RELIABILITY AND ACCELERATED LIFE TESTS OF THE AC MODULE MOUNTED OKE4 INVERTER

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ABSTRACT

The quality, reliability and expected life time of the AC module inverter OKE4 is discussed. Performance with respect to harmonics, power factor and efficiency, based on laboratory and field tests meets existing standards, both in Europe and the USA. The OKE4 will also meet the Dutch national safety standard. The expected life time of AC module inverters is generally questioned as these will be mounted on the back side of the modules, while the cell temperature of thermally isolated PV modules can easily go up to 80^{o}C. In order to estimate the life time accelerated life tests are currently being executed. To perform these tests special equipment was developed and the inverter was modified.

1. INTRODUCTION

An AC module is a PV module with integrated DC to AC converter which generates grid conform AC power. AC modules are an interesting alternative for conventional grid connected PV systems as it offers possibilities to overcome problems with respect to high DC voltage levels, safety, cable losses, risk of DC arcs, fire hazard and protection. Moreover, PV systems based on AC modules are highly modular, which allows easy system expansion with units of about 100 Watts and lowers the threshold for application by individuals. In view of these advantages of AC modules, an AC module inverter of about 130 Watts was developed: the OKE4 inverter.

In order to compete with central inverters it is essential that the quality of the OKE4 is comparable with conventional inverters. Especially the life time of AC module inverters seems to be a point of concern as the internal temperatures of these kinds of inverters can become very high.

In this paper quality, reliability, safety and expected life time of the OKE4 is discussed. Laboratory and field tests, and where appropriate user experiences, are presented. In order to estimate the life time of the inverter, accelerated life tests started. The assumptions, test set up and equipment are discussed.

Figure 1. OKE4 inverter

2. TECHNICAL PERFORMANCE PARAMETERS

The power quality of the OKE4 follows from the data presented in Figure 2, in which the power factor and total harmonic distortion are presented. It shows that the total harmonic distortion at full load is less than 3%, meeting the IEEE standard. The power factor is > 0.9 at power levels exceeding 0.1 Pnom and approaches unity at high power levels.

The individual line harmonics at 50 W output power are all below 2% of the fundamental, meeting easily the European standard EN60555 for devices up to 500W. In view of harmonics there is virtually no limit to the number of AC modules with OKE4 inverters that can be paralleled.

We have experienced that many test institutes are measuring much higher values for harmonic distortion, especially at low power levels. Generally this is caused by the noise level of the measuring equipment itself, which is only suitable for testing devices in the kW range, not for measuring power levels in the range of 10-100 Watts.

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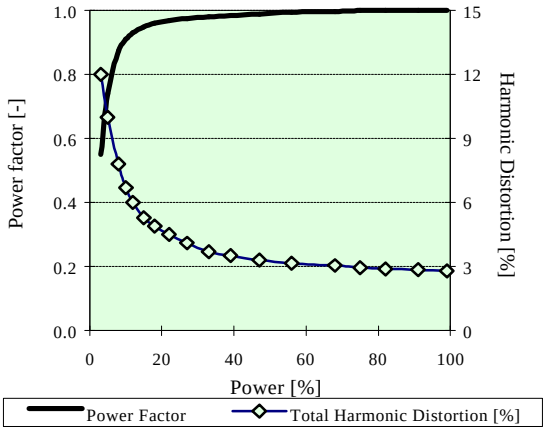


Figure 2. Power factor and total harmonic distortion OKE4

3. FIELD AND USER EXPERIENCES

In the summer of 1995 at *ECN, Netherlands Energy Research Foundation*, a field test has started including 6 AC modules with OKE4 inverters. The results are very satisfactory: the efficiency and power quality equal the measurements performed in the laboratory. The efficiency of the OKE4 is presented in Figure 3, with a peak of approximately 92% at 22% of the maximum power.

Furthermore, the field measurements show that the inverter will start generating power at an irradiation of 10-15 W/m^2 when connected to a PV module of 100 Wp (< 0.4W at 24 V). Earlier measurements showed that the MPP tracking in first instance (September 1996) was not performing optimal. Based on these results the MPPT software, which is incorporated in the microprocessor of the OKE4, was changed. The adapted software for MPPT has shown to work well with an efficiency exceeding 99% at power levels above 10% of the maximum input power. Even at very lower power levels the inverter's MPPT still has an efficiency higher than 95% (fig. 4).

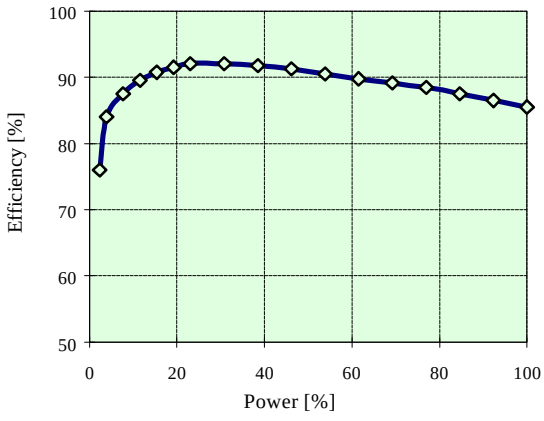


Figure 3. Efficiency of OKE4

The stand-by losses are too low to be measured exactly: they are calculated to be less than 0.003 W. The energy loss during one year stand-by (365 night) is compensated within 10 minutes of full sunshine when the OKE4 is connected to a PV module of 100 Wp.

A lot of customers complained that their OKE4-inverter would not start. It appeared that this was generally caused by the voltage window. For example, although in Europe the standard 230 Volts grid should always be within the limits of 200-240 Volts, in many cases the grid voltage was outside this range. This problem could easily be solved by the customers themselves: the voltage and frequency window can be adjusted by means of the OKE485 interface and the accompanying software. However, to prevent these problems in the future, the default factory setting of the voltage window of the European version was adjusted to 190-250 Volts. Also the voltage window of the US-version of the OKE4 needed to be adjusted and is currently 95-125 Volts.

In order to determine whether the customers are satisfied with the inverter, an evaluation form will being send to them. Data will become available by the end of 1996.

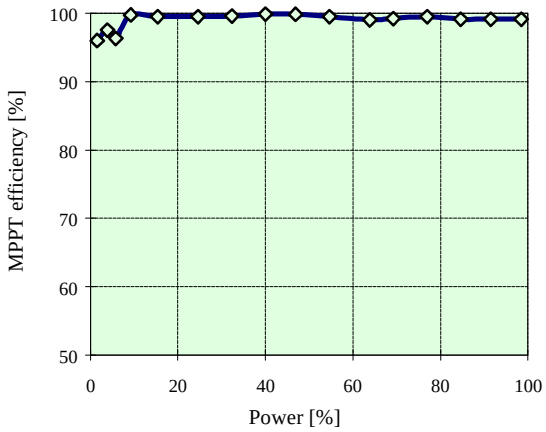


Figure 4. MPPT efficiency of OKE4
[Source: ECN, May 1996]

4. SAFETY AND IMMUNITY

Already in 1995 a preliminary test on safety was executed by *KEMA, Transmission and distribution*, Arnhem, the national test institute on safety in the Netherlands. It showed that the inverter needed some modifications. These were implemented in the first series of the OKE4 (summer 1996). KEMA has developed a national safety standard for AC module inverters, the first national standard for these devices in the world. The OKE4 will meet the requirements described in this standard.

To determine the behaviour of the AC module with OKE4 inverter for close-in lightning strokes, KEMA has also performed full scale lightning tests. The AC module was subjected to a 10kA peak lightning stroke at a distance of 0.5 metres. The rise-time of the current was less than 3 µs. The di/dt of the current was therefore over 3.3 kA/µs which corresponds with the average values of a lightning stroke. The AC module was tested when it was switched off, switched on but not illuminated and switched on and illuminated. All

results showed that the induced voltages remained within the design specifications of the AC module. Neither the module nor the OKE4 was damaged by the experiment.

KEMA also performed several immunity tests, which determines the sensibility to EMC. The tests included: electrostatic discharge (ESD), fast transients (EFT), injected currents 0.15 MHz to 230 MHz, injected currents 0.15 MHz to 80 MHz, radio frequency electromagnetic fields and surges. The results show that the OKE4 is a product of good quality. However, some improvements will be implemented.

5. EXPECTED LIFE TIME

5.1. Introduction

The expected life time of AC module inverters is generally questioned as these will be mounted on the back side of modules, while the cell temperature of thermally isolated PV modules can easily go up to 80°C. Taking into account the dissipation of the inverter itself, this implies that the internal temperature of an AC module inverter will become as high as 100°C. Generally, functioning at such high temperatures will have a negative impact on the life time of electronics. Novem, the *Netherlands agency for energy and the environment* recognized the importance of this aspect for the possible success of AC modules and therefore initiated a concerted action mainly focusing on accelerated life tests. These will answer the question whether life time of the AC module inverter is comparable with that of large inverters, or even with the PV module itself.

Regarding the OKE4 inverter two tests were foreseen:

- exploratory tests to be executed by OKE-Services on the thermal - inside - behaviour of the OKE4 inverter in order to improve the thermal design.
- accelerated life tests to be performed by *ECN, Netherlands Energy Research Foundation*.

The exploratory tests on the thermal design were executed and have led to several improvements. Because of the well defined thermal design and the use of high thermally conducting potting material, the expected life time of the inverter is over 20 years. The accelerated life tests, although planned to start at the beginning of 1996, have not started yet. As the results of these tests are really required, accelerated life tests were started about one month ago at NKF.

5.2. Accelerated life tests of OKE4: assumptions

Normally a so-called effective working temperature of a product or component is specified, e.g. 200000 hours at 40°C. Generally the expected life time of a product or component decreases when it functions at a higher temperature and increases when it functions on a lower temperature.

Usually the input capacitor is considered to be the limiting component with regard to life time. Therefore, this capacitor can be used as the base for calculating the expected life time of the OKE4. The capacitor is specified for 4000 hours at 105°C. Roughly the life time of the capacitor will increase a factor 2 when the temperature decreases 10°C. Thus, the expected life time of the capacitor will be 8000 hours at 95°C, 16000 hours at 85°C, 32000 hours at 75°C, etceteras.

This phenomena also works vice versa and can be used for predicting the life time within a couple of months. In case the capacitor will function more than 1000 hours at 125°C it implies a life time exceeding 4000 hours at 105°C. So, testing the inverters at high temperatures for a relatively short period of time, will answer the question how long they will keep functioning given a certain effective working temperature. It is expected that the life time of the input capacitor will exceed the manufacturer's specifications by a factor 2 to 4, due to the thermal and mechanical design.

This approach and calculations will not only be executed for the input capacitor, but also for other temperature sensitive components, like the semiconductors.

5.3. Test set up and equipment

The tests are being performed at NKF Kabel B.V., where a large oven is available. Currently the oven is set at a temperature of 80°C. For this test 10 PV simulators were built, allowing 10 inverters to operate independently (fig. 5).

Figure 5. Test set up at NKF.
On the left the oven with 10 inverters inside, in the middle 10 PV simulators and on the right the monitoring computer.

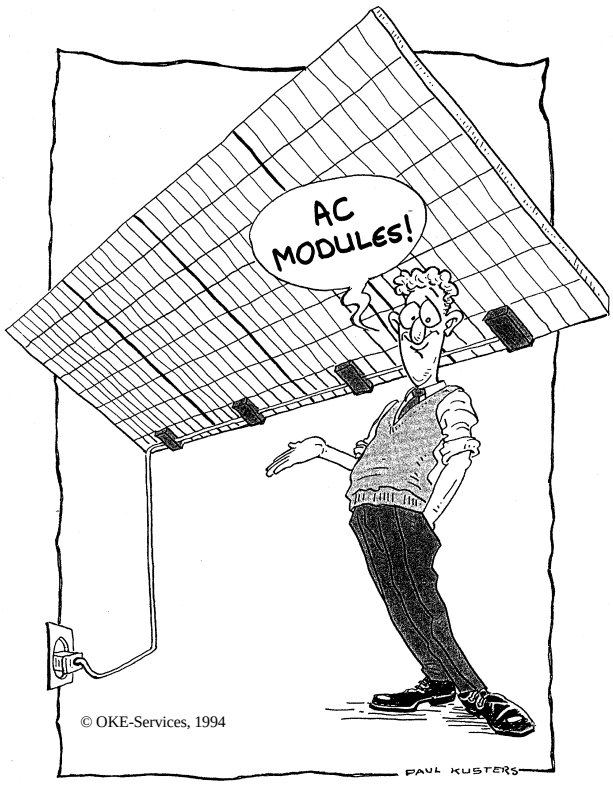
Moreover, the inverters normally decrease power when an internal temperature of 100°C is reached. In order to perform tests at higher temperatures, the (internal) operating parameters were modified: they will not decrease power automatically when reaching 100°C. To measure the actual junction temperature of both the power mosfets and the high frequency power rectifier some special modifications were implemented.

Currently the inverters are being tested at full power in an ambient (oven) temperature of 80°C. It implies that the inverters are functioning at an actual inside temperature of the inverter of approximately 105°C. The test is running now for more than one month, being approximately 1000 hours.

5.4. Further testing

Currently the inverters are being monitored visually, i.e. by checking if the inverters are working or not working. At the end of May 1996 a more intensive test procedure at 100°C will start. Each week all inverter performance parameters and the capacity of the input capacitor will be determined. This will give a good impression of the inverter deterioration. It will also answer the question whether inverter deterioration accelerates its own deterioration. For example, in case deterioration causes a decreasing efficiency, this will result in higher temperatures, which on its turn will result in increasing deterioration, etceteras. Results in terms of expected life time will become available in autumn 1996.

Besides, ECN will start in the summer of 1996 a test programme on AC module inverters, which also includes accelerated life tests of the OKE4. The results will be very useful to verify the tests performed at NKF.



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6. CONCLUSIONS

In section 2 it is shown that the technical performance is comparable with existing, conventional inverters. These are confirmed by field experiences. The OKE4 will meet the recently developed Dutch national safety standard. Finally, accelerated life tests have started. Until to date results are satisfactory. However, more intensive tests need to be executed in order to estimate the life time of the inverter.

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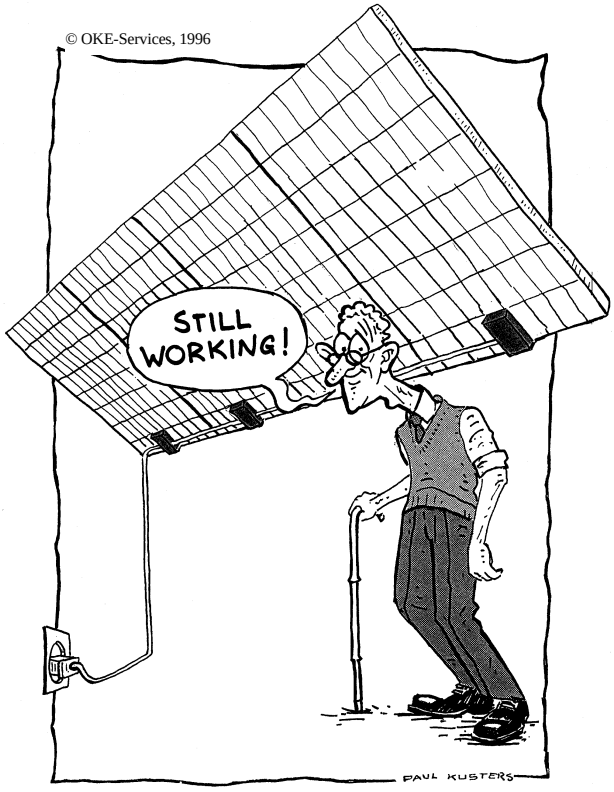

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