DC ARC FAULT SCENARIOS AND DETECTION METHODS IN BATTERY STORAGE SYSTEMS

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Further information on this publication can be found here:
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]
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:
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
  - \( I_{Arc}(f) = V_{Arc}(f) / Z(f) \)
- 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
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
Arc fault scenarios in battery systems

Arc mitigation through EMS

- Conditions for stable arc:
  \[ V_{\text{Arc, min}} \approx 15 \text{ V}, \ I_{\text{min}} \approx 1 \text{ A} \]

- Conditions not met for battery systems \( \leq 60 \text{ V} \)
  - Operational area of battery voltage or resulting currents to small

![Diagram showing operational and prohibited areas for different battery voltages](image)
Arc fault scenarios in battery systems

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- Series arc faults are actively mitigated by EMS in battery systems \( \leq 60 \text{ V}! \)
Arc fault scenarios in battery systems

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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

![Graphs showing noise analysis in PV and Battery systems](image)
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

\[ V_{\text{Bat}} \neq V_{\text{EMS}} \]

- \( V_{\text{Bat}} \neq V_{\text{EMS}} \) is a simple characteristic for detection of series arcs in battery systems!
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)
Fault simulation in DC systems
Replay method: realisation

Specification:
- 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
Conclusion

- Arc fault risk depends on system configurations
  - Battery systems $\leq 60$ 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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Sources
