New DC-LISN for EMC-Measurements on the DC side of PV Systems: Realisation and first Measurements at Inverters

H. Haeberlin
Berner Fachhochschule, Hochschule fuer Technik und Architektur, Jlcoweg 1, CH-3400 Burgdorf, Switzerland
Phone +41 34 / 426 68 11, Fax +41 34 / 426 68 13
e-mail: heinrich.haeberlin@fhburg.ch, internet: http://www.pvtest.ch

ABSTRACT: As power converting PV components contain switching power electronic circuitry, an important quality characteristic of such devices is a sufficient EMC behaviour to avoid interference to adjacent electronic systems. Measurements of radiated electromagnetic fields are difficult and expensive. A easier approach is the measurement of conducted RF emissions at a defined terminating network (LISN). On AC side, well established standards about such LISNs and the limits to be applied exist for 150 kHz to 30 MHz (e.g. EN55014, EN50081-1). For DC side, limits are indicated only in EN55014. These limits have been used in the past to assess RF emissions of PV inverters. Based on the informative annex of EN50081-1, HTA Burgdorf and Schaffner AG, Luterbach, have realised a quite simple DC-LISN with a common mode impedance Z_{CM} = 150 Ω and used it for RF measurements on the DC side.

In 1998 - 2000, in an EU project (PV-EMI, JOR3 CT98 0217, partners: FhG/ISE, HTA Burgdorf, KEMA) extended measurements and simulations of impedance values and radiated electromagnetic fields of real PV generators were carried out. Based on this work, the project group agreed on new values for the impedance of a DC-LISN (defined values for common-mode and differential mode) and for the limits to be applied on the DC side.

After the end of the project in summer 2000, a new DC-LISN meeting the specifications above could be realised in winter 2000/2001. Sample measurements with the new DC-LISN and with the old DC-LISN with Z_{CM} = 150 Ω at several inverters from different manufacturers mostly showed only minor differences in the measured RF voltages. Measurements also showed that modern inverter designs have RF emissions considerably lower than the specified new limits. Thus measurement of RF voltages at such a DC-LISN can ensure EMC of PV equipment also on the DC side. Efforts were also made to work out a joint EMC-proposal with the co-ordinator of another EU project group (ESDEPS).

Keywords: Electromagnetic Compatibility (EMC) – 1 : Inverters – 2 : DC-Line impedance stabilisation network – 3

1. Introduction

HTA Burgdorf's PV laboratory has carried out tests at grid-connected PV-inverters since 1988. As power converting PV components (e.g. inverters and charge controllers) contain switching power electronic circuitry, an important quality characteristic of such devices is a sufficient EMC behaviour to avoid interference with adjacent electronic systems. Internal switching frequencies are mostly between a few kHz up to 100 kHz, therefore the frequency range of 150 kHz to 30 MHz is of major importance. As measurements of radiated electromagnetic fields are quite difficult and expensive, a very simple approach is the measurement of conducted RF emissions at a defined terminating network, a line impedance stabilisation network (LISN). Such a LISN should have a stable, well defined impedance that comes close to impedances measured in the field.

On the AC side, well established standards about such LISNs and the limits to be applied exist (e.g. EN55014, EN50081-1).

On the DC side of PV systems, the situation is essentially different. The PV generator and its wiring may act as an antenna, which radiates electromagnetic fields. Under unfavourable conditions even λ/4 or λ/2 resonances can occur. Thus the possible RF radiation may be significantly higher, especially close to resonance frequencies.

Only in a few standards limits for connections other than the line connections can be found. In EN55014 limits for RF voltages are indicated, which have to be measured by means of a measuring probe with an impedance of 1500 Ω. These limits are intended for short leads of only a few meters. In the informative annex of EN50081-1 it is proposed to measure RF currents at a terminal impedance of 150 Ω to RF ground and limits for such RF currents are given.

If conducted RF emissions of PV equipment are to be measured, the device under test should be subjected as far as possible to the same operating conditions as under normal operation, that means it should be powered by a PV generator or a PV generator simulator. However, the frequency dependence of the RF impedance of such devices is undefined. Moreover, they may act as antennas and pick up RF signals or even produce RF disturbances themselves.

During the first years of EMC measurements performed at HTA Burgdorf, such external disturbances were suppressed by means of current compensated ferrite chokes. However, the RF impedance is not defined after such chokes. Therefore already in 1992 the idea was born to use a DC LISN of 150 Ω to measure DC-sided RF emissions. However, such LISNs are difficult to realise due to the high voltages and currents they have to handle besides a good RF behaviour.

2. Realisation of a DC-LISN with Z_{CM} = 150 W (150 kHz – 30 MHz)

Based on the impedance value given in the informative annex of EN50081-1, HTA Burgdorf and Schaffner AG have realised a quite simple DC-LISN with Z_{CM} = 150 Ω (according to EN61000-4-6) and used it for RF measurements on the DC side. Fig. 1 shows the schematic diagram of this DC-LISN. It is now available from Schaffner AG, CH4542 Luterbach. The frequency dependence of Z_{CM} of the realised DC-LISN is displayed in fig. 2. Z_{CM} has are only slight deviations from the target value of 150 Ω. However, it is obvious that Z_{DM} is not exactly defined, varies considerably and has even a series resonance (see fig. 5). Resonance points are undesirable in RF measurement technology. With this DC-LISN, RF emission measurements have been done at many inverters. ISET Kassel has used a commercially available network with Z_{CM} = 75Ω (2·150Ω in parallel) from Schaffner AG for similar measurements.

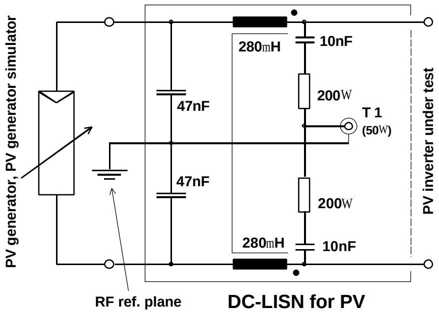

Fig. 1: Schematic diagram of the realised circuit for a DC-LISN with Z_{CM} = 150W according to EN 61000-4-6. When T1 is terminated with a 50 W resistor, the RF common–mode impedance Z_{CM} of both lines together to ground is 150 W. RF voltages can be measured directly at the 50 W port T1 (attenuation 9.5dB). Differential mode impedance Z_{DM} is not defined (see fig. 5).

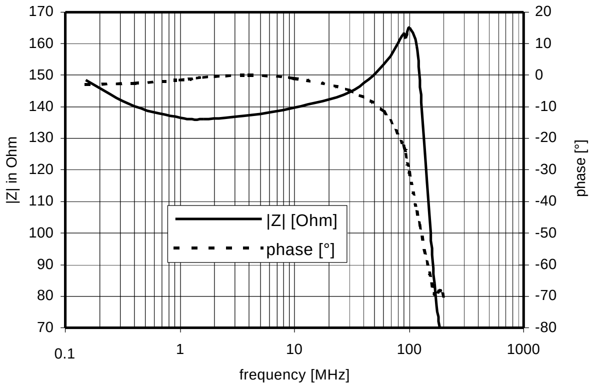

Fig. 2: Impedance $\underline{Z}_{CM}$ of the realised DC-LISN with Z_{CM} = 150 W according to fig. 1 ("old DC-LISN"). Differential mode impedance of this LISN is undefined (see fig. 5).

3. Result obtained during Project PV-EMI

In 1998 - 2000, in an EU project (PV-EMI, JOR3 CT98 0217, partners: FhG/ISE, HTA Burgdorf, KEMA) extended measurements and simulations of impedance values, antenna factors and radiated electromagnetic fields of real PV generators were carried out. A similar, in some way complementary EU-project (ESDEPS, co-ordinated by ISET) has also been performed in 1998 – 2001. In both projects, there is a clear intent to measure RF emissions on the DC side with a suitable DC-LISN and to establish limits for such measurements based on field measurements.

Based on extended measurements and simulations during the project PV-EMI, the following values for the impedances of a DC-LISN and the limits were agreed upon by the project group at the end of the project:

Common mode : Z_{CM} = 250 Ω (+100%, -50%) ;
differential mode : Z_{DM} = 100 Ω (+100%, -50%).

Limits for RF-voltages at a DC-LISN with the impedance values given above (average values 10dBµV lower):

150 kHz < f < 500 kHz : 80 dBµV quasi-peak ;
500 kHz < f < 30 MHz : 64 dBµV quasi-peak.

For f > 500 kHz the proposed values are 10 dBµV lower than the values for "other connections" in EN55014.

As the initial DC-LISN circuit of HTA Burgdorf did not meet the above specifications, at the end of the project PV-EMI only a tentative circuit for the realisation of such a DC-LISN could be given. Due to time limitations, a practical realisation and comparative measurements could not yet be performed during the project itself.

4. Realisation of a new DC-LISN

After the end of the project in summer 2000, a new DC-LISN meeting the specifications above could be realised in winter 2000/2001 for voltages up to 1000 V and currents up to 75 A. Different versions of this DC-LISN were realised and tested, all fitting into the relatively wide impedance range specified above. Depending on the internal elements chosen, for medium frequencies values for Z_{CM} up to 220 Ω could be obtained. However, in order to make a practical realisation possible and to ensure reproducible measurements, especially at higher frequencies (e.g. > 10 MHz), the target impedance values should not be too high. A value of Z_{CM} = 150 Ω would be preferable in that range. Therefore an other version of a DC-LISN with a very constant Z_{CM} = 150 Ω +/-25 Ω was built, too. *Z_{CM}–values of 150 W are also well established in other EMC standards.* In fig. 3 the schematic diagram of a suitable circuit for both versions (Z_{CM250} and Z_{CM150}) and in fig. 4 measured impedance values for Z_{CM} are indicated.

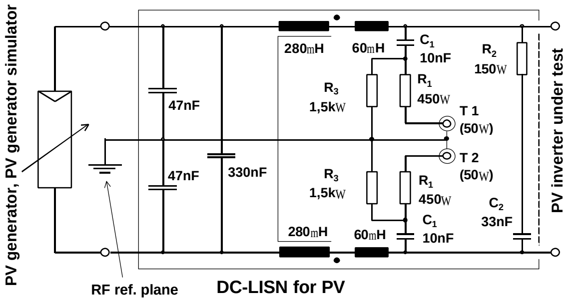

Fig. 3: Schematic diagram of the new DC-LISN (1 kV/ 75 A) with Z_{CM} = 150 W and Z_{DM} = 100 W. At T1 and T2 (terminated with 50 W) attenuated measurement signals (-20 dB) are available.

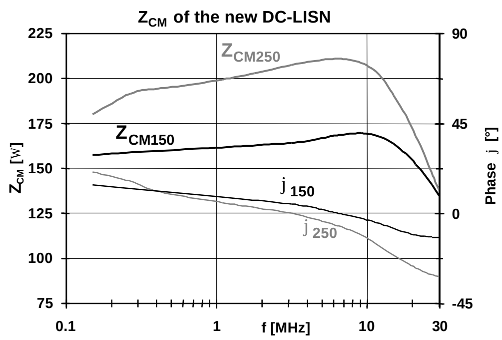

Fig. 4: Measured common mode impedance $\underline{Z}_{CM}$ for both versions of the new DC-LISN according to fig. 3: Z_{CM} = 250 W (R_3 = ¥) and Z_{CM} = 150 W (R_3 » 1.5 kW).

The practical realisation of a DC-LISN can not only be considered strictly from a RF point of view. Other requirements (e.g. sufficiently low residual 50 Hz-currents for inverters without transformers) must also be taken into account. Therefore relatively low values for the capacitors to ground must be chosen.

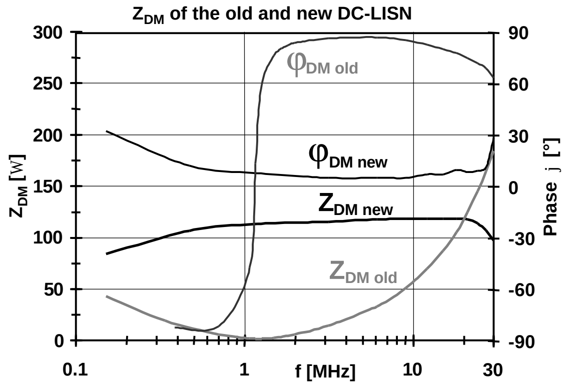

Fig. 5: Measured differential mode impedance $\underline{Z}_{DM}$ of old and new DC-LISN according to fig. 1 and 3 (no differences for Z_{CM} = 150 W or 250 W).

Due to the large currents on the DC side of inverters, relatively large chokes are needed on the DC side. Such large chokes have significant capacities to ground reducing impedance at higher frequencies. Therefore it is very difficult to realise the relatively high value of Z_{CM} agreed upon by the project group PV-EMI. Fig. 4 shows, that for the target value Z_{CM} = 250 Ω the value of Z_{CM250} varies considerably, but the relatively wide tolerance band is respected. However, it would make more sense to mark that curve with Z_{CM} = 200 Ω. On the other hand, for a target value Z_{CM} = 150 Ω the value of Z_{CM150} is relatively constant and still within the desired tolerance band. For the sake of reproducibility and as Z_{CM}–values of 150 Ω are also well established in other EMC standards, a Z_{CM} of 150 Ω makes much more sense.

Usually it is more difficult to stay below the limits at lower frequencies. Some inverter manufacturers with insufficient test results on DC-side criticised, that an impedance value of Z_{CM} 150 Ω was too low at low frequencies. Therefore by reducing the value of C_1, a third version of a DC-LISN was optimised to obtain a better match to the capacitive behaviour of PV arrays at low frequencies, with values for Z_{CM} up to 300 Ω around 150 kHz, dropping down to 150 Ω +/-25 Ω for f >1 MHz. By reduction of C_1 a high-pass (HP) filter is created, but its influence can easily be corrected arithmetically after the measurement.

Fig. 6 shows Z_{CM} vs. frequency of such a modified DC-LISN with Z_{CM} = 300 Ω / 150 Ω and Z_{DM} = 100 Ω .

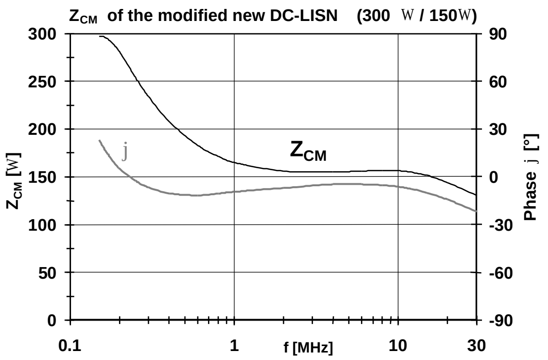

Fig. 6: Measured common-mode impedance $\underline{Z}_{CM}$ of modified DC-LISN for Z_{CM} = 300 W / 150 W (300 W at low / 150 W at higher frequencies).

However, it is easy to demonstrate, that if RF voltages are measured, higher load impedances Z_L = Z_{CM} always result in higher measured RF voltages. Therefore, when RF voltage limits have to be respected, it is favourable for the devices under test to be measured at lower impedances (see fig. 7).

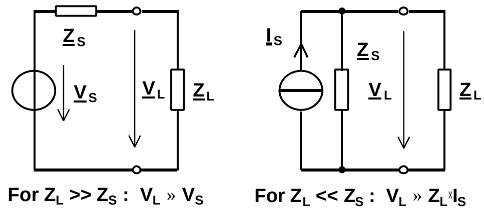

Fig. 7: Equivalent circuits for calculation of load voltage V_L .

This fact can also be confirmed by practical measurements. Fig. 8 shows the RF voltages produced by an inverter with no RF filters on DC side and high source impedance Z_S at a DC-LISN with Z_{CM} = 300 Ω / 150 Ω according to fig. 6 and a DC-LISN with Z_{CM} = 150 Ω according to fig. 3 and 4 (Z_{DM} always 100 Ω). Due to the higher impedance at low frequencies, the voltages below 300 kHz are a few dBµV higher at the DC-LISN 300 Ω / 150 Ω . At higher frequencies, there are no differences.

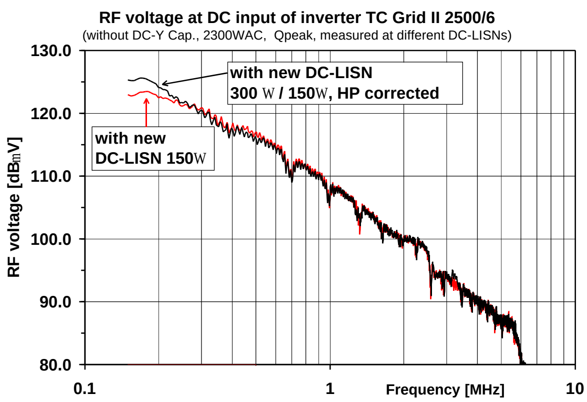

Fig. 8: RF voltages produced by an inverter with high source impedance Z_S at a DC-LISN with Z_{CM} = 300 W / 150 W according to fig. 6 and a DC-LISN with Z_{CM} = 150 W according to fig. 3 and 4.

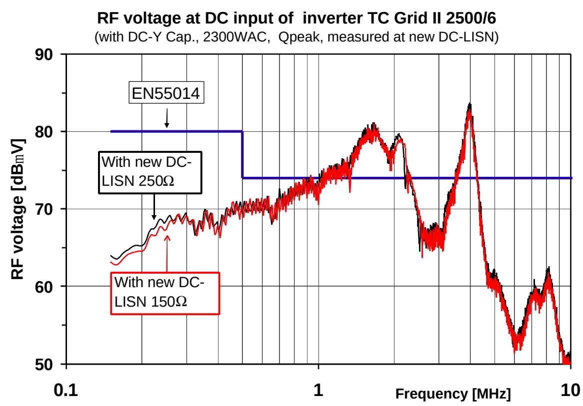

Fig. 9 RF voltages produced by an inverter with some RF-filtering on DC-side at DC-LISNs with Z_{CM} = 250 W and 150 W according to fig. 3 and 4.

Fig. 9 shows that there are only very small differences in measured RF voltages produced by an inverter with some RF-filtering on DC-side at DC-LISNs with Z_{CM} = 250 Ω and 150 Ω according to fig. 3 and 4 (Z_{DM} = 100 Ω).

As differential mode disturbances are also considered (with a factor of 0.5) with the new DC-LISN with Z_{CM} = 150 Ω according to fig. 3, especially at lower frequencies RF voltages measured at the new DC-LISN may be somewhat higher than those measured at the old DC-LISN according to fig. 1, where only common mode voltages are taken into account (see fig. 10). This is the very same situation like with the approved V-LISNs used on AC side, therefore this measuring method makes sense also on DC.

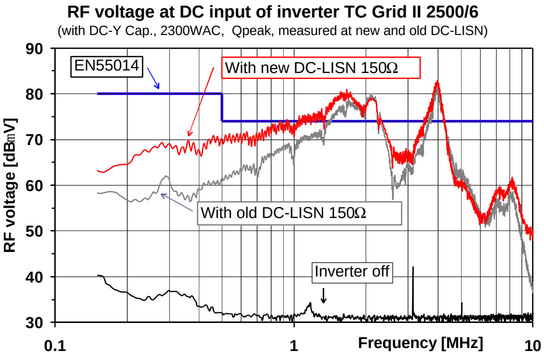

Fig. 10: RF voltages produced by an inverter with some RF-filtering on DC-side at old DC-LISN according to fig. 1 and at new DC-LISN according to fig. 3 (both with Z_{CM} = 150 W).

5. Sample Measurements at Inverters

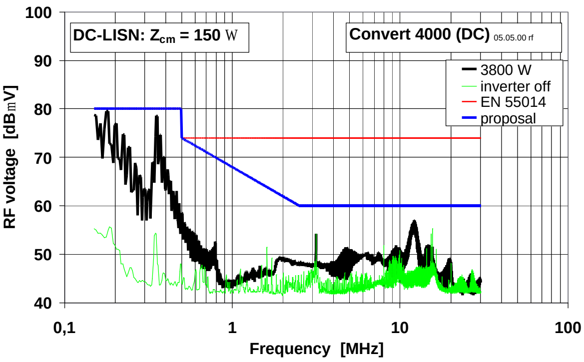

Fig. 11: RF voltages (quasi-peak) produced by a Convert 4000 on DC side (at a DC-LISN according to fig. 1).

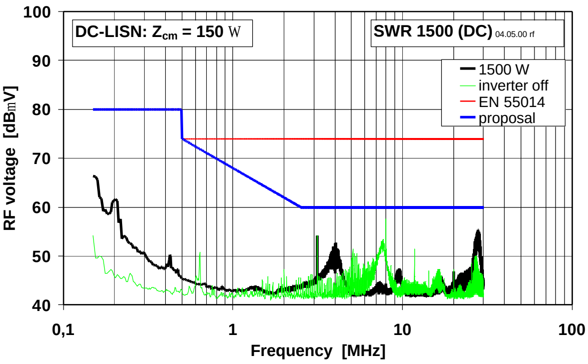

Fig. 12: RF voltages (quasi-peak) produced by a SWR 1500 on DC side (at a DC-LISN according to fig. 1).

Sample measurements with these new DC-LISNs and with the old DC-LISN with Z_{CM} = 150 Ω at several inverters from different manufacturers mostly showed only minor differences in measured RF voltages. *Measurements at DC-LISNs with Z_{CM} = 150 W (instead of higher Z_{CM}–values) are always in favour of the inverters.* Measurements also showed that new inverter designs from experienced manufacturers have RF emissions considerably lower than the limits specified above. Not only the old limits according to EN55014 but also the new, more stringent limits proposed below are no problem for these inverters (see fig. 11 and 12).

6. Conclusion

At the end of both EU projects [1, 2, 4, 6] dealing with the EMC of PV systems, many additional measurements and intense discussions between the people involved in order to obtain a best match to existing standards and to the project results, the following joint proposal about a DC-LISN and the limits to be applied was established :

Impedance of a DC-LISN for PV (150 kHz – 30 MHz):

Common mode : Z_{CM} = 150 Ω (+30%, -30%) ;
differential mode : Z_{DM} = 100 Ω (+30%, -30%).

RF-voltage limits (quasi-peak) at DC-LISN with the impedance values given above (average values 10dBµV lower):

150 kHz < f < 500 kHz : 80 dBµV,
500 kHz < f < 2.5 MHz : slope from 74 dBµV to 60 dBµV,
2.5 MHz < f < 30 MHz : 60 dBµV.

Measurement of RF voltages at such a DC-LISN can ensure EMC of PV equipment also on the DC side.

ACKNOWLEDGEMENTS

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REFERENCES

[1] S. Schattner, G. Bopp, T. Erge, R. Fischer, H. Häberlin, R. Minkner, R. Venhuizen, B. Verhoeven: "PV-EMI – Developing Standard Test Procedures for the Electromagnetic Compatibility (EMC) of PV Components and Systems". Proc. 16th EU-PV-Conference, Glasgow, 2000.

[2] T. Degner, W. Enders, A. Schülbe, H. Daub et al:"EMC and Safety Design for Photovoltaic Systems (ESDEPS)". Proc. 16th EU-PV-Conference, Glasgow, 2000.

[3] S. Schattner, G. Bopp, T. Erge, R. Fischer, H. Häberlin, R. Minkner, R. Venhuizen, B. Verhoeven: "A new Measurement Technique ensuring the EMC of Photovoltaic Systems". Proc. 14th EMC Zurich Symposium, 2001.

[4] Publishable Final Report: „Development of standard test procedures for electromagnetic interference (EMI) tests and evaluations on photovoltaic components and plants (PV-EMI Project)“. Contract JOR3 CT98 0217, Aug. 2000.

[5] H. Häberlin: "Evolution of Inverters for Grid-connected PV Systems". 17th EU-PV-Conference, Munich, 2001.

[6] N. Henze, T. Degner, H. Häberlin and G. Bopp: "Radio Interference on the DC side of PV Systems and Limits of RF Emissions". 17th EU-PV-Conference, Munich, 2001.

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