



Inverter Interconnection Tests Performed in the LABEIN-Tecnalia Microgrid Involved in the DERlab Round-Robin Testing Activity

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Abstract—One of the key objectives of DERlab *Network of Excellence* is the development of internationally acceptable test and certification procedures for Distributed Energy Resources (DER)-components and systems connection and operation, which could be proposed to European standardisation bodies.

Interconnection of inverters to the electrical grid has been identified as a key issue for the wide integration of DER, especially when international standards scenario is highly unclear. As a prenormative research, a round-robin test of two small scale photovoltaic inverters has been performed by nine DERlab laboratories during the period of January - July 2009. The test activity was focused on the verification of individual test procedures, common interpretation of standards and requirements, and determination of problems related to the equipment and facilities involved in conducting round-robin tests. Compilation of test results and first conclusions of this activity will be available during this year.

As part of the intercomparison campaign, this paper is focused on the round-robin tests carried out in the microgrid of LABEIN-Tecnalia in Derio (Spain) in February 2009. It shows the results obtained and explain the lessons learned from this series of experiments to assess the application of a unified testing procedure across different testing environments

Keywords—*inverter; round-robin test; Network of Excellence; distributed energy resource (DER); certification, standardisation.*

I. INTRODUCTION

DERlab is a European Network of Excellence of independent laboratories working on the integration of distributed energy resources (DER) into electricity grids. The Network tries to support the transition towards more decentralised power generation by performing tests, pre-competitive and pre-normative research, as well as training activities.

DERlab Consortium is composed by 11 partners: ISET from Germany (coordinator), ARSENAL from Austria, KEMA from The Netherlands, INES-CEA from France, CESIRICERCA from Italy, LABEIN-Tecnalia from Spain, UKDG Centre from UK, NTUA from Greece, RISOE-DTU from Denmark, TUSofia from Bulgaria, and TULodz from Poland. This network aims at the creation of a reference laboratory in Europe in the field of DER integration.

As new decentralised energy resources are integrated into distribution network, it is necessary to use laboratory tests to validate new concepts and components and their impact on the performance of the whole system. DERlab provides critical support to the development of a common European research and development platform related with DER integration into power systems, taking into account needs and concerns of the European utilities and manufacturers. Further to this, DERlab supports formulation of European and international standards

by executing exemplary research activities, which provide the required technical information and input for standards.

As an example of these activities, a round-robin test of two small scale photovoltaic inverters has been performed by nine DERlab laboratories during this year 2009. Documentation for four mandatory test procedures in detail and two optional test procedures was developed with the help of DERlab partners. Test activity was focused on the verification of individual test procedures, common interpretation of standards and requirements, and determination of problems related to the equipment and facilities involved in conducting the round-robin tests.

Being a part of this intercomparison campaign, this paper presents a summary of the round-robin tests carried out in the microgrid of LABEIN-Tecnalia in Derio (Spain) from 11th to 13th February 2009. Tests were jointly conducted by LABEIN-Tecnalia specialists assisted by invited DERlab researchers from ARSENAL (Austria), RISOE (Denmark) and UKDG Centre (UK).

Performed tests are a selection of the most representative inverter tests specified in the still unclear scenario of European standards in this field. Tests covered the following issues: under/over voltage and frequency detection (anti-islanding protection), efficiency measurements, harmonic current measurements, DC current injection, and PV leakage current.

One of the main round-robin test specific feature is that the testing was done completely independent from the inverter manufacturer. Experiments highlighted that the proper simulation of the DC input, specifically the Photovoltaic Array is one of the key issues for testing the functionality of solar inverters. As there was no full Photovoltaic Array Simulator available during the tests, additional methods needed to be implemented. Specifically, behaviour of the solar inverter's DC input was an important factor to be considered. Some inverters have a stable DC link that changes its voltage slowly while others have a DC/DC stage that allows quick changes in the input voltage: each case needs a proper performance of the DC source and results are not always as predicted.

II. LABORATORY SET-UP

In order to accomplish the tests, the behaviour of the electrical grid and the PV array must be simulated.

An AC power source was connected to the AC side of the solar inverter. This power source must be able to change the characteristics of its output quickly and precisely. Normally the grid simulators are based on AC/AC converters and not all of them accept power in a bidirectional way, so, when the test is done over a device that delivers power, additional load must be added to avoid tripping of the power source. The effect of adding these loads is a slight change in the output impedance of the power source. In case of LABEIN's tests, a three-phase Pacific Power Source was used as AC power source, only one of the phases being connected to the inverter, one of the other phases being used as a trigger to know when the frequency changes occurred.

At the DC side of the inverter a PV Array Simulator must be placed, in order to create the characteristic U-I curve of PV arrays. Normally the power source has an external signal to allow the control of its output. If this can not be done in a linear manner and flexibly enough to represent a PV curve, the PV system can be emulated. Thus, the output voltage can be controlled as a function of the output current or the output current as a function of the output voltage. Normally, power source is provided with this signals, otherwise the adequate analogue signal must be created.

The fact that PV inverter manufacturer was not present during the test constitutes a problem, since usually it is the manufacturer who is expected to configure the inverter according to the test requirements.

Depending on the configuration of the inverter its input can behave as a current controller or as a voltage controller. Normally, if the inverter has a DC/DC stage, an inductor is placed in the input and the inverter usually changes its input voltage more quickly. On the other hand, if the input of the inverter is directly linked to a DC bus, this tends to stabilise the voltage and it changes in a slower manner. Depending on the behaviour of the inverter it is better to control the output of the DC source in a different way. If the inverter input behaves as a current controller (reactance) it is better to control the inverter as a voltage source. If the inverter tries to stabilise its input voltage (DC bus) it is better for the power source to behave as a current source.

Additionally, if the inverter acts as a current controller its control speed is usually faster than in the case of a DC bus. This fast changes in the input state can cause problems to the DC power Source. If the MPPT control loop of the inverter is faster or similar to the reaction time of the power source, the source does not have enough time to control its output and the PV simulation is not accurate enough. In these cases the MPPT is not able to find the maximum and, normally, fluctuates in a broad range. To solve this problem and to limit the fluctuations, some resistances can be added to the output of the power source, in order to separate the output voltage of the power source from the input voltage of the inverter and allow both controls to behave in a more decoupled manner. The PV cell itself has an output resistance, which is represented in the PV curve. If an external resistance is added, it must be subtracted from the model and from the PV curve to be simulated, otherwise voltage sense feedback must be done in the inverter input.

Finally, some inverters have more than one PV input with individual MPP Trackers which control the PV arrays independently. This valuable feature makes more difficult the test performance in the whole range of the output power of the inverter. In these cases more than one DC voltage power source could be necessary to reach the nominal power of the inverter as it is not always possible to connect different inputs to the same power source.

In order to measure the electrical parameters, the following elements have been used:

- Precision multimeters for current and voltage measuring on AC and DC side.

- Grid analyser for measuring voltage, current, and voltage and current harmonics on the AC side. This device is able to record the wave shapes. The instrument suitable for this purpose must comply with EN61000-4-30 standard [1].
- Digital signal analyzer for the simultaneous current and voltage measuring on DC and AC side.

III. ROUND-ROBIN INDIVIDUAL TESTS

A. Harmonic current test

The aim of this test is to assess the current harmonics injection of the PV inverter into the grid.

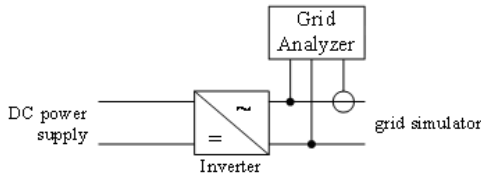


Figure 1. Harmonic current measurement.

The inverter was turned on and the current harmonics were measured on the inverter output, by means of a grid analyser installed on the AC output (as shown in Fig. 1).

The current THD and the current harmonics from 2nd to 39th were recorded according to the IEC 61000-3-2 ($I < 16$ A) [2] and the IEC 61000-3-12 (16 A $< I < 75$ A) [3]. The nominal power of the device was 4000 W, with a resulting nominal output current of 17 A; therefore, the latter document was applied. In all the cases, the resulting harmonic current level was clearly below the limit.

The current THD and the current harmonics from 2nd to 39th were recorded for values of output power equal to 5%, 10%, 20%, 25%, 50%, 75%, 100%. It was not possible to reach the nominal output power level, due to the limited number of DC sources and the maximum input current of each DC string of the inverter. For adjusting the different power levels several PV curves were introduced in the DC source.

B. PV leakage current test

The aim of the test is to assess the capacity of the PV inverter to detect PV leakage current and to discriminate hazardous events. The test was divided into two parts:

- First of all, the DC current value was measured (both on positive and negative terminals of the PV array). This determines the intervention of the protection.
- Then, the protection effectiveness was verified, measuring the time between the leakage current and the disconnection of the inverter.

Due to the fact that many inverters today include a step-change detection, the trip time has to be verified for the following three leakage current levels (RMS values): 30 mA, 60 mA, 150 mA.

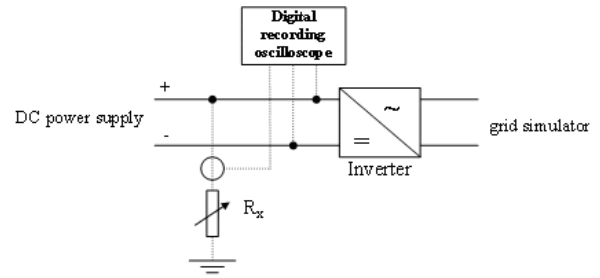


Figure 2. Measurement of the current trip value for slow variations on the negative terminal.

The positive pole of the PV generator was connected to the ground by means of a 10 k Ω variable resistor, whose value is slowly decreased in order to increase the current, until the value that determines the intervention of the protection is reached. This trip value was then recorded as current trip value for slow variation on the positive terminal. The above procedure was then carried out for the negative terminal, in order to measure the current trip value for slow variations on this negative terminal.

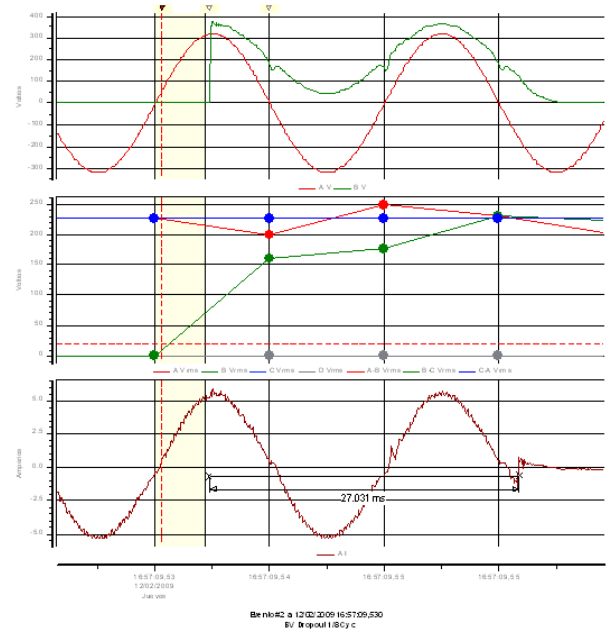


Figure 3. Measurement of the time delay when applying 150 mA to the positive terminal.

After the system was restored to initial conditions, the resistor was set to a value R_x which creates a leakage current according to the above mentioned levels (30 mA/60 mA/150 mA). The resistor was then instantaneously connected between the positive terminal and the ground, in order to measure the time of intervention of the protection.

As the terminal-ground voltage was around 230 V on the DC side, the resistor was tuned to 8 k Ω , 4 k Ω , and 1.5 k Ω .

Fig. 3 shows the delay between the connection of the resistor (voltage across the resistor, in green), and time the current trips (in brown, at the bottom).

C. DC current injection test

The aim of this test is to detect the value of the DC current injected to the AC grid.

The inverter was turned on, operating in parallel to the grid. The multimeter was connected to the AC side, set for DC current measurement.

The test has to be performed for output power levels of 5%, 10%, 20%, 25%, 50%, 75% and 100%, whereas only 92% of the nominal output power rating of the device under test can be achieved. This was again due to the limited maximum input current of each DC string and the availability of only one controllable DC source.

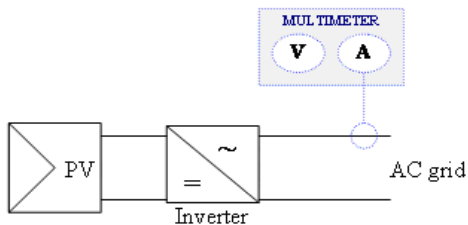


Figure 4. DC current injection measurement.

The measured value of the DC current must be under the 0,5% of the maximum rated inverter AC current, according to the Italian standard (CEI 11-20; V1) [4]. The rated inverter current, in this test, was 22 A, so the DC current should be less than 110 mA. The results showed that the injected current was, in all cases, less than 50 mA and therefore still within the required limits.

D. Anti-islanding protection test (under/over voltage and frequency)

The aim of this test was to evaluate the inverter behaviour during fault conditions, in order to assess the performance of the islanding prevention measures. According to most European standards, the grid interface of the inverter has to detect grid failures and has to disconnect from the mains in order to avoid uncontrolled power injection.

To analyse this feature, the following set of protections was considered: under/over-voltage and under/over-frequency.

The inverter was connected to the DC power supply on its DC side and to a controllable grid simulator on its AC side. The measured parameters are the output AC voltage and frequency, and the time between a frequency/voltage threshold crossing and the inverter anti-islanding protection intervention.

Protection tests were performed by the measurement of each threshold and the verification of the correct operation of the disconnecting device (contactor). Furthermore, the operation delays were also measured. Fig. 5 shows the general architecture of the testing set-up.

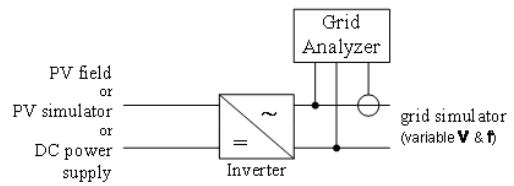


Figure 5. Anti-islanding protection measurement.

Initially, the voltage was slowly increased and the tripping threshold level was registered. The initial conditions were restored and an instantaneous variation of voltage was made from the same central point to a value above the measured overvoltage threshold. The time between the voltage step and the intervention of the protection was measured. Each intervention time was measured 5 times.

The above procedure was repeated decreasing the voltage in order to obtain the undervoltage threshold. The initial conditions are restored and an instantaneous variation of voltage is made from the same central point to a value below the measured low-voltage threshold and the time between the voltage step and the intervention of the protection is measured. Each time was measured 5 times.

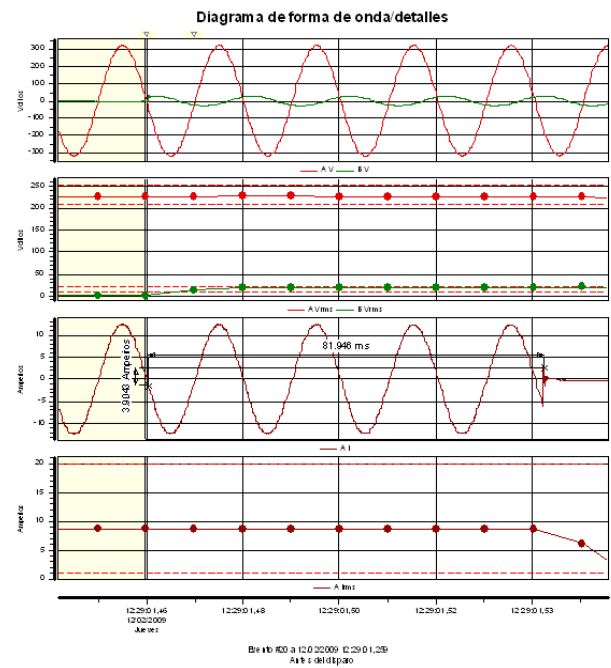


Figure 6. Underfrequency response time.

The same procedure was repeated to determine the overfrequency and underfrequency thresholds. The time between the frequency step occurred and the intervention of the protection was measured.

In the case of the over/under frequency intervention time measurement, an additional signal was used to know the exact time when the frequency changed. The frequency measurement

of the power analyser was not always available for each cycle: in the analysed case, it was only available each second, so it was very difficult to determine the exact instant the frequency changed. To avoid this problem, the second phase of the AC power source was used to trigger the measurement.

The results showed a reproducible performance except for the case of the decreasing frequency, in which one of the time measurement was significantly longer than the others: 142 ms compared to 82 ms.

E. Efficiency measurements

The aim of this test was to measure the electrical conversion efficiency of the PV inverter at different operating conditions.

The inverter was connected to a DC power supply on its DC input, and to the grid simulator on its AC output side. The instantaneous values of all currents and voltages on the AC and DC terminals of the inverter were simultaneously acquired, in order to determine the instantaneous DC and AC power.

All the measurements were properly smoothed in order to reduce both the effects of the MPPT and the input ripple. In the measurements, 5 second average values were used to calculate the efficiency.

In order to plot the efficiency curve, the test was repeated for values of output power equal to 5%, 10%, 20%, 25%, 50%, 75%, 100%, 120% of the inverter rated power. The above output power levels were chosen according to the IEC 61683 [5]. The test was repeated for three different DC voltage values, minimum voltage, rated voltage, maximum voltage, as defined in IEC 61683 standard [5]. Some of the points of the measurements were not reached due to the current limitation of a single input of the inverter and the resistors used to stabilise the behaviour of the inverter.

In this test the main difficulty was to stabilise the DC input at the points defined by the test procedure. The PV-emulated curve had to have its maximum power point in the voltage and power values defined for the test. For achieving this objective, the better way was the simplification of the PV curve and its division in two parts:

- First part corresponds to an almost pure current source with a constant current until the test voltage is reached: at this point, the power has to be the one required by the test.
- Second part of the curve is a slope in where the current decreases down to zero for a voltage value similar or smaller to the maximum voltage accepted by the inverter. The smaller the slope of this part of the curve, the easiest the inverter is stabilised in the required operation point. However, if the slope is too small (this is, if the zero-current voltage is bigger than the double of the test voltage), the maximum power point of the curve is not located in the vertex, but along the slope, and the reached point will be different from the desired one.

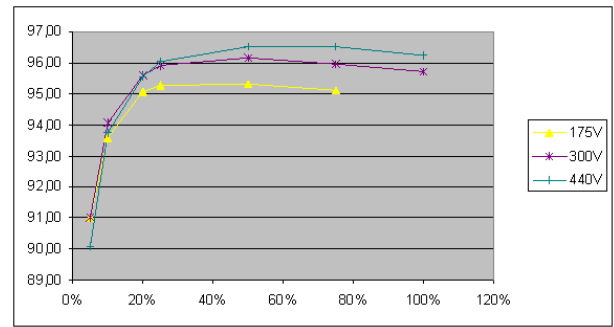


Figure 7. Results of the efficiency measurements.

IV. CONCLUSIONS

This paper presents a summary of the round-robin test of a small scale photovoltaic inverter performed by experts of four DERlab laboratories and carried out at the microgrid of LABEIN-Tecnalia. It shows the results obtained and explains the lessons learned from this series of experiments to show the application of a unified testing procedure across different testing environments.

The main difficulties found when performing the typical tests of PV inverters were those related to the DC power source and the power equipment required to do them. One of the major problems was that the inverter was always trying to find the maximum power point, which made very difficult to stabilize its behaviour in conjunction with the available DC source. Adding a resistor at the output of the DC source helped to stabilize the system.

The results make clear that for accurate tests of photovoltaic inverters, a proper high performance emulation of the photovoltaic array is one of the key prerequisites. Special efforts and measures must be taken when using non-ideal DC supplies as a source, and a careful assessment is mandatory concerning its influence in the test performance and test results.

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