



High-Level Harmonic Distortion during Geomagnetic Disturbances

CIGRE Grid of the Future
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Geomagnetic Disturbances Impacts

- **Increased var losses**
- **Transformer heating**
- **Harmonics**
 - Protection
 - Electronics
 - Generator heating
 - Loss of var support



1989 Blackout of Hydro Quebec System

Vulnerability Assessment Hurdles

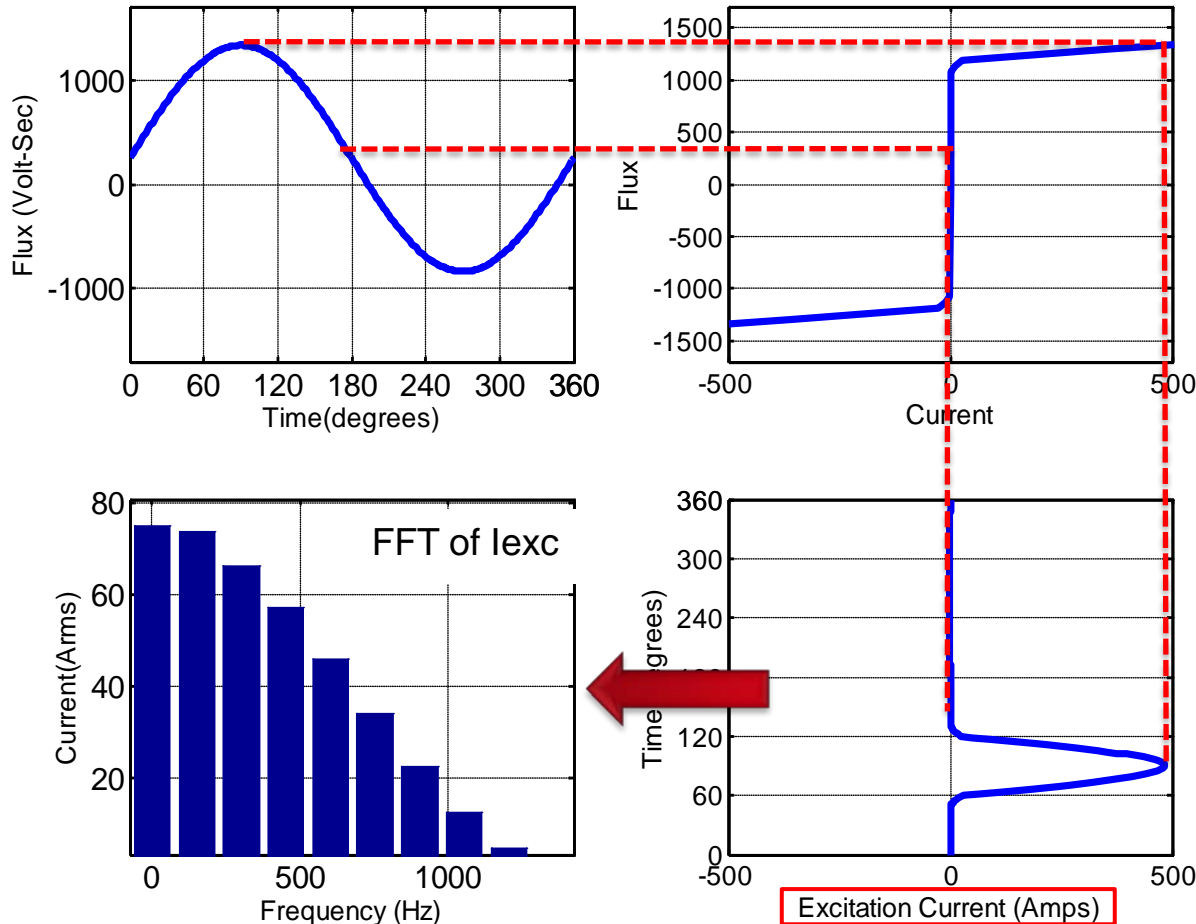
Models	Transformer and system
Methods	GIC prediction → system harmonics
Metrics	Withstand capability

Agenda

- Harmonic Injection during GMD
 - Half-cycle saturation
 - Single-phase transformer response
 - Three-phase transformers
- Illustrative case
- Harmonic analysis tools
- Future research efforts



Harmonic Injections during GMD



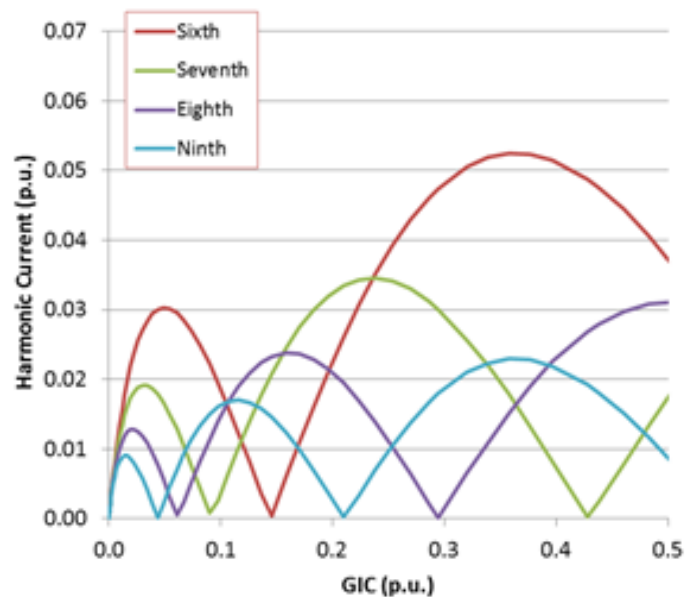
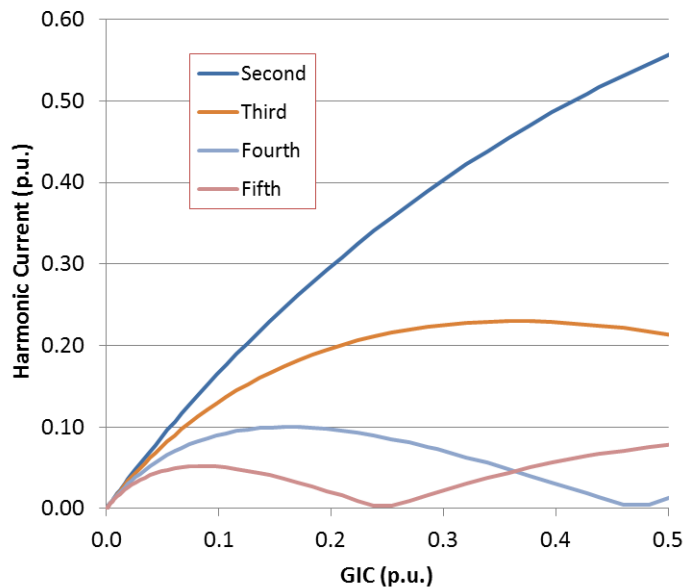
- Both even and odd harmonics
- Generally decreasing with harmonic order
- Harmonic currents can exceed the fundamental

Single-phase Transformer Response

Can be solved analytically

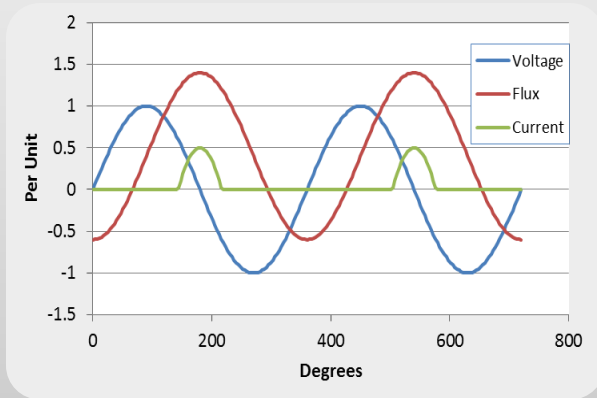
- Simple magnetic structure
- Magnetically balanced
- Sequence components

Harmonic magnitudes exhibit beating behavior

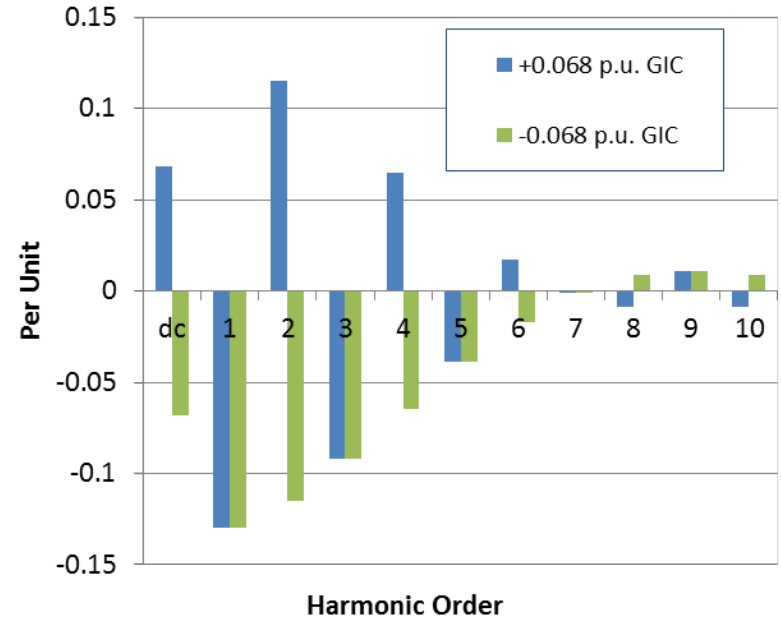


Harmonic Phase Angles

- Polarity of GIC offset



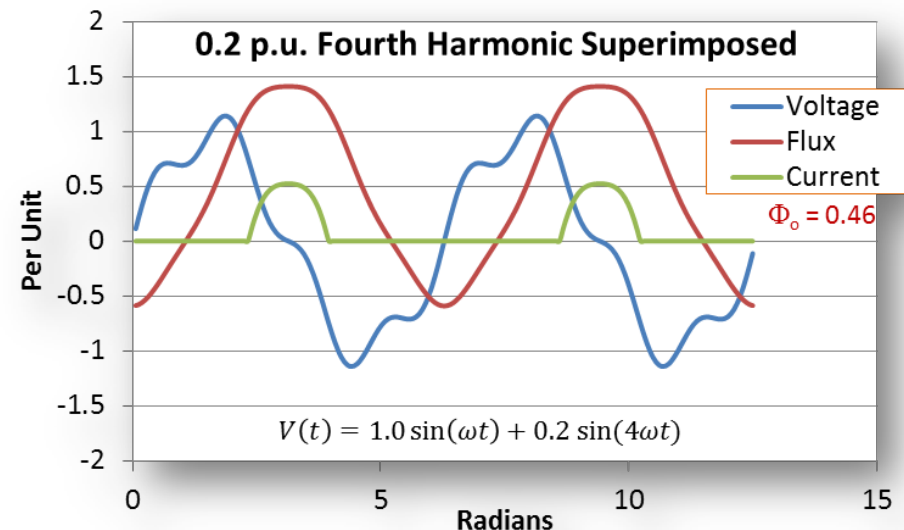
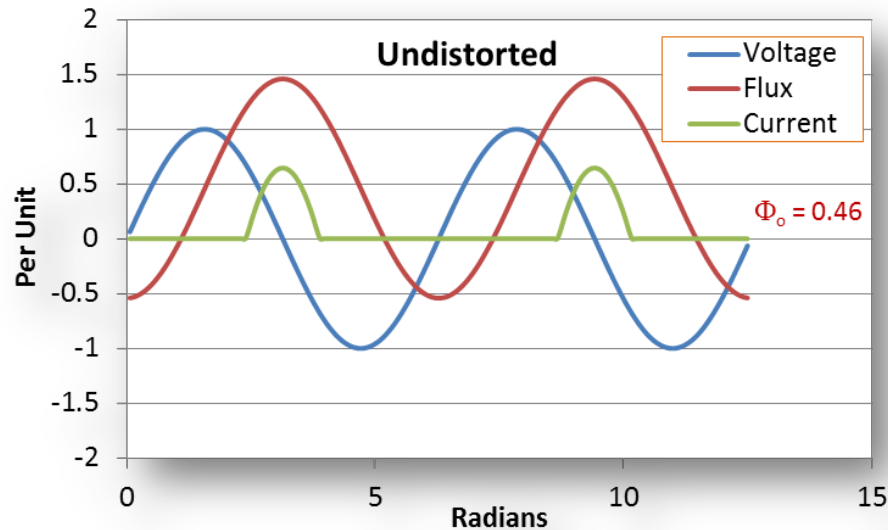
- Fundamental voltage phase angle ϕ
shift n^{th} harmonic phase angle by $n\phi$



Must be linked with

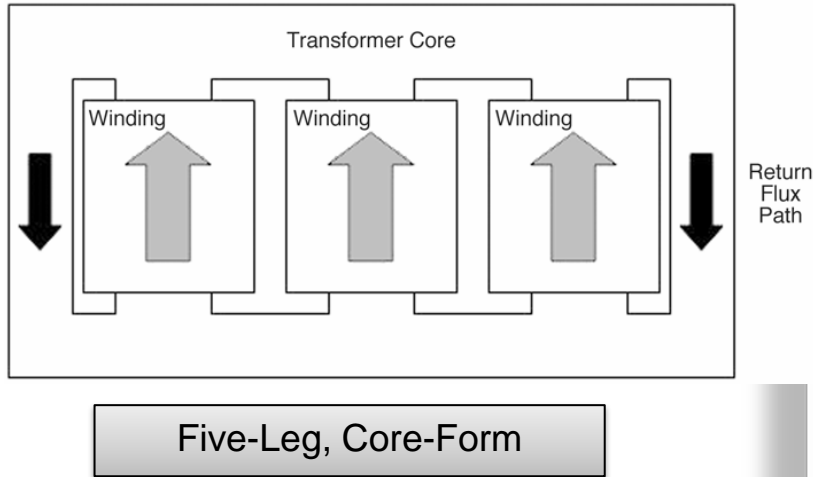
- GIC network calculations
- Fundamental load-flow analysis

Impact of Voltage Distortion on Current Injection



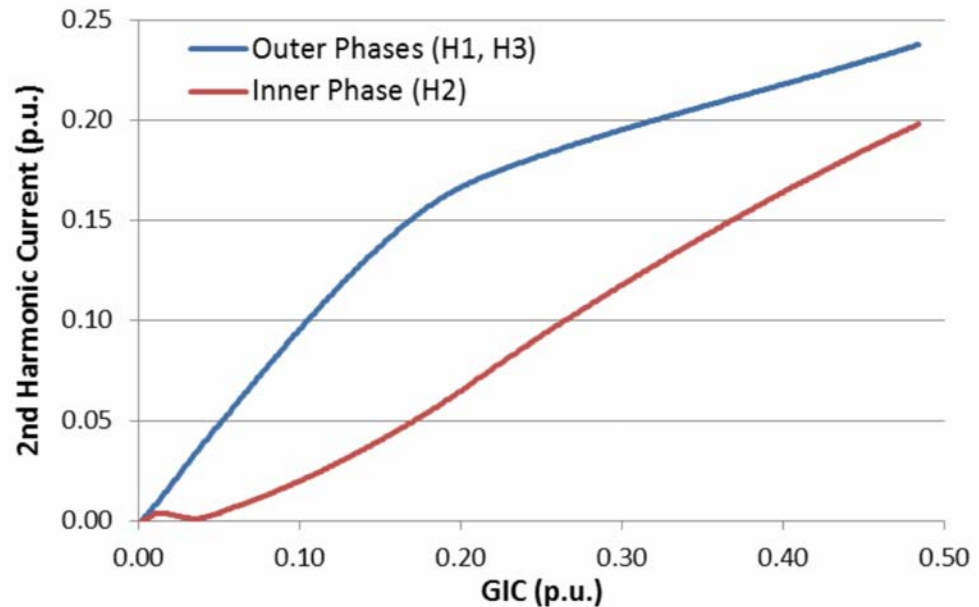
Harmonic injections are a function of voltage \neq ideal current sources

Three-phase Transformers

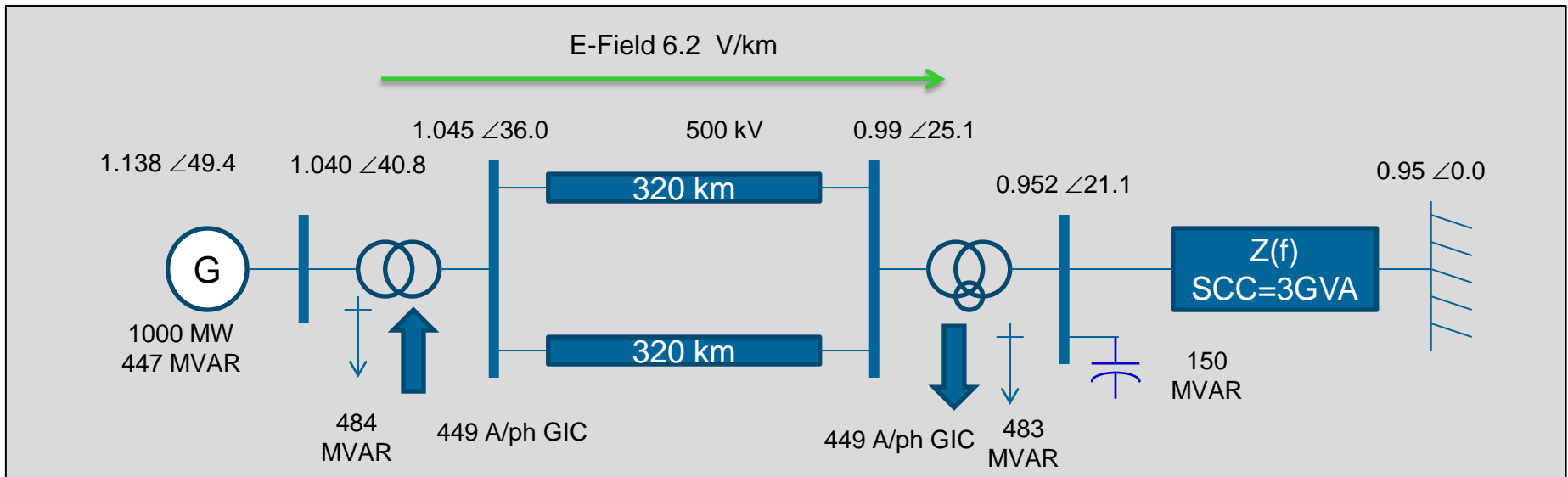
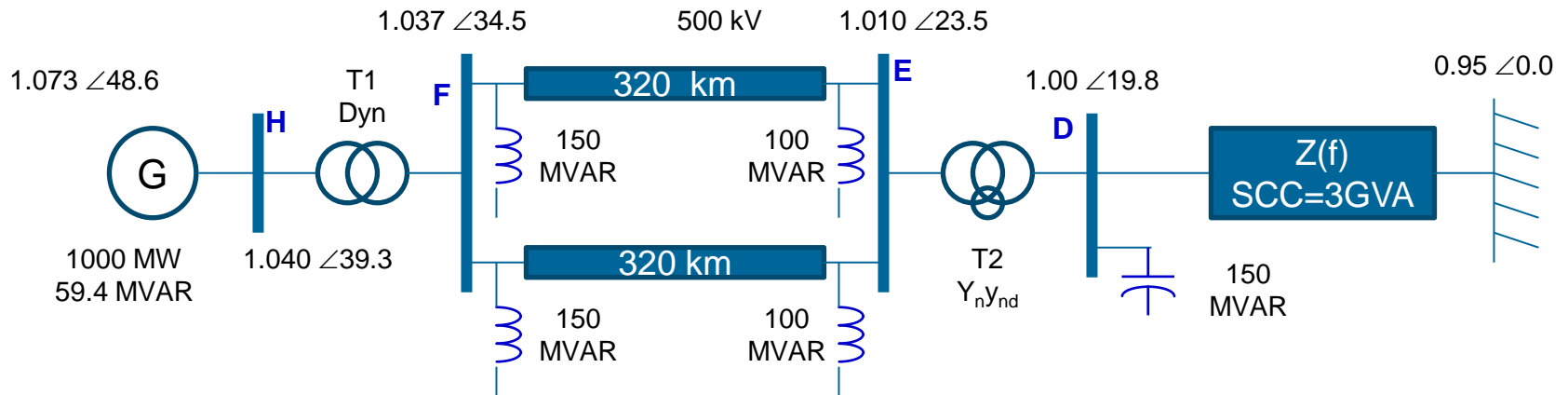


- More complex magnetic structure
- Not magnetically balanced

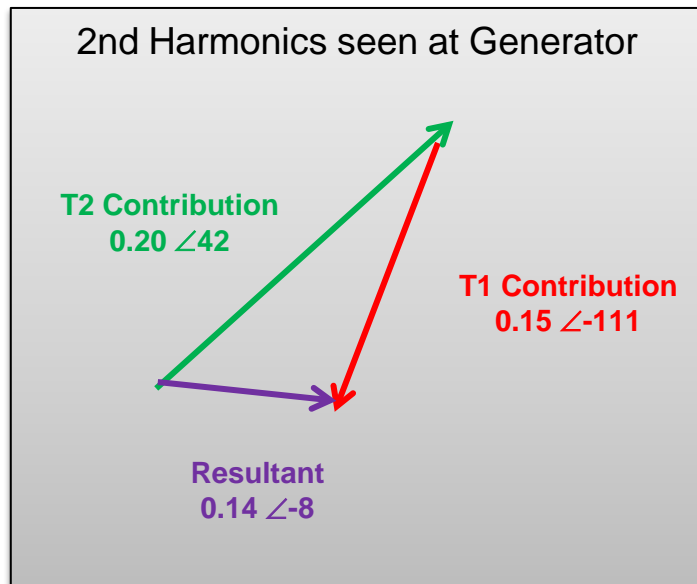
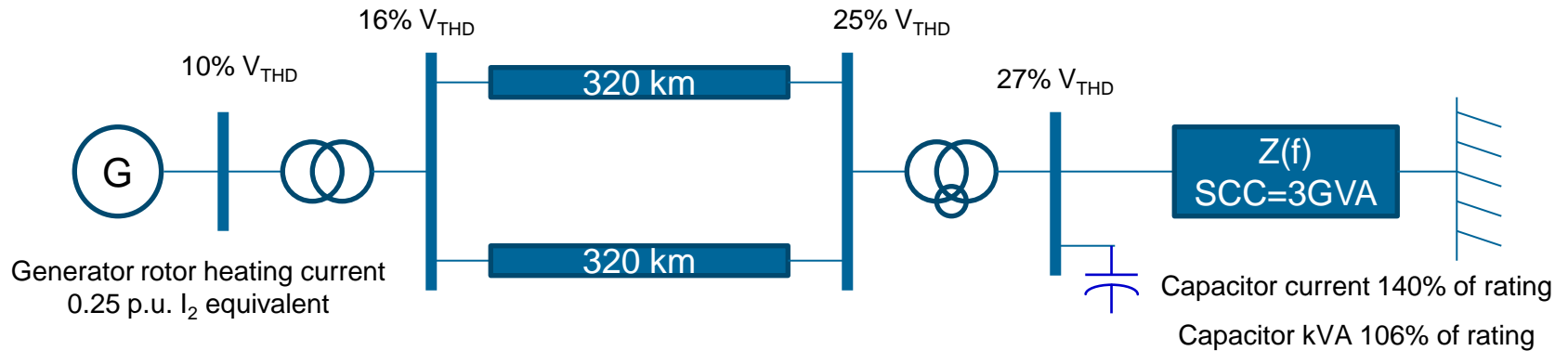
Behavior analysis requires time-domain models and/or transformer testing



Illustrative Example Case



Illustrative Example Case

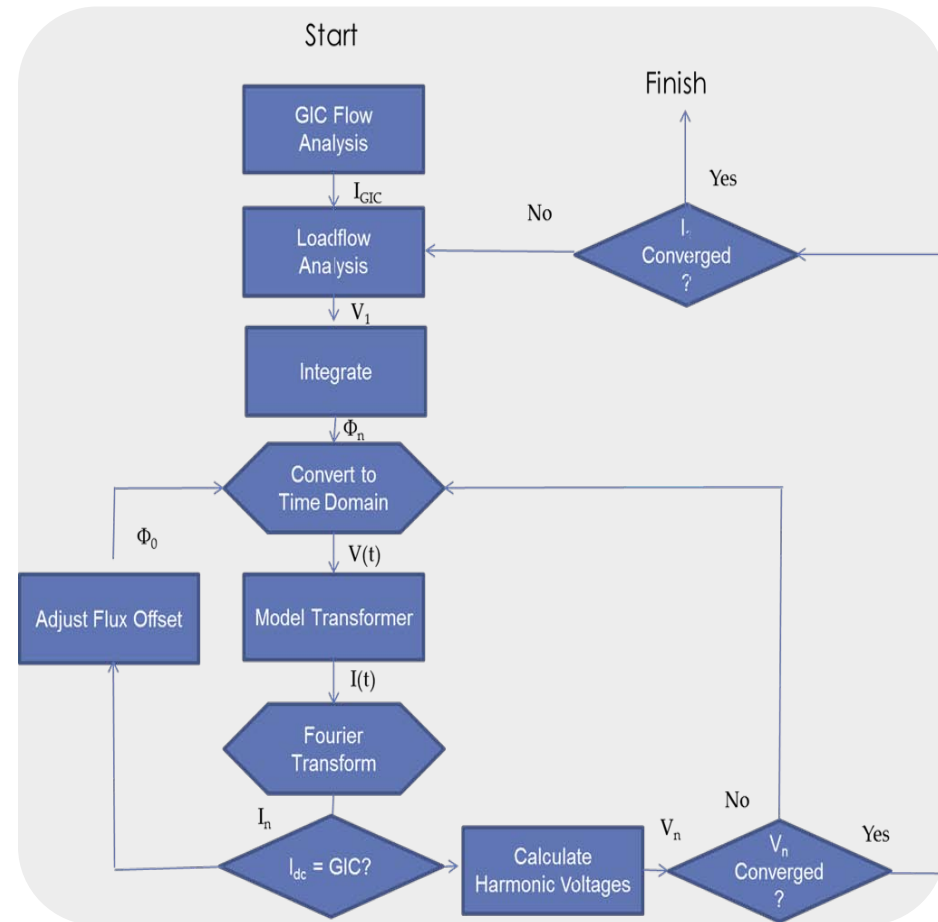


GMD harmonic impacts must be evaluated on a system basis

GMD Harmonics Analysis

Harmonic analysis tools

- Large-scale system analysis
- Many coherent sources
- Unbalanced injections
- Non-ideal current sources
- Link to GIC calculations and fundamental load-flow



Continued R&D

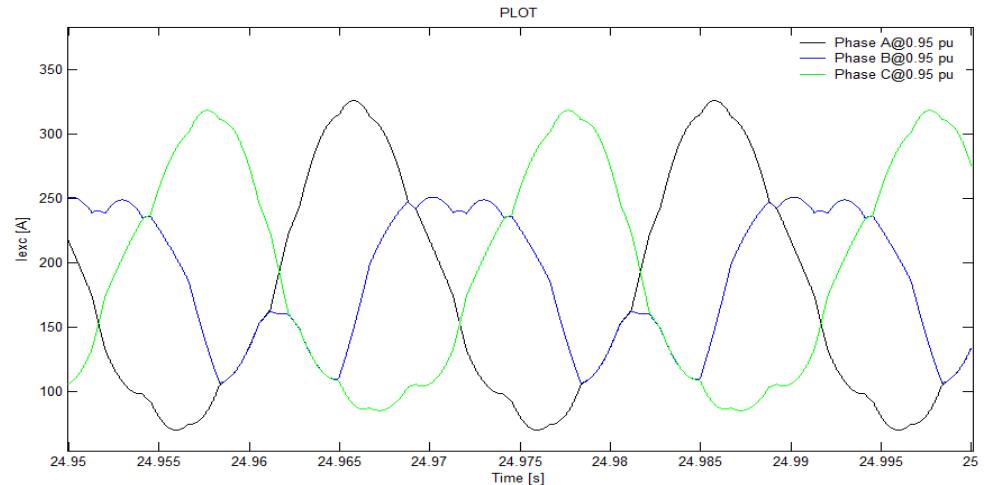
Transformer models

- Laboratory testing
- Time-domain models
- In-situ monitoring

Harmonic analysis tools

Harmonic analysis assessment guidance

Asset harmonic withstand capabilities



EPRI Reports:

- [Electromagnetic Transient-Type Transformer Models for Geomagnetically-Induced Current \(GIC\) Studies \(3002000832\)](#)
- [Analysis of Geomagnetic Disturbance \(GMD\) Related Harmonics \(3002002985\)](#)

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