

FERC GMD Technical Conference

March 1, 2016

Luis Marti
Director Reliability Studies, Standards & Compliance
Hydro One Networks
Ontario, Canada

Key points

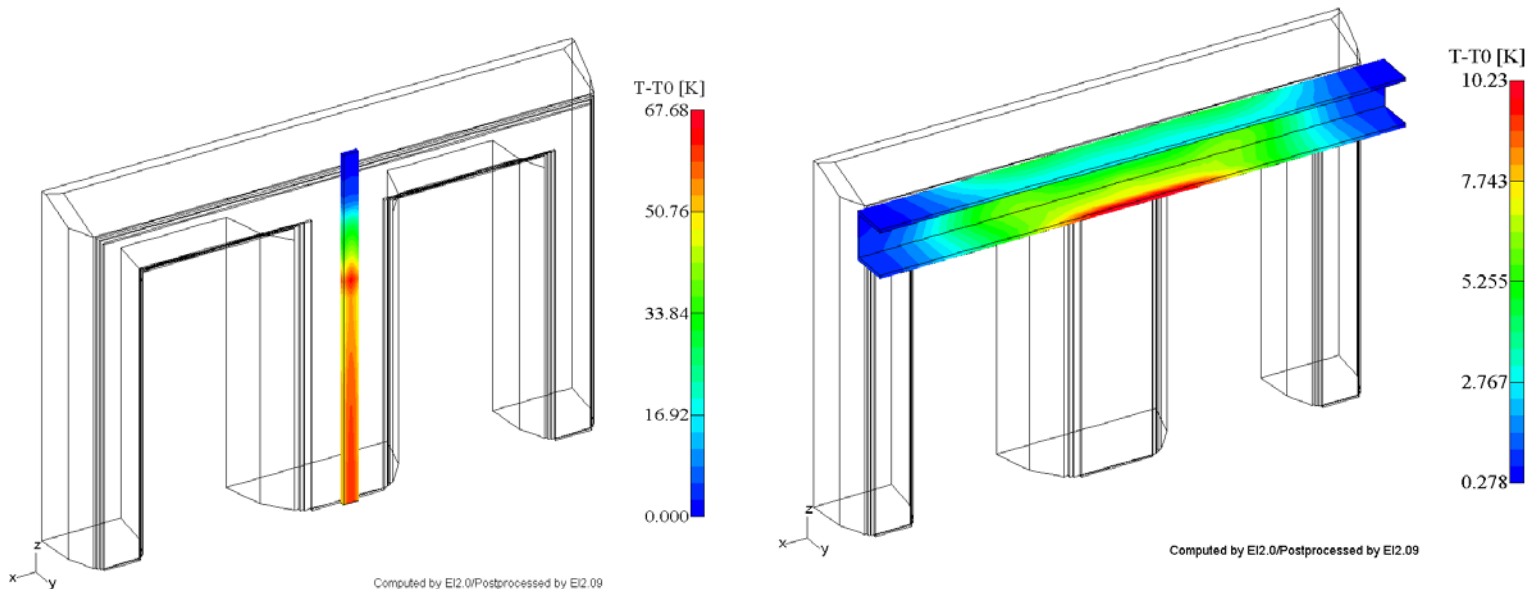
- State of knowledge of thermal modelling
 - Empirical formulas
 - FEM
 - Thermal transfer functions
 - Measurements
 - Simulations
- Screening threshold
- Why the March 1989 waveshape?

State of Knowledge and Modelling Capability Regarding Transformer Thermal Assessments

- Thermal issues during half-cycle saturation are winding hot spots and structural hot spots
- On the basis of available information, winding hot spots are not the limiting factor
- Assessment of metallic hot spot heating response
 - Finite Element Methods
 - Proprietary empirical formulas
 - Measurements
- Practical numerical techniques
 - Thermal transfer functions

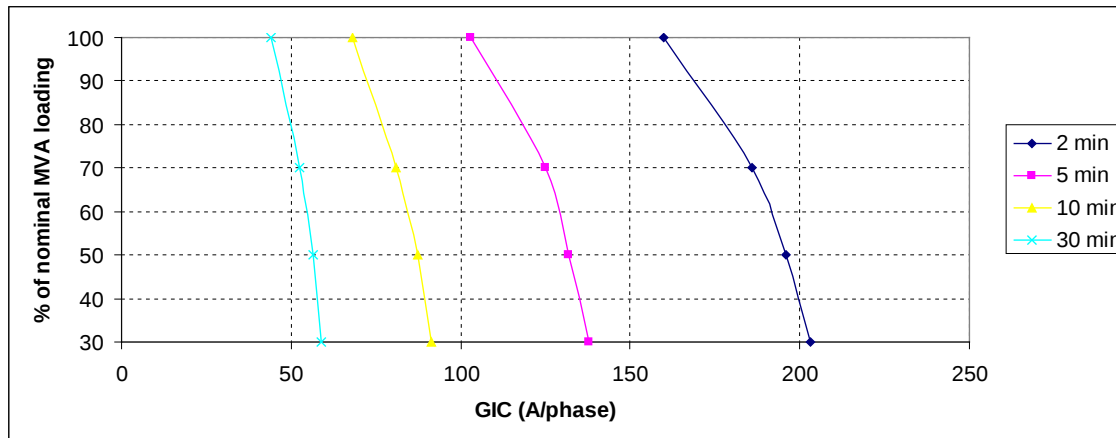
Finite Element Methods

- Require detailed design information
- Computationally intensive
- Limited to step dc currents overlaid on power frequency loading



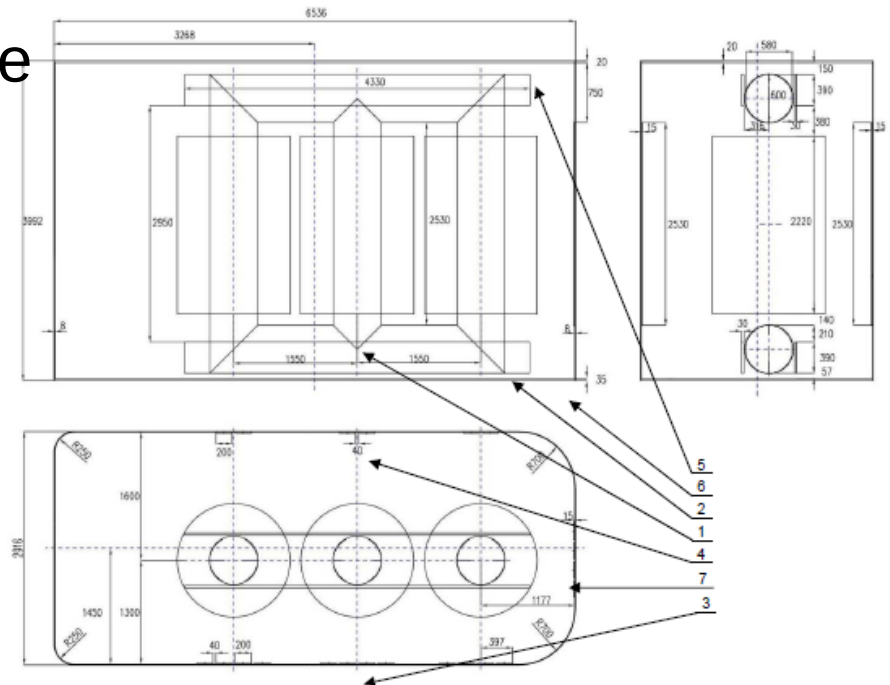
Proprietary empirical formulas

- Require detailed design information
- Computationally intensive
- Limited to step dc currents overlaid on power frequency loading
- Typically result in transformer capability curves: permissible constant GIC over a period of time



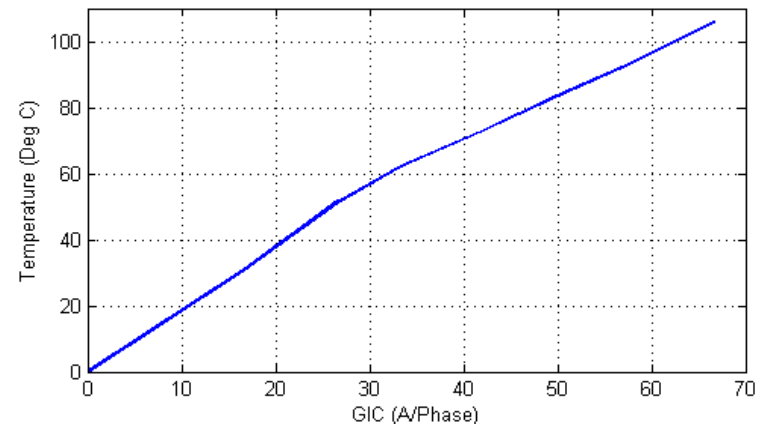
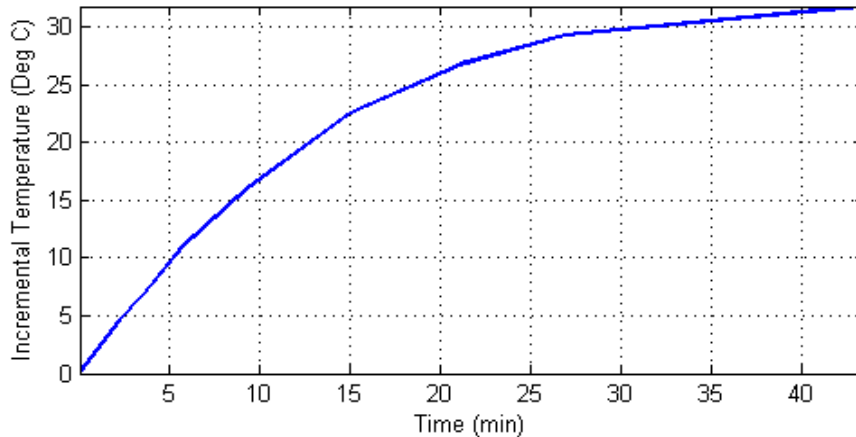
Measurements

- Multiple thermocouples to capture highest temperature
- Field measurements (e.g., Fingrid)
- Test bed limitations
- Best test data to date
 - SoCo
 - Fingrid
 - Hydro One
 - Hydro Quebec



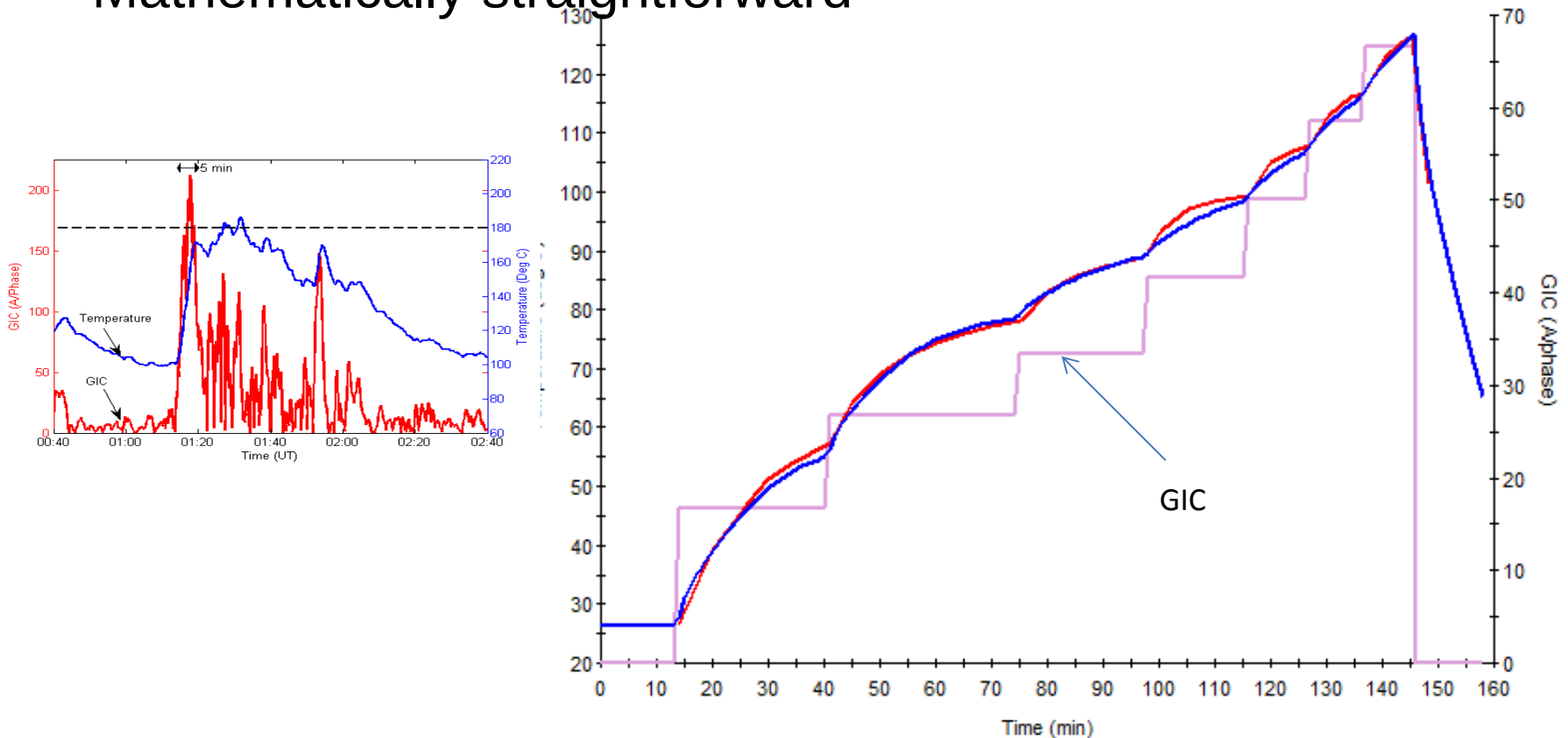
Practical Numerical Techniques

- Thermal transfer functions.
 - Use the thermal step response (either measured or calculated using FEM or other methods)
 - Measuring the temperature increase to multiple dc current steps
 - Computationally fast. Used in the Hydro One real-time simulator.
 - Used to obtain the benchmark threshold values



Thermal Transfer Functions

- Allows the efficient calculation of temperature rise to an arbitrary $GIC(t)$
- Reproduces Fingrid measurements quite well.
- Mathematically straightforward



Benchmark Screening Threshold

- Selected the highest thermal responses known to date: Measured, calculated with FEM and with empirical methods.
- Many conservative assumptions are built in
 - Ignored local oil viscosity effects
 - Ignored structural part saturation.
- 75 A/phase is an instantaneous value.
- Represents an incremental hot spot temperature increase of 70°C.
- This temperature is not sustained over time. Short term emergency loading duration is not taken into account.

Benchmark Screening Threshold

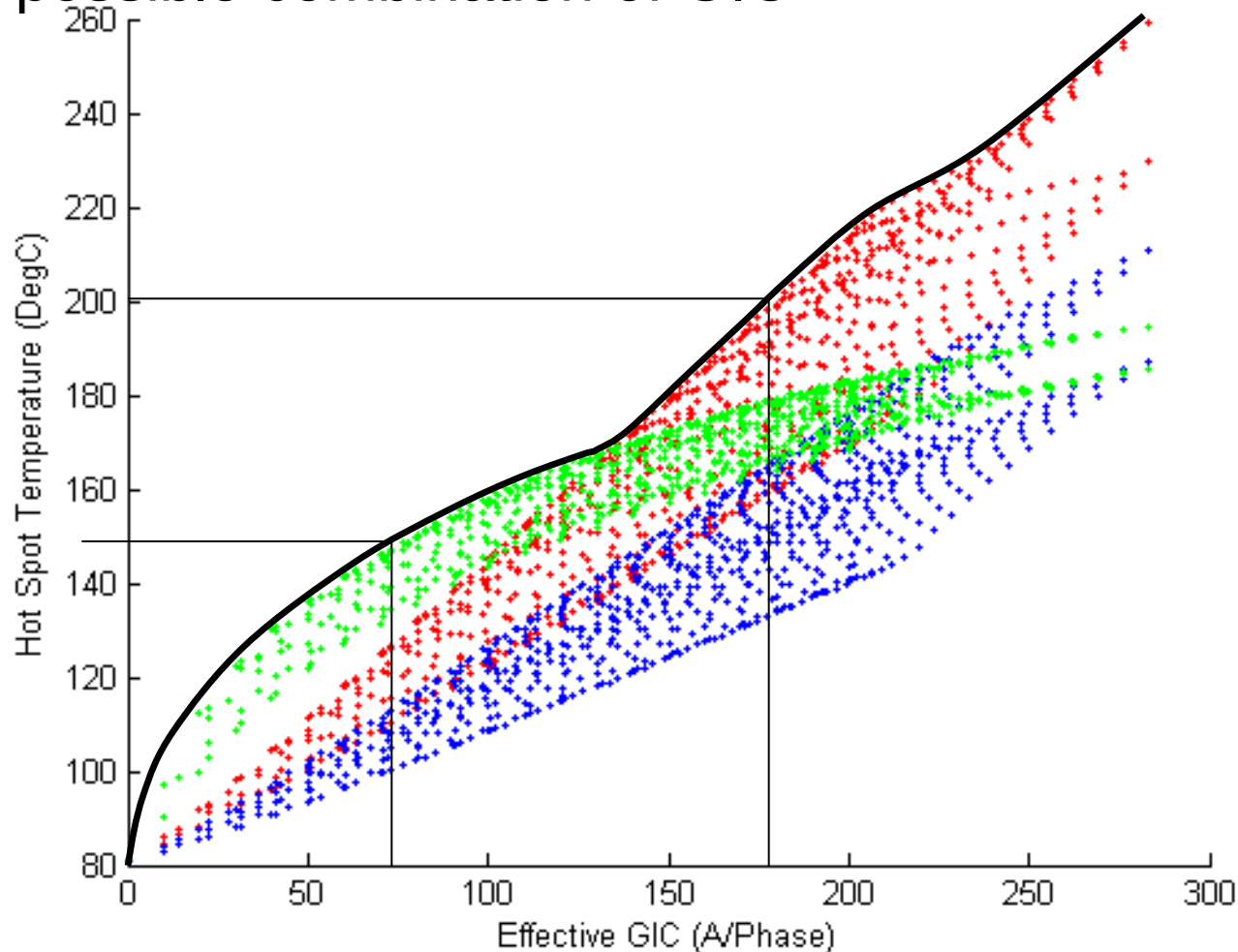
- Limits based on Std. IEEE C57.91-2011 recommendations
- A healthy transformer would not fail if these limits are reached.

Excerpt from Maximum Temperature Limits Suggested in IEEE C57.91-2011

	Normal life expectancy loading	Planned loading beyond nameplate rating	Long-time emergency loading	Short-time emergency loading
Insulated conductor hottest-spot temperature °C	120	130	140	180
Other metallic hot-spot temperature (in contact and not in contact with insulation), °C	140	150	160	200
Top-oil temperature °C	105	110	110	110

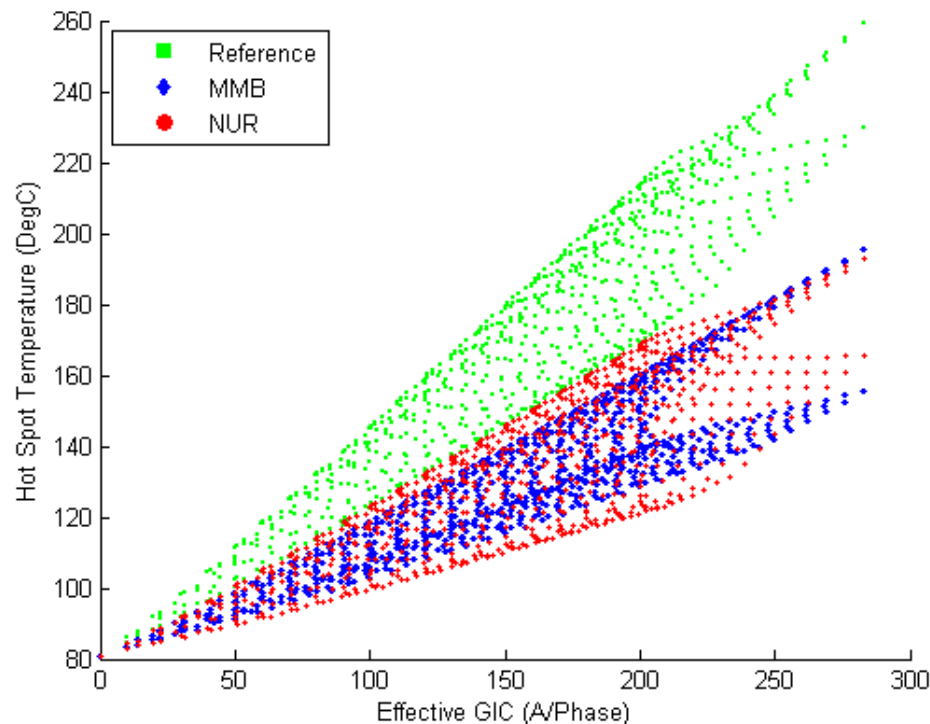
Benchmark Screening Threshold

- Based on thousands of thermal simulations using the benchmark waveshape to account for every possible combination of GIC



Benchmark Waveshape

- Why the March 1989 waveshape?
 - Because it produced the highest temperature increase when compared to the waveshape of other events from different geomagnetic observatories (consistently using 10s data and same peak GIC value).



Concluding remarks

- The state-of-the-art of transformer thermal modelling needs more experimental validation of analytical models (e.g., FEM). However, several measurement-based models are currently available and have been used to develop a conservative screening threshold.
- Publicly-available tools can be used by asset owners to carry out thermal assessments. The thermal response can be obtained from the manufacturer or from conservative defaults.
- The screening threshold is based on known transformer thermal behaviour.
 - Contains a number of conservative layers
 - It is not based on anecdotal evidence.
- As more thermal responses (either measured or from measurement-supported calculations) are known, the threshold can be modified.