PHOTOVOLTAIC CONVERSION:

PV-Technology, System Design, Market Data, Cost Development, Lessons Learned

Heinrich Wilk
Energie AG Oberösterreich. A-4021 Linz

Introduction

One of the most promising renewable energy technologies is photovoltaics (PV). PV is a truly elegant means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid-state devices simply make electricity out of sunlight, silently with no maintenance, no pollution and no depletion of materials. There are no rotating engines, vessels and turbines. Photovoltaics are also exceedingly versatile – the same technology that can pump water, grind grain and provide communications and village electrification in the developing world can produce electricity for the buildings and distribution grids of the industrialised countries. [1] [2].

In most countries of the world photovoltaic applications started with stand-alone systems to power small loads in places without electric grid service. The very first autonomous photovoltaic systems were used to supply electricity on board of satellites. In Europe early applications of solar electric systems could be found in micro wave transmitter stations and mountain cabins in the Alps. This market segment developed very well – even without funding.

Photovoltaics stand for innovation, ecology, energy efficiency, long term thinking and smart technology. All this attributes attract a wide range of enthusiasts from different sectors of science, industry, electric utilities and trade.

Demo projects with a rated power of more than 1 MW have been installed in several countries. Grid connected photovoltaic plants are modular units. Power conditioners (inverters) are converting direct current from the solar cells into alternating current suitable for grid interconnection. They are available in units with a rated power of 100 Watt to converter cabinets with up to 1.000 kW. Solar panels can be integrated in roof surfaces and facade elements in the building sector. The market developed well with the help of numerous funding systems:

- PV Funding Programme Upper Austria, 1991
- 200 kW Rooftop Programme, Austria, 1992
- 1.000 – Rooftop Programme, Germany, 1993
- PV-Tariff Carinthia, 10 ATS/kWh, 1996
- 70.000 – Roofs Programme, Japan, 1996
- 1 Million Roofs Programme, USA, 1997

- 100.000 – Roofs Programme, Germany, 1.1.1999
- Renewable Energy Law, Germany – PV: 0,99 DM/kWh, 1.4.2000
- EU Project: “HIP HIP”, Grid Connected Systems, 3 MW, July 2000

Market Development

The PV market developed very well recently. In 1999 approximately 200 MW of solar modules have been sold all over the world (see attached diagrams). This corresponds to the installation of a total module area of 2.000.000 m^2 per year. In the last 3 years the market volume increased by 30 % per year [3]. About 20 % of all solar cells are produced in Europe [4].
Four major companies deliver more than 50 % of the worlds photovoltaic shipments. The following table gives the real production figures of the biggest manufacturers of PV modules in 1999 :

- BP Solarex 32,5 MW
- Kyocera 30,3 MW
- Sharp 30,0 MW
- Siemens Solar 26,0 MW
- Sanyo 13,0 MW
- AstroPower 12,0 MW
- Photowatt 10,0 MW
- ASE 10,0 MW [6]

Shell Solar and ASE are rapidly expanding their production capacity:

- Shell Solar 25 MW, Gelsenkirchen
- ASE 13 MW, Alzenau

Technology

The crystalline silicon cell is still the dominating technology. 93 % of all PV modules used outdoors are made from crystalline silicon wafers. There are several emerging technologies. It is interesting to see that companies are building new production capacities in this sector:

- Siemens Solar CIS USA
- Solarex 10 MW a-Si USA

• BP-Solar	10 MW	CdTe	USA
• Antec-Solar Freiberg		CdTe	D
• Würth Solar Marbach	1 MW	CIS	D

We can expect that c-Si devices will be dominating the market for the next decade. Record values of conversion efficiency could be reached with c-Si cells:

mono-Si: 24,4 %
poly-Si : 19,8 %

Most of the c-Si solar cells are now made from scrap materials from the chip production factories. For 1 kW of solar cells 10 to 15 kg of pure silicon is used. Approximately 2.000 tons/year of solar-grade silicon is needed world-wide to produce solar cells. This is about 10 % of the total amount of electronic-grade silicon used in the electronic industry. With this situation going on the PV sector is somewhat linked to the boom cycles of the chip industry.
The base material for all electronic producers is metallurgical grade silicon. Companies in Norway and Canada are producing approximately 800.000 tons a year (99 % pure silicon). To reduce the feedstock costs there are some research efforts to produce solar-grade silicon from metallurgical grade silicon without the complicated Trichlorsilan process.
Reducing the thickness of the cells will also help to decrease PV module production costs.
The development effort in the field of advanced thin film panels will probably lead to cost efficient products in a few years. Copper Indium Diselenide (CIS) is also a promising technology with stable conversion efficiencies of more than 10 % for large area modules (Siemens, Würth Solar etc.). With the development of thin film technologies the silicon demand could be reduced dramatically.

Lessons Learned

In 1999 we distributed a questionnaire to the 189 owners/operators of PV-systems in our low voltage grid. We wanted to learn more about their experiences with PV and their lessons learned. 52 % of all questionnaires have been returned to be analysed. 90 % of them have been returned within 4 weeks time. In total we got reports about 4.267 months of system operation.
The motivation to build a PV system was given to be:

- Improve the environment 79,8 %
- Technical interest 72,6 %
- Demonstration 27,4 %

In 1990 the first private PV system started operation. 58 % of all inverters came from a local company (FRONIUS). 60 % of the solar modules have been delivered by KYOCERA. About 63 % of the operators said that their PV system worked without any failure. The average specific yield was calculated to be 840 kWh/kW (1997 and 1998). With 36 system a total of 46 failures and outages were reported. Almost all of the problems were linked to inverter failures. In some cases the grid voltage at the interconnection point was to high or too low and the inverter switched off.

List of Failures:

1x DC-fuse in solar array circuit
1x Grid voltage too low
2x ENS detects too high values of grid impedance
9x Indirect lightning stroke
14x Power stage transistors defect
1x Choke coil burned
1x Cold solder point
7x Failure of different components in the inverter
1x Change of micro processor
4x Software-update needed

The time of waiting for repair and the repair time was reported to be between 1 week and 6 weeks. In most cases 1 week was needed to repair or exchange the inverter. In average the probability for a system failure was 1 in 8 years of operation. If we exclude well known early design problems of inverters we can expect **1 failure in 15 years**. The probability of a lightning induced failure is 1 in 40 years in Upper Austria.

IEA Cooperation

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organisation for Economic Cooperation and Development (OECD) which carries out a comprehensive Program of energy cooperation among its 23 member states. The European Commission also participates in the work of the Agency. IEA work is concentrated in 4 sectors:

- Conservation
- Fossil Fuels
- Renewable Energy
- Fusion

Cooperation of the experts of the member states is organised in Implementing Agreements. **The Photovoltaic Power Systems Programme (PVPS)** is one of the implementing agreements. It is the only one that deals with photovoltaics. It was started in 1993 by an agreement of 21 member states to work in the field of PV.

Detailed work is done in several subgroups, named tasks:

- Task I „Exchange and Dissemination of Information on Photovoltaic Power Systems“, Dr. Gerd Schauer und Dr. Georg Beyer/VERBUND:
  Annual Report, Newsletter, International Survey Report, Conferences, Publications etc.
- Task II „Operational Performance, Maintenance and Sizing of PV Power Systems and Subsystems“, DI. Michael Zoglauer/TIWAG, DI. Michael Heidenreich/ARSENAL: Monitoring, lessons learned, data base, yield statistics, guide lines etc.
- Task III „Use of Photovoltaic Power Systems in Stand-Alone and Island Applications“
  Reliability of stand-alone systems, lessons learned, hybrid systems, cost optimisation etc.
- Task V „Grid Interconnection of Building Integrated and other Dispersed Photovoltaic Power Systems“, Dr. Gerd Schauer/VERBUND und DI. Christoph Panhuber/FRONIUS: Compare test results of existing plants, grid structures, survey of national guide lines for grid interconnection, standards and codes for the grid interface etc.
- Task VII „Photovoltaic Power Systems in the Built Environment“, Dr. Karin Stieldorf/TU-WIEN, Prof. Dr. Reinhard Haas/TU-WIEN, DI. Heinrich Wilk/ENERGIE AG: PV building integration, system technology (Task V), non technical barriers, demonstration and dissemination etc.
- Task VIII „Study on Very Large Scale PV Power Generation Systems“, Japan leads this activity, feasibility study, system design, cost reduction, etc.
- Task IX „Deployment of Photovoltaic Technologies – Cooperation with Developing Countries“

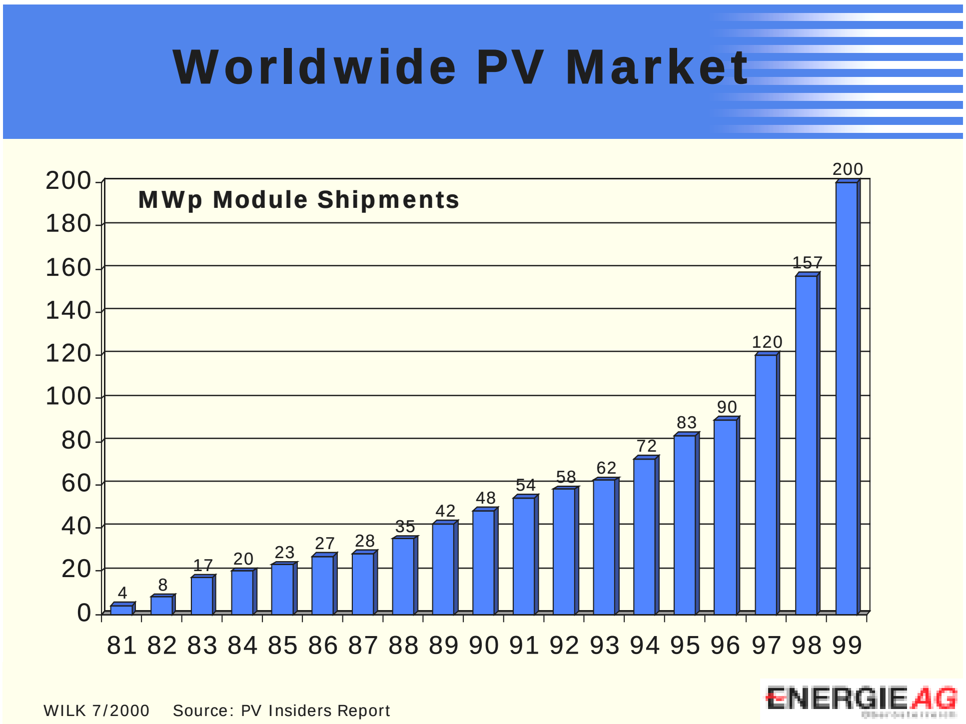
Austrian experts could contribute to the work in the different tasks in a very positive and experienced way. They are integrated in a big network of expertise including also non-European countries as US, Japan and Korea.

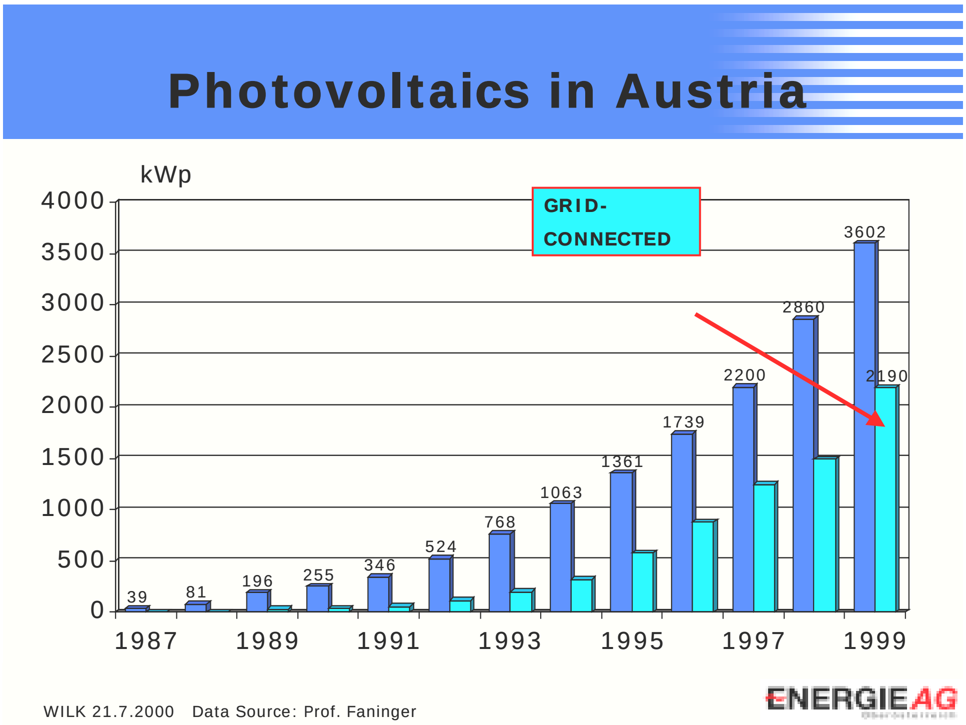
References:

1) Strong S.:“The Dawning of Solar Electric Architecture”, Proceedings of “Building Energy” – Conference, 1996, NESEA, Boston
2) Wilk H.:„Grid connected PV Systems in Austria“, Plenary Presentation, 2. PV World Conference, Vienna 1998
3) Curry Richard: „Photovoltaic Insiders Report“ Vol. XVIII No. 8, 1999
4) Faninger G.: „Der Photovoltaikmarkt in Österreich 1999“, Arge Umweltenergie, Wirtschaftskammer, 14. 4. 2000

5) Räuber A.: PV-Studie, Photovoltaik Symposium Staffelstein, 3/99
6) PV News: PV productions statistic 1999
7) Datenquelle: Land OÖ und OÖ EVU
8) siehe OÖ Einspeiseverordnung vom 29. 9. 1999
9) siehe Ausschreibung „Strom aus erneuerbaren Energien in OÖ“ (18. 1. 2000)
10) IEA PVPS: „Annual Report 1993...1999“ and other publications

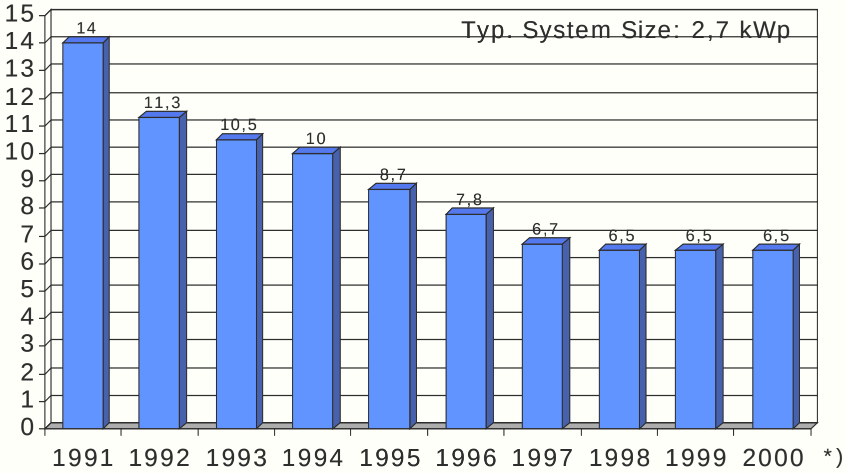
Figures presented at the Summer School by Heinrich Wilk





Specific Cost of PV Systems

EURO/Wp - grid connected excl. tax



WILK 21.7.2000, Data Source: Land OÖ *) Estimation for 2000

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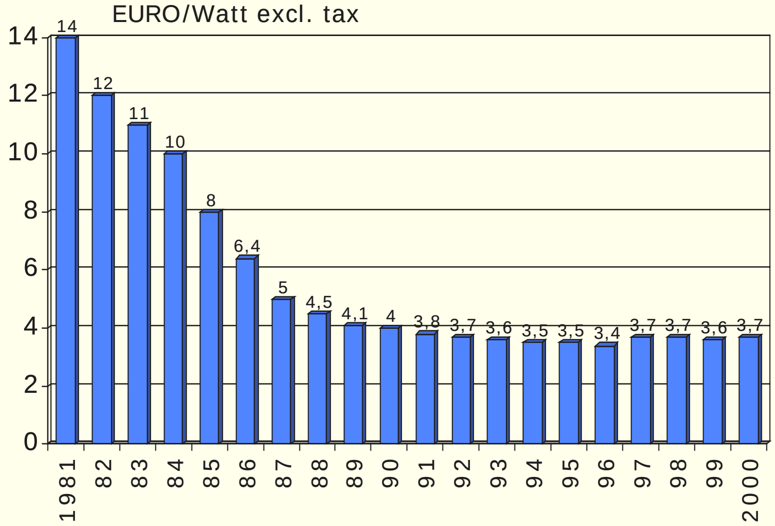
Cost Trend of Solar Modules

EURO/Watt excl. tax



WILK 7/2000 Source: PV Insiders Report, „PV in 2010“ DGXVII

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HAUS DER ZUKUNFT, Wels/Oberösterreich

Roof-integrated PV-System: 2,4 kWp

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SOLARBAUM IN GLEISDORF/Steiermark

Feistritzwerke Gleisdorf: Solarbaum 7 kWp

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30 kW grid-connected PV-plant on the mountain Loser, Bad Aussee/Austria

Façade-integrated 20 kW-PV-system in the office of SBL-Linz, Austria