A generic model for fuses to calculate the transients in low-voltage power networks

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Scope of ProFuDiS
The increase of decentralized energy resources leads to a lot of changes in electrical power networks and therefore also a lot of changes for the protection systems used in electrical LV- and MV-power networks.

The ProFuDiS project has the objective to identify requirements and solutions for existing and future protection systems.

Cooperating partners of ProFuDiS
RWTH Aachen University; FGH e.V.; HTW des Saarlandes University; RWE Deutschland AG; SMA Solar Technology AG; Omicron electronics GmbH; NH/HH-Recycling e.V.; ABB AG; Schneider Electric GmbH; Siemens AG;
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- Introduction
- Impact of distributed generation in low-voltage power networks
- Generic software based models for fuses
  - "Black Box"-Fuse model from the power network point of view
    - Based on the network calculation program ATPDesigner/ATP
    - Based on the network calculation program PowerFactory
- Short-Circuit tests in the IFHT 0,4kV-test center
- Validation of the software based models using the short-circuit tests
The Current Situation in LV-Power Networks

- Fuses are mainly used to protect the equipment e.g. transformers, lines, etc.
- Only methods to calculate the steady-state are used to select the right fuse
  - Short-circuit calculation acc. to IEC 60909 (VDE 0102)
- Neither transients nor harmonics are considered

The Impact of Inverter based Distributed Generator Systems (I-DG)

- From the power network point of view: I-DG e.g. photovoltaic systems are current sources, not voltage sources
- I-DG have an increasing influence in case of a short-circuit (SC) regarding the behaviour of fuses
Distributed Systems in Radial Low-Voltage Power Networks

- **Without I-DG**: 100% SC-Current flows from MV-network → Fuses Fu1 and Fu2 → to the SC-location

- **With I-DG**: SC-Current flows ① from MV-network → Fuses Fu1 and Fu2 → the SC location **AND** ② from I-DG → the SC-location
Distributed Systems in Radial Low-Voltage Power Networks

- **With I-DG:** SC-Current flows ① from MV-network → Fuses Fu1 and Fu2 → the SC-location AND ② from I-DG → the SC-location

- **And the Consequences?**
  - SC-Current infeed of I-DG leads to a *reduction of the SC-current* at both fuse
  - The *tripping times* of both fuses increase up to a non-tripping, so called *blinding*

The behaviour of I-DG and fuses must be investigated from the power network point of view, steady-state and transient.
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Software based Model of a Fuse implemented in ATPDesigner/ATP

- ATP is a worldwide used software to calculate transients in electrical power networks
- New user specific models e.g. of a fuse can be developed using the programming language MODELS

What will be needed for the fuse model?

- Switch to interrupt the SC-current
- Resistance \( R_{Arc}(t) \) to represent the arc
- Software to implement the fuse model analyzing the time dependent phase-currents \( i_{L123}(t) \)
Software based Model of a Fuse implemented in ATPDesigner/ATP

1. R.M.S. Calculation using a numerical integration
2. Current \( I > \) exceeded ?
3. Thermal energy calculation
4. \( I^2t \)-melting energy exceeded ?
5. Starting the arc model
6. Arc resistance small enough ?
7. Interrupting SC-current

\[
I_{\text{rms}} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0+T} i^2(t) \cdot dt}
\]

\[
E = \int_{t_0}^{t} i^2(t) \cdot dt
\]

\[
\frac{d}{dt} g(t) = \frac{1}{\tau} (G - g(t))
\]

Start Simulation

End Simulation

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**Calculation of the Melting Current only using Software**

- Each phase-current sampled with $\Delta t = 100\mu s \Rightarrow N = 200$ samples per cycle
- Calculation of r.m.s. value using a high-accuracy integration method
  - All frequency and DC components considered

**Numerical integration algorithm** ➔ **Simpson Rule**

$$I_{r.m.s.} = \sqrt{\frac{1}{T} \cdot \frac{\Delta t}{3} \left( i^2[0] + 2 \cdot \sum_{i=1}^{(N/2)-1} i^2[2 \cdot i] + 4 \cdot \sum_{i=1}^{N/2} i^2[(2 \cdot i) - 1] + i^2[N] \right)}$$

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Short-Circuit in a LV-Power Network: Phase-Currents $i_{ABC}(t)$

- 3-Phase-to-ground short-circuit ABCG at 80% of the line
- Short-circuit current $I_{SC} = 2.6\, \text{kA}$

“Small” decaying DC-Component, typical for LV-power networks
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„Black Box“-Fuse Model from the Power Network Point of View

EXEC
CNT:=CNT+1
if (((CNT mod STEP)=0) then
CNT:=0
for i:=0 to (NMAX-1) do
APIBu[i]:=APIBu[i+1]
BPIBu[i]:=BPIBu[i+1]
CPIBu[i]:=CPIBu[i+1]
endfor
APIBu[NMAX]:=IL[1]
BPIBu[NMAX]:=IL[2]
CPIBu[NMAX]:=IL[3]
SIL[1..3]: = 0
SIL[1]:=((APIBu[0]**2)+(APIBu[NMAX]**2))
SIL[2]:=((BPIBu[0]**2)+(BPIBu[NMAX]**2))
SIL[3]:=((CPIBu[0]**2)+(CPIBu[NMAX]**2))

„Black Box“-Fuse Model
Real-time software implementation using the MODELS programming language of the ATP
Short-Circuit in a LV-Power Network: Fuse Currents $i_{ABC}(t)$

- Interrupting SC-current phase A and B $\Rightarrow t_{SC} + 20\,\text{ms}$
- Interrupting SC-current phase C $\Rightarrow t_{SC} + 250\,\text{ms}$

Reduction of SC-current in phase C after SC-interrupting in phases A and B

$I_{SC\,\text{phase}\,C} = 2.6\,\text{kA} \Rightarrow 1.2\,\text{kA}$
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Reduction of SC-Current
- Fault type changes ABCG → ACG → CG

![Graph showing fault type changes and time intervals](image-url)

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The Behaviour of the Fuse Model in Phase B

- Continuous calculation of thermal energy and $I^2t$-value

Thermal Energy = $I^2t \Rightarrow$ Starting $R_{Arc}(t)$
Considering the Arc Resistance $R_{\text{Arc}}(t)$ only using Software

- Differential equation to simulate the arc resistance $R_{\text{Arc}}(t)$

More realistic behaviour interrupting SC-current using $R_{\text{Arc}}(t)$

\[
\frac{d}{dt} g(t) = \frac{1}{\tau} (G - g(t))
\]
An alternative „Black-Box“ model for a Fuse with Arc Resistance implemented in PowerFactory

- Based on the implementation using a parallel capacitance and controlled arc resistance $R_L(i)$ [PSG89]
- Implemented using PowerFactory DSL Language

Over-current threshold exceeded

$I^2t$ calculation & threshold comparison

$I^2t$ characteristic reached

Simplified arc resistance $R_L(i)$

Switch S opened

Switch S closed

Test Measurements in the IFHT 0,4kV Test Center

- **Exemplary single line tests of**
  - 100A / 250A NH2 gG fuses
  - Different manufacturers / preloading / ages

- **Supply**
  - 400kVA, 10kV / 0,4kV Dyn5 transformer

- **Cable**
  - 40m H07RN-F, 4x1x240mm²

- **Short circuit**
  - Short circuit emulator (3 phase / asymmetrical / variable, asymmetrical fault impedance)
  - Test-currents: $I_k/I_N = 6 / 8 / 10$

- **Measurement**
  - DEWETRON DEWE-571 Grid-Analyser
Test Measurements in the IFHT 0.4kV Test Center

- Transformer: 110kV / 10kV YNyn0, $S_N = 40MVA$
- Cable: ca 400m, 4x1x240 mm²
- Short-circuit emulator
- Dist.-Box with NH-fuse: 10kV / 0.4kV Dyn, $S_N = 400kVA$
- NH-Fuse: 40 m H07RN-F 4x1x240 mm²
- Test-currents: $I = 6 / 8 / 10$

Measurement: DEWETRON DEWE-571 Grid-Analyser

Exemplary single line tests of:
- Transformer
- Dist.-Box with NH-fuse
- Cable
- Short-circuit emulator

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Exemplary result:
- 250A NH2 gG fuse
- \( I_{test} = 10 \cdot I_N = 2500A \)

 Interruption time:
- \( T_{fuse} = 0.417s \)

Arcing within the last half-cycle
- \( V_{Arc} = 120V \)
Test Measurements in the IFHT 0,4kV Test Center

Summary of the test results:
- Variation of the interruption times of up to 15%
- Variation of the maximum arcing voltage
- Possible causes:
  - Drift in the test-current due to heating of the resistive load elements of up to 1,5%
  - Different manufacturers, ages, preloadings, point on wave regarding fault initiation
- Good match of the simulation & current-time-characteristic

Variation of the timing / arcing characteristic necessary
- Both models provide the capability for these variations

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Thank you for your attention

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