PERFORMANCE ANALYSIS OF PV MODULES INSTALLED IN THE ALPINE REGION

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ABSTRACT: Several mono- and bifacial mc-Si PV modules were installed at a location 2500 m above sea level in the Alps and grouped in six segments with different inclinations 30°, 70° and 90°. The PV modules and the meteorological conditions are monitored minutely and compared to a 30° tilted PV module installed in the urban region of Zurich. During the analysis period between October 2018 and September 2020, the yield loss due to snow coverage was minimal. The highest loss was 2.3 % (2018/19) and 3.6 % (2019/20) for the 30° inclined PV modules evaluated by the introduced snow coverage model based on electrical and weather data. The two segments with a 30° inclination showed a 20.9 % to 27.2 % higher yield than the PV module installed in the urban region, mostly produced in the winter season. The bifacial alpine energy yield is about twice as high as that of the urban PV module from November to May. The highest yields of 1800 Wh/Wp in 2018/19 and 1696 Wh/Wp in 2019/20 was measured at the 70° tilted bifacial PV module without losses due to row shading as it is expected in PV plants.
Keywords: alpine region, bifacial, monitoring, performance, photovoltaic

1 INTRODUCTION

The Alps are known for having more sunny days in winter than in the Swiss midlands because there are less foggy days at higher altitudes. Photovoltaic installations in the Alps could therefore be a part of the future electricity generation based entirely on renewables and produce more electricity during wintertime feeding the higher electricity demand. Additionally, the generated PV electricity could be used locally such as in the ski areas and in the numerous existing mountain villages.

The average annual irradiance is up to 1.5 times higher in the Swiss Alps than in the Swiss midlands [1]. The average snow cover duration was 190 days for locations 2000 m above sea level in the years 2011 to 2016 [1]. This increases the electricity production of PV further due to the high albedo effect and thus, steeper tilt angles of PV installations can be considered without having to accept major energy yield losses as it is the case in urban region. In a case study in Austria, the performance of a PV installation on the Pitztal glacier (2900 m.a.s.l.) was compared to a reference PV installation in the valley (625 m.a.s.l.). The high alpine PV plant showed an additionally yield of 25 % in the year 2016 and 2017. The production profile was more balanced throughout the year, with the winter electricity accounting for 40 to 50 % of the total production [2].

In 2017, the electricity utility of the canton of Zurich (EKZ) installed several mono- and bifacial mc-Si PV modules in the alpine region (figure 1). The goal is to analyse the impact of the climatic conditions of the location at 2500 m above sea level on the PV module performance. The most interested climatic parameters are the module temperatures, the snow coverage of the PV modules and the effect of the high albedo during wintertime. Furthermore, the PV modules in the test setup have different inclinations for determining the individual performances during high albedo conditions.

In this work, the low light and temperature behaviours are modelled and the performance factors [3] are extracted and compared for each installed segment. The module temperature of the bifacial PV modules needs to be modelled because the temperature sensor could not be mounted directly behind the solar cells. The results of the 30° tilted segment are compared to a PV module installed with the same inclination in the urban region Dietikon, Switzerland, which is used for a long-term performance study and therefore well-known and analysed [4]. Additionally, the annual irradiation differences as well as the yield differences between the alpine and the urban region in Switzerland are elaborated. Finally, the influence of the weather-based parameters (irradiance, albedo and snow coverage) and the influence of the PV model-based parameters (inclination, bifaciality, module temperature, low-light behaviour and an aggregated factor accounting for spectral and degradation behaviour) on the PV module performance are determined.

2 APPROACH AND MEASUREMENT SETUP

The PV test facility is installed at the Totalp near the town Davos, Switzerland. There are 6 different PV segments indicated with letter from A to F with three to four PV modules each as shown in figure 1. The tilt angle can be individually chosen for each segment. The segments A and B have a tilt angle of 30°, C and D are tilted by 70° and the last segments E and F are installed vertically. The segment B is shown in figure 1 with a 50° tilt angle. For the analysis period, the inclination of this segment was also 30°. All PV modules are south oriented without nearby shading objects in front. The PV modules on the segments D and E are bifacial mc-Si modules from PVP (PVP-GE285M). The other segments have monofacial PV modules PVP-GE280M either with or without frame (segment A and C with frame). Figure 2 shows the detailed PV modules layout in the PV plant. Each module is connected to a commercial power optimizer (SolarEdge OPA300 for monofacial and OPA400 for bifacial PV modules), which ensures the MPPT. Different electrical, thermal and meteorological quantities such as voltage, current, module and ambient temperatures, wind speed, irradiances in every plane of array (POA) as well as the reflected irradiance due to the albedo for the segments C to F are measured every minute. The small weather station and the 6 PV segments are additional monitored by several webcams to analyse snow coverage.

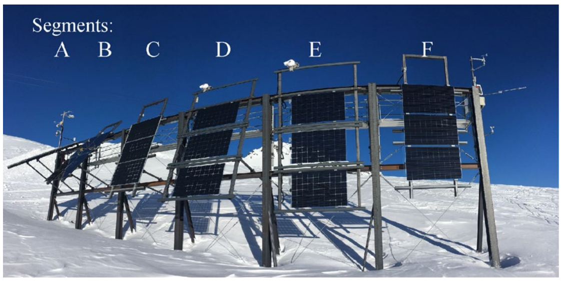

Figure 1: Setup of the PV test facility at the Totalp, Davos, Switzerland (Source: EKZ [5]). Pyranometers were used as irradiance sensors.

The Totalp test power plant is one of the highest PV plants in Switzerland, located 2500 m above sea level and it is equipped with a high-quality measurement system. The analysis period ranging from 1st of October 2018 to 30th of September 2020 showed a very high measurement uptime of 94.4 % and 95.3 %. Unless otherwise mentioned in this work, minutely averaged data were used for the analyses.

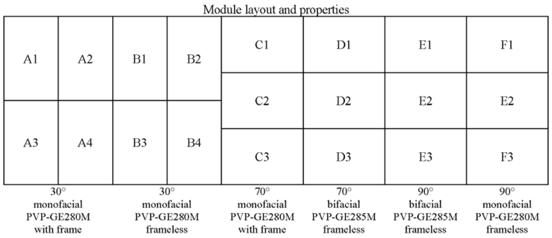

Figure 2: PV module layout and properties at the test facility.

3 MODELLING

For the analyses performed in this work, four models are used and described. First, the snow covering need to be detected to address the yield losses in terms of snow. Then, the low-light and thermal modelling is required as an input to the PV performance model. The performance model is used to quantify the influences of weather-based or PV model-based parameters as well as to model the PV power output without snow covering when there is snow on the PV modules.

3.1 Snow cover detection

To identify the snow coverage, an algorithm using only measured electrical and weather parameters is developed (no webcam image processing used). Therefore, the time has to be known when a snow cover was present. For this purpose, different days were selected with and without snow coverage according to the webcam images. For these days, daily patterns, MPP voltage vs currents diagrams and various parameter combinations, such as MPP current per irradiance, were analysed and statistically evaluated. Based on that, the snow cover detection algorithm was elaborated and visualised in the flow chart in figure 3a. This algorithm was then tested on different days and compared with webcam images [6]. This algorithm is not a general solution for snow detection on the PV module surface. It was developed just for the purposes of successfully quantifying the yield losses due to snow coverage within this work. Figure 3b shows the resulting plot when the algorithm is applied on the measurements of segment B on 29th of December 2019.

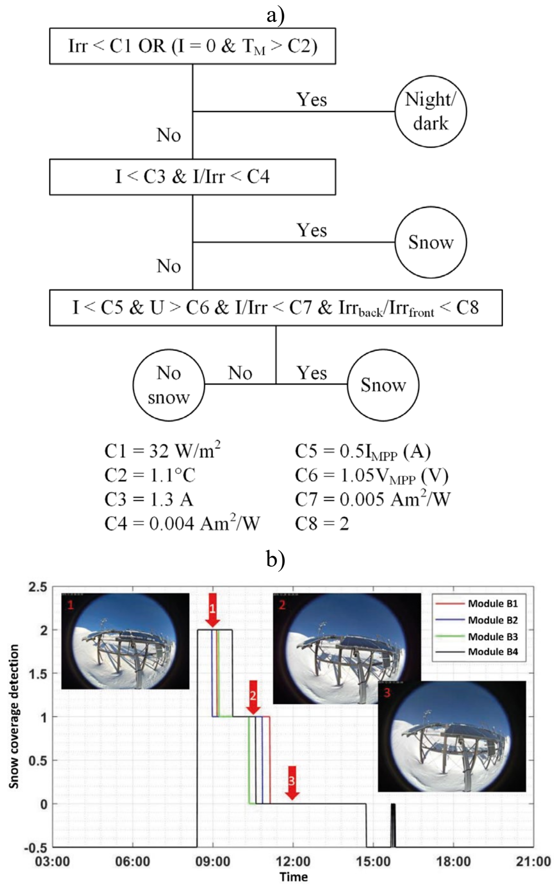

Figure 3: The flow chart a) shows the algorithm that is used to detect the snow coverage of the PV module installed in the Alps. "Irr" stands for measured irradiance and "I" for the measured current at MPP. The plot b) shows the snow coverage detection for the case on 29th of December 2019.

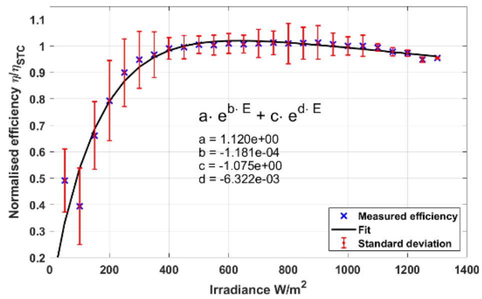

Figure 4: Normalised efficiency of the PV module C3 for the 26 irradiance intervals between 50 and 1300 W/m². The double exponential fit is used in the PV performance model.

3.1 Low-light behaviour of the PV modules

For the analysis of the low-light behaviour, the measured module outputs were sorted into bins with ±25 W/m² intervals at irradiance levels between 50 – 1300 W/m². This high upper limit of irradiance is due to the high albedo in the Alps. Additionally, the data were selected only when clear sky conditions were met according to an algorithm from the SANDIA labs [7]. For each interval, the efficiency at 25 °C was calculated using the linear regression between the measure module power and the measured module temperature. A more detailed description of this method can be found in the papers [3, 4]. Figure 4 shows the resulting low-light behaviour evaluated for the PV module C1.

3.2 Thermal model

The module temperature modelling uses irradiance, ambient temperature and wind measurements as model inputs. The model is based on the thermodynamic law of conservation of energy, which considers the solar radiation Q_S, the generated electrical energy W_{PV}, the convection Q_C and the heat radiation of the modules to the sky $Q_{m\to s}$ and the ground $Q_{m\to g}$. The time derivative of the energy balance is described in the differential equation (1) by using the equation (2) to (5).

$$C_m \frac{dT_m}{dt} = \dot{Q}_S - \dot{Q}_C - \dot{Q}_{m\to s} - \dot{Q}_{m\to g} - P_{PV} \quad (1)$$

$$\dot{Q}_S = E_{POA}\, A_m \quad (2)$$

$$\dot{Q}_C = A_m\, U(v_w)\, (T_m - T_a) \quad (3)$$

$$\dot{Q}_{m\to s} = \varepsilon_m\, \varepsilon_s\, F_v\, \sigma\, A_m\, (T_m^4 - T_s^4) \quad with\ T_s = 0.0552\, T_a^{1.5} \quad and\ \varepsilon_s = 0.72 + 0.005\, \vartheta_a^{1.5} \quad (4)\ [8]$$

$$\dot{Q}_{m\to g} = \varepsilon_m\, \varepsilon_g\, F_v\, \sigma\, A_m\, (T_m^4 - T_g^4) \quad (5)$$

The following simplification or assumptions were made for the modelling of the PV module temperature:

- The temperature of the ground T_g is equal to the ambient temperature T_a.
- The emissivity ε_s and the temperature T_s of the sky are modelled according to Mittag et al. [8].
- The emissivity ε_m of the PV module and ε_g of the ground are assumed to be 0.9.
- The view factors F_v are set equal to 1.

The empirical model [9] was used to determine the convective heat transfer coefficients, modelling constant free convection with U_0 and forced convection, which increases linearly with wind speed, with U_1. The clear-sky data were averaged over 10 min to consider equation (1) as quasi-stationary. The linear regression was used to determine the convective heat transfer coefficients from equation (6). Only irradiance levels between 990 and 1010 W/m^2 were considered in this analysis.

$$\frac{\dot{Q}_S - \dot{Q}_{m\to s} - \dot{Q}_{m\to g} - P_{PV}}{A_m\, (T_m - T_a)} = U_0 + U_1\, v_w \quad (6)$$

The average heat transfer coefficient U_0 was found to be 8.8 W/m^{2}K. The coefficient U_1 modelling the forces convection depends on the tilt angle of the PV resulting to average heat transfer coefficients of 4.7 Ws/m^{3}K (30°), 3.4 Ws/m^{3}K (70°) and 2.6 Ws/m^{3}K (90°).

The PV module heat capacity C_m could be determined by minimising the root mean square error (RMSE) between the measured module temperature and the simulated module temperature by solving the differential equation (1). The average heat capacity was found to be 32.7 kJ/K.

This analysis was performed only with the monofacial PV modules. The temperature sensor of the bifacial PV module could not be mounted directly behind the solar cells which made this analysis impossible for this type of module. Thus, the convective heat transfer coefficients and module heat capacity had to be assumed to be equal to those values of the monofacial PV modules with the corresponding tilt angles. This assumption can be made because the monofacial modules are also glass-glass modules.

3.3 PV performance model

The power output of the PV modules installed at the Totalp, Davos, are modelled by equation (7). The following parameters serve as input:

- Irradiance at the module level E_{POA} including the reflected irradiance on the rear side for the bifacial modules.
- PV module area A_m.
- Efficiencies of the modules (16.9 % for monofacial and 17.2 % for bifacial PV modules at STC) including their low-light behaviour $\eta(E_{POA})$.
- Temperature coefficient δ according to the manufacturer's datasheet (-0.42 %/K for the mono- and -0.4 %/K for the bifacial PV modules).
- The performance factor k_P for modelling the spectral influences, degradation, setup errors and irradiance inhomogeneities on the frontside and backside of the bifacial PV modules

$$P_{PV} = k_P\, E_{POA}\, A_m\, \eta(E_{POA})\, (1 + \delta\, \Delta T) \quad (7)$$

The performance factor k_P was determined after all other parameters and models had been carried out. For this purpose, the RMSE between the measured power and the simulated power has been minimised.

The individual performance factors that influence the performance of the PV modules on the Totalp was determined for the period from 1st of October 2019 to 30th of September 2020. The other two individual weighted and averaged performance factors k_{LL} and k_T were calculated. The product of the factors k_P (spectral influences, degradation, measurement setup), k_{LL} (low light behaviour) and k_T (temperature behaviour) represents the performance ratio PR (8). The resulting performance factors and ratios are given and discussed in the section 4.

$$PR_{DC} = \frac{W_{PV}\, 1\frac{kW}{m^2}}{G_{POA}\, P_{STC}} = k_P\, k_{LL}\, k_T \quad (8)$$

4 RESULTS

First, the measured yields of the alpine installation are presented. Then, the modelled yields are compared to the measured yields and the performance factors are determined for the different tilted PV modules in the Alps and compared to the reference PV module in the urban area (230 Wp, Sunways). Finally, the yield losses due to the snow coverage of the PV modules are elaborated.

4.1 Measured yield and performance ratio

The PV module yield was analysed for the period ranging from 1st of October 2018 to 30th of September 2020. The measurement setup had a very high uptime of 94.4 % and 95.3 % for the two years. For the comparison to an urban PV module, the data sets from both sites were matched for this yield analysis reducing the uptime slightly to 92.3 % and 91.2 %, respectively.

Table I: Analysed irradiations, PV module yields and PR for the individual PV segment on the Totalp and the reference module (230 Wp, Sunways) in the urban region during the periods 2018/19 and 2019/20. For the bifacial PV modules, a distinction was made between the PR with respect to only the irradiation on the frontside and a second PR that considers the sum of the front and backside irradiation.

Segments	A	B	C	D	E	F	Dietikon	Units
			1st of October 2018 to 30th of September 2019 (Uptime 92.3 %)					
G_{POA}	1644.2	1658.8	1539.9	1539.9	1530.3	1530.3	1294.3	kWh
G_{Albedo}	-	-	-	701.9	733.9	-	-	kWh
Yield	1502.4	1428.2	1526.4	1799.7	1662.5	1373.9	1181.4	kWh/kWp
PR_{DC}	0.914	0.861	0.991	1.169	1.086	0.898	0.913	-
PR_{DC} (incl. rear side irr.)	-	-	-	0.803	0.734	-	-	-
			1st of October 2019 to 30th of September 2020 (Uptime 91.2 %)					
G_{POA}	1533.4	1541.5	1373.3	1373.3	1365.9	1365.9	1353.1	kWh
G_{Albedo}	-	-	-	618.7	640.9	-	-	kWh
Yield	1372.5	1315.9	1383.8	1696.1	1563.9	1221.4	1234.2	kWh/kWp
PR_{DC}	0.895	0.854	1.008	1.235	1.145	0.894	0.912	-
PR_{DC} (incl. rear side irr.)	-	-	-	0.851	0.779	-	-	-

Table I includes the annual measurement results for the alpine installation as well as the reference PV module installed in Dietikon, the urban area of the canton of Zurich. Table II shows the monthly yield ratios of the bifacial and the monofacial PV modules meaning the monthly yield of the bifacial setups are divided by the corresponding yield of the monofacial setup with same inclination at Totalp test setup.

Table II: Ratio of the monthly energy yield of the bifacial module segments to the monofacial module segments in the Totalp installation for the time period 2019/20.

Month	Oct	Nov	Dec	Jan	Feb	Mar
Seg D/C	1.15	1.24	1.21	1.16	1.26	1.28
Seg E/F	1.20	1.35	1.27	1.20	1.27	1.26
Month	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Seg D/C	1.27	1.31	1.35	1.12	1.13	1.13
Seg E/F	1.26	1.43	1.55	1.23	1.20	1.18

The annual PR of the segment A in 2018/19 was 0.914 and thus equal to the PR of the reference module in Dietikon with the same 30° south inclination. In the second year, the PR of segment A was 1.7% % higher than that of the PV module in the urban area. Segment B had PRs that were 5.2% and 5.8%, respectively, lower than the urban reference module. The monofacial PV modules of segment C (70°) had a very high PR between 0.99 and 1.01. Segment F (90°), on the other hand, had a lower PR of 0.898 and 0.894, although the irradiation yield was almost identical to that of segment C. The reason can be seen in the performance factor k_P of the segment C in the subsection 4.3, which is much higher than the according factor of segment F. With a very high probability, there must be an error in the setup of the measurement system.

The PR of the bifacial PV modules of segment D (70°), considering the albedo radiation on the rear side, was 0.803 and 0.851. For the bifacial PV modules of segment E (90°), a PR of 0.734 and 0.779 was observed. One reason for the low PR compared to the monofacial PV modules is the overestimation of the influence of the irradiation on the rear side in the performance ratio calculation. This effect was also observed in the evaluations of the simulations in the subsection 4.2 where the simulations showed an overestimation of the energy yield between 3.4 % and 12.8 %. A second point is a module failure of segment D (70°) and E (90°) from 17 October to 5 November 2018 as described in the subsection 4.2.

The monthly energy yields ratios between bifacial PV modules of segments D and E and the corresponding segments C and F with the same inclination show that the energy yields of the bifacial PV modules are between 12 % and 55 % higher than the monofacial PV modules. Especially in the months of May, June and July, the additional yield for the analysed period can be between 42 % and 55 %. Over the entire period from October 2019 to September 2020, an additional yield of 22.6 % and 28.8 % could be measured for segment D (70°) and segment E (90°), respectively.

The additional yield of the PV modules installed in the alpine region compared to the urban PV module in Dietikon depends strongly on the respective year. An additional yield of 27.2 % (segment A) and 20.9 % (segment B) could be measured in 2018/19. The following year showed a significantly lower additional yield of 11.2 % (segment A) and 6.6 % (segment B). Overall, a yield difference between the two years of 14.0 % to 17.3 % was observed on the Totalp in Davos.

For the year 2019/20, segment A (30°) showed an increase in yield of 4.1 % compared to the segment B (30°) and 11.2 % compared to Dietikon (30°). The PV modules of segment F (90°) showed a yield reduction of 12.2 %. compared to segment A (30°) and thus produced about the same as the PV module in Dietikon. The use of the bifacial PV modules at the given tilt angles resulted in an additional yield of 26.2 % (segment D 70°) and 15.5 % (segment E 90°) compared to segment A (30°). Compared to the reference module in Dietikon, these were 37.4 % and 26.7 % respectively.

Table III: Modelled and measured energy yield of the analysed PV segments in the Alps for period from 1st of October 2018 to 30th of September 2019.

Segment	A	B	C	Units
Modelled	1541.3	1521.9	1593.8	kWh/kWp
Measured	1559.8	1482.5	1577.4	kWh/kWp
Difference	-1.19	2.66	1.04	%
Segment	D	E	F	Unit
Modelled	2054.4	1947.8	1392.0	kWh/kWp
Measured	1870.2	1727.0	1420.6	kWh/kWp
Difference	9.85	12.79	-2.02	%

4.2 Model verification

The modelled energy yields for every PV segment are compared to the corresponding measurement results for the two years. Table III and figure 5 show the results for the time period from 1st of October 2018 to 30th of September 2019. Table IV and figure 6 includes the data for the following year (1st of October 2019 to 30th of September 2020)

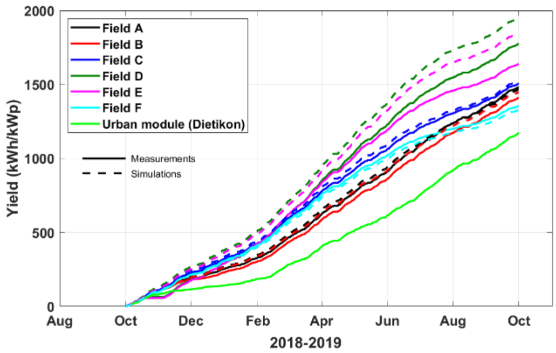

Figure 5: Measured and simulated cumulated yield of the six different segments installed in the Alps in 2018/2019. The measured yield of the reference PV module in the urban region is included for the same time period.

Table IV: Modelled and measured energy yield of the analysed PV segments in the Alps for period from 1st of October 2019 to 30th of September 2020.

Segment	A	B	C	Units
Modelled	1445.3	1424.9	1433.4	kWh/kWp
Measured	1449.1	1390.0	1455.3	kWh/kWp
Difference	-0.26	2.51	-1.51	%
Segment	**D**	**E**	**F**	**Unit**
Modelled	1844.3	1741.6	1247.2	kWh/kWp
Measured	1783.3	1641.6	1282.4	kWh/kWp
Difference	3.42	6.09	-2.75	%

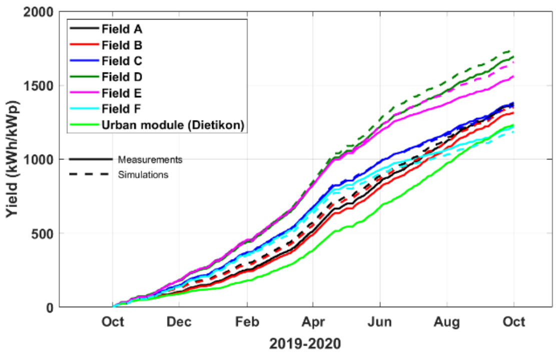

Figure 6: Measured and simulated yield of the six different segments installed in the Alps in 2019/2020. The measured yield of the reference PV module in the urban region is included for the same time period.

The modelled yields for the monofacial modules for 2018/19 and 2019/20 are within 3 % of the measured yields. In the last year, the modelled yields of the bifacial module deviate 3.42 % (segment D) and 6.09 % (segment E) from the measured yields. The overperformances of the simulation of the bifacial PV modules occurs mainly in the summer months as shown in figure 5. In the first year 2018/19, the model of the bifacial PV modules had a significant overperformance of 9.85 % (segment D) and 12.79 % (segment E). The reason for this deviation between the two consecutive years is the power outage of the two segments (reason unknown). However, the measurement system worked, which is why these measurements were included in the evaluation. According to the simulation, the yield losses were 88.4 kWh/kWp for segment D and 82.2 kWh/kWp for segment E, which corresponds to a share of 4.3 % and 4.2 % of the simulated annual energy yield, respectively. Taking this into account, the model overperformance is 5.55 % and 8.59 % for that year and it is again evident that the rest of the overperformance occurs in the summer months (see figure 6). For both years, this overperformance is driven by the overestimation of the albedo radiation on the backside of the PV modules.

4.3 Performance comparison alpine vs urban

The performance model of equation (8) serves as the basis. From this model, the individual average power-weighted performance factors could be determined. The product of the factors k_P (spectral influences, degradation, measurement setup), k_{LL} (low-light behaviour) and k_T (temperature behaviour) represents the DC performance ratio PR_{DC}. Table V lists the individual performance factors, the PRs calculated from these values and the modelled PR. The performance factors of the reference module in the urban environment in Dietikon serve as a comparison. These reference values were analysed for the year 2012 [3], two years after commissioning.

The performance factors k_P for alpine installations are lower than in Dietikon except for the segment C. This factor includes spectral influences, degradation and uncertainties in the measurement setup, because the alpine measurement setup does not have four-wire measurement technology. An additional uncertainty are the power optimisers that are used for MPPT. Segment C has a performance factor k_P of 1.055, which indicates are failure in the setup.

The low-light behaviour of the PV reference polycrystalline silicon module from Sunways in the urban area leads to an increase in performance. This is no longer the case with the PV modules on the Totalp. The determined low-light characteristics of the PV modules installed alpine region show a lower increase in performance with irradiance levels between 500 W/m^2 and 800 W/m^2 compared to the PV module in Dietikon. Furthermore, the maximum irradiance levels on the Totalp are significantly higher than in the urban area.

The weaker performance due to the low-light behaviour is partly compensated by the better temperature behaviour. The bifacial PV modules have the lowest k_T values because more solar radiation is converted into heat due to the bifaciality. The results of the temperature influence of the bifacial PV modules should be treated with caution, as the temperature simulation could not be verified with temperature measurements so far.

4.4 Yield loss due to snow coverage

The yield losses due to snow coverage were close to inexistent for the vertical installations (segment E and F) and the 70° bifacial installation (D). The losses were between 0.12 % and 0.31 %. The 70° monofacial installation in segment C had snow coverage losses of 1.5 % for both years. The losses of the 30° tilted PV segments were between 2.3 % (2018/19) to 3.6 % (2019/20) of the corresponding annual yield.

Table V: The performance ratios according to equation (8) were determined by analysing the data in the year 2019/20 which is two years after commissioning. The PR was calculated based on these performance factors as well as based on the simulated power. The performance factors of the reference module in the urban region in Dietikon, Switzerland, were calculated for the year 2012, which corresponds also to two years after commissioning [3].

Segments	A	B	C	D	E	F	Urban [3]
k_P (spectral, degradation, setup)	0.942	0.906	1.055	0.938	0.886	0.925	0.963
k_{LL} (low-light)	0.965	0.968	0.961	0.961	0.960	0.957	1.007
k_T (temperature)	1.002	1.003	1.003	0.976	0.969	0.992	0.960
PR_{DC} (performance factors)	0.912	0.879	1.017	0.880	0.825	0.878	0.930
PR_{DC} (simulation)	0.898	0.880	0.996	0.881	0.826	0.873	-
Difference (simulated - measured)	-1.53 %	0.09 %	-2.03 %	0.17 %	0.17 %	-0.61 %	-

5 CONCLUSIONS AND OUTLOOK

The yield losses due to snow coverage were surprisingly lower than expected. The vertical installation had hardly any losses. The highest yield loss of 3.6 % was observed at the segment B in the year 2019/20.

The advantages of lower temperatures in the alpine area resulted in a performance increase of 0.9 % to 4.3 % compared to the urban area. The low-light performance loss in the alpine area relative to STC was 3.2 % to 4.3 % compared to the urban area.

The additional yield in the alpine region differed heavily between the two analysed years. In the period 2018/19, the yield was between 14.0 % to 17.3 % higher compared to the period 2019/20. The segments A and B with a 30° inclination had a 27.2 % and 20.9 %, respectively, higher yield than the PV module installed in the urban region with the same tilt angle during the period 2018/19. In the second analysed year, the additional yield was lower and resulted in a factor of 11.2 % and 6.6 %, respectively. The vertically installed monofacial PV modules (segment F) had a significantly lower yield, which was 11.0 % lower than that of the 30° tilted PV modules (segment A). Thus, it produced about the same amount of electricity as the PV module in the urban region, but mostly during the winter period. The use of the bifacial PV modules under the given tilt angles 70° and 90° resulted in an additional yield of 23.5 % and 13.9 %, respectively with respect to the modules in segment A. The additional yields of the alpine-installed PV modules for 2019 occurred mainly in the months February up to May. While the PV module in the urban region produced around 100 Wh/Wp electricity per month during this period, the monofacial PV modules in the Alps generated 1.5 times as much electricity. The measured yield of the bifacial PV modules was twice as high during these months.

The measurement data from this test facility is continuously evaluated for the most recent year. In addition, the albedo radiation should be better reflected in the modelling. For this purpose, new diffuse and direct irradiance measurements are being analysed and evaluated. A further point will be the adaptation to the size of PV power plants, in which row shading must be considered and albedo effects need to be adjusted.

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