DC ARC FAULT SCENARIOS AND DETECTION METHODS IN BATTERY STORAGE SYSTEMS

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ICDCM

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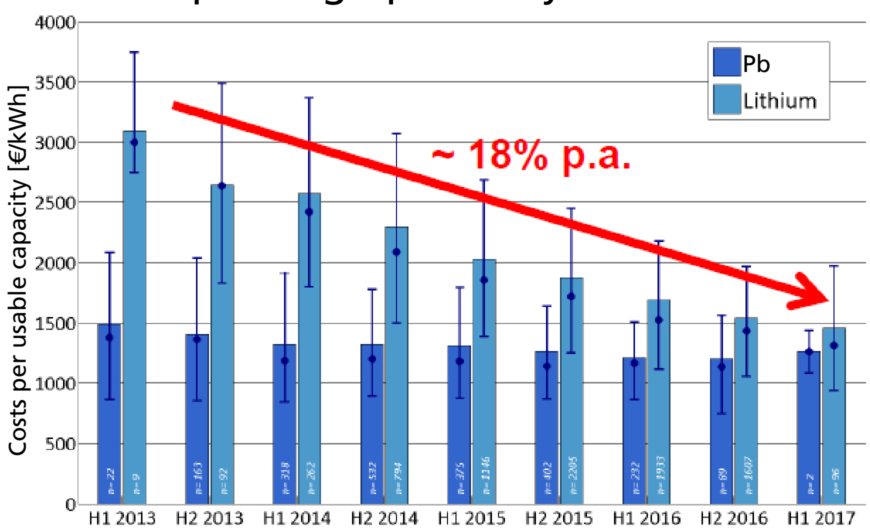
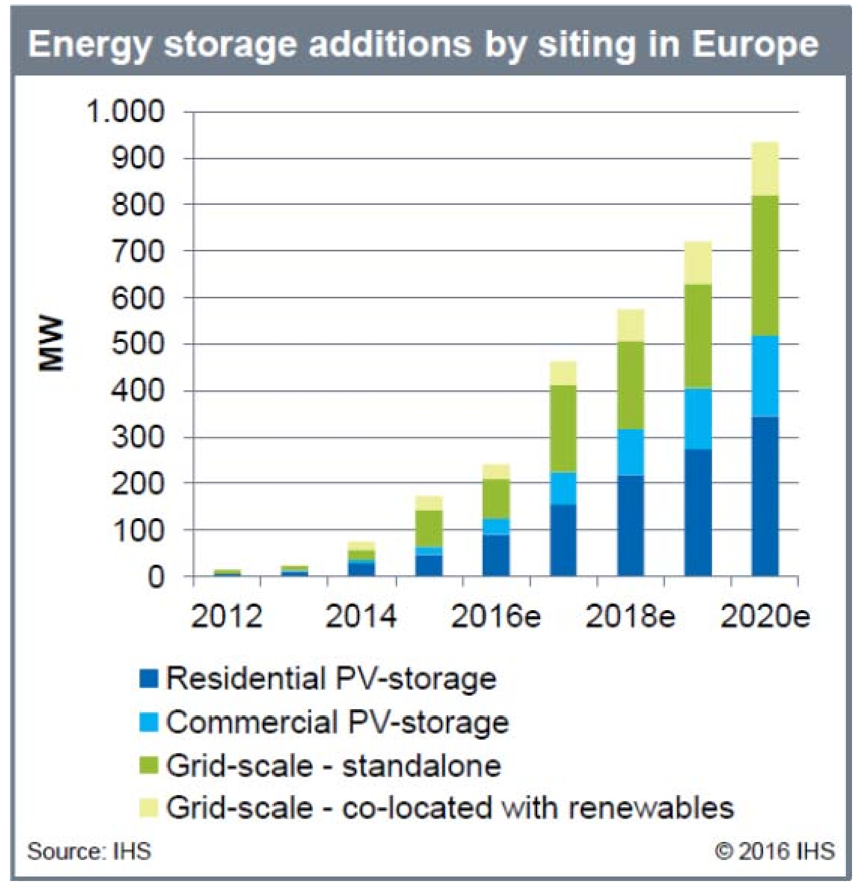
AGENDA

- Introduction
- Basics of DC arc faults
- Arc fault scenarios in battery systems
- Fault simulation in DC systems
- Conclusion

Introduction
Market developments

- Falling prices for Lithium-Ion batteries have driven demand upwards
- More than 60.000 residential Li-Ion systems installed in Germany (20.000 in 2016!)
- Growing market to be expected from low up to high power systems





Source left: K.-P. Kairies, ISEA, RWTH Aachen, 2017 [1]

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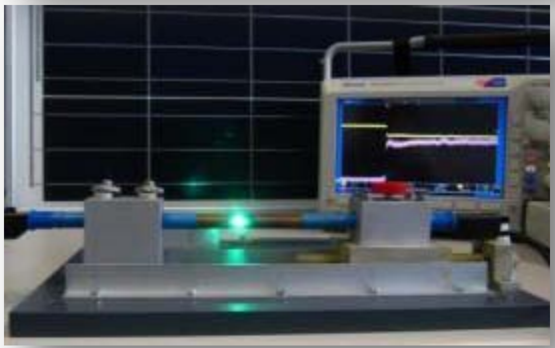
Introduction
Research motivation

- Every electrical installation bears an inherent risk of fire, mainly through
  - Increasing contact resistances or
  - Arc faults
- Arc faults in DC systems are more critical than in AC due to continuous current flow
- High levels of energy density in battery storage systems require quality standards and fire prevention methods
- Research project SPEISI is aiming at these open issues



Project partner:

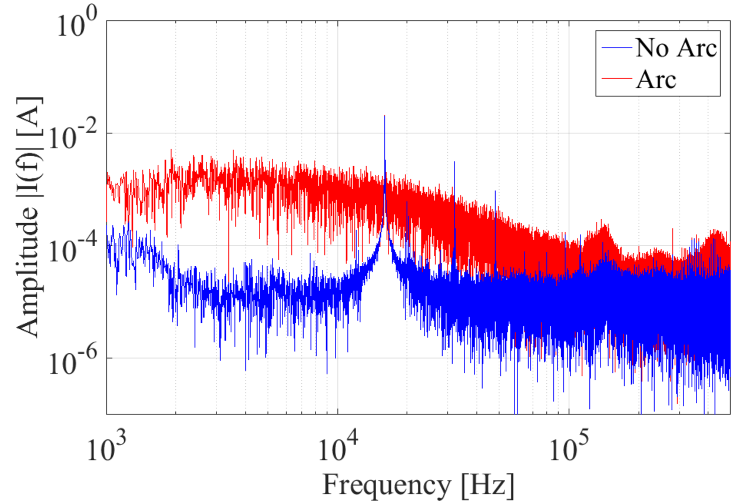
TÜVRheinland® Genau. Richtig.

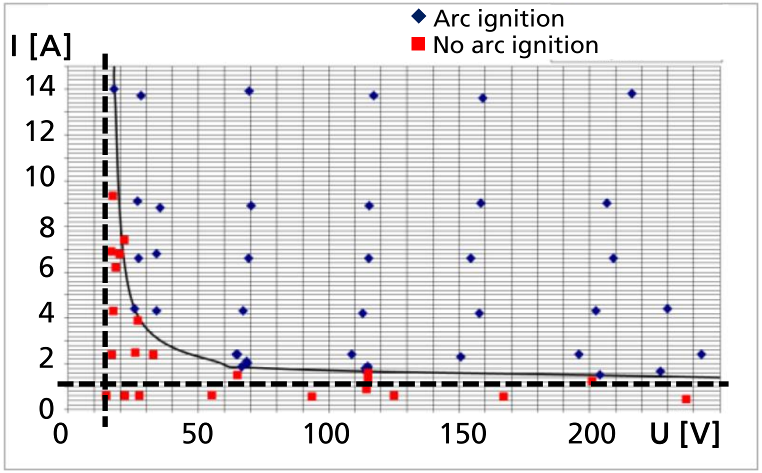
DGS Berlin
Deutsche Gesellschaft für Sonnenenergie e.V.
International Solar Energy Society, German Section

ZSW

Basics of DC arc faults
Characteristics

- Series arc faults triggered by loose contactors, broken isolation, bad solder joints etc.
- Arc emits a broadband high frequency voltage noise with a 1/f characteristic (pink noise)
  - Measurable as impedance-dependent current noise
  - $\underline{I}_{Arc}(f) = \underline{V}_{Arc}(f) / \underline{Z}(f)$
- Minimal voltage for stable arc ca. 15 V
- Minimal current ca. 1 A
- Arcing voltage will change operating point of DC system





Source down: J. Zornikau, TÜV Rheinland [2]

Basics of DC arc faults
Application

- DC arc fault detection (AFD) mandatory in Photovoltaic systems in the USA since 2011
- Triggered by changes in high frequency current noise and/or operating point

- Inverter integrated devices,…
- combiner integrated devices…
- and standalone devices available.

Source: SMA Solar Technology

Source: SolarBOS

Source up: Santon,
down: E-T-A

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Arc fault scenarios in battery systems
Overview

AC-Coupling

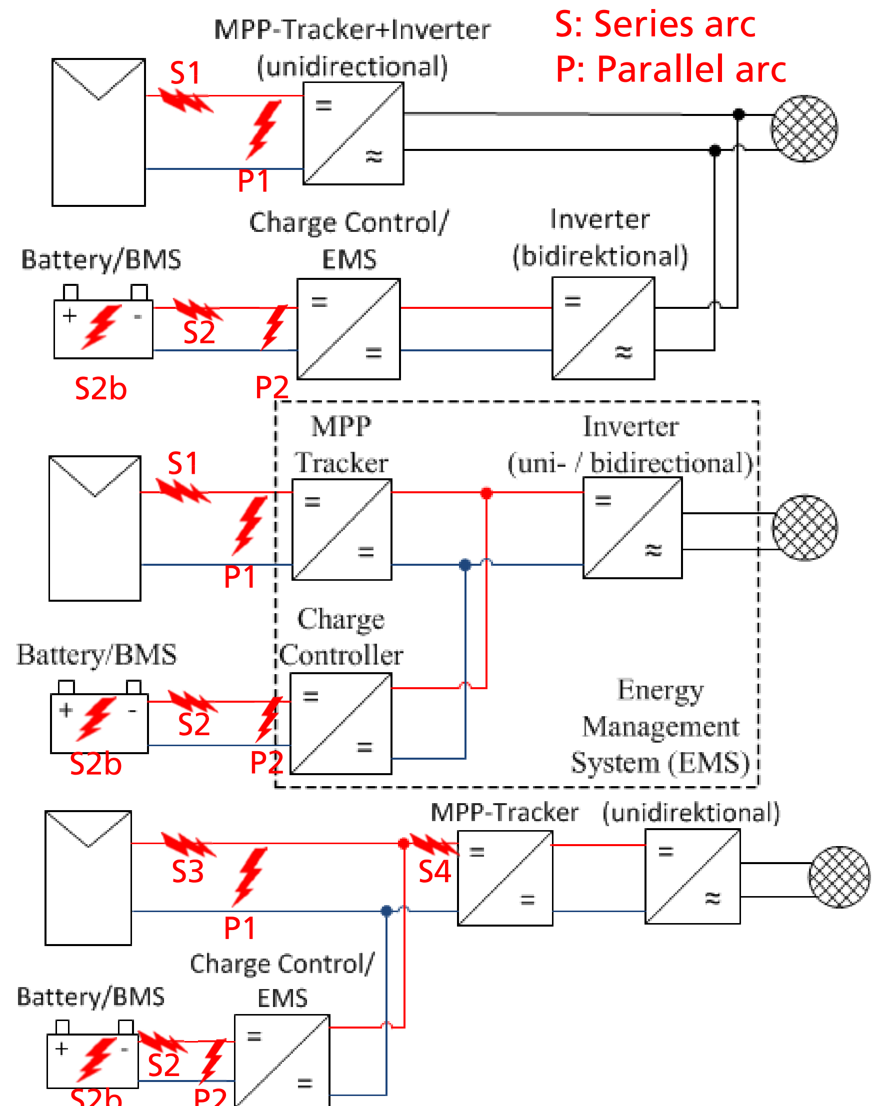
- Sonnenbatterie, SMA Sunny Boy Storage, Varta home, Kaco blueplanet gridsave

DC-Coupling

- Fronius Symo Hybrid, ABB React, Kostal Piko, SMA Sunny Boy Smart Energy, nedap PowerRouter

Generator-Coupling

- Solarwatt MyReserve, sia energy Pro



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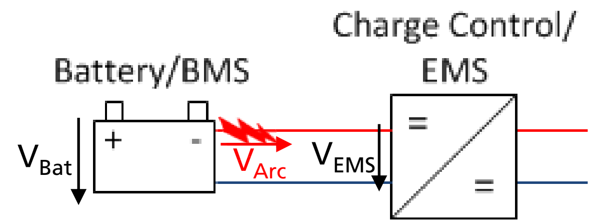
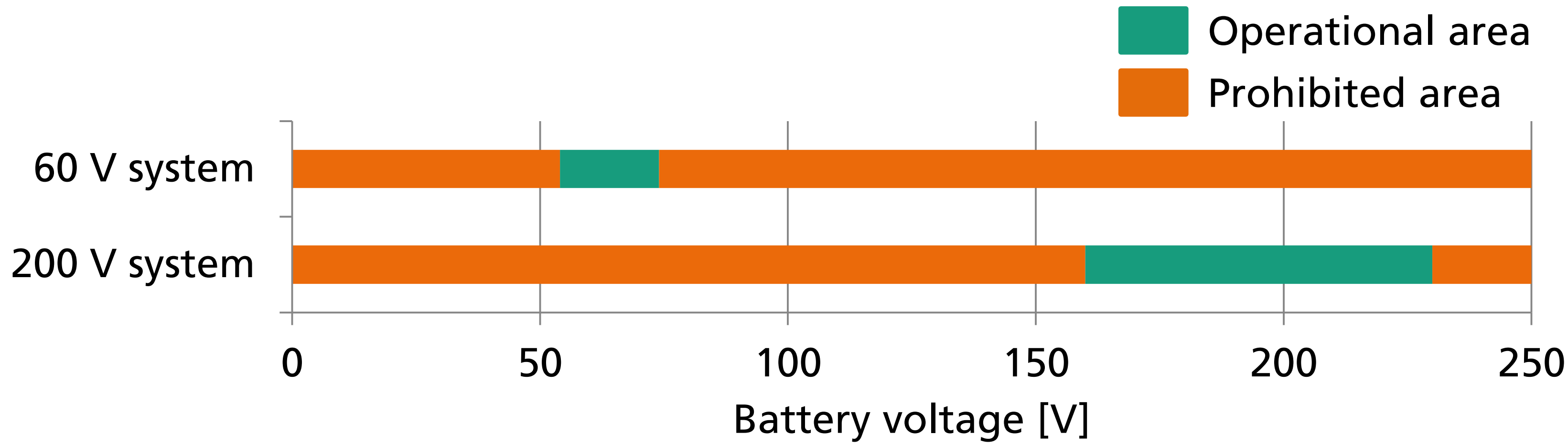
Arc fault scenarios in battery systems

Arc mitigation through EMS



- Conditions for stable arc:
  $V_{Arc,min} \approx 15$ V, $I_{Min} \approx 1$ A
- Conditions not met for battery systems ≤ 60 V
  - Operational area of battery voltage or resulting currents to small



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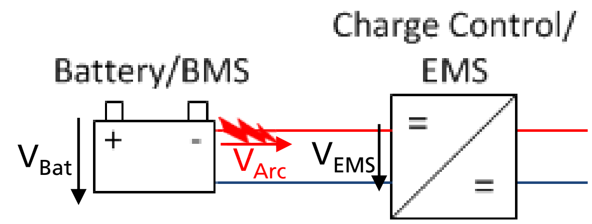
Arc fault scenarios in battery systems

Arc mitigation through EMS



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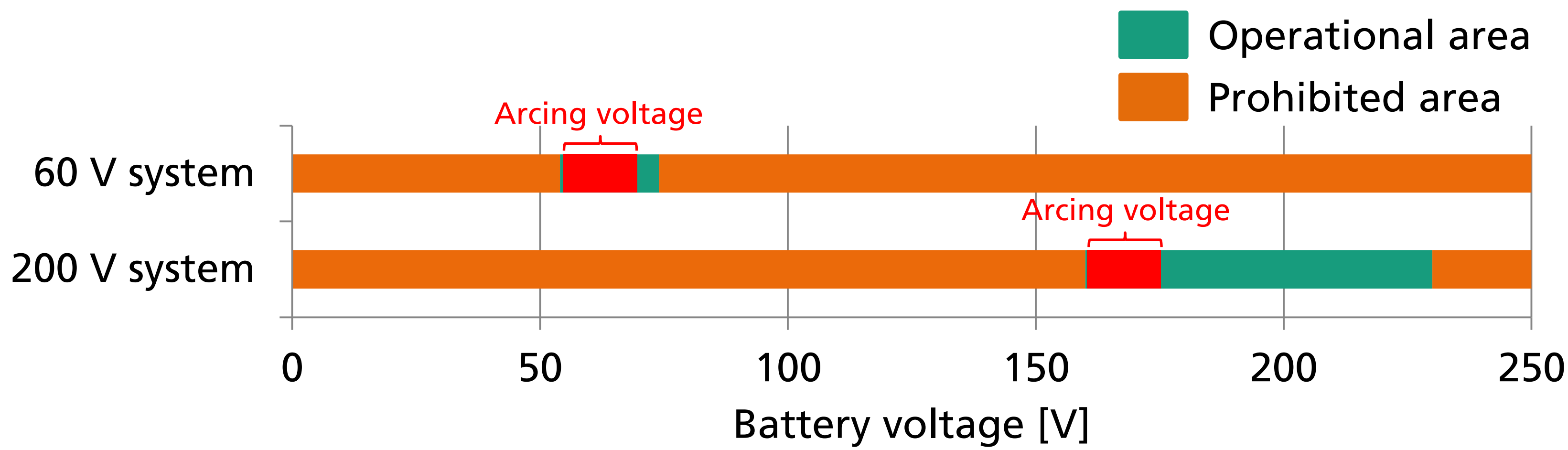

- Series arc faults are actively mitigated by EMS in battery systems ≤ 60 V!

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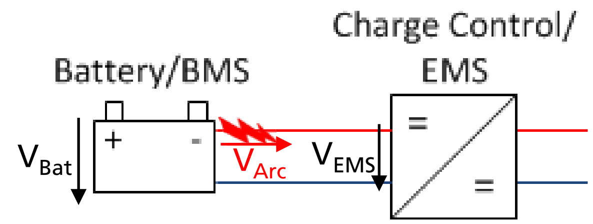
Arc fault scenarios in battery systems

Arc mitigation through EMS



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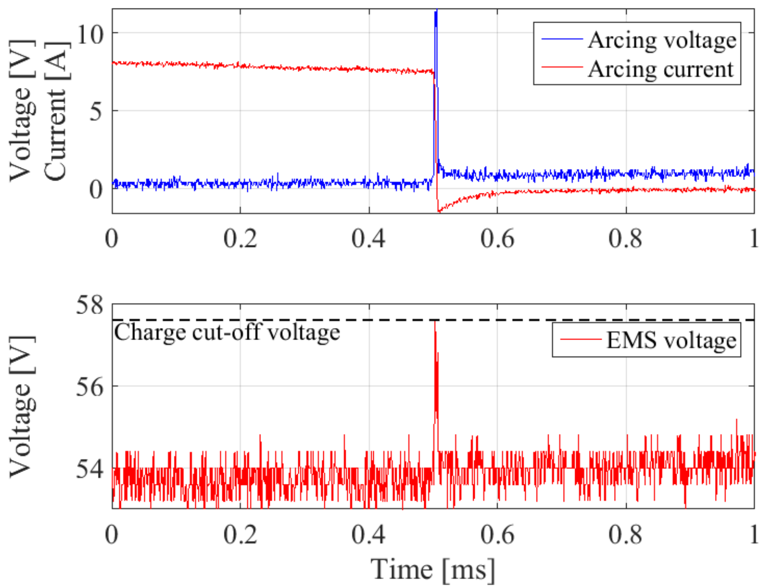

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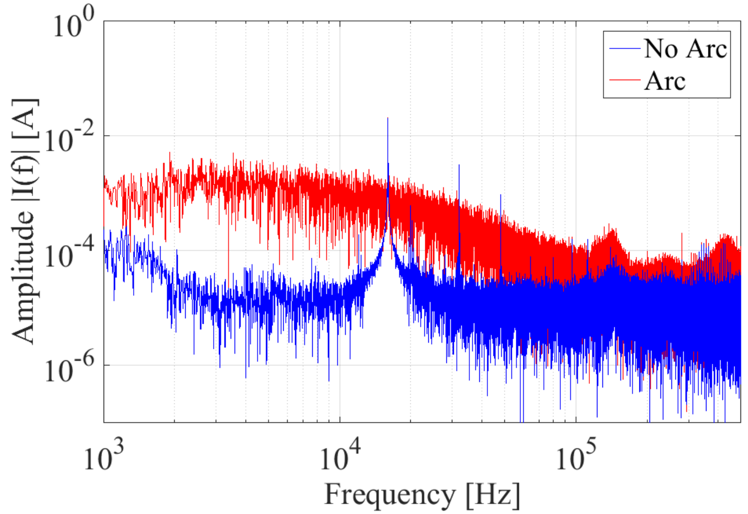
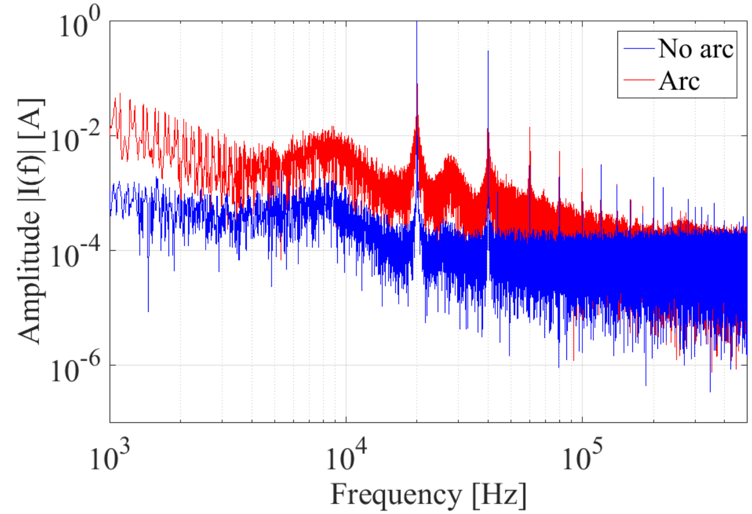
Arc fault scenarios in battery systems
Arc detection via noise analysis

- As in PV systems detection is possible via current noise analysis, but:
  - Only possible for DC currents up to 20 A
  - Low system impedance
  - Higher ambient and arcing noise levels
  - Clipping of standard PV AFDs possible

PV system

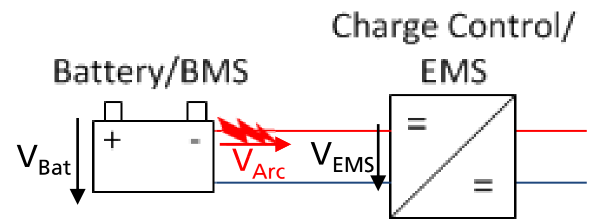


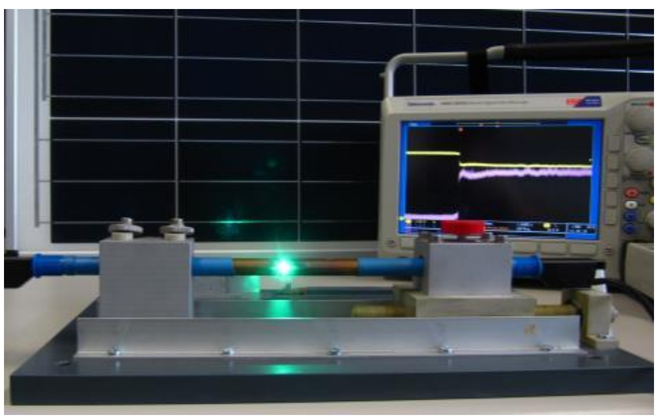
Battery system

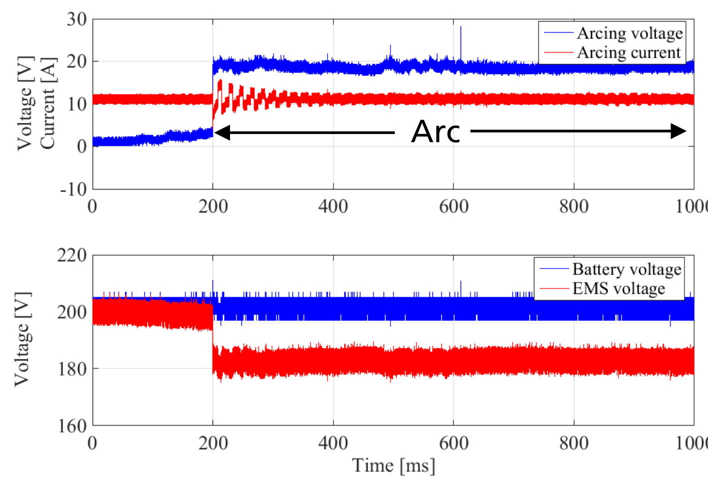


Arc fault scenarios in battery systems
Arc detection via voltage analysis

- Arc fault in 200 V battery system during discharge
  - EMS voltage within operational area
  - Constant current, stable arc







$V_{Bat} \neq V_{EMS}$!

- $V_{Bat} \neq V_{EMS}$ is a simple characteristic for detection of series arcs in battery systems!

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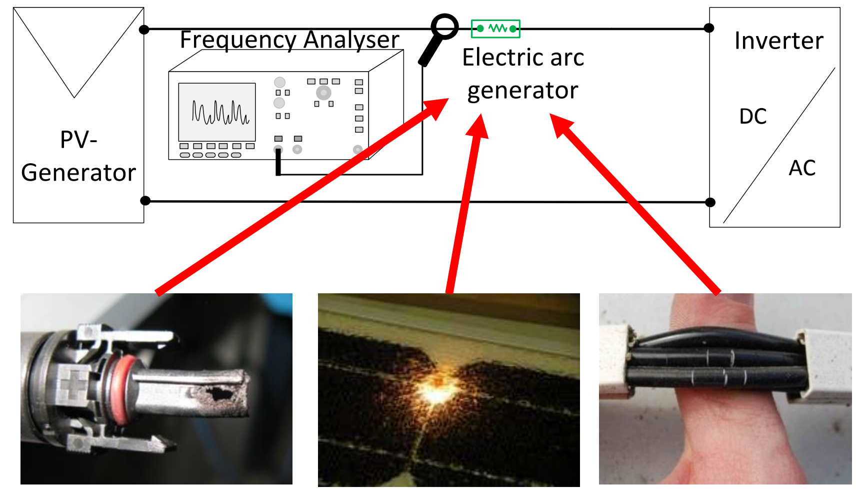
Fault simulation in DC systems
Replay method: scheme

Step 1

- Recording of arcing signal or perturbation in the DC system under test
- Creation of a database with various fault locations, materials, system impedances…



Step 2

- Induction of recorded current signal on DUT in DC circuit
- Control circuit with semiconductor can reproduce the recorded noise up to high frequencies
- Reproducible, partly automatable tests

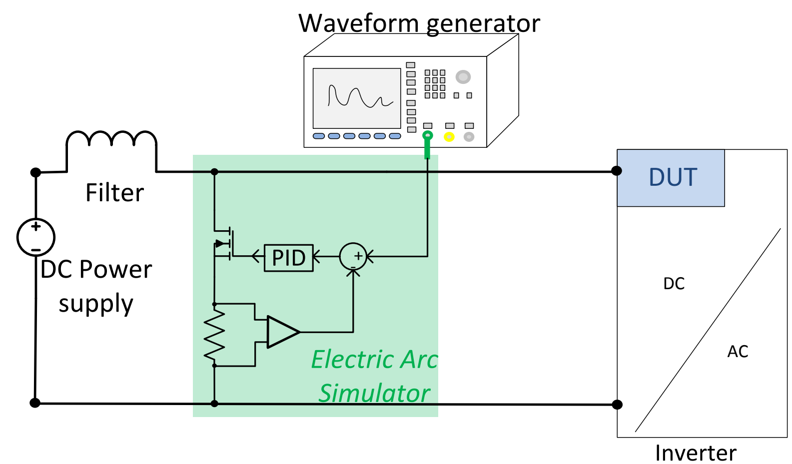


 Image Sources: TÜV Rheinland (middle), Sachverständigenbüro Kuchlmayr, München (right)

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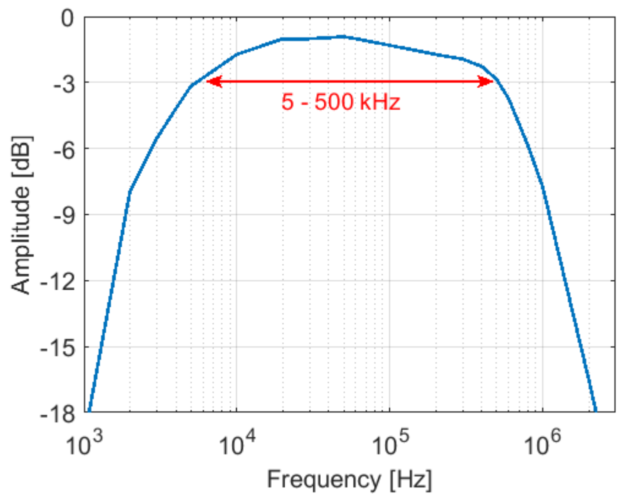
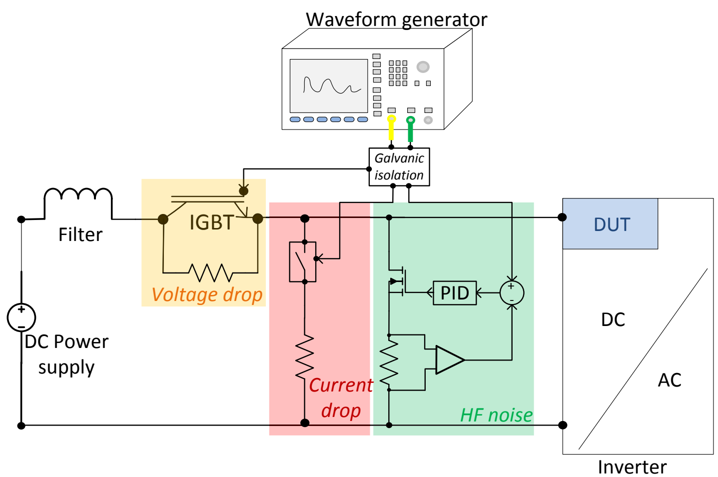
Fault simulation in DC systems
Replay method: realisation

<u>Specification</u>:

- Applicable for DC systems up to 1000 V and 24 A
- Reproduction of noise signals from ca. 5 up to 500 kHz
- Galvanically isolated input signals
- Optional: steps in operation point of up to 40 V or 4 A





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Conclusion

- Arc fault risk depends on system configurations
  - Battery systems ≤ 60 V have no need for arc fault detection
- Simple arc fault detection through voltage measurement at battery and EMS possible
  - Sufficient resolution and data sampling rate required
- Reproduction of arc fault scenarios and other noise perturbations in various DC systems using Replay method
  - Fraunhofer ISE is collecting signal database and is looking for collaboration
- Fire prevention, safe installation and operation of stationary battery systems needs appropriate standards like VDE AR-E-2510-50 or BATSO 01
  - International standards are not covering these topics sufficiently
  - Luckily very few cases of fire through faults at stationary Li-Ion systems are known

Thank you for your kind attention!

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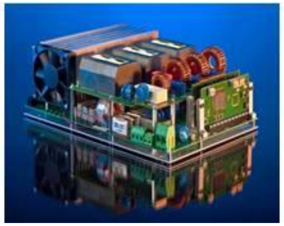
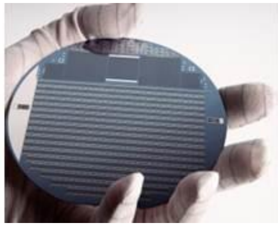


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Sources

[1] K.-P. Kairies, „Die neue KfW-Photovoltaik-Speicherförderung", 32. Symposium Photovoltaische Solarenergie, Bad Staffelstein, March 2017

[2] J. Zornikau, „Untersuchung der Entstehung von Lichtbögen in Photovoltaik- Modulen und Bewertung der Risiken", Diploma thesis, TÜV Rheinland, Cologne, 2007

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