

INVESTIGATION OF TYPICAL PROBLEMS OF PV-INVERTERS

DI Dr.W.Enders, DI Ch.Halter, DI P.Wurm
Österreichisches Forschungs-und Prüfzentrum arsenal research,
Faraday.3, A-1030 Wien
Tel.:+43 50550/6213, Fax:+43 50550/6533
e-mail: wolfgang.enders@arsenal.ac.at

ABSTRACT: Many problems with PV-plants are caused by the inverters and their different technical methods to deal with environmental conditions. Unsuitable behaviour can cause dangers for the environment or the inverters itself. The recent situation is that a lot of environmental situations which can occur with a relative high probability are not defined normative. Environmental conditions in the case of different short-circuits in the grid and induced values in the case of lightning-surge impacts were examined. Further special test-series at inverters of different technologies and for different applications (stand-alone and grid-connected) were performed at the special test-stand in Vienna with the ability of generator and net-simulation and the high-voltage and high-current test-laboratory to simulate environmental conditions with extreme parameters. The aim of the tests was to develop suitable measurements against disturbances and dangers (risks) and to get a base for new test-parameters for PV inverters.

The work was done under the mainframe of the EU-Project ESDEPS(EMC and Safety Design of PV-Systems)[1],[7]

Keywords: Qualification and Testing - 1: Inverter - 2:Safety - 3

1. INTRODUCTION

General demands for the different components inserted in PV-plants are,

- they must not cause disturbances or dangers for the environment and
- the interaction between environment and device must not cause disturbances or dangers at the device

Typical disturbances or dangers for the environment are [2],[3],[4],[5]

- harmonic and radio-frequency-emission generated from the inverter
- over-voltages at the end of PV-line in the case of high PV-penetration
- islanding after disconnection of the LV-transformer and over-voltages generated by inverter disconnection
- Resonance-effects between the inverters and the grid
- DC-current-injection into the grid in the case of a trafoless inverter-configuration

Typical disturbances or dangers for the devices are [2],[5]

Harmonic content of the grid

- Over-voltages, voltage dips and switching transient effects in the grid
- Short circuits in the grid including re-closing actions
- Transients caused by the influence of lightning surges
- Line-coupled data transfer

2. THE RECENT NORMATIVE SITUATION

There exists no specific product standard for EMV-aspects. In such a case *generic standards* have to be applied There exist:

Emission Standards

EN 50081-1 for residential, Commercial and light industry
EN 50081-2 for industrial environment

Immunity Standards

EN 50082-1 for residential, commercial and light industry
EN 50082-2 for industrial environment

An other way is to refer to product-group standards for *household appliances* .EN 55014

But many of special problems of PV-components are not considered here.

A very actual work is the Draft 82/257/CD(with closing date 310801) for IEC 62093 with the title

- Balance of system components for PV-systems-Design qualification and type approval***

Some information's about the electrical environment of grid-connected inverters can be obtained with the standard

- EN 50160. ***Voltage characteristics of electricity supplied by public distribution systems***

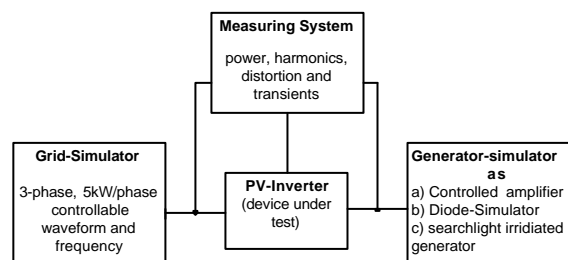
3. PERFORMING OF TESTS

3.1 Test equipment

The test equipment consists of the following essential parts:

- Universal inverter-test-stand with the ability of generator- and grid-simulation [9]
- High-current laboratory to simulate the grid-situation in the case of fuse-interrupted short-circuits
- Measuring station for lightning-surge influence into the grid and PV-components (at the mountain "Gaisberg" near Salzburg)
- High-voltage laboratory for lightning-surge-simulation

Fig.1 shows the block-diagram of the inverter test-stand developed and built up at arsenal research

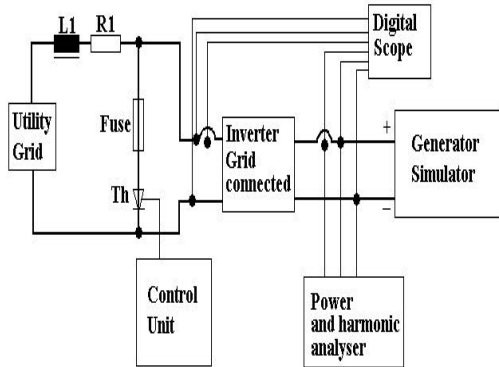


Pict.1 Block-diagram of the inverter test-stand

3.2 Test-results

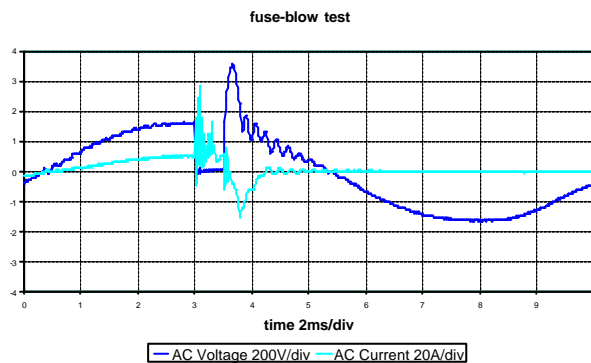
3.2.1 Short-circuit interrupted by a fuse

The special test-circuit is shown in pict.2



Pict.2 Special test-circuit for the influence of a short-circuit interrupted by a fuse in a branch of the grid

The short circuit is triggered by the thyristor Th. During the time up to the moment of the fuse-interruption energy is stored at the inductance L1. After fuse-interruption a high energy impulse will occur in the grid. Picture 3 shows the influence of such a pulse to a connected inverter with a nominal power of 1,8kW.

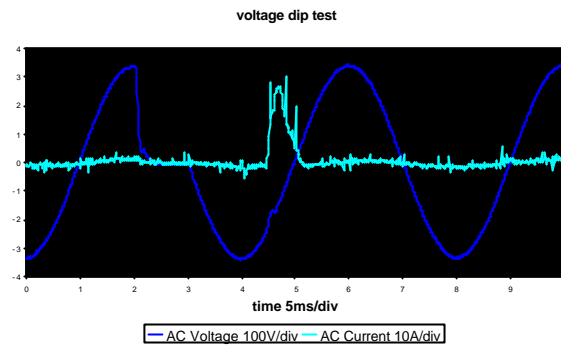


Pict 3: Fuse-blow test with a Fuse F10 and a net-inductance of 1,2mH

The result of this test was a maximum grid-voltage of 700V and a maximum output current of the inverter of 56A. There was made a high number of tests with different kinds of fuses and protective circuit breakers and different net-impedance's. While circuit breakers normally did not cause considerable over-voltages, the interruption with fuses caused over-voltages up to 3kV. The energies of the transient pulse can be up to several kJ and can lead to defects of components if no suited measurements are inserted.

3.2.2 Voltage-dip-test

Voltage dips are e.g. the result of start of high-power motors or other low-impedance-loads in the grid. Pict.4 shows an example of the inverter-reaction to a voltage-dip to zero with a duration of a quarter period.



Pict.4 Voltage-dip test at an inverter with 250W nominal power

The result of this test was a very high peak-current (30A or nearly 20 times the nominal current) a half period later which lead to automatic grid-disconnection of the inverter. The high output-over-current is caused by saturation effects of the output transformer.

Some test objects were very sensitive for such kind of impact and disconnected already at voltage-dips of 5%, others only at 70% voltage-decrease.

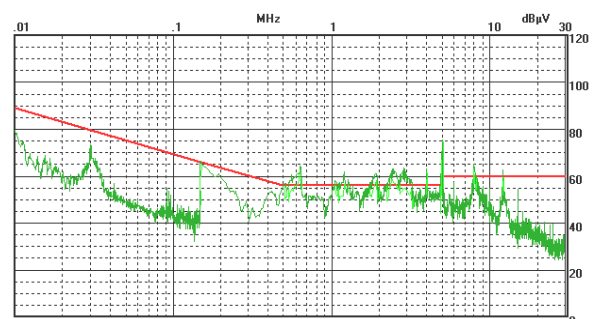
This test is defined normative in the basic standard EN 61000-4-11. But the parameters like amplitude and durance of the dip and the behaviour of the inverter should be defined normative for the concrete product.

3.2.3 Conducted Radio-emission

The limits for line-coupled radio emission between 10kHz and 30MHz are defined in EN 55014. The frequency area is divided in the 2 sections, the area with "recommended limits" between 10kHz and 150kHz and that with "regulated limits" between 150kHz and 30 MHz.

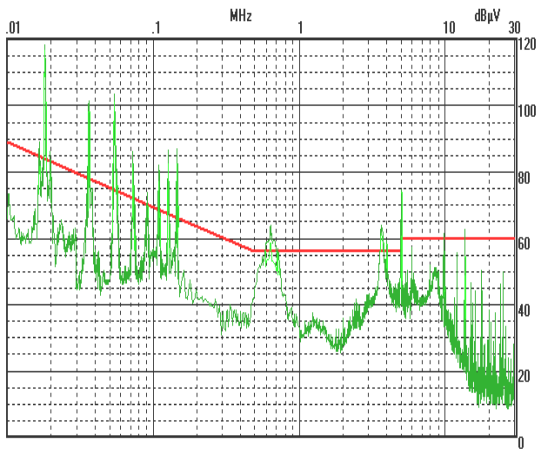
The measuring result was, that the conducted radio-emission of many devices under test exceeded the limits at both sections in considerable manner.

Picture 5 shows the test result of an inverter with 100W nominal power which exceeds the limits in the regulated area in only few manner. But this kind of device is constructed to be parallel connected with a high number of identical products(e.g. up to 100). In this case a very high exceeding of the regulated values at the common connection-point can be expected. This problem can only be solved if the normative limits depend on the nominal power of the concrete device.



Pict.5 Conducted radio emissions of an inverter with 100W nominal power

The diagram for a trafo-less inverter with 2600W nominal power is illustrated in Pict.6

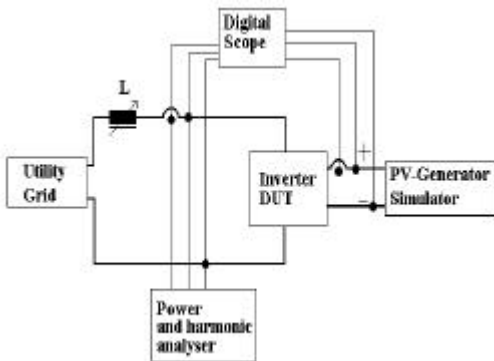


Pict.6 Conducted radio emissions of an inverter with 2600W nominal power.

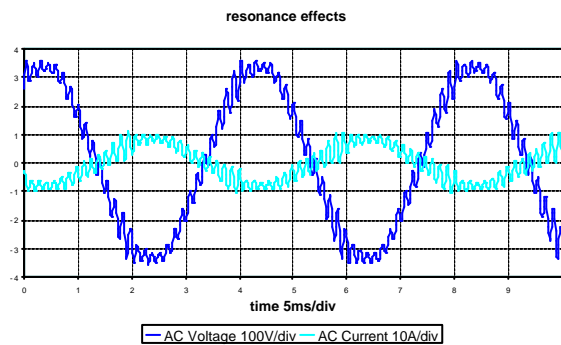
There are very high values in the recommended area (up to 120dB) caused by switching frequency and it's harmonics. In that case the inserted filter is to small which can also generate resonance-effects as illustrated in the next point

3.2.4 Resonance-effects between inverter and grid

Pict.7 shows the test-circuit for resonance-effects The variable inductance L is inserted for simulation of a LV-line with different length. Some test-objects show exciting resonance-effects at special values of L.



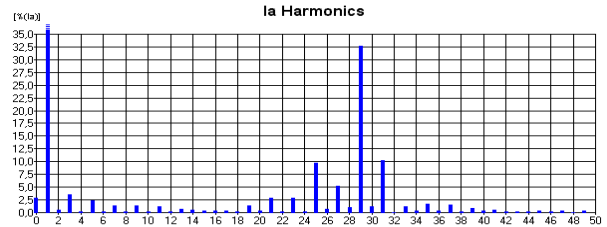
Pict.7 Test circuit for resonance-effects



Pict.8 Resonance effects between grid and trafo-less inverter

The variable inductance L is inserted for simulation of LV-lines with different lengths. Some test-objects showed exciting resonance-effects at special values of L.

The oszillogramm Pict.8 and harmonic-spectrum Pict.9 show the result of an inverter with a nominal power of 2,6 kW at an net-inductance of 1,3mH. The current-harmonics exceed 30%.



Pict.9 Harmonic spectrum in the resonance-situation

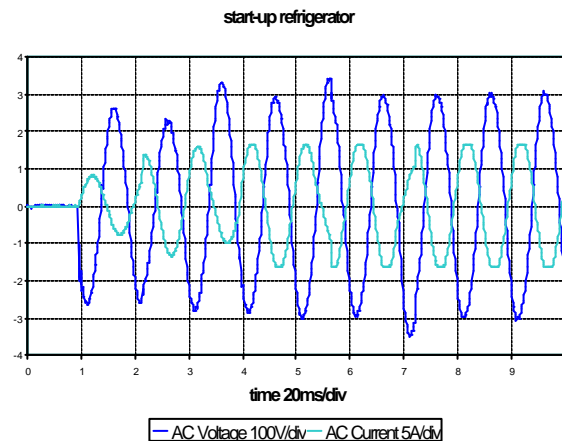
3.2.5 DC-current injection into the grid

DC-current-injection into the grid is possible with inverters in trafo-less configuration in the case of inverter-bridge-defects or an inaccurate bridge-control. These effects can cause saturation effects at power transformers as well as at protective elements in the grid. Recently many inverters don't react with disconnection in the case of supplying DC-components into the grid.

3.2.5 Inrush-currents at the output of island-inverters

Usually the start of an asynchron-motor causes transient over-current. To protect the devices most of the island-inverters have an output-current limitation which can cause voltage-reduction in the case of a motor-start. Pict. 10 shows an oszillogramm for the start of a compressor (nominal power 200W) with an inverter (nominal power 800W).

The result of this test was, that the inverter could not supply enough voltage during the start-period of the motor but did not disconnect. So the motor did not reach it's nominal revolution which lead to it's stationary overload.



Pict. 10 Start of a compressor with an island inverter

3.2.6 Signal-superposition in the frequency-area between 200Hz and 300kHz

The amplitude-levels of the test signals were chosen in relation to the maximum allowed send-levels in standard EN50065 and EN50160.

The result was, that no inverter-defect could be observed. In the area between 200Hz and 3kHz no considerable reaction to the sent signal could be observed. In the higher frequency area some inverters answered with resonance-effects causing over-voltages in the grid or short-circuit for the signalling voltage. Some inverters were very robust against control signals and did not react, others were very sensitive and disconnected.

The conclusion is, that the behaviour of inverters in the case of signal-superposition should be defined normative.

3.2.7 Influence of lightning surges [3],[6],[8],[10]

Since about 2 years the influence of a direct lightning surge impact into a broadcasting antenna on top of the mountain Gaisberg (Salzburg) into PV-components and a LV-Grid at an average distance of 200m to the antenna is examined by arsenal research. About this experiment is referred in detail at this conference [8]

Important results were, that even though the distance to the lightning surge impact was not very small,

- the amplitudes induced into the grid exceeded 5kV
- the frequency content of induced values was up to 5MHz
- the voltages induced into the PV-generator exceeded 50V per PV-panel. PV panels have resonance-frequencies in that area and are often connected in series in a high number. Therefore over-voltages in the area of some kV in the generator are relative probable, if there is no limiting measure installed.

4. SUMMARY AND CONCLUSIONS

Many different tests were performed at considerable number of PV-inverters manufactured in different technologies in the power area between 100W and 3kW. Many of the test levels are not defined in the generic standards or other applicable standards but were selected on the base of the experience of arsenal research and additional studies. Such studies were done about induced lightning effects and the retroaction of grids to fuse-interrupted short-circuits.

The insertion of the devices with the simulated environmental conditions showed problems in some cases beginning with disturbances of the normal operation up to defect of the device. Many of the problems could be solved with relative simple and cheap technical measurements but there is no economic reason for the manufacturer to set these measurements if he is not forced to prove special qualities of his product. Therefore additional special tests for PV-inverters and the expected behaviour of the device under test should be defined normative.

The emphasis of such a definition should be

- Amplitude and test-pulse-shape to simulate induced lightning effects with reference to basic-standards
- Amplitude and energy of test-pulse to simulate the grid in the case of fuse-interrupted short-circuits
- Test-conditions for short-circuits and interruption with re-closing activities

- Amplitude and durance of low-frequency over-voltages and voltage-dips with reference to generic standards
- Limits of harmonics and conducted radio-frequency emissions in dependence of the nominal output-power of the device
- Definition of a test circuit to examine resonance-effects
- Definition of a circuit to test the behaviour in the case of non-linear loads and inrush currents
- Definition of the behaviour in the case of DC-injection into the grid
- Test circuit for islanding effects after LV-transformer-disconnection suitable for all known methods (not only ENS-method)
- Definition of test levels to simulate line-coupled data transmission

5. REFERENCES

- [1] T.Degner, W.Enders, A.Schülbe, H.Daub et.al. : EMC and Safety Design for Photovoltaik Systems(ESDEPS) 16th European Photovoltaik Solar energy conference, Glasgow(2001),2253-2256
- [2] H.Wilk, G.Schauer, H.Harich, W.Enders: Testing inverters for utility interactive operation. 2nd Photovoltaik World Conference, Vienna (1998),2082-2085
- [3] Utility aspects of grid connected power systems IEA PVPS T5-01(1998)
- [4] M.Burns: Impedance-effects of low-voltage residential ac utility networks upon power quality requirements for distributed ac PV-inverters 2nd PV world conference in Vienna (98), 2841-2844
- [5] H.Wilk, G.Schauer. Operational behaviour of small power conditioners for grid interactive PV-systems 14th European PV-Conference Barcelona (1997)
- [6] H.Becker, W.Vaaßen, F.Faßen: Lightning and over-voltage protection in Photovoltaik (PV) and solar thermal systems 16th European Photovoltaik conference Glasgow(2001), 2257-2260
- [7] T.Degner, H.Daub, W.Enders, A.Schülbe et.al. EMC and Safety Design for Photovoltaic Systems. Research Results from the ESDEPS –project 17th European Photovoltaic Solar Energy Conference, 2001-10-22
- [8] Ch.Halter, W.Enders. The indirect influence of lightning Impacts on PV-PV-Systems 17th European Photovoltaic Solar Energy Conference, 2001-10-22
- [9] W.Enders, P.Scheibenreiter. PV- Wechselrichterprüfstand 11th Symposium Photovoltaische Solarenergie 13.-15.03 96
- [10] H.Häberlin, R.Minkner. Einfache Methode zum Blitzschutz von Photovoltaikanlagen Bulletin des SEV/VSE 19/94,S.47-52