Name of research institute or organization:

Bern University of Applied Sciences BFH, Dept. Engineering and Information Technology (EIT), Electrical Engineering and Information Technology / Photovoltaic Laboratory (PV LAB)

Title of project:

Long-term study on the efficiency of photovoltaics at alpine sites

Project leader and team:

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Project description:

1. Introduction

The solar power plant, mounted in 1992 on the façade of the Jungfraujoch research building (Figure 1) at 3 450 m asl in the Swiss Alps, has been monitored by the PV LAB at BFH since the end of 1993. The plant was extended with new technology in 2014 (see Fig. 1 and [1]).

In order to examine the relationships between the solar energy yield produced at Jungfraujoch and the degradation of the PV modules in operation at Jungfraujoch since the mid-1990s, two of the PV modules installed in 1992 were removed for flasher inspection in the PV LAB at BFH in Burgdorf in June 2017 [2]. The results of the flasher inspection in the PV LAB (Section 2) were compared (Section 4) with calculations (Section 3) on performance losses of the solar power plant.

Figure 1. The Jungfraujoch research station is operated by the "International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat" in Bern, Switzerland. New solar power plant (2014) on the left, old solar power plant (1992) on the right, picture by Martin Fischer HFSJG.

2. Flasher Inspection of two PV Modules Installed at Jungfraujoch in 1992

On 12-13 June 2017, the PV LAB at BFH detached two PV modules Siemens M75 (48Wp) from the solar power plant installed in 1992 at Jungfraujoch and brought them to the laboratory at Burgdorf for examination in view of potential damage and degradation [2]. The examination (measurement of the current performance of the modules) was carried out using the flasher at the PV LAB at BFH-TI. The flasher inspection of the two PV modules evidenced a nominal power output of 48 Wp and a production tolerance of ± 10 % (see Table 1). The expected maximum output power of such a module is hence 52.8 Wp while the expected minimum output power is 43.2 Wp.

Based on discussions between the former PV LAB leader (emer. Prof. Dr. Heinrich Häberlin) and the module producer in 1992, it is known that the real performance of the modules in 1992 (i.e., when the modules were new) was then lower than the nominal 48 Wp. Consequently, the estimated effective power output of the examined PV modules detached from the Jungfraujoch solar power plant in June 2017 must have been between 43.2 Wp and 48 Wp back in the early 1990s.

The power output of the two PV modules as measured in the PV LAB in June 2017 reveals a mean of 43.207 Wp (Table 1), which is near the expected minimum value in the early 1990s.

Modul No.	Sample 1	Sample 2	Median	Mean
SN 670897	41.565 Wp	41.635 Wp	41.600 Wp	41.600 Wp
SN 670898	44.800 Wp	44.827 Wp	44.814 Wp	44.814 Wp
Median / Mean over all samples			43.218 Wp	43.207 Wp

Table 1. After 24 years of operation (1994-2017), the minimum nominal power of 43,2 Wp of the PV modules is still reached.

3. Calculating the Performance Loss of the Solar Power Plant since 1994

The normalised yields (Y_A) of the PV modules (generator) and the normalised reference yield (Y_R) of the pyranometers were used to calculate the performance loss of the solar power plant at Jungfraujoch since 1994 (Figure 2).

Symbol / Term	Meaning / Definition	Unit
▸ Y_R = Reference Yield = theoretical yield measured by the pyranometer	Y_R is equal to the time witch the sun has to shine with G_0 = 1kW/m2 to irradiate the energy H_G onto the solar generator	$\left[\frac{kWh/m^2}{d \cdot 1kW/m^2}\right] = \left[\frac{h}{d}\right]$
▸ Y_A = Array Yield = Generator (DC-) performance	Y_A is equal to the time witch the P_V plant has to operate with its nominal power P_0 to generate array (DC-) energy E_A	$\left[\frac{kWh}{d \cdot 1kW}\right] = \left[\frac{h}{d}\right]$

Figure 2. Calculation method of the degradation.

Y_R represents the effectively captured energy yield and Y_A represents the eventually converted energy. The quotient Y_A to Y_R is a measure for the degradation of the PV modules. It is illustrated in Figure 3 (blue dotted curve) from 1995-2014.

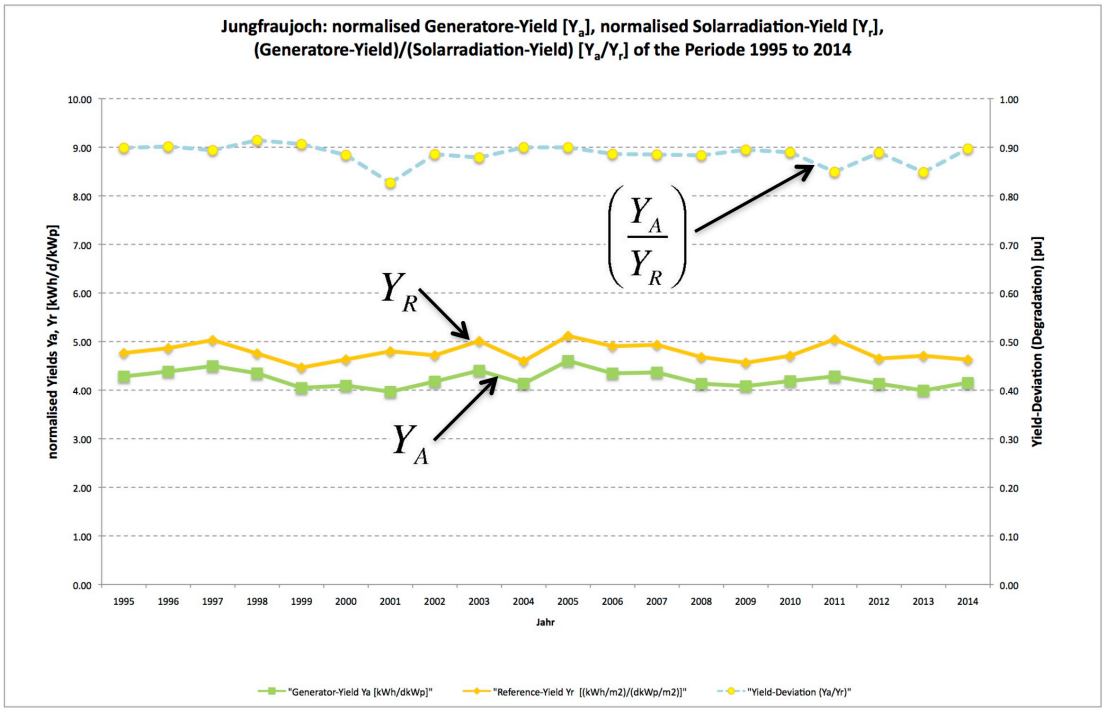

Figure 3. Time-series (1995-2014) of the quotient Y_A / Y_R representing the degradation of the PV modules mounted at Jungfraujoch in 1992.

Application of linear curve fitting to the degradation curve in Figure 3, of the form $y = ax + b$ where factor a represents the gradient of the degradation per year in per-units [pu], results in a degradation of 0.0011 [pu] or 0.11 % per year (Figure 4).

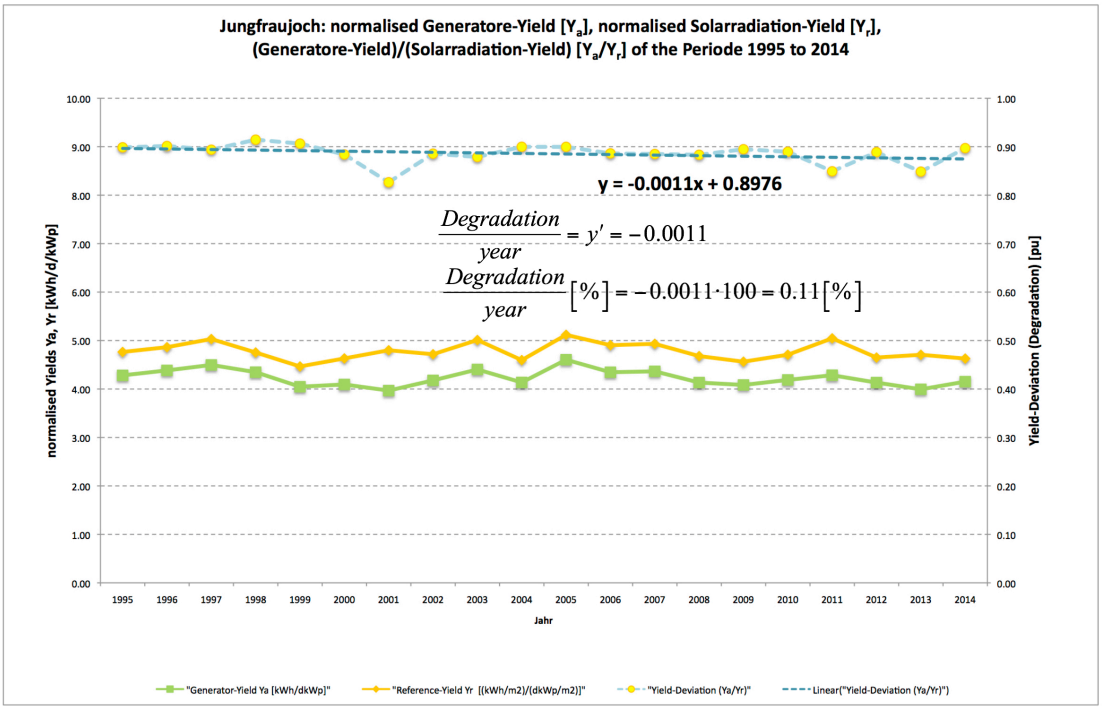

Figure 4. Linear curve fitting to the time-series of the quotient Y_A / Y_R shown in Figure 3.

4. Comparisons

The degradation of 0.1 % / year (calculated in Section 3) is displayed in Figure 5 (red curve). It is illustrated that a degradation of 0.11 % / year provides a calculated power output of 45.8 Wp in 1995. This is near the effective power output of the examined PV modules assumed for the early 1990s in Section 2 and hence strengthens these assumptions. These numbers are further strengthened by the green curve in Figure 5, illustrating the PV module degradation if the PV modules mounted at Jungfraujoch in 1992 had a minimal power of 43.2 Wp in the mid-1990s.

As a comparison, a degradation of (i) 0.2 % / year and (ii) 0.4 % / year is evidenced for the assumption if

(i) the PV modules mounted at Jungfraujoch in the mid-1990s had a nominal power of 48 Wp back then (yellow curve),

(ii) there is a theoretical maximum power of 48 Wp of the PV modules and an upper tolerance band border of + 10 % (blue curve).

As outlined in Section 2, the performance of the PV modules back in the 1990s was lower than the nominal 48 Wp, and a degradation of 0.2 % / year is hence not feasible. Similarly, a degradation of 0.4 % / year is not realistic.

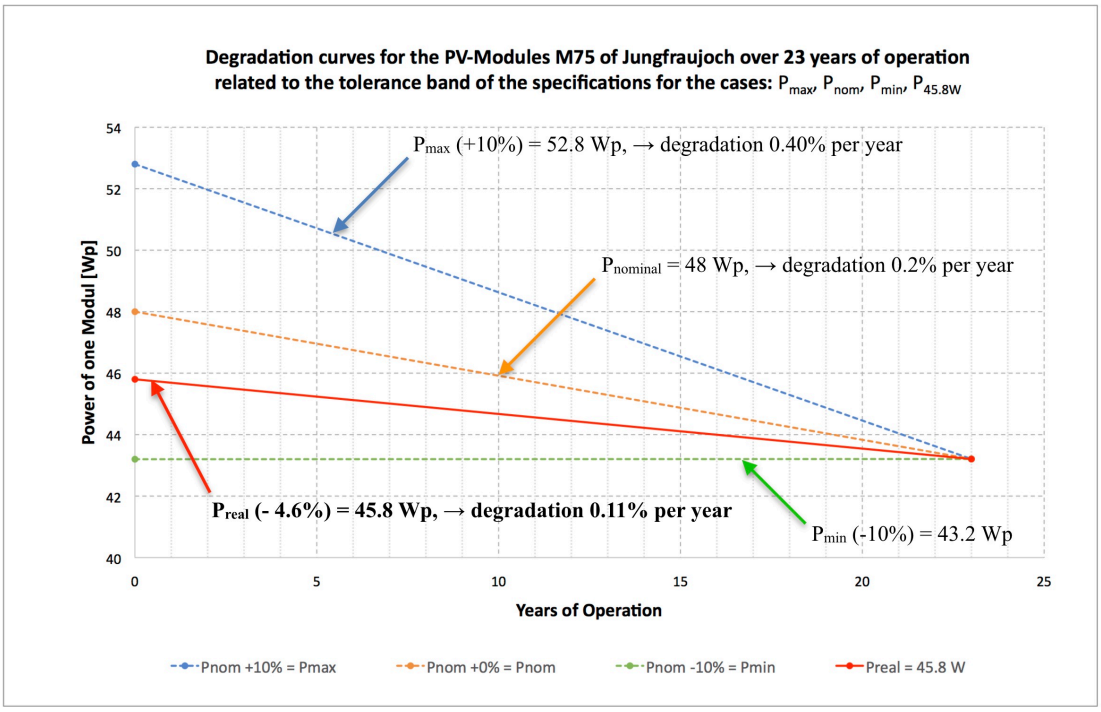

Figure 5. Comparison of the calculated degradation (0.11 % / year) (red) for 1995-2017 with degradation estimates based on three different specifications of the PV modules back in the early 1990s: Wp min (green), Wp 48 (yellow), Wp 52.8 (blue).

4. Summary and Conclusions

Performance losses of the solar power plant, operational at Jungfraujoch since 1992 and measured since the end of 1993 were calculated based on generator and pyranometer data at Jungfraujoch. A degradation of 0.11 % / year was found over the 1995 to 2017 (June) period for the Jungfraujoch solar power plant. The calculations were compared with flasher results of two inspected PV modules mounted at Jungfraujoch in 1992 and detached in June 2017 for flasher examinations in the PV LAB at BFH in Burgdorf. The comparison confirms a degradation of 0.11 % / year from 1995-2014 and thus reveals an unexpected long-term stability of the PV modules mounted at Jungfraujoch (3 450 m asl) in the Swiss Alps in 1992. The first conclusion is that PV installations in the Swiss climate last longer and much better than expected. The -0.11 % / year performance loss shows a much lower figure than the standard degradation of modern PV modules of - 0.8 % / year. Therefore, PV installations under the Jungfraujoch weather conditions last longer and perform better than expected. These results will now be compared with two similar installations, i.e., the 60 kWp plant on the PV laboratory building "Tiergarten" in Burgdorf and the 550 kWp PV plant on Mont-Soleil. All three installations have a similar age and the same PV module technology and product.

References:

[1] Muntwyler, U., T. Schott and E. Schüpbach, Long-term study on the efficiency of photovoltaics at alpine sites, HFSJG Activity Report 2014, 138-142, 2014. https://www.hfsjg.ch/wordpress/reports/2014/144_BFH_Muntwyler_cf.pdf

[2] Breitinger, D. and J. Moser, Auswertung 25 Jahre PV-Anlage Mont-Soleil, Bachelor Thesis, BFH, 2017.

Key words:

Solar power plant, photovoltaics (PV), PV modules, Jungfraujoch (3 450 m asl), Swiss Alps, degradation, long-term stability

Internet data bases:

[1] https://www.ti.bfh.ch/index.php?id=6947
[2] http://www.bfe.admin.ch
[3] http://sccer-furies.epfl.ch

Collaborating partners/networks:

Studiengesellschaft Mont Soleil

Scientific publications and public outreach 2017:

Conference papers

Schott, T., D. Breitinger, J. Moser, U. Muntwyler and E. Schüpbach, Robustness of the PV Installations at Mont Soleil and Jungfraujoch (2001-14), Poster at the SCCER-FURIES Annual Conference 2017, Swiss Tech Convention Center, EPFL Lausanne, Lausanne, Switzerland, November 2, 2017.

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