Machine-Learning-Based DC Series Arc-Fault Detection

Technical Computing Camp

10 September 2026

EATON
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We protect what matters

Protect **people**, **property** and **assets**

More than **2,000,000** fires are reported in Europe each year.

On average, **90%** of fires in the EU occur in buildings.

4000 people are killed in fires in Europe every year, equivalent to 11 deaths per day.

70 000 people are hospitalised in Europe each year with severe fire-related injuries.

Fire damage costs Europe **€126 billion each year**, equivalent to 1% of European GDP.

Source: Fire Safe Europe

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On average, more than **25%** of fires in Europe are caused by

electrical faults.

Source: Geneva Association, Risk and Insurance Economics

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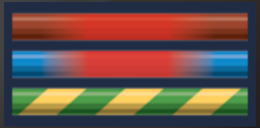
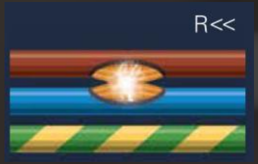
Typical faults detected by conventional protective devices



Overcurrents: typical causes

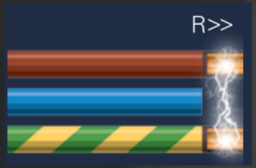
- Insulation defects
- Breakdowns between phases
- Breakdowns between phase and neutral



Short-circuit currents: typical causes

A phase-to-neutral short circuit through a very low resistance, caused by:

- Insulation breakdown
- Mechanical damage to wiring
- Water



Fault currents: typical causes

Changes in the condition and resistance of insulation caused by:

- Ageing
- Mechanical stress
- Dust, dirt and other contaminants

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Another danger remains undetected by these devices:

Electrical arc faults that can ignite fires

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The most common causes of arc faults

- Crushed or pinched wires
- Insulation penetrated by nails or screws
- Insulation degraded by ageing or UV exposure
- Broken conductors
- Cables damaged by pets or rodents
- Loose contacts and connections
- Plugs and wires damaged by excessive mechanical stress

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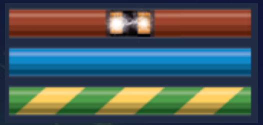
Arc-fault **types**

An arc is similar to microscopic lightning and can ultimately cause major fires and extensive damage. Arcing can originate in:

- Cables and wires
- Fixed electrical installations
- Cables connected directly to equipment
- Cables of equipment connected via socket outlets

Arc faults typically remain undetected by conventional circuit breakers.



Series arcs, approximately 90%

Usually below the rated current:

- **The miniature circuit breaker does not trip**

Parallel arcs, approximately 10%

Often below the rated current:

- **The miniature circuit breaker does not trip**

Between line and protective earth, L–PE

Typically above 30mA

- **The RCD trips**

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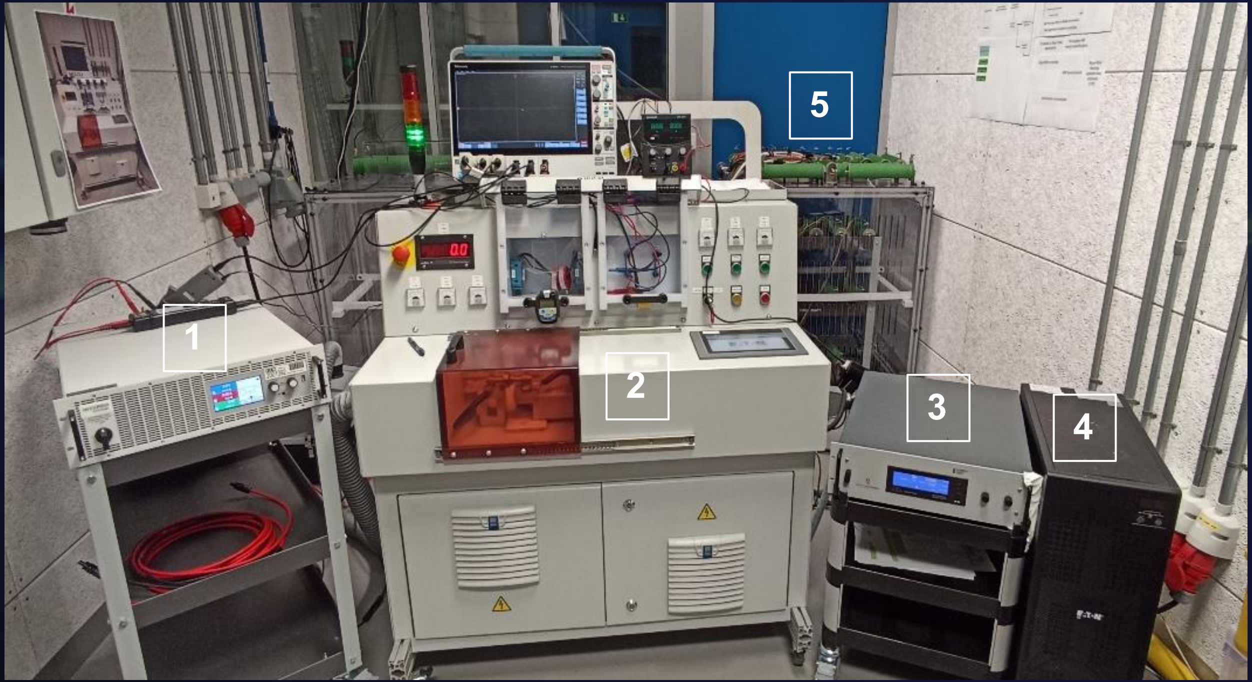
Arc-Fault Generation at the Eaton European Innovation Center



1. Electronic load
2. Arc generator
3. Power source
4. UPS
5. Test area for cables and loads

We perform measurements to collect data that closely represent real-world operating conditions. The data are then analysed and processed to develop an algorithm capable of accurately distinguishing between fault and non-fault conditions. The objective is to create a prototype that can help prevent accidents, fires and other damage in DC grids.

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Arc-Fault Generation at the Research and Innovation Centre for Electrical Engineering

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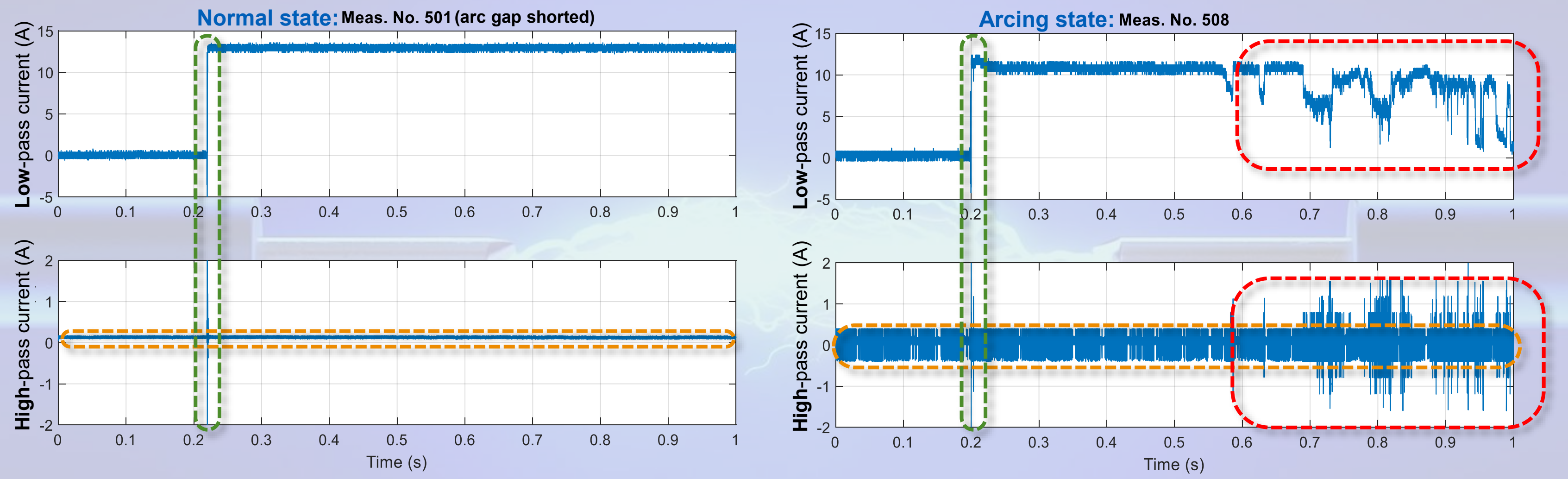
High-Frequency Current Signatures of Arc Faults



Ideal signal decomposition:

Signal = Step change + Measurement noise, present even before switch-on + Arcing noise

Ideal signal decomposition often cannot be achieved, but various signal-processing techniques can provide a useful approximation.

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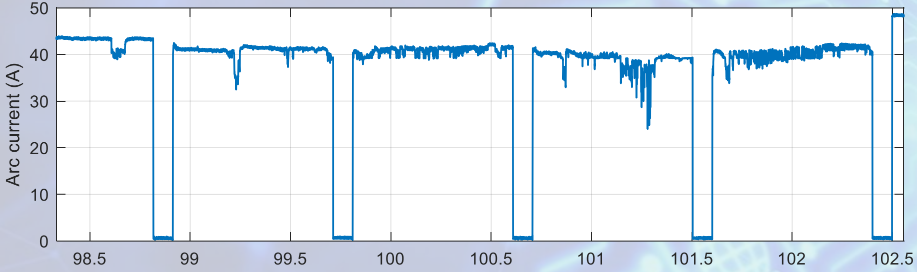
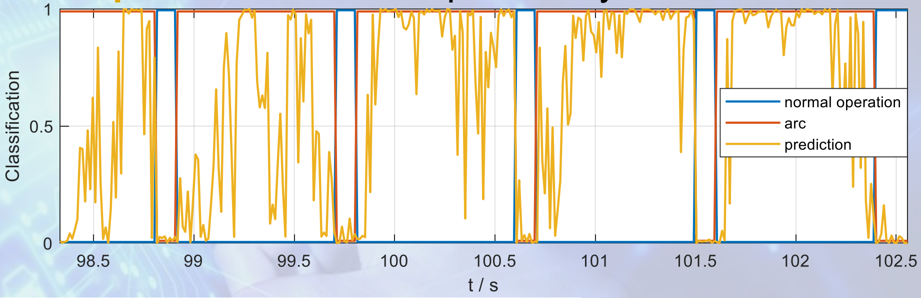
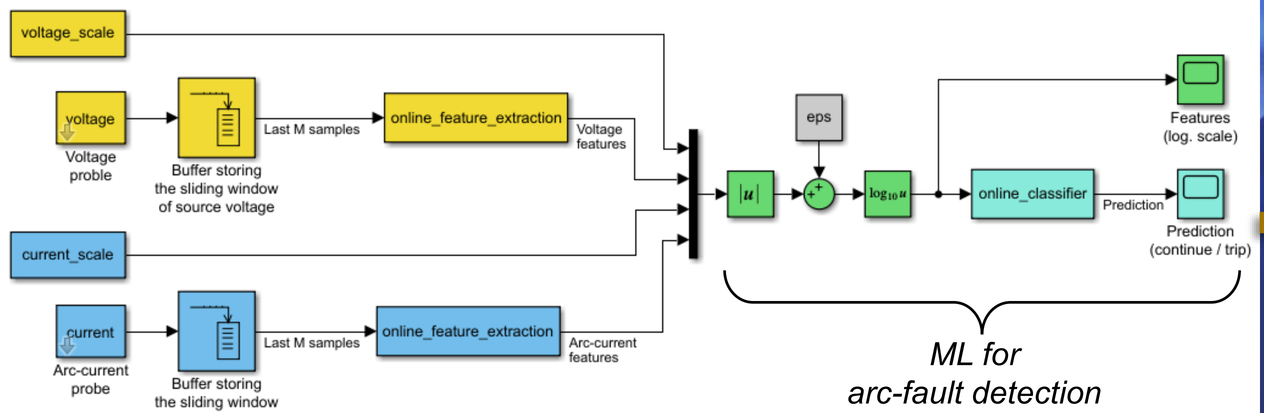
Simulation of Arc-Fault Detection Methods in MATLAB

Measured data: Measured current waveform



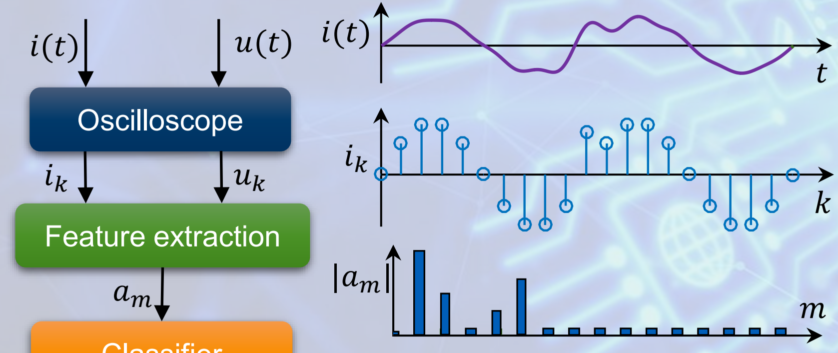
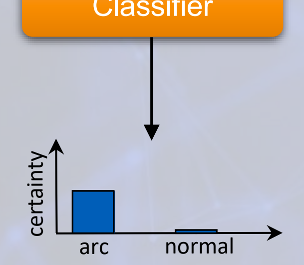
Output data: Predicted probability of an arc fault



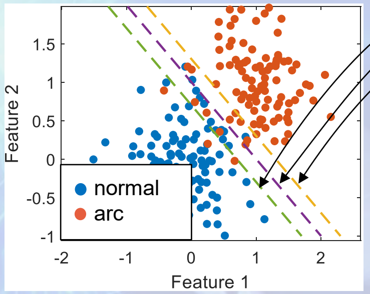


Training Arc-Fault Detection Models Using the Classification Learner App

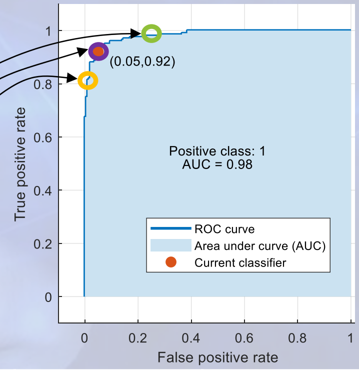
Signal processing chain

Feature space



Receiver operating characteristic



	Method	Abbreviation	Accuracy	Complexity
	Ensemble of logistic regression models	—	☺	☺
	Ensemble of boosted decision trees	CART	☺	☺
	Sparse representation-based classification	SRC	☺	☹
	k-nearest neighbours	KNN	😐	☹
	Support vector machine	SVM	☹	☺
 	Linear and quadratic discriminant analysis	LDA, QDA	☹	☺

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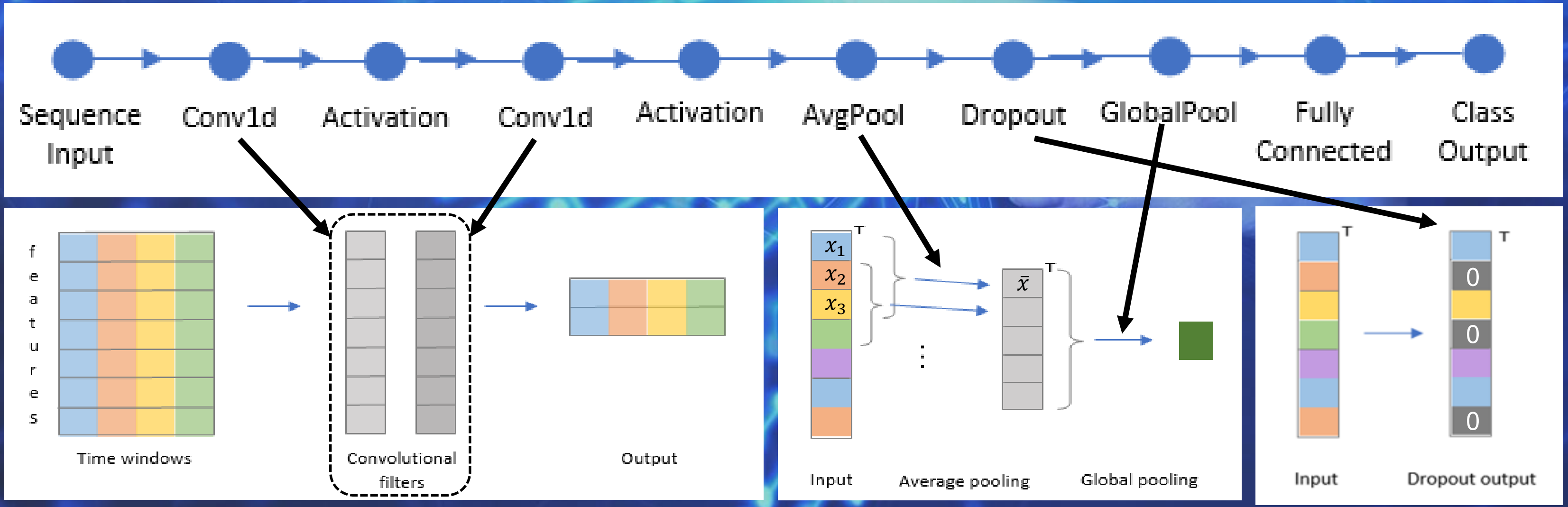
Example of a Shallow Convolutional Neural Network, CNN

- Multiple CNN architectures were evaluated using MATLAB Deep Learning Toolbox.
- Example of architecture used in the cross-validation experiments:



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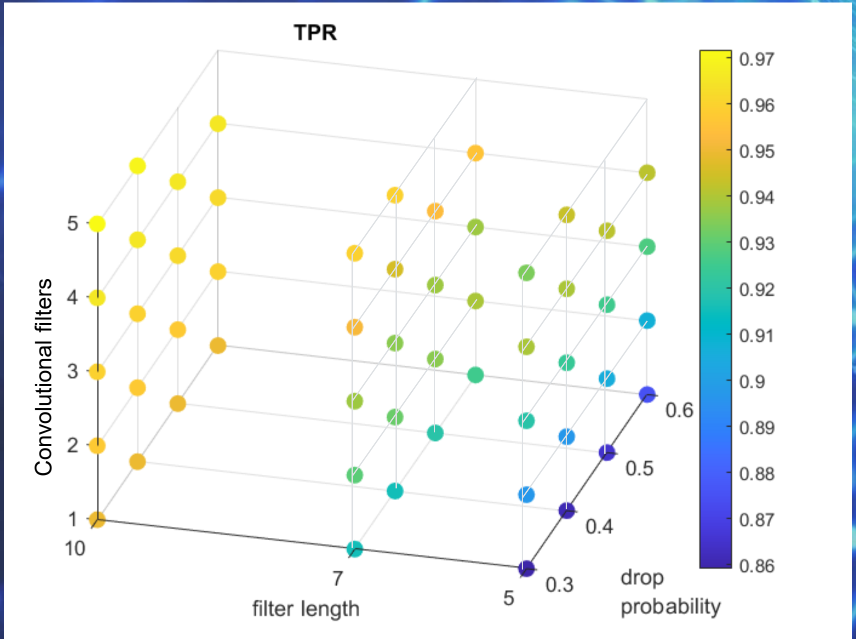
Example of CNN Hyperparameter Optimization Using Grid Search



A total of **144 CNN configurations** were trained using the following hyperparameter values:

- Number of convolutional filters: 1–5
- Dropout probability: 0.3–0.6
- Mini-batch size: 64, 128 or 256
- Pooling-window length: 5, 7 or 10
- Performance metric: **balanced accuracy**, BA

$$BA = \frac{TPR + TNR}{2}$$

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From MATLAB Algorithm to Validated Prototype

Classification Learner workflow:

1. **Train and validate** a classifier in MATLAB Classification Learner
2. **Export** the trained **model** to MATLAB Coder
3. **Generate C/C++ code** for classifier prediction
4. **Integrate** the generated prediction code into the AFDD+ prototype

AC AFDD+

Arc Fault Detection Device with integrated MCB/RCD

DC Protection and switching devices for photovoltaic

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