

Name of research institute or organization:

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**Berner Fachhochschule (BFH), Technik und Informatik (TI),  
Photovoltaik-Labor**

Title of project:

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Long-term energy yield and reliability of a high alpine PV (photovoltaic) plant at Jungfrauoch (3454 m)

Project leader and team

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Prof. Dr. Heinrich Haeblerlin, project leader  
Philipp Schaerf, project assistant

Project description:

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PV plant Jungfrauoch (1.152 kWp, 3454 meters above sea level) was planned and realised by the laboratory for photovoltaics (PV) of the Berne University of Applied Sciences (BFH) during summer and fall 1993. At the time of its erection it was the highest grid connected PV plant in the World.

**Purpose and Goals of the project:**

- Test of PV components: Operation in high altitudes is a very hard stress for all components due to extremely high irradiance peaks of more than 1.7 kW/m<sup>2</sup>, heavy storms and thunderstorms, and large temperature differences. PV components surviving in such a harsh environment should perform more reliably under normal operating conditions.
- Long-term operating experience: Experimental demonstration that high PV energy yields for high alpine PV plants can not only be simulated, but can actually be obtained in practical operation over many years.
- Intensive analytical monitoring with redundant sensors to ensure maximum reliability in order to get long-term data about energy yield and reliability of the plant.
- Maximum availability of energy production and monitoring data (AMD ≈ 100%).

In 2011, normalized energy production of PV plant Jungfrauoch (rated peak power 1.152 kWp, effective peak power 1.13 kWp, 3454 m above sea level) increased somewhat to **1433 kWh/kWp/a or 1433 h/a**. Like already in 2010 also in 2011 an increase of about 2.9% compared to 2010 could be registered. This was mainly due to a significant increase in irradiation. Irradiation into the array plane was about 6.1% higher than in 2010 and about 8.7% higher than in 2009. Energy production was somewhat higher than the long-term mean value according to table 1. Performance ratio PR decreased slightly due to two periods of snow coverage in March and November (see fig. 2 and 3).

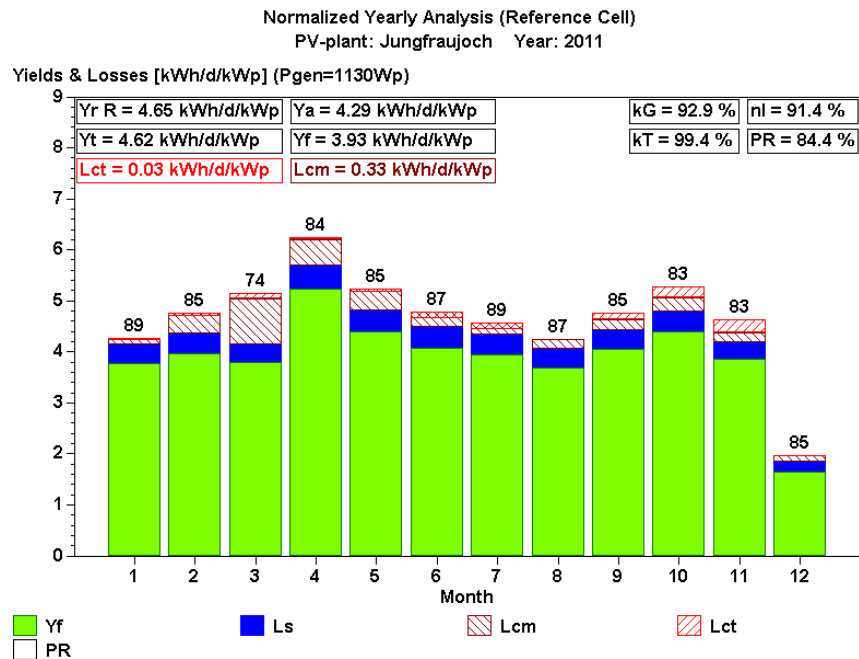
The long-term annual average from 1994 to 2011 of PV plant Jungfraujoch increased a little to 1409 kWh/kWp/a or 1409 h/a with a winter energy fraction of 46 %.

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean
$Y_f$ (h/a)	1272	1404	1454	1504	1452	1330	1372	1325	1400	1467	1376	1537	1449	1453	1375	1358	1393	1433	1409
$PR = Y_f / Y_r$ in %	81.8	84.1	84.7	85.3	87	84.8	84.6	78.6	85.2	84.9	86.2	86.9	85.5	85.9	86.4	87	87.1	84.4	85.0

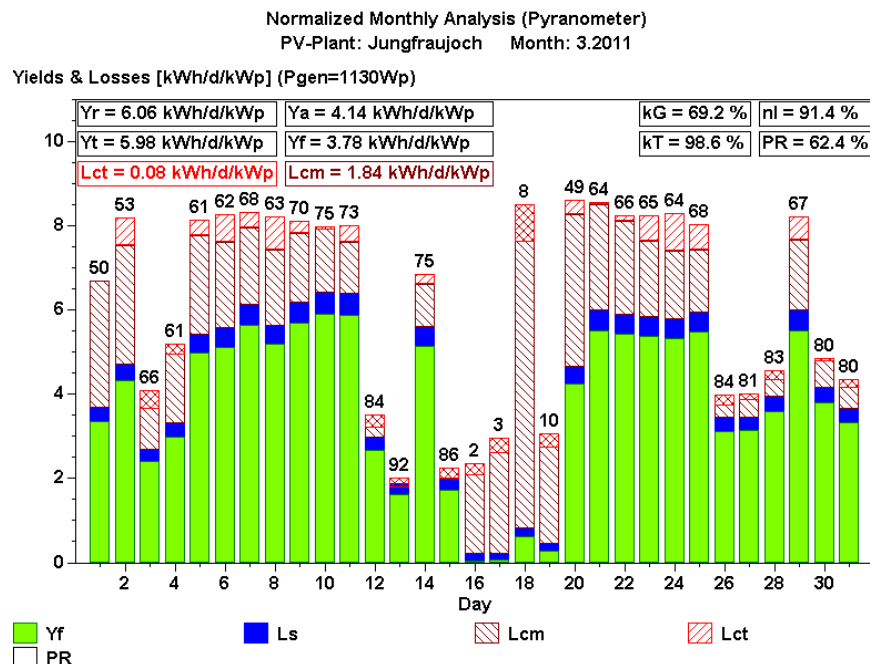
**Table 1.** Annual energy production (referred to effective STC-power) and performance ratio PR (referred to reference cell irradiance measurement) from 1994 – 2011. Eighteen-year average values are also indicated.

**Figure 1.** Normalized monthly energy production for 2011.

In March, PV production was affected by snow coverage of the PV array. Between Nov. 4<sup>th</sup> to 8<sup>th</sup>, the whole PV array and the reference cells were covered by snow. Between Dec. 4<sup>th</sup> and 8<sup>th</sup> data were lost.

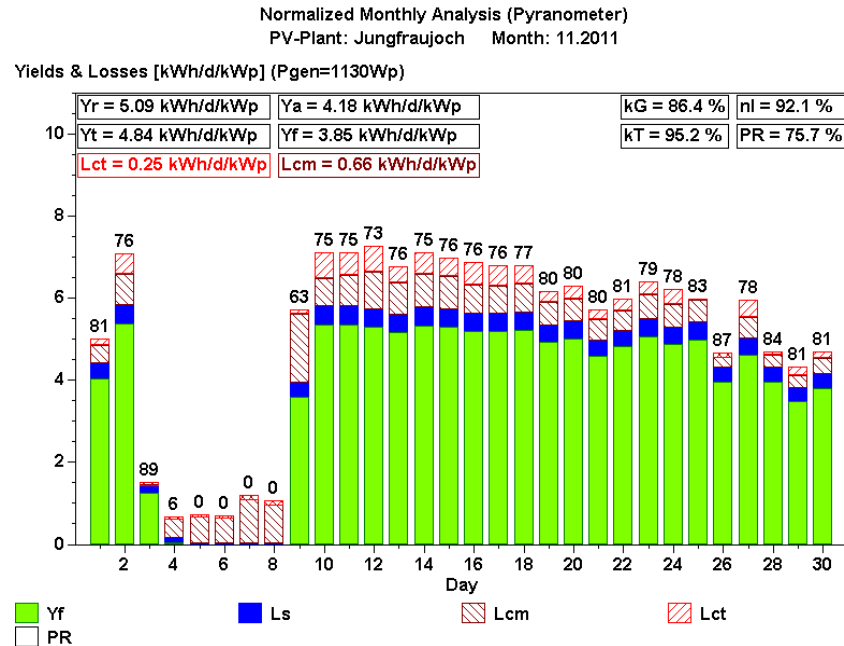


**Figure 2.** Normalized daily energy production for March 2011. Between Feb. 23<sup>rd</sup> and March 29<sup>th</sup> PV production was affected by snow coverage of the PV array.



**Figure 3.**  
*Normalized daily energy production for November 2011.*

*Between Nov. 4<sup>th</sup> to 8<sup>th</sup>, the whole PV array including the reference cells was completely covered by snow! Only the heated pyranometers could register some irradiation.*



Due to a defect on a printed circuit board in the telephone distribution of the research station, the telephone line used to transmit the data of PV plant Jungfrauoch down to the PV laboratory in Burgdorf was interrupted between Dec. 4<sup>th</sup> and Dec. 12<sup>th</sup>. Therefore the data between Dec. 4<sup>th</sup> and 8<sup>th</sup> were lost, as the memory in the data logger was not sufficient to cover the whole period without available communication.

As there was no inverter defect during this time, attempts will be made to reconstruct the irradiation and energy yield data approximately using irradiance data from the meteo station at Jungfrauoch Sphinx and the PV plant Birg with the same inclination about 10 km away.

A detailed description of the plant, measurement results of earlier years and definitions used can be found in earlier annual reports (2000 - 2010) and in several publications (many publications can be downloaded under [www.pvtest.ch](http://www.pvtest.ch)) and two extended books published 2007 and 2010. A translation of the edition 2010 will be published by Wiley in early 2012.

Diagrams similar to fig. 1 for the years 1994 – 2010 and normalized monthly diagrams can be downloaded under [www.pvtest.ch](http://www.pvtest.ch) > plant overview > Jungfrauoch.

Key words:

Grid-connected PV plants, energy yield, high alpine

Internet data bases:

<http://www.pvtest.ch>

Scientific publications and public outreach 2011:

In 2011 no specific publications about PV plant Jungfrauoch, but several other publications about PV including a large project report in German containing also data from PV plant Jungfrauoch:

H. Häberlin, L. Borgna, D. Gfeller, D. Joss, M. Münger, W. Reichen, Ph. Schärf:  
"Photovoltaik-Systemtechnik (PVSYSSTE2007-2010)".  
Schlussbericht BFE-Projekt SI/500077 / SI/500077-01, 2007 - 2010 / Februar 2011.  
Available under [www.pvtest.ch](http://www.pvtest.ch) > Publications [150] (German version).

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