INVERTERS FOR GRID CONNECTED PV SYSTEMS: TEST RESULTS OF SOME NEW INVERTERS AND LATEST RELIABILITY DATA OF THE MOST POPULAR INVERTERS IN SWITZERLAND

H. Haeberlin, Ch. Liebi and Ch. Beutler
Ingenieurschule (ISB), Jlcoweg 1, CH-3400 Burgdorf, Switzerland
Phone +41 34 / 426 68 11, Fax +41 34 / 426 68 13
e-mail: heinrich.haeberlin@hti.bfh.ch, internet: www.pvtest.ch

ABSTRACT: ISB's PV laboratory has carried out a lot of tests under continuous computer monitoring with small and medium grid connected PV inverters in the past. In spring 1994, a new test center for PV systems with solar generator of 60kWp became operational. Since spring 1995 the PV laboratory has a PV simulator to measure inverters up to 10kW. Now the most important tests can be performed in a few weeks.
In this paper the *results of intensive tests* of some recently developped inverters used in many grid connected PV systems in Europe are presented. Test were performed in 1995 and 1996 at ISB's PV laboratory. In addition, data obtained from analytical monitoring project in the Canton of Berne are used to get *informations about reliability* of older and newer inverter models.
Keywords: Inverter - 1: Grid-Connected - 2: Reliability - 3

1 TEST PROGRAM

The most important properties measured at ISB's test site were DC-AC conversion efficiency, harmonics, RF interference (RFI) on DC and AC side, islanding and sensitivity to telecontrol signals.

When some initial problems with the PV simulator were resolved, *tests of maximum power tracking efficiency* (MPT efficiency) could also be carried out.

In addition to [1] the following new grid connected inverters were tested :

- **NEG 1600** (1.5 kW, single phase, LF transformer), made by UfE, Germany
- **SPN 1000** (1.0 kW, single phase, LF transformer), made by Siemens Solar GmbH, Germany
- **SWR 700 'Sunny Boy'** (0.7 kW, single phase, LF transformer), made by SMA Regelsysteme GmbH, Germany
- **Sunrise 2000** (2.0 kW, single phase, LF transformer), made by Fronius Schweissmaschinen, Austria
- **Edisun 200** (0.18 kW, single phase, HF transformer), made by Edisun Power AG, Switzerland
- **Top Class 2500/6 Grid III** (2.25 kW, single phase, LF transformer), made by ASP, Switzerland
- **Top Class 4000 Grid III** (3.5 kW, single phase, LF transformer), made by ASP, Switzerland

Type	S_N	U_{DC}	Turn on power	Continuous Grid Impedance Monitoring	European Efficiency	Harmonics of current (<2kHz)	Islanding	EMI AC	EMI DC	Sensitivity to telecontrol signals
	kVA	V	W_{DC}		%					
NEG 1600	1.5	96	15	no	90.4	+	++	++	0	++
SPN 1000	1.0	64	15	yes	89.8	+	++	+	++	0
SWR 700	0.7	160	6	yes	90.8	0	++	0	++	+
Sunrise 2000	2.0	160	12	no	89.3	0	++	++	+	0
Edisun 200	0.18	64	2.5	no	90.7	++	++	++	0 [1])	++
TC 2500/6/III	2.25	96	24	*	91.5	+	++	+	++	++
TC 4000/III	3.5	96	23	*	91.9	+	++	+	++	++

++ very good, meets the standard easily
\+ good, meets the standard
0 satisfactory, meets the standard nearly
[1]) sufficient for module inverters (extension of DC wiring very small)
\- insufficient, doesn't meet the standard
-- bad, doesn't meet the standard at all
* future standard equipment

Table 1: Most important specifications and main test results of ISB's newest inverter tests.

2 MAIN TEST RESULTS

Table 1 shows the most important specifications and the main test results of the inverters tested.

The measuring concept, the test site used and some results of earlier tests are described in [1, 4, 5]. Due to space limitations, only a few highlights of the many new test results can be given here.

'European efficiency' was calculated with the formula below (index value = percent of rated load).

$$\eta = 0.03\,\eta_5 + 0.06\eta_{10} + 0.13\eta_{20} + 0.1\eta_{30} + 0.48\eta_{50} + 0.2\eta_{100}$$

2.1 DC-AC Conversion Efficiency

Efficiencies of the third generation inverters tested have increased about 2% compared to the devices of the second generation (e.g. Top Class Grid II). Partial load efficiencies are much better compared to earlier designs (e.g. SI-3000, PV-WR-1500, PV-WR-1800), too.

For inverters with galvanic separation between DC and AC, peak efficiency is between 91.5% and 93.4%, European efficiency between 89.3% and 91.9%.

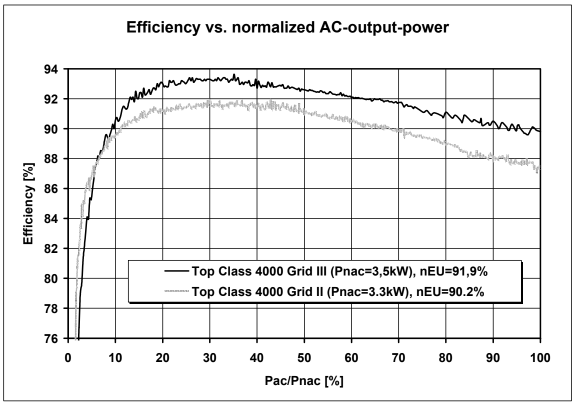

Fig. 1: Efficiency vs. normalized (referred to rated power) AC power of single phase inverters Top Class 4000 Grid II and Top Class 4000 Grid III. The European efficiency of ASP's third generation inverter Grid III is 1.7% higher than that of Grid II, a device of the second generation.

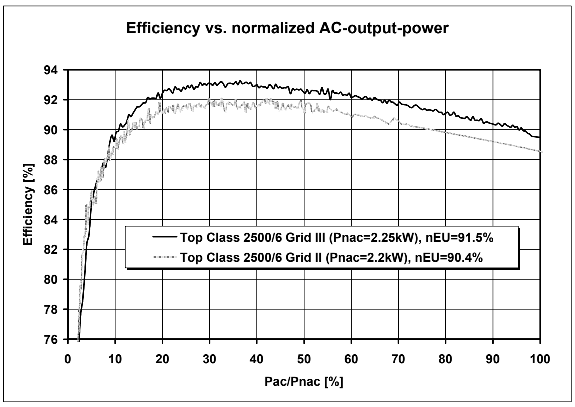

Fig. 2: Efficiency vs. normalized (referred to rated power) AC power of single phase inverters Top Class 2500/6 Grid II and Top Class 2500/6 Grid III.

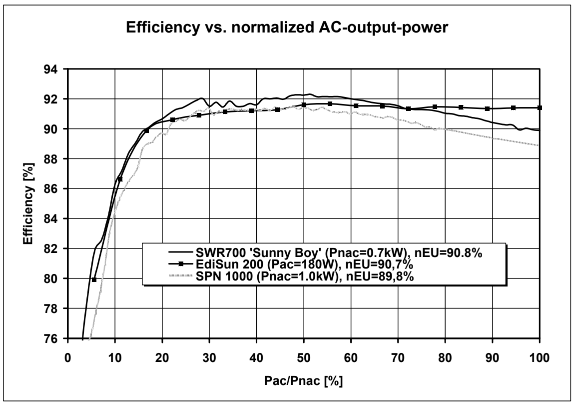

Fig. 3: Efficiency vs. normalized (referred to rated power) AC power of single phase inverters SWR 700 'Sunny Boy', EdiSun 200 and SPN 1000.

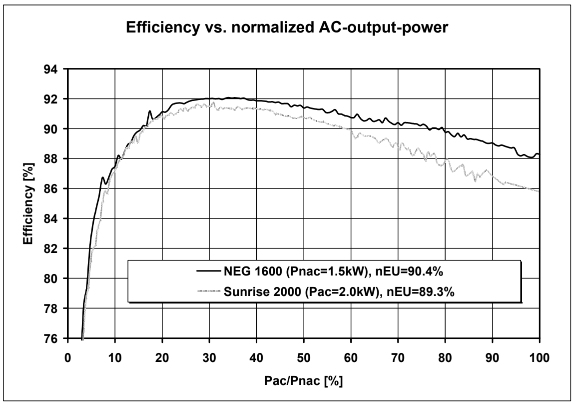

Fig. 4: Efficiency vs. normalized (referred to rated power) AC power of single phase inverters NEG 1600 and Sunrise 2000.

2.2 Maximum Power Tracking Efficiency

When some initial problems with the PV simulator were resolved, ***tests of maximum power tracking efficiency*** (MPT efficiency) were carried out. At medium and higher power levels, MPT efficiencies of most inverters were close to 100%. Fig. 5 shows static MPT efficiency vs. available MPP power of the PV array for a Sunrise 2000.

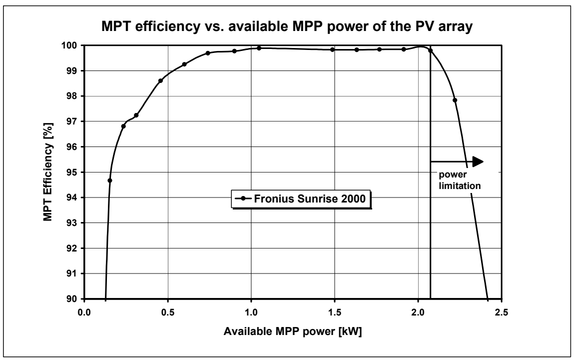

Fig. 5: Static MPT efficiency vs. available MPP power of the PV array for a Sunrise 2000.

2.3 Harmonics of current

All inverters tested are self commutated with high frequency pulse width mudulation. Therefore harmonic currents injected into grid are below the limits of EN60555-2 with most inverters. With some inverters, limits may be slightly exceeded at higher frequencies (usually > 25th harmonic), when they are operated close to rated power. Thus harmonics should not cause problems in practical operation, unless line impedance is too high.

The harmonics of current of the inverters SPN 1000, NEG 1600, EdiSun 200, Top Class 2500/6 Grid III and Top Class 4000 Grid III are completly below the limits of EN60555-2 over the full operating range. Only the inverters SWR 700 and Sunrise 2000 exceeded the limits for some very few harmonics slightly.

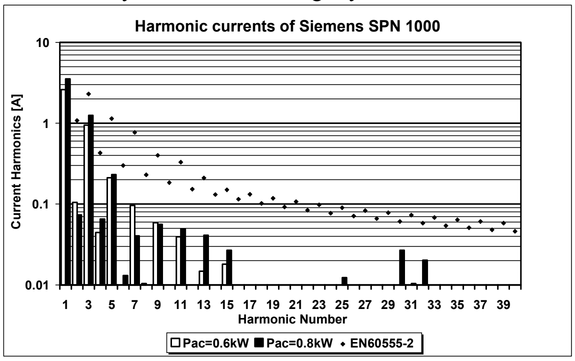

Fig. 6: Current harmonics of SPN 1000 at AC power of 0.6kW and 0.8kW compared to limits of EN60555-2.

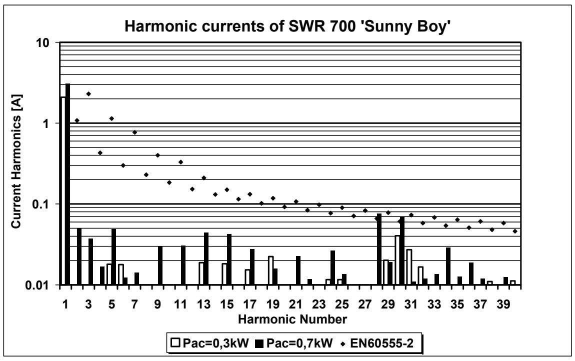

Fig. 7: Current harmonics of SWR 700 'Sunny Boy' at AC power of 0.3 kW and 0.7 kW compared to limits of EN60555-2.

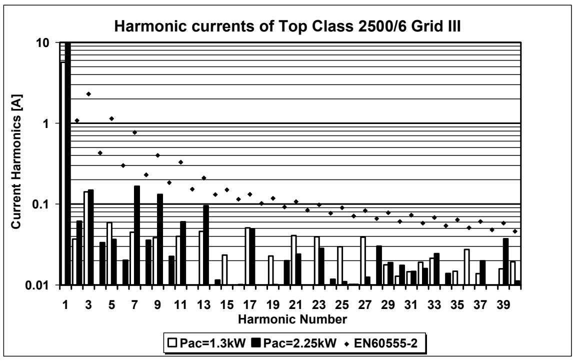

Fig. 8: Current Harmonics of Top Class 2500/6 Grid III at AC power of 1.3 kW and 2.25 kW.

2.4 Radio Frequency Interference (RFI)

Compared to earlier designs, RF voltages on AC and DC side have been reduced considerably and are now mostly below applicable standards.

On AC side, RF voltage levels of most inverters tested at power levels between 50% and 100% of rated power were below the limits of EN55014. Sunrise 2000, NEG 1600, EdiSun 200 and SPN 1000 were below these limits on all frequencies, Top Class 2500/6 Grid III and Top Class 4000 Grid III only for frequencies above 250 kc/s. SWR 700 had a RF voltage peak at 2.6 Mc/s (1 dB more than the limits, thus in the range of measuring accuracy).

On DC side all inverters except NEG 1600 and EdiSun 200 were below the limits on all frequencies. NEG 1600 and EdiSun 200 exceeded these limits at some frequencies slightly. For a module inverter (like EdiSun) this will cause no practical problems, as the extension of the DC wiring is very small. The Grid III inverter of ASP is now much better than the previous Grid II version because of its standard DC ring core choke (Fig. 9).

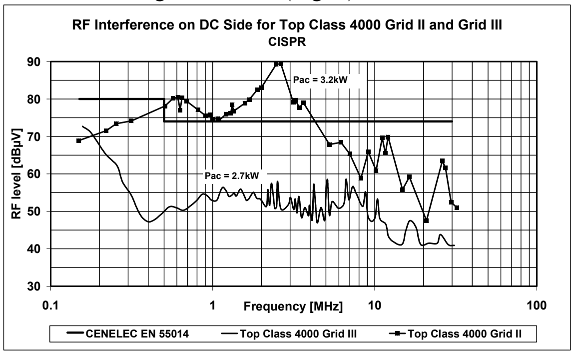

Fig. 9: RF voltages of Top Class 4000 Grid II and Grid III on DC side compared to the limits of EN55014.

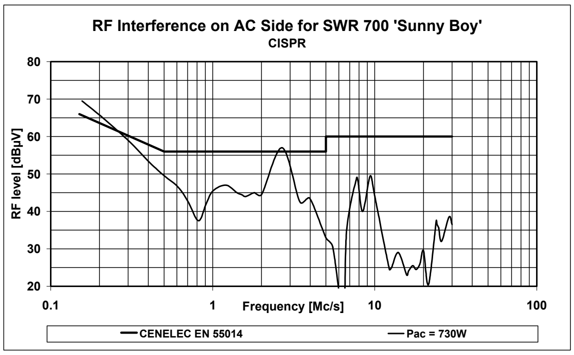

Fig. 10: RF voltages of SWR 700 on AC side at Pac=730W compared to the limits of EN55014.

2.5 Sensitivity to Telecontrol Signals

All inverters were subjected to simulated telecontrol signals produced by ISB's telecontrol signal generator. Although quite high voltages (up to 18V) were used, no hardware defects occurred. Most inverters did not show malfunctions, too. Only Sunrise 2000, SWR 700 and SPN 1000 sometimes switched off for a few seconds after a strong telecontrol signal, but resumed normal operation afterwards. Higher sensitivity to telecontrol signals in case of SPN 1000 and SWR 700 is possibly caused by the grid impedance monitoring circuit to prevent islanding after loss of line voltage.

Inverter	Month of operation	Hardware failures per year						HW failures	HW failures per inverter operation year
		92	93	94	95	96	97	total	
PVWR 1500	58	0	0	0	0	0	0	0	**0.0**
PVWR 1800	201	0	3	5	4	0	0	12	**0.7**
Solcon 3300	77	0	0	0	0	1	0	1	**0.2**
Solcon 3400HE	162	1	1	4	0	0	1	7	**0.5**
Solarmax S	275	0	0	0	0	5	0	5	**0.2**
TopClass 1800	43	0	0	0	0	0	0	0	**0.0**
TopClass 2500/4 Grid III	10	0	0	0	0	0	0	0	**0.0**
TopClass 2500/6 Grid II	72	0	0	0	0	1	0	1	**0.2**
TopClass 2500/6 Grid III	10	0	0	0	0	0	0	0	**0.0**
TopClass 3000	106	1	2	1	1	1	0	6	**0.7**
TopClass 4000/6 Grid II	133	0	0	0	2	0	0	2	**0.2**
TopClass 4000/6 Grid III	31	0	0	0	0	1	0	1	**0.4**
Solarmax 15	24	0	0	0	0	0	0	0	**0.0**
SolarMax20	41	0	0	1	0	0	0	1	**0.3**
EcoPower20	40	0	0	5	0	3	1	9	**2.7**
EdiSun 200	7	0	0	0	0	0	1	1	**1.7**
Total	**1290**	**2**	**6**	**16**	**7**	**12**	**3**	**46**	**0.4**

Table 2: Hardware defects for different inverter types (June 92 - May 97).

2.6 Islanding

None of the newest inverters had a problem with islanding under special load conditions (matched load) after loss of line voltage. Siemens SPN 1000 and SMA SWR 700 'Sunny Boy' have a continuous grid impedance monitoring to detect islanding (ENS/MSD). Besides the Swiss islanding test they have also passed the new more stringent German test [2, 3].

ISB's PV laboratory also tested a new prototype of ASP's Top Class 4000 Grid III equipped with a continuous grid impedance monitoring. After some initial problems with the software the inverter passed the German test, too. This feature will be available as a standard equipment in the future.

3 Reliability and Inverter Defects

In the past (1989-1991) a few hardware defects per year were usual. Reliability of new inverter designs monitored in this project is now by factors better (less than one hardware defect per year). Under normal line conditions, the number of hardware defects would have been considerably lower. Telecontrol signals no longer cause hardware defects. Test results also show that energy production is not only affected by hardware defects, but also by sporadic inverter malfunctions that can be detected only by close monitoring used in this project.

Monitoring data used in this project were sampled at least every two seconds. From these data average values of 1 minute to 15 minutes were generated. Therefore it was possible to distinguish between hardware defects and other sporadic inverter malfunctions. Many more inverter problems than usual could be recognized. When only monthly values are used like in some other studies about inverter reliability, only really severe problems of long duration can be detected. However, due to cost limitations, the number of plants monitored in this project could not be very high. Thus a lot of major and minor inverter problems could be seen. Table 2 shows hardware defects for different types of inverters. The tendency recognised already in 1995 [1] has been confirmed by further monitoring in 1996 and 1997 and the sample size could be increased considerably, making conclusions more reliable. Results obtained indicate, that new inverters coming from an experienced manufacturer, that have been manufactured for a few month at least before installation, seem to be more rugged and reliable than other inverters.

Important Notice

Information contained in this paper is believed to be accurate. However, errors can never be completely excluded. Therefore we disclaim any liability in a legal sense for correctness and completeness of the information or from any damage that might result from its use.

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