Organizational Matters

> Solar Academy contact data
  > Phone: +49 (0)561-9522-4884
  > E-Mail: Solaracademy@SMA.de

> Download areas:
  > [http://www.SMA.de/handout](http://www.SMA.de/handout)
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Functions of a PV inverter

Technical requirements:

> Good system efficiency → Finding and keeping the MPP (maximum power point)
> Low disturbances in supply systems

> Easy function control → Access to operating data

Economic requirements:

> Reasonably priced in the system → Simple, robust design
> High reliability

Requirements to the installation → Simple and quick installation
Characteristics curves PV generator

The operating point determines the output power of the PV generator.
Characteristic curves PV generator

The operating point determines the output power of the PV generator.
String inverter with transformer
String inverter with transformer

SUNNY BOY 3000HF

- DC input [x2 plug connectors]
- ESS
- MPP tracking
- Step-up converter
- Inverter
- High frequency transformer
- Rectifier
- H4 bridge
- SMA Grid Guard

- Bluetooth
- Optional communication interfaces
- Graphic display
- Ground fault monitoring
- Optional multifunction relay with fault indication function
- Country configuration via rotary switches
Sunny Mini Central without transformer
Multistring inverter without transformer

1. Functions
2. Topology
3. Working areas
4. Plant design
5. AR-N4105
6. Reactive Power
7. Energy management
8. Backup

IntensiveInverter-EN120910
Three-phase inverter without transformer

SUNNY TRIPOWER 8000TL / 10000TL / 12000TL / 15000TL / 17000TL

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IntensiveInverter-EN120910
Adjustment of PV generator and inverter
Working areas PV generator/inverter

The working areas of a PV generator and an inverter are not congruent!
A better solution is:

> Over-dimensioning  (every operating point is possible)  or

> Under-dimensioning
Lowest MPP Voltage

Case 1: The PV generator has its MPP at a voltage below the minimum input voltage of the inverter.

Reaction: The inverter remains in operation and feeds the power delivered by the PV generator at the minimum input voltage into the grid.
Flexible MPP range in case of SB3800

The minimum input voltage depends on the current value of the grid voltage!

![Diagram showing minimum MPP voltage of the Sunny Boy 3800](image)

Examples:
- SB 1200: 139 V...151 V
- SB 1700: 139 V...151 V
- SB 2500: 224 V...246 V
- SB 3000: 268 V...291 V
- SB 3800: 200 V...219 V
Largest open-circuit voltage

Case 2: The PV generator has an open-circuit voltage which is higher than the maximum input voltage of the inverter.

Reaction: **Critical - inverter in danger**!
Depending on the intensity of the overvoltage and the module temperature, the device might be damaged.
Current /output limitation

Case 3: The PV generator could deliver a higher power than the maximum input power of the inverter.

Reaction: The inverter remains in operation and feeds its maximum power into the grid.
Under-dimensioned inverter

Example for an under-dimensioning:

\[ V_p = \frac{\text{Input power of inverter}}{\text{Nominal power of PV generator}} = \frac{4600 \text{ W}}{5000 \text{ W}_p} = 92\% \]
Energy utilization

Effectiveness of a PV plant with inverters with a different maximum power

Energy utilization factor

PV annual yield in MPP
The efficiency

Operating conditions of the inverter

> The efficiency indicates how effectively the inverter works.

\[ \eta = \frac{\text{Output power}}{\text{Input power}} = \frac{P_{AC}}{P_{DC}} \]

> The efficiency depends on power and voltage.

> The weighted European efficiency

\[ \eta_{\text{euro}} = 0.03 \times \eta_{5\% P_n} + 0.06 \times \eta_{10\% P_n} + 0.13 \times \eta_{20\% P_n} + 0.1 \times \eta_{30\% P_n} + 0.48 \times \eta_{50\% P_n} + 0.2 \times \eta_{100\% P_n} \]

> assesses the partial load behavior for PV plants in Central Europe.

This value is used to compare similar devices.
Efficiency in partial load

Efficiency of a Sunny Boy 3000

- Maximum efficiency: approx. 95%
- At a nominal power of 50%

Weighted European efficiency: 93.6%
Power-dependent course of efficiency

$\eta$ of SB inverters with $U_{ac} = 230$ V (const.)
Efficiency of the Multi-String - Sunny Boy 5000TL-21

Efficiency curve SUNNY BOY 5000TL

- Eta ($V_{pv} = 175$ V)
- Eta ($V_{pv} = 400$ V)
- Eta ($V_{pv} = 500$ V)

Output power / Rated power

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Plant design: general

> +70 °C: MPP voltage > min. input voltage inverter

> -10 °C: open-circuit voltage < max. input voltage inverter

> Power ratio is in the range between 90%... 100 %
  (Power ratio: input power inverter/peak power PV)
Plant design: Multi-String systems

> High efficiency can only be achieved with a high MPP voltage.

> Maximize string length (limitation: observe open circuit voltage at -10°C)

> Switch identical strings in parallel and if possible use only one input

> Avoid MPP voltages below 200 V
Summary: PV plant design

> Keep the solar cells out of shaded areas.

> If partial shadowing cannot be avoided:
   Limit the shadow to one string.

> Optimize alignment, if possible.
## Summary: PV plant design

<table>
<thead>
<tr>
<th>Specific annual yield</th>
<th>Supplementary charge of Power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1200 kWh/kWp</td>
<td>___</td>
</tr>
<tr>
<td>~ 1200 ... 1600 kWh/kWp</td>
<td>+ 5 %</td>
</tr>
<tr>
<td>&gt; 1600 kWh/kWp</td>
<td>+ 10 %</td>
</tr>
</tbody>
</table>
Summary: PV plant design

<table>
<thead>
<tr>
<th>Derating causes</th>
<th>Supplementary charge of Power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inverter with heat sink</td>
</tr>
<tr>
<td>Ambient temperature ~ 30 °C</td>
<td>+ 5 %</td>
</tr>
<tr>
<td>Insolation (800 W/m²)</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature &gt; 40 °C</td>
<td>+ 10 %</td>
</tr>
<tr>
<td>Insolation (800 W/m²)</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature &gt; 50 °C</td>
<td>+ 15 %</td>
</tr>
<tr>
<td>Insolation (800 W/m²)</td>
<td></td>
</tr>
</tbody>
</table>
### Summary: PV plant design

<table>
<thead>
<tr>
<th>PV Tracker</th>
<th>Supplementary charge of Power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td></td>
</tr>
<tr>
<td>one-axis</td>
<td>+ 5 %</td>
</tr>
<tr>
<td>two-axis</td>
<td>+ 10 %</td>
</tr>
</tbody>
</table>
New Code of Practice AR-N-4105

VDEW NS directive

VDE 0126-1-1

Transition period of both directives are valid

VDE-AR-N-4105

Validity is mandatory since January 1st, 2012

2011-08-01

2011-12-31

2011-12-31
Core Topics of the New Code of Practice for PV Plants

1. Feed-in management
   > Active power output
   > Feed-in during overfrequency

2. Grid support
   > Reactive power supply from 3.68 kVA

3. Grid connection
   > Unbalanced load limit
   > Three-phase current connection

4. Grid and plant protection
   > Integrated interconnection circuit breaker
   > Central interconnection circuit breaker

5. Proofs
How does reactive power develop?

> Inductive phase shifting reduces the grid voltage
> Capacitive phase shifting increases the grid voltage

„In phase“
Pure active power
\[ \cos \phi = 1 \]

Inductive shift
Pure reactive power
\[ \cos \phi \neq 1 \]
How does reactive power develop?

> Phase shift can naturally occur in two directions

> It occurs when coils and capacitors are in the AC circuit – which is usually the case:
  > All engines and transformers have coils (for inductive shifts)
  > Capacitors (for capacitive shifts) are also commonly found

> High voltage overhead lines can be seen as extremely long coils

> Multi-conductor cables also function like a capacitor
Calculation formulas

 Phythagorean theorem

\[ S^2 = P^2 + Q^2 \]
\[ S = \sqrt{P^2 + Q^2} \]
\[ S = \frac{P}{\cos(\varphi)} \]
\[ P = S \cdot \cos(\varphi) \]
\[ Q = \sqrt{S^2 - P^2} \]

- S: apparent power
- P: active power
- Q: reactive power
- \( \cos \varphi \): power factor
Relieving grids and regulating voltage

> Existing phase shifts can be compensated through inverters
  > This reduces conduction losses and leads to the grid only being loaded with active power
  > The freed capacities can be used for transferring more active power

> Another effect: Capacitive or inductive phase shifting increases or reduces the grid voltage
  > Stabilizing the voltage by feeding in reactive power might be the most economical option
Impact on the performance of the inverter

\[ \cos \varphi = 1 \]

\[ P = S = 11 \text{ kW} \]
\[ Q = 0 \text{ kVar} \]

\[ S = 11 \text{ kVA} \]

> S: apparent power
> P: active power
> Q: reactive power
> \( \cos \varphi \): power factor

\[ P = S = 100\% \]
\[ Q = 0\% \]
Impact on the performance of the inverter

\[ \cos \phi = 0.95 \]

- \( S \): apparent power
- \( P \): active power
- \( Q \): reactive power
- \( \cos \phi \): power factor

\[ S = 11 \text{ kVA} \]
\[ Q = 3.6 \text{ kVar} \]
\[ P = 10.4 \text{ kW} \]
Conclusion

> Providing reactive power through solar inverters is an important step für integrating photovoltaics into the grid control

> Due to their mode of operation inverters are excellent for this
Intelligent Energy Management & Self consumption
Backup Systems – Self consumption

> Generation and consumption of electricity without the use of storage systems:
Backup Systems – Self consumption

> Generation and consumption of electricity while using storage systems:
How is Self-consumption Measured? – Meter Configuration

> PV self-consumption = PV power generation - Grid feed-in
> Total power consumption = Purchased electricity + PV self-consumption
> Self-consumption rate = PV self-consumption / PV power generation

*acc. to German Association of Energy and Water Industries (BDEW) supplement to technical connection requirements 2007 - § 33, paragraph 2 Renewable Energy Sources Act (EEG) 2009
Optimizing Self-consumption within the Home

> Adjusting usage patterns
  > House management

> Intelligent control of household appliances based on generation and consumption of power
  > SMA multi-function relay
  > Sunny Home Manager

> Using local storage systems
  > Sunny Backup

> Combinations of local storage systems and intelligent control units
  > Sunny Backup and Sunny Home Manager
SMA Multi-function Relay

Provided as standard in

> Sunny Boy 3000/4000/5000TL-20
> Sunny Tripower 10000/12000/15000/17000TL-10
> Optionally available in Sunny Boy 2000/2500/3000HF-30

> Range of usage
  > Fault indicator relay
  > Temperature-based connection of an external fan
  > Switch between communication devices
  > If a specific power is exceeded, switch as follows
    > to a universally used signal
    > with a minimum switch-on time to connect loads

Simple solution for automatically increasing self-consumption
SMA Multi-function Relay

SUNNY EXPLORER

**My PV plant 1**

- **Device (Solar Inverter)**
  - **Circuit breaker**
    - **Rated current**
    - **Maximum active power**
    - **Current active power limit**
    - **Temporary control of the power limitation**
  - **Configuration of "Logic" operating mode**
    - **Differential factor of power control**
    - **Integral factor of power control**
    - **Proportional factor of power control**
    - **Constant deviation of power control**
    - **Coefficient of power calculation based on U/I**
    - **Coefficient of power calculation based on U/I**
    - **Coefficient of power calculation based on U/I**
  - **Multi-function relay**
    - **Operating mode**
    - **Retrofit control**
      - **Maximum active power**
      - **Maximum active power limit**
      - **Temperature before transition**

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SMA Solar Technology AG  IntensivelInverter-EN120910
SMA Multi-function Relay

SUNNY EXPLORER

- Operating mode: Fault indication
- Battery bank
  - Minimum power: 3,000 W (100 - 3,000 W)
  - Maximum power: 5,000 W (1,500 - 5,000 W)
- Control via communication
  - Status: OFF
- Self-consumption
  - Maximum power: 1,000 W (100 - 1,000 W)
  - Minimum power: 500 W (1 - 500 W)
- Operation
  - Load parameter
  - Operating condition
  - Reset operating data
- Settings
  - Field device: OFF

- Device settings (communication products)
- Country settings
  - Country code: DE
  - Language: English

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Sunny Home Manager – System configuration
Sunny Home Manager

> Intelligent energy management in the household
  > Increasing self-consumption

> Comprehensive load management
  > Weather forecast for predicting the amount of solar power generation
  > Consideration of variable electricity tariffs
  > Adjusting power consumption in the household and to the energy supply in the power distribution grid

> Plant monitoring via Sunny Portal
  > Sophisticated plant monitoring with communication monitoring and inverter comparison

> Direct communication with intelligent domestic appliances (Miele SG)
Sunny Home Manager – Optimization of Self-consumption

- Display of the current self-consumption status
- Recommended action for 24 hours in advance taking into consideration PV generation forecast and electricity tariffs
- Straightforward overview for customers who can adjust their behavior accordingly
- Recommended actions result in increased yield due to increased self-consumption

- Self-consumption rate can be increased by up to 15 percent by adjusting consumption
Sunny Home Manager – Transparency of Your Own consumption Pattern

> Straightforward overview on generation, share of self-consumption, total consumption in the household

> Quick overview on the yield using figures

> Quick interface (live mode) for direct feedback when switching loads on and off

The transparency allows you to adapt the consumption profile and helps saving energy costs*

*Reduce energy costs by approximately 10 percent points by analyzing your own consumption behavior (according to various studies)
Sunny Home Manager – Load Status and Analysis

> Rapid and simple commissioning of the radio-controlled sockets via Bluetooth®

> Straightforward configuration in Sunny Portal using a few parameters for supporting various device types

> Transparency of the consumption behavior up to the device level by measuring power consumption

> Automated, intelligent load control taking into consideration the current consumption and generation situation, PV generation forecasts and electricity tariffs

> Increase in self-consumption through automatic load management
Sunny Home Manager – Plant Monitoring in the Sunny Portal

> Sophisticated plant monitoring with communication monitoring and inverter comparison

> Display of the self-consumption information and recommended actions

> Configuration of the Home Manager and radio-controlled sockets

> Access to current energy information, also while on the go

> Comfortable operation via PC and smartphone

Easy to use plant monitoring ensures yields
Sunny Home Manager – Technical Information

- Inverter communication: SMA Bluetooth® Wireless Technology
- Sunny Portal communication: 10/100 Mbit Ethernet
- Max. number of devices: 16 Bluetooth® participants of which there is a max. of 12 inverters
- Meter interfaces: 3 S0 inputs and 3 D0 inputs
- Load control: Up to 10 radio-controlled sockets via Bluetooth®
- Power supply: External plug-in power supply (100 V – 240 V AC; 50/60 Hz)
- Ambient temperature: -25°C ...+60°C
- Configuration: Using Sunny Portal
- Accessories: SMA radio-controlled sockets with Bluetooth®, Sunny Portal, Sunny Backup
Increase in Self-consumption
Backup Systems for Increasing Self-consumption

> Increase in self-consumption by approximately 25 percent thanks to Sunny Backup
> Grid-parallel operation, "emergency power system" function remains intact
Increased Self-consumption Thanks to Intermediate Storage

By using energy storage batteries, the PV energy generated during the day can be used in the evening and at night. Additional increase in self-consumption irrespective of it being stored for subsequent use. Self-consumption is shown in green + yellow.
Backup Systems as an emergency power supply system

> We are becoming increasingly dependent on electric current: heating, communications, ventilation, control systems ...

> Many households now already have their own PV plant. The PV plant deactivates in the event of a power outage!

> The Sunny Backup System takes over automatically the grid-replacement supply with the integrated PV plant!
Backup Systems as an emergency power supply system

> Use of the PV plant in the event of a power outage
> At night, the loads are fed from the battery
> There is no reduction in the PV efficiency
Principle of a PV Backup System

PV feed-in meter

Grid outage

Consumption meter

AS-Box

SMA Solar Technology AG

IntensiveInverter-EN120910
Let’s be realistic and try the impossible!