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

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ABSTRACT:

DC arcs in PV plants with high DC voltage are much more dangerous than AC arcs, as there are no zero-crossings of current. Despite the still relatively small number of PV plants, such arcs have already caused quite a number of fires worldwide, causing expensive damage. In the early nineties such fires have occurred at several PV plants (e.g. Mont Soleil (560 kWp)). In spring 2006, a smouldering fire occurred in the connector box of an 11 years old PV plant in Burgdorf and a considerable number of arcs occurred in defective BP modules in many countries. Only with a lot of luck major damages at buildings did not happen. With the rapidly increasing number of PV plants and especially due to the increasing age of these plants the number of such events will probably increase considerably in the next years.

Already in 1994 to 1998, at first in a national and then in an EU project in co-operation between BFH's PV laboratory and Alpha Real, an arc detector was developed, which was successfully tested in several PV plants in Europe and USA [1], [2]. These devices were realised as stand-alone devices (with an integrated supply and an expensive electromechanical disconnecting switch). At many inverters additional filters were needed due to high RF emissions on the DC side. With the increased EMC quality of modern inverters also on the DC side, the detection of such arcs is now much easier, therefore such arc detectors can now be integrated directly into the inverter, reducing considerably the cost and at the same time making possible much more sophisticated detection strategies. Such an arc detector should be an integral part of a modern inverter in order to increase the long-term safety of a PV plant.

KEYWORDS: Electrical safety, DC arcs, fire hazard protection.

1. Introduction

DC arcs in PV plants with high DC voltage are much more dangerous than AC arcs, as there are no zero-crossings of current. Despite the still relatively small number of PV plants, such arcs have already caused quite a number of fires worldwide, causing expensive damage. With the rapidly increasing number of PV plants and especially due to the increasing age of these plants the authors believe that the number of such events will increase considerably in the next years.

Also in Switzerland already in the early nineties such fires at PV plants have occurred at PV plant Mont Soleil (560 kWp) and at a PV plant on the roof of a farmhouse, that originated from the PV plant [3]. In the last year, the problem of DC arcs showed up again. In spring 2006, a smouldering fire occurred in the connector box of an 11 years old PV plant in Burgdorf. In 2006 (and also some time before), a considerable number of arcs occurred in defective BP modules [4]. Only with a lot of luck major damages at buildings did not happen.

In principle these events should cause the PV community now to pay sufficient attention to this problem and to take appropriate countermeasures. Unfortunately there is a tendency to treat these problems as single events, i.e. a problem of the manufacturer or the installer concerned and not as an inherent long-term problem of PV plants. Considering the fast growing demand for PV equipment, the temptation to ignore this problem and to go on doing business as usual is obvious.

This paper describes an efficient and cost effective solution to prevent the danger arising from possible DC arcs in PV arrays. Because of the increasing operating voltages and currents in the strings of PV plants, the rapidly increasing number of plants and the increasing age of many plants, the need for an additional safety device should increase, like residual current breaking (RCD) devices prescribed in AC low voltage circuits with increased risk of shock hazard (e.g. outdoor installations and bathrooms).

2. Idea for an arc detector

Already in 1992 Alpha Real AG had the idea for an arc detector (AD) that is sensitive to electromagnetic disturbances caused by an electrical arc and a very simple device (modified AM radio) was built. However, this device was not suitable for practical application in PV plants. Therefore the PV laboratory of BFH was contacted. In a student's project and a diploma thesis, a first version of an operational arc detector was developed.

As the complexity of the problem was higher than initially expected, further developments and improvements were necessary, which were carried out in co-operation with Alpha Real during a national project, funded by NEFF (nationaler Energieforschungsfonds).

In a subsequent EU-project in the JOULE framework, 6 ADs for low (55 V - 140 V) and 6 ADs for high voltage (400 V - 1000 V) were developed. Together with the foreign project partners (FhG/ISE, ANIT, ENEL) they were tested at PV plants in several countries (Germany, Switzerland, Italy and USA).

The arc detectors were completely autonomous, they did not need an external power supply, but took their operating power directly from the PV array. Therefore it was possible to insert an additional RF filter between an inverter with high RF emissions and the AD, but in order to take appropriate countermeasures in case of an arc, an expensive electromechanical switch rated for high DC voltages was needed.

In 1994/1995, a patent was applied for, but owing to the missing interest of the (then still very small) PV industry it was not maintained to avoid unnecessary cost.

3. Operating principle and properties of the arc detectors developed in the nineties and results of the field tests

Fig. 1 shows the block diagram and the location of AD in a PV plant. It could be shown that ADs can successfully detect arcs over distances up to 100 m - 200 m, if the other devices (e.g. inverters) have a sufficiently low emission of conducted RF as required nowadays in newer EMC standards (e.g. EN61000-6-3). However, many of the inverters used then still had too high RF voltages on the DC side. Therefore, in order to make operation of the ADs possible, quite often modifications of the wiring of the PV plant and additional filters at the DC input of the inverter were necessary. Moreover, with some inverters, from time to time sporadic erroneous arc detections occurred, especially during start-up and shut-off of the inverter.

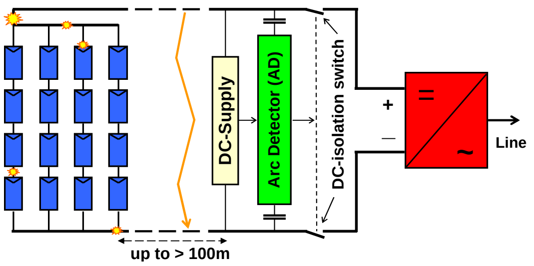

Fig. 1:
Basic version of the autonomous arc detector (AD) developed in the mid-nineties. When an electrical arc occurs on the DC side, in a combination of two resonant circuits a high-frequency signal is detected. After certain checks to avoid erroneous triggering, the isolation switch is activated and the DC side of the inverter is disconnected. For an autonomous device, the power must be supplied directly from the PV array and a separate electromechanical DC isolation switch is necessary, which is quite expensive. The arc detector can also recognise the (much rarer) parallel arcs between + and – (large orange arc in fig. 1).

4. Ideas for improvements of the arc detector

During the field tests with stand-alone ADs, from time to time erroneous detections of arcs occurred during the start-up and turn-off procedure of the inverters that caused unwanted interruption of inverter operation. Such sporadic erroneous tripping of an AD is not acceptable of course. Therefore an intelligent detection unit (IDU) was developed, that undertakes a more sophisticated analysis of the signal from the AD before generating a turn-off signal and that can also distinguish between series and parallel arcs, which need different countermeasures.

An important lesson learned is that it would make very much sense to realise such an arc detector not as a stand-alone device (with an integrated supply and a disconnecting switch), but as an *integral part of an inverter*. The inverter control circuit (usually a micro-processor or a microcontroller) knows, when the inverter starts up and shuts down and can ignore signals form the arc detector during that phase. Moreover, in the inverter there is already a DC supply for the electronics and the AD can benefit from it at virtually no additional cost. Therefore such an integrated arc detector can be realised at a small fraction of the cost of a stand-alone device and is not prone to erroneous triggering. By means of suitable software algorithms, even more intelligent methods in detecting arcs and suppressing erroneous triggering are possible. In the end of 2006, a patent was filed for the new ideas to improve the AD that were not contained in the initial patent.

5. Possible application of arc detectors today

The damage owing to smouldering fires in module connector boxes described in [4] was very likely also caused by electrical arcs. Such arcs would have been detected by a properly designed AD with high probability. The AD would then have shut off the plant on the DC side and therefore have brought it into a safe condition.

However, this problem will probably not be limited to BP modules that were highlighted in 2006 due to these events. In PV plants today already about 5 billion DC contacts are operational worldwide, which are loaded with DC currents. The probability, that a small fraction of these contacts increases its resistance and warms up in course of the expected lifetime of 25 to 40 years, increases proportional to the number of installed plants and probably more than proportional with the age of these plants. Thereby the evolution of the damage is programmed: The resistance in the contact increases, the contact warms up under load, which leads to an additional increase of resistance and an additional warming. Finally the temperature of the contact has become so high that the contact opens, which in most cases ends in a dangerous DC arc. Because of the DC current this arc is quite intense also at low moderate power levels and is able to ignite surrounding inflammable material.

Similar events were registered also in other products and plants, e.g. in 1992 in a power switch in the PV plant at Mont Soleil and in 1993 in a farmhouse in Switzerland. In spring 2006, a smouldering fire occurred in the connector box of an 11 years old PV plant (15 kWp, $U_{MPP\text{-}STC} \approx 590$ V) in Burgdorf that has been under analytical monitoring by the PV laboratory of BFH since 1995. According to the traces found, this smouldering fire was probably caused by a soldered joint that increased its resistance slowly in course of time. By means of the analytical monitoring data it could be seen that it probably finally melted during a cloud enhancement. The open soldering point then ended up in a DC arc that damaged the connectors soldered to the printed circuit board (see fig. 2 and 3). As there was a metal box (fortunately), the further access of oxygen was not possible, the smouldering fire extinguished after some time, but the affected string was out of order afterwards.

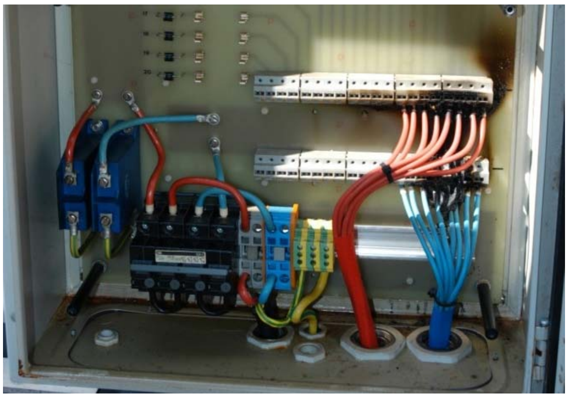

Fig. 2:
Damage caused by a smouldering fire, which occurred in the connector box of an 11 year old PV plant in Burgdorf. Fortunately this fire was in a metal cabinet that kept it confined.

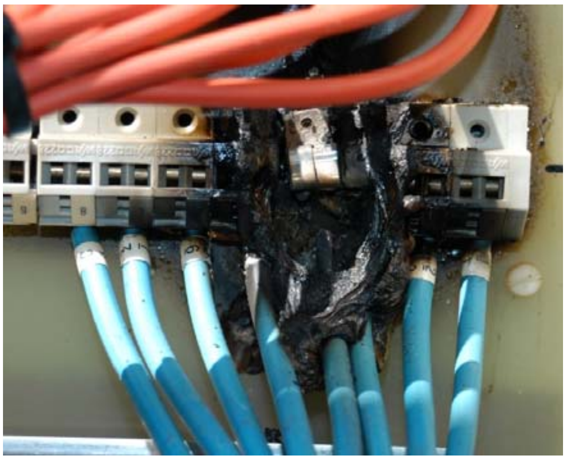

Fig. 3:
Close-up view of the origin of the fire. A soldering point on the printed circuit board or a connection gradually warmed up and finally melted, developing an electrical arc causing the fire.

Also in this case an AD would have switched off the PV plant on the DC side and brought it into a safe condition.

In two other older plants with lower operating voltages around 100V, also smouldered contacts were registered that shut off parts of the array, but due to the lower voltage in the arcs the damage was mostly limited to the connectors themselves.

At BFH's PV plant of 60kWp commissioned in 1993, there were two modules out of about 1100, in which internal connections opened in course of time during 14 years. Fortunately the bypass diodes were not defective and could take over, therefore the power in the arc was very low and only a small brown spot developed at the back sheet. If the bypass diode would have been defective, a significant amount of the power of the whole string would have been in the arc and the damage would have been more severe. With a thermographic camera, in some older modules (still operational) quite hot con-nections can be seem, part of which will certainly also get open in course of the coming years. If the bypass diodes will not take over, an arc might arise.

6. Concept and operating principle of an improved arc detector

As far as EMC standards are concerned, today the situation is much better than in the nineties. Also on the DC side of PV inverters there are now limits for RF disturbances (e.g. in EN61000-6-3). Therefore for properly designed devices additional filters are no longer needed. Moreover, most inverters are controlled today by microprocessors or microcontrollers that in many cases are not fully loaded and might fulfil some additional tasks by a suitable extension of their software (see fig. 4). Thus a more or less significant part of the hardware needed to implement the arc detection could be implemented by suitable software algorithms, making possible even more intelligent methods in detecting arcs and suppressing erroneous triggering. The inverter control software knows exactly when the inverter turns on or switches off, therefore it can easily ignore remaining erroneous arc signals during that time.

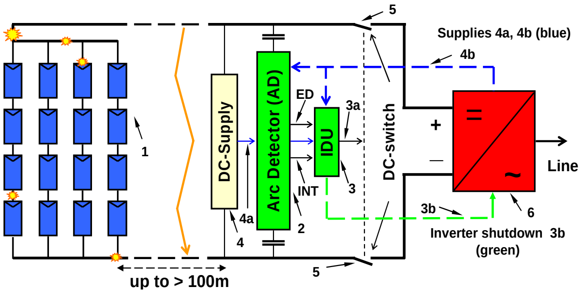

Fig. 4:
Block diagram of an improved arc detector (AD) for reliable remote detection and extinction of dangerous arcs on the DC side of PV plants. If the unit is an integral part of the inverter (preferable, as this is the best and most cost effective solution), the expensive parts 4 and 5 are not necessary.

The arc detector (AD) is primarily intended to protect the PV array and the DC wiring of a PV plant (1) from dangerous series arcs in modules and wiring and from fires at neighbouring objects (e.g. roofs of buildings) provoked by them. Some possible locations of such arcs are shown in the block diagram of fig. 4. An AD can not only detect arcs in the DC main cable, but also in one of the strings, if the number of parallel strings is not too high. The core part of the AD (2) contains two coupled resonant circuits tuned to a frequency of a few 100 kHz and is activated by the high frequency oscillations in the plant that are caused by an arc. Compared to fig. 1, the intelligent detection unit IDU (3) is new. It analyses the signals produced by the actual AD further and only generates an output signal, if there is actually a dangerous arc on the DC side. Moreover the IDU can distinguish between a series and a parallel arc. Only in an autonomous AD, an independent DC supply (4) from the PV array and an electromechanical isolation switch with load breaking capability (5) are needed, two parts that considerably increase the total cost of such a device. However, if the arc detector is integrated in an inverter (6), only the green elements (2) and (3) are necessary, the expensive elements (4) and (5) are not needed. Detection of a parallel arc between + and – (large orange arc) is also possible. In order to extinguish such a (very rare) parallel arc, an additional short circuit switch between + and – (not shown) would be necessary.

The intelligent detection unit IDU (3) can be realised either by hardware or by software by frequent sampling of the output signals of the AD (2) by the inverter control circuitry. Mixed forms are also possible, in which a certain part of the functions of the IDU is realised by hardware, reducing the necessary sampling rate and therefore relieving the microcontroller of the inverter. Besides avoiding the cost for the most expensive components (4) and (5), the integration of the AD into an inverter makes possible also much more sophisticated detection procedures that are therefore much more secure and less sensitive to external disturbances and erroneous triggering. Moreover, in order to extinguish a (very rare) parallel arc, it would probably be possible to short circuit the input circuit by a suitable excitation of the power electronic without the need for an expensive electromechanical short circuit switch.

Although further development of the arc detector was stopped in the end of 1998 due to lack of interest of the PV industry, in 2006 some ADs that were still available at BFH's PV laboratory could be equipped with the new IDU and could be tested successfully with modern inverters of leading manufacturers, e.g. with inverters from SMA, Fronius, Sputnik, Kaco and ASP. These inverters had all sufficiently low RF emissions on the DC side for proper operation of the AD. Therefore integration of the AD in these inverters should be quite simple.

For these new ideas and the IDU, in fall 2006 a new patent application was filed, primarily to avoid that a manufacturer gets a patent for itself alone and therefore prevents the integration of ADs into inverters of other manufacturers. The realisation of an AD integrated in an inverter (therefore at very low cost with all the advantages mentioned above) can be realised only in close co-operation with interested inverter manufacturers. The technical know-how and reports containing the results of all tests and developments are available and operational stand-alone arc detectors can be demonstrated at the PV laboratory of BFH-TI.

The arc detector not only operates with a PV array, but for laboratory test also with PV array simulators with sufficiently low conducted high frequency voltages. Fig. 5 shows the test arrangement used for such tests. It is a model of a PV plant with an arc detector located immediately at the inverter. However, the AD used is still autonomous, as it can not be reasonably integrated into an inverter without the active co-operation of the manufacturer. If an arc is detected, a separate electromechanical DC switch is activated (QDC switch with AA), which opens the DC input circuit of the inverter and therefore extinguishes the series arc. The DC connection at the PV array simulator is effected by means of clamp (fig. 6) which can be loosened to provoke a series arc (fig. 7).

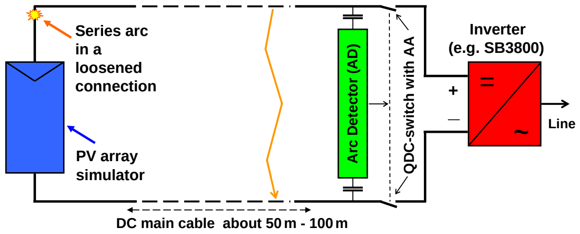

Fig. 5:
Experimental setup for tests of the improved arc detector (AD) at the PV laboratory of BFH-TI. Upon recognition of a series arc in the loosened clamp, the arc is extinguished by opening of an electromechanically activated QDC switch.

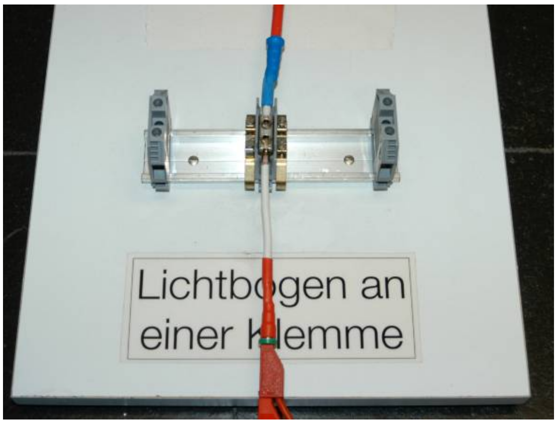

Fig. 6:
The positive lead of the cable (length about 50 m) between the PV array simulator on one side and the AD and the inverter at the other side is connected to a clamp immediately at the PV array simulator. If this clamp is loosened, dangerous arcs can occur (see fig. 7).

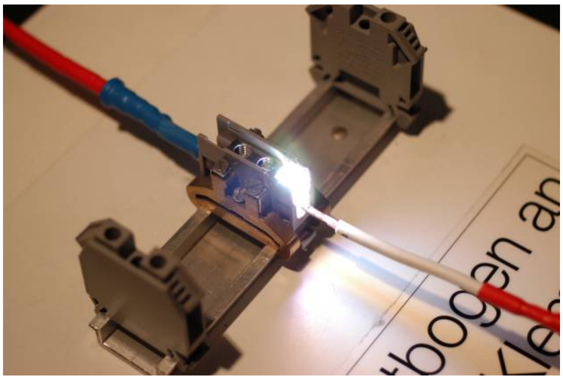

Fig. 7:
If the clamp is loosened, an arc is created in the clamp, which is detected and switched off immediately by the arc detector. With activated AD, usually only a small (if any) spark can be seen.
Note: In order to obtain a nice long arc looking dangerous, the AD was temporarily deactivated to obtain this picture!

Fig. 8:
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. For convenience, many parts were used that would not be needed for an AD integrated into an inverter. In this experimental setup, the electromechanical activation of the QDC switch is performed by means of auxiliary circuit and a relay shown in the lower part of the picture.

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

The improved arc detector (AD) described above, that has already been developed and field tested could be a valuable additional safety feature in order to increase long-term safety of future PV plants. It is capable to detect arcs immediately after their appearance before they can cause a significant damage and shut off the plant on the DC side. Such an AD integrated in an inverter can be realised relatively easy 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 €. However, for each inverter a certain development time to implement and integrate the AD into the device would be necessary, until it operates reliably in this environment.

In the coming years in Germany alone many hundreds of thousands PV plants with many 10 millions external and many billions internal contacts will be operating. Of all these contacts, despite a high manufacturing and installation quality, a significant number will probably get defective in course of the projected many years of operation (hopefully 25 – 40!). It is obvious that when such a defect occurs, quite often a dangerous electrical DC arc will be created that may cause a fire hazard. An arc detector integrated in each inverter would considerably increase the safety of PV plants to prevent such damages. A similar protection measure (adaptive DC-RCD-monitoring device) to prevent electrical shock hazard is already required and realised in inverters without transformers.

A simple estimation shows that the benefit from such an additional safety feature by far exceeds the low additional costs. The authors believe that from today's point of view no other measure can prevent the occurrence of fires provoked by DC arcs as efficiently as the arc detector presented here. As a matter of fact, besides the principle of hope that among all the billions of installed contacts no one will change its resistance value excessively and end up in an arc in the next 25 – 40 years, no other technical solution is feasible at present.

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.

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 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 manufacturer make an effort to solve problems that occur in other parts of the PV plant?

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.

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.

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.

For retrofitting existing PV plants, it would be possible to manufacture also improved stand-alone arc detectors with an IDU, however, they would be significantly more expensive than arc detectors integrated in the inverter, because they need an additional power supply (preferable from the PV array itself) and an electromechanical switching device.

8. Conclusions

The integration of such arc detectors into commercial inverters is a very efficient and cost effective solution to increase the long-term safety of PV plants. It can not be realised by the PV laboratory of BFH alone, but only in co-operation with interested inverter manufacturers.

According to the Swiss office for intellectual property (IGE) the information contained in the original patent application of 1994/1995 is now publicly available. However, this application does not yet contain later results obtained during the field tests and new ideas for improvement. A patent for these new ideas was applied for in the end of 2006, mainly to prevent that a manufacturer applies for such a patent for him alone and thus excludes other manufacturers from using arc detectors in their products.

Interested manufacturers can save a lot of development time by a co-operation with the laboratory of BFH, where the technical know-how and reports containing the results of all tests and developments are available and operational stand-alone arc detectors can be demonstrated. We are looking forward to a fruitful co-operation!

Important Notice

References:

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Further information about the research activities of the PV laboratory of BFH-TI (former names: ISB or HTI) can be found on the internet: **http://www.pvtest.ch.**

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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

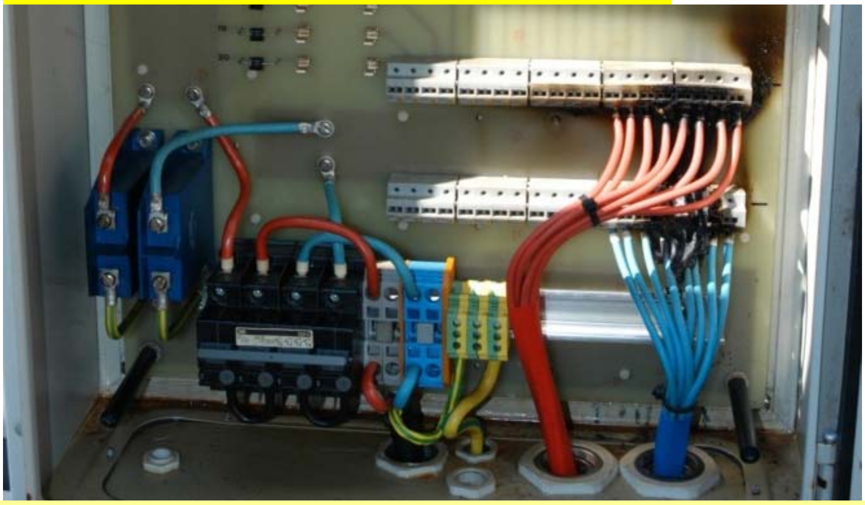
PV module and roof support structure damaged by smouldering fire caused by a DC arc in a module connector box

Source of picture:

Photon 8/2006

Berner Fachhochschule
Technik und Informatik
Labor für Photovoltaik, Prof. Dr. H. Häberlin

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.

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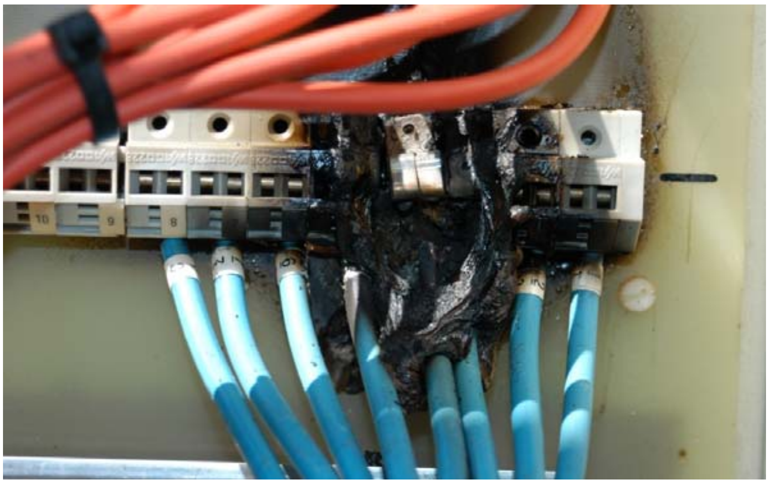

Close-up view of the origin of the fire. A soldering point on the PC board or a connection gradually warmed up and finally melted, developing an electrical arc causing the fire (V_{MPP} was about 500V).

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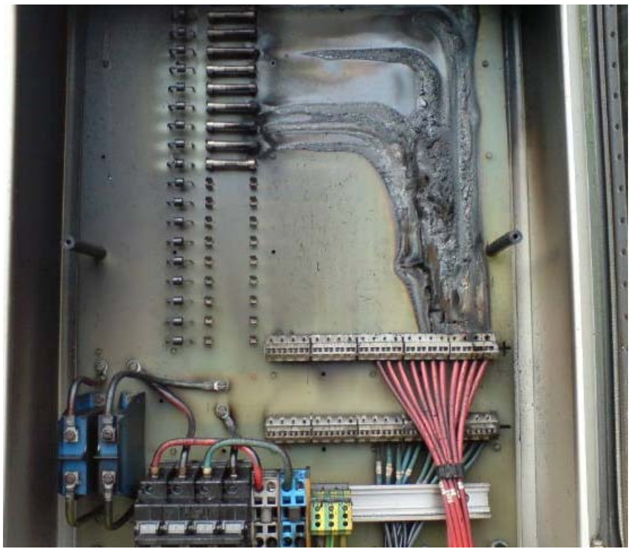
Another, more serious case of such a damage



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)

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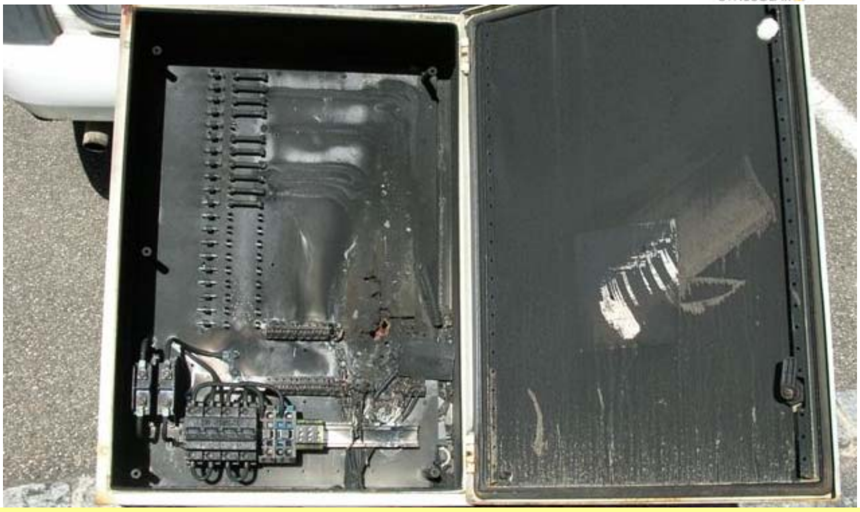

After opening, additional oxygen could enter the cabinet and a catastrophic fire occurred that destroyed the cabinet completely. (Source of picture: EBL)

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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)

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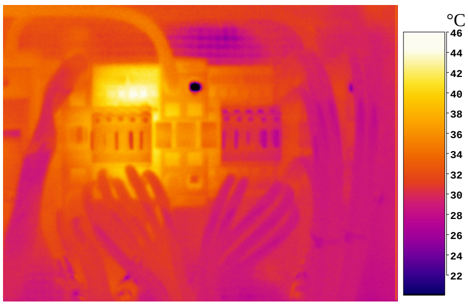
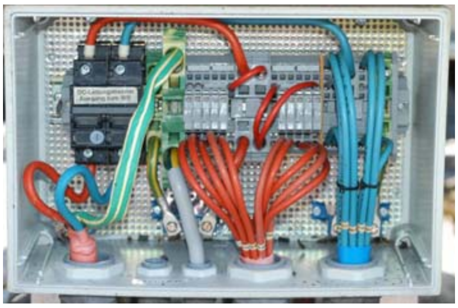
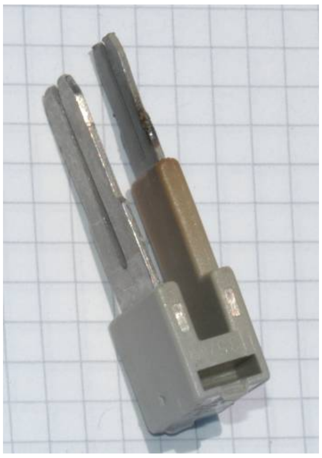
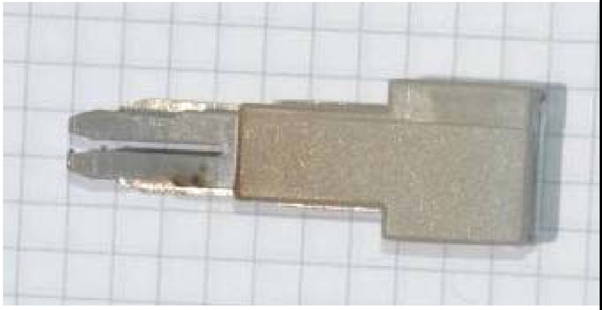
Minor damage by burned connector (no arc) at lower V_{MPP}





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.

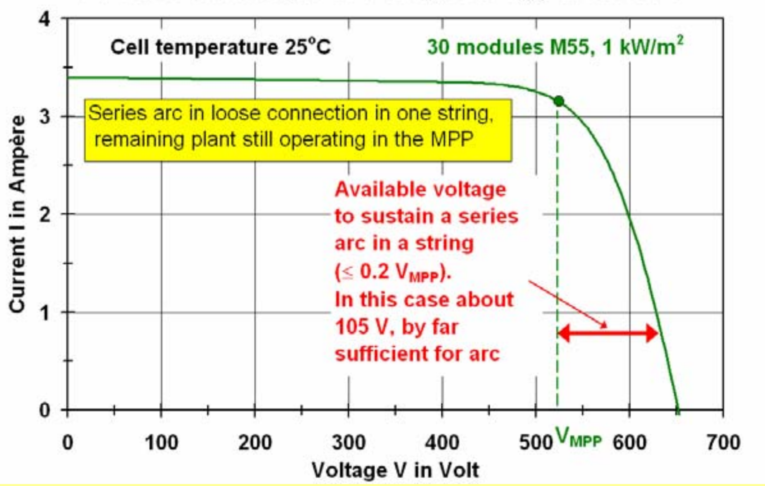




Bridge connectors with damaged (slightly burned) contacts that were used to join the two halves of the PV array in the middle of the array connector box. In this case, due to the low voltage available to sustain the arc (about 0.2 V_{MPP}), no arc occurred.

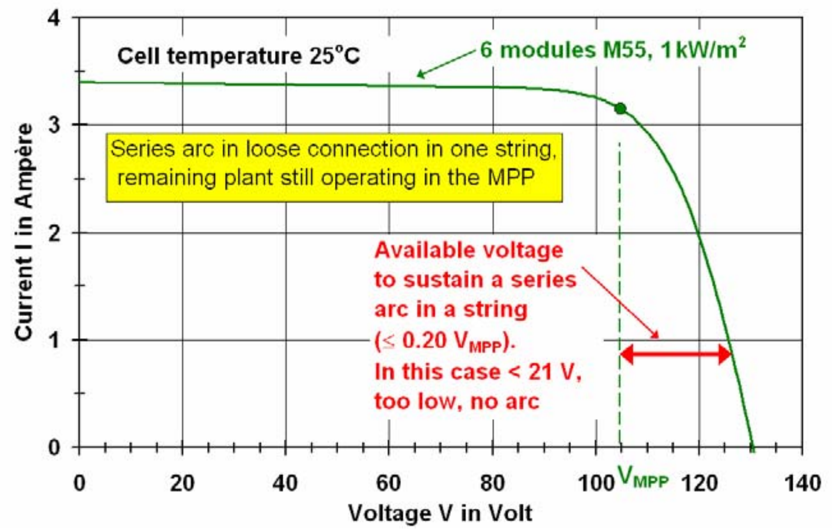
Explanation for observations in the field

I-V-curve of a string of a PV array with V_{MPP} about 500 V



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

I-V-curve of a string of a PV array with V_{MPP} about 100 V



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

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**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!

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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

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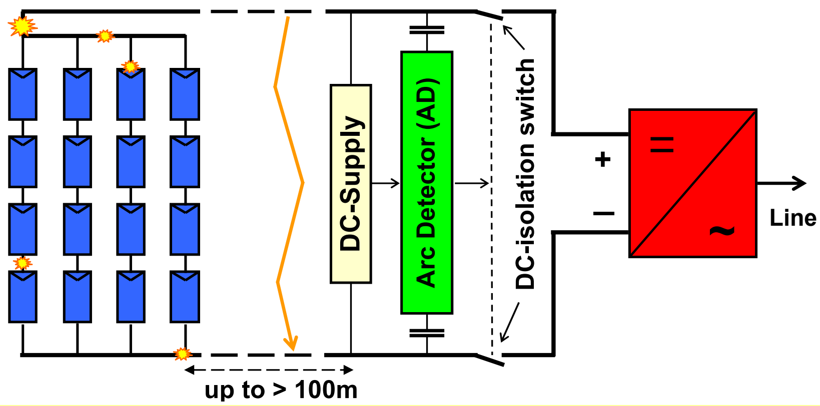
3. Arc detectors developed in the nineties



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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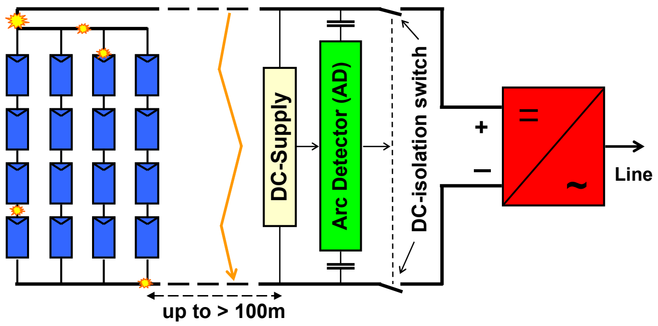
Field tests 1996-1998 in EU-project



- 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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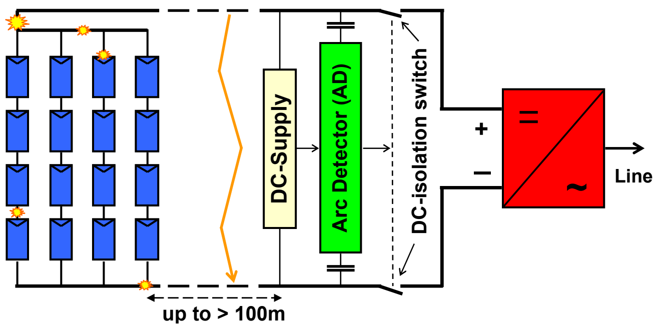
Field tests 1996-1998 in EU-project



- 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!

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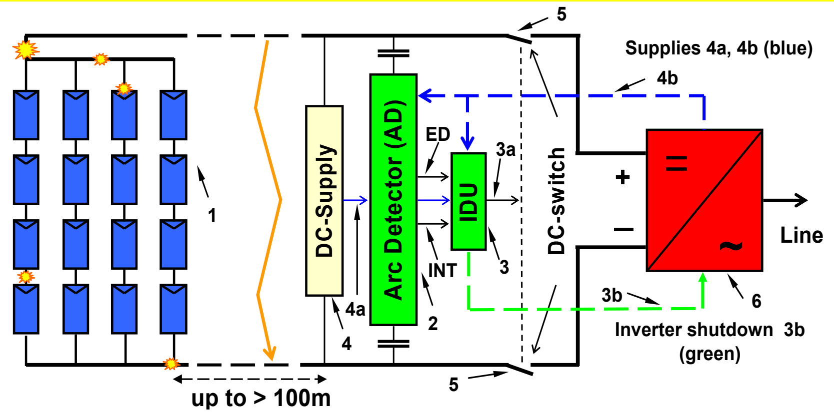
Improved arc detector



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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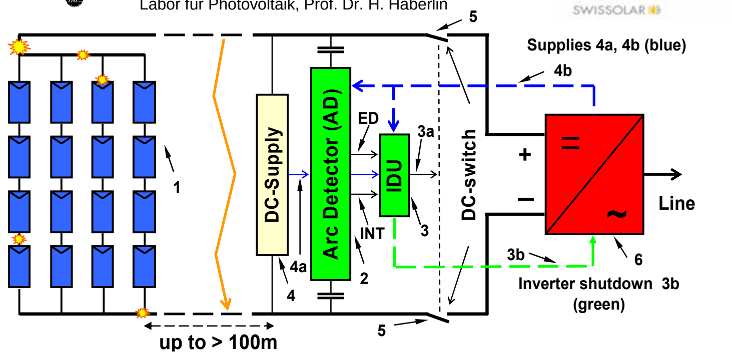

- The intelligent detection unit (IDU, (3)) can be realised by hardware or software (frequent sampling of the output signals of the AD core unit (2) by the inverter control).
- Mixed forms are also possible, in which part of the IDU is realised by hardware, reducing the necessary sampling rate of the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

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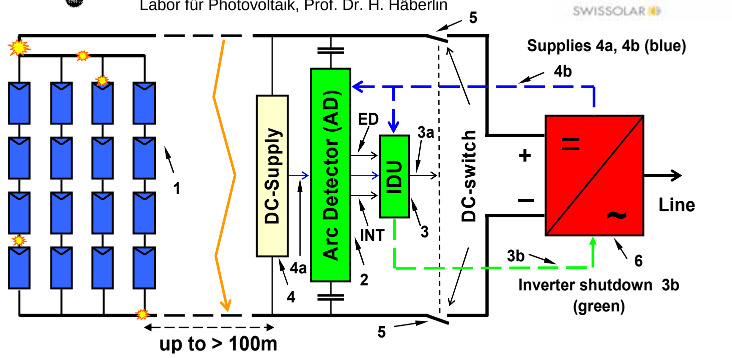

- Integration of the AD in the inverter saves the cost of the most expensive components (DC supply + isolation switch), but also allows more sophisticated detection methods.
- Some ADs still available in the PV lab were equipped with the new IDU in fall 2006 and tested successfully with modern inverters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

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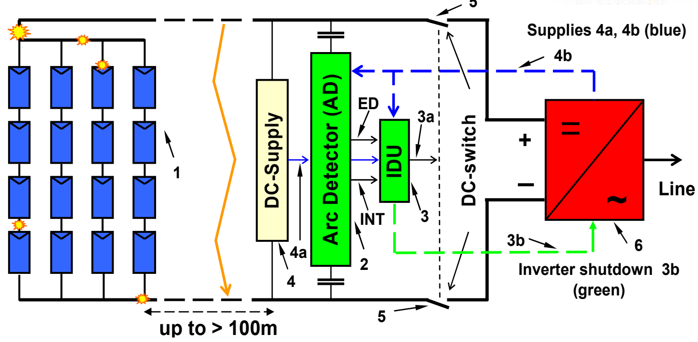

- In fall 2006, for these new ideas and the IDU, a new patent was applied for, primarily to prevent that a manufacturer makes a patent for him alone and thus hinders integration of ADs into the inverters of other manufacturers.
- Realisation of an AD integrated in an inverter is only possible in close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

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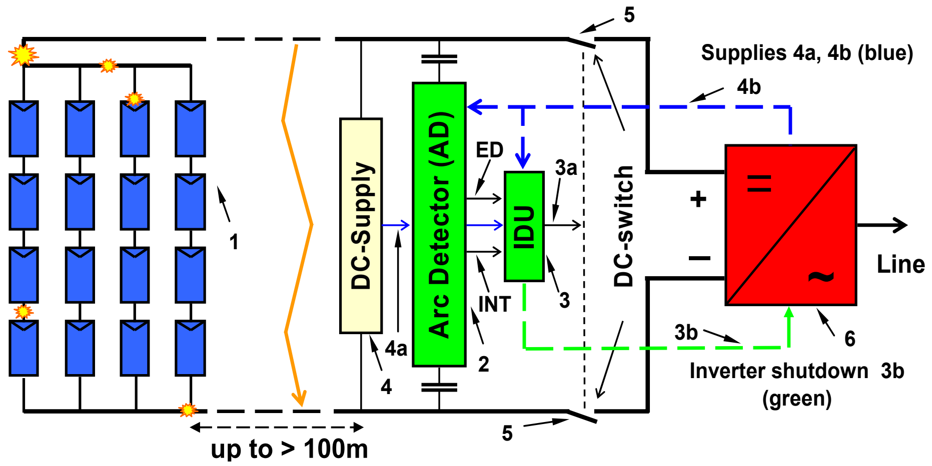
5. Present legal situation concerning patents (Oct. 2007)

- 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:

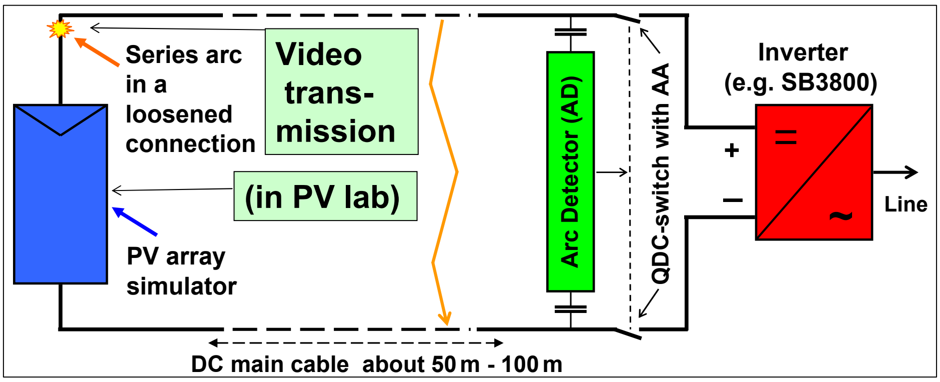
1. How to promote AD without creating unnecessary fear fear of PV with potential customers?
2. Is an inverter manufacturer liable for damage if an AD does not detect an arc?
3. Why at all should a inverter manufacturer make an effort to solve problems that occur not in the inverter, but in other parts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

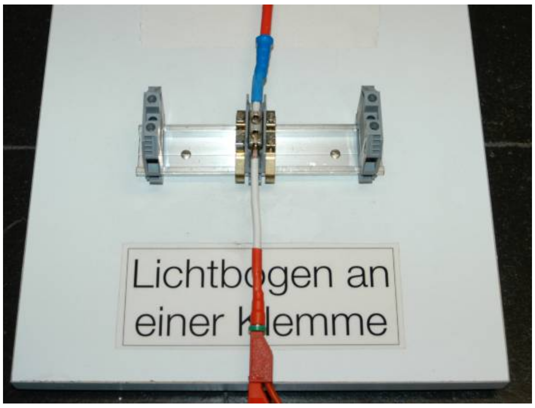
2. Considering point 2, it can be noted that additional safety protection devices can not always prevent damages that occur after a long period of time due to another, primary cause. However, they can reduce the probability and the dimension of such damages, e.g. the manufacturer of an RCD or an air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

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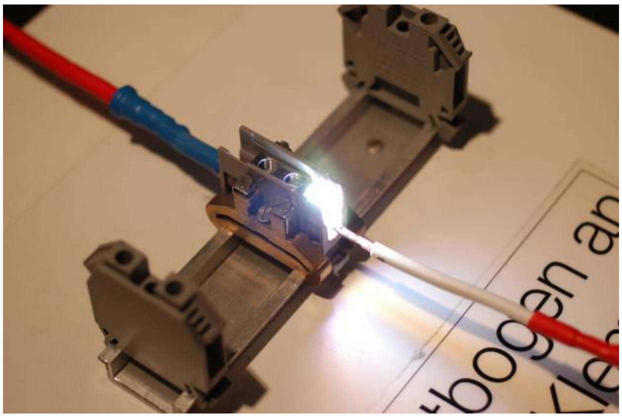

With a loosened connection an arc occurs, which is recognised by the AD and switched off immediately.

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.**

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- **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!**

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END

Many thanks for your attention

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

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