

## NEW HIGH ALPINE PV INSTALLATION ON THE “TOP OF EUROPE”

Eva Schuepbach, Thomas Schott, Franziska Kuonen, Urs Muntwyler  
 Bern University of Applied Sciences BFH, Department of Engineering and Information Technology  
 Institute for Energy and Mobility Research, Photovoltaic Laboratory (PV LAB)  
 Jlcoweg 1, CH-3400 Burgdorf, Switzerland  
 Tel. +4134 426 68 37, Fax +4134 426 68 13, urs.muntwyler@bfh.ch

**ABSTRACT:** The Photovoltaic Laboratory (PV LAB) at Bern University of Applied Sciences BFH in Burgdorf, Switzerland, has concentrated on performance measurements of alpine PV-installations since the 1980s. As a reaction to an enhanced interest in winter electricity production from alpine PV-installations and its role for the implementation of the Swiss Energy Strategy 2050, the PV LAB enforced its research activities in the field. In 2014, an already existing PV-site installed in 1993 at the high-elevation research station at Jungfrauoch (3 454 m asl) in the Swiss Alps was extended with new PV technology. The analysis of recorded energy yields produced in 2015 demonstrates an enhanced power output of the new PV technology as compared to the state-of-the-art technology 20 years ago. The results are expected to offer new insight into alpine PV production through the comparison of photovoltaic technology.

**Keywords:** Environmental Effect, Performance, PV Module, Solar Cell Efficiencies, System Performance

## 1 INTRODUCTION

From the early 1980s till today, energy yield produced at alpine PV sites in Switzerland has been of great interest, initially for off-grid telecommunication repeater stations and later for grid-connected PV-installations. The first research PV-site in the Swiss Alps was installed in the early 1980s at 3 300 m asl on the Piz Corvatsch (eastern Swiss Alps). It was mainly a test site for off-grid installations for telecomm repeaters.

In these times, Professor Urs Muntwyler, the current head of the Photovoltaic Laboratory (PV LAB) at Bern University of Applied Sciences BFH in Burgdorf, Switzerland [1], was responsible for the first P+D-PV-installations in Switzerland mounted by the Swiss industry company Hasler AG. In 1993 Professor Dr. Heinrich Häberlin [2], the founder of the PV LAB at BFH in Burgdorf, Switzerland, mounted a PV-installation on the façade of the famous alpine research station at Jungfrauoch (3 454 m asl) in the Bernese Oberland. This research station is operated by the University of Bern through its International Foundation “High Altitude Research Stations Jungfrauoch and Gornergrat” [3].

Since the 1980s, the PV LAB at BFH Burgdorf in Switzerland has continuously strengthened its research efforts on the performance measurements of alpine PV-installations. Currently, there is an enhanced interest in winter electricity production from alpine PV and its role for the implementation of the Swiss Energy Strategy 2050 [4]. In the frame of the Swiss Center for Competence in Energy Research on the Future Swiss Electrical Infrastructure, SCCER FURIES [5], a new project for an extension of the existing PV-installation at Jungfrauoch (capacity in 1993: 1 152 Wp) was hence started. The project is supported by Swiss industry partners.

## 2 TOWARDS A NEW ALPINE PV INSTALLATION

At around 3 000 m asl, the weather, climate and environmental factors (lightning, wind, ice, snow, albedo, solar radiation) impacting PV-installations can be extreme. The technology needs to withstand these harsh conditions. Of all the 35 sites in the Swiss PV monitoring

network operated by the PV LAB (see Section 3.2), the PV modules at Jungfrauoch in the Swiss Alps have shown the least degradation past the last 20 years. This is one of the reasons why Jungfrauoch was selected for an extension of the existing (from 1993) PV-installation with new technology.

The other reason is that the PV-installation at Jungfrauoch has been running extremely smoothly over the last two decades. The data gathered at Jungfrauoch provide evidence for a high and stable energy yield throughout the year [6], also in winter.

As renovations were scheduled on the façade of the Jungfrauoch research building in 2013, the opportunity was seized to start the extension project. The underlying project idea is to demonstrate the power ratio (PR) and differences in power output of the new PV technology as compared to the state-of-the-art technology 20 years ago as mounted at the high-elevation site at Jungfrauoch (3 454 m asl) in Switzerland (Table 1).

**Table 1:** Specifications of old (1993/Joch 1) and new (2014/Joch 2) PV technology installed at Jungfrauoch (3 454 m asl) in the Swiss Alps.

	Joch 1	Joch 2
<b>Tilt:</b>	90°	90°
<b>Module:</b>	Siemens M75	Sunpower X21 345
<b>Inverter:</b>	ASP TopClass 2500	SolarMax 3000P
<b>P<sub>Gen</sub>:</b>	1'152 Wp (nominal)	2x1380Wp
<b>Installation:</b>	October 1993	September 2014

The planning work was carried out by a Bachelor student registered at BFH and supervised by PV LAB staff. The mounting of the new technology, i.e., high-efficiency modules of Sunpower (2 760 Wp) at the Jungfrauoch research building (Fig. 1) was done by engineer Thomas Schott. The installation work had to be delayed to September 2014 because of adverse weather conditions at Jungfrauoch in summer 2014.

The new PV modules were installed on the south and southwest wall, alongside the already existing 20 year old PV-installation at the Jungfrauoch research building (Fig. 2a-b).

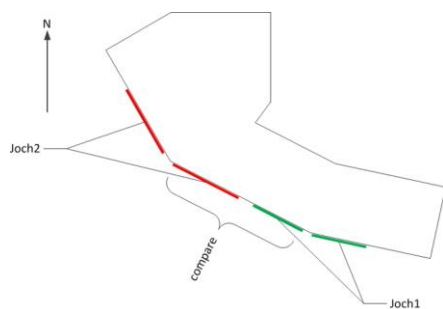


**Figure 1:** Installing new PV technology on the façade of the Jungfrauoch (3 454 m asl) research building in the Swiss Alps in autumn 2014.



**Figure 2a:** Jungfrauoch research building with existing PV-installation (from 1993) on the right façade and new (2014) PV modules on the left façade.

The new PV-modules mounted in 2014 (Fig. 2) have an area of 13m<sup>2</sup>. Although this is only slightly (30%) bigger than the existing PV installation from 1993 with 10m<sup>2</sup>, the nominal power is higher by 140%.



**Figure 2b:** Position of the old and new PV modules on the Jungfrauoch research building (Joch 1: PV-installation of 1993; Joch 2: PV-installation of 2014).

They were extensively tested and connected to the grid (Fig. 3). A high resolution, precise measurement was installed for a normalized presentation of the new PV data. First results of power output differences between Joch 2 (2014 PV-installation) and Joch 1 (1993 PV-installation) are presented in Section 3.



**Figure 3:** Grid-connection of new PV modules mounted at Jungfrauoch in 2014 (right), next to old ASP inverter from 1993 (left).

### 3 FIRST RESULTS

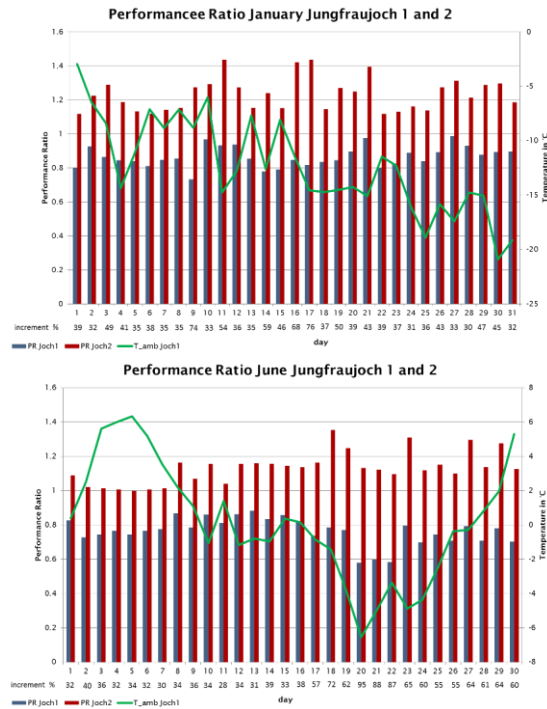
#### 3.1 Performance Ratio of PV Modules

The new PV modules installed in 2014 (Table 1) have an efficiency of about 21% as compared to the PV modules from 1993 (with an efficiency of ca. 12%). Hence, the energy yield produced from the 2014 PV modules is expected to amount to 2 760 Wp as compared to 1 152 Wp from the PV installation in 1993, i.e., an increase by a factor of 2 [7].

But how is the normalised yield?

As data gathering from the new PV-installation started in December 2014, first comparisons of the energy production between the old (1993/Joch 1) and new (2014/Joch 2) PV-installation at Jungfrauoch were drawn between January 2015 and June 2015.

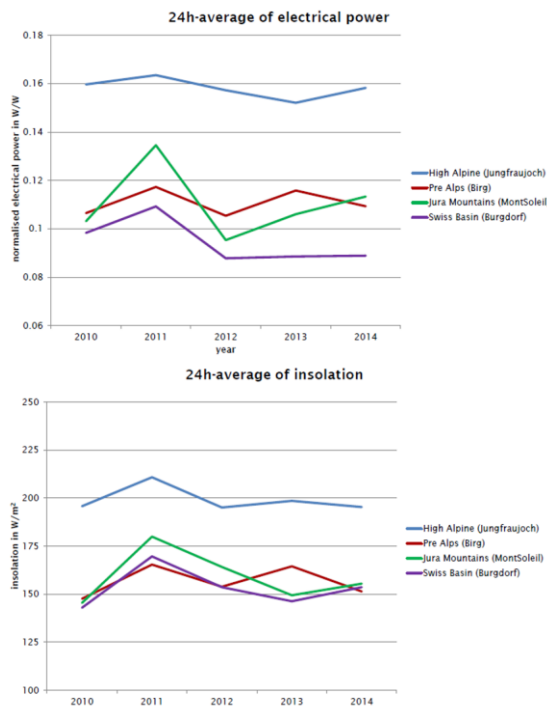
Fig. 3 provides evidence that the new PV modules at Jungfrauoch, mounted in 2014, have an increased performance ratio (PR) by about 30%.



**Figure 3:** Performance ratio of energy yield produced at Jungfrauoch (3454 m asl) from new (2014) and old (1993) PV modules in January 2015 (top) and June 2015 (bottom).

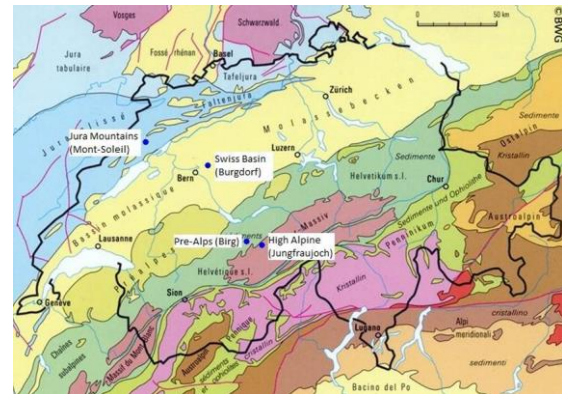
### 3.2 Wafer Reaction to Alpine Climate Stress

The “thick” wafers (about 300µm) from the 1993 PV-installation at Jungfrauoch have resisted well to the high-alpine climate stress so far.



**Figure 4:** Electrical power and insolation of selected sites in typical topographic regions in Switzerland.

Fig. 4 compares the 24h-averages of electrical power and insolation among PV-sites from typical topographic regions in Switzerland. The data of the PV-sites is taken from the Swiss monitoring network with more than 35 PV-installations operated by the PV LAB at BFH [1,6]. The network not only includes the high-alpine PV site at Jungfrauoch, but also lower-elevation PV-installations in the other topographic regions in Switzerland. These are the Swiss Basin, the Jura Mountains, and the Pre-Alps (Fig. 5).



**Figure 5:** Topographic regions in Switzerland with location of PV-sites selected for comparison in Fig. 4.

The selected PV-sites representing these topographic (lower-elevation) regions in Switzerland are “Gfeller Burgdorf” (Swiss Basin), “Mont Soleil” (Jura Mountains) and “Birg” (Pre-Alpes). Specifications of these sites are listed in Table 2.

**Table 2:** Specifications of the selected PV-installation sites for comparison with Jungfrauoch in Fig. 4.

Site	lat/long	masl	Module	Inverter	Installation	Monitoring Start
High Alpine: Joch 1	46.55°N, 7.98°O	3'454	Siemens M75	ASP TopClass 2500/4 Grid III	27.10.1993	29.10.1993
	Joch 2	46.55°N, 7.98°O	3'454	Sunpower X21 345	SolarMax 3000P	01.09.2014
Pre-Alps	46.56°N, 7.86°O	2'677	Siemens M55	ASP TopClass 4000/6 Grid III	21.12.1992	22.12.1992
Jura Mountains	47.16°N, 6.99°O	1'270	Siemens M55	ABB	28.04.1992	01.06.2001
Swiss Basin	46.96°N, 7.46°O	540	Siemens M55	ASP TopClass 4000/6 Grid III	24.06.1992	01.07.1992

## 4 OUTLOOK

PV-installations like the one at Jungfrauoch (3454 m asl) in Switzerland can help to understand the economic benefit of high alpine PV production. Previous studies [8] revealed that the energy yield from high-elevation PV-sites (above 1500 m asl) in Switzerland can produce an energy output that is similar to PV-installations in southern Europe or Northern Africa.

In the context of economic winter electricity production in Switzerland, some burning research questions can now be addressed with the data gathered from the new PV technology mounted at Jungfrauoch in 2014.

Among them is a cost-benefit analysis, i.e., can the additional costs of alpine PV constructions be justified and economically covered in the future, as compared to the investment for hydroelectricity? In view of this objective, the long-term impact of the high-alpine climate on the thinner (about 180  $\mu\text{m}$ ) wavers need to be assessed.

For the monitoring and quality-control of the new PV modules at Jungfrauoch, the PV LAB developed its own IR Multicopter Drone. The system was extensively tested on the roof-top PV-installation at the BFH-building hosting the PV LAB, applied to two large PV-installations in Switzerland [9], and now allows a rapid routine thermal inspection of operating PV-modules.

Given that the drone is electric, it offers an especially added value for the high-alpine PV-installation at Jungfrauoch [9], where the PV LAB records the longest time-series of energy yield from PV in the Alps. The “Top of Europe”, as Jungfrauoch is also termed, is the world’s most elevated research facility, with highly sensitive instruments measuring trace gases in the lower free troposphere over Continental Europe [10]. Hence, no disturbing emissions are allowed.

#### Acknowledgements

We gratefully acknowledge financial support from BFH and the Swiss Commission for Technology and Innovation (CTI). This project is carried out in the frame of the Swiss Centre for Competence in Energy Research on the Future Swiss Electrical Infrastructure (SCCER FURIES). Collaboration with the University of Bern (International Foundation “High Altitude Research Stations Jungfrauoch and Gornergrat) and Jungfrauoch Railway ([www.jungfrau.ch](http://www.jungfrau.ch)) is highly appreciated.

#### References

- [1] [www.pvtest.ch](http://www.pvtest.ch)
- [2] H. Haeberlin, Phovoltaik: Strom aus Sonnenlicht für Verbundnetz und Inselanlagen, Electrosuisse (2010), ISBN 978-3-905214-62-8 ([www.electrosuisse.ch](http://www.electrosuisse.ch)).
- [3] [www.hfsjg.ch](http://www.hfsjg.ch)
- [4] <http://www.bfe.admin.ch>
- [5] <http://sccer-furies.epfl.ch/>
- [6] E. Schuepbach, U. Muntwyler, M. Jost, T. Schott, Proceed. 29th European Photovoltaic Solar Energy Conference and Exhibition, 22-26 September 2014, Amsterdam, The Netherlands (2014), 2689-2691.
- [7] U. Muntwyler, T. Schott, E. Schuepbach, Activity Report 2014, International Foundation High Altitude Research Stations Jungfrauoch + Gornergrat HFSJG, University of Bern, Switzerland (2014), 145-149.
- [8] U. Muntwyler, 8th International Conference and Exhibitions on Ecological Vehicles and Renewable Energies, Monaco (2013).
- [9] U. Muntwyler, E. Schuepbach, M. Lanz, Infrared (IR) drone for quick and cheap PV inspection (2015), this volume.
- [10] E. Schuepbach, T.K. Friedli, P. Zanis, P.S. Monks, S.A. Penkett, Journal of Geophysical Research 106 (2001) 20,413-20,427.