LONG-TERM PERFORMANCE OF SWISS PHOTOVOLTAIC (PV) INSTALLATIONS

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ABSTRACT: The long-term performance and stability of photovoltaic (PV) installations have been "hot topics" in Switzerland since the late 1970s, when the first pilot- and demonstration installations for telecommunication purposes were built. When the feed-in-tariff system for PV was invented by the city of Burgdorf (Switzerland) in the 1990s, the nearby Photovoltaic Laboratory (PV LAB) at Bern University of Applied Sciences (BFH) in Burgdorf started monitoring an extended PV-installation network. Today, more than twenty different PV technologies are monitored at more than ten sites, providing valuable information on the stability of PV technology and long-term energy harvesting. The network includes high-altitude sites like Jungfraujoch (3,454 m asl) in the Swiss Alps. Mean energy yields (1994-2013) at Jungfraujoch display a near-constant annual cycle. In contrast, mean annual cycles of energy yields at PV-installations in the Swiss Basin (ca. 500 m asl) are characterized by a maximum in summer and minimum in winter. Winter energy yields from PV-installations at high elevation in the Swiss Alps are hence a research focus in the analysis of data from the monitoring network. Current efforts in a Swiss Competence Center for Energy Research include mounting new technology at Jungfraujoch to compare measured energy yields with data from equipment older than 20 years.
Keywords: Long-Term Monitoring, Reliability, System Performance

1 THE MONITORING NETWORK

In the context of the "Energy Strategy 2050" of the Swiss Government, PV will be the most important new electricity source with 12 TWh in 2050. Considerable investment in this technology is hence expected in the future. All aspects associated with cost/ production ratio, safety, reliability and use of PV installations are, therefore, of outmost importance.

The Photovoltaic Laboratory (PV LAB) at Bern University of Applied Sciences (BFH) in Burgdorf, Switzerland, has been working on these aspects for more than 20 years. Following the invention of the feed-in-tariff system for PV in Burgdorf in the 1990s, the PV LAB started to set up a monitoring network of PV-installations in Switzerland. PV-installations added to the network more than 10 years ago include three sites with thin-film modules and the well-known 550 kWp installation at Mont Soleil in the Jura mountains (ca. 1,270 m asl). The latter is jointly monitored with the utility company BKW and the research organisation "Studiengesellschaft Mont-Soleil". In 2005, the PV installation in the football stadium in the capital city of Bern with more than 1.35 MWp was integrated in the network.

After arrival of the new Director of the PV LAB in 2011, Prof. Urs Muntwyler, who has pioneered the field since 1982 [1], another 10 new PV installations were incorporated. Among them is an installation with 37 kWp near the capital city of Bern with Solyndra-PV-modules and a Sputnik S-inverter. Today, more than twenty different PV products and PV technologies are monitored in an extended network of about ten PV-installation sites, providing a comprehensive and valuable data set (Table I).

Some of the PV-installations have now been operated for more than 20 years (Table I) and provide valuable information on the reliability and quality of ageing PV technology and long-term PV measurements. The two newest PV-installations were constructed in 2013 on the BFH Campus in Burgdorf, home of the PV Lab (Fig. 1a,b) and in 2014 at Jungfraujoch (modernizing existing equipment; Fig. 7).

Table I: PV-installations in the monitoring network operated by the PV LAB at BFH Burgdorf, Switzerland.

Site	Subsystem	lat/long	m asl	Module	Inverter	Installation
Joch	Joch 10	46.55°N, 7.98°O	3'454	Siemens M75	ASP TopClass 2500/4 GridIII	27.10.1993
	Joch 21	46.55°N, 7.98°O	3'454	Sunpower X21 345	SolarMax 300P	9.2014
	Joch 22	46.55°N, 7.98°O	3'454	Sunpower X21 345	SolarMax 300P	01.09.2014
APH Burgdorf	APH07-1	47.05°N, 7.63°O	530	Sharp NUSOE3	SMA Sunnyboy 3300	8.2007
	APH07-2	47.05°N, 7.63°O	530	Sharp NUSOE3	SMA Sunnyboy 3300	8.2007
	APH07-3	47.05°N, 7.63°O	530	Sanyo HIP-210NHE5	SMA Sunnyboy 3300	8.2007
	APH08-1	47.05°N, 7.63°O	530	Solarworld SW220 poly	SMA Sunnyboy 3800	9.2009
	APH08-2	47.05°N, 7.63°O	530	Sunpower SPR215	SMA Sunnyboy 3800	9.2009
	APH08-3	47.05°N, 7.63°O	530	Schott Solar 170 poly	SMA Sunnyboy 3800	9.2009
	APH08-4	47.05°N, 7.63°O	530	Kyocera LC175GHT-2	SMA Sunnyboy 3800	9.2009
	APH08-5	47.05°N, 7.63°O	530	Kyocera LC175GHT-2	SMA Sunnyboy 3800	9.2009
Birg		46.56°N, 7.86°O	2'677	Siemens M55	ASP TopClass 4000/6 GridIII	21.12.1992
EBL Liestal		47.49°N, 7.73°O	327	Kyocera LA361H51	SolarMax20	23.09.1992
Gfeller Burgdorf		46.96°N, 7.46°O	540	Siemens M55	ASP TopClass GridIII 4000/6	24.06.1992
Mont Soleil		47.16°N, 6.99°O	1'270	Siemens M55	ABB	28.04.1992
Newtech Burgdorf	NT1	47.04°N, 7.63°O	540	Siemens ST 40	ASP TopClass Spark	17.12.2001
	NT2	47.04°N, 7.63°O	540	Solarex Millennia MST 43-LV	ASP TopClass Spark	17.12.2001
	NT3	47.04°N, 7.63°O	540	Uni-Solar US-64	ASP TopClass Spark	17.12.2001
Schlossmatt Burgdorf		47.05°N, 7.63°O	540	Siemens M55	Sunways NT4000	17.03.1995
Tiergarten Burgdorf	Ost	47.06°N, 7.61°O	530	Siemens M55	SolarMax25c	12.01.1994
	West	47.06°N, 7.61°O	530	Siemens M55	SolarMax25c	12.01.1994
	Mitte	47.06°N, 7.61°O	530	Siemens M55	Edisun 200, TopClass 1800, TopClass 2500/6 GridIII, TopClass 4000/6 GridIII, Fronius IG30	12.01.1994
Stade de Suisse, Bern	AA1	46.96°N, 7.46°O	560	Kyocera KC175GHT-2	SolarMax125	16.08.2007
	AA2	46.96°N, 7.46°O	560	Kyocera KC175GHT-2	SolarMax125	16.08.2007
	BI1	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
	BI2	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
	CI1	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
	CI2	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
	CI3	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
	DA1	46.96°N, 7.46°O	560	Kyocera KC175GHT-2	SolarMax125	16.08.2007
	DA2	46.96°N, 7.46°O	560	Kyocera KC175GHT-2	SolarMax125	16.08.2007
	DI1	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
	DI2	46.96°N, 7.46°O	560	Kyocera KC-167GH-2	SolarMax125	18.03.2005
Worblenpark Ittigen		46.97°N, 7.48°O	493	Solyndra SL-001-182	SolarMax 35S	16.08.2011
Localnet Gsteighof		47.05°N, 7.61°O	540	Solarex MSX120	SolarMax 15	18.05.1995

Figure 1a: The tracker PV-installation with 4,8 kWp serves as a tracker reference station on the BFH Campus.

Figure 1b: The new solar carport-installation with 2,9 kWp was installed in 2013 on the BFH Campus and serves as a test station for new equipment.

2 LONG-TERM ENERGY YIELDS (1994-2013)

2.1 Jungfraujoch (Swiss Alps)

Some of the PV-installations in the monitoring network are high-alpine sites located in the Swiss Alps, e.g., at Jungfraujoch (Table II; Fig. 2).

Table II. PV-installation at Jungfraujoch.

Monitoring Station:	Jungfraujoch (3,454 m asl)
Orientation:	12 / 27° west
Tilt:	90°
Module:	Siemens M75
Inverter:	ASP top class 2500
Pgen:	1,152 Wp (nominal)
Installation:	27 October 1993

Figure 2: PV-installation at Jungfraujoch (3,454 m asl).

2.2 Gfeller Burgdorf (Swiss Basin)

Many of the sites in the monitoring network are located in Burgdorf, home of BFH and KEV invention in the 1990s. For comparison with Jungfraujoch, the PV-installation at Gfeller Burgdorf is used (Table III; Fig. 3).

Table III. PV-installation at Gfeller Burgdorf.

Monitoring Station:	Burgdorf (540 m asl)
Orientation:	10° east
Tilt:	28°
Module:	Siemens M55
Inverter:	ASP top class 3000
Pgen:	3‘180 Wp (nominal)
	24 June 1992

Figure 3: PV-installation at Burgdorf (540 m asl).

2.3 Annual Cycles of Energy Yields

The mean long-term energy yield (1994-2013) at Jungfraujoch is nearly constant throughout the year (Fig. 4). This performance is due to the high solar irradiation and albedo of the glacier in front of the generator.

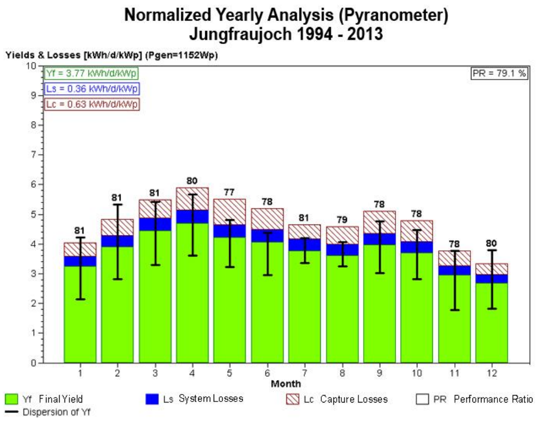

Figure 4: Mean annual cycle (1994-2013) of energy yield at Jungfraujoch in the Swiss Alps.

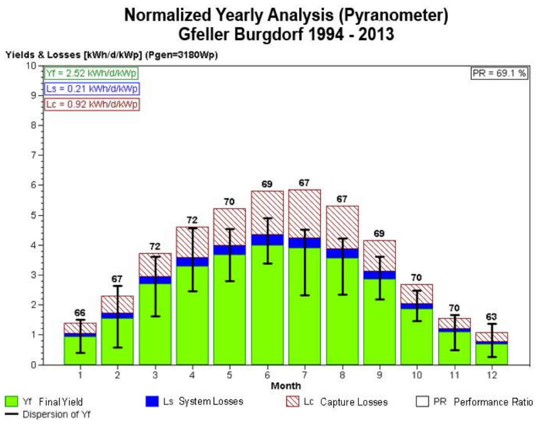

Figure 5: Mean annual cycle (1994-2013) of energy yield at Gfeller Burgdorf in the Swiss Basin.

For comparison, the energy yields at the PV-installation in the Swiss Basin (Gfeller Burgdorf) displays a mean annual cycle with a maximum in summer and minimum in winter (Fig. 5) from 1994-2013.

2.4 Winter energy yields

In addition to the mean seasonal performance, the tong-term records of PV system measurements in the monitoring network also provide valuable estimates on the long-term stability. Fig. 6 evidences the stability of the energy harvesting in winter (December-February) at the Jungfraujoch PV-installation since the beginning of the measurements. For comparisons, the mean energy yield at the Gfeller Burgdorf PV-installation, after years of operation, is also shown.

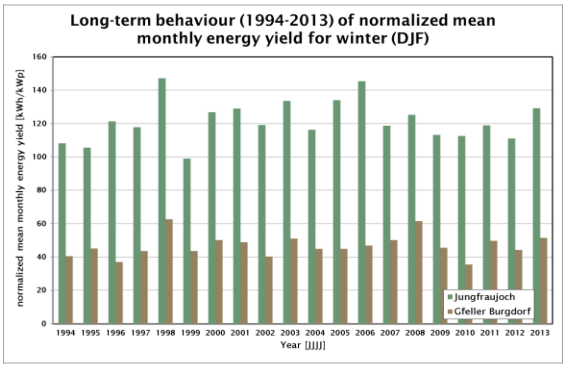

Figure 6: Mean winter (December-February) energy yields at Jungfraujoch and Gfeller Burgdorf (1994-2013).

3 FURTHER AVENUES

The wealth of data monitored in the PV-installation network forms an important archive to quantify the role of PV for electricity production in the energy transition strategy of Switzerland. In the coming years, the PV-installation network will be modernised (technology, monitoring system, automated data quality control procedures). An example is the extension of the existing PV-installation at Jungfraujoch. Currently, new Sunpower modules are mounted at the high-alpine site (Fig. 7). On-site tests of new technology and procedures are carried out in the tracker PV-installation and solar carport installed in 2013 in front of the University building (see Fig. 2a-b).

The new technology will allow for comparative studies of measured energy yields with data from equipment older than 20 years. Efforts will also be undertaken towards rigorous data quality control of all measured data as in [2]. Knowhow-transfer will be achieved in an international Workshop on 3-4 October 2014 at BFH Burgdorf (Switzerland) and at Jungfraujoch (www.pvtest.ch).

Much of the work (including dissemination activities) is undertaken within the Swiss Competence Center for Energy Research SCCER FURIES; http://sccer-furies.epfl.ch/), an initiative launched by the Swiss Government. The SCCER FURIES also finances new equipment to test PV inverters at the PV LAB, which has been conducting PV inverter tests for more than 20 years. The expected outcome is a test bench able to simulate the characteristics of three independent sub-arrays with a total power of about 35kW. For the biggest inverter test bench (100 kWp), certification is aimed at in 2014/15. After certification, the PV LAB at BFH Switzerland will be able to measure in a defined precision and complying with current norms.

Figure 7: Modernising the high-alpine PV installation at Jungfraujoch (3,454 m asl) in autumn 2014 with new Sunpower modules.

4 CONCLUSIONS

Long-term monitoring of PV-installations provides essential information on the performance and lifetime of PV technology and hence stability of energy yields. This information is essential if future investments of the Swiss Government are to be economically viable in the frame of implementation of the "Energy Strategy 2050".

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