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Peter Breuhaus (IRIS)

PV Challenges

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13.11.2017 — Peter Breuhaus, Project Manager — Sign.date

13.11.2017 — Project Quality Assurance, M. Mansouri — Sign.date

15/11-17 — Øystein Arild, Research Director, New energy, risk management and well construction — Sign.date

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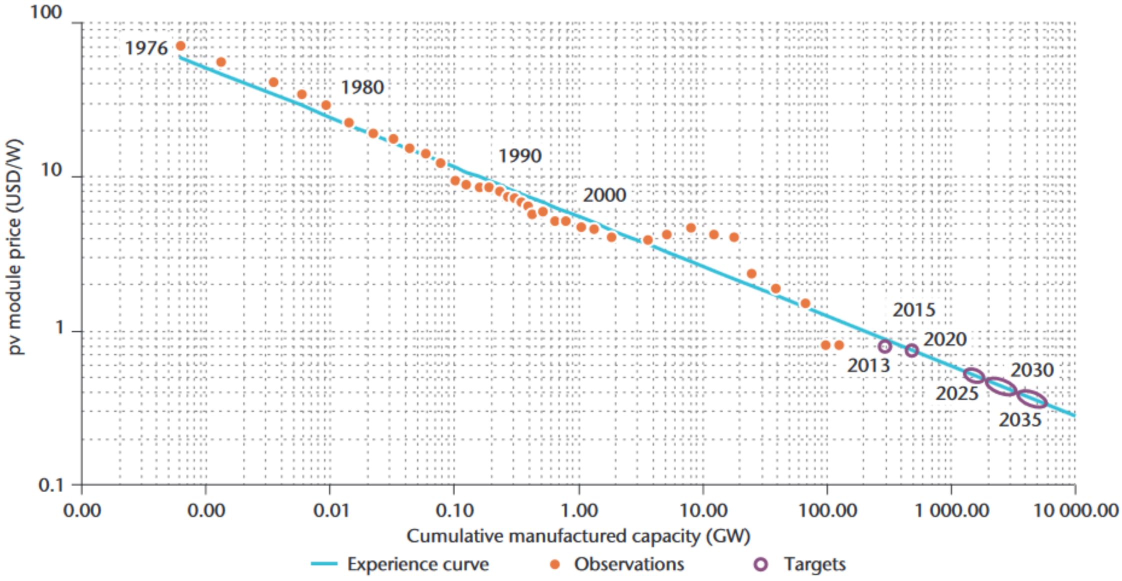
Introduction

In order to meet emission targets and to cover local energy demands with locally produced power is solar energy in the focus in Norway and where “the Energi21 board recommends strong growth in public funding for research, development and demonstration.”[1]. One of the six focus areas is solar energy.

Solar energy, especially electricity generation via photovoltaic became very attractive during the recent years, not at least due to the continuous reducing costs (Figure 1).



Notes: Orange dots indicate past module prices; purple dots are expectations. The oval dots correspond to the deployment starting in 2025, comparing the 2DS (left end of oval) and 2DS hi-Ren (right end).

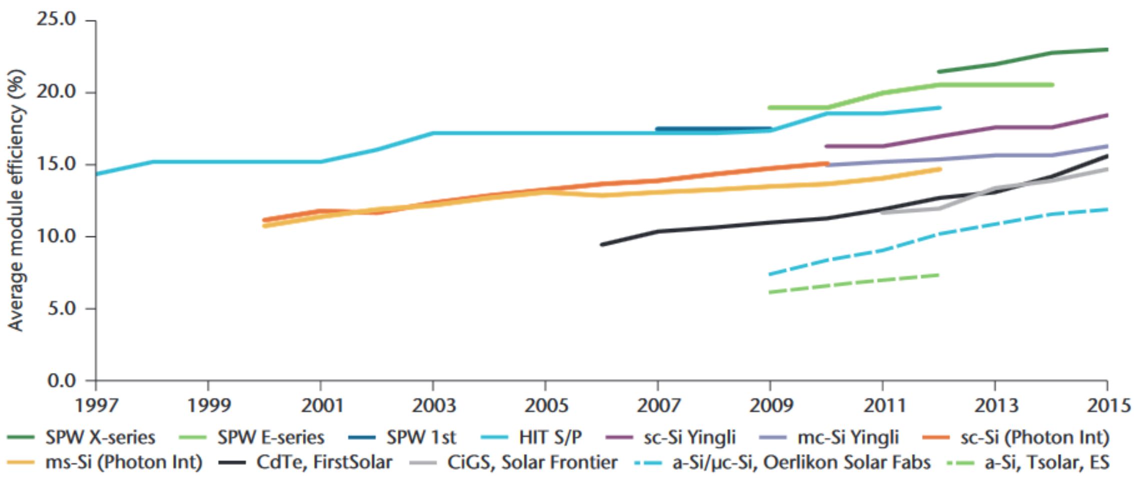
Figure 1: Past modules prices and projection to 2035 based on learning curve[2]

At the same time is the efficiency continuously increasing (Figure 2). This development makes it in consequences also interesting to install units in Norway. However these installations are connected to some technical challenges in installation and integration of the technology into the grid. Some of the challenges are related to the fact that many installations are expected to be applied to existing buildings, therefore often because for the already existing building, compromising towards what would be the optimal installation and operation in a green field application.

In Forus at 2020 park are two different systems installed and in operation. These two installations are used to evaluate some of the challenges connected to their installation and operation. This is done both, from the theoretical side as well as based on available experimental (i.e. measured) data.

1 Strategy 2014 – National Strategy for research, development, demonstration and commercialisation of new energy technology; Part 1/2 ; available at https://www.energi21.no/prognett-energi21/Strategidokumenter/1253955410657

2 International Energy Agency “Technology Roadmap – Solar Photovoltaic Energy”, available at https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapSolarPhotovoltaicEnergy_2014edition.pdf



Note: SPW stands for *SunPower*, HIT S/P stands for *Heterojunction Intrisic Thin layer Sanyo/Panasonic*.

Source: De Wild-Scholten, M. (2013), "Energy payback time and carbon footprint of commercial PV systems", *Solar Energy Materials & Solar Cells*, No. 119, pp. 296-305.

Figure 2: Commercial 1-sun module efficiencies (actual and expected)[2]

2 Challenges of installation

There are two different installations at 2020Park. One consisting of three parts mounted on the flat / horizontal roof and one as a building integrated one mounted vertically on the on the wall.

Those on the roof consist of in total twelve parts (panels) which have a tilt angel of 10^{o} relative to the horizontal roof. Four elements are oriented towards geographical east, four to south and four to west. In contrast to this installation are the vertically mounted ones facing south only. Both installations were installed on an already existing building and are therefore need to making use of be integrated into the given building geometry. The difference of the two installations directly result in questions on the impact of the tilt angle (relative to horizontal positioning) and that one of the orientation (East, south, west).

2.1 Impact of tilt angle

The impact of the tilt angle is analysed using results of calculating the expected solar irradiation with the program PVGIS for Europe[3] with specifying the location of 2020Park (Latitude: 58°53'24" North, Longitude: 5°44'15" East, see Figure 3). The program calculates the solar irradiation for different tilt angles, which are defined relative to the horizontal plant. It returns as results average values for a year (per month) or day (per hour) and different cloud conditions. These are clear sky, covered with clouds and a value representing an average mix of clouds and clear sky. In addition are values calculated assuming a two-axis tracking system. Such a system continuously

3 Tool available under http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe (last called on 24.08.2017)

optimises the orientation of the PV panel relative to the sun so that the maximum possible energy can be harvested. However due to the necessary tracking system and support structure are such systems relatively heavy and costly and therefore seldom installed on existing buildings.

For the evaluation of the impact of the tilt angle are four calculated irradiation intensities calculated. These are the above mentioned three with the pre-defined and fixed tilt angle. In addition is the one representing those with a two-axis tracking system with clear sky used for comparison as representing the maximum.

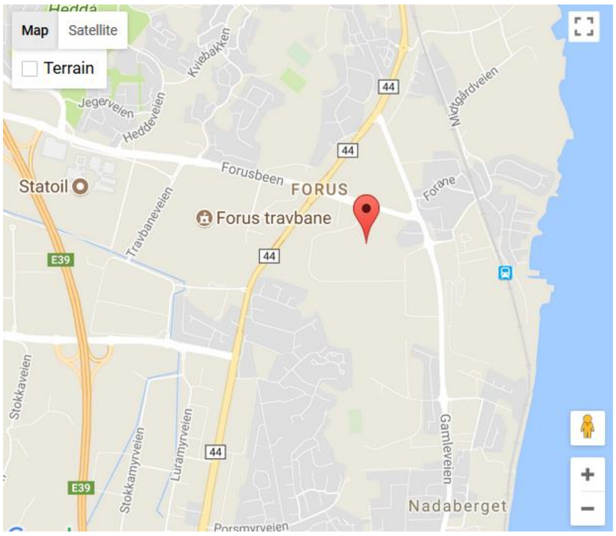


Figure 3: Selected location on PVGIS for Europe

Figure 4 below shows simulation results for a 10° tilt angle in December and June.

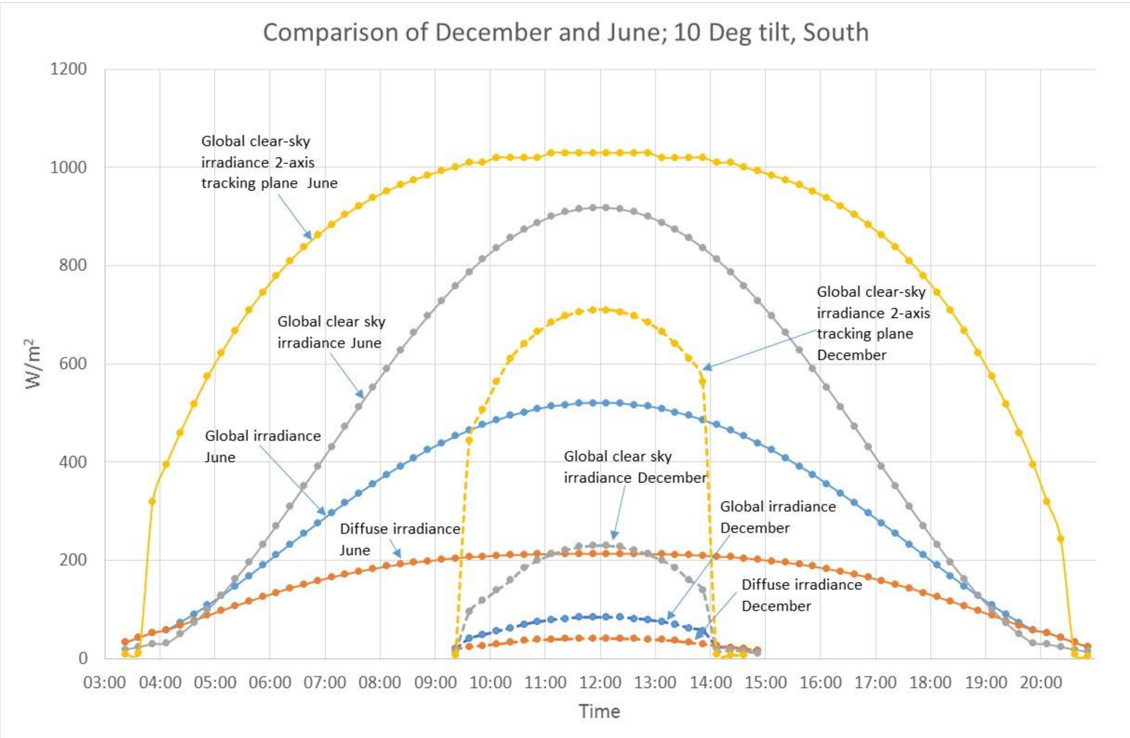


Figure 4: Solar irradiation values for June (solid line) December (dashed line) and 10° tilt

The graph shows:

- The large difference in possible duration of sunshine in the Stavanger area (see the time scale on the x-axis)
- The impact of the tilt angle by comparing the curve of the two axis tracking system (yellow) and the one for a clear sky and fixed tilt angle. During winter

time with the sun rising not too largely over the horizon is the impact of the tilt angle significantly larger than in summer.

The similar graph for 90^o tilt angle is shown in Figure 5. Especially in comparison with Figure 4 is the impact of the tilt angle directly visible. The irradiation on the PV plane in summer is significantly lower due to the large deviation from an optimum 90^o angle between incoming solar radiation and the PV panel. In contrast to it is the situation in winter close to optimum as the curve for the global clear sky irradiance almost overlaps with the curve with a two-axis tracking system. The irradiation intensity onto the PV panel is even higher in December than in June.

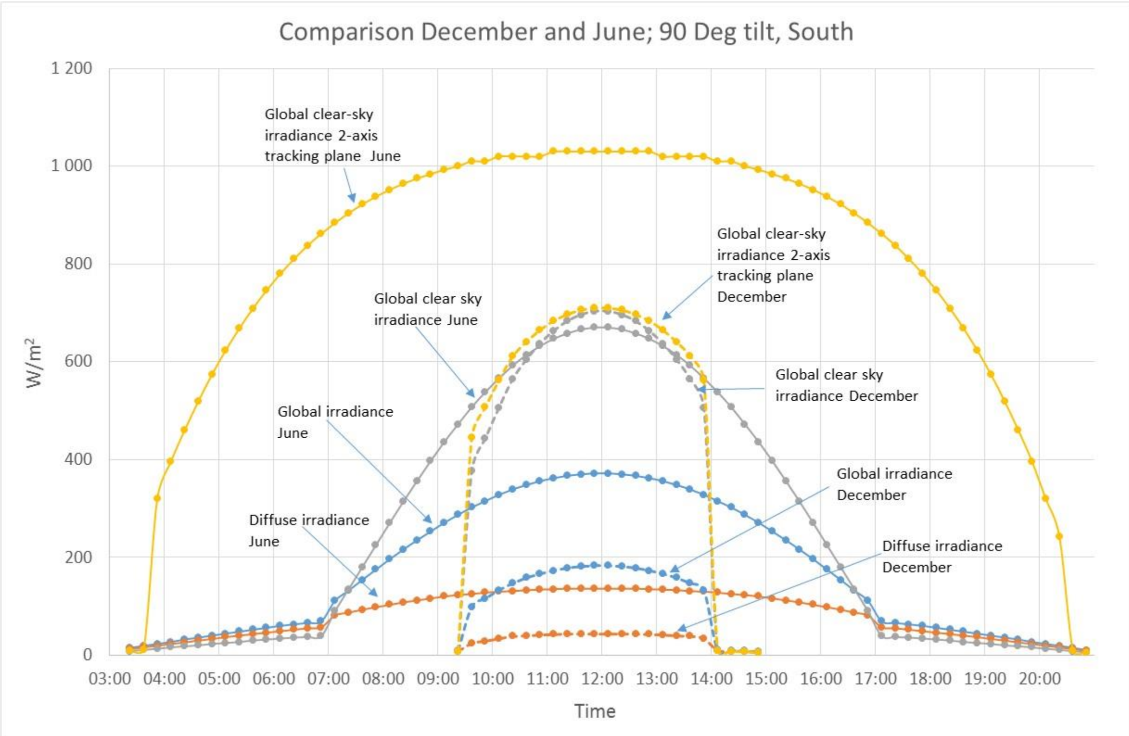


Figure 5: Solar irradiation values for June (solid line) December (dashed line) and 90^o tilt

When running similar simulation for a tilt angle of 45^o are, as was more or less to be expected, the curves between those for 10^o and 90^o tilt (see Figure 6). It is remarkable that this tilt angle results in an irradiation with the maximum value closest to that one of the 2-axis tracking system in June. When integrating the solar intensity for all the cases

	Two-axis tracking	10 Deg tilt angle	45 Deg tilt angle	90 Deg tilt angle
June clear sky	587 kWh/m^2	356,3 kWh/m^2	346,4 kWh/m^2	194,5 kWh/m^2
June average sky	315 kWh/m^2	226,6 kWh/m^2	215,4 kWh/m^2	127,9 kWh/m^2
June cloudy	121 kWh/m^2	113,6 kWh/m^2	103,6 kWh/m^2	60,5 kWh/m^2
December clear sky	120,2 kWh/m^2	35,9 kWh/m^2	94,7 kWh/m^2	114,2 kWh/m^2
December average sky	31,8 kWh/m^2	14,2 kWh/m^2	27,2 kWh/m^2	30,1 kWh/m^2
December cloudy	8,3 kWh/m^2	7,8 kWh/m^2	9,2 kWh/m^2	7,8 kWh/m^2

Table 1: Solar energy per day and m^2 for June and December for different tilt angles

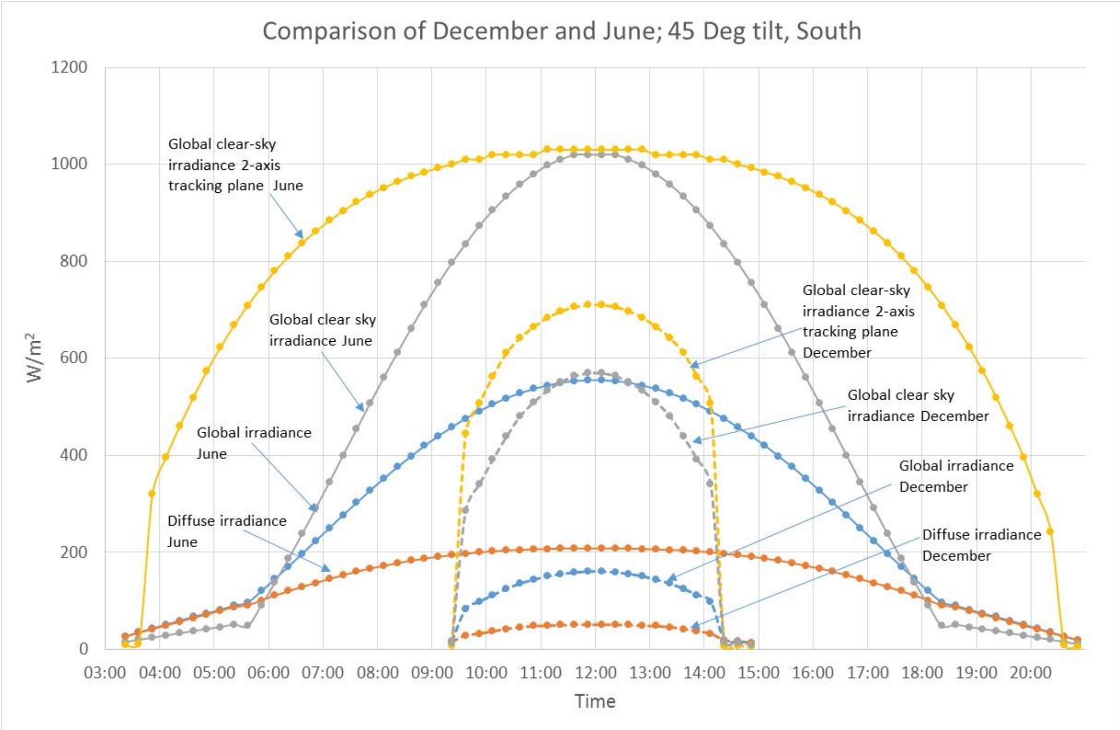


Figure 6: Solar irradiation values for June (solid line) December (dashed line) and 45° tilt

for one day can be the Table 1 generated allowing to compare accumulated solar irradiation. Based on the table and considering the fixed angle applications only, it seems that an application with 90° tilt angle has the highest performance in December while in June the 10° option performs best. However integral over the year is a fixed tilt angle of about 45° the one having the highest solar irradiation rate. This is visible in Figure 7. However, it needs to be noted that:

- a 45° tilt angle requires a larger distance between two neighbouring rows of panels in order to compensate for shadowing effects and in consequence might reduce the gain in produced power compared to a, for example 10° angle. The magnitude of it depends on the situation on site and should be subject to site specific optimisation.
- it might not be possible to implement such a tilt angle especially on flat roofs of existing buildings. This is due the comparatively high wind load on the panels and structural limitations of installing the necessary support structure and fixation.
- it is also visible that larger tilt angles are beneficial during winter time as they perform better when the sun is relatively low over the horizon. This might match well with the, in most cases, higher energy demand during winter months and the connected higher costs of electricity during this period of the year.

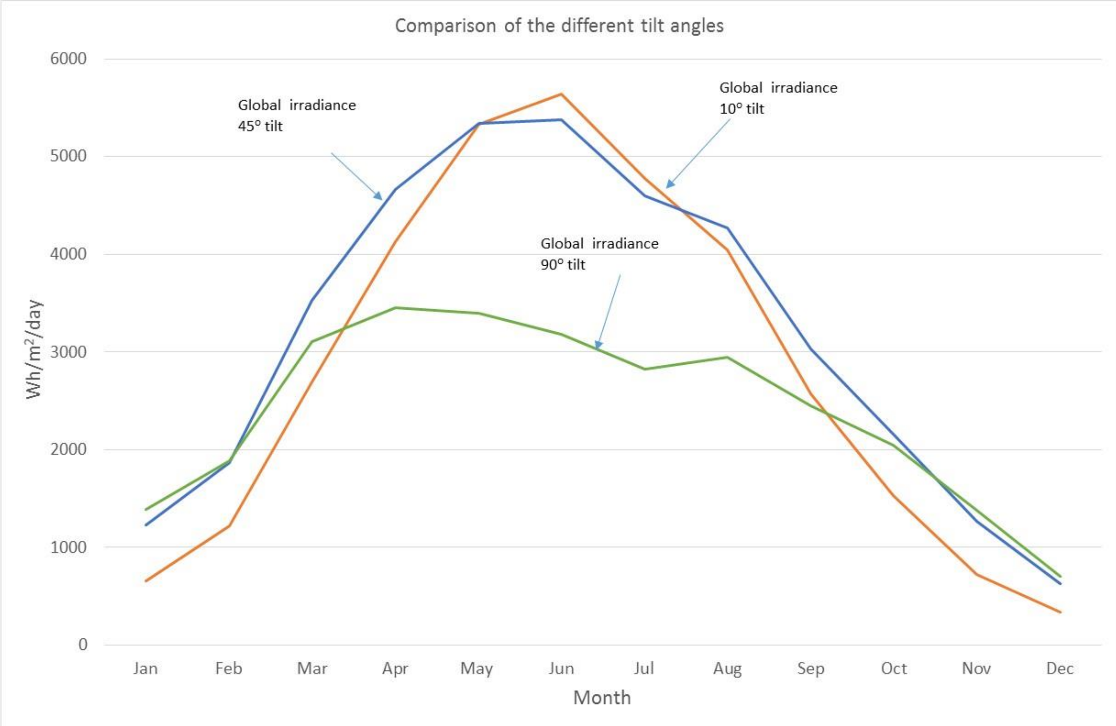


Figure 7: Comparison of solar irradiation per day on PV panels facing south for different months of the year.

2.2 Impact of orientation

Another parameter to consider during the layout of a PV installation is its direction towards East, South or West. For the three different cases of tilt angels were simulations run considering orientation to each of the directions. Considered were values of global irradiance, which are representing the case of an average cloud / clear sky share (Figure 8, Figure 9 and Figure 10).

The case with a tilt angle of 10^o deg (Figure 8) indicates that the impact of a different orientation relative to pure South orientation amounts to be between +60 W/m^2 and -68 W/m^2 in June. In December is the deviation only negative, as an orientation to East or West results in always lower values compared to facing south. The maximum deviation for December is -32 W/m^2. The difference between a 2-axis tracking system and a 10^o South-facing one amounts to -102 W/m^2 in December due to the low position of the sun.

In case of 45^o deg (Figure 9) is the deviation much more pronounced (+245 W/m^2 and -278 W/m^2 in June and -126 W/m^2 in December). The graph indicates that a combination of PV panels oriented into the three directions would get close towards the irradiance curve of a two-axis tracking system. Also in December has a south facing panel a significantly higher irradiance than the 10^o deg version, almost twice the irradiance.

For 90^o deg (Figure 10) is the deviation even further pronounced (+336 W/m^2 and -282 W/m^2 in June and -167 W/m^2 in December). The larger spread indicates the impact of the orientation and position of the sun relative to the horizon. This vertical inclination is, as well as the 45^o one, especially during morning and evening hours relatively close to that with a 2-axis tracking system. Interesting also the performance of the 90^o south orientation in December, where it matches almost fully with that of the 2-axis tracking.

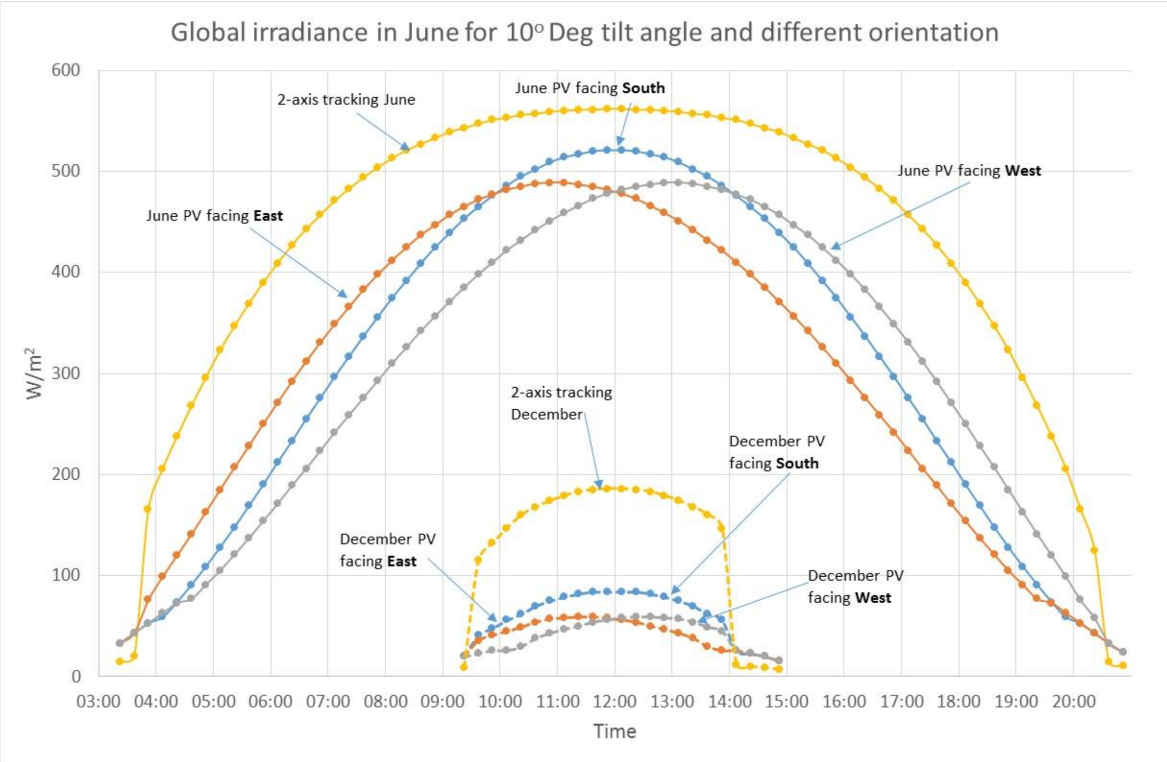


Figure 8: Effect of PV-panel orientation on the solar irradiance for 10° tilt angle

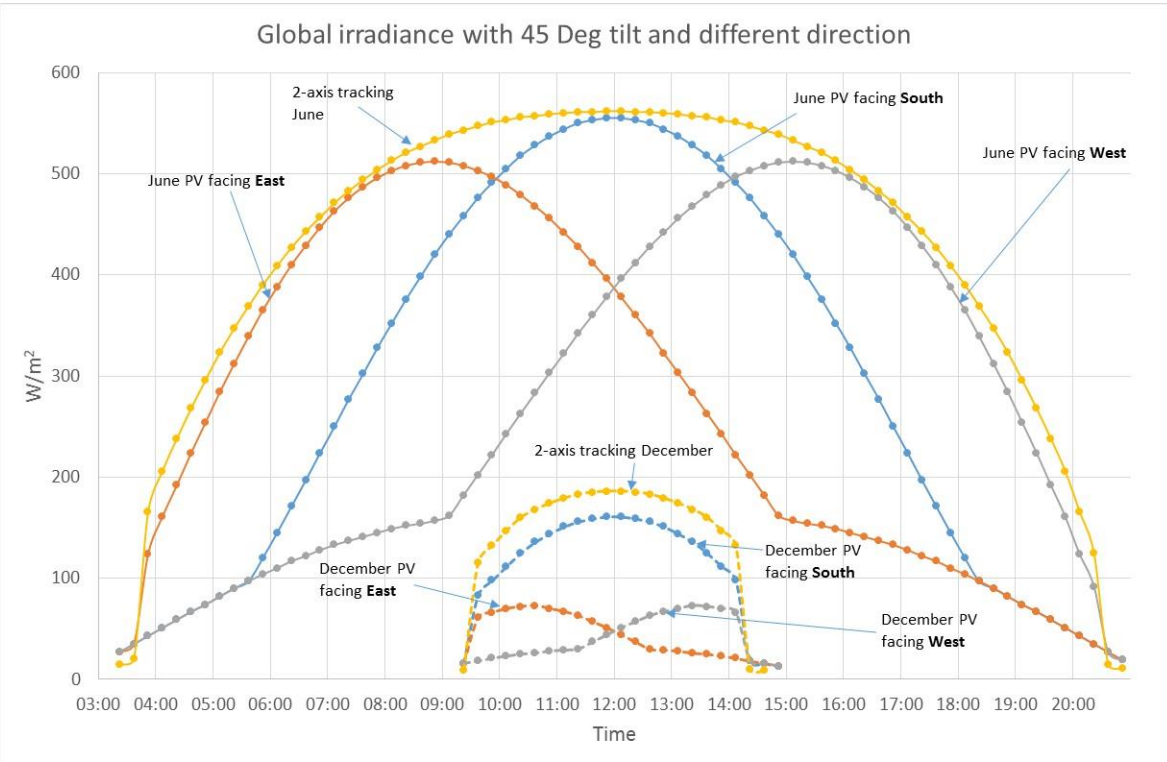


Figure 9: Effect of PV-panel orientation on the solar irradiance for 45° tilt angle

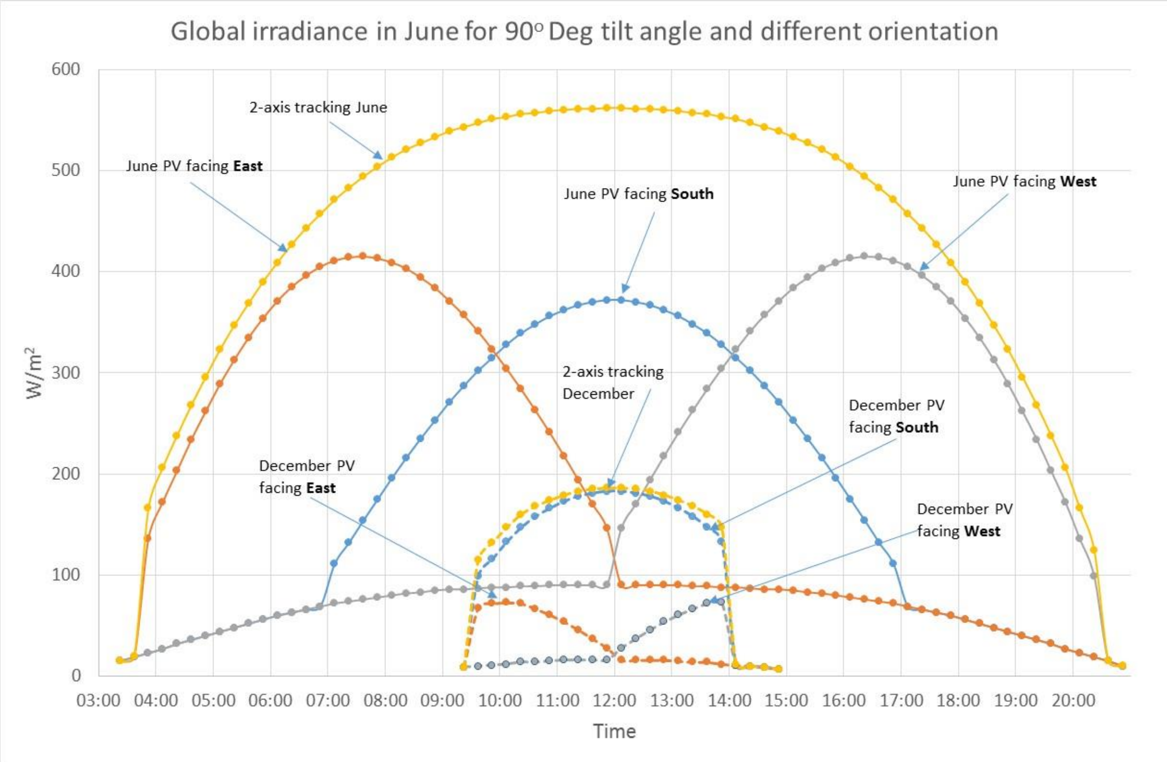


Figure 10: Effect of PV-panel orientation on the solar irradiance for 90° tilt angle

2.3 Discussion of the simulation results

The different diagrams shown above, even though they were covering extreme positions and orientations only, demonstrate their impact. Even though current practice is to produce as much energy as possible (i.e. kWh/year) allows a closer evaluation of the electricity demand plus a careful design of the PV installation in terms of orientation and tilt can support to cover the local demand as far as possible. Further more might be electricity prices be considered when designing PV systems. From that point of might for example a 90° tilt preferred to one of 45° or 10° because of it significantly better irradiance characteristic during winter when electricity price is much higher than in summer while at the same time demand is increased.

Furthermore might solutions for on-grid and off grid systems differ due to the abovementioned reasons.

3 Measurement results

For this study were two applications evaluated, both installed at 2020Park. These two different installations are an on-roof installation with 10° tilt angel and an equal PV area oriented towards east, south and west. The second one is a south oriented installation on the wall of one of the buildings resulting in a 90° tilt angle. For both of them were, to evaluate production rates system output produced as a standard monitoring system of the suppliers used. Data in forma excel tables etc. for further in-depth analysis were unfortunately not available. Given the evaluation above was the main focus of this part towards the electricity delivered and coupling to the grid and not considering all aspects of orientation of the cells.

3.1 Measured data

Data available is based on information retrieved from the PV-system via the web-page of the supplier. The main source is the inverter unit making it possible to collect data on the DC and AC side of the inverter as well as the delivered energy. A typical graph is shown in Figure 11. Within the graph indicates the x-axis the time of the day.

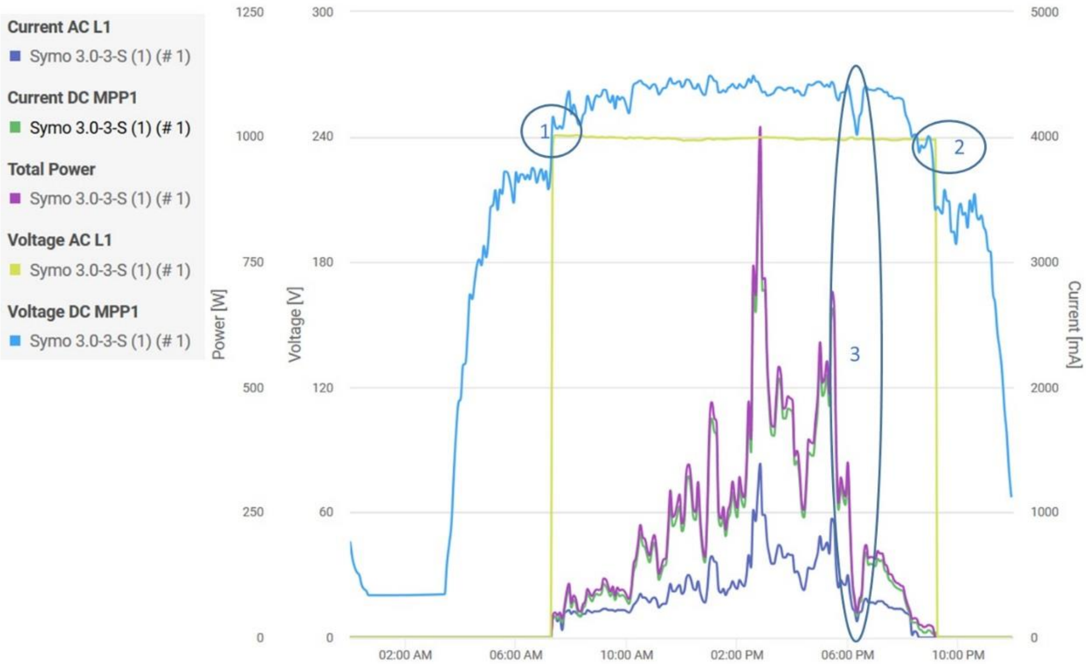


Figure 11: Measured data of a PV-Panel on 18.06.2017

Visualized are on the DC and AC side of the inverter current and voltage as well as the total power (pink line).

The diagram indicates that:

- The threshold vale of about 240V DC needs to be reached before energy will be transferred to the grid
- The threshold has a certain bandwidth of tolerance before establishing or stopping the connection to the grid as can be seen at 1 and 2 2 in the figure above. At 1 seems DC voltage to be higher than the AC on to connect while at 2 it seems to be lower before PV is disconnected from the grid. However, to evaluate it in more detail and clarity would be necessary to install laboratory like instrumentation and data acquisition system guaranteeing a well synchronized and high speed collection of measurements (e.g. 20 msec between two samples).
- At 3 3 is the drop-in power production closely coupled with a drop in DC-voltage. This might be remarkable as at earlier times of the day such a pronounced effect is not directly visible. A reason might be that the power level is lower, but this might require an in-depth analysis.
- Of interest for connecting to energy storage systems are periods outside connection to the electrical grid. While DC voltage does not seem to be sufficient to deliver energy to the grid might it be still used for charging batteries.

Challenges resulting from a day with several passing clouds is visible in data collected on 25.06.2017 (Figure 12)

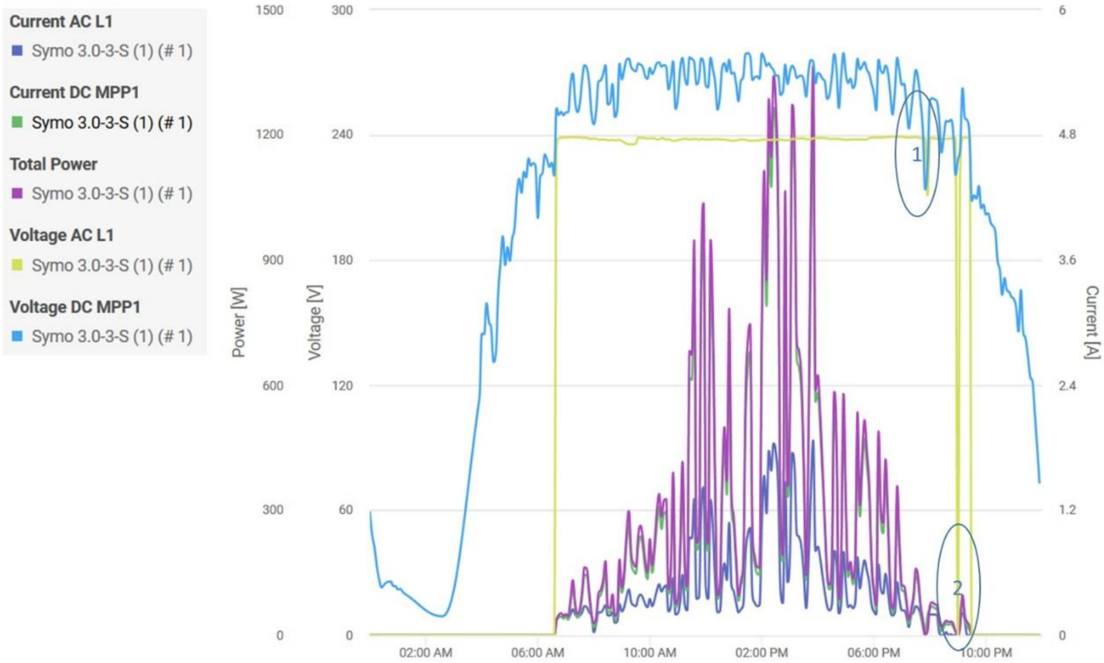


Figure 12: Data measured on 25.06.2017

This figure indicates:

- Large and fast variations of the power within very short time frame. This will, in case of large installations and a significant share of power produced by PV result in challenges for a stable grid. In those cases might it be necessary to install fast reacting storage capacities to avoid significant disturbances in the grid, support its stability and avoid the danger of outages.
- It seems that the system allows for larger deviation of the voltage 1 from the desired 240V also on the AC side while the criterion for disconnecting from the grid seems to be the produced power 2. This is supported by data collected on 23.09.2017 (Figure 13). The historian of the unit shows that 16:55 DC voltage drops down to a value of 152,3V, well below the AC voltage of, in average, 237,47V without disconnecting from the grid.

These findings indicate that criteria for connecting and disconnection for the grid differ. It is also visible that the selected sampling rate / rate stored in the historian is too low for being able to identify. The rate available is $1/_{5\ minutes}$ while grid frequency is 50 Hz $\left(1/_{20\ milli\ sec}\right)$. I can be expected that a sampling rate close that of controller speed might allow a detailed evaluation. However, capturing data at such a high rate will result in extraordinary large data volume. It might be possible to reduce the stored amount of data via event-driven data storage. This technology is using a, in time sliding window of a high sampling rate which is only saved in case of a detected event. Otherwise is data saved based on the standard resolution (e.g. $1/_{5\ minutes}$). This allows for keeping required storage capacity low while at the same time allowing an in-depth analysis of data in case of an event.

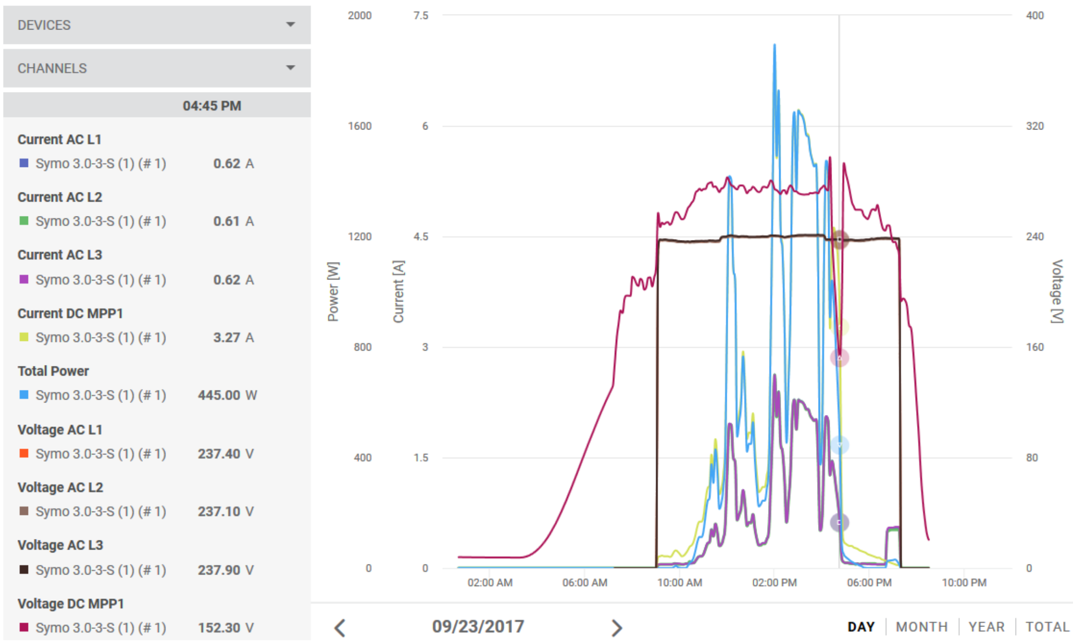


Figure 13: Measurement data 23.09.2017 indicating low DC voltage without disconnecting the unit

3.2 Solar intensity measurements

As available data for the PV installation is available with 10 sec resolution only show results of detailed measurements of solar intensity, collected at a different test site in the area of Forus in 2016, the level of fluctuation due to passing clouds.

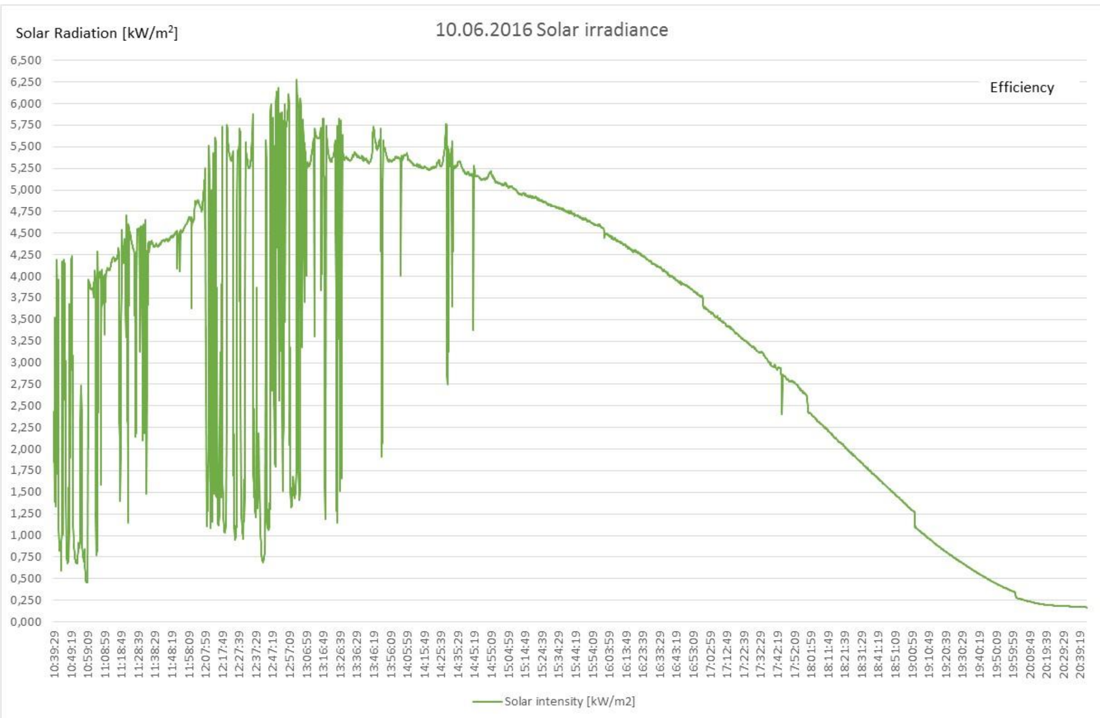


Figure 14: Solar irradiance measurements on 10.06.2016

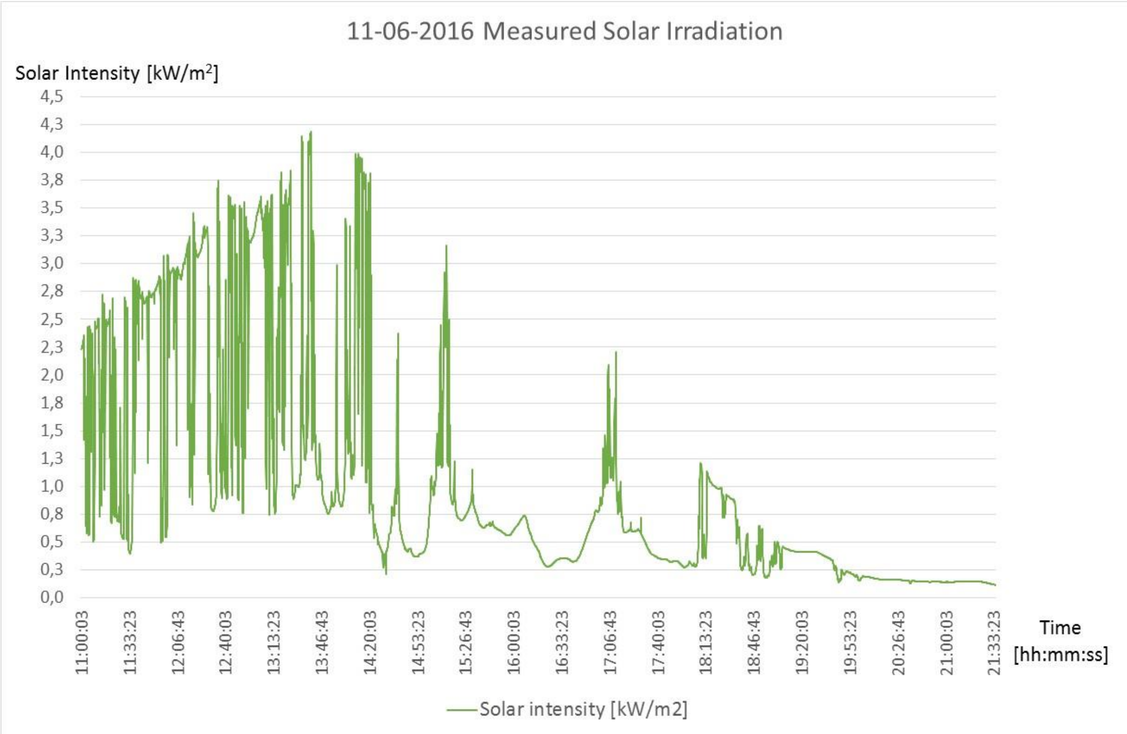


Figure 15: Solar irradiance measurements on 11.06.2016

The aim of visualising this data here is to show the rapid change in solar intensity in a very short time due to passing clouds. Measurements were collected at an interval of 10 sec. Analysis of the data show that solar energy was changing with even more than 75% between two recorded data (i.e. 10 sec). These changes are, in case no energy storage / buffer is implemented, directly coupled to the change in exported PV-based electricity. Especially in case of connecting large PV plants to the gird directly, will it be necessary to balance these fast changes in order to avoid stability problems in the electrical grid.

Storage technologies to compensate for these fast fluctuations are batteries, flywheels and power to gas technology (e.g. pressurized PEM electrolyser/fuel cell), with the power to gas technology being well suited for bulk energy storage and back-conversion. Tabell 1 below gives an overview over technologies for storing electrical energy, their characteristic as well as their maturity level (2016). Especially technologies with discharge/reaction time of max. a second are well suited for balancing fast fluctuating PV.

Technical characteristics of some selected energy storage technologies.

Technology	Energy density Wh/kg(W h/L)	Power density W/kg(W/L)	Power rating	Discharge time	Suitable storage duration	Life time (years)	Cycle life (cycles)	Capital Cost			Round trip efficiency (%)	Technological maturity
								$/kW	$/kWh	$/kW h-per cycle		
Flywheel	10–30(20–80)	400–1500(1000–2000)	0–250 kW	ms–15 min	s–min	~15	20,000+	250–350	1000–5000	3–25	85–95	Commercial
PHES	0.5–1.5(0.5–1.5)		100–5000 MW	1–24 h+	h–months	40–60		600–2000	5–100	0.1–1.4	65–87	Matured
CAES	30–60(3–6)		5–300 MW	1–24 h+	h–months	20–60		400–800	2–50	2–4	50–89	Developed
GES												
GPM	1.06(1.06)	3.13(3.13)	40–150 MW		h–months	30+		1000			75–80	Concept
ARES			100–3000 MW	34 s	h–months	40+		800			75–86	Concept
HES												
Fuel cell	800–10,000(500–3000)	500+(500+)	0–50 MW	s–24+h	h–months	5–15	1000	10,000+		6000–20,000	20–35	Developing
Gas engine	33,300(530–750)		0–50 MW	s–24+h	h–months						40–50	Developing
Super-capacitor	2.5–15	500–5000	0–300 kW	ms–60 min	s–h			100–300	300–2000	2–20	90–95	Developed
Batteries												Commercial
NaS	150–240(150–250)	150–230	50 kW–8 MW	s–h	s–h	10–15	2500	1000–3000	300–500	8–20	80–90	Commercial
NaNiCl	100–120(150–180)	150–200(220–300)	0–300 kW	s–h	s–h	10–14	2500+	150–300	100–200	5–10	85–90	Commercial
VRB	10–30		30 kW–3 MW	s–10 h	h–months	5–10	12,000+	600–1500	150–1000	5–80	85–90	Demonstration
FeCr	10–50	16–33	5–250 kW	s12+h	h–months				250		70–80	Commercial
ZnBr	30–50(30–60)		50 kW–2 MW	s–10 h	h–months	5–10	2000+	700–2500	150–1000	5–80	70–80	Demonstration
Zn-air	150–3000(500–10,000)	100	0–10 kW	s–24h+	h–months			100–250	10–60		50–55	Demonstration
Li-ion	75–200(200–500)	500–2000	0–100 kW	min–h	min–days			1200–4000	600–2500	15–100	85–90	Demonstration
SMES	0.5–5(0.2–2.5)	500–2000(1000–4000)	100 kW–10 MW	m–8 s	min–h	20+	100,000+	200–300	1000–10,000		95–98	Demonstration
LAES	97		350 kW–5 MW	1–24 h+	h–months	20+		1000–2000			50–70	Demonstration

Tabell 1: Electricity storage technologies[4]; PHES – pumped hydro energy storage, CAES – compressed air energy storage, GES – gravity energy storage, HES – hydrogen energy storage, SMES - Superconducting Magnetic Energy Storage, LAES - Liquid Air Energy Storage

4 M.Aneke, M. Wang: *Energy storage technologies and real life applications – A state of the art review* Applied Energy 179 (2016) 350-377

3.3 Possibilities besides energy export

As visible in Figure 11 and Figure 12 exists also outside the periods of energy export a certain Voltage level which could be utilized by integrating energy storage (e.g. battery). However, estimating the possible saved energy is, given the available information, relatively uncertain. As is visible in Figure 16 below is the inverter connected to three phases on the AC side. It is interesting to see that, while the voltage level is more or less identical for all three AC phases, the current might vary in very wide range as for example at 10:00. Phase one current is given as 0 mA, phase two as 140 mA and phase three as 260 mA. The voltage between the phase varies only by in maximum 2,3 V at an average level of 233,77 V.

The relatively large difference in current between the three phase might result in imbalance between the phases and therefore a poor power quality. The impact of the imbalance on the grid and power quality depends on the size of the PV field as well as on the grid. However, it needs to be considered and might be worth a separate in-depth evaluation.

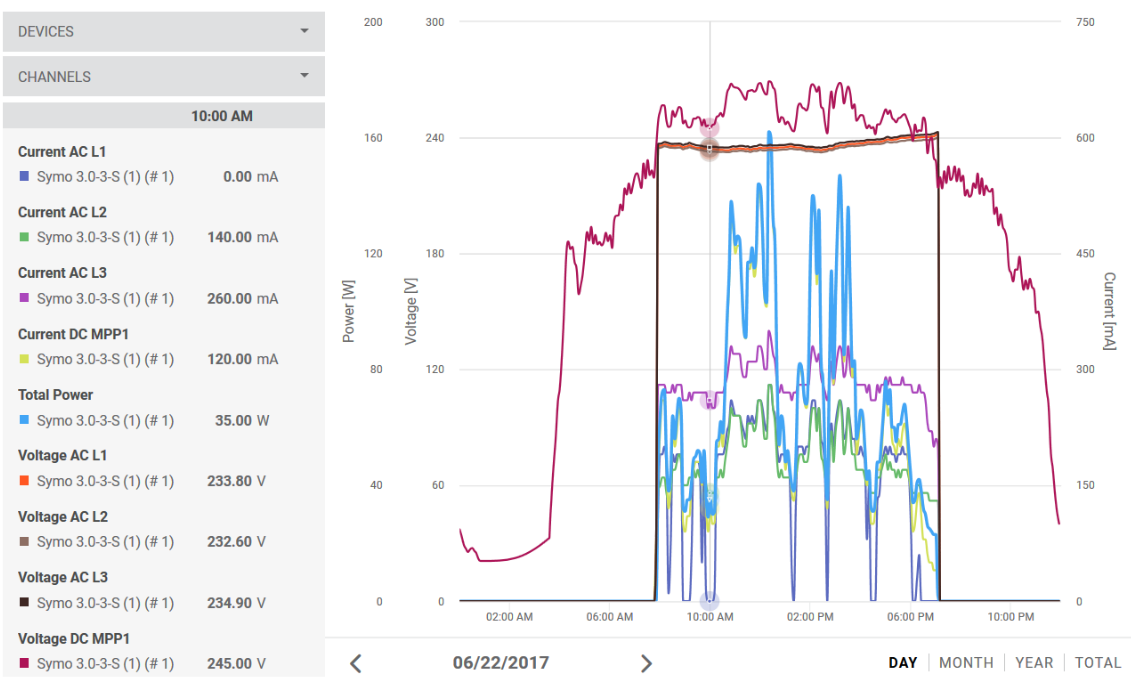


Figure 16: Measurement of 22.06.2017, visualising all available data (standard). The table contains values collected at 10:00 local time and demonstrating the imbalance of the phases on the AC side / energy exporting.

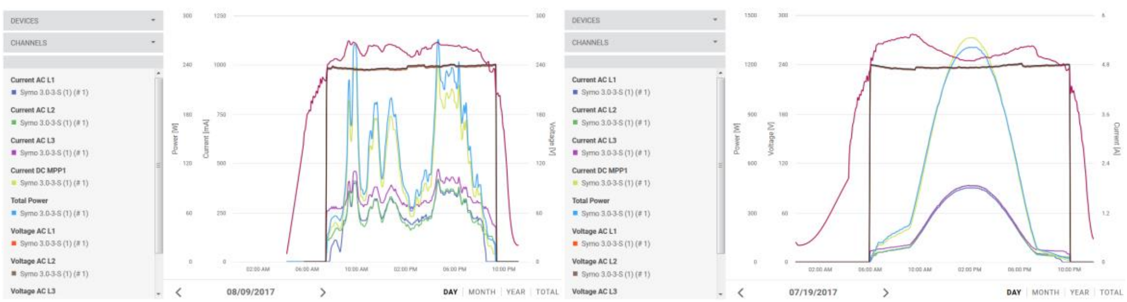


Figure 17: Measurements on 09.08. and 19.07., indicating differences between phases

In fact, a comparison of measurement on different days and irradiance shows that the discrepancy between phases occurs not always (Figure 17) and it might be an issue especially in case of low energy production, which might reduce its impact. However a more detailed evaluation might be necessary.

4 Impact on the grid in case of large PV installations

Connecting larger PV arrays to the grid might result, due to the large fluctuations in solar intensity, in disturbance in the grid. The main impact is related to voltage fluctuations, harmonics and performance characteristics programmed in PV inverters (see for example [5]). These issues are described in the following paragraphs

4.1 Network voltage

Voltage fluctuations due to the integration of a variable source of electricity generation i.e., PV systems into electricity networks and measures to reduce the impact were studied in numerous publications. Voltage fluctuation are defined as changes in the voltage magnitude caused by short term solar irradiance variations. They might have a significant impact on equipment connected to the network. Main issues arising from PV systems are categorised as follows: voltage imbalance (three phase voltage), voltage rise leading to reverse power flow (load side voltage larger than the upstream voltage) and power output fluctuations (due to PV variability)[6]. If PV systems are used in stand-alone systems, the voltage stability problem is lower compared to that in network integrated PV systems. It has also been demonstrated that the reactive power control mechanism within the solar inverters can reduce the voltage fluctuation. However, in contrast, controlling the real power output is more cost effective than using reactive power control mechanisms ([5]). Reactive power support can be separately arranged by the utility or consumer ([7], [8]). The interactions and impacts of both the real and reactive power injection and absorption at the point of common coupling to control feeder voltage is well demonstrated in [9].

5 T. Jamal e.a.: *Technical challenges of PV deployment into remoteAustrailian elecytricity networks: A review;* Renewable and Sustainable Energy Reviews 77 (2017) 1309-1325

6 Passey R, Spooner T, MacGill I, Watt M, Syngellakis K. *The potential impacts of grid-connected distributed generation and how to address them: a review of technical and non-technical factors*. Energy Policy 2011; 39: 6280–90.

7 Xiaoyan X, Huang Y, He G, Zhao H, Wang W. *Modeling of large grid-integrated PV station and analysis its impact on grid voltage.* Sustain Power Gener Supply 2009:1–6.

8 Jv Appen, Braun M, Stetz T, Diwold K, Geibel D. *Time in the sun: the challenge of high PV penetration in the german electric grid*. Power Energy Mag, IEEE 2013;11:55–64

9 Alam MJE, Muttaqi KM, Sutanto D, Elder L, Baitch A. *Performance analysis of distribution networks under high penetration of solar PV.* In: Proceedings of 44th international conference on large high voltage electric systems; 2012

4.2 Network harmonics

Total harmonic distortion might cause a technical issue in high impedance networks such as typically the distribution network. The impact on voltage might be low. The impact on current depends on the PV power output. In case of higher power generation "the study from Fekete et al. ([10]) shows that the current THD is reduced below 20% and when generation is comparatively lower, during the early morning and evening hours, the current THD value is comparatively higher which might reach up to as much as 95%. Shading effects from cloud events contribute greatly to higher current THD values, which have an adverse impact on distribution networks." However, a survey [11] on modern age inverters indicated that they have high conversion efficiency and that the total harmonic distortion is as low as only 5%

4.3 Impact of PV inverters on the network

The impact to a large extend depends on the technology implemented and the local / national regulations of the utilities. In Germany, for example, exist rules based on the inverters depending on the size of the plant ([5]):

- For systems over 100 kW, facilities have to be provided so that the network operator can remotely curtail a system's power output and observe a system's current power output.
- For PV systems between 30 and 100 kW, facilities have to be provided so that the network operator can remotely curtail a system's power output
- PV systems with less than 30 kWp, no need to have facilities/external communication for remote curtailment. System operators agree to limit their real power export to 70% of the installed system capacity.

However, inverters might also provide additional technical services which are, in most cases, provided only in case of large installations, but they never the less might also contribute to securing the power quality in the grid. These additional services are for example:

- Reactive power compensation
- Fault ride through
- Power quality improvement
- Maintaining voltage barriers
- Balancing three phase voltages
- Reduction of network capacity utilisation
- Anti-islanding operation
- Black start capability (automatic restart capability and / or restarting as standalone network)

10 Fekete K, Klaic Z, Majdandzic L. *Expansion of the residential photovoltaic systems and its harmonic impact on the distribution grid*. Renew Energy 2012;43:140–8

11 Eltawil MA, Zhao Z. Renewable and Sustainable Energy Reviews; 2010;4, p.112–29

A study [12] expresses hat, a PV penetration level of around 33% should be fine without significantly increasing distribution losses. The performance of small scale solar PV systems is largely dependent on inverter settings and thus inverter operating characteristics have an impact on the acceptable penetration level of small-scale PV systems. There are some technical impacts in the network due to various operational strategies of inverters, e.g. operating frequency, active power curtailment, operating power factor etc. Hence, selection of inverter's operating power factor and other technical services to support network voltage and frequency is a challenge. While doing so, there might be few negative impacts observed on some parameters in the network which need vigilant supervision – voltage and power deviations in the connection points, different power quality issues in the feeder, spinning reserve issues etc. ([13]).

5 Conclusions

As per the chapters above is it possible to summarize the findings in connection with future layout and integration of PV-based electricity production as follows:

- Evaluation of the demand profile (per hour, day, week & month) will allow for optimisation of the tilt angle and orientation of the PV-panels.
- Consideration of electricity prices (Figure 18) can further contribute - in connection with the previous bullet point - to a technical and economical optimised system. This layout might differ from the current process of optimisation for maximised power output.

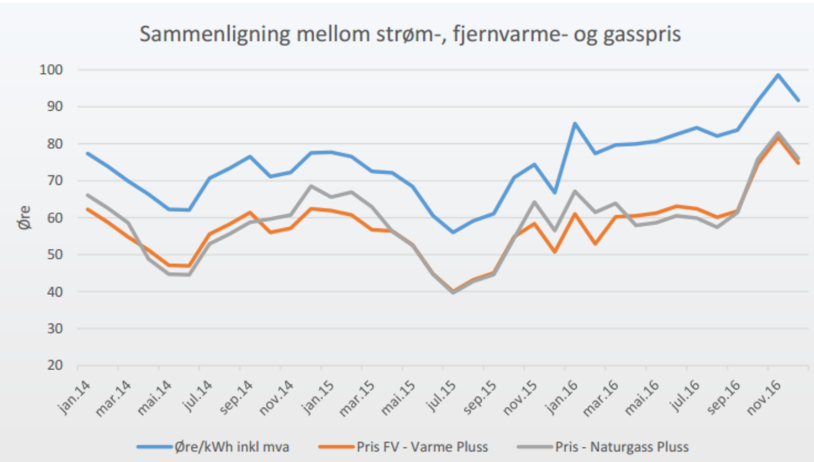


Figure 18: Example of variation of energy price to the end user for a year.

12 Hasan ASMM, Chowdhury SA. *Solar diesel hybrid mini-grid design considerations: Bangladesh perspective*. In: Proceedings of the3rd international conference on the developments in renewable energy technology (ICDRET); 2014. p. 1–4.

13 Sayeef S, Heslop S, Cornforth D, Moore T, Percy S, Ward J, et al. *Solar intermittency: Australia's clean energy challenge - characterising the effect of high penetration solar intermittency on Australian electricity networks*. CSIRO; 2012.

- With increasing share of PV might imbalance between phases as well as fast fluctuations in produced energy increase the need to introduce devices for improved power quality and / or the need for energy storage and buffering.
- Storage and buffering might contribute to the long term economic viability of the investment as it might allow for longer term (e.g. seasonal) energy storage. In this case is it possible to produce and store energy while the price is low and release it during periods of high price. Differences to consider are in the range of up to 30% (see Figure 18). A recent publication on energy storage and techno-economics can be found in[14]

A decent overview over possibilities to ensure a high-level power quality in grids with a high share of fluctuating renewables can be found in chapter 6 of [5]. Also, there is the integration of storage and control considered as an important part of the overall energy systems integration with a high sharer of e.g. PV to ensure grid-stability.

14 A. Abdon; X Zhang, D. Parra, M.K. Patel, C. Bauer, J. Wortlischek: *Techno-economic and environmental assessment of stationary electricity storage technologies for different time scales* Energy 139 (2017) 1173-1187