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# Efficiency Ranking of Photovoltaic Microinverters and Energy Yield Estimations for Photovoltaic Balcony Power Plants †

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**Abstract:** The market for microinverters is growing, especially in Europe. Driven by rising electricity prices and an easing in legislation since 2024, the number of mini-photovoltaic energy systems (mini-PVs) being installed is increasing substantially. Indoor and outdoor studies of microinverters have been carried out at Paderborn University since 2014. In the indoor lab, conversion efficiencies as a function of load have been measured with high accuracy and ranked according to Euro and CEC weightings; the latest rankings from 2024 are included in this paper. In the outdoor lab, energy yields have been measured using identical and calibrated crystalline silicon PV modules; until 2020, measurements were carried out using 215 $W_p$ modules. Because of increasing PV module power ratings, 360 $W_p$ modules were used from 2020 until 2024. In 2024, the test modules were upgraded to 410 $W_p$ modules, taking into account the increase from 600 W to 800 W of inverter power limits, which is suitable for simplified operation permission ("plug-in") in many European countries within a homogenised legislation area for such mini-photovoltaic energy systems or "balcony power plants". This legislation for simplified operation also covers overpowered mini-plants, although the maximum AC output remains limited to 800 W. Presently, yield assessments are being carried out in the outdoor lab, which will take at least a year to be valid and comparable. Kits consisting of PV modules, inverters, and mounting systems are also being evaluated. Yield rankings sometimes differ from efficiency rankings due to the use of different MPPT algorithms with different MPP approach speeds and accuracies. To accelerate yield assessment, we developed a novel, simple formula to determine energy yield for any module and inverter configuration, including overpowered systems. This is a linear approach, determined by just two coefficients, *a* and *b*, which are given for several inverters. To reduce costs, inverters will be integrated into the module frame or the module terminal box in the future.

**Keywords:** microinverter; EU efficiency; CEC efficiency; MPPT; energy yield rating; balcony power plant; system performance; AC modules



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## 1. Introduction

Microinverters are inverters that are often connected to a single PV module (or occasionally to two modules; few are available for four modules, and these are not considered here). Thus, each module–inverter combination acts as an independent power plant. The microinverter consists of a maximum power point tracker (MPPT), the DC–AC inverter, and an islanding protection unit [1]. For higher power requirements, several module–inverter combinations are interconnected in parallel on the AC output side. This configuration offers various advantages, including easier planning and installation and the easy up- and down-scaling of a plant, which allows for extensions or repairs to be carried out during power plant operation. The logistics are simplified, and the effect of shadowing is very limited. Due to low system voltages, potential induced degradation (PID) does not occur. A review of the topologies, an overview of the development, and advantages of microinverters were presented by S.B. Kjær et al. [2], J.M.A. Myrzik and M. Calais [3], H. Oldenkamp [4], and Stellbogen et al. [5]. However, the costs of power plants based on microinverters are about 10–20% higher than systems equipped with string or central inverters. Some of the inverters cannot be operated by themselves and require a control unit (often combined with a remote shutdown option and a monitoring system) or a protective device for grid interfacing (depending on national regulations), thus adding extra costs. Additionally, the conversion efficiency may not be as high as for central inverters. Due to smart master–slave concepts, centralised solutions with multiple but relatively large inverters may offer higher yields under weak light conditions. A performance comparison of systems with microinverters, power optimisers, and central inverters is given in [6].

This paper is an extended version (new measurements) of our paper published in the Proceedings of the 8th World Conference on Photovoltaic Energy Conversion 2022 [7].

## 2. Measurement Methods

### *2.1. Methods for Conversion Efficiency Measurements (Indoor)*

Due to the reproducible test conditions in the indoor lab, the inverters were examined individually with predefined and controlled input data. While a traditional examination of the electronic circuits inside the inverters was almost impossible due to extensive casting compounds, components with deleted numberplates, and secret control algorithms in the microcontrollers, the investigation followed a "black box" approach, observing the input and output behaviour of the device. The input was a PV module simulator, with the data set to correspond to the modules used in the outdoor test. The main output data were the delivered AC power of the inverters, which is fed into the public grid. Output is also a function of input voltage. If the input voltage is too low, the inverters stop operating.

The following examinations were based on the possible range of input data (including voltage) given for the specific PV module used for the outdoor investigation.

The efficiency measurements were carried out by utilising the DC input and AC output measurements (see Figure 1) obtained from a calibrated precision power metre ZIMMER® LMG 670 (Oberursel, Germany). The measurement accuracy was 0.025–0.1% (depending on the measurement type and range). The output power values used for the inverters (adjusted by controlling the DC input current) were continuously increased in 1024 steps from 0 to the maximum. Furthermore, every 500 ms a measurement was taken for the same power level for 8 s. Figure 2 shows an example of the measuring procedure. We tested each inverter for its maximum power, which can sometimes be slightly higher than the rated power. This procedure was only used to determine the general overall course of the efficiency curve. The exact measurements for determining the efficiencies were carried out by directly approaching the relevant numbers for EU and CEC weighted efficiencies. Between 90 and 150 measurements of 500 ms each were carried out, meaning that transient effects were not relevant.

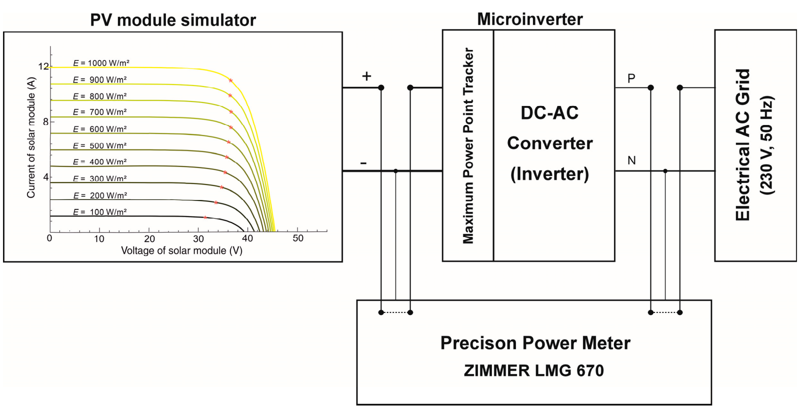


**Figure 1.** Setup of the indoor power and efficiency measurements using a black box approach via utilising a precision power metre for inputs and outputs.

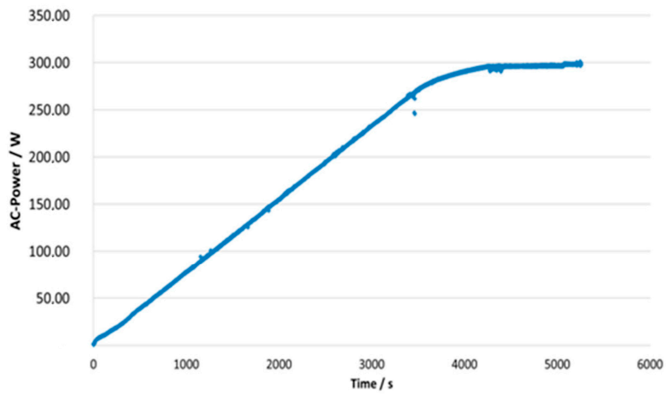


**Figure 2.** Measured AC power output (in Watts) as a function of measurement duration (in seconds) for a linear increasing DC input current for a 300 W inverter.

Peak efficiency is often reached close to the maximum load of the inverter. Peak efficiency (often promoted in data sheets) is not a helpful value, since most of the time, the inverters operate in the range of 20% to 40% of their rated power under non-arid conditions. Consequently, an adequately weighted efficiency is a more useful value to rate conversion devices. One type of weighted efficiency is the "European Efficiency" $\eta_{Euro}$, which is calculated by the following:

$$\eta_{Euro} = 0.03 \cdot \eta_{5\%} + 0.06 \cdot \eta_{10\%} + 0.13 \cdot \eta_{20\%} + 0.1 \cdot \eta_{30\%} + 0.48 \cdot \eta_{50\%} + 0.2 \cdot \eta_{100\%} \quad (1)$$

The other is the "CEC efficiency" of the California Energy Commission (CEC). The CEC efficiency $\eta_{CEC}$ is computed as an average value of DC–AC conversion efficiencies at six pre-defined relative output values between 10% and 100% of its rated power (with an emphasis on higher irradiance levels), and is calculated as follows:

$$\eta_{CEC} = 0.04 \cdot \eta_{10\%} + 0.05 \cdot \eta_{20\%} + 0.12 \cdot \eta_{30\%} + 0.21 \cdot \eta_{50\%} + 0.53 \cdot \eta_{75\%} + 0.05 \cdot \eta_{100\%} \quad (2)$$

For the "European Efficiency", the weighting factors for high relative power values are lower according to the European irradiance statistics. $\eta_{x\%}$ stands for the conversion efficiency at x% of relative load.

### *2.2. Test Arrangement for Electrical Energy Yield Measurements (Outdoor)*

For the PV outdoor test lab (see Figure 3) installed on the roof of Paderborn University (51.707° N, 8.771° E), a specific test system was employed. Figure 3 depicts the electrical layout of the system, including the PV modules on top with the attached microinverters and the measurement system. Each PV module consisted of 60 solar cells from the same batch of the factory. In the stated plant, these equal and calibrated modules were the input for each microinverter. The goal of the investigation was to analyse the performance of the inverters under real operating conditions, comparing their energy yield simultaneously with the climatic conditions and solar irradiance. The climatic conditions were monitored during the whole test period. The meteorological monitoring equipment consisted of two calibrated pyranometers in the plane of the module (CMP 21 and SP 2 lite by Kipp and Zonen), a 3D ultrasonic anemometer (by Thies), a thermo-hydro sensor (by Thies), and a thermo-moisture metre with a wind sensor, which was WXT 520 (by Vaisala). Each microinverter was directly connected to a calibrated electrical energy metre with an $S_0$-interface (see Figure 3). To ensure an accurate yield measurement, the calibrated electrical energy metres were replaced on a regular basis with freshly calibrated ones. All $S_0$-interfaces were connected to a server-based data acquisition system.

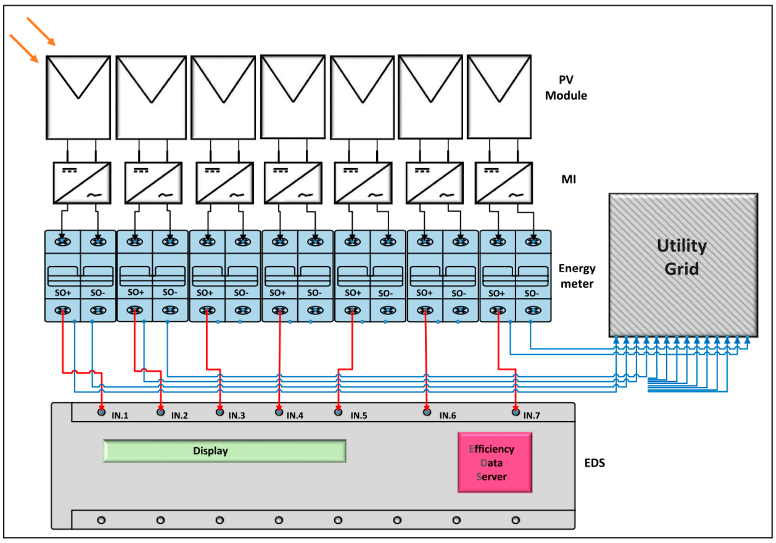


**Figure 3.** Outdoor measurement setup for the microinverters (MIs).

We used 215 $W_p$ modules until 2020, and from 2020 to 2024, we used ten 360 $W_p$ modules (lower row, from left), as shown in Figure 4. The modules were manufactured by Solarwatt®, and the power output at the STC of each module was measured in the factory (Dresden, Germany). Additionally, one module was sent for a precision measurement to the testing laboratory ISFH (Hameln, Germany). The factory measurements were found to be very accurate (362 $W_p$ vs. 359.34 $W_p$ ±3% at ISFH in July 2021). In 2024, the modules were substituted with modules with a nominal power of 405 $W_p$, also manufactured by Solarwatt®.

**Figure 4.** Layout of the PV modules of the PV outdoor laboratory in 2023 for the electrical energy yield comparison of microinverters using eight to ten equal, calibrated PV modules (of 360 $W_p$ each) as inputs.

## 3. Results

### *3.1. Conversion Efficiency Measurements (Indoor)*

The measured DC–AC conversion efficiencies over the entire operation range of all inverters are shown in Figure 5 (with one input for one module) and Figure 6 (with two inputs for two modules).

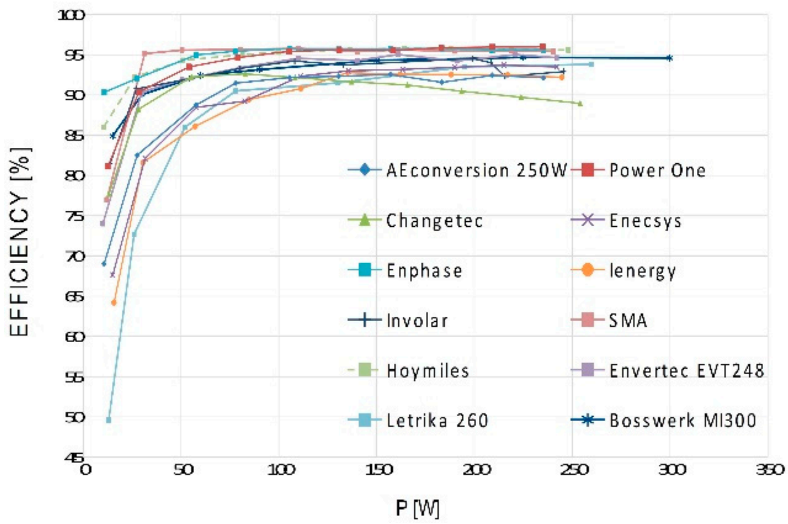


**Figure 5.** Measured DC–AC conversion efficiencies as a function of power outputs for 12 microinverters with single PV module inputs.

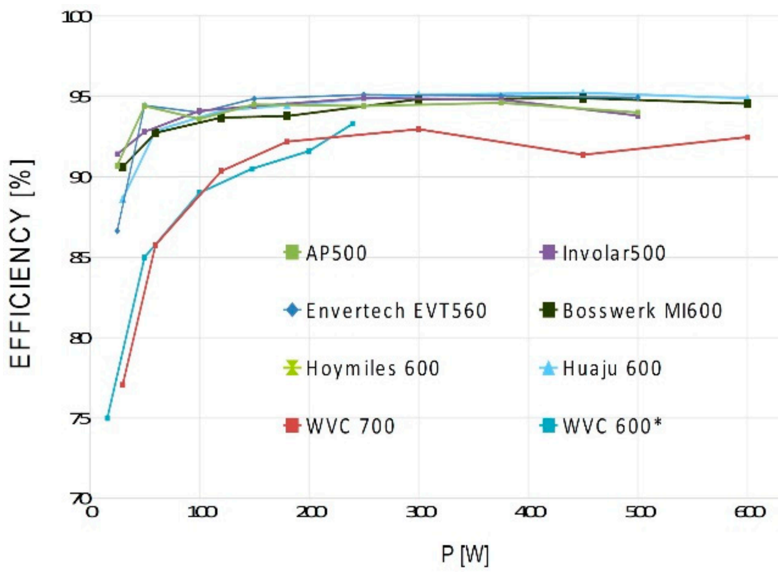


**Figure 6.** Measured DC–AC conversion efficiencies as a function of power outputs for eight microinverters with two PV module inputs. * failed.

Based on these measurements, the EU and CEC efficiencies for the microinverters were calculated according to (1) and (2). A total of eleven microinverters were designed for single modules, and nineteen inverters had inputs for two PV modules: Anker Solix MI 60; APSystems YC 500, DS3-S; Involar MAC 500; Deye Sun 600 G3; Ecoflow Powerstream 600; Envertech EVT-560; Hoymiles MI 500, 600, 700, 800; Huaju HY 600; NEP BDM 600; Bosswerk Mi 600; Parkside PBKW-300-A1; Technaxx TX 204; Tsun TSOL-MS600; and WVC 600, 700.

The ranking, considering the EU conversion efficiency (1), is shown in Table 1. Envertech EVT 560 and PowerOne/ABB Micro-0.25-i had the same conversion efficiency, sharing rank number five. Hoymiles HMS-800W-2T, DeyeSun G3, and Huaju HY600 had the same EU conversion efficiency, sharing rank seven. This also applied to Involar MAC 500 and Bosswerk Mi600, sharing rank 10, while AEconversion INV 250-45 and Enecsys SMI-S-240W were ranked at position 25.

**Table 1.** Ranking of the tested microinverters by the weighted "European Conversion Efficiency" according to (1). Nominal power (in W) is indicated in the type name.

| Rank | Brand/Type | EU Conversion Efficiency |
|---|---|---|
| 1 | SMA Sunnyboy 240 | 95.4% |
| 2 | Enphase M 215 | 95.2% |
| 3 | Hoymiles MI 500 | 95.0% |
| 4 | Hoymiles MI 600 | 94.7% |
| 5 | Envertech EVT-560 | 94.6% |
| 5 | PowerOne/ABB Micro-0.25-i | 94.6% |
| 7 | Hoymiles HMS-800W-2T | 94.5% |
| 7 | Deye Sun 600 G3 | 94.5% |
| 7 | Huaju HY 600 | 94.5% |
| 10 | Involar MAC 500 | 94.3% |
| 10 | Bosswerk Mi 600 | 94.3% |
| 12 | Technaxx TX 204 | 94.2% |
| 13 | APSystems YC 500 | 94.1% |
| 14 | Anker Solix MI 60 | 93.6% |
| 15 | Bosswerk Mi 300 | 93.5% |
| 16 | Envertech EVT-248 | 93.2% |
| 17 | APSystems DS3-S | 93.0% |
| 18 | Ecoflow Powerstream 600 | 92.7% |
| 18 | Involar MAC 250 | 92.7% |
| 20 | Hoymiles HM 700 | 92.5% |
| 20 | NEP BDM 600 | 92.5% |
| 22 | Tsun TSOL-MS600 | 92.4% |
| 23 | WVC 700 (at 600 W) | 91.6% |
| 24 | Changetech ELV 300-25 | 90.9% |
| 25 | AEconversion INV 250-45 | 90.4% |
| 25 | Enecsys SMI-S-240W | 90.4% |
| 27 | Ienergy GT 260 | 89.9% |
| 28 | Parkside PBKW-300-A1 | 88.9% |
| 29 | Letrika 260 | 88.7% |
| 30 | WVC 700 (at 700 W) | 73.3% |
| 31 | WVC 600 (failed) | 0.0% |

Table 2 shows the same type of ranking, but with the CEC efficiency formula (2) applied. Hoymiles HMS-800W-2T 600 and Huaju HY 600 had the same CEC conversion efficiency, therefore sharing rank six. Envertech EVT-560, Involar MAC 500, and Bosswerk Mi600 had the same conversion efficiency (within the accuracy of the measurement), sharing rank nine. Bosswerk Mi 300 and Envertech EVT-248 were both ranked 14, while Anker MI 60 and Involar MAC 250 shared rank 16. Ecoflow Powerstream 600 and NEP BDM 600 shared rank 18, and Hoymiles HM 700 and Letrika 260S-C60-P260 shared rank 24.

WVC 600 stopped operating at a measured power output of 250 W. After a test run at higher temperatures, the inverter consistently failed. Since the functioning of the WVC 600 and WVC 700 inverter has been extremely poor in tests, its rated power has been assumed. For this reason, WVC 700 is shown first in the table, with a rated power of 600 W (at rank 23), and then with the assumed 700 W rating (according to its type name); however, the final maximum measured power of the WVC 700 inverter was 600 W only.

**Table 2.** Ranking of all microinverters by "CEC Efficiency" according to (2). Nominal power (in W) is indicated in the type name.

| Rank | Brand/Type | CEC Conversion Efficiency |
|---|---|---|
| 1 | Enphase M 215 | 95.6% |
| 2 | PowerOne/ABB 0.25-i | 95.5% |
| 3 | Hoymiles MI 500 | 95.4% |
| 4 | SMA Sunnyboy 240 | 95.1% |
| 5 | Hoymiles MI 600 | 95.0% |
| 6 | Hoymiles HMS-800W-2T 600 | 94.9% |
| 6 | Huaju HY 600 | 94.9% |
| 8 | Technaxx TX 204 | 94.8% |
| 9 | Envertech ENV-560 | 94.6% |
| 9 | Involar MAC 500 | 94.6% |
| 9 | Bosswerk Mi 600 | 94.6% |
| 12 | APSystems YC 500 | 94.5% |
| 13 | Deye Sun 600 G3 | 94.4% |
| 14 | Bosswerk Mi 300 | 94.1% |
| 14 | Envertech EVT-248 | 94.1% |
| 16 | Anker Solix MI 60 | 93.9% |
| 16 | Involar MAC 250 | 93.9% |
| 18 | Ecoflow Powerstream 600 | 92.9% |
| 18 | NEP BDM 600 | 92.9% |
| 20 | Tsun TSOL-MS 600 | 92.8% |
| 21 | APSystems DS3-S | 92.7% |
| 22 | Enecsys SMI-S-240W | 92.0% |
| 23 | WVC 700 (at 600 W) | 91.6% |
| 24 | Hoymiles HM 700 | 91.5% |
| 24 | Letrika 260 | 91.5% |
| 26 | Ienergy GT 260 | 91.4% |
| 27 | AEconversion 250 | 91.2% |
| 28 | Changetech ELV 300-25 | 90.9% |
| 29 | Parkside PBKW-300-A1 | 89.7% |
| 30 | WVC 700 (at 700 W) | 87.5% |
| 31 | WVC 600 (failed) | 0.0% |

Influence of the Operation Temperature on the Results

During the comparative measurements of different PV microinverters, issues arose that were not observed in the conventional efficiency measurements, but which may have an impact on the electrical energy yield.

First, either very slow or very nervous maximum power point tracking algorithms were identified, leading to a reduced energy yield. This issue was addressed by the subsequent outdoor yield measurements.

Thermal issues were also identified. As a first explanation for the reduced energy yield, it is assumed that the conversion efficiency degrades at higher operating temperatures. Therefore, measurements of conversion efficiency and long-term power output at elevated temperatures of 40 °C, 50 °C, and 65 °C were carried out in a heating chamber, specifically a Heratherm Oven (made by Thermo Scientific Inc., Waltham, MA USA), using the same efficiency measurement equipment as mentioned above. The results were published in [8]. A change in efficiency could not be detected at temperatures up to 50 °C, despite the high-precision measurements and repeated procedures. These results corresponded to the results presented above. However, it was found that individual inverters temporarily interrupted or completely stopped operating at longer operating times and higher temperatures, and a reduction in the maximum power was also observed, which could result in yield losses. Therefore, attention must be paid to the appropriate selection of inverters for the situation and ambient temperatures. Unfortunately, datasheet information is not always sufficient or reliable, and in the low-cost segment, the information is often missing.

*3.2. Results of Energy Yield Measurements (Outdoor)*

Figure 7 shows an example of the collected data for a single day. Due to the high time resolution, some specific characteristics could be observed, e.g., starting behaviours, MPP tracking (accuracy and speed), dropouts, and performance.

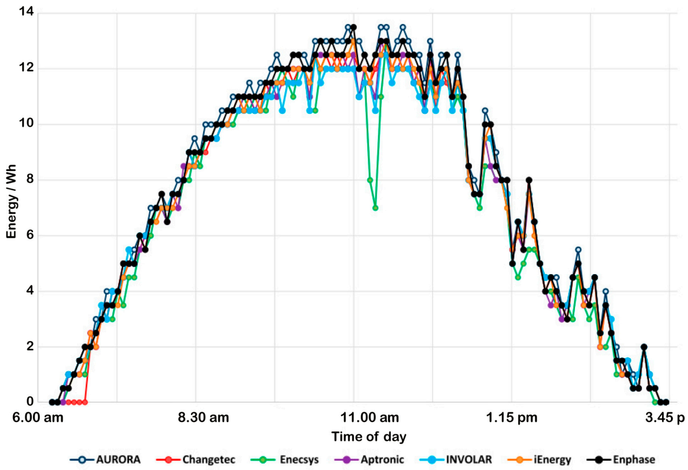


**Figure 7.** Actual recorded data of AC energy generation (over integrals of 5 min) for seven microinverters during the day on 31 October 2013.

Figure 8 shows an example of the collected data for a single day during the spring of 2015 (including the new SMA microinverter). Some inverters had difficulties following the rapid changes in the irradiance levels during that day (e.g., Ienergy).

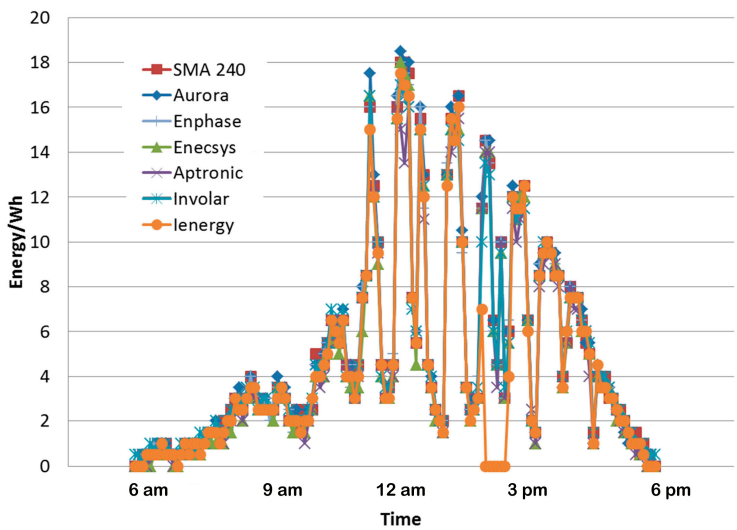


**Figure 8.** Actual recorded data of AC energy generation of seven microinverters (over integrals of 5 min) during the day on 6 April 2015.

An initial ranking list of the total AC energy yield of the microinverters during the common operation period (winter/spring 2014/15) was published in [6], but the specific results are largely outdated now.

Besides the effects already observed with the 215 $W_p$ modules, such as the distinct conversion efficiencies at different irradiance levels, speeds, and accuracies of MPPT algorithms, and the minimum thresholds for initiating operation, temporal saturation effects were also observed for some inverters with the 360 $W_p$ and 405 $W_p$ modules.

The resulting electrical energy yields during the course of one day for the different microinverters and module configurations are shown in Figure 9. To some extent, the above-mentioned effects could be observed. While the different types of effects made it difficult to predict an energy yield for several configurations at some locations, a more consumer-friendly, yield-predicting method was generated by performing a yield data analysis.

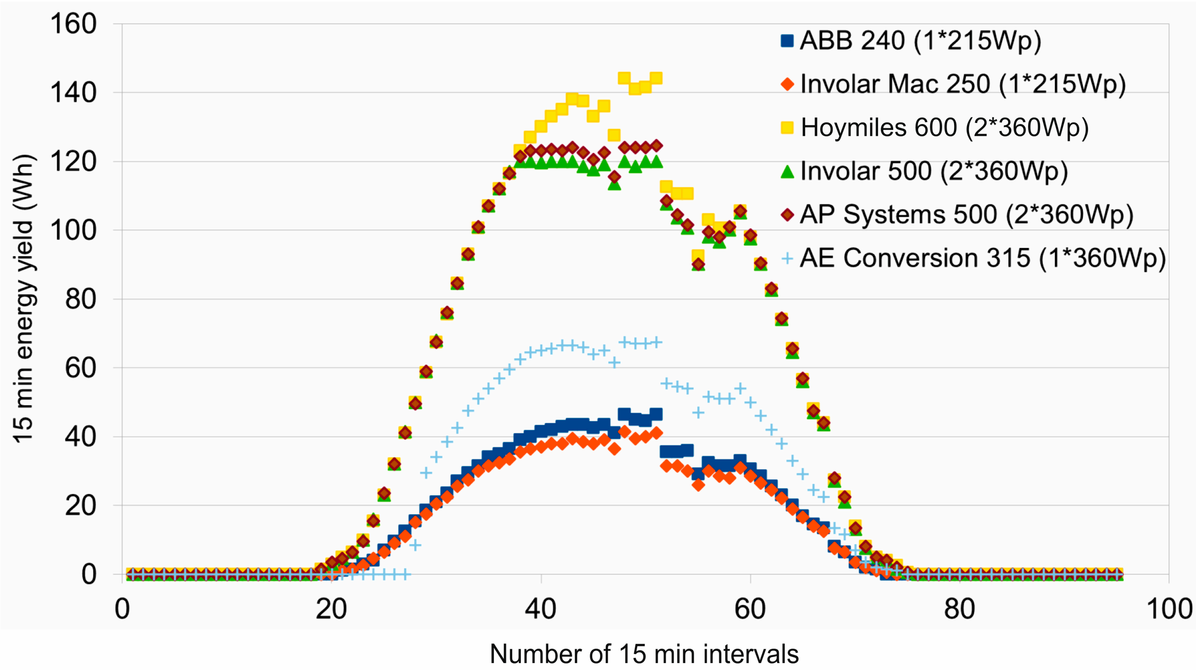


**Figure 9.** Example of electrical energy yield measurements (during intervals of 15 min) of different inverters and two different PV module sizes during a mostly clear day (some clouds in the afternoon).

## 4. Universal Yield Assessment

To simplify the characterisation of a specific combination of the PV module and microinverter, a linear equation was applied to the well-investigated reference characteristics of a very good inverter, without issues regarding low irradiance, MPPT, and saturation. The inverter chosen as a reference was the Enphase M 215, which was ranked #1 in the CEC efficiency ranking.

Plotting a function of the actual daily average yield (y) against the reference yield (x) gave y = $a$ x + $b$ with the trivial coefficients $a$ = 1 and $b$ = 0 for the reference configuration (Enphase M 215 with the Q-cells 215 $W_p$ module). Figure 10 shows the original configuration with the inverters for single modules connected to 215 $W_p$ modules. The coefficients of the different inverters for the relative yield equation y = $a$ x + $b$ are given in Table 3, e.g., it can be observed that for low daily yields, Involar MAC 250 performed a little better than the reference, so $b$ was above 0. For high yields, its performance decreased (relative to the reference), so $a$ was above 1. The characteristics were the opposite for the Envertech EVT 300. The performance at low yields was worse than the reference, so $b$ was negative. The relative performance increased towards high reference yields, so the steepness of the curve was higher, resulting in $a > 1$.

Figure 11 shows the characteristics of different microinverters that can serve two modules, either with two 215 $W_p$ (older measurements) or two 360 $W_p$ modules (latest measurements). Table 4 shows the corresponding coefficients $a$ (for "steepness") and $b$ (for "offset") of the relative daily yield curve.

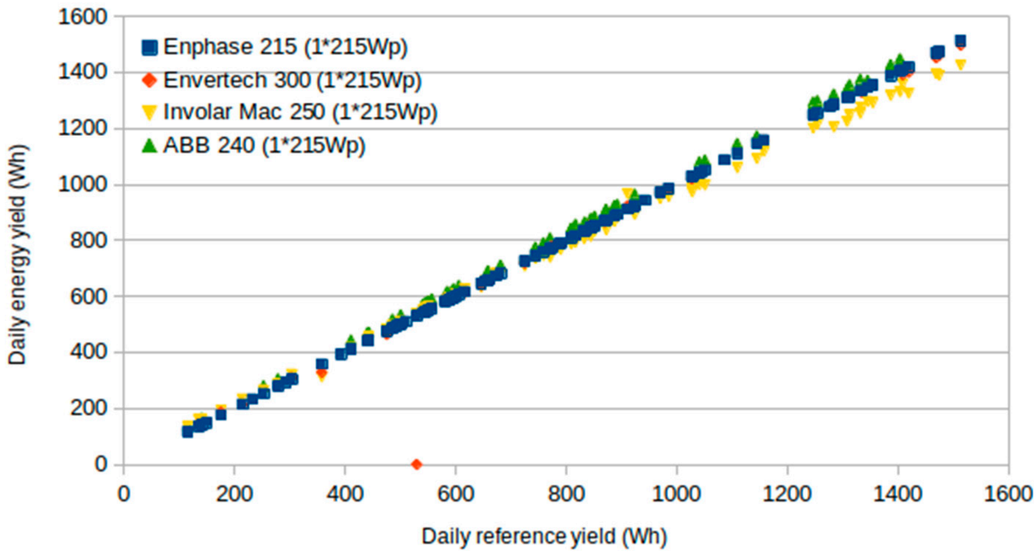


**Figure 10.** Electrical energy yields of different inverters for single PV modules, each connected to a single 215 $W_p$ module. The daily reference yield (*x*-axis) is the energy yield (AC) achieved by an Enphase M 215 inverter with a single 215 $W_p$ module attached.

**Table 3.** Coefficients for the relative daily yield y = *a* x + *b* (referenced to Enphase M 215, all with a single 160 $W_p$, 215 $W_p$, or 360 $W_p$ module). The yield is given in daily average AC electrical energy, and the order is alphabetical.

| Manufacturer | Type (Module Power) | *a* | *b* (Wh) |
|---|---|---|---|
| APSystems | DS-L (1 × 360 $W_p$) | 1.66 | −17 |
| Bosswerk | Mi 300 (1 × 215 $W_p$) | 0.97 | +5 |
| Enphase | M 215 (1 × 215 $W_p$) | 1.00 | ±0 |
| Envertech | EVT 300 (1 × 215 $W_p$) | 1.02 | −33 |
| Involar | MAC 500 (1 × 215 $W_p$) | 0.92 | +43 |
| Lidl Parkside | PBKW-300-A1 (1 × 160 $W_p$) | 0.67 | −41 |
| Power One/Aurora/ABB | Micro-0.25-i (1 × 215 $W_p$) | 1.01 | +26 |

**Table 4.** Coefficients for relative daily yield y = *a* x + *b* for microinverters serving two modules, with either a 215 $W_p$, 360 $W_p$, or 405 $W_p$ capacity (refers to Enphase M 215 with one 215 $W_p$ module). The yield is given in daily average electrical AC energy, and the order is alphabetical.

| Manufacturer | Type (Module Power) | *a* | *b* (Wh) |
|---|---|---|---|
| APSystems | DS-S (2 × 360 $W_p$) | 3.20 | +63 |
| APSystems | DS-M (2 × 405 $W_p$) | 3.90 | +112 |
| APSystems | YC 500 (2 × 360 $W_p$) | 2.95 | +255 |
| Bosswerk | Mi 600 (2 × 360 $W_p$) | 3.12 | +112 |

**Table 4.** *Cont.*

| Manufacturer | Type (Module Power) | *a* | *b* (Wh) |
|---|---|---|---|
| Deye | Sun 600 G3 (2 × 215 $W_p$) | 1.88 | +62 |
| Deye | Sun 600 G3 (2 × 360 $W_p$) | 3.12 | +92 |
| Deye | Sun 800 G4 (2 × 405 $W_p$) | 3.68 | +90 |
| Envertech | EVT 560 (2 × 215 $W_p$) | 1.98 | +38 |
| Envertech | EVT 560 (2 × 360 $W_p$) | 3.23 | +110 |
| Hoymiles | MI 600 (2 × 360 $W_p$) | 3.19 | +168 |
| Hoymiles | MI 700 (2 × 360 $W_p$) | 3.25 | +133 |
| Hoymiles | MI 700 (2 × 405 $W_p$) | 3.64 | +296 |
| Hoymiles | HM 800–T2 (2 × 405 $W_p$) | 3.81 | +142 |
| Huaju | HY 600 (2 × 360 $W_p$) | 3.14 | +154 |
| Involar | MAC 500 (2 × 360 $W_p$) | 2.89 | +181 |
| NEP | BDM 600 (2 × 360 $W_p$) | 2.70 | +276 |
| Technaxx | TX 204 (2 × 360 $W_p$) | 3.16 | +190 |
| WVC | WVC 700 (2 × 360 $W_p$) | 2.75 | +172 |

The coefficients of determination *R* for all regressions of all measurement values to determine the coefficients *a* and *b* were in the vicinity of 0.98.

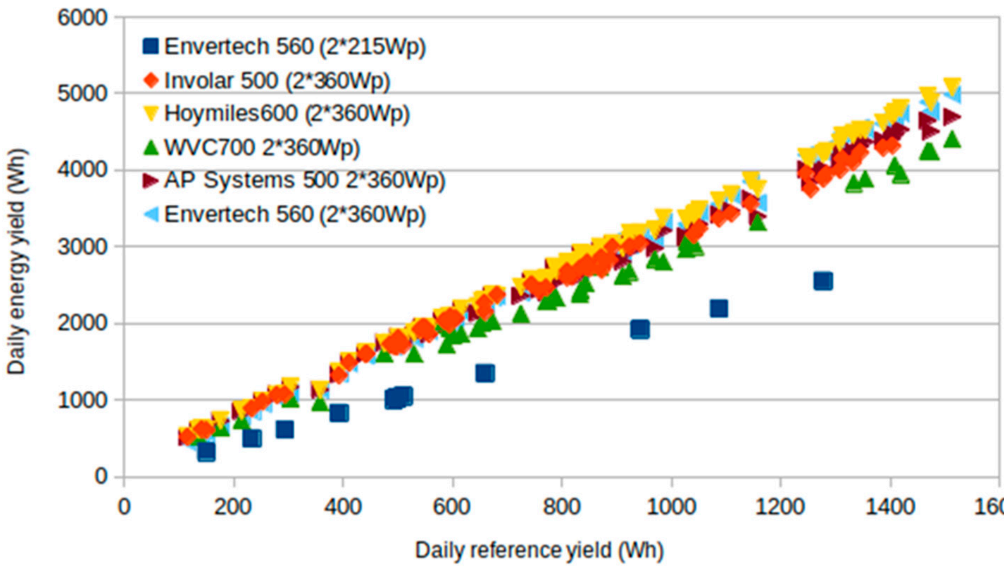


**Figure 11.** Average daily energy yields (AC) of different inverters for two modules with two 215 $W_p$ or 360 $W_p$ modules attached. The reference yield (*x*-axis) is the yield achieved by an Enphase M 215 with a single 215 $W_p$ module applied.

## 5. Conclusions

A comparison of most microinverters on the European market in terms of DC-AC conversion efficiencies (covering the full range of load conditions) has been conducted by precision measurements. According to the requirements for the weighted European and CEC efficiency, a ranking has been established and has been updated regularly over a period of more than ten years. This allows the reader to put the weighted efficiency differences into perspective within a cost–benefit comparison of the preferred types and brands of microinverters.

The influence of operation in a high-temperature environment has been examined. It was found that individual inverters temporarily interrupted or completely stopped operation at longer operating times and higher temperatures, and a reduction in the maximum power was also observed.

Efficiencies alone do not necessarily reflect the energy yield due to differing MPPT capabilities, so yield measurements are helpful, carried out, and described in previous publications, e.g., [6]. However, due to drastically reduced module prices and relatively stable inverter prices, overpowering has become quite common, which makes specific yield measurements ineffective due to the enormous number of possible configurations of inverter and module sizes.

The use of a reference configuration together with the two coefficients of a linear equation is a simple method to describe the daily yield performance of any microinverter in combination with any PV module, even under- or oversized ones. While prices of PV modules are decreasing at a higher rate than prices for microinverters, we will see more configurations with oversized modules and more saturated microinverters more often in the future. Legislative bodies in various countries (e.g., in Austria, Germany, and Switzerland) are considering overpowered systems, often limiting power on the AC side only. This highlights the necessity of a method, such as the one described here, to extrapolate the energy yield.

## 6. Outlook

While the costs of the PV modules are now typically lower than the costs of the inverters, the pressure for cost reduction in inverters is evident. After a cost investigation of the internal components of a typical microinverter, it was determined that further cost reductions are not possible on this side. However, for the external components, such as the cables, connectors, and casing, a reduction in cost may be possible if the inverter can be integrated into the module terminal box or the frame of the module, making most of the external components obsolete. A step in this direction was carried out by the company SolarNative©, which integrated the inverter into a square tube that could be placed inside the module frame. Going further, this would lead to an “AC module” that would use the casing provided by the module frame or module terminal box, such that the DC wiring would be internal only, making DC connectors obsolete and thus making the installation of the complete PV system easier. Such AC modules have been described in the literature, e.g., [4,9,10]; however, they have not yet made it past prototype status. A significant challenge are the stringent tests for PV module certification based on the IEC 61215, which would have to be applied to the integrated inverter as well. These include quick thermal changes between −40 °C and +85 °C and a 1000 h damp heat test at 85 °C and 85% humidity. Usually, electronics fail under such conditions.

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