FERC TM: Panel 2: Vulnerability assessments

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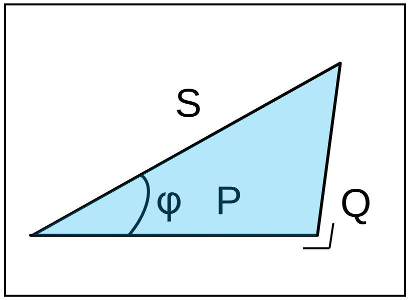
2.1 Harmonics, GPT, cap/SVC, Q, and effect on system

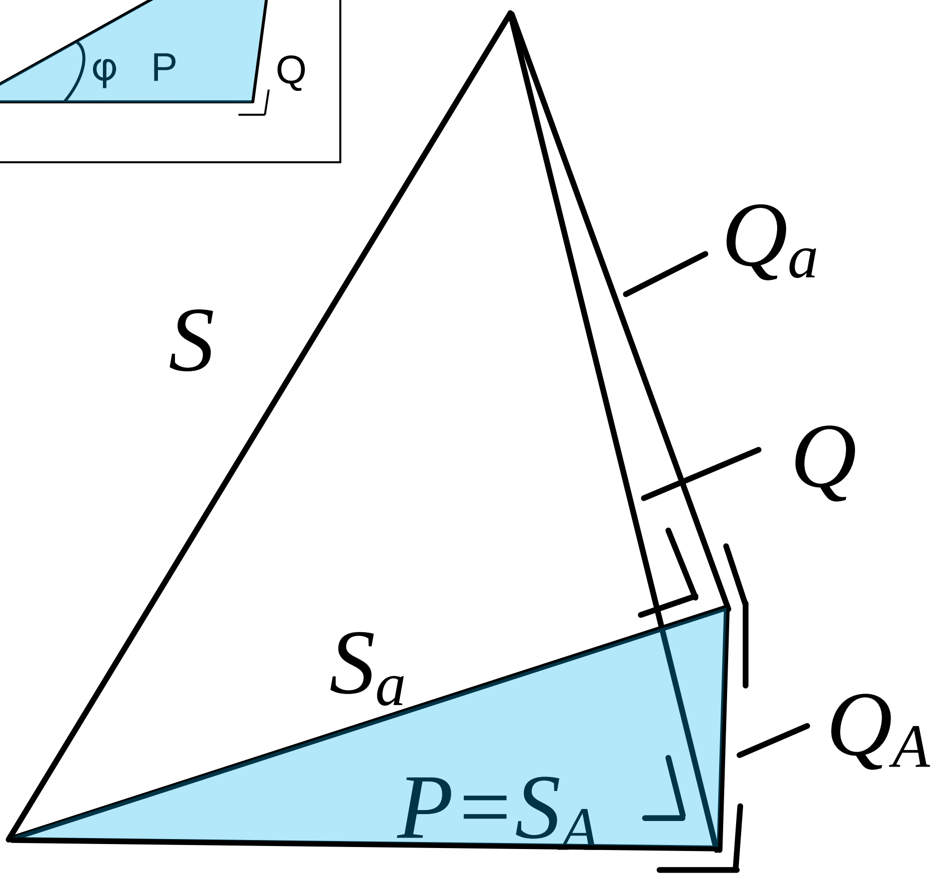
- State of knowledge and modeling capabilities iro harmonics and vibration.
- Impacts of harmonics and vibration on equipment (e.g. protection, reactive sources, generators).
- Power system impacts of reactive power demand.

GICs, reactive power and harmonics

- GICs in transformers generate harmonics and unbalance, and GIC is not constant.
- Quebec event : voltage and reactive power swings preceded system collapse [Balma, 1992].
- Vars from transformers change with GIC magnitude and direction, compounded by capacitor banks tripping to protect them from overheating by harmonics.
- IEEE Std 1459-2010 represents conventional knowledge of reactive power. Includes distortion by harmonics, but not unbalance and DC.
- General power theory (GPT) [Malengret & Gaunt, 2008, 2011, 2012, 2013] accommodates all shape distortion.

GPT for distorted conditions





Components of non-active power are orthogonal.

Q **= total non-active power**

***Q*a = <u>component compensated without energy storage</u>**

***Q*A = <u>component needing energy storage for compensation</u>**

S **= apparent power without compensation**

***S*a = apparent power after comp without energy storage**

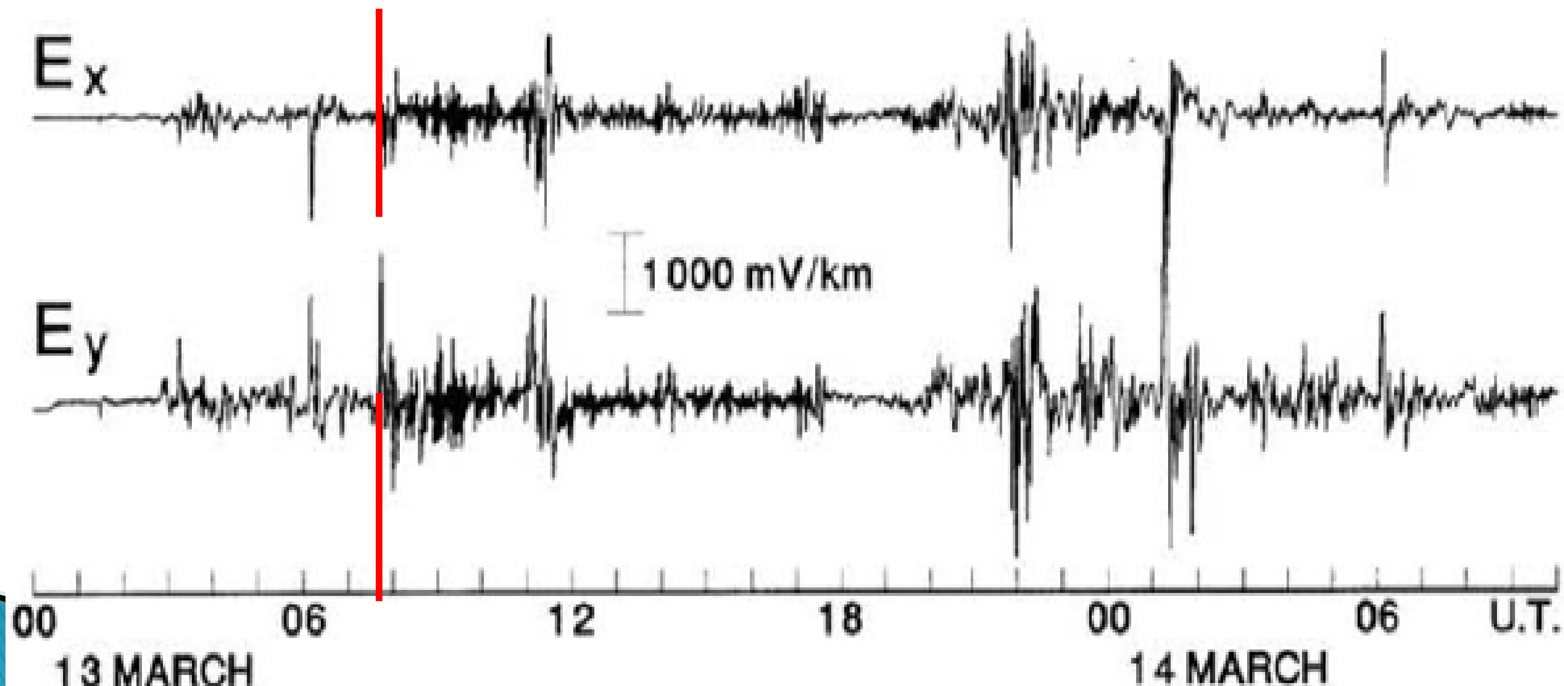
***S*A = apparent power after complete compensation,**

so $S_A = P$

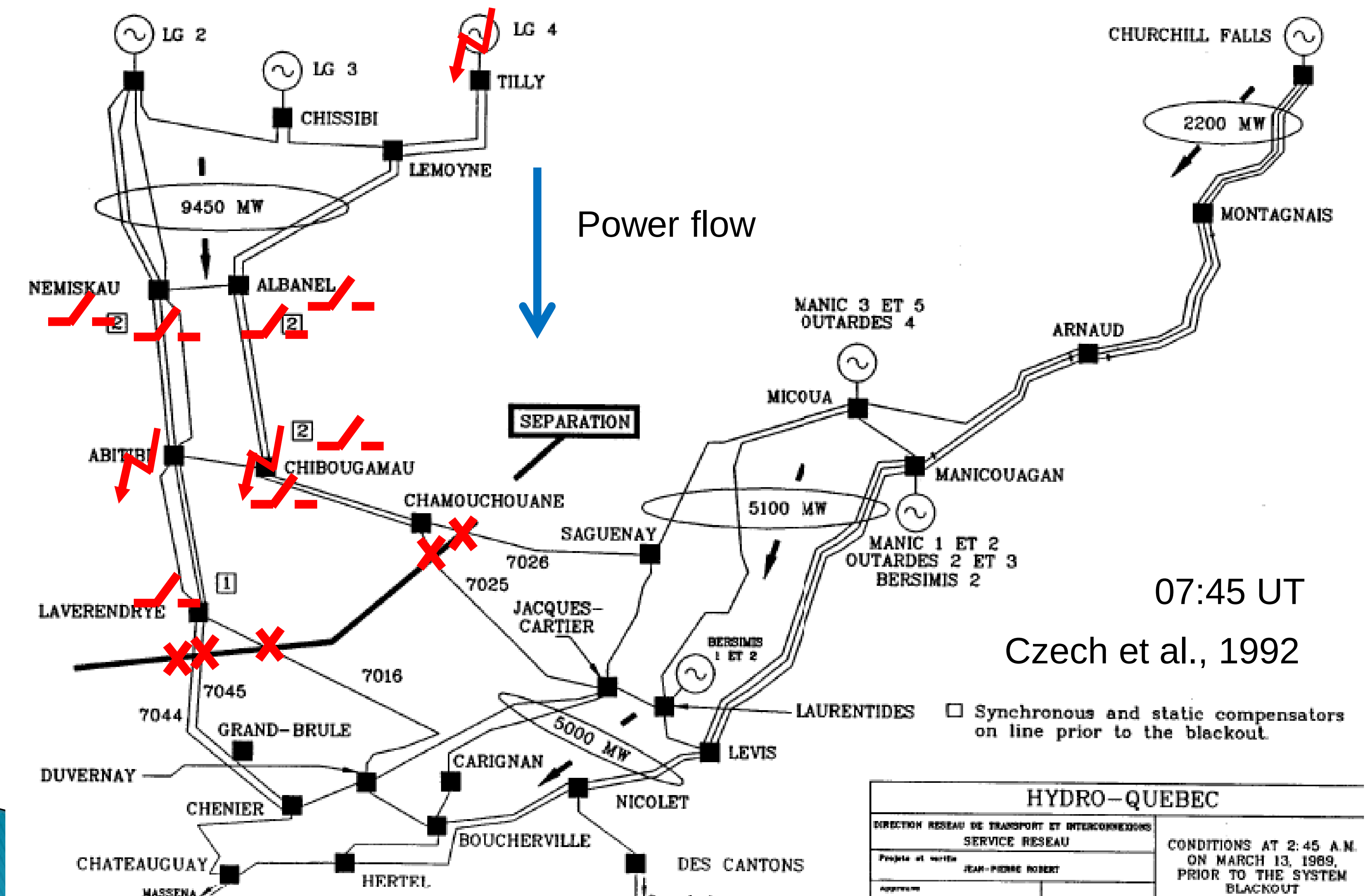
<u>Power factor is index of relative efficiency of delivery</u>.

Caps, SVCs

- **Capacitor banks and SVCs correct Q by storing energy to control V-I phase shift.**
- **Harmonic distortion and unbalance trip capacitors to protect them.**



Quebec Hydro 02:45 in 1 min



Effect of Q on system

- **Tripping of cap. banks and SVCs increases Q required from source:**

  → lowers efficiency of power delivery,

  → voltage falls.

- **Distortion reduces efficiency further (not defined in IEEE Std 1459-2010):**

  → probability of <u>system collapse higher than expected</u> from standard load flow analysis.

- **High apparent power S contributes to heating and degradation.**

2.2 Transformer thermal assessment

- GIC threshold requiring thermal impact assessment of transformer; 75 A/ph?
- System assessments, including interaction with equipment vulnerabilities (e.g. harmonics).

Effect on transformers

- **In half-wave saturation, leakage flux causes eddy current heating in core plates, windings and tank.**
- **Heating intensity and location vary with GIC magnitude, transformer core structure and design details.**
- **NERC proposes transformers be checked by simulation if simulated GIC exceeds 75 A/ph (225 A in neutral).**

Characteristic GMDs and GICs

Four GMDs cause disruption:

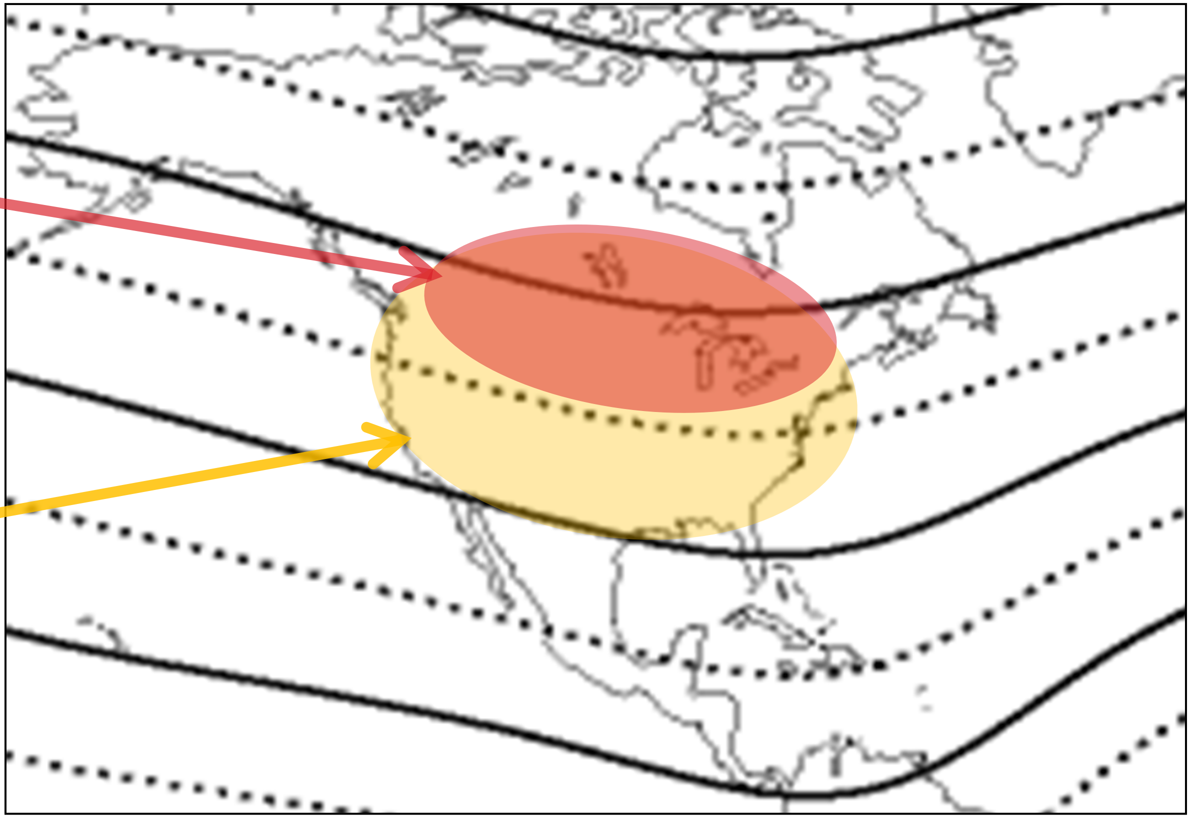
1. **Intense short (10-120 sec) disturbance, possibly local, initiates spurious or correct relay tripping; cascade tripping possible (Quebec 1989).**
2. **Sustained high GMD, high GICs >50 A/ph for 1-60 min, overheats transformers (Salem and UK 1989); transformer fails in days.**
3. **Moderate GMD and GICs ~40A(n) cause rapid localised heating in transformer; degradation continues after GIC, transformer fails in weeks to months (SA, 2003).**
4. **Regular (nightly) GMD from coronal holes; cumulative low energy degradation.**

Two risk zones?

Extreme events:

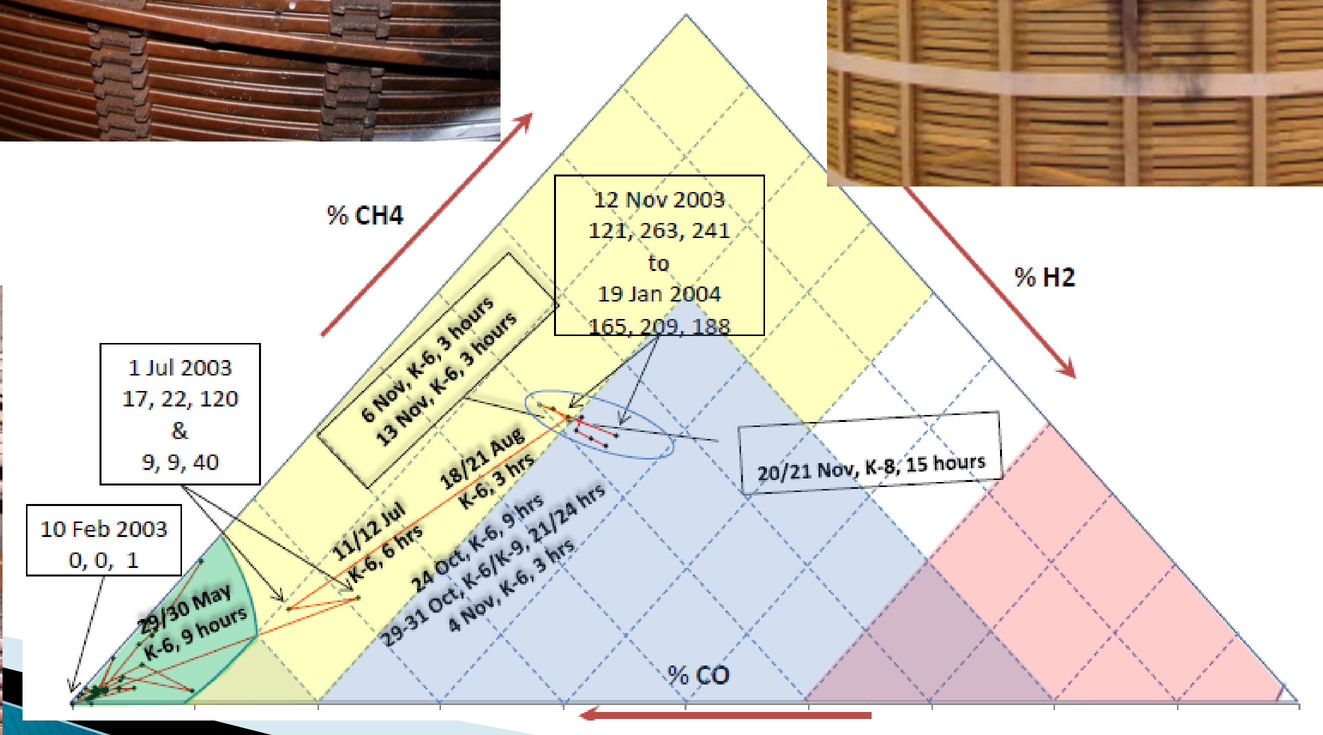
System collapse

Equipment damage



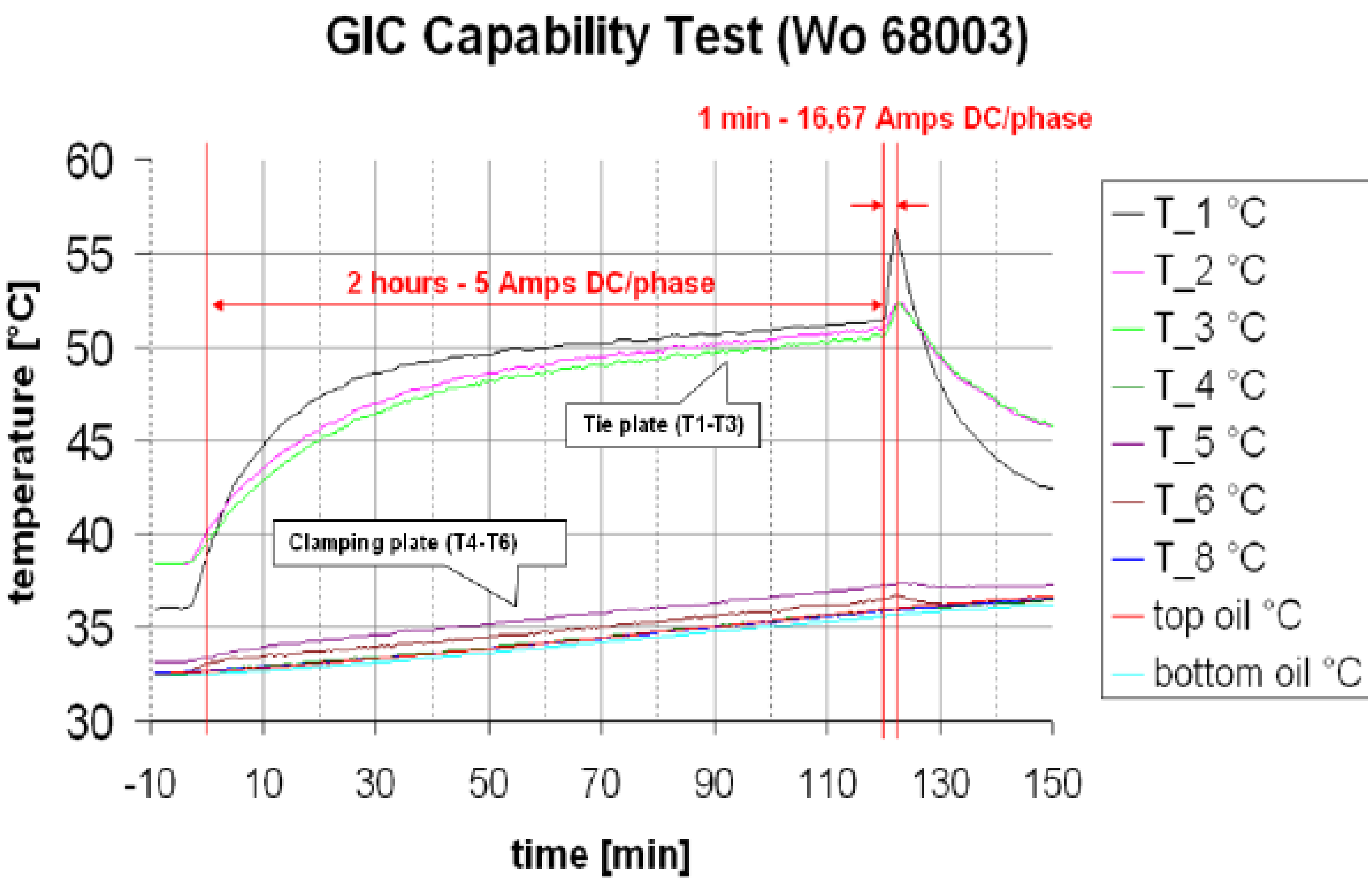
Experience in SA

Halloween Storm: 29-31 October 2003.



Modern transformer testing

Rapid heating with only 16.7 A/ph (50 A neutral)



Measured metallic parts and oil temperatures during GIC test

Transformer degradation withstand

Different transformers respond differently to GICs.

- **Practical experience of rapid transformer failure below 75 A/ph.**
- **Factory tests show rapid heating with 16.7 A/ph.**
- **Successive GMDs have cumulative effects.**
- **NERC's 75 A/ph threshold for assessment is too high.**

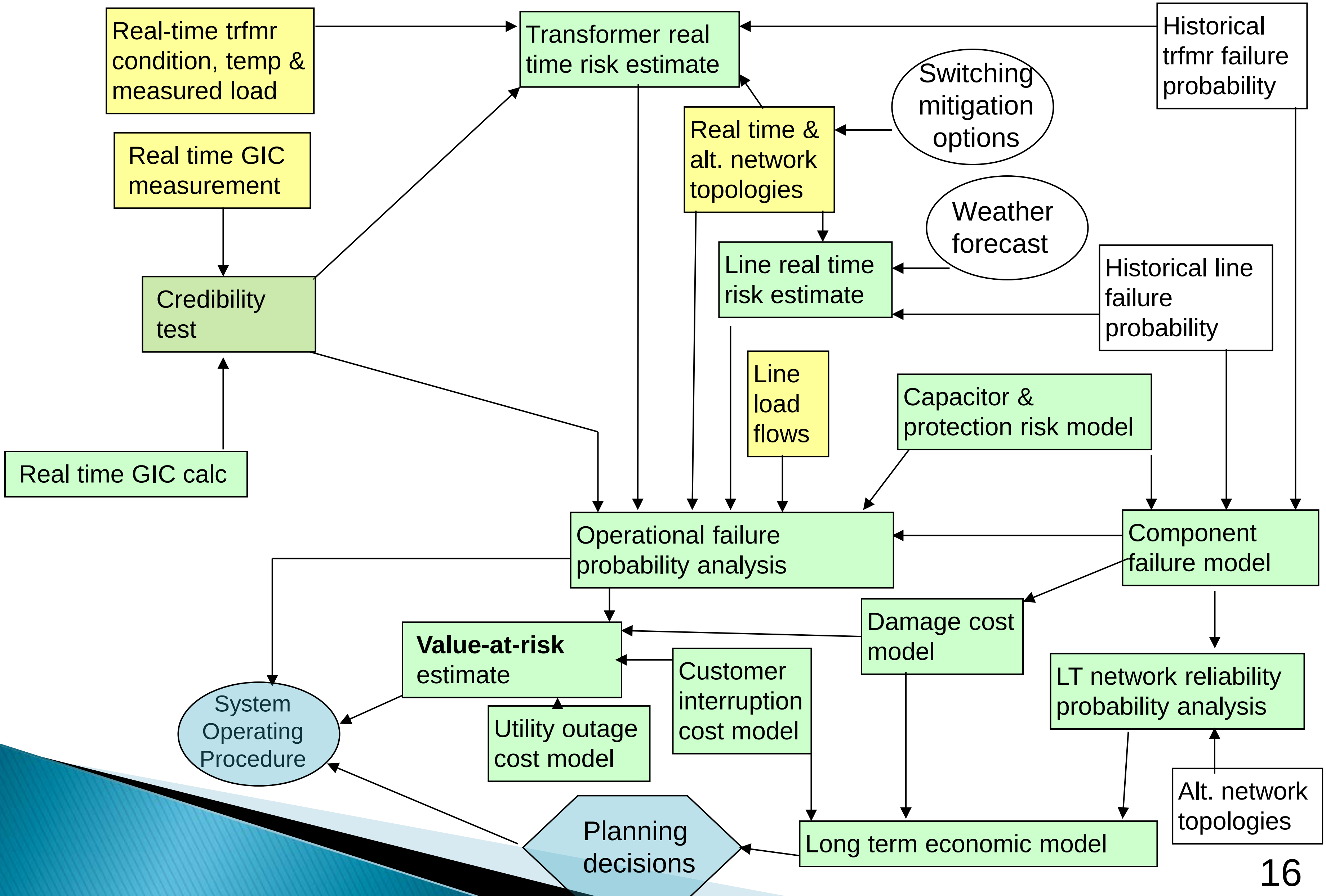
Recommend threshold: 15 A/ph.

System assessment

- **Failure cost =**

  $f_{season/time}$ (loads, faults, interruption cost)
- **GIC impact added.**
- **Probabilistic modeling assesses Value@Risk.**
- **V@R reflects ‘public benefit’, and is basis of assessing mitigation options.**
- **V@R replaces N-1, N-2 Contingency Assessment.**

Simplified GIC cost-of-failure model



2.3 Non-uniform E-fields

- Modeling capabilities to use non-uniform E-fields to calculate grid GIC flows – present and soon.

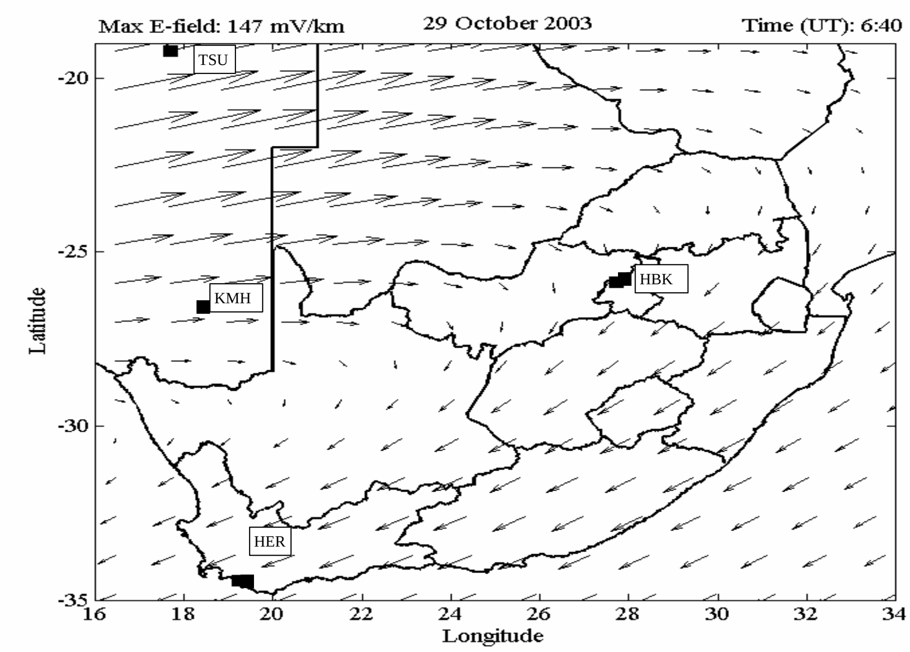
- Advantages/disadvantages of using non-uniform E-fields in GIC calculations.

Non-uniform E-fields

SECS method allows GICs in non-uniform fields to be calculated – history and real-time.

NERC's uniform field benchmark over-simplifies reality.

- Real GICs have greater dispersion, changing Q impact.
- Variables of non-uniform GMD require scenario testing.
- More complex planning.



Summary

State of knowledge and modeling capabilities are advanced and advancing all the time,

… but are not implemented.