RELIABILITY TESTING OF AC-MODULE INVERTERS

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Abstract: AC-modules are relatively large PV modules (approx. 100-200W) with an integrated inverter, mostly attached to the back of the PV-module. The AC-module can directly be connected to the grid. The flexibility and the modularity of the AC-modules make this technology a very promising one. One of the question marks of this AC-module technology, however, is the reliability and lifetime. The reliability tests that are performed at ECN consist of an accelerated lifetime test (high temperature test) and a temperature cycling test. Test results of the high temperature test will be presented. In order to determine realistic temperature distributions 12 AC-modules will be monitored while mounted outdoors on a tilted roof.

Keywords : AC-modules - 1 : Qualification and Testing - 2 : Lifetime - 3

1. INTRODUCTION

AC modules have a number of clear advantages over conventional large PV inverters in PV systems, [1]. At the moment the technology of AC modules is still improving rapidly. Before large numbers of these high-tech devices are coming on the market the product needs to be tested for reliability and expected lifetime. PV systems with AC modules will contain normally large numbers of AC inverters, which are located at places difficult to reach for maintenance. It is obvious that for these reasons it is desired that the expected lifetime of the inverter is of the same order of magnitude as that of the PV module, to which it is firmly attached.

In co-operation with Dutch partners ECN is involved in a project "Lifetimetests of AC modules". In the framework of this project ECN will perform four tests on two types of AC inverters, the Mastervolt Sunmaster 130S and the OKE4E-100.

- High temperature test - ten of each type of AC inverters are tested. During 2000 hours working in an stove at 70°C and 85°C
- Temperature cycling test - two of each type of AC module inverters are tested during 200 cycles. Temperatures will vary between -20°C and 85°C
- Humidity freezing test - two of each type AC module inverter are tested during fifty cycles. Temperatures will vary between -20°C and 85°C. At temperatures above 25°C, the relative humidity will be 85 %.
- Monitoring AC modules with inverters under real operating conditions on a roof.

The laboratory tests are performed in climatic chamber where the PV modules can be placed and put in operation under varying temperatures and humidity. The aim of the temperature cycling test and the humidity freezing test is to test the mechanical strength of the inverters and the constituent parts. The high temperature test is meant to investigate the reliability of the electronic components, such as capacitors.

On a south facing roof with a tilt of 45° angle AC modules are placed and monitored. During normal operation the modules are monitored by a PC based monitoring system. The temperatures of the modules and the internal inverter temperature is measured. The purpose is to get real temperature distributions for the various parts of the AC modules.

2. THEORY BEHIND THE TESTS

2.1 High Temperature test

This test is performed to determine the lifetime of the electronic components of the inverter. For this purpose the ambient temperature of the inverter is increased above the normal operating temperature. Normal ageing processes will be accelerated. When the normal operating temperature is T1 and the test is performed at inverter temperature T2 it is assumed that the ageing process is accelerated by a factor A, where A is given by the Arrhenius relation, see [2], [3], [4]

\[
A = \exp\left(\frac{-E_A}{n \cdot k} \cdot \left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right)
\]

with E_A/n being the activation energy and k the Boltzmann constant. The constant n is introduced in lifetimetest theory to describe the parameter drift in time. As the value of E_A/n is as yet unknown it is custom to put it at 0.6 eV. This would result in an acceleration factor of about 51. Assuming 12 hours of daily operation under normal operating conditions 2000 hours at 85°C would equal an ageing at 25°C during twenty years. The purpose of the test is to make an estimate of the effective activation energy of the AC inverter.

2.2 Temperature cycling test

This test is performed to investigate the mechanical strength of the inverter. Temperature fluctuations will lead to thermal expansion and contraction, this can cause damage to the components or the printboard. Here too the ageing can be described by an adapted form of
the Arrhenius relation. Different effects have to be taken into account:

1. the warming-up, cooling-down and the dwell time at elevated temperatures
2. thermal expansion and contraction
3. changing activation energy temperature

As shown in figure 1 the cycle can be divided into three time intervals. For every interval the following expressions describe the ageing process

1. \[ A = \frac{1}{T} \int \exp\left(\frac{-E_a(T)}{n \cdot k} \left[ \frac{1}{T_0} - \frac{1}{T(t)} \right] \right) \cdot dt \]

2. \[ B = \exp(-\eta \int \frac{dT(t)}{dt}) \]

3. \[ E_a(T(t)) = C_0 + C_1 \cdot \left( T(t) - T_0 \right) \]

A is the acceleration factor caused by temperatures above the normal operating temperatures. B is the acceleration factor caused by the thermal expansion and contraction, where \( \eta \) is a proportionality factor. A linear dependence of the activation energy on temperature is assumed in expression 3. Combination of these expressions on all time intervals yields the total acceleration.

The test is performed according to the ISPRA-503 specification.

2.3 Humidity freezing test

At the back of a PV module the inverter experiences during its lifetime many temperature and humidity cycles. This test is performed to investigate the influence of these cycles. After an extended period of high temperature and humidity a short time interval follows with low temperatures. It is assumed that the Arrhenius relation holds here too. To our knowledge there is no mathematical relation to describe the acceleration caused by the humidity. Figure 2 shows the temperature during the various time intervals during the test, \( t_1=60 \text{ min.}, t_2=20 \text{ hours}, t_3=85 \text{ min.}, t_4=25 \text{ min.}, t_5=40 \text{ min.}, \) and \( t_6=25 \text{ min.} \). This test is performed according to the ISPRA-503 specification.

2.4 Outdoor measurements of AC modules

On a small south facing testroof with tilt angle of 45° twelve AC modules are to be placed. Three types of backside insulation are tested: 1 - freely mounted modules, 2 - modules with backside insulation having limited ventilation and 3 - modules with fully insulated backside. A PC based monitoring systems registrates regularly the irradiance by means of a reference cell, the ambient temperature and the temperatures of the modules and the internal parts of the inverter. The purpose of these measurements is to investigate the influence of the mounting technique of the module on the internal temperatures of the inverters.

3. TESTS AND RESULTS

The tests with the OKE4E-100 will start this summer. Until now all tests were performed on the Sunmaster 130S.

3.1 High Temperature test

Ten Sunmasters 130S have been for 2000 hours in an ambient temperature of 75°C while operating under 80% of full load by means of a IV simulator. The internal inverter temperature rose to 90°C. After this test no defects were observed. The test will be prolonged to see if defects occur after longer periods. In order to make an crude estimate of the activation energy it is inevitable to have some defect inverters.

The effective series resistance of the electrolyte capacitors on the dc side could be measured. At the beginning of the test the average ESR value was 21.7 mΩ, at the end of the test it was 31.8 mΩ. This means a relative increase of 46%. The manufacturer of the capacitors specifies that a capacitor whose ESR value has double should be considered defect. If the underlying assumptions of the acceleration factor of section 2.1 are correct, the estimated lifetime of these
capacitors would exceed the average lifetime of PV modules of twenty years.

3.2 Temperature cycling test
The temperature cycling test is not yet finished. After 120 of the foreseen 200 cycles the AC models show no visual defect and are able to operate normally.

3.3 Humidity freezing test
This test is under preparation and will be started after the temperature cycling test.

3.4 Outdoor test
The temperature of a PV module is determined by the local conditions such as ambient temperature, the irradiance, windspeed and humidity, as well as the thermal properties of the module.

The thermal properties depend on the type of mounting of the module, which influence the amount of air convection on the backside. For the Dutch situation the main application of AC modules will be for roof-integration. In the testfacility of ECN three types of module mounting are investigated:

1. free mounted AC modules - mounted 10 cm above the roof tiles, thus there is an optimal convection of air at the backside
2. AC modules with a insulated backside - a steel box is connected at the back on the module frame. The inside of the box is thermally
3. AC modules with a insulated steel box at the back, as above, only at the top and at the bottom of the box there are ventilation slits which allow a limited amount of ventilation. This situation is assumed to resemble best the roof integrated PV module

If we assume that the temperature difference between the ambient and the PV module is mainly determined by the irradiation, the measured difference as a function of irradiance can be fitted to the expression

\[ T_{\text{mod}} = T_0 + k \cdot G \]

where \( T_{\text{mod}} \) is the module temperature, \( T_0 \) is the ambient temperature, both in °C, \( G \) is the irradiance in kWh/m² and \( k \) is the so-called k-factor.

For the fully insulated AC module a k factor of 35.4×10⁻³ was found, this means that at 1000W/m² the module temperature will be 35°C higher than the ambient temperature. For the case with the limited ventilation the k factor was 28.0×10⁻³. This simple expression ignores the influence of wind and humidity. Measurements shown that the temperature differences may be 10°C higher than indicated by the k-factor, thus the module temperatures can go as high as 75°C and interior inverter temperatures can reach 90°C.

Figure 3 shows for a clear day in May the measured temperatures as a function of time for the three mounting types described above. The temperature differences of the freely mounted module and the one with limited ventilation are small, which indicates how effective the slits are in cooling the back of the module.

![Module temperatures as a function of time during a clear day, for three types of mounting AC modules](image)

Figure 4 shows the inverter temperature of the AC modules with the insulated backside, with and without ventilation, together with the ambient temperatures, during a week in April. The inverter temperatures for the fully insulated AC modules reach 60°C in this relatively cool month.

![Inverter temperature and ambient temperature of the AC modules during 7 days in April](image)

For the fully insulated AC module the maximum inverter temperature is 5-10°C higher than for the AC module with limited ventilation.

4. CONCLUSIONS
Reliable statements concerning the reliability and expected lifetime of AC modules can only be made after the tests have finished. The Mastervolt AC inverters passed the high temperature test without any serious defects. Prolonged tests are needed to make an estimate of the effective activation energy of these devices. Air convection on the backside of AC modules can decrease the maximum inverter temperatures by about 10°C, which can substantially increase the expected lifetime.

5. ACKNOWLEDGEMENT

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6. REFERENCES


