors are responsible of the poor effectiveness of the a-si: STEABLER-WRONSKI effect [21] and the low mobility of holes within the material.

## Conclusion

The experimental results show that the three PV technologies have a different behaviour depending on the days. This differences are mainly due to the variations of the spectral component, the weather condition, the installation type, etc. this study on the silicon PV modules of different technologies was performed in order to understand the impact of the different parameters and to evaluate the consequences on the energetic production. The obtained results show that: the efficiency's maximal values for the PV array on a cloudy day are 8.21%, 14.56% and 13.55% for a-si, c-si and p-si respectively. As for the system efficiency we have obtained as maximal values: 7.57%, 13.49% and 12.68% for a-si, c-si and p-si respectively, also on a cloudy day. In the clear day, the maximal values of system efficiency are 93.50%, 94.14% and 95.25% for a-si, c-si and p-si respectively. $Y_A$, $Y_F$ and $L_C$ were shown to have maximal values for the three technologies on a clear day. The maximal values of PR are 72.10%, 91.53% and 86.20% for a-si, c-si and p-si respectively, these values were obtained on a clear day. We concluded that the c-si and p-si modules considering their yields are the best performing modules in the three days. However, in an unfavourable weather conditions the a-si modules begin to perform better due to its better handling of the diffused irradiation.

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