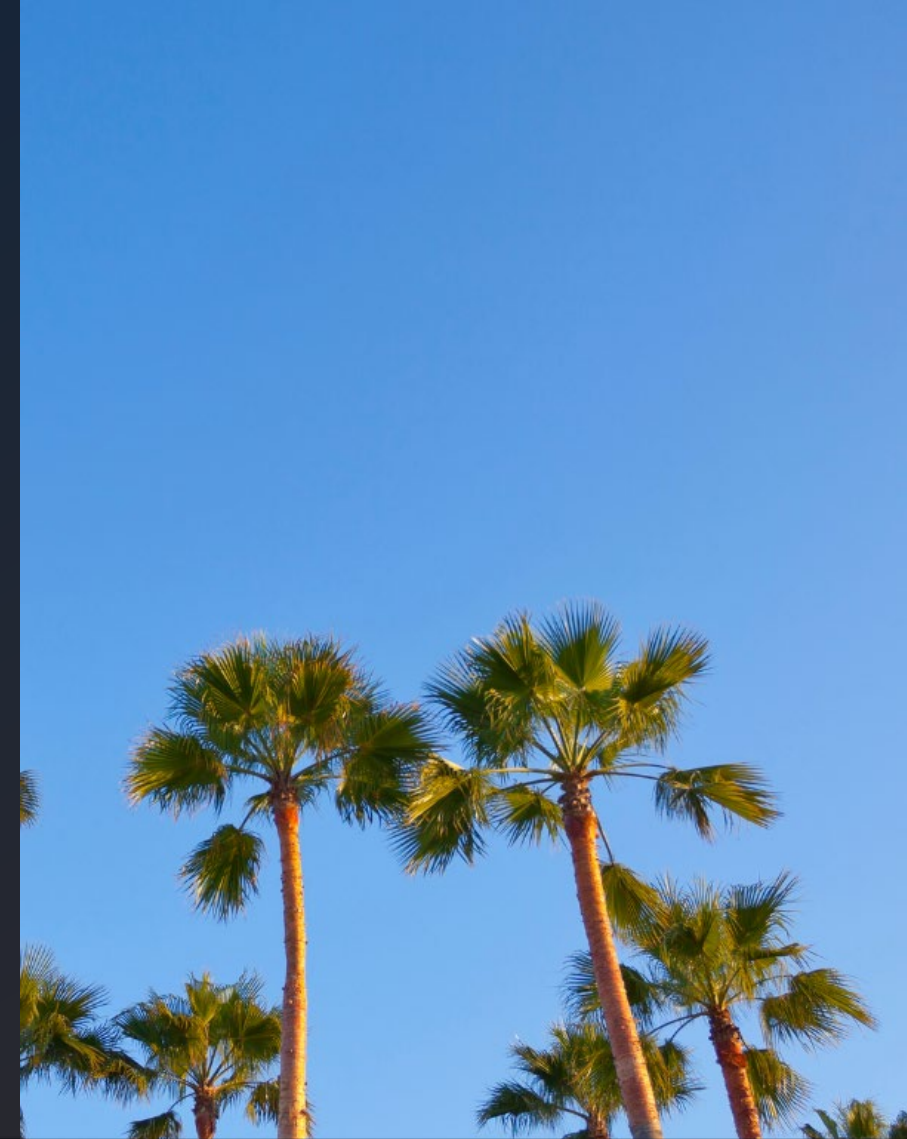




Evaluating RTDS Arc Fault Modeling for High Impedance Faults in Distribution Systems

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2026 APPLICATIONS & TECHNOLOGY CONFERENCE
IRWINDALE, CALIFORNIA, USA



Introduction

High impedance faults

- High impedance faults (HIFs) in distribution systems are faults that do not reliably trip traditional protective devices (e.g. relays).
- Caused by a variety of factors:
 - Downed energized conductors
 - Vegetation contact
 - Aging/deteriorating equipment
- Dangerous if not detected promptly, e.g. may ignite and result in wildfires.



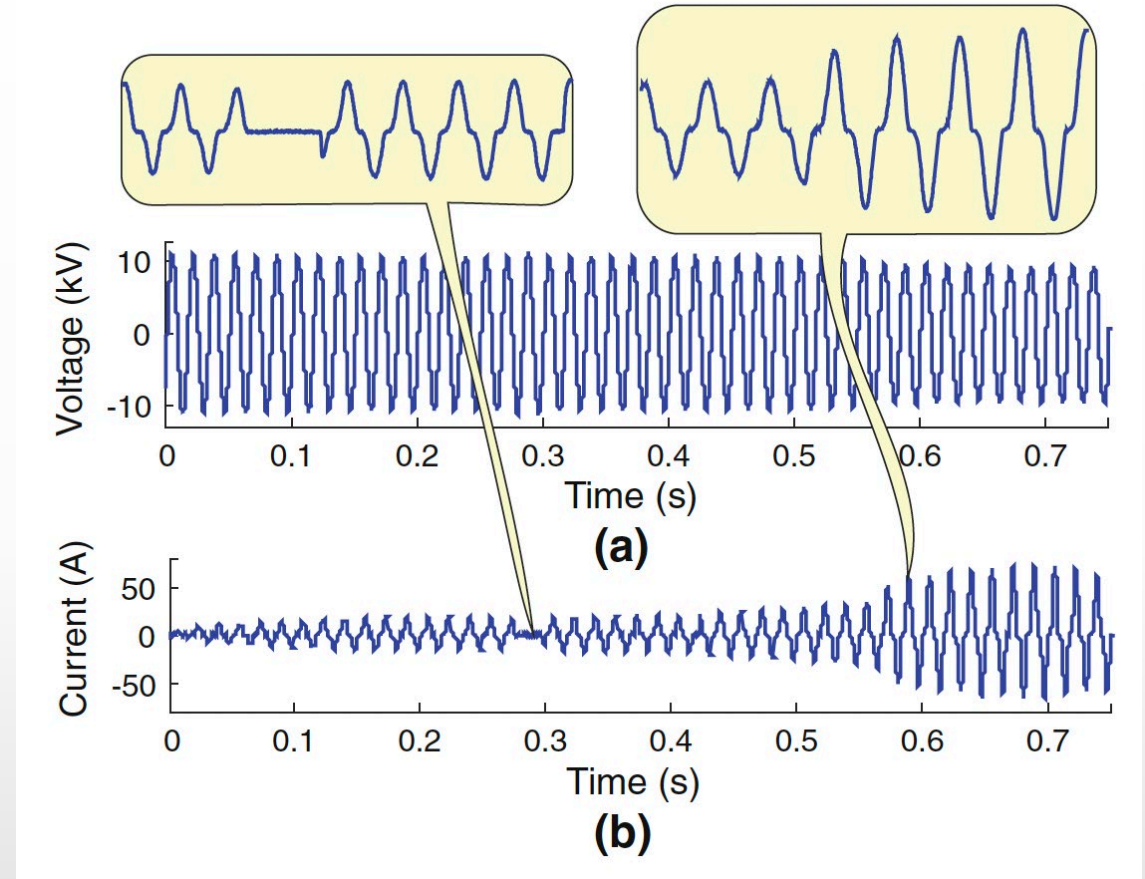
Motivation

- Fault detection algorithms centered around HIFs often require large amounts of real-world data, e.g. to train machine learning (ML) models.
- Challenging to collect adequate amount of high-resolution waveform of actual HIFs or to recreate these in a laboratory setting.

Can we properly model and simulate categories of HIFs to help develop detection algorithms?

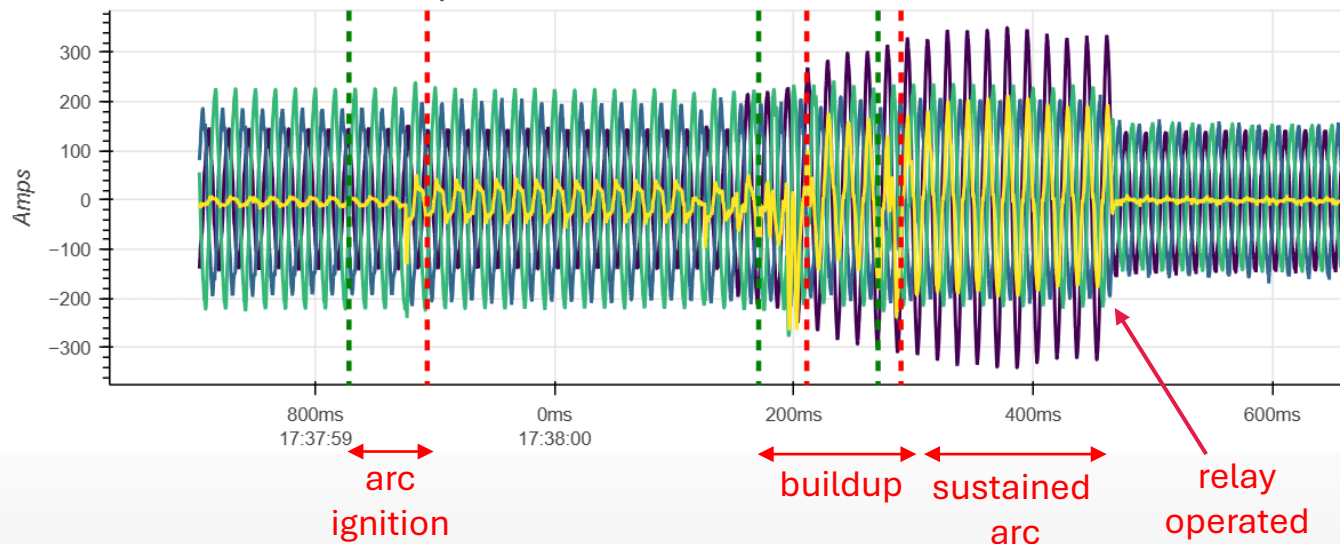
Characteristics

- For distribution-level shunt HIFs, this work targets:
 - High impedance faults due to downed conductor
 - Self-clearing (shunt) discharges
- General characteristics include:
 - Non-linearity and asymmetry of current waveform
 - “Shoulders” near/at zero-crossing
 - Highly variable, e.g. for downed



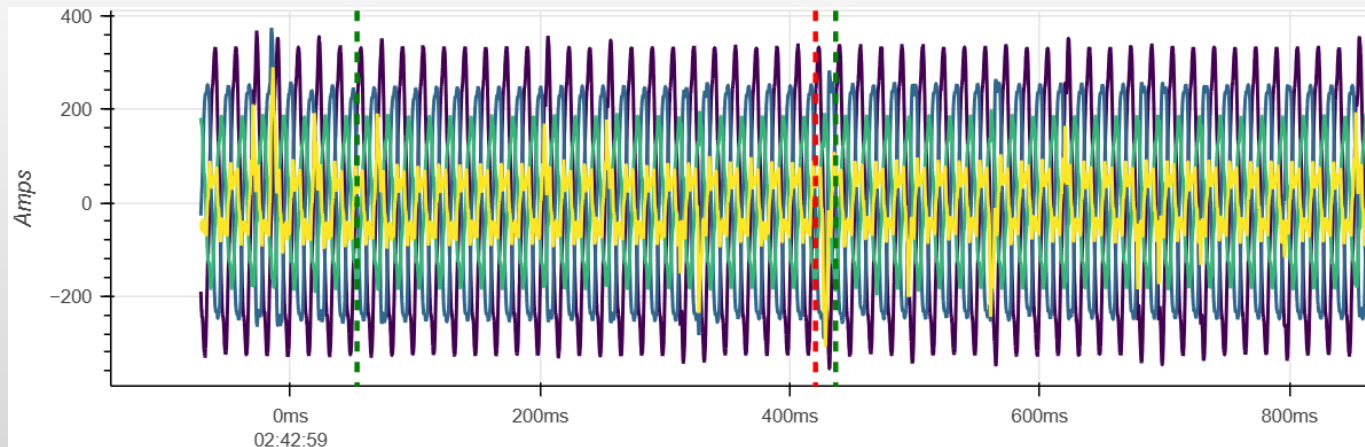
W. C. dos Santos et al., “High impedance faults: From field tests to modeling,” *J. Control Autom. Elect. Sys.*, vol. 24, no. 6, pp. 885-896, 2013.

Characteristics



HIF due to energized downed conductor w/ eventual relay operation

- Build-up period indicating conductor settling on surface.
- Variable by (surface) contact medium.



Shunt discharges, precursors to underground cable failure, also observed in transformer failures.

- Intermittent current spikes.
- Can be self-clearing for a long time leading up to failure.

Approach

RTDS fault arc component

- Originally built for transmission-level single pole breaker arcs (rtds_sharc_FLTARC).
- Segmented into primary/secondary arcs:

	Primary	Secondary
Source	Active power source	Coupled conductors during single pole reclosing operations
Length	Fixed	Dynamic; can be user defined

- Modeled by the following equation:

$$\frac{dg}{dt} = \frac{1}{T} (G - g)$$

g is the time-varying arc conductance

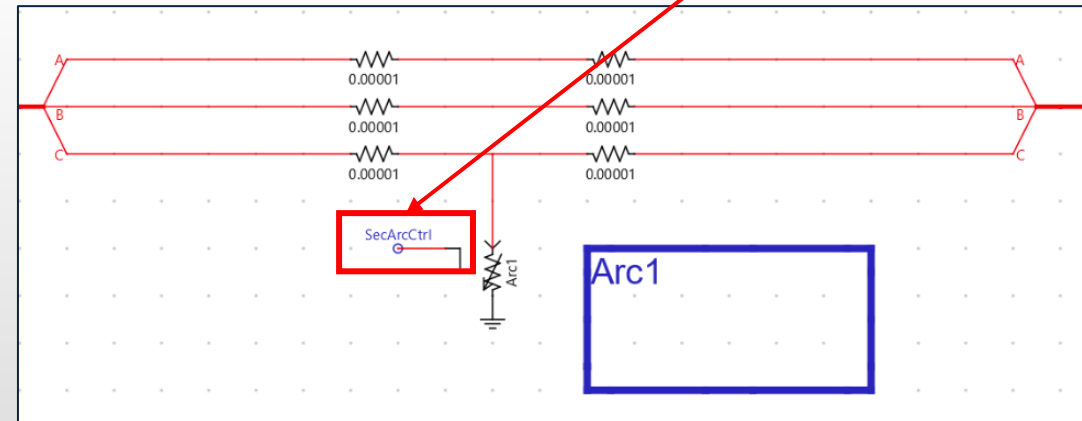
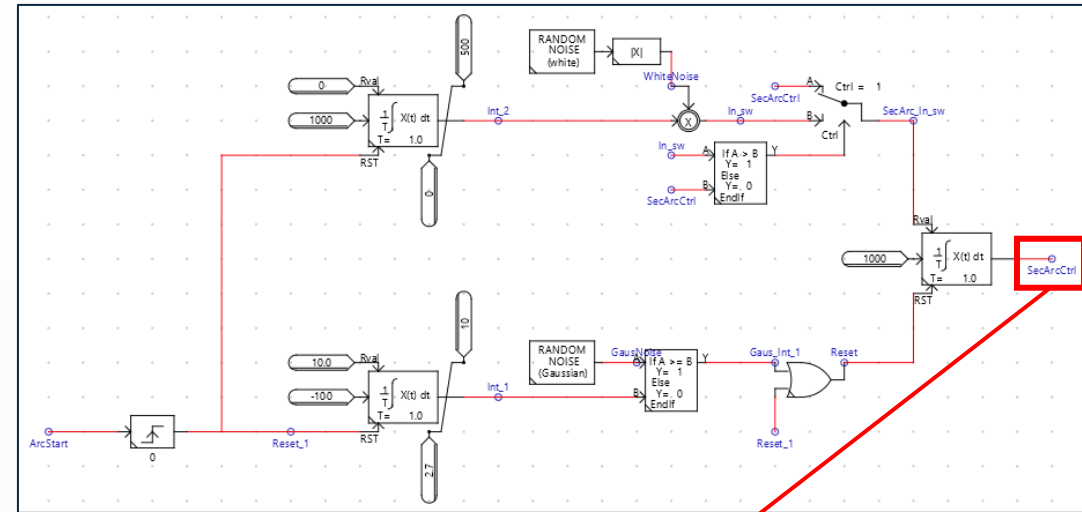
G is the stationary arc conductance

T is the time constant

For further details: RTDS Technologies, "The Secondary Fault Arc Model".

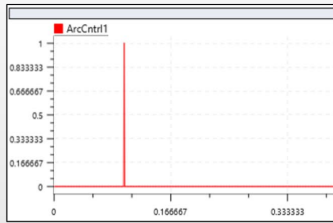
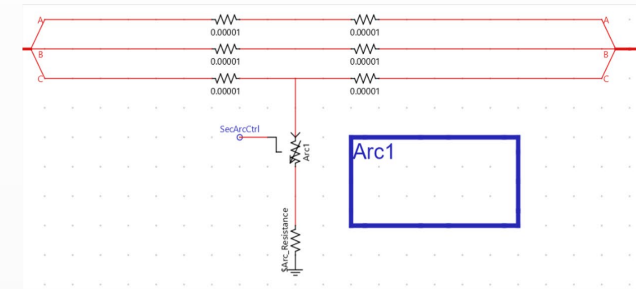
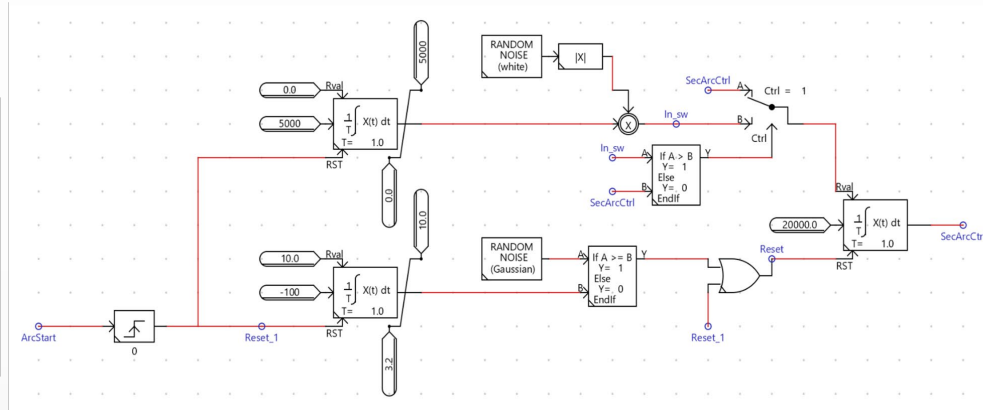
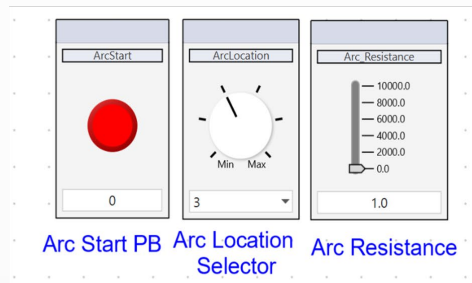
Arc control

- Applied as a single phase-to-ground fault in this work.
- Primary arc control is fixed, while secondary arc control parameters can be adjusted to simulate a constant arc elongation rate that can contract back to a shorter arc length.
- SecArcControl component is tuned to adjust to distribution-level arc length and fault magnitudes.



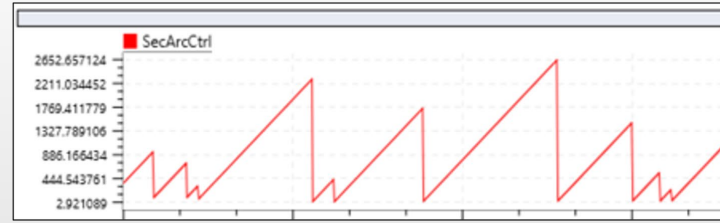
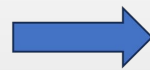
SecArcControl logic modified from default to adapt to distribution-level faults.

Arc control



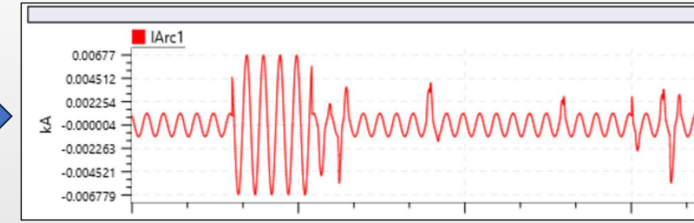
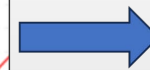
Arc Start Control Signal

Arc Start push button signal starts the arc control



Arc Length over Time

Secondary Arc Control produces linear time varying arc elongation at a constant rate.

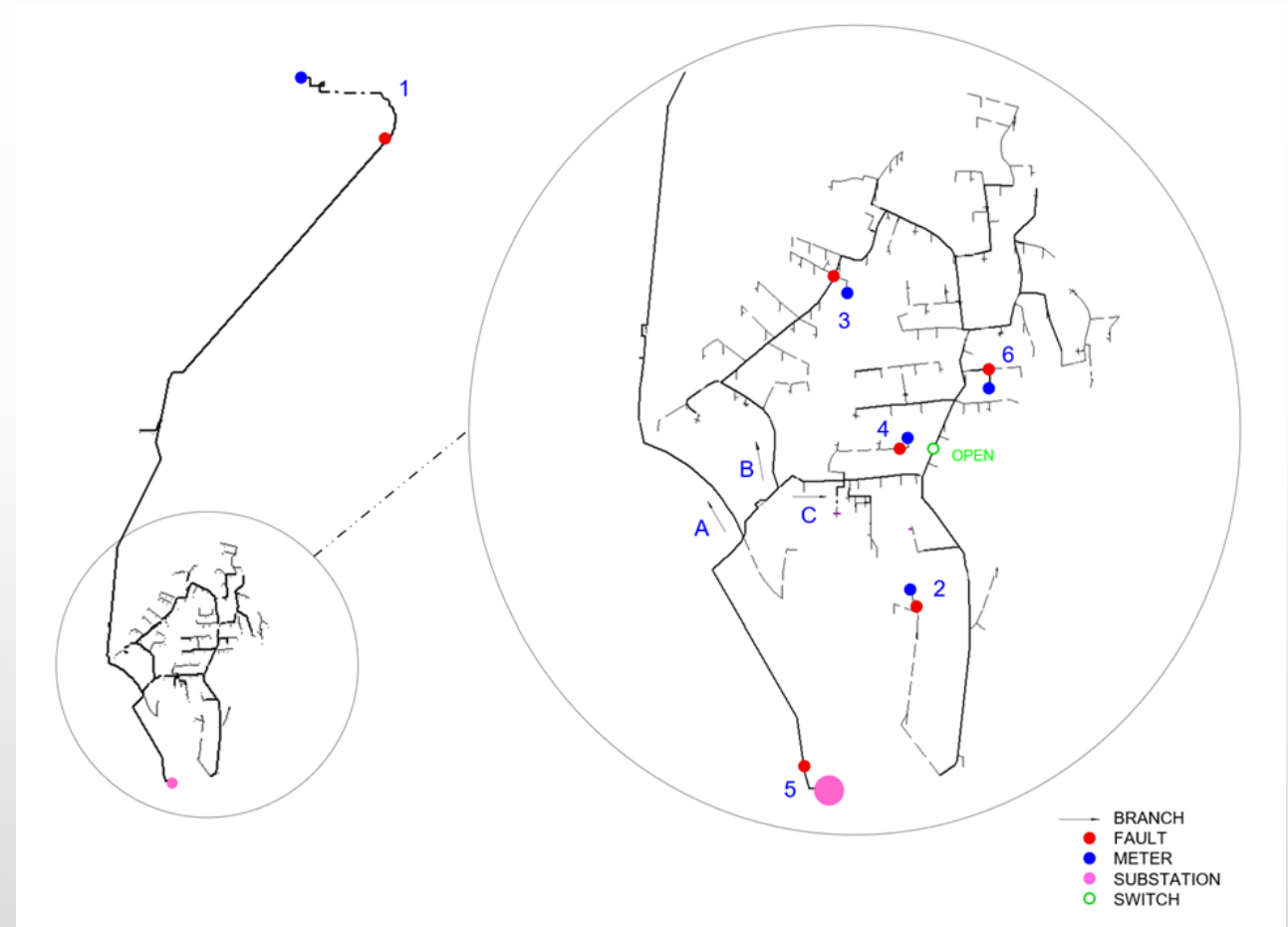


Instantaneous Arc Fault Current

Time varying arc length produces dynamic arc fault current until arc elongates to a length that extinguishes the arc.

Circuit topology

- Six arc fault locations are added at various locations on the circuit to provide a range of topographic scenarios:
 - Distance from circuit head
 - Branching
 - Underground vs overhead lines
 - Upstream loading
- Six waveform measurement points are also included within the model:
 - (1) Medium voltage WMU¹
 - (5) Low voltage WMU¹



¹ WMU – Waveform Measurement Unit

Python automation

- RTDS Python API implemented to generate batches of fault signatures, varying SecArcControl parameters and arc fault location.

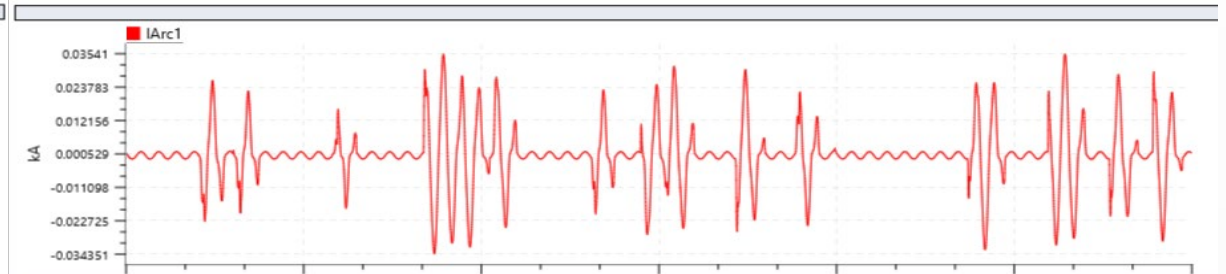
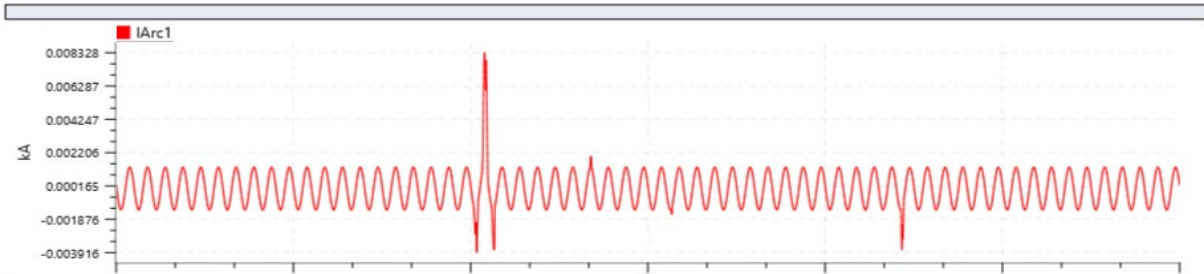
Parameter	Description
<u>Extrn</u>	External control of secondary arc length, allowing users to control the secondary arc length.
<u>rmin</u>	Fault on minimum resistance, controls arc fault magnitude.
<u>rmax</u>	Fault off resistance, setting the resistance when the fault is not present.
<u>isec</u>	Secondary current threshold used to determine if primary arc will transition to secondary arc.
<u>ioff</u>	Fault off current threshold used to “turn off” secondary arc.
<u>arcl</u>	Constant arc length used for the primary arc, helps control the “shoulder” effect on the arc fault current.

SecArcControl parameters, accessible through RTDS Python API.

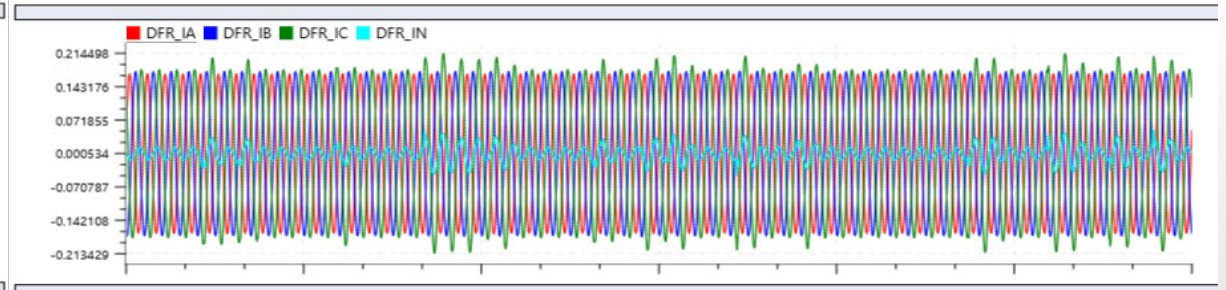
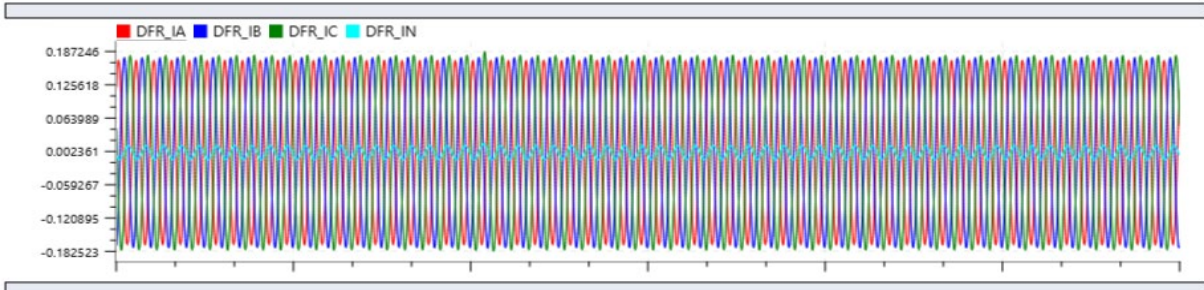
Results

Simulated waveforms – shunt discharges

Arc Current



Circuit Head



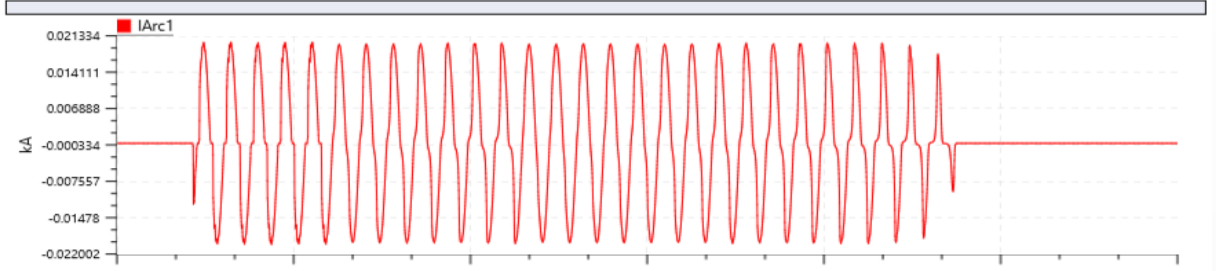
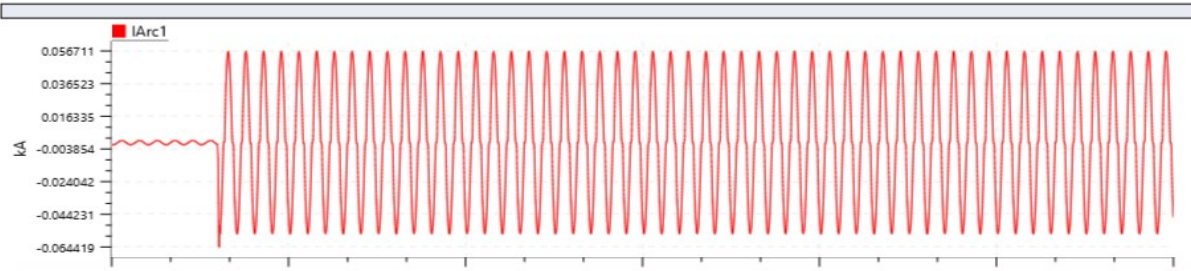
short current spike arc

short arc bursts

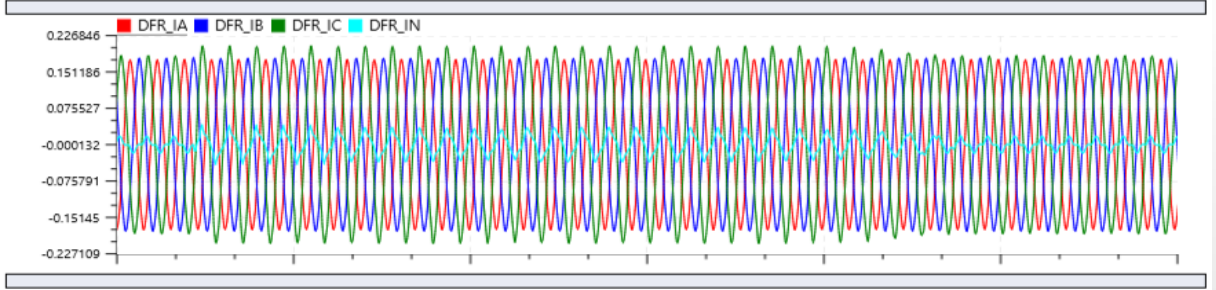
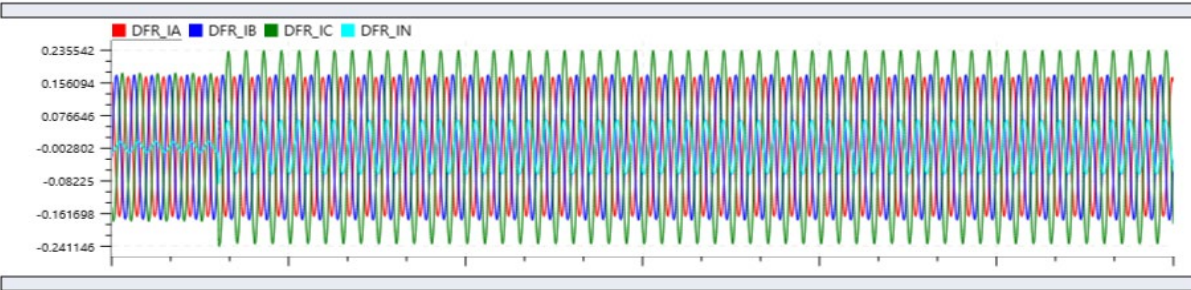
Note: Primary arc segment not shown in these figures.

Simulated waveforms – downed conductor

Arc Current



Circuit Head



sustained arc w/ constant arc length

dynamic arc length

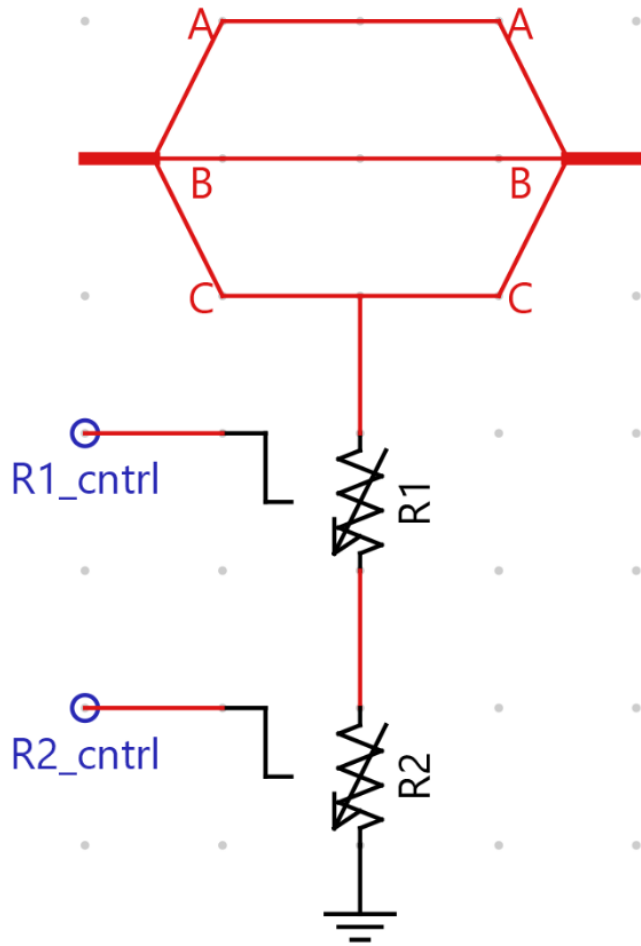
Challenges

- Primary arc segment is static and fixed duration, furthermore, does not match arc ignition characteristics (build-up) in HIFs.
- Tuning of arc parameters is highly iterative to create HIF characteristics and maintain arc ignition beyond the primary arc segment.
- Changing arc fault scenarios (downed conductor vs shunt discharges) requires significant manual configuration change and tuning.
- Change in fault circuit impedance (different arc location) requires retuning of arc parameters.

Opportunities for improvement

- Predefined arc control for different scenarios
 - Downed conductor vs shunt discharges
- More deterministic arc control based on user selected scenario
 - Tunable time windows
 - Bounded settings based on defined scenario
- Bounded randomness of arc behavior
 - Amplitude
 - Arc length
 - Variability in ignition and extinction

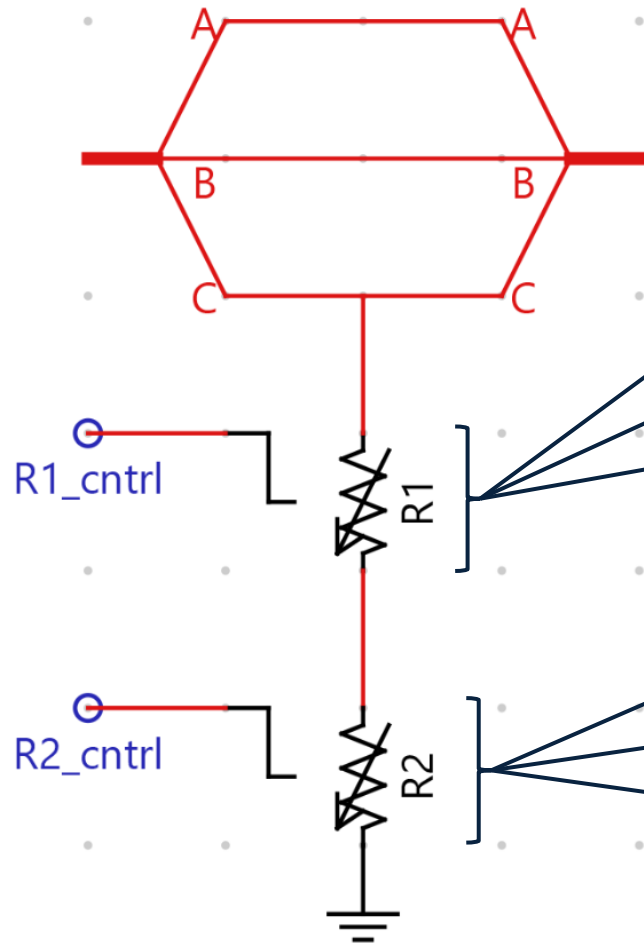
Conceptual Redesigned Arc Control



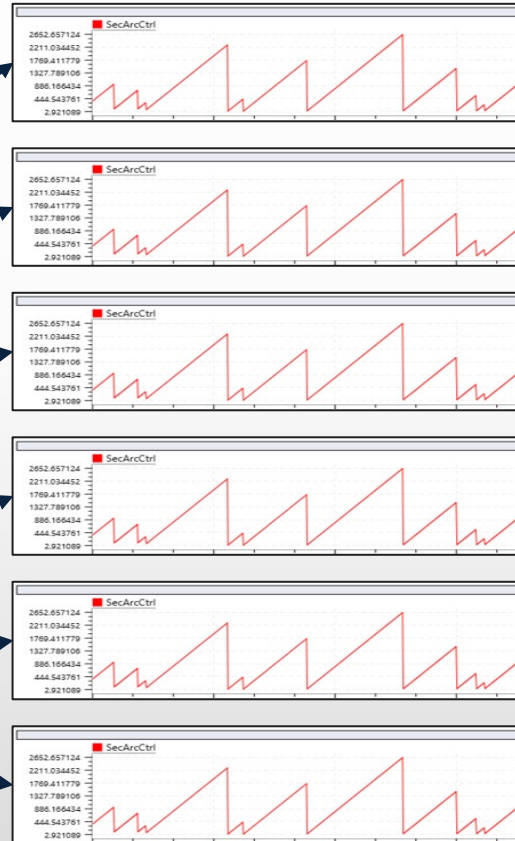
- 2 series time-varying resistor model enables separate and configurable arc segment control
- R1
 - Analogous to “primary arc segment”
 - Controls ignition / build-up segment of the arc fault
 - Time duration configurable decay to 0 as arc control transitions to R2
- R2
 - Analogous to “secondary arc segment”
 - Controls post-ignition segment to arc extinction

Idea conceptualized by W. C. dos Santos et al., “High impedance faults: From field tests to modeling,” *J. Control Autom. Elect. Sys.*, vol. 24, no. 6, pp. 885–896, 2013.

Conceptual Redesigned Arc Control



Arc length profiles for illustrative purpose only



Scenario 1

Scenario 2

Scenario 3

Scenario 1

Scenario 2

Scenario 3

A user selectable arc fault scenario toggles R1 (primary segment) and R2 (secondary segment) arc control parameters.

Conclusion

- Detecting HIFs is important in order to mitigate wildfire risks and perform timely equipment maintenance.
- Challenging to curate a well-defined dataset of HIF waveforms from real-world data – *can it be generated through simulation instead?*
- Modified RTDS fault arc component to adapt to distribution-level HIFs and cross-checked with known real-world case studies.
- Proposed next steps include ideating and designing a deterministic HIF component w/ bounded randomness to support HIF studies and algorithm development.

Questions?

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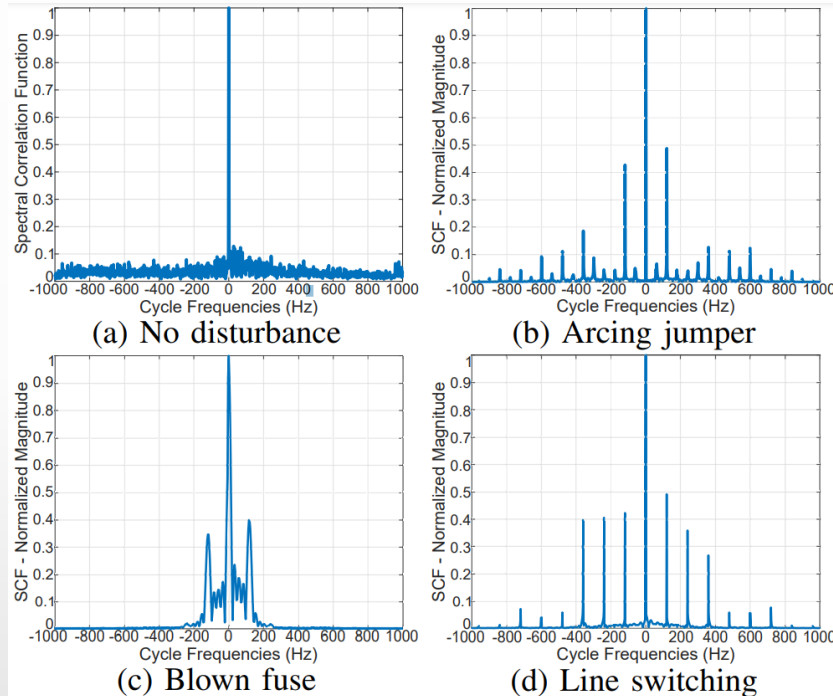
Acknowledgment

The presenters would like to acknowledge Saman Babaei and Ali Mehrizi-Sani from Right Analytics for contributing to the arc modeling work.

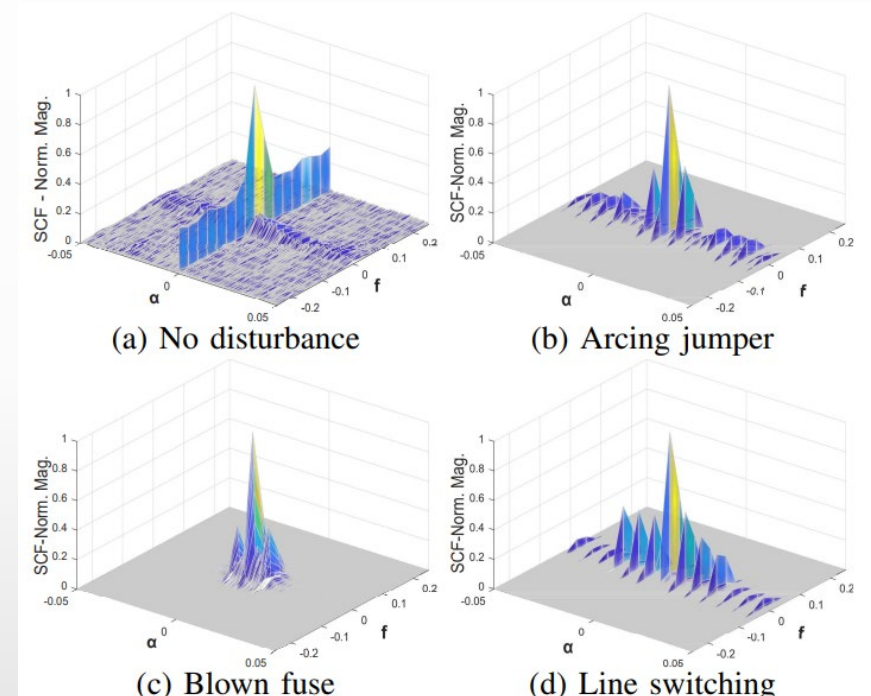
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Appendix

Detection of grid signal distortions using Spectral Correlation Function (SCF)-based feature extraction



(2D Observation): Magnitudes of SCF versus cyclic frequencies for 4 types of grid-signature distortions.



(3D Observation): Normalized SCF magnitude for 4 distortion types as a function of frequency f and cyclic frequency α .

O. Alaca et al., "Detection of Grid-Signal Distortions Using the Spectral Correlation Function," in *IEEE Transactions on Smart Grid*, vol. 14, no. 6, pp. 4980-4983, Nov. 2023, doi: 10.1109/TSG.2023.3309532.

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- O. Alaca *et al.*, "Event-Type Identification in Power Grids Using a Spectral Correlation Function-Aided Convolutional Neural Network," in *IEEE Open Access Journal of Power and Energy*, vol. 11, pp. 653-664, 2024, doi: 10.1109/OAJPE.2024.3513776.