

日本太陽エネルギー学会 第9回セミナー  
「太陽光発電システムの火災リスク対策における現状と課題(2)」

## 電気火災におけるアーク(電弧)について

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テクニカルセンター  
安藤健志

### 放電

出典: フリー百科事典『ウィキペディア (Wikipedia)』

**放電**(ほうでん)は電極間にかかる電位差によって、間に存在する気体に絶縁破壊が生じ電子が放出され、電流が流れる現象である。形態により、雷のような**火花放電**、**コロナ放電**、**グロー放電**、**アーク放電**に分類される。(電極を使用しない放電についてはその他の放電を参照)

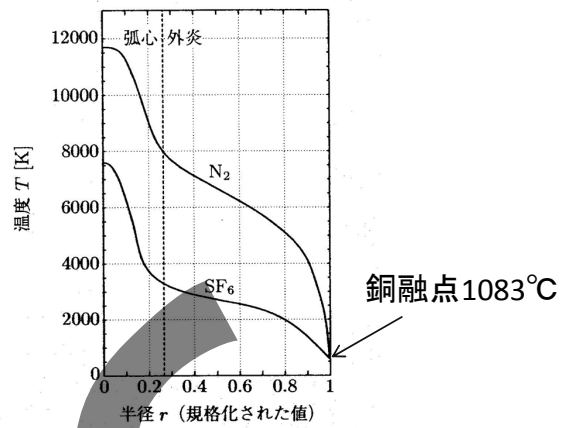
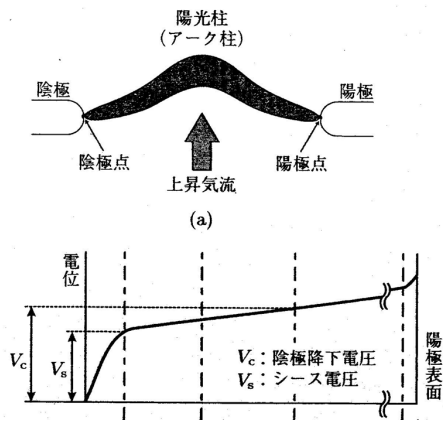
もしくは、コンデンサや電池において、蓄積された電荷を失う現象である。この現象の対義語は充電。

典型的な放電は電極間の気体で発生するもので、低圧の気体中ではより低い電位差で発生する。電流を伝えるものは、電極から供給される電子、宇宙線などにより電離された空気中のイオン、電界中で加速された電子が気体分子に衝突して新たに電離されてできた気体イオンである。

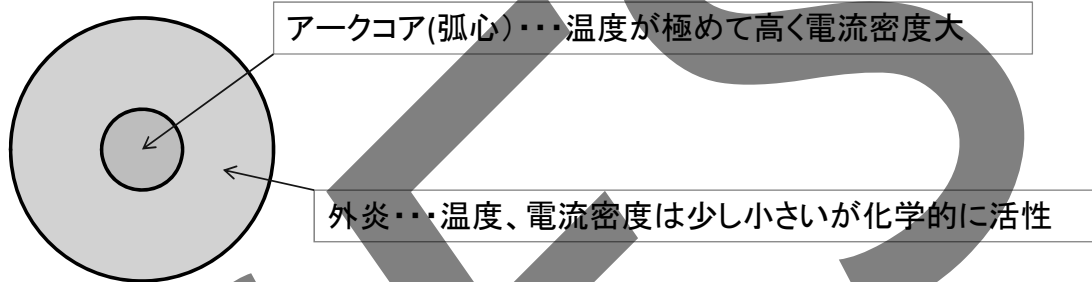
- ・火花放電 : 絶縁破壊による放電、間欠的 例: 雷、自動車プラグ、接触不良
- ・アーク放電 : プラズマ、電流の継続に伴う高温と高周波ノイズの発生

# アーク (電弧: Electric Arc)

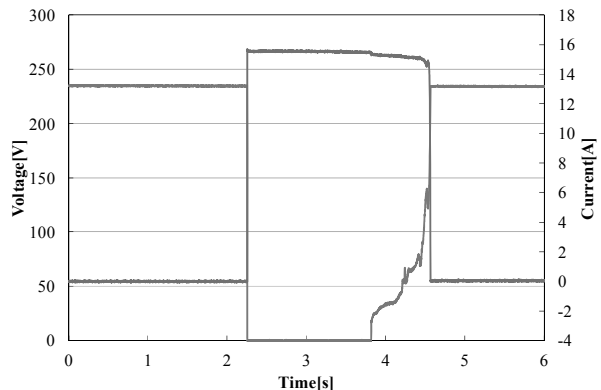
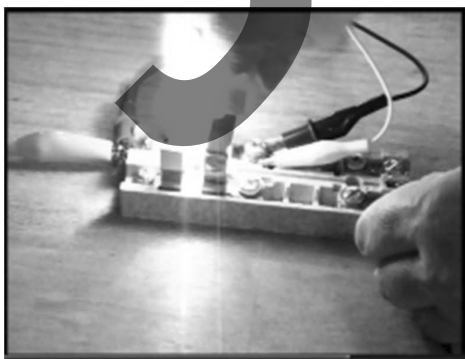
高電圧大電流工学 電気学会大学講座  
4.3アーク放電 p.83-87, 2000年2月



## アーク柱 (陽光柱) 断面図



## 太陽光パネル アーク実験



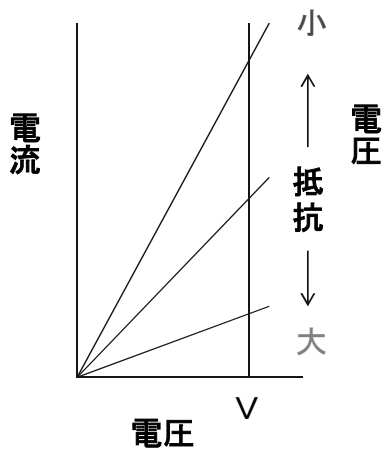
日射強度1020[W/m<sup>2</sup>]

動画

動画

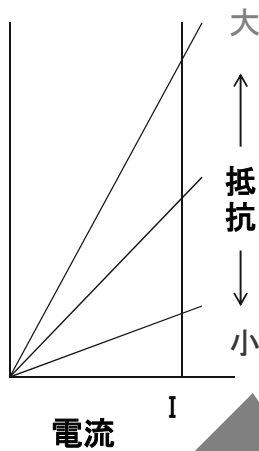
# 電源の種類とI-V特性

## 定電圧源



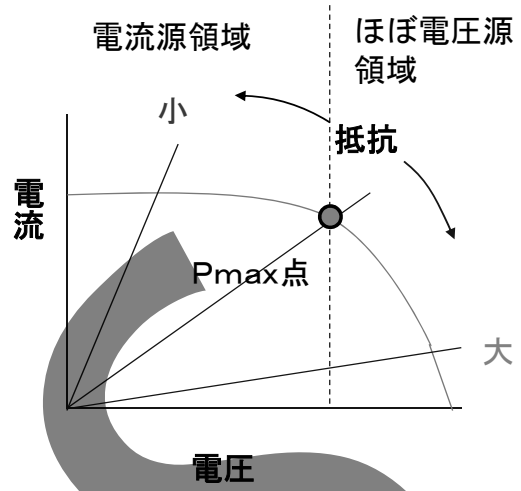
- ・柱上トランス (商用交流電源)
- ・鉛蓄電池等

## 定電流源



- ・直流リアクトル
- ・交流L分
- ・その他電流源

## 太陽電池



# International Workshop „Arcing in Photovoltaic DC-Arrays, Burgdorf 10,2007 出典(1)

**International Workshop**  
**Arcing in PV DC-Arrays**

**Scope**  
DC Currents in PV Systems carry the potential of generating arcs and hot spots. This may cause damage to materials, cause losses and represents a risk to human life. The wide and fast growth of the PV-market requires careful investigations and assessment of the different risks involved. Also, better understanding of failure mechanisms is called for and the reduction and elimination of the risk of such incidences occurring have to be considered and implemented. The workshop aims to initiate and support this process. Highly-qualified and experienced experts will report on the subject and discuss future strategies for improved safety.

**Who should attend:**

- PV module and inverter manufacturers
- Educational sector such as universities, colleges of advanced technology and lecturers of training courses
- Research Institutes
- Industry for PV BOS-components such as switching devices, cables, fuses, junction boxes and connectors
- Engineering offices, systems developers and PV experts

**International Workshop**  
**Arcing in Photovoltaic DC-Arrays – Potential dangers and possible solutions**

**Date: Wednesday, 31st October 2007 // BFH Burgdorf, Switzerland**  
Organizer: Swissolar in collaboration with Prof. Dr. H. Häberlin, BFH, Electrosuisse and Working Group Members of IEC TC82  
Moderator: Dr. Markus Real

1. Inception, inscription, Coffee	09:30 – 09:30	
2. Welcome	09:30 – 09:40	Dr. S. Nowak, Programmierchef BFE Th. Hostettler, Delestage Geneva
3. Failure mechanism of contact faults in the DC-circuit of PV Arrays	09:40 – 10:10	Wili Vassian, TÜV
4. Arcing potential in contacts and plugs	10:10 – 10:30	Markus Kiefer, Mülheim
5. Arcing in a DC circuit breaker: lessons learned at the Mont Soleil PV plant	10:30 – 10:50	Dr. Rudolf Minder, Minder Energy Consulting, Speaker: Th. Hostettler
6. Coffee break	10:50 – 11:20	
7. Arcing potential in fuses: missing standards for adequate testing of fuses in PV application	11:20 – 11:50	Peter Kriem, Head of DEF-373 and 4221.1.4
8. Arcing potential within PV Module contacts and solutions	11:50 – 12:20	Martin Conrad, Sunlog PV, UK
9. Risk Analysis as a Prerequisite for Insuring of Product Liability	12:20 – 12:45	Christoph Sigrist, Zurich Obbel Corporate Switzerland
10. Lunch	12:45 – 14:30	
11. Solutions, State of the art, missing elements in standards	14:00 – 14:30	Chuck Wheatley, BEV Engineering, USA
12. Arc detector, principles and functionality	14:30 – 14:50	Prof. Dr. H. Häberlin, BFH, Burgdorf, Switzerland
13. Demonstration of arcs and functionality of an arc detector in a real life situation, video transmission	14:50 – 15:20	Prof. Dr. H. Häberlin and Jaskarik
14. Coffee break	15:20 – 15:40	
15. Podium session How serious is the problem of arcs for the potential dissemination of PV? What are the solutions against arcing and their consequences? Are there new needs for standards or possible IEC standards?	15:45 – 16:45	Moderator: Markus Real Podium: Martin Conrad, Herrlich-Häberlin, Markus Kiefer, Peter Kriem, Peter Tagg, Wilko, Wili Vassian and Chuck Wheatley
16. Closing of the International Workshop on Arcing in PV DC-Arrays – Potential dangers and possible solutions	16:45 – 16:50	Dr. Markus Real

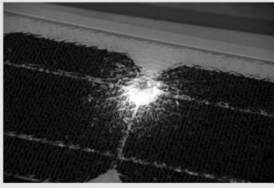
Workshop supported by Swissolar, B.C. Chelmsford, BFH (Bern University of Applied Sciences – Engineering and Information Technology)

Co-Sponsors:

Registration fee for the one-day workshop is CHF 250,- including lunch, coffee and documents as PDF. Participants will receive an agenda. Deadline for registration is October 12, 2007.

## 出典(2)

**Failure Mechanism of Contact Faults in the DC- Circuit of the PV Arrays**  
 - Are the existing safety concepts for grid-connected photovoltaic systems sufficient? -

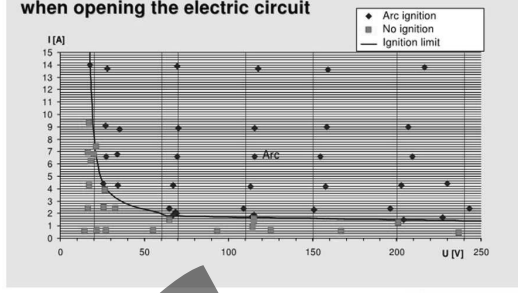


Willi Vaaben, Jan Zornikau  
 TÜV Rheinland Immissionsschutz und Energiesysteme GmbH  
 Am Grauen Stein, 51105 Köln, Germany  
 Tel.: 0221/806 2910, Fax: 0221/806 1350  
 E-Mail: willi.vaassen@de.tuv.com  
 Internet: www.eco-tuv.com

1 International Workshop, Arcing in Photovoltaic DC-Arrays, Burgdorf 10.2007

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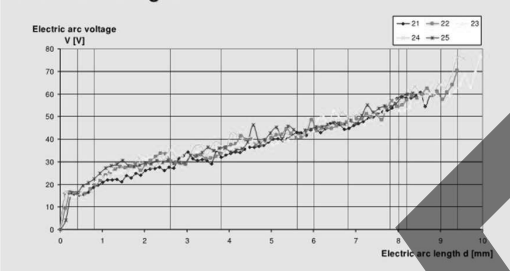
**Electric arc investigations**  
 Circuits and voltages at electric arc ignition when opening the electric circuit



12 International Workshop, Arcing in Photovoltaic DC-Arrays, Burgdorf 10.2007

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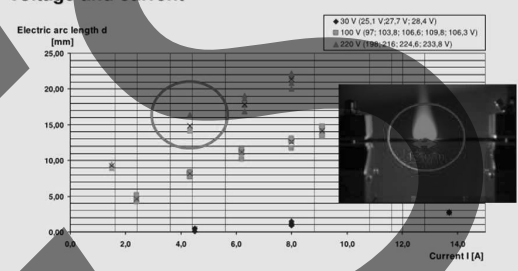
**Electric arc investigations**  
 Dependence of the electric arc voltage from the electric arc length



14 International Workshop, Arcing in Photovoltaic DC-Arrays, Burgdorf 10.2007

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**Electric arc investigations**  
 Maximum electric arc length in dependence of voltage and current



15 International Workshop, Arcing in Photovoltaic DC-Arrays, Burgdorf 10.2007

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## 出典(3)

**Arcing potential in fuses: missing standards for adequate testing of fuses in PV application**


Dipl.-Ing. Ing.(grad) Peter Kremer  
 Head of DKE K373 and K221.1.4 (VDE and DIN)

Arcing in PV DC-Arrays

IEC electrosuisse SWISSOLAR  
 DKE VDE DIN

**Arcing potential in fuses**  
 3 PROBLEMS WITH FUSE-LINKS

Picture 4:  
 The day after without PV array junction box

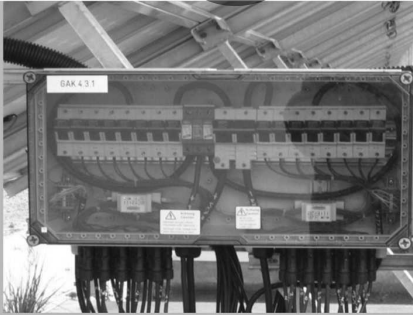


Arcing in PV DC-Arrays

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**Arcing potential in fuses**  
 3 PROBLEMS WITH FUSE-LINKS

Picture 3:  
 PV array junction box in operation  
 This PV array junction box with 8 fuses in "+" string cable and 8 fuses in "-" string cable was operating properly for 2 years in a multi megawatt PV power plant.




Arcing in PV DC-Arrays

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 DKE VDE DIN

**Arcing potential in fuses**  
 3 PROBLEMS WITH FUSE-LINKS

Picture 5:  
 PV generator junction box commissioning



Arcing in PV DC-Arrays

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Picture 6:  
A very nice standing arc

Arcing in PV DC-Arrays

**If we have to install fuses in PV installations then we need a PV fuse standard for requirements and testing (e.g. arcing test) including fuse-holder.**

**Ask PV module manufacturers for the specification of the recommended fuse-link.**

Arcing in PV DC-Arrays



Picture 7:  
Bye bye junction box

Arcing in PV DC-Arrays

**Use only approved PV-fuse-links if they are available.**

**Prefer fuse-less PV installations that's the best solution because it is easy, very save and reliable.**

Arching in PV DC-Arrays

ドイツPV火災事例 Photon 2009/8



BP Solar's product recall

Since 2003, installers have submitted frightening reports of charred junction boxes in BP Solar's modules. The manufacturer reacted as you would expect a multinational concern like BP to react, considering its solar division's total turnover is so insignificant when compared to its other divisions: it didn't do a thing. The BP wheels only got moving once it was clear that the module problem would have repercussions for the entire company's reputation. Believe it or not, at the end of 2006, a whole 3 years after the first complaint, the company launched a product recall.

Indeed, the problem was highly combustible: cold solder joints in the junction boxes produced faulty contacts and, in turn, electric arcs. BP suggested that customers with systems installed near combustible materials shut down their systems and began to replace the faulty products in the winter of 2006. This recall is still ongoing, a fact demonstrated by the missing modules in the 5 MW system in Birstadt, Germany.

A year later, in December 2007, BP Solar was struck by another problem. This time it wasn't a fire hazard, but the risk of electric shock. Apparently, the cell connections were cut with shears rather than a crimping tool. The result was metal bands with sharp edges that could damage the back-side foil. In a



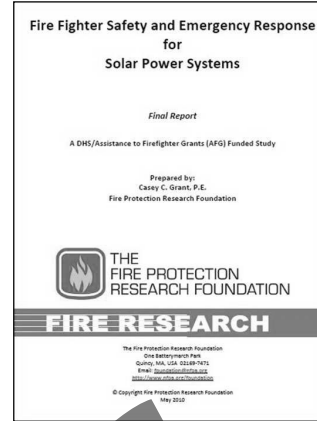
▲ The 5 MW system in Birstadt, Germany, just prior to its completion in April 2005. Of 31 sections – each located on half a shed roof – 15 were covered with BP Solar's Saturn 5 modules, which were recalled in 2006. Today, 11 of these sections are still waiting on new modules. The fire on June 27 started in a section of the system covered with Saturn 7 modules (circled here, at the back right, near the tower).

worst case scenario, this could result in insulation defects and energize the solar generator.

When the second breakdown occurred, the company reacted in good time and without the need for any outside pressure, and started another recall. This recall could be considered

almost exemplary: in fact, in certain ways, BP Solar even profited. Since then, many installers and system operators have realized a milestone: like the one that struck BP can happen to other manufacturers, but no other company is in a position to launch a similar recall.

# アメリカ



出典(4)

- ・2003年ごろからPV火災消火時消防士が感電することがあり問題視されはじめた
- ・2010年5月 「太陽電池に対する消防士の安全かつ迅速な対応」 火災保護研究協会が発行(2013/10改訂)
- ・2011年 NFPA70 NEC 690.11 アーク事故回路保護 追加

## NEC ARTICLE690 Solar Photovoltaic (PV) Systems

2008年版

- 690.10 自立型システム
- Ⅲ 断路装置
- 690.13 全ての導体

2011年版

- 690.10 自立型システム
- 690.11 アーク事故回路保護(直流)
- Ⅲ 断路装置
- 690.13 全ての導体

### 690.11

80V以上のPVシステムにはリストに載ったアーク事故回路を遮断する装置を設置しなければならない。

## ナショナルセミコンダクターアーク検出評価ボード

National Semiconductor Corporation  
2300 Semiconductor Drive  
PO Box 50000  
Santa Clara, CA 95052-8000 USA  
+1 408 721 5000 Tel  
www.national.com

**NEWS RELEASE**

For More Information Contact

ナショナル セミコンダクター 太陽光発電システムの危険なアーク故障を検出するSolarMagicチップセットとファームウェアを発表

米国電気規格 (NEC) 準拠のアナログ・フロント・エンドICとマルチバンド・ダイナミック・フィルタリング・ファームウェア

2011年6月9日

### アーク評価ボード 2011年半ば

環境の中にある色々なノイズ(ノイズ)からアークによる成分を検出するフィルタ技術(アナログ)を用い、-40Cから+125Cの動作温度範囲をもち、大きさが50mm×30mmの最小サイズを実現した。

#### 特性

- 耐圧(絶縁) 1000 V<sub>rms</sub>
- 最大直流電流 15 A<sub>rms</sub>
- LED 表示
- 動作温度範囲 -40 C ~ +125 C
- サイズ 50 mm × 30 mm
- 低消費電力 < 400 mW

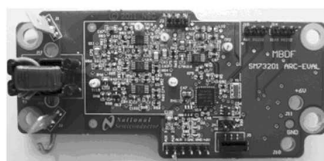


FIGURE 1. Evaluation board

### アークと正常時のスペクトル比較(10~30kHz)

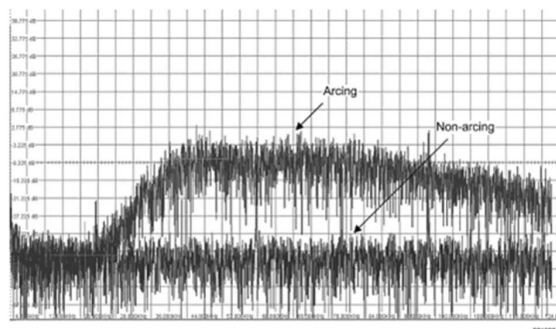


FIGURE 2. Spectrum of Digitized Current on SM73201

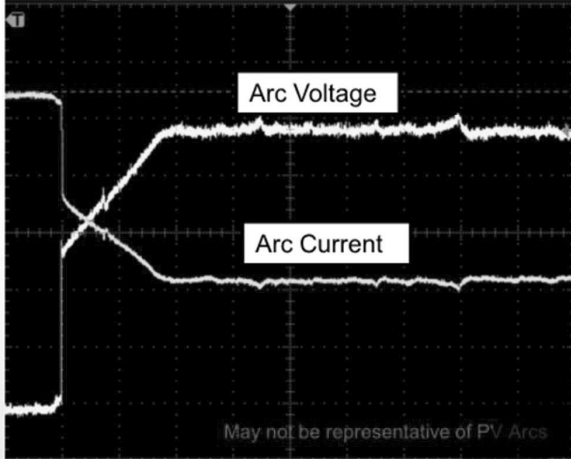
# Overview of Arc-Faults and Detection Challenges

出典(5)

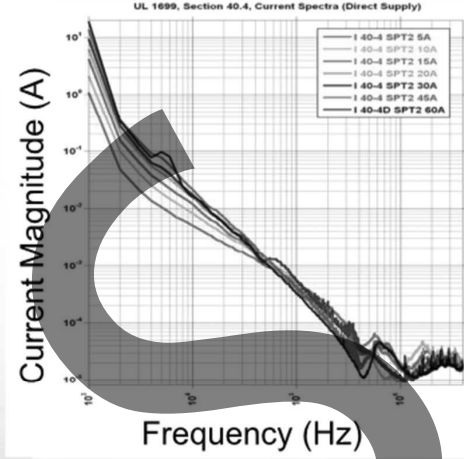
2/8/2011

Jay Johnson  
Sandia National Labs  
(505) 284-9586, jjohns2@sandia.gov

- What is the electrical behavior of an arc?
  - In series arcs, voltage surges and current drops [4]
  - The arcing frequency content is approximately  $1/f$  (pink noise).



Series Arcing Behavior in Time Domain with Increasing Air Gap [4]



Arcing in Frequency Domain [5]

[4] Hastings, J. K., Zuercher, J.C. and Helzmannseder, E., "Electrical Arcing and Material Ignition Levels," SAE 2004 World Congress & Exhibition, Detroit, MI, March 2004.  
[5] Brazis, P. W. Jr., Private Transaction with Underwriters Laboratories.



Jay Johnson

2/8/2011

Slide 4 of 5

Sandia National Laboratories

出典(6)

## PV Arc Fault Protection

Tim Zgonena  
Underwriters Laboratories Inc (UL)

February 8, 2011

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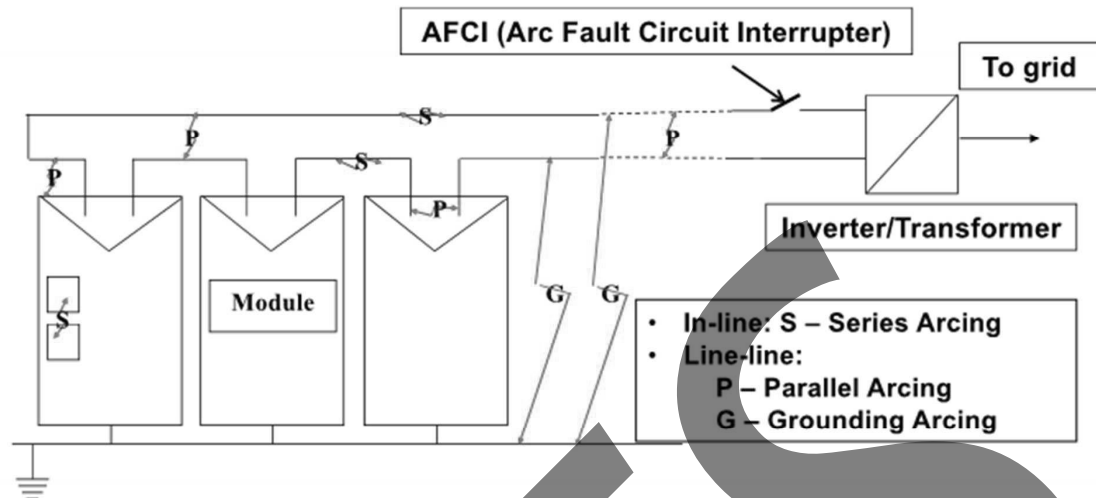
### Residential PV Arc and Fire 2/10/2009



6



# PV Arcing



On this chart, AFCI only works for series arcing, if installed on modules, it can protect from parallel or grounding arcing.



3

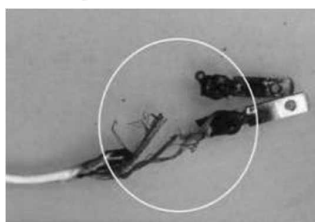
## 電気火災の種類

- ・金原現象.....ラス張り建材での配線工事不良による木材の炭化・発火(?)
- ・亜酸化銅増殖発熱現象・・端子部の電気接続不良による火花・微小間欠アークによる亜酸化銅を介した通電発熱・発火・極間短絡・アークに至る
- ・トラッキング.....絶縁物の炭化により極間短絡、アークの発生による発火  
コンセントへの埃堆積による極間短絡・アーク・火災
- ・アーク.....電気火災原因の最終形

電気痕と火災 <http://www7a.biglobe.ne.jp/~fireschool2/d-A1-56-3.html>

短絡痕には、「一次痕」と「二次痕」そして「熱の溶融塊」がある。

- ・一次痕は火災出火場所に多く、二次痕はコードなどが炎で焼け落ちて極間短絡などで発生する。(溶融痕は高温により電線部材が溶けて出来るようである)



プラグの直近で、半断線で短絡出火した一次痕



換気扇の器具コードに発生した二次痕

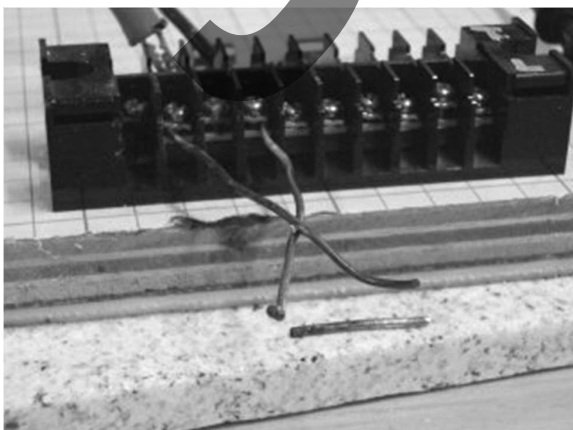
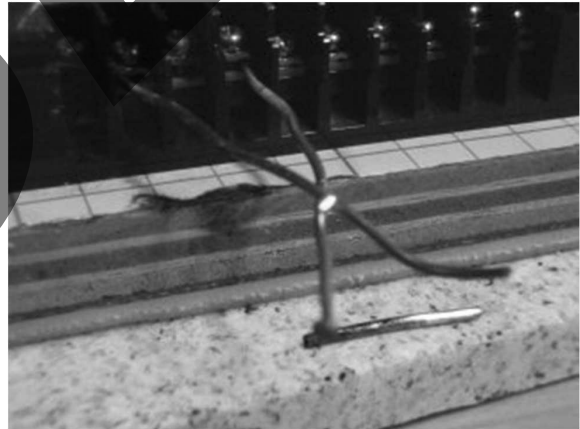


## 電流による亜酸化銅の増殖・発熱現象

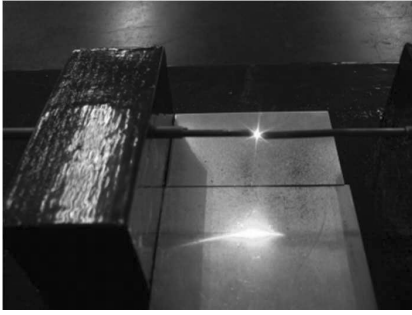
堀田 悦博 北西 晃久  
(名古屋市消防局)

### 1. まえがき

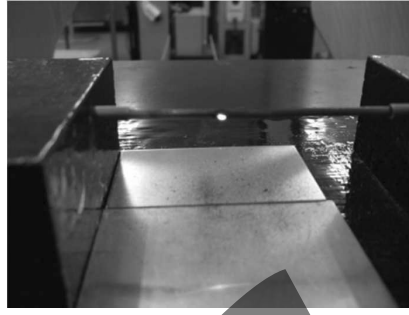
電気回路の一部分に銅または銅合金をもって構成される接触点があって、その接触状態が電氣的に不良になった場合、未知のあるキツカケによって接触点に亜酸化銅( $Cu_2O$ )が生成し、それが電流の作用によって成長して行くことがある。この現象が発生しているときは、抵抗発熱によるかなりの温度上昇があるため、一般の電気器具または設備の一部においてこの現象が発生すると、一アンペア未満の小電流によっても絶縁物や支持造管材を加熱して発火させるほどの発熱をすることが確認され、実際にしばしば火災の原因になっている。従来不可解とされた小電流による電線等の接続点の発熱発火の機構は、この現象によって説明できるのであり、火災ないし故障の発生防止のためにも注意を拂うべき現象である。



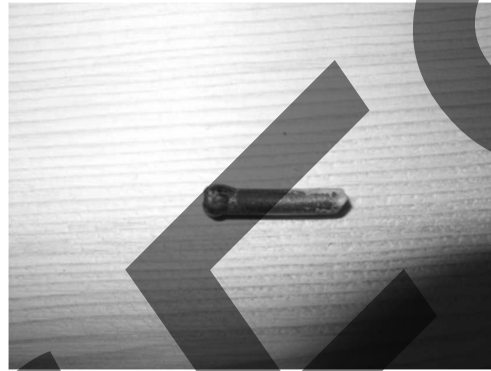
60.3V 5.6A アーク



数度のアーク実験で亜酸化銅増殖  
発熱になった

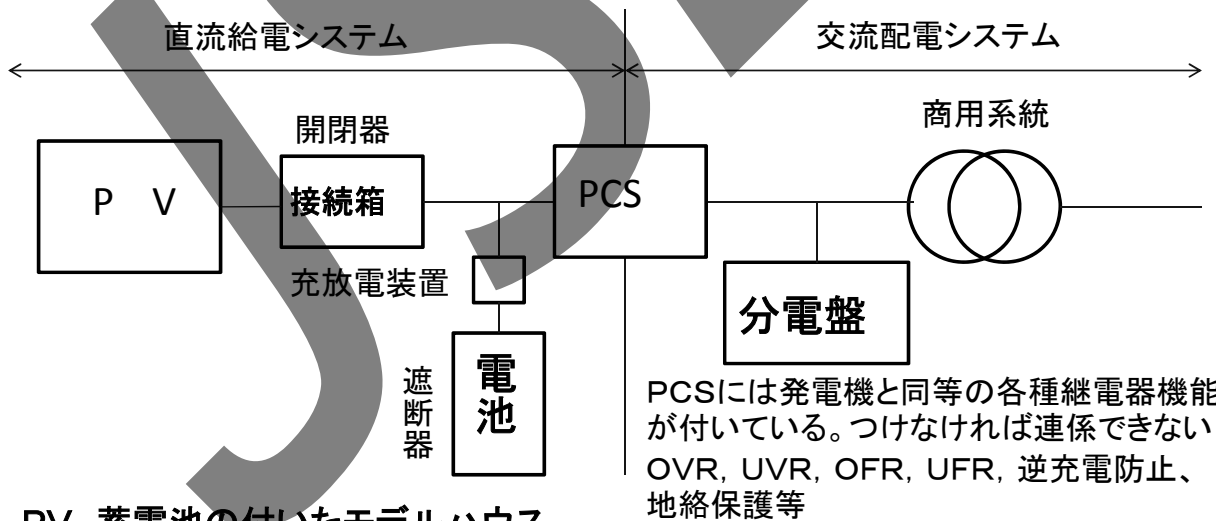


実験後の銅材の先端 電気痕ではなく亜酸化銅



動画

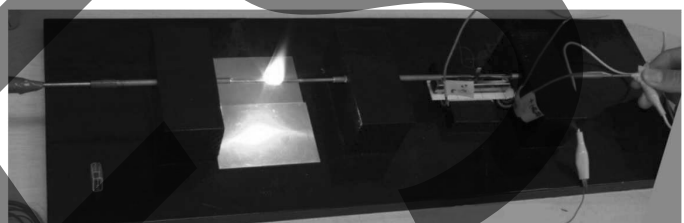
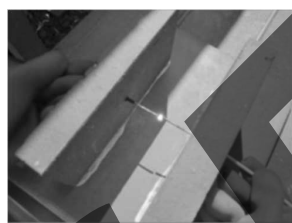
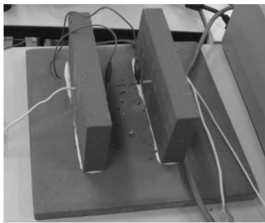
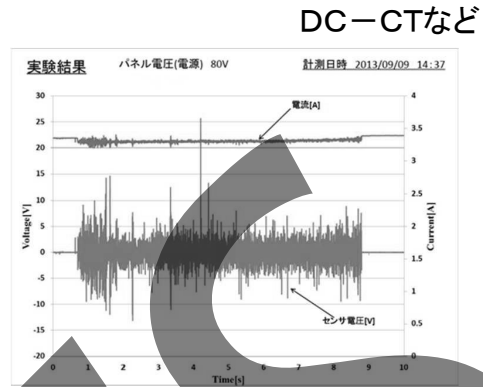
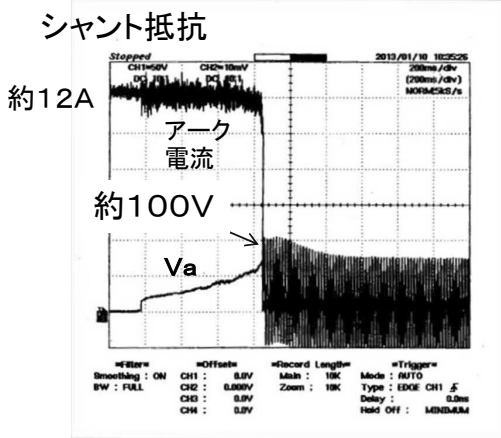
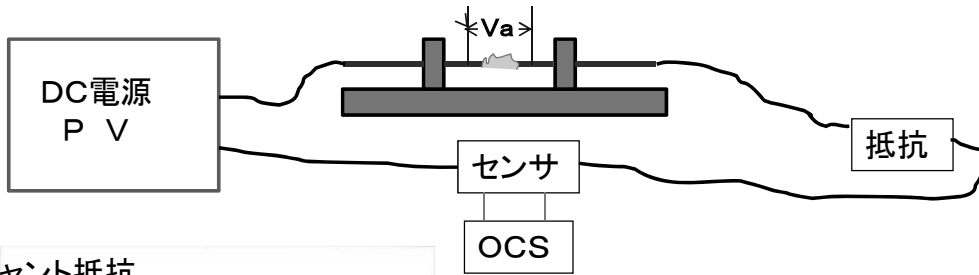
## 太陽光発電システム例



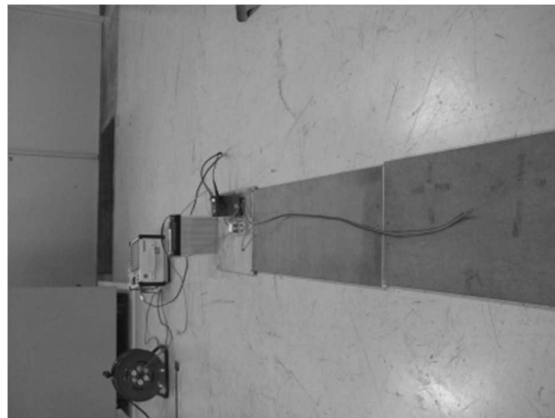
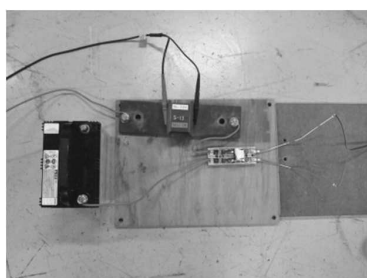
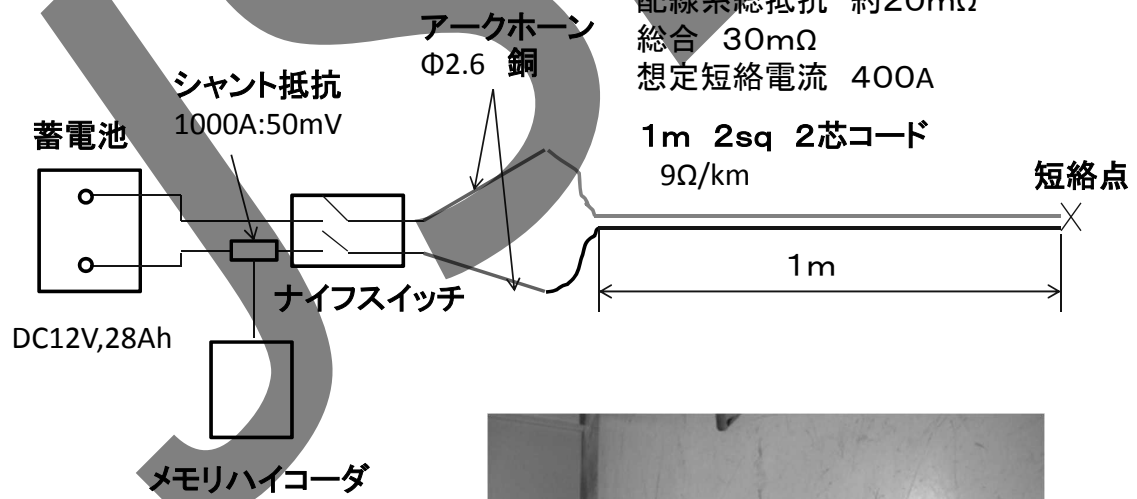
PV, 蓄電池の付いたモデルハウス



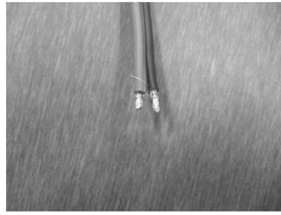
6kWh  
リチウムイオン電池



### 蓄電池短絡実験



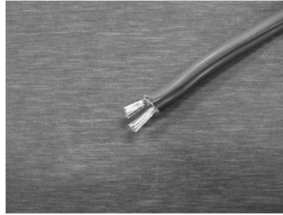
Φ0.2で先端短絡



短絡線溶断のみ  
最大400A程度

動画

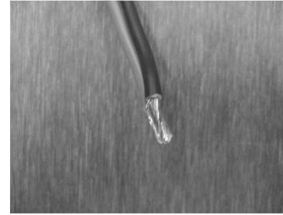
芯線1本短絡



芯線溶断のみ  
最大400A程度

動画

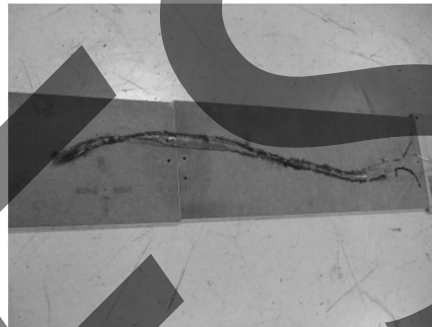
両極よりあわせ



被覆が溶け電磁反  
発で電線が離れる  
200Aで継続中止

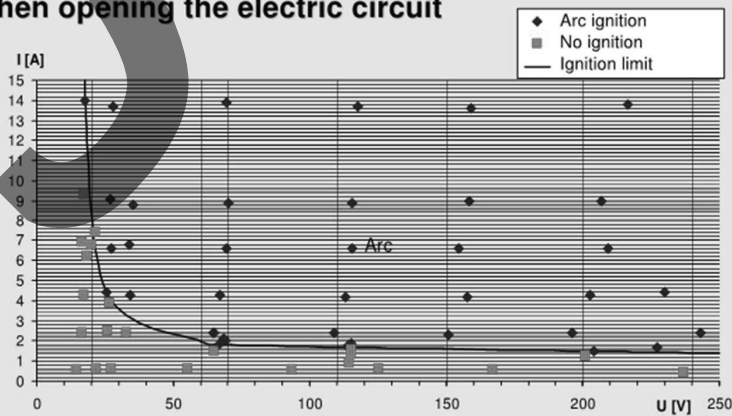
動画

### より合わせでの短絡結果



- ・電流は200A~400Aと大きくても、電圧が12V程度と低いためアークは出なかった  
アークを出すには電池が4直程度は必要
- ・先端を寄った場合は過電流で加熱し被覆が溶け、電磁反発で芯線は離れる  
また芯線は赤熱し抵抗が大きくなり電流は200Aとなった

### Electric arc investigations Circuits and voltages at electric arc ignition when opening the electric circuit



## 出典一覧

(1)[http://www.pvtest.ch/fileadmin/user\\_upload/lab1/pv/Workshop\\_Tagungen/Flyer\\_minutes\\_workshop\\_arcing.pdf#search='International++Workshop+%2CArcing+in+Photovoltaic+DCArrays%2C+Burgdorf++10%2C2007'](http://www.pvtest.ch/fileadmin/user_upload/lab1/pv/Workshop_Tagungen/Flyer_minutes_workshop_arcing.pdf#search='International++Workshop+%2CArcing+in+Photovoltaic+DCArrays%2C+Burgdorf++10%2C2007')

(2)[http://www.pvtest.ch/fileadmin/user\\_upload/lab1/pv/Workshop\\_Tagungen/W\\_Vaassen\\_Lichtbogen-Burgdorf\\_E.pdf](http://www.pvtest.ch/fileadmin/user_upload/lab1/pv/Workshop_Tagungen/W_Vaassen_Lichtbogen-Burgdorf_E.pdf)

(3)[http://www.pvtest.ch/fileadmin/user\\_upload/lab1/pv/Workshop\\_Tagungen/C\\_Koerner\\_Arcing\\_potential\\_in\\_fuses\\_DKE\\_Kremer\\_1031.pdf](http://www.pvtest.ch/fileadmin/user_upload/lab1/pv/Workshop_Tagungen/C_Koerner_Arcing_potential_in_fuses_DKE_Kremer_1031.pdf)

(4)<http://www.nfpa.org/~media/Files/Research/Research%20Foundation/Research%20Foundation%20reports/For%20emergency%20responders/RFFirefighterTacticsSolarPowerRevised.pdf#search='Fire+Fighter+Safety+and+Emergency+Response+for+Solar+Systems'>

(5)[http://www.solarabcs.org/about/publications/meeting\\_presentations\\_minutes/2011/02/pdfs/Johnson\\_Presentation.pdf](http://www.solarabcs.org/about/publications/meeting_presentations_minutes/2011/02/pdfs/Johnson_Presentation.pdf)

(6)[http://www.solarabcs.org/about/publications/meeting\\_presentations\\_minutes/2011/02/pdfs/Zgonena\\_Presentation.pdf#search='PV+ARK+PROTECTION+UL+8%2F2011'](http://www.solarabcs.org/about/publications/meeting_presentations_minutes/2011/02/pdfs/Zgonena_Presentation.pdf#search='PV+ARK+PROTECTION+UL+8%2F2011')

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