Reliability, Safety and Performance of a New Type of Photovoltaic Module Inverter: Laboratory and Field Test Results

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ABSTRACT

Reliability, safety and quality requirements for a new type of photovoltaic module inverter have been identified and its performance has been evaluated for prototypes. The laboratory tests have to show whether the so-called PV2go inverter can comply with the expectations and where improvements are still necessary. Afterwards, the inverters with the photovoltaic modules (AC modules) have been tested under typical European field conditions.

1. Introduction

In the framework of the European research and demonstration project PV2go, a new type of photovoltaic module inverter has been developed. In this research work, reliability, safety and quality requirements for this inverter have been identified. Its performance has been evaluated for prototype inverters. In laboratory tests carried out at the K.U.Leuven, special concern was given to the subject of unintended islanding. The reliability of the inverter is assessed through Highly Accelerated Life Testing (HALT) and High Temperature Tests.

Field tests have been carried out according to IEC 61724 [1] at the K.U. Leuven tests facilities for two AC modules. The objective was to evaluate the performance of the AC-module under actual meteorological conditions.

2. Experimental

Reliability Tests: Highly Accelerated Life Testing is used to validate reliability of new electronic products by uncovering potential design and component weaknesses. High temperature tests are done by placing inverters (visually and electrically examined) into a climatic chamber with controlled temperature and relative humidity. This test procedure is in accordance with IEC 68-2-3.

Islanding Tests: For testing the islanding behavior of the inverter, a generally applicable test circuit is available (Fig. 1.).

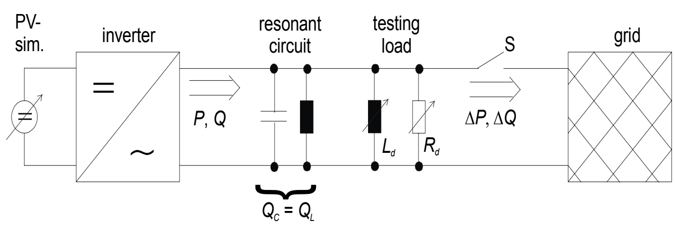

Fig.1 Test circuit for islanding protection [2]

Assuming constant active and reactive output power before and after grid disconnection, the power balance leading to voltage and frequency in islanding operation is implied by the following equations.

$$\frac{\Delta P}{P} = 1 - \frac{U_{grid}^2}{U_{island}^2} \quad (1)$$

$$\frac{\omega_{island}}{\omega_{grid}} \cdot \frac{\Delta P}{P} - \frac{\Delta Q}{Q} = \left(\frac{\omega_{island}^2}{\omega_{grid}^2} - 1 \right) \cdot \frac{Q_C}{Q} + \frac{\omega_{island}}{\omega_{grid}} - 1 \quad (2)$$

For a given capacitance and inverter power, it is possible to determine a so-called non-detection zone (NDZ) in the ΔP-ΔQ-domain where an inverter with predefined voltage and frequency limits will operate in islanding mode.

Performance Tests: Efficiency and power quality parameters have been measured for a number of indicative operating points and the European efficiency has been calculated according to

$$\eta_{EU} = 0.03\ \eta_5 + 0.06\ \eta_{10} + 0.13\ \eta_{20} + 0.1\ \eta_{30} + 0.48\ \eta_{50} + 0.2\ \eta_{100}. \quad (3)$$

Field Tests: At the K.U. Leuven test site, the two PV2go AC modules have been under field test. AC modules and monitoring work trouble-free since 1 July 2002.

3. Results and Discussion

The highly accelerated life test have shown that the PV2go inverter can operate within and beyond the specified temperature of –20°C < T_{amb} < 40°C. For ambient temperatures higher than 55°C the inverter is progressively derating its power by switching the output power on and off.

Two soft failures were found. First the inverter operates outside the maximum power point at temperatures higher than T_{amb}=60°C. Secondly at a temperature of T_{amb}=120°C the inverter switched off. The inverter did not start its normal operation at lower temperatures. At room temperature the inverter had to be reset by tuning off and on the input voltage and grid voltage. No explanations were found for the two found soft failures. At temperatures higher than T_{amb}=90°C the core of the transformer saturates. This leads to a hard failure. The switching device in series with the primary winding of the transformer became defective twice. Five inverters were tested in a high temperature test. The inverters were operated under full power at T_{amb}=40°C and RH=95%. No inverters have failed during the complete test and therefore all inverters have passed the reliability test.

For islanding tests, the NDZ has been recorded for different load conditions as required by different national and international standards. Figure 2 shows, the size of the NDZ generally corresponds to the theoretical NDZ, indicating the proper functioning of the inverter power control algorithms and of its frequency and voltage relay settings. Generally, the results correspond well to those from previous measurements with different other module inverters [3].

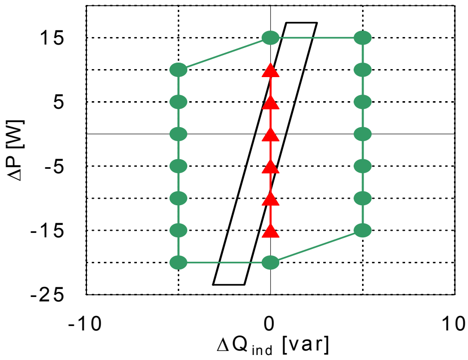

Fig.2 Non-detection zone, P = P_r, Q_C = 100 VAr (Q_r = 1), NDZ = 150 W·VAr

The NDZ's are rather narrow in the ΔQ direction, but large in ΔP direction. This is because the frequency relay could be set rather narrow, while the voltage relay setting always has to consider the wider variability of the grid voltage in the field.

Figure 3 shows the conversion efficiency of prototype inverter. The European efficiency measured in the laboratory is 91.50% with the maximum efficiency being 92.3% for a wide power range. The total harmonic distortion (THD) as well as the magnitude of all higher-order harmonics are within the limits of international standards, including the strict US standard IEEE 929:2000[4].

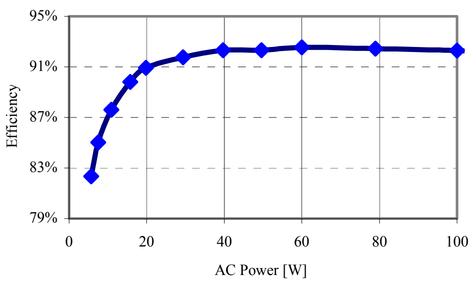

Fig.3 Conversion efficiency as a function of AC power

Field test results have been shown in Fig. 4. The yield and losses of both modules normalized on the reference yield before shadowing, thus indicating the system performance being independent of the solar irradiation at the particular months. Final yield normalized to reference values as indicated in Fig.4 is equal to the monthly performance ratio.

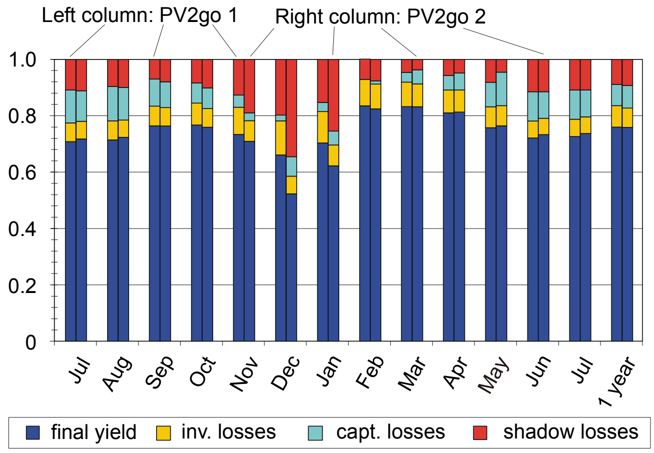

Fig.4 Comparison of daily yield and losses for the two AC modules after normalization on reference yield throughout the year

4. Conclusions

The PV2go AC module inverter has thoroughly been tested with regard to reliability, islanding and other parameters of performance and power quality. In addition the performance of the new inverter has been assessed in the field.

Inverters tested for reliability have passed the tests. At low power, islanding did not occur. At high power, islanding occurred for all relevant load conditions. The harmonic distortion of Prototype 2 is considerably reduced in comparison to Prototype 1.

From the field tests, it can be concluded that the PV2go AC modules perform well under actual operating conditions in a moderate maritime climate. The inverter efficiency in the field equals the laboratory efficiency from 91 up to 93 %.

ACKNOWLEDGEMENT

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