PV-WATCHDOG:
A PV-MODULE INTEGRATED SENSOR FOR CLEAR, COST EFFECTIVE MONITORING

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ABSTRACT: The PV-watchdog is a highly accurate monitoring device, which gives a visual warning by means of a red visible LED when (fore example) more than 10% of the available power is not taken from the PV-module. Since the PV-watchdog is integrated in the PV-laminate, the irradiation, cell temperature and module voltage can be measured very accurately. Based on these measurements and data obtained during the factory flash test of the PV-module, the PV-watchdog continuously calculates the relative power that is lost because the module is not loaded at its maximum power point voltage. When the power loss is higher than the programmed threshold (for example 10%) and the irradiation is more than 50 W/m^2, a red LED will be turned on by the micro-controller. Besides powerful and simple monitoring, the PV-watchdog offers many advantages, which will lead to a further reduction of PV system costs:
Keywords: monitoring, cost reduction, reliability

1 INTRODUCTION

More and more grid-connected PV-systems are being installed and many efforts are being made to further improve the efficiency of PV-systems. This will contribute to decreasing the kWh costs from photovoltaics. But the focus should not only be on cell efficiencies and cost reduction of components. Attention should also be paid to proper design and installation of PV-systems and costs of maintenance. And the inverter, the electrical interface between the PV-modules and the utility grid, should have a good functioning maximum power point tracking.

In practice, even a well designed PV-system may not perform optimal, caused by minor mistakes during installation. Though after completion of the installation usually several measurements are performed to ensure proper operation of the system, in practice a 100% check appears hard to perform. Many cases are known that after a year of operation the yield of a PV-system appeared to be much lower than expected. In that case usually one or more strings are not working properly.

The lower system's yield may be caused by malfunctioning of one of the system's components, like failures in the laminates, failures of by-pass diodes, wrong wiring, problems with the inverter, et cetera.

This paper introduces the PV-watchdog, a very accurate and extremely small monitoring device, which is integrated into the PV-module. When the red LED is ON more than 10% of the power is lost. The PV-watchdog is mounted on the back of one solar cell of a PV-module, in such a way that the LED is visible between two cells at the front of the PV-module (see Figure 1).

In this paper the working principle, the advantages, and the development of the PV-watchdog are presented.

Figure 1: PV-watchdog integrated into SOLON's PP220 PV-module

The PV-watchdog is patented internationally.

2 WHAT IS A PV-WATCHDOG?

The PV-watchdog is a highly accurate monitoring device, which gives a visual warning by means of a bright red LED when more than 10% (for example) of the available power is not taken from the PV-module.

It consists of a miniature electronic circuit, which is mounted directly to the back of one cell of a PV-module. The main components of a PV-watchdog are:

- a micro controller,
- a photo-diode,
- a temperature sensor and
- a bright red LED.

The dimensions of the PV-watchdog are 15 x 28 x 1,3 mm (see Figure 2).

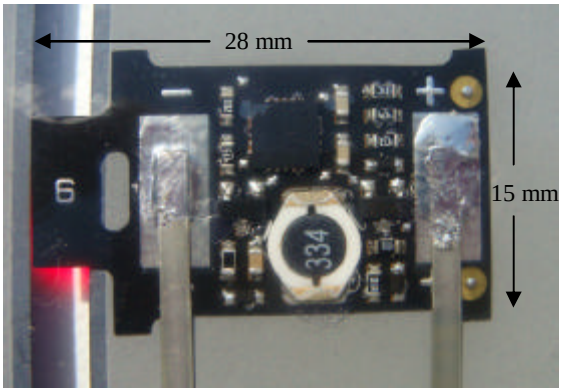

Figure 2: Close-up of the PV-watchdog. Photo of rear side of a PV-module with laminated PV-watchdog (with transparent Tedlar).

3 WHY USE A PV-WATCHDOG?

The PV-watchdog continuously analyzes the PV-module's operation. When the LED is OFF, the PV-module is loaded properly. This means that when the LEDs of all PV-watchdogs in a PV-system are OFF, the whole system is working correctly. During operation, periodic checks can be executed by the owner of the PV-system simply by viewing whether the LEDs are ON.

The PV-watchdog continuously alerts for:

- Poor system design, e.g. unequally illuminated modules in series
- Wrong wiring, e.g. when a string of 5 PV-modules is connected in parallel with a string of 7 PV-modules.
- Failure of the connectors, wires or fuses
- Poor maximum power point tracking of the inverter
- Bypass diode failures: a short-circuited or inverted bypass diode
- Grid or ENS problems, e.g. a switched off or failing inverter
- Module failures which change the module characteristics too much
- Mismatch of modules in a string, e.g. when the characteristics of one ore more PV-modules in a string differ too much
- Mismatch of strings in parallel, e.g. when the characteristics of one ore more strings in parallel differ too much

Besides powerful, simple monitoring, the PV-watchdog offers the following advantages, which may contribute to a further reduction of kWh costs from PV:

- A simple visual check immediately after installation is sufficient to make sure that each module of the PV-system is operating properly.
- No expert knowledge is required to verify proper operation of PV-systems, since just a visual inspection of the LEDs is enough.
- No electrical tests at system level are required to verify system performance.
- Periodical checks can be executed by the owner of a PV-system.

As a consequence the PV-watchdog enables customers to check and see immediately after installation whether their PV-system is working fine. If not all the LEDs are OFF, something in the PV-system is wrong and the installer has done a poor job. If so, the PV-watchdog offers solid proof that indeed the installer should repair the system.

4 HOW WAS THE PV-WATCHDOG DEVELOPED?

In 2003 the first development steps were taken with making and verifying theoretical models about the behavior of PV-cells, diodes and transistors. In order to verify the models many measurements have been executed both by OKE and ECN (Petten, The Netherlands). This study was financially supported by SenterNovem (Utrecht, The Netherlands) and successfully completed [2]: at the 19th EU PVSEC in June 2004 we presented the PV-watchdog as the first module integrated MPP-indicator.

By the end of 2005 SOLON showed its interest in the PV-watchdog and a close cooperation started. One of the main issues was the thickness of the PV-watchdog, because it affects the lamination process and might have consequences for the Tedlar and thus for the PV-module. Therefore the PV-watchdog was made even thinner, resulting in a thickness of only 1,3 mm.

Another important adaptation concerned the colour of the LED. In earlier versions a blue LED indicated that the PV-module was working fine. However, a market survey executed by SOLON showed that customers prefer a red LED which indicates the PV-module is **NOT** working properly.

The red LED has been developed especially for the PV-watchdog. It has a very high optical efficiency (40 lumen/W), is very flat, and can burn on maximum intensity even at laminate temperatures of 85 °C. The maximum light flux is approximately 1 lumen. This is enough for clear LED visibility, even in full sunlight (Figure 5). In fact the visibility is that good, that taking a picture of a complete PV-system with a digital camera one can see at a glance whether one of the LEDs is ON.

5 HOW DOES THE PV-WATCHDOG WORK?

Mono and multi crystalline PV modules are free of memory effects. Therefore, for any equally illuminated module, the operation point is fully defined by the module characteristics, the voltage, the irradiation and the temperature of the cells.

For each module the individual characteristics obtained during the factory flash test are stored in the micro controller of the PV-watchdog. So by continuously measuring the voltage, the irradiation and the temperature, the micro controller can calculate the actual relative power loss.

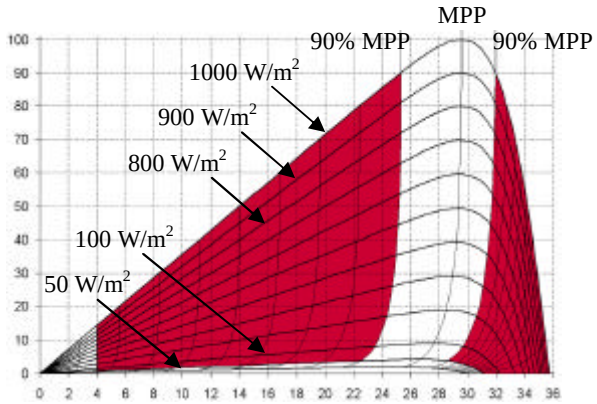

Figure 3: P/Pstc at 25 °C

So the PV-watchdog assesses whether the PV-module is working close enough to its maximum power point by means of the following steps (see Figure 4):

- When the irradiation (G) is below a minimum specified level the LED will be OFF. Currently this level is set at 50 W/m^2.
- Otherwise the voltage and temperature are measured and the relative loss is calculated.
- If the power loss is more than the set threshold the LED will be switched ON. See Figure 3 for an example in which the threshold is set at 10% power loss.

6 HOW IS IT DONE?

Irradiation, cell temperature and module voltage can be measured very accurately, because the PV-watchdog is integrated in the PV-laminate. However, usually the inverter will superimpose a certain amount of harmonics of the grid frequency on the DC voltage of the PV-module. And, in case AC wires are close to the PV-watchdog, it is very well possible that the fundamental and its harmonics are induced in the PV-watchdog's measuring circuitry. Therefore, an additional digital filter is used to suppress 50 Hz and 60 Hz and all the harmonics on irradiation (G), temperature (T) and voltage (V) signals.

Based on these measurements and data obtained during the factory flash test, the PV-watchdog is able to calculate continuously the relative power that is lost because the module is not loaded at its maximum power point voltage.

To ensure the correct operation of the PV-watchdog, the following steps during manufacturing are essential.

5.1 Manufacturing and programming

After manufacturing the PV-watchdog, the device is accurately calibrated. Next the IR-communication protocol and the physical model are programmed into the micro controller of the PV-watchdog.

5.2 Integrating and laminating

The PV-watchdog is wired at the back of a solar cell, in such a way that the LED and the photo diode are visible at the front of the PV-module between two cells. (see Figure 5). Then the PV-module, including PV-watchdog, is laminated.

5.3 Uploading data and settings

Immediately after the flash test, the flash test data and the set point for the relative power loss (e.g. 10%) of the PV-watchdog are wireless uploaded into the micro-controller of the PV-watchdog. Now the PV-watchdog is ready for operation.

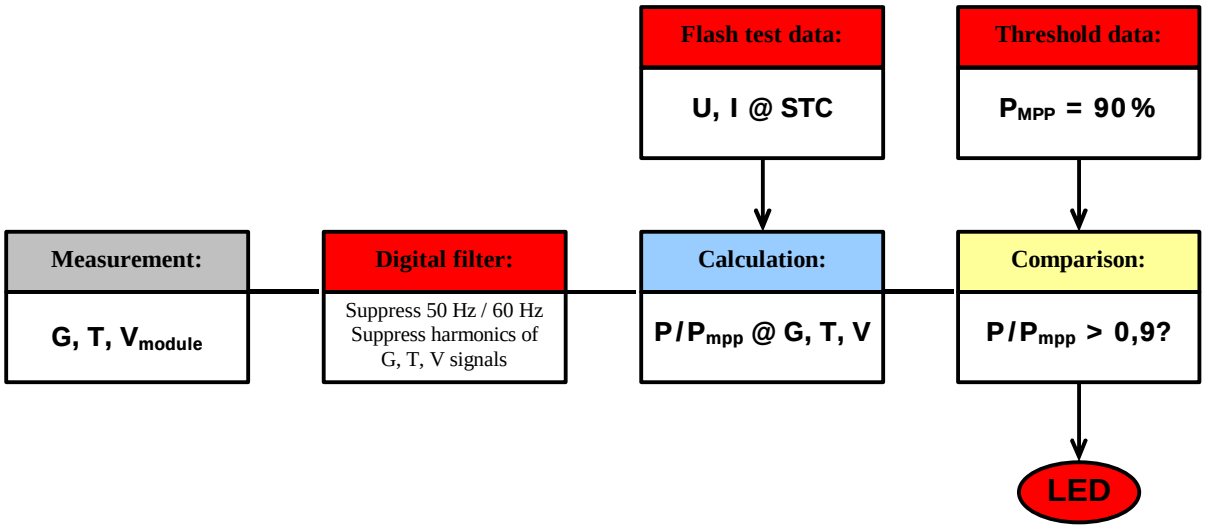

Figure 4: How the PV-watchdog assesses whether a PV-module is working in its MPP [3]

7 HOW ABOUT RELIABILITY AND LIFE TIME?

The PV-watchdog is designed in such a way, that even in case of multiple component failures it cannot take significant power from the PV-module. Moreover, all realistic faults will result in a situation in which the LED is OFF. So, loss of power or false alarms due to a malfunctioning PV-watchdog is unlikely to occur. Also it should be noted, that all the components of the PV-watchdog are operating well below their maximum ratings. Therefore a minimum lifetime of 20 years seems realistic.

However, the PV-watchdog will be integrated in the PV-laminate, which is not done before. Due to thermal variations and long term UV irradiation, other faults than just electrical faults may occur. Therefore intensive temperature cycling tests were executed on the laminated PV-watchdog.

Early 2007, 20 laminated PV-watchdogs were subjected to a temperature cycling test (200 cycles from - 40 °C to + 85 °C). Unfortunately, none of the PV-watchdogs passed this test. Many PV-watchdogs even showed multiple failures. It appeared that all faults were caused by broken solder joints. The small thermal movements in the laminate caused fatigue cracks on these joints.

Following this result the PV-watchdog's printed circuit board was mechanically optimized and in June 2007 a second temperature cycling test started. Again problems arose, since only 60% of the PV-watchdogs passed the test. However, this time all failures were related to a fault of one component. Currently this component is being improved by the manufacturer. It is expected that eventually all PV-watchdogs will pass the thermal cycling test.

8 AND WHAT IS NEXT?

Though market introduction is expected in 2008, PV-modules with PV-watchdog will only be introduced on the market once it is proven that the reliability and lifetime of the PV-watchdog is comparable with those of PV-modules. Good results of upcoming temperature cycling tests are crucial.

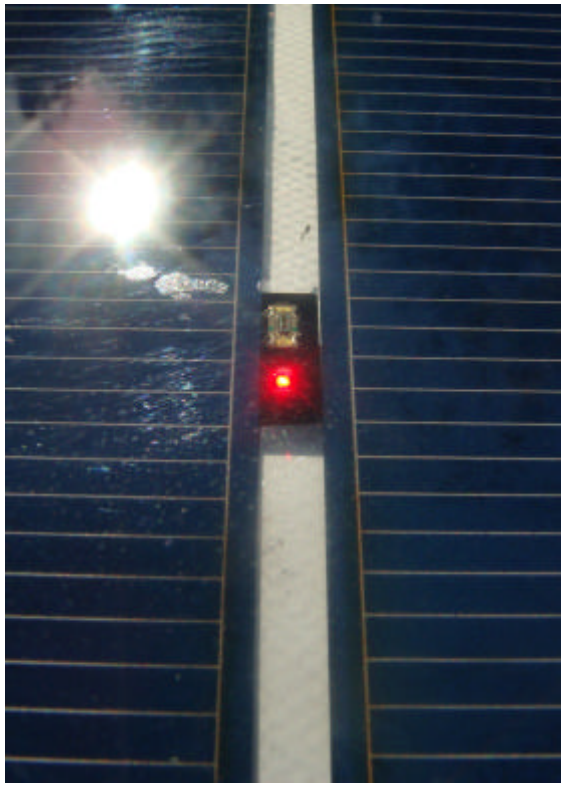

Figure 5: Close-up of PV-watchdog in bright sunlight. Photo of front side of PV-module with laminated PV-watchdog (with transparent Tedlar).

9 REFERENCES

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