# ANALYSIS AND COMPARISON OF PERFORMANCE OF PHOTOVOLTAIC SYSTEMS FROM THE "COUNTING THE SUN" PUBLIC AWARENESS CAMPAIGN ON PV PERFORMANCE

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ABSTRACT: Detailed analysis of 5000 systems that took part in the 2014 measurement campaign "Counting the Sun" was performed as besides the weekly yield also system descriptions were available. With average energy yield of 33.4 kWh/kWp, and average performance ratio of 0.74 for all systems, performance ratio was found to be dependent on the ratio of inverter DC nominal power and system DC rated power. For low cost inverters, this ratio was 1.16, while for high cost inverters it was 0.95. Apparently, expected better performance does not warrant higher capacity inverter, in the case of high cost inverters. However, due to the 1-week period, performance ratio was found not to be dependent on this ratio. Also, different components (modules, inverters) do not conclusively influence performance ratios. A longer monitoring period is expected to lower variation of these values such that statistically relevant differences can be observed.
Keywords: PV performance, inverter to system power ratio, cost, performance ratio

## 1 INTRODUCTION

"Counting the Sun" (Dutch: Tel De Zon) was a measurement campaign for the public to raise awareness of monitoring their PV system within the framework of the Dutch Solar Days. During one week only, i.e. between May 12 and May 18, 2014, participants were asked to measure or determine the amount of generated energy by their PV systems. Some 5000 systems, well spread over the country were taking part, constituting in total 16.2 MWp, with an average installation size of 3.5 kWp. The total weekly yield was 531 MWh, and the average weekly yield was 33.4 kWh/kWp [1].

Results show that PV systems in the Netherlands in general are performing well, with performance ratio values of 0.74±0.09, evenly spread over the country, with ~10% of the systems suffering from some kind of shadowing. The weekly yield varies over the country, with 25% higher yields at the coast, and this correlates well with irradiation variations over the country in the week. Note that a recent repeat of this campaign for the week of 1-7 June 2015 showed nearly identical results regarding performance ratio, while the variation of weekly yield over the country was only 10% due to the different weather conditions.

As participants generously supplied PV system information, i.e., system location (postal code), system capacity (Wp), number of panels, brand and type of panels, inverter capacity, inverter brand and type, orientation, tilt, year of installation, and potential shading issues, a detailed analysis was possible. This paper will focus on comparison of performance related to module and inverter brands, and will show how performance ratio varies as a function of the ratio of inverter capacity and system size.

## 2 ANALYSIS METHOD

### 2.1 Yield and performance ratio

The time and weather dependent nature of solar power makes it difficult to apply the conventional performance indicators that are used for the regular power plants. In order to compare and evaluate different systems normalized indicators are necessary. The most common indicator is the final system yield, which is the net energy delivered for the specific period divided by the rated power output of the installed array and it has units kWh/kWp [2]. It is a convenient way to compare the energy produced by different PV systems as it normalizes the energy produced according to system size. It has the advantage to be a straightforward indicator as the only measurement that it requires is the actual produced energy. However, it varies widely by climate, by the length of the calculation period and by how the two parameters are defined (e.g., array DC level or inverter AC output). Final system yield is defined as:

$$Y_f = \frac{E}{P_0} \qquad (1)$$

with $E$ the generated amount of energy and $P_0$ the nameplate capacity of the system. The Performance Ratio (PR) is another indicator that is widely used as a measure of the quality of the PV system. It describes the relationship between the actual and theoretical or reference energy output of the PV plant. The actual energy yield is the utilizable AC electricity that is measured at the feed in meter and it is divided by the amount of energy that could be generated if the system operated under Standard Test Conditions. The difference between 100% and the PR value aggregates all the possible energy losses including inverter efficiency, wire losses, panel degradation, mismatch, shades, dust, thermal inefficiencies and system failures [3]. PR is a dimensionless quality indicator and is calculated by dividing final system yield $Y_f$ by reference yield $Y_r$ [3]:

$$PR = \frac{Y_f}{Y_r} \qquad (2)$$

In order to calculate the reference energy yield for each system the plane of array irradiation (POA) needs to be determined. This was done using quarterly global horizontal irradiance (GHI) values from 31 meteorological ground stations in the Netherlands (Royal Netherlands Meteorological Institute, KNMI). Finally, the measured energy yield was used to calculate the performance ratio

2.2 Plane of array irradiation data

For the determination of PR the total plane of array irradiation is necessary. For that reason the KNMI data was used. A number of models for determining the solar global irradiation on inclined surfaces derived from the global horizontal have been developed and according to studies, the model by Olmo *et al*. was found to have the better match between the predicted and the experimental values [4]. Moreover, it has the advantage to depend only on the clearness index and avoids the separation of the solar beam in to direct and diffuse components. Therefore, we have used the Olmo model for calculating POA irradiance.

## 3 RESULTS

3.1 System components

The systems of the participants are well spread over the country, and obviously linked to urban areas [1]. As mentioned already, the total capacity of the systems was 16.2 MWp, with an average installation size of 3.5 kWp. This constitutes ~2% of the total amount of PV capacity at that time (mid 2014) in the Netherlands. The majority of participants use monocrystalline silicon modules (51.5 %) but there is also a large number that has installed multicrystalline silicon modules (34.3 %). Thin film technology is only marginally installed: amorphous silicon 0.3 %, copper-indium-selenide (CIS) 1.5 %. Interestingly, 12.5% of the participants are not aware of the PV technology on their roof. Table I shows the market share of the module manufacturers in the Netherlands, based on the participants information. In this sample set clearly three manufacturers are dominant, i.e., ET-Solar, Yingli and ZNShine, where it should be noted that the share of ZNShine is increasing fast in 2014. Also, from the fact that the 'Others' category contains over one-third of the sample it can be seen that hundreds of different brands actually are installed.

**Table I**. Market share (in %) of module manufacturers based on total amount and installation year. Note that data for 2014 is based on installations for January to May. * denotes CIS.

| Brand | 2011 | 2012 | 2013 | 2014 | Total |
|---|---|---|---|---|---|
| ET-Solar | 6.7 | 10.5 | 12.7 | 10 | 11.1 |
| Yingli | 5 | 8.6 | 14.6 | 6.2 | 10.6 |
| ZNShine | 2 | 2.5 | 8 | 22.6 | 8.9 |
| Canadian Solar | 1.6 | 10.3 | 5.7 | 2.8 | 6 |
| Suntech | 9.3 | 16 | 1.8 | - | 5.6 |
| CSUN | 22.9 | 4.5 | 6 | 2 | 5.2 |
| Sunrise | - | 1 | 3 | 9 | 3.5 |
| Renesola | - | 1.5 | 4 | 2.6 | 2.9 |
| JA Solar | - | 2 | 3 | 3 | 2.6 |
| Astronergy | - | 3 | 2.7 | 2 | 2.4 |
| UPT | - | - | 2.4 | 1 | 1.4 |
| BYD | - | 2 | 1.3 | 1.4 | 1.4 |
| EGing | 0.8 | 1 | 1.6 | 1.3 | 1.3 |
| Sharp | 6 | 2 | - | - | 1.2 |
| Solar Frontier* | - | 0.4 | 0.8 | 3.5 | 1.2 |
| Others | 45.7 | 34.7 | 32.4 | 32.6 | 34.7 |

Table II shows the market share of inverter brands. SMA is the dominant brand with over 40% market share, with Omnik and Growatt quickly growing. The Dutch brand Mastervolt is losing market share fast. The market share of microinverters is increasing slowly.

**Table II**. Market share of inverters manufacturers based on total amount and installation year. Note that data for 2014 is based on installations for January to May. * denotes microinverters.

| Brand | 2011 | 2012 | 2013 | 2014 | Total |
|---|---|---|---|---|---|
| SMA | 41.2 | 57.3 | 41 | 29.1 | 41.5 |
| Omnik | | 3.6 | 20.4 | 19.4 | 14.4 |
| Mastervolt | 14.3 | 11 | 3.9 | 0.4 | 6.7 |
| Growatt | | | 4.4 | 19.6 | 6 |
| Delta | 2.5 | 4.5 | 4.2 | 2.7 | 4 |
| Power-One | 4 | 3.5 | 1.7 | 1.5 | 2.1 |
| Samil | | | 2.4 | 3.6 | 2 |
| SolarEdge | | 0.8 | 1.7 | 4.4 | 2 |
| Chint | 21.8 | 2.7 | 0.7 | | 1.8 |
| Steca | 6.7 | 1 | 0.5 | 1.6 | 1.5 |
| Enphase* | | 1.1 | 2.7 | 1.6 | 2 |
| Enecsys* | | 1.3 | 1.5 | 1.8 | 1.4 |
| Others | 9.5 | 13.2 | 15 | 14.3 | 14.6 |

Analysis of the ratio of inverter DC nominal power and system DC rated power reveals an interesting fact, shown in Fig. 1. Usually, as a rule-of-thumb, a ratio of 0.8 is used in PV system design [5], while the average as well as the spread of ratios is much larger: 1.01±0.15. The 0.8-ratio is based on the fact that maximum DC output of a PV system in practice will never be reached due to temperature effects, i.e., the negative temperature coefficient of silicon technology. Note that the rule-of-thumb was based on hourly irradiation data, which has been criticized in Ref. 9. Especially in partly overcast situations, irradiance variations are fast and using a ratio of 1 or larger will actually lead to lower inverter-related losses in the PV system. In Fig. 2 the ratio is depicted using the price difference on the market of the inverters of Table 2. Price information is taken from [6]. It can clearly be seen that a ratio lower than 1 is used for high-cost inverters (average value is 0.95±0.10), while it is actually larger than 1 for lower cost inverters, i.e., 1.16±0.12. The rule-of-thumb of 0.8 was also inspired by the cost of inverters in the past. Considering this aspect, using high cost inverters would increase the cost of system at limited increase of performance. With cheaper inverters, a ratio of 1 or larger still is economically attractive.

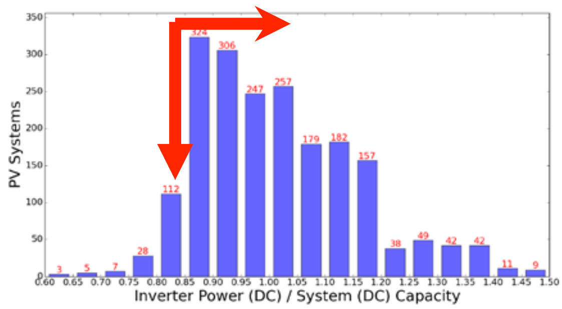


**Figure 1.** Distribution of the ratio of inverter DC nominal power and system DC rated power.

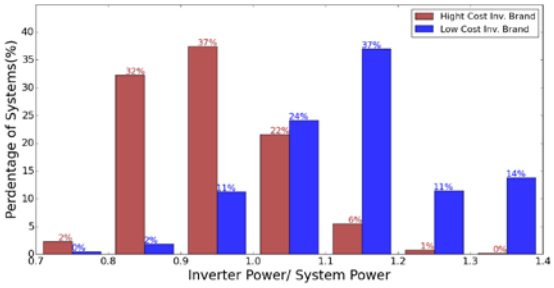


**Figure 2.** Distribution of the ratio of inverter DC nominal power and system DC rated power for high- and low-cost inverters.

4.2 Yield and performance ratio

Total weekly yield was 531 MWh, and the average weekly yield was 33.4 kWh/kWp. The distribution of weekly yield is shown in Fig. 3, with a clear variation that is linked to the variation of irradiance over the country: highest in coastal areas (see [1]). The average GHI during the measurement week was 41.9 kWh/m$^2$, with the four first days with cloud cover and rainfalls, while the last three days were clear with average daily GHI >7 kWh/m$^2$ [1].

The distribution of performance ratio values is shown in Fig. 4; the average PR = 0.74±0.09. Systems that operate with PR values less than 0.60 represent 6.1% of the total sample. Average performance (PR in the range 0.60-0.70) constitutes 18.6% of the sample while good performance (PR in the range 0.70-0.85) has 67.5% of the sample. Only 7.8% of the installations have exceptional performance (PR larger than 0.85). The geographical variation of PR is absent [1]: systems all over the country do perform similarly well. One of the most important factors that affect the performance of PV systems is shading. The effect of shading is difficult to quantify since it depends on the architecture of the whole system. In total ~15% of the participants reported that their panels have shading issues. The average PR of those systems is 0.71. On the other hand, the average PR for systems of which there was no report for shading was only slightly higher at 0.75. Note that absence of reporting of a shading problem does not indicate that shading issues do not exist.

Following the analysis of the ratio of inverter DC nominal power and system DC rated power in the previous section, a lower performance ratio was expected for ratios lower than 0.9. Figure 5 shows that this was not observed for the measurement week. Most probably, a longer measurement period should be used to show this effect.

Calculation of PR requires local irradiance data, which are taken from the 31 meteorological stations of KNMI. This may induce incorrect irradiance data, as the distance between station and PV system may be substantial, as the weather conditions may very well vary on a much smaller scale. However, as Fig. 6 shows, a dependence of performance ratio on the distance between the PV system and the closest meteorological stations is absent, at least for the week under study. Note that unrealistic values of PR most probably result from incorrect data supplied by participants. Also, most of the systems are at maximum 25 km from a meteorological station.

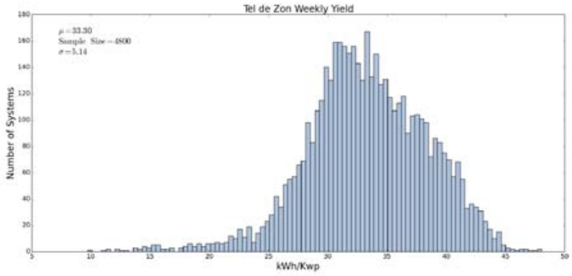


**Figure 3.** Distribution of weekly annual yield.

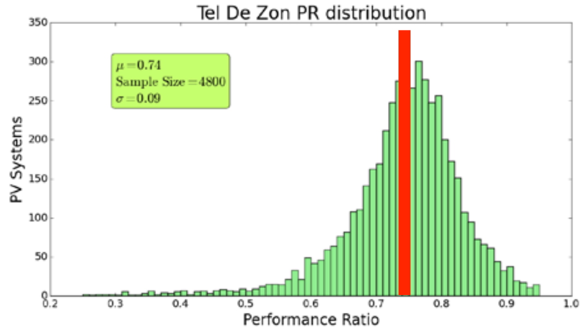


**Figure 4.** Distribution of performance ratio.

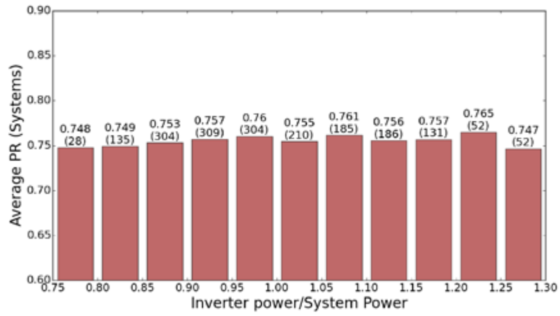


**Figure 5.** Average PR as a function of ratio of inverter DC nominal power and system DC rated power.

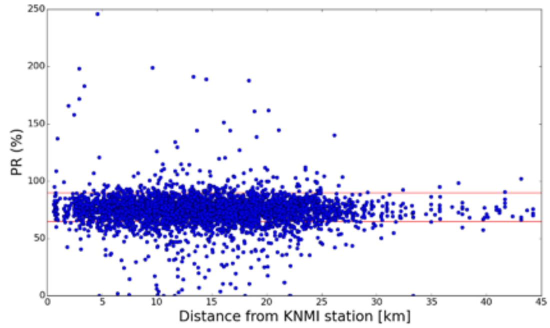


**Figure 6.** PR of all systems as a function of the distance between the system and the nearest meteorological station.

Figures 7 and 8 show the performance ratio of the systems for different module and inverter manufacturers, respectively. Although differences in average values are evident, the associated variation per module is quite large so that clear conclusions are not possible.

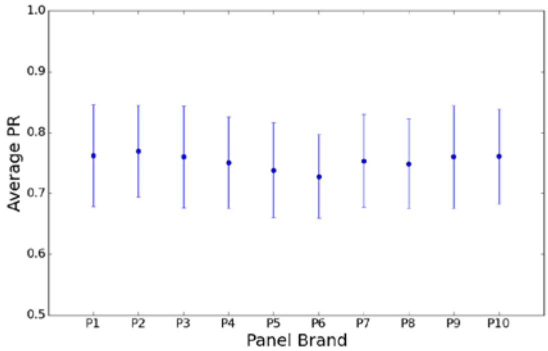


**Figure 7.** PR of all systems as a function of module manufacturer.

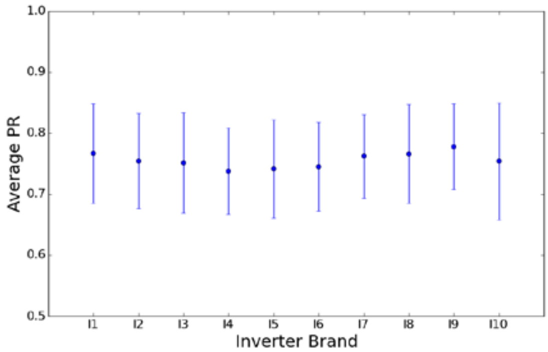


**Figure 8.** PR of all systems as a function of inverter manufacturer.

## 4 CONCLUSION

We have performed a detailed analysis of the data that were available from the "Counting the Sun" public campaign aiming at raising awareness among PV system owners that was organized as part of the Dutch Solar week in May 2014 [1]. It was found that the rule-of-thumb 0.8-value for the ratio of inverter DC nominal power and system DC rated power is only observed for systems with a high-cost inverter. For low cost inverters, this ratio was much larger at 1.16. At the expense of extra cost for the inverter, performance of system was expected to be higher. For low cost inverters, additional cost is low anyway. We did not find an increased performance ratio for higher values of the ratio of inverter DC nominal power and system DC rated power. This effect would be clearer when determining annual PRs.

Results further show that components (modules, inverters) do not conclusively influence performance ratios. Also here, a longer monitoring period is expected to lower variation of these values such that statistically relevant differences can be observed.

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