Arc Detector for Remote Detection of Dangerous Arcs on the DC Side of PV Plants

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International workshop "Arcing in Photovoltaic DC-Arrays – Potential Dangers and Possible Solutions", October 31st in Burgdorf/Switzerland

Content:

1. Introduction

- DC-arcs in PV-plants are much more dangerous than AC-arcs (no zero-crossing, current source characteristic of PV array!).
- Worldwide already several fires have been caused by such arcs (e.g. Mt. Soleil 1992, CH-farmhouse 1994).
- In the last year the problem has emerged again (smouldering fires at PV-modules (Photon 8/06) or in connector boxes of older PV plants).
- With increasing number and age of PV plants the risk of fires caused by DC arcs will increase significantly in the coming years.

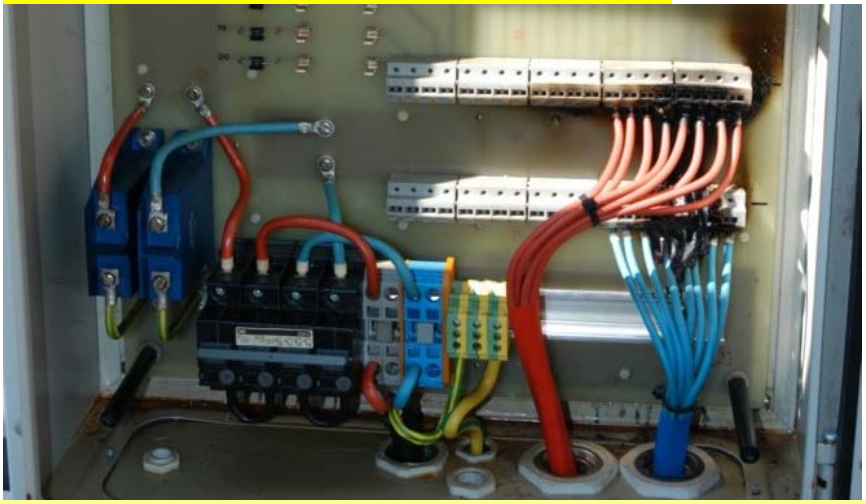
Damage by arcs in PV modules

PV module and roof support structure damaged by smouldering fire caused by a DC arc in a module connector box

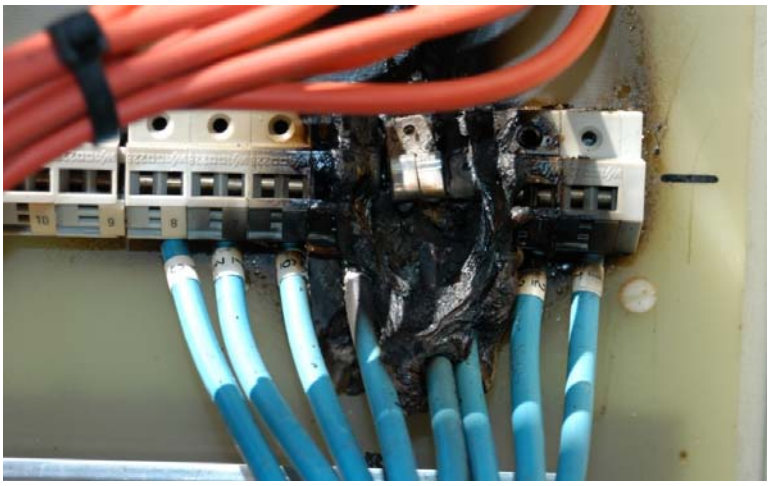
Source of picture:

Photon 8/2006

Damage by arcs in array connector boxes

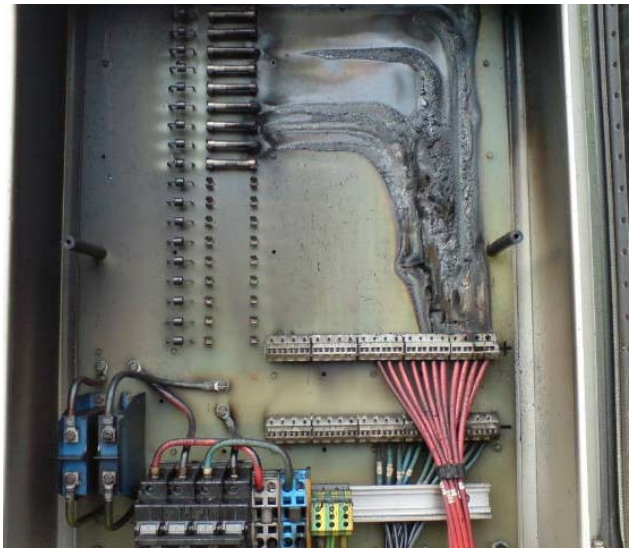


Damage caused by a smouldering fire, which occurred in the connector box of an 11 year old PV plant (15kW) in Burgdorf.



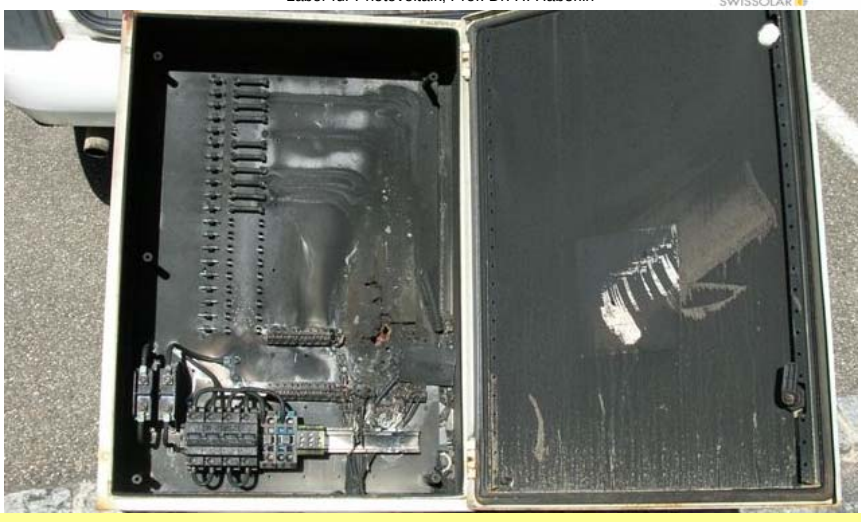
Close-up view of the origin of the fire. A soldering point on the PC board or a connection gradually warmed up and finally melted, developing an electrical arc causing the fire (V_{MPP} was about 500V).

Another, more serious case of such a damage



PCB tracks already charred by series arcs in an array connector box of a similar PV plant of 20kW (V_{MPP} about 500V) immediately after opening of the cabinet.
In this condition, the PV power was already very much reduced.

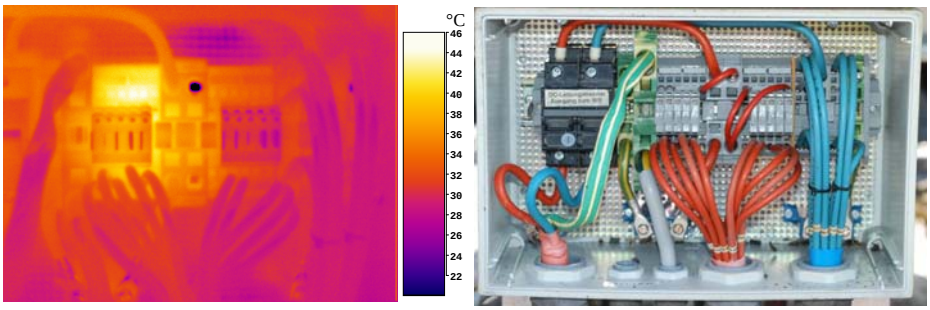
(Source of picture: EBL)



After opening, additional oxygen could enter the cabinet and a catastrophic fire occurred that destroyed the cabinet completely. (Source of picture: EBL)

Damage at the outer wall (with external thermal insulation) of the building, on which the connector box was mounted.
The arc in the cabinet even melted a hole through the back wall of the metal cabinet!
(Source of picture: EBL)

Minor damage by burned connector (no arc) at lower V_{MPP}



At a PV plants with a lower V_{MPP} of about 100V, a connector that joins the two halfs of the array in the middle of the connector box burned and caused an interruption (see thermographic picture at left, repaired connector box with wires replacing the defective connectors at right). Due to the lower V_{MPP}, no arc and no fire has occurred in this case.

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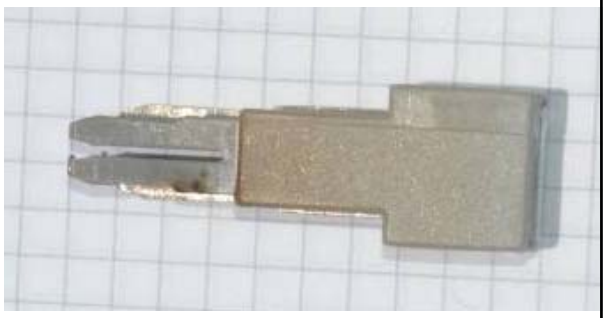

Bridge connectors with damaged (slightly burned) contacts that were used to join the two halves of the PV array in the middle of the array connector box. In this case, due to the low voltage available to sustain the arc (about 0.2 V_{MPP}), no arc occurred.

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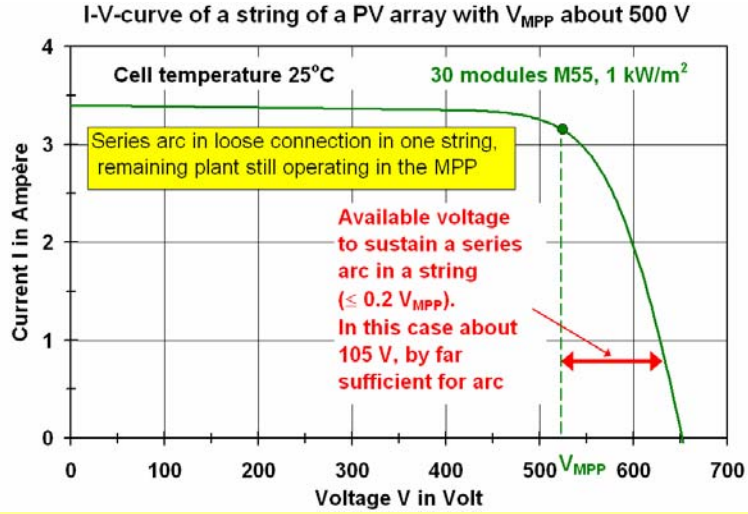
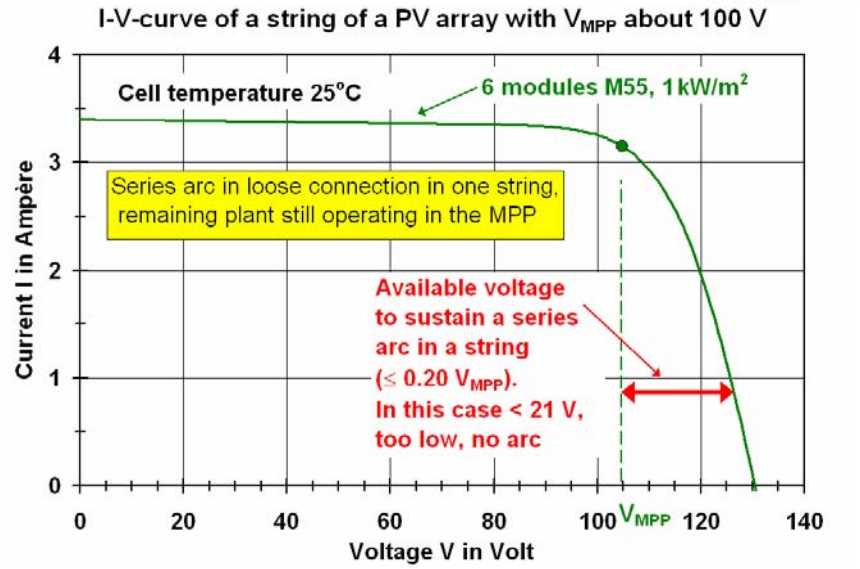
Explanation for observations in the field



A high MPP-voltages V_{MPP}, series arcs are possible



A low MPP-voltages V_{MPP}, series arcs are hardly possible

Increasing string voltages and currents rapidly increasing number of plants, increasing age of many plants,

⇒ Increasing risk of DC arcs

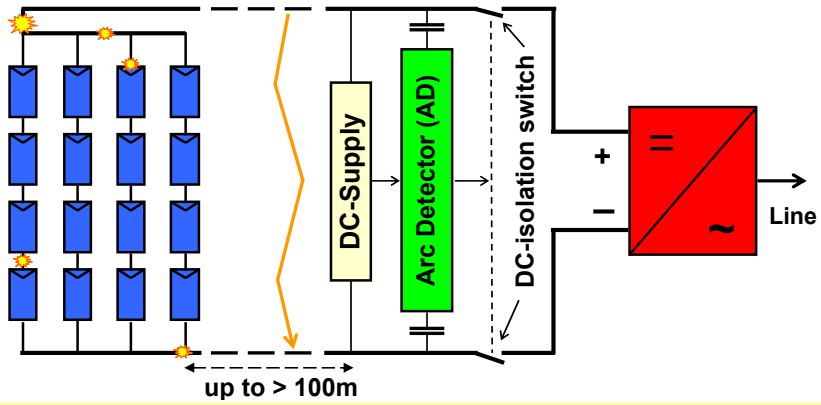
⇒ additional safety device required, which eliminates fires caused by DC arcs, like residual current breaking (RCD) devices prescribed in AC circuits with higher risk.

⇒ Solution: Integration of an arc detector in the inverter!

2. Idea for an arc detector (AD)

- Initial idea for such a device from Alpha Real AG (1992)
- First prototype modified AM-radio
- Not suitable for use in a PV plant ⇒ Contact with BFH's PV laboratory for development of a functional device
- First version of an operational arc detector developed in students project and diploma thesis in 1993/1994
- Problem much more difficult than initially assumed ⇒ Further development in a Swiss research project (NEFF)
- First patent application 1994

3. Arc detectors developed in the nineties



When an electrical arc occurs on the DC side, in *a combination of two resonant circuits* a high-frequency signal is detected. After certain checks the isolation switch is activated and the DC side of the inverter is disconnected.

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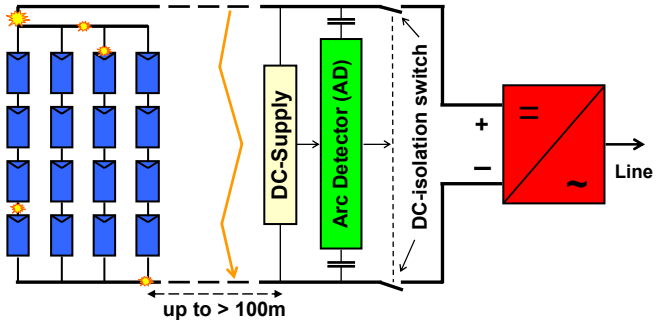
Field tests 1996-1998 in EU-project



- Production of 12 *autonomous* prototypes (fed directly from PV plant) and field test (in CH, D + I) 1996 – 1998.
- ADs can detect arcs over distances of *100 m to 200 m,* if the inverters do no produce excessive RF voltages on their input lines on the DC side.

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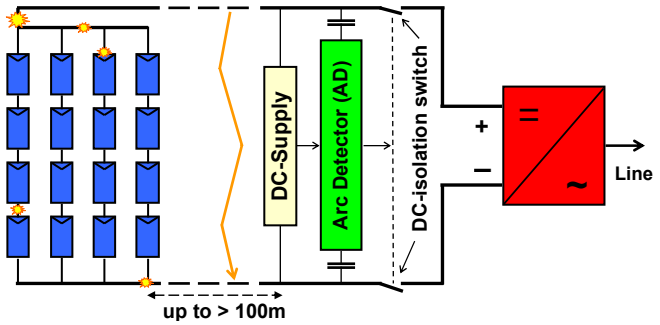
Field tests 1996-1998 in EU-project

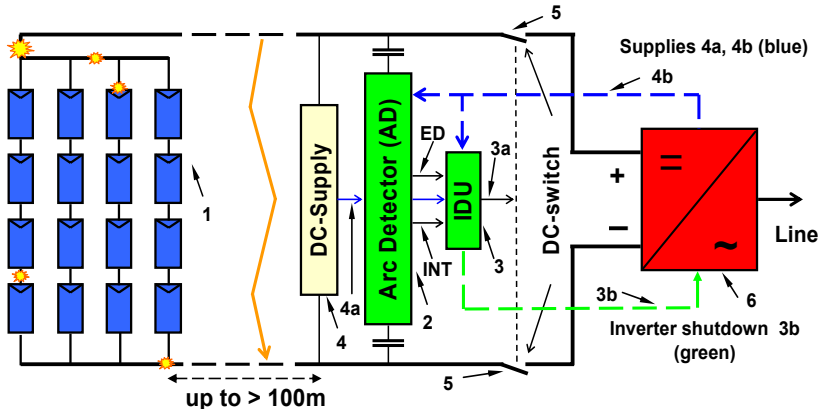


- Sometimes problems due to high RF voltages on the DC side ⇒ sometimes additional filters were necessary.
- With some inverters erroneous detections during start-up.
- First patent application dropped due to lack of interest from the PV industry (still small then).

4. Ideas for improvement of arc detectors

- Today also limits for RF voltages on the DC side ⇒ conditions for widespread use of ADs are much better now.
- To avoid erroneous detections during start-up + shut-down: Development of an intelligent detection unit (IDU) for a detailed analysis of the AD-signals before disconnection and distinction between series and parallel arcs.
- The most expensive element in an autonomous AD is the DC switch, which has to bring the DC side into a safe state in case of an error. The power supply of the AD's electronic directly from the array is also quite costly.
  ⇒ AD integration in inverter ⇒ significant cost reduction!

Improved arc detector



Block diagram of an improved AD for a reliable remote detection and interruption of dangerous arcs on the DC side of PV plants.

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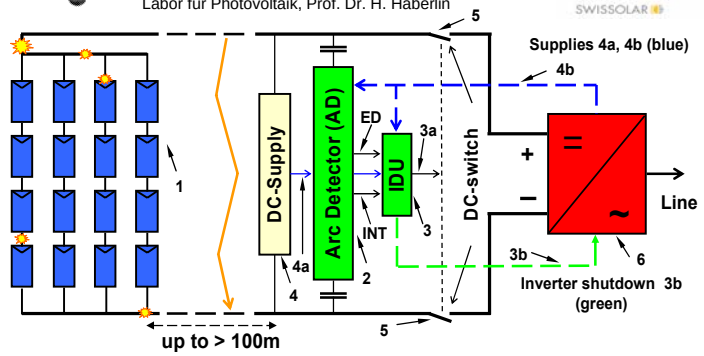

- The intelligent detection unit (IDU, (3)) can be realised by hardware or software (frequent sampling of the output signals of the AD core unit (2) by the inverter control).
- Mixed forms are also possible, in which part of the IDU is realised by hardware, reducing the necessary sampling rate of the inverter control and the software complexity.

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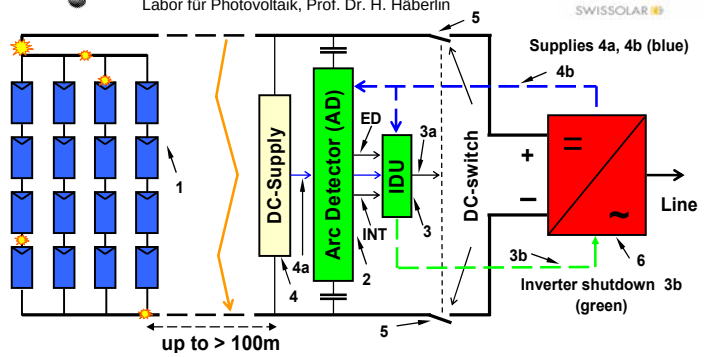

- Integration of the AD in the inverter saves the cost of the most expensive components (DC supply + isolation switch), but also allows more sophisticated detection methods.
- Some ADs still available in the PV lab were equipped with the new IDU in fall 2006 and tested successfully with modern inverters of leading manufacturers (SMA, Fronius, Sputnik, KACO and ASP).

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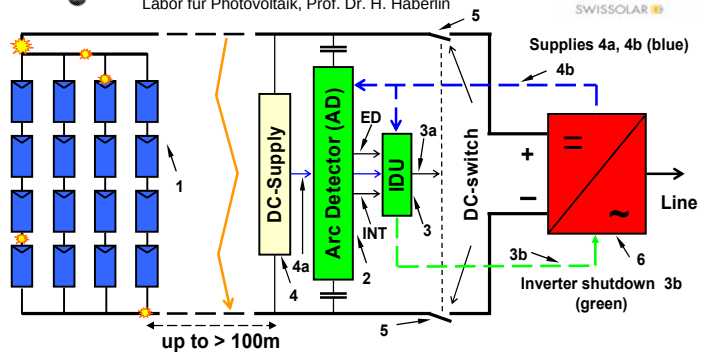

- In fall 2006, for these new ideas and the IDU, a new patent was applied for, primarily to prevent that a manufacturer makes a patent for him alone and thus hinders integration of ADs into the inverters of other manufacturers.
- Realisation of an AD integrated in an inverter is only possible in close co-operation with inverter manufacturers.

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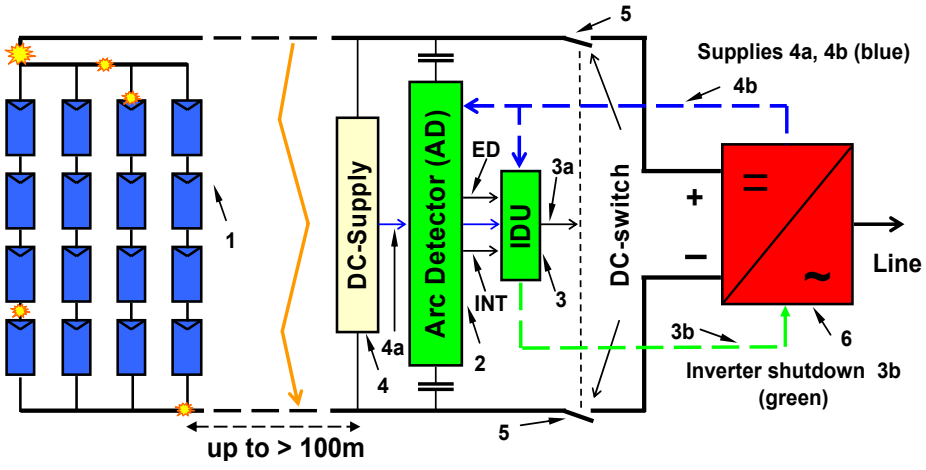
5. Present legal situation concerning patents (Oct. 2007)

- The content of the old patent filed in 1994 is freely available and with some effort it can be found in patent data bases.
- The patent applied for in 2006 in Switzerland was not maintained, too, as some project internal documents containing essential details were disclosed already in 1996 to the partners of the EU project to facilitate the field tests and there is no written non-disclosure agreement available covering the project time. According to our patent attorney, this must be considered as a publication and therefore no patent covering these new ideas is possible. However, the content of this dropped Swiss application is not contained in any patent data base and therefore is quite hidden and probably actually only available at our PV laboratory.

- On the other hand, when our first patent application from 1994 that was also filed as an EU patent application was no longer maintained, the published content became freely available and some later patents in some Asian countries using these ideas were applied for after 1996. If the content of these patents is in conflict with the (legally published) content of our first patent, or with the further developments during the EU-project (described in the second Swiss patent application of 2006, which is quite hidden), the content of these later patents can be ignored, if they would prevent the use of our arc detectors for PV arrays.
- Therefore the legal situation is very favourable for interested inverter manufacturers, as in principle no royalties have to be taken into account, but only the cost of the own development and the consulting of the PV laboratory of BFH.



The know-how, and extended reports about all former tests are available at BFH's PV laboratory. An operational AD will soon be presented here.

6. More safety in PV-plants owing to arc detectors

- The improved arc detector (AD) described above, which has already been developed and field tested could be a valuable additional safety feature in order to increase long-term safety of PV plants.
- It can detect arcs immediately after their appearance before they can cause a significant damage and shut off the plant on the DC side.
- An AD integrated in an inverter can be realised quite easily and cost effectively, as good modern inverters have already sufficiently low RF emissions on the DC side, an internal power supply for the internal electronic is already there and an AD integrated in the inverter easily realises, when an inverter starts up or shuts down.

- Together with the improved detection methods realised in the IDU, it should be possible to virtually eliminate any erroneous detection of arcs.
- With a sufficient quantity, it should be possible to realise an AD integrated into an inverter at an additional cost of about 10 €.
- In the coming years hundreds of thousands of PV plants with many 10 millions of external and many billions of internal contacts will be operational.
- After many years even with the highest quality standards during production and installation some of them will go defective and end up in dangerous DC arcs.

- **At least for *PV arrays integrated into roofs with wooden support structures* such arc detectors would be a very useful additional safety element (like RCD monitoring devices that are mandatory in certain AC installations), which would improve the long-term security against fire hazards.**
- **If in the future from time to time fires would occur owing to such arcs in PV plants on buildings, and if the general public and political decision makers would become aware of that, not only the manufacturer of the defective device and the installer, but the PV community as a whole could face major problems.**

Motivation for inverter manufacturers to use ADs

For manufacturers that are interested in integrating an AD in their inverters some questions might arise:

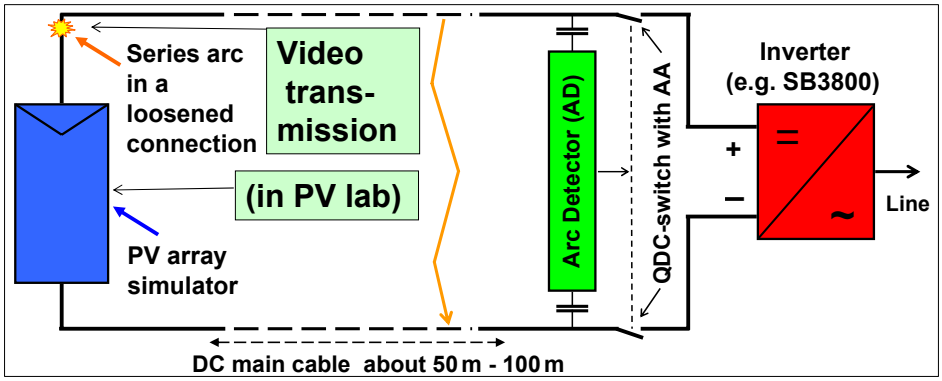
1. **How to promote AD without creating unnecessary fear fear of PV with potential customers?**
2. **Is an inverter manufacturer liable for damage if an AD does not detect an arc?**
3. **Why at all should a inverter manufacturer make an effort to solve problems that occur not in the inverter, but in other parts of the PV plant?**

1. Considering point 1, it must be noted that an AD must be promoted primarily as an additional safety device. According to applicable standards, inverters without transformers must have an integrated, adaptive RCD monitoring device. Moreover, in each PV plant, also a DC isolation switch is required according to existing standards. These elements are not necessary in normal operation, but in case of a problem, they can cope with the problem they are designed for and prevent a more serious damage. An AD could be seen in that context and be promoted as an additional part of an ″integrated PV array safety monitoring device″ without mentioning the name ″arc detector″ explicitly.

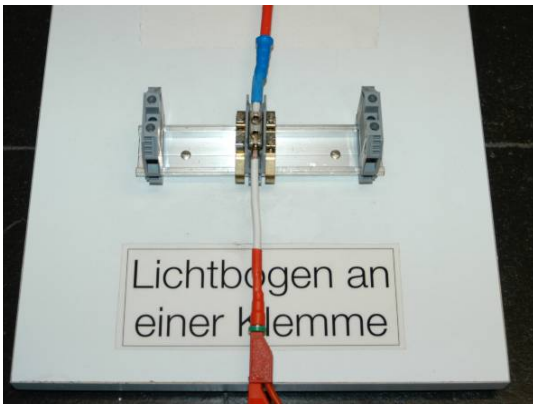
2. Considering point 2, it can be noted that additional safety protection devices can not always prevent damages that occur after a long period of time due to another, primary cause. However, they can reduce the probability and the dimension of such damages, e.g. the manufacturer of an RCD or an air bag is not liable for the damage of an accident that happens all the same.

3. Considering point 3, it must be emphasised again that electrical arcs occurring more frequently on the DC side of PV plants in the future could cause problems to the whole PV industry. Inverter manufacturers are a part of this industry and depend on the size of the PV market. In the inverter, the problem can be solved most efficiently and most cost effective. Even today many inverters with transformers already have integrated isolation monitoring devices that detect ground faults, although such ground faults usually occur in the PV array and its wiring and not in the inverter itself.

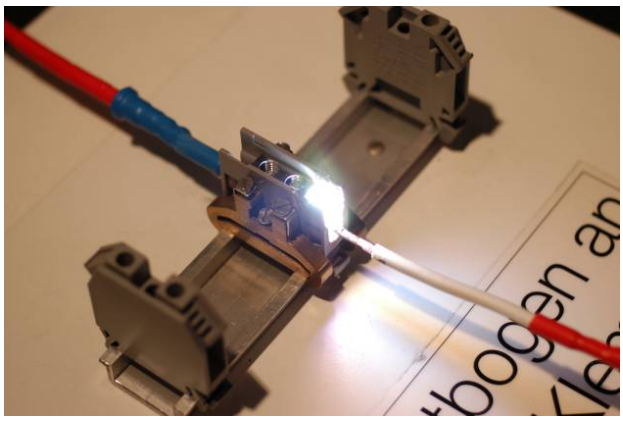
7. Demonstration of an improved AD in the laboratory



Upon recognition of a series arc in the loosened connection, the arc is interrupted by means of a electromechanical QDC switch.



The plus-connection of the cable to the AD and the inverter is passed across a connection that can be loosened.



With a loosened connection an arc occurs, which is recognised by the AD and switched off immediately.

Note: In order to obtain a nice long arc looking dangerous, the AD was disabled for a short time for this picture!

The arc detector (AD) with IDU which was used for these tests performed in autumn 2006 was composed of parts that were still available from earlier projects. Many parts were used that would not be needed for an AD integrated into an inverter.

Final Conclusions

- **In the coming years hundreds of thousands of PV plants with many 10 millions of external and many billions of internal contacts will be operational.**
- **After many years even with the highest quality standards during production and installation some of them will go defective and end up in dangerous DC arcs.**
- **If in the future from time to time fires would occur owing to such arcs in PV plants on buildings, and if the general public and political decision makers would become aware of that, not only the manufacturer of the defective device and the installer, but the PV community as a whole could face major problems.**

- **The simplest and most cost effective solution to this problem would be an arc detector integrated in each inverter as an additional security measure.**
- **Interested manufacturers can save a lot of development time by a co-operation with the PV laboratory of BFH.**
- **If you are interested, we are looking forward to a fruitful co-operation!**

END

Many thanks for your attention

The slides of this presentation are available on the internet:
www.pvtest.ch under > publications [124].

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