

Name of research institute or organization:

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

Title of project:

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

Project leader and team

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

Project description:

PV plant Jungfraujoch (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%).**

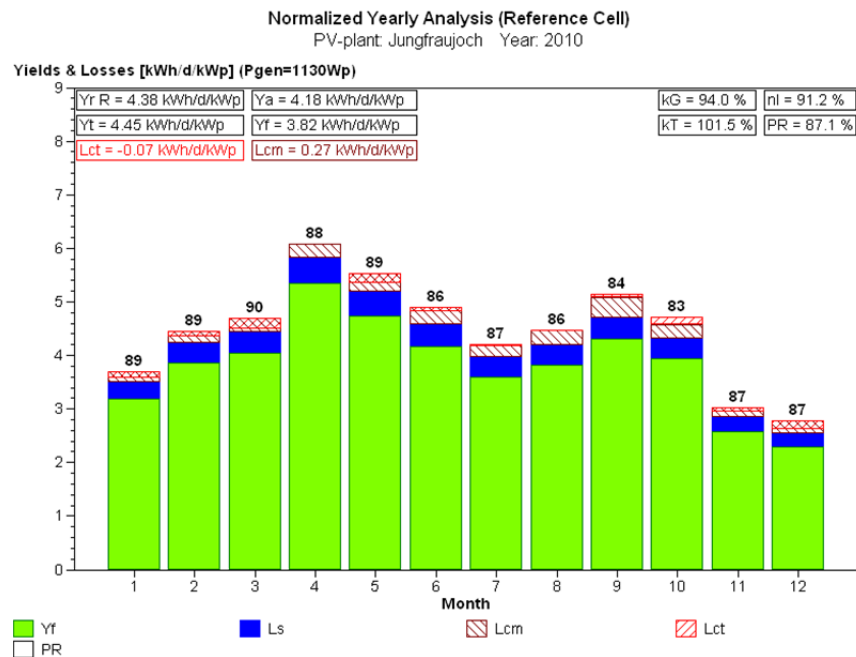
In 2010, normalized energy production of PV plant Jungfraujoch (rated peak power 1.152 kWp, effective peak power 1.13 kWp, 3454 m above sea level) increased somewhat to **1393 kWh/kWp/a or 1393 h/a**. After two years with significant decrease, an increase of about 2.6% compared to 2009 could be registered. This was mainly due to an increase in irradiation compared to 2009. Irradiation into the array plane was about 2.5% higher than in 2009 and about 0.8% higher than in 2008. However, energy production was still a little lower than the long-term mean value according to table 1. Performance ratio PR increased again slightly due to the low snow coverage this year.

The long-term annual average from 1994 to 2010 of PV plant Jungfraujoch decreased a little to 1407 kWh/kWp/a or 1407 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	Mean
$Y_i$ (h/a)	1272	1404	1454	1504	1452	1330	1372	1325	1400	1467	1376	1537	1449	1453	1375	1358	1393	1407
$PR=Y_i/Y_r$ 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	85.1

**Table 1: Annual energy production (referred to effective STC-power) and performance ratio PR (referred to reference cell irradiance measurement) from 1994 – 2010. Seventeen-year average values are also indicated.**

**Fig. 1:**  
Normalized  
monthly energy  
production for  
2010.



A detailed description of the plant, measurement results of earlier years and definitions used can be found in earlier annual reports (2000 - 2009) and in several publications (many publications can be downloaded under [www.pvtest.ch](http://www.pvtest.ch)) and a book. In 2010, an updated and extended second edition of this book was published. An English translation of this book will be published by Wiley in 2011.

Diagrams similar to fig. 1 for the years 1994 – 2009 and normalized monthly diagrams can be downloaded under [www.pvtest.ch](http://www.pvtest.ch) > plant overview > Jungfrauojoch.

Key words:

Grid-connected PV plants, energy yield, high alpine

Internet data bases:

<http://www.pvtest.ch>

Scientific publications and public outreach 2010:

H. Häberlin: “Photovoltaik – Strom aus Sonnenlicht für Verbundnetz und Inselanlagen”, 2010. Electrosuisse-Verlag, CH-8320 Fehraltorf, ISBN 978-3-905214-62-8 and VDE Verlag, Berlin, ISBN 978-3-8007-3205-0 (in German).

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