German Experience on the Support Mechanism and Technical Aspects of Grid Connectivity of Solar PV Rooftop-Systems

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Milestones of the German Roof Top Policy

- Electricity Feed Act 1991 (Stromeinspeisungsgesetz) – FiT
- 1,000 Roofs Programme 1991-1995 (1.000 Dächer Programm) - Grant
- 100,000 Roofs Programme 1999-2003 (100.000 Dächer Programm) - Loan
- Renewable Energy Source Act 2000 (EEG) - FiT
- Amendments and Revisions of EEG 2004/2009 - FiT
Policy Milestones and Development of PV Sector

- 1,000 Roof Programme 1991-1995
- Electricity Feed Act 1991
- 100,000 Roof Programme 1999-2003
- Renewable Energy Source Act 2000
- Amendment of EEG 2004
- Amendment of EEG 2009

2011: 24,800 MW
PV-Market Segments in Germany – Dominant Rooftop Sector

- Private buildings: 1-10 kWp (9%)
- Social, commercial, agricultural buildings: 10-100 kWp (53%)
- Large commercial buildings: > 100 kWp (22%)
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Electricity Feed Act 1991

- Feed-in-Tariff with low Tariffs
- **Central Elements:**
  - A. Obligation to remunerate
  - B. Obligation to take up all generated electricity

- Remuneration for Solar: 90% of average revenue/kWh of the electricity price for final consumers – not cost effective for solar

- Introduction of an Obligation to accept the generated electricity as a consequence of the dominant position of generating utilities and the weak position of small RES generators
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1,000 Roofs Programme 1991-1995 - Overview

- Capital Grant Promotional Programme

- **Objective:** “evaluation of the already achieved level of technology” and “evaluation of the required development need for small grid connected installations” [due to very low No. of installations]

- Grid connected PV Installation with a capacity between 1–5 kWp on Roof Tops of Single and Two-Family-Houses

- Grant of 70% of the Investment + Mounting Costs (50% covered by the Federation; 20% by Federal States)

- Quota of eligible No. of Installations per Federal State
1,000 Roofs Programme 1991-1995 – Conditions I

- Only Installations of German Producers were eligible for Promotion (Local Content) – Abroad produced Modules were eligible

- Every Installation had to install 3 Meters:
  1. Generation Meter, metering Production
  2. Feed-In Meter, metering the fed Electricity
  3. Import Meter, metering the purchased Electricity
1,000 Roofs Programme 1991-1995 – Conditions II

- Obligation for Installation Operators to record over 5 years the monthly Meter Results
- Quarterly Transmission of results to Fraunhofer ISE Research Centre that evaluated the results for the Government
- In addition, a supporting sociological study was carried out by the Environmental Research Centre of Leipzig
- The study involved Installation Operators as well Installation Companies; voluntary participation
1,000 Roofs Programme 1991-1995 – Development

Source: Sonnenenergie Nov./Dez. 2008
100,000 Roofs Programme 1999-2003 – Overview

- Loan Programme through KfW (Reconstruction Credit Institute)
- **Objective/Cap**: 300 MW of newly installed Capacity from PV
- Loans at reduced rate of interest (Soft Loan)
- Interest Rate of 1.91% APR (instead of 6.4%; discount of 4.5%)
- Installations of min. 1 kWp of Individuals, Freelancers or SMEs
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Renewable Source Energy Act 2000 (EEG)

- 20% RES Share of Elect. Supply by 2020
- Priority Uptake Obligation for Utilities of produced Electricity from RES
- Each kWh from RES must be purchased by the Utility (higher Tariffs than 1991)
- Fixed feed-in Tariff Payment over 20 Years
- Reduction of the Feed-in Tariff each year for newly installed RES Systems (Degression)
- Feed-in Tariffs are no State Subsidy, Costs are redistributed to the Final Consumer via the Electricity Bill
- Aim: to trigger a broad Demand and create a national RES Industry
Amendments/Revisions of EEG (2004 & 2009)

- 30 % RES Share on Electricity Supply by 2020 (2004)
- Expansion of the Priority Regime to also include the Connection of RES Installations (before only priority take up of produced Electricity) (2004)
- Introduction of a flexible Degression Mechanism (Degression Corridor) (2009) - Solar
- Introduction of Clearing House EEG (Clearingstelle EEG)
- Further Reform of the EEG in 2012
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Performance of Photovoltaics in Germany

The Performance of PV in Germany

What is the current status of photovoltaics in Germany? This is an interesting question, and one to which you will receive a clear answer on this website based on daily updated information. Here, you can view at any time the total output of all PV plants in Germany installed up to the specified cutoff date. As required, you can view this information as an absolute value or as a percentage of total installed output.

Now you can look at individual regions as the data is additionally classified according to the respective zip code areas. Here, you can take a closer look at the regional relative power in the respective areas, or in other words, the current performance of the PV plants in proportion to the nominal power of these plants.

The animated graphics demonstrate the role already played by photovoltaics in generating electricity in Germany today, and show that PV systems also contribute to reducing the high cost of midday peak demand.

Our Data Calculation Model

For comparison: The average net power consumption in Germany amounts to around 80 GW (source: AS Energieblanzen).
Generation in Germany on a holyday Sunday June 12, 2011
PV performance compared to conventional generation

European Energy Exchange (EEX) 12 a.m.:
Conventional generation 26.4 GW / Wind 0.52 GW, **PV: 30.1 %**
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Scheme of PV Rooftop Installations and Remote Control for Data Acquisition and Inverter Programming

Source: SMA

Data evaluation programmes, Automatic control algorithms

Internet Accessable (VPN) Remote Control

PV system

meter

gird
Example: Monitoring of a 5 x 200 kW Rooftop Installation

Chicken farm

Power: 5 x 196.56 kW
Commissioning: 12/2008
Modules: EPV (a-Si)
Inverters: 181 x Danfoss ULX 5400

Monitoring on inverter level
Direct Online Access to Operational Data

Observations:
- Daily, weekly, monthly, yearly data.

Alarm control:
- Any damage or manipulation will be monitored. Irregular operational mode or failures will lead to immediate alarm messages.
City Utility Introduced Web-based PV-Benchmarking

- Number of PV systems: 40
- Individually accessible
- Different sizes, modules, inverters, inclination
- Public access via internet

http://karlsruher-sonnendaecher.de/
Individual Analysis and Benchmarking

Performance ratio to be the benchmarking figure!

Performance ratio > 100% only possible due to irregular operation (fraud)!

Performance ratio in %:

- Anlagenstandort: 94.2%
- Sonnenbad: 89.9%
- Verkehrsbetriebe KA 4: 88.2%
- Parkhaus 1: 87.4%
- Müldepoine West: 87.3%
- Kulissenlager*: 86.7%
- Verkehrsbetriebe KA 3: 85.4%
- Pädagogische Hochschule: 84.9%
- Europäische Schule Geb. C: 84.0%
- Schule Diedenhofen: 83.8%
- Schulzentrum Neureut 1: 83.7%
- Fiduza: 83.6%
- GE MS Göttingen: 83.4%
- KA Rüppurr: 83.2%
- Verwaltungsgeb. SW KA: 83.1%
- Kranichsee: 82.9%
- Verkehrsbetriebe KA 1: 82.7%
- Möbau: 82.7%
- Amt für Abfallwirtschaft*: 82.1%
- Hochschule KA Geb. E: 81.7%
- Städt. Klinikum Geb. S: 81.7%
- Walter-Eucken-Schule: 80.7%
- Heinrich-Hertz-Schule: 80.7%
- Sonnenbad: 80.7%
- Sonnenbad Beflagung: 79.9%
- Karlsruher Sonnendach: 79.9%
- Verkehrsbetriebe KA 5: 78.2%
- Europäische Schule 1: 78.2%
- Städt. Klinikum Geb. D: 78.0%
- Verkehrsbetriebe KA 1: 77.7%
- Hochschule KA Geb. F: 77.7%
- Parkhaus 2: 77.7%
- Verkehrsbetriebe KA 2: 77.2%
- Sonnenbad R-Plus: 76.5%
- Müldepoine West: 76.4%
- Europäische Schule 2: 76.1%
- Hochschule KA Geb. M: 75.6%
- Melsch: 75.5%
- St. Dominikus: 74.8%
- GS Wolfartweier: 70.4%
- Schulzentrum Neureut 2: 69.8%
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Reduction in Transmission Losses

Losses along the transmission network:
- High-voltage network,
- Medium-high-voltage network,
- Distribution network
- Total losses estimated to reach up to 25%.

Tail-End Photovoltaic Systems:
- Avoid network losses
- Increase network stability, esp. distribution level
- Reduce costs of grid strengthening.

Each 1 kWh from photovoltaic avoids 1,25 kWh conventional (coal) power!
Small to Mid Size Grid Connected Photovoltaic
- 3 examples -

Step-up transformer station

Grid 10 kV 400 V (3 phase) line PV 2

Grid up to ~3 kW 1 phase 3 phases
PV 3
~ 10 kW to 2 MW

PV 2
~ 3 to ~15 kW 3 phases
PV 1

up to ~3 kW 1 phase 3 phases
PV

Source: SMA, own calculations
Technical Parameters of Transformers and Grid Lines determine max PV Capacity

- Point of evacuation, line length and capacity
- Inverter capacity and reactive power
- Peak power of PV modules' capacity
- Total AC power of inverters should not exceed 80% of transformer KVA
## Example: Inverter Data Sunny Boy 2500

### AC Output

<table>
<thead>
<tr>
<th>Protection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input-side disconnection device</td>
<td>yes</td>
</tr>
<tr>
<td>Ground-fault monitoring / grid monitoring</td>
<td>yes / yes</td>
</tr>
<tr>
<td>DC surge arrester Type II, can be integrated</td>
<td>—</td>
</tr>
<tr>
<td>DC reverse-polarity protection / AC short-circuit current capability /</td>
<td>yes / yes / yes</td>
</tr>
<tr>
<td>galvanically isolated</td>
<td></td>
</tr>
<tr>
<td>All-pole sensitive residual current monitoring unit</td>
<td>—</td>
</tr>
<tr>
<td>Protection class (according to IEC 62103) / overvoltage category</td>
<td>I / III</td>
</tr>
</tbody>
</table>

| AC Voltage Range             | Rated power at 230 V, 50 Hz | 2 300 W                       |
| Maximum apparent AC power    | 2 500 VA                     |
| Rated mains voltage          | 230 V                        |
| Nominal AC voltage           | 220 V/230 V/240 V            |
| AC voltage range             | 160 V ... 265 V              |
| Nominal AC current at 220 V  | 10.5 A                       |
| Nominal AC current at 230 V  | 10.0 A                       |
| Nominal AC current at 240 V  | 9.6 A                        |
| Maximum output current       | 12.5 A                       |
| Total harmonic factor of output current at AC THF voltage < 2%             | ≤ 3%                           |
| AC power > 0.5 AC rated power |                              |
| Operating range at AC power frequency 50 Hz | 45.5 Hz ... 54.5 Hz |
| Operating range at AC power frequency 60 Hz | 53.5 Hz ... 64.5 Hz |

Source: SMA
FNN directive "generator plants on the low-voltage grid"

- First grid code of the FNN (forum for grid technology and operation) in the VDE
- Draft published in July 2010
- After considering the 1,200 objections, the directive came into effect on August 1, 2011 with transitional period until January 1, 2012

Paradigm replacement now also in LV grid:

- Feed-in management
- Frequency-dependent reduction in active power above 50.2 Hz
- Voltage support (reactive power)
  - From 13.8 kVA from July 7, 2011
  - From 3.68 kVA from January 1, 2012

>> New amendment is required!

Source: SMA, Dr.-Ing. Bernd Engel
Voltage support: power flow reversal – a technical issue?

- Objective: To support the voltage criterion in accordance with EN 50160 ($U_N \pm 10\%$)
- Example: Compensation for the voltage drop in the cabling:

  Stationary adjustment to the transformation ratio at the transformer on the grid station

>> Until now, the distribution grid was designed for consumption

Source: SMA, Dr.-Ing. Bernd Engel
Voltage support: power flow reversal – a technical issue?

- Example: PV plant installation: In the low load hours before lunch, a power flow reversal occurs. **Violation of the voltage criterion** in accordance with EN 50160

- Voltage Problems were previously associated with costly grid development involving increased amounts of copper, new cables and more powerful transformers.

Source: SMA, Dr.-Ing. Bernd Engel
Supporting voltage through reactive power supply

- New grid connection directives: PV plants must make their **reactive power** available during normal operation.
- Grid operator specifies $Q_{\text{Set}}$, $\cos\varphi_{\text{Set}}$ or $\cos\varphi(P), Q(U)$ characteristics.
- **MV guidelines:** Operate with a shift factor ranging from $\cos\varphi = 0.95_{\text{inductive}}$ to $0.95_{\text{capacitive}}$.
- **LV directives:** Operate with a shift factor ranging from $\cos\varphi = 0.90_{\text{inductive}}$ to $0.90_{\text{capacitive}}$.

By supporting the voltage in the inverter, the capacity of the low-voltage grid can potentially be **tripled** (source: Federal Ministry for Environment, Nature Conservation and Nuclear Safety project PV-EMS).
Dynamic grid support: Fault Ride Through (FRT)

- As a general rule, in the event of a grid failure, PV plants should not be disconnected from the grid!
- Behavior required:
  - upper boundary 1: Stable operation
  - between boundary 1 and 2: Instability permitted
  - below boundary 2 (30 % $U_{Nom}$): Immediate disconnection allowed
- In the LV grid, feed-in of a capacitive reactive current is not desired: limited dynamic grid support through temporarily blocking of the semiconductor

>> PV installations can even provide support in the event of failure to the grid.

Source: SMA, Dr.-Ing. Bernd Engel
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Recommendations

- First set of installations should be installed on larger rooftops (official or commercial buildings) in standardized segments of e.g. ~10 kW, ~50 kW, ~100 kW
- Solar cities may see promotion schemes to be surveyed by research institutions to allow public benchmarking
- Regular data-monitoring allows for detection and avoidance of fraud or an allowed feed-in
- Utilities should see roof-top solar as a possibility to enforce the grid from the tail-end by acknowledging technical and economical advantages
- 1 kWh of tail-end solar power replaces ~1.25 kWh of coal power
Thank you for your attention....

....visit us on

E.Quadrat energy economy
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ideas into energy.
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www.eclareon.eu

SolarGuidelines.in
A Pathway to Project Finance and Implementation.

Ministry of New and Renewable Energy
Government of India

On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany