IEEE PES Presentation
March 27, 2012

Geomagnetically Induced Currents (GIC) and Manitoba Hydro

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System Planning Department

Presentation Goals

1. What is the relationship between the sun's sun spot activity and the power system?

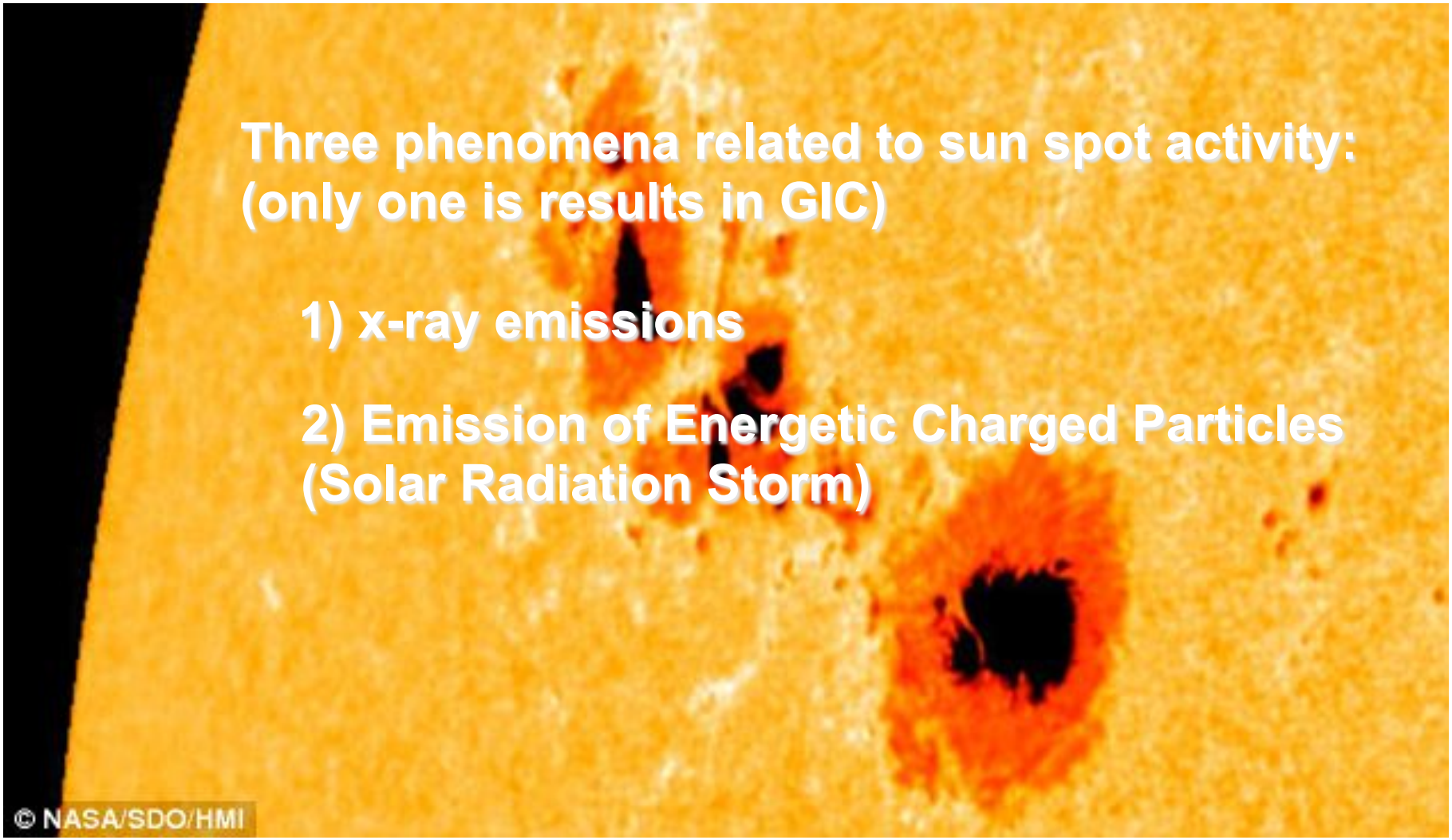
2. What does this all have to do with a Geomagnetic Storm?

3. 1989 Quebec Hydro Black-out.

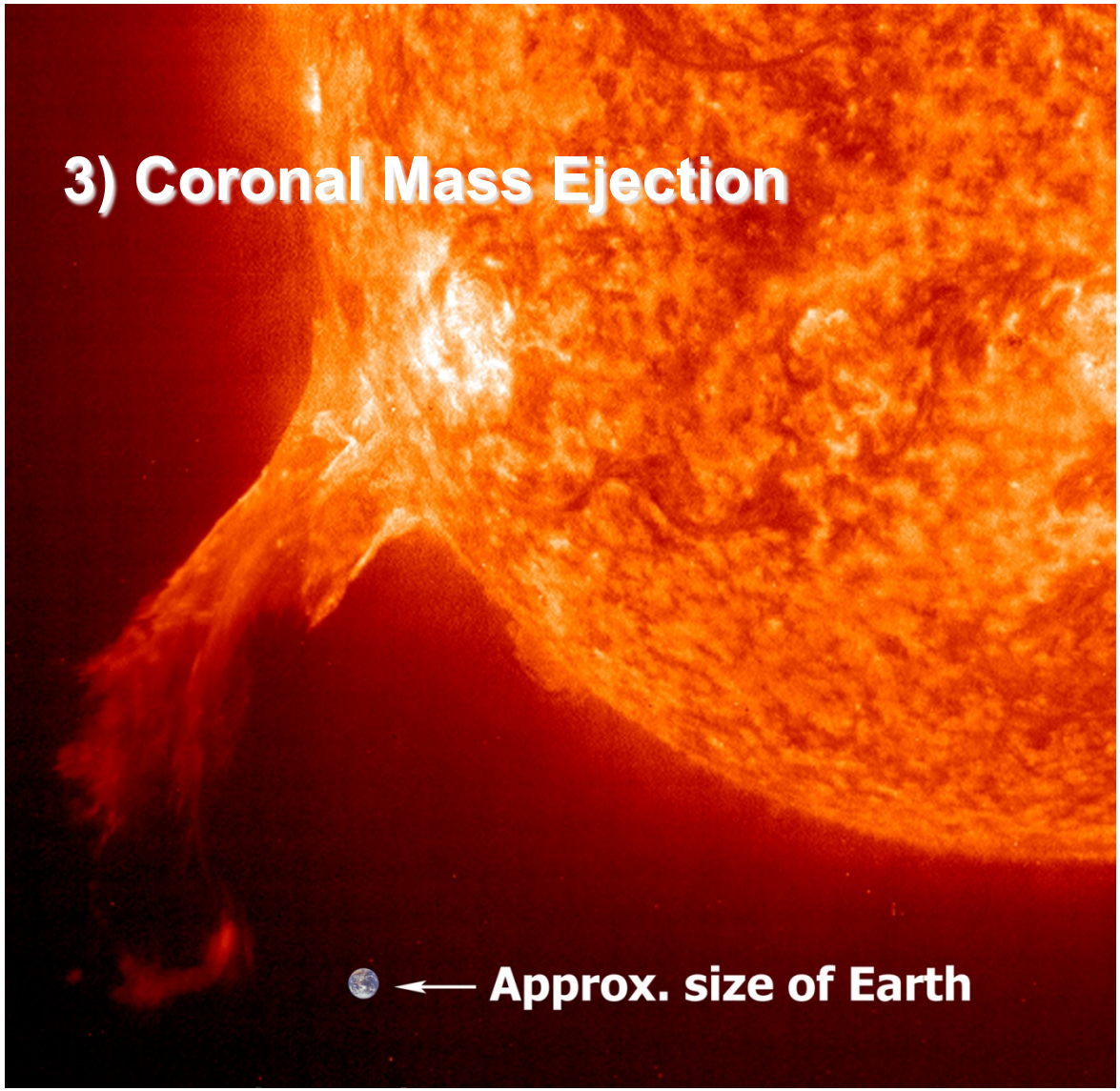
4. What has Manitoba Hydro done in the past?

5. What is Manitoba Hydro currently doing?

Solar Storm (Sun Spot Activity)

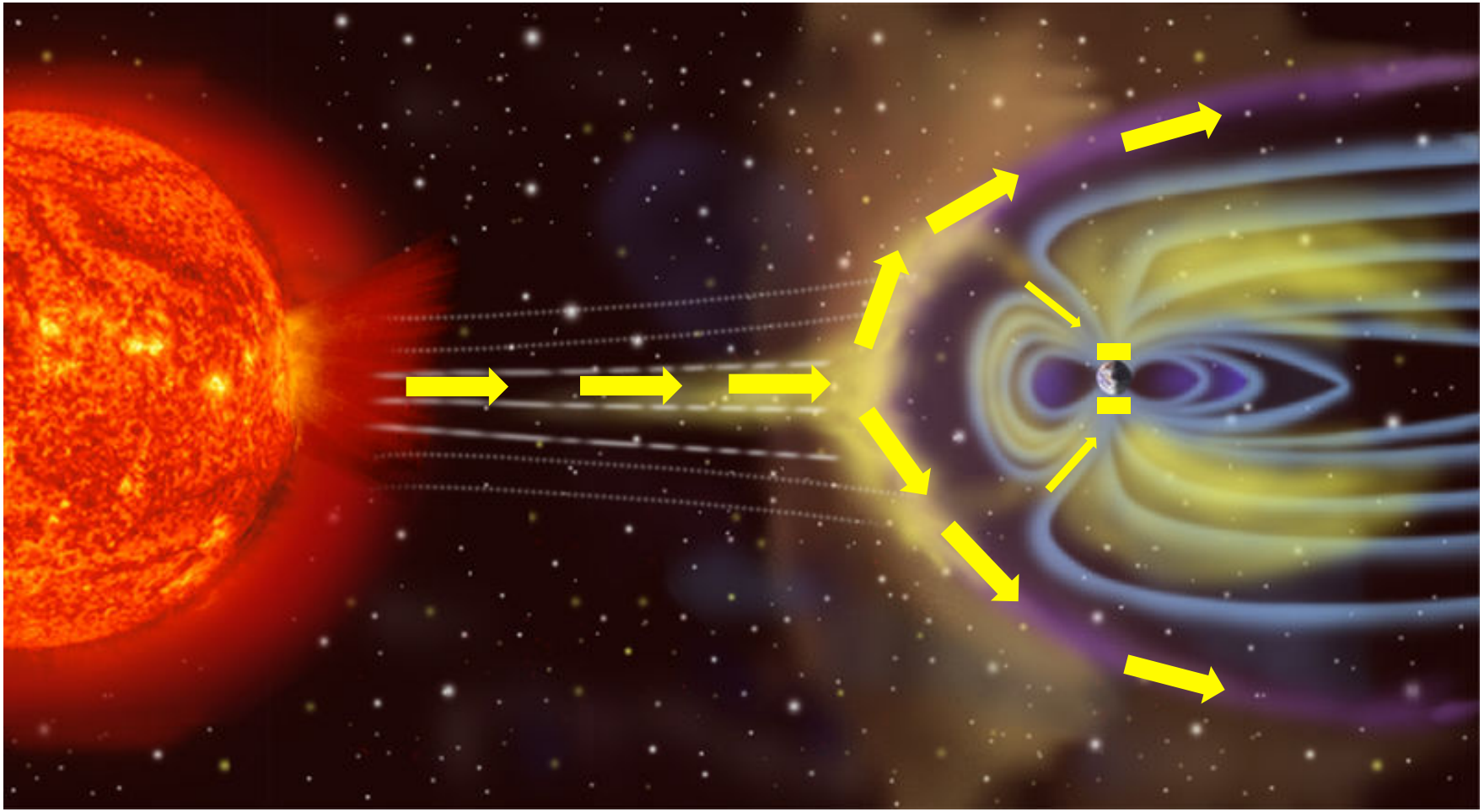


Solar Storm (Sun Spot Activity)

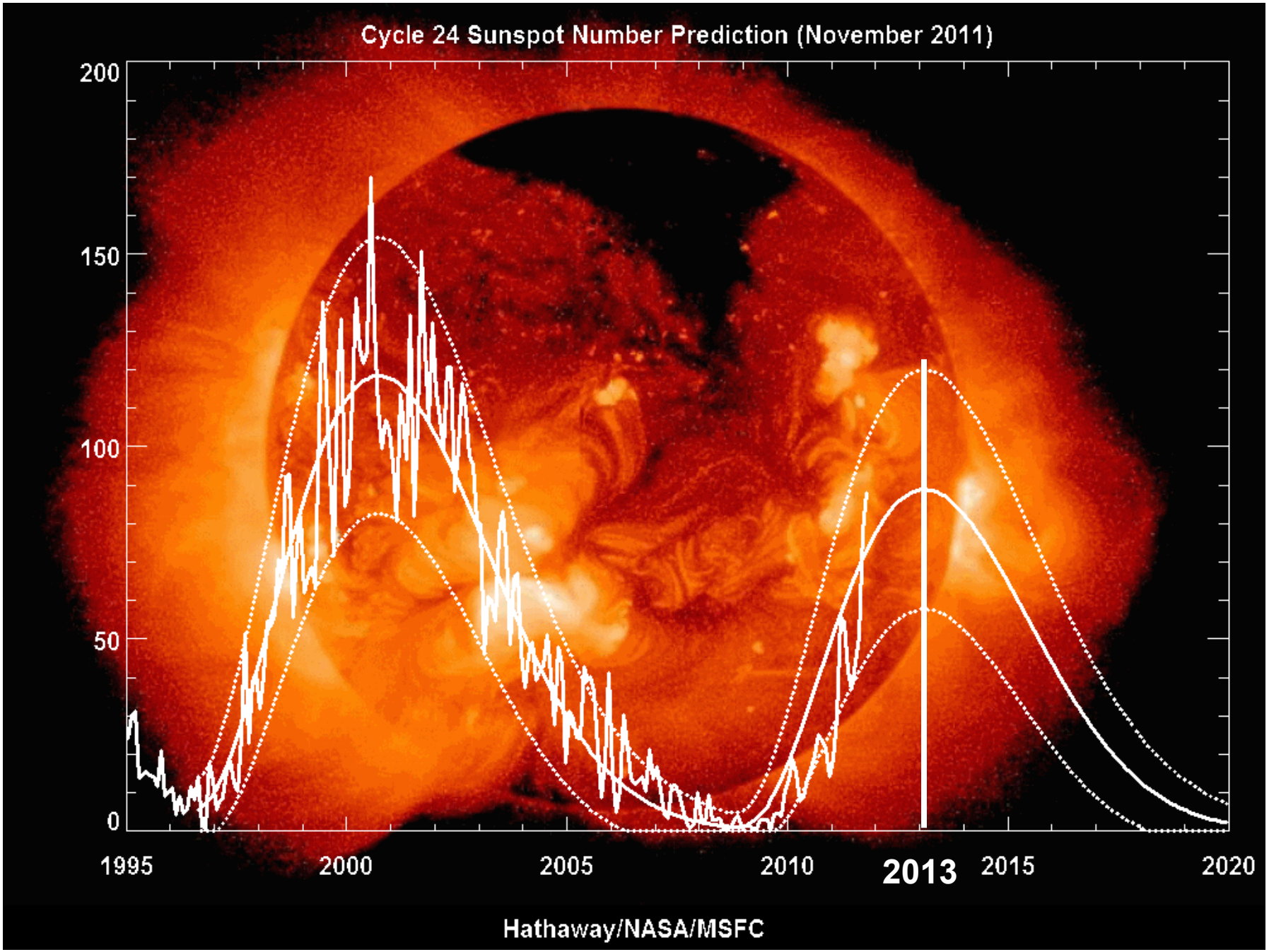


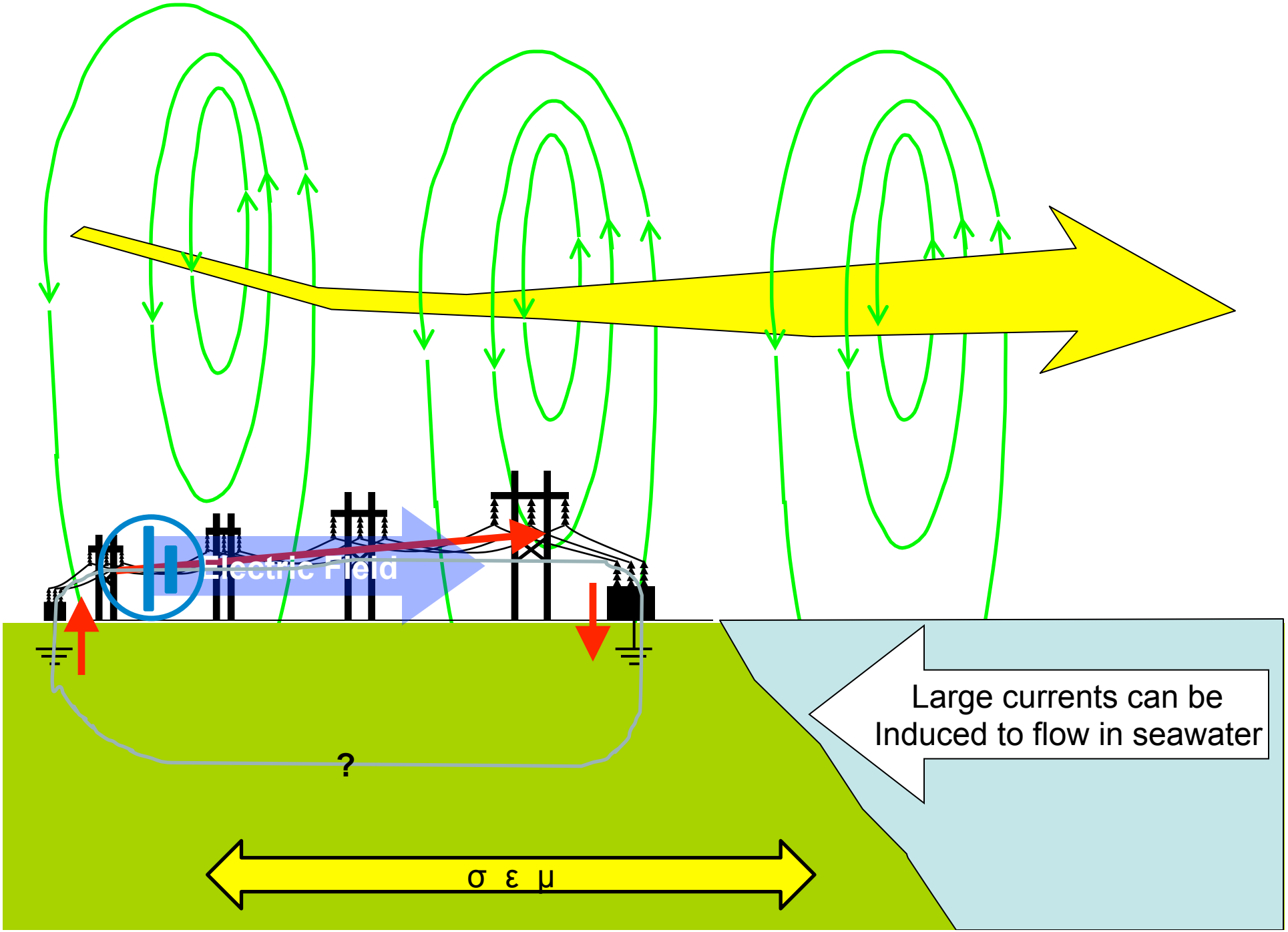
http://science.nasa.gov/science-news/science-at-nasa/2006/21dec_cycle24/

Bringing the CME down to earth.



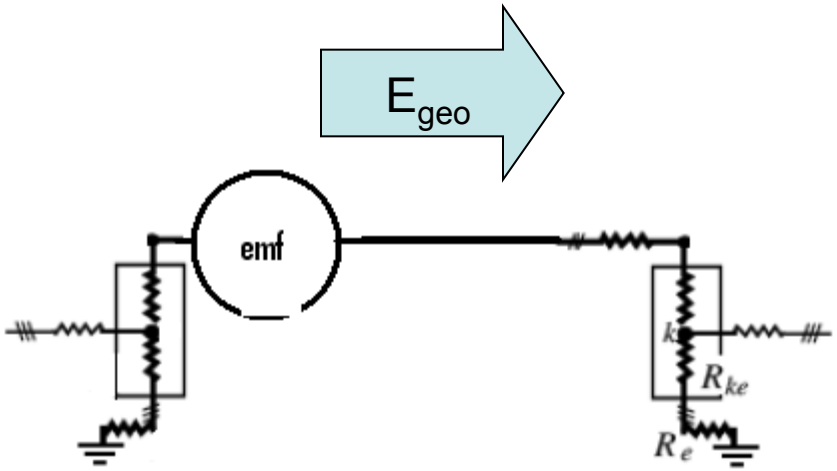
By Tim Loewen, Manitoba Hydro
PR 280 between Thompson and Gillam


Cycle 24 Sunspot Number Prediction (November 2011)
200
150
100
50
0
1995
2000
2005
2010
2013
2015
2020
Hathaway/NASA/MSFC


Electric Field
?
σ ε μ
Large currents can be
Induced to flow in seawater

GIC Impacts on the Power System

- Almost all of the utility system impacts from GIC are directly or indirectly related to transformer saturation.



$$emf = -\int \vec{E}_{\text{geo}} d\vec{\ell}$$

$$V^{*}_{\text{primary}} = V_{\text{primary}} + emf$$

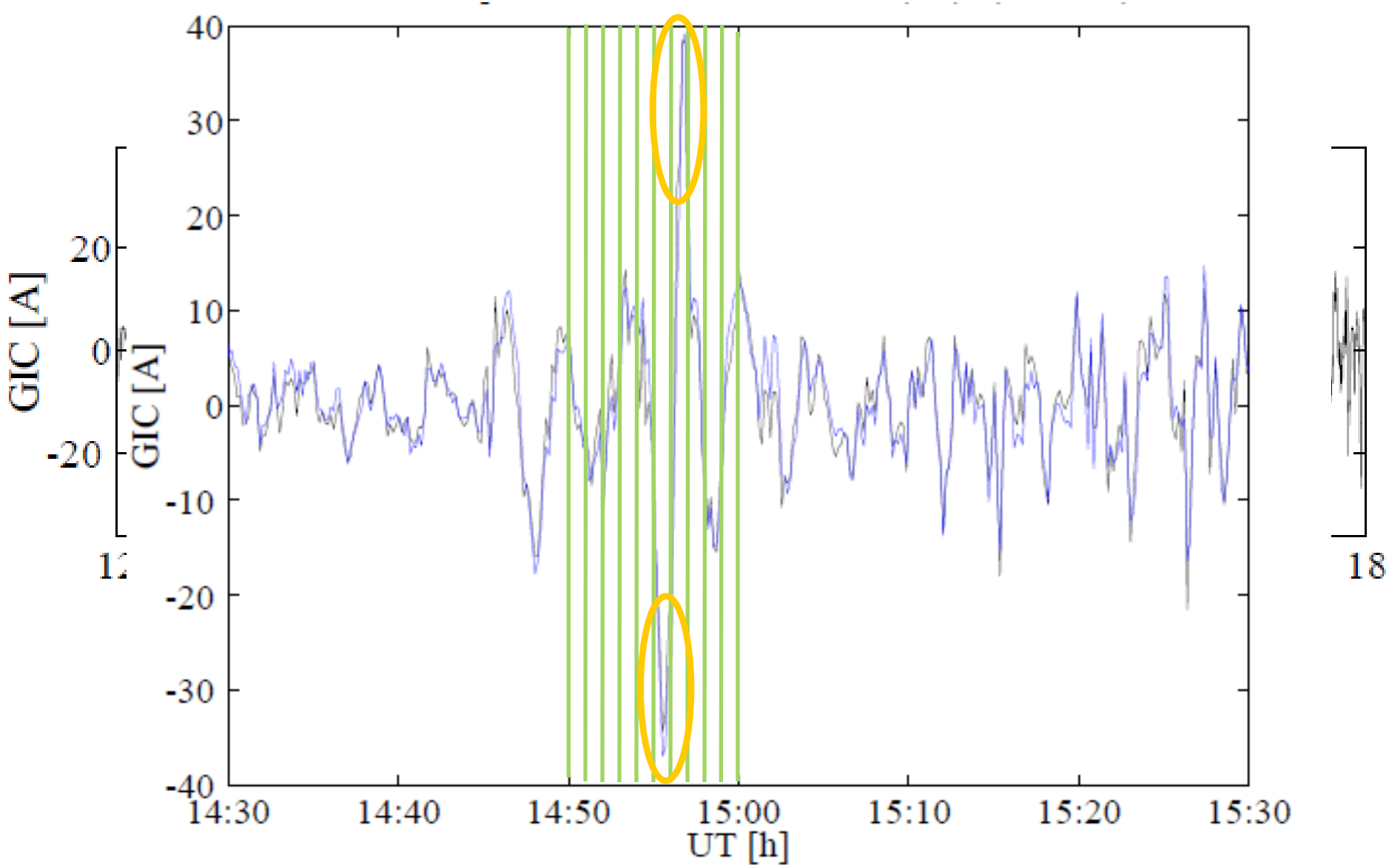
$$\varphi \propto I_{\text{primary}}(t) \propto V^{*}_{\text{primary}}(t)$$

$$V_{\text{secondary}}(t) \propto -\frac{d\varphi}{dt}$$

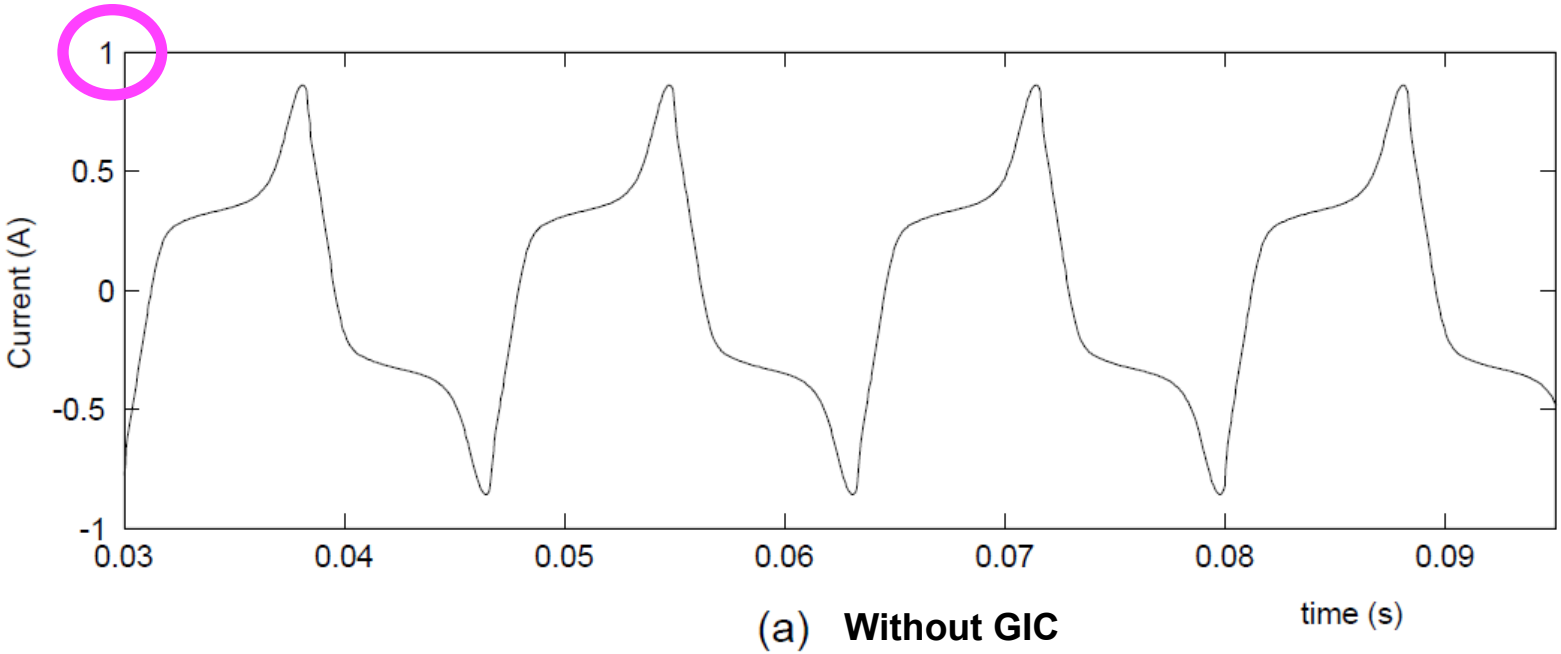
Typical Transformer GIC

Grand Rapids (Unit 1) October 29, 2003

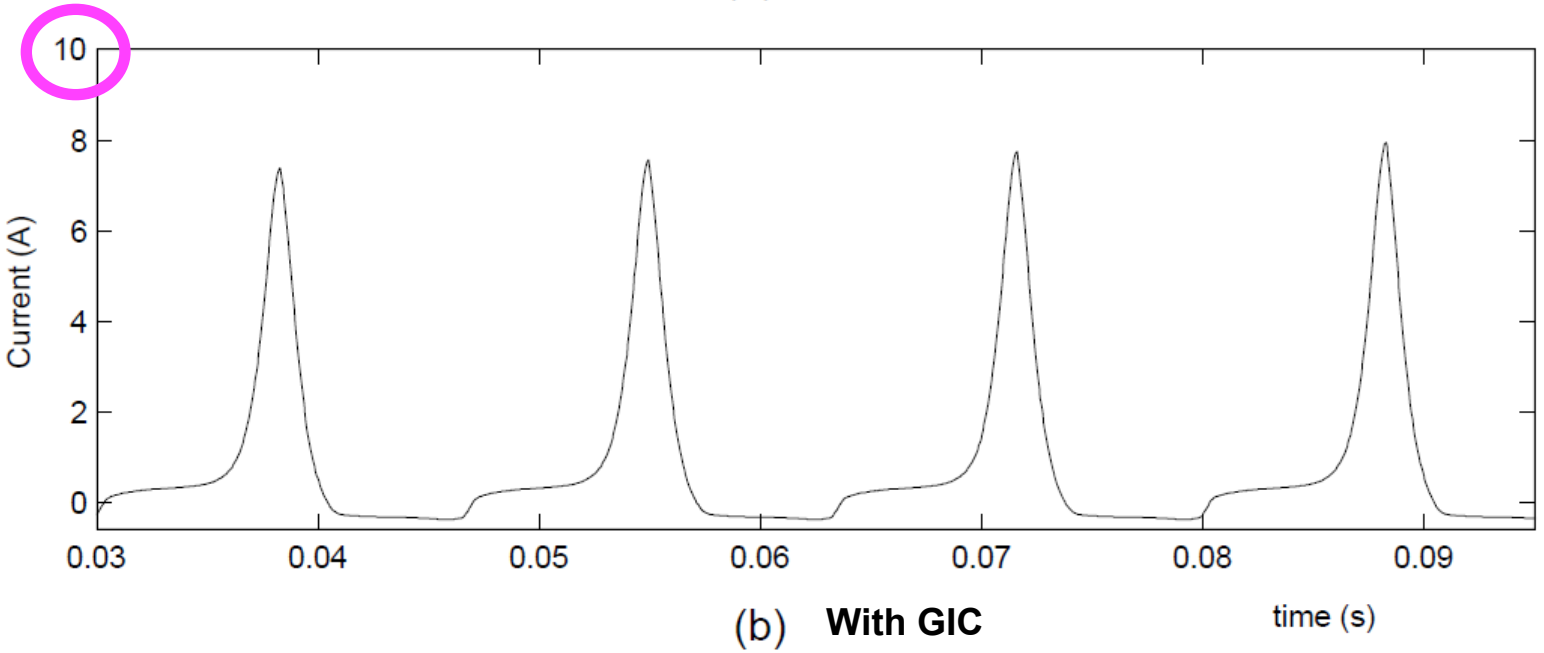
Sunburst Monitor



Transformer Magnetizing Current



(a) **Without GIC**

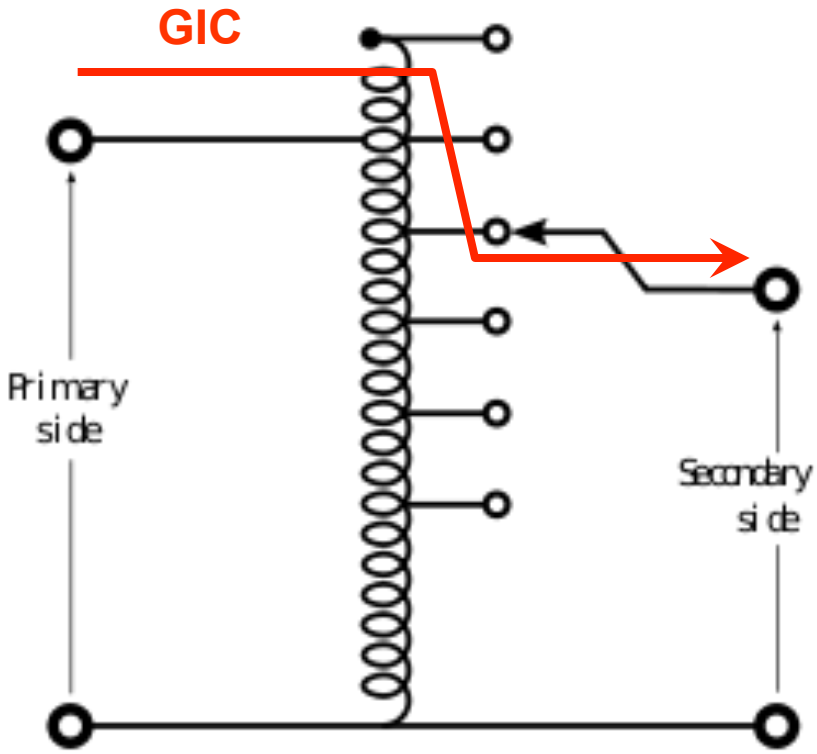


(b) **With GIC**

GIC Impacts on the Power System

- Transformer Damage
  - Heating, insulation, mechanical (stray flux).
- Transformer core saturation.
  - reactive power sinks
    - Voltage depression
    - Depletion of system's reactive capacity.
- Production of harmonics.
  - Relay miss-operation.
  - Shunt capacitor banks
    - Overload.
    - Trip-out.
    - Generators may overheat
- Distorted voltages
  - Commutation failure in HVDC systems and Static VAR Compensators.
  - Automatic Voltage Regulators may miss-operate.
  - Increased switching voltages.

Auto Transformers



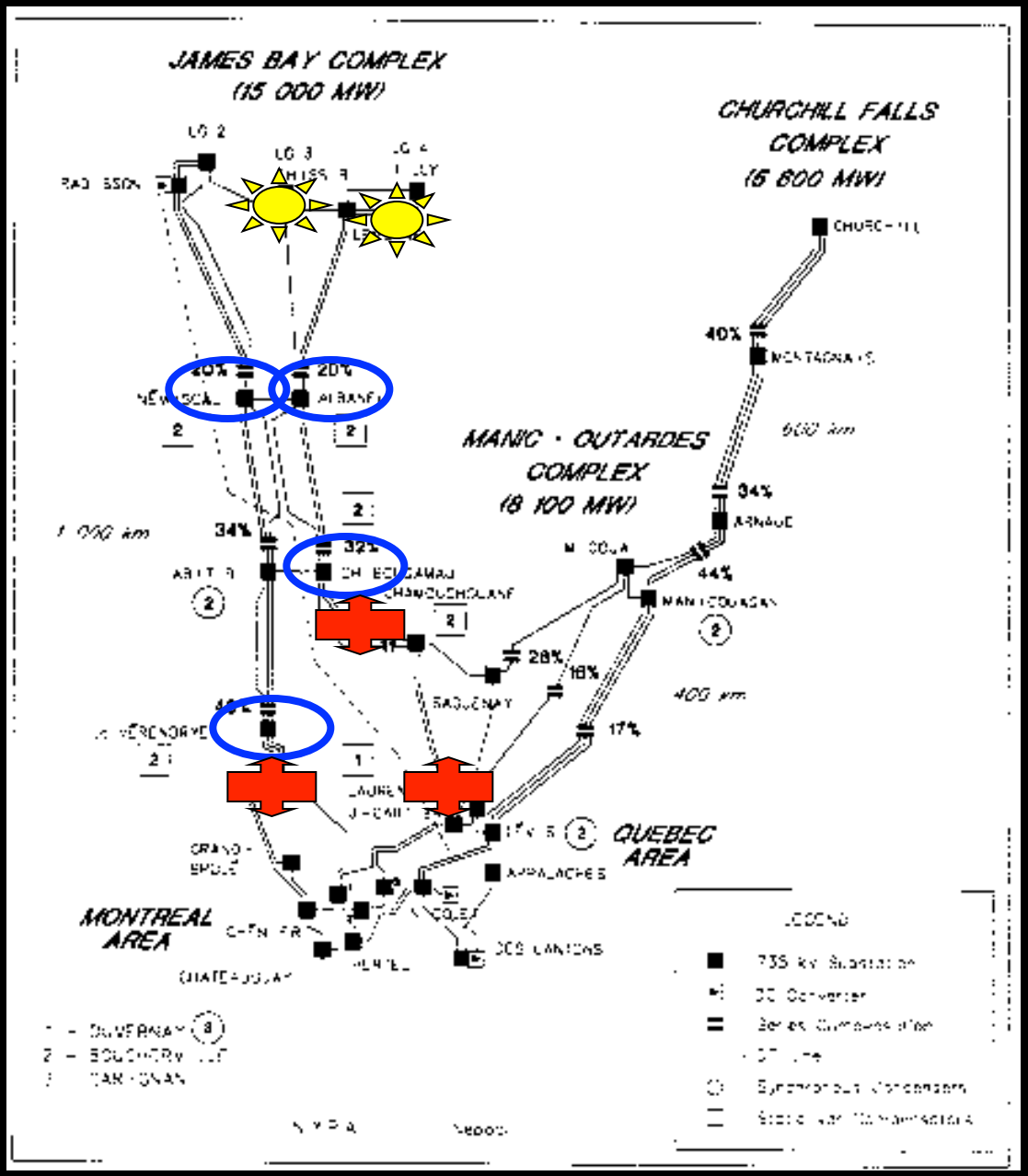
- Source of GIC from the high side through windings onto low side.
- Many of MH Transmission Transformers are Auto Transformers.
  - 230/500 kV auto
  - 115/230 kV auto
  - 138/230 kV auto

Quebec
Power
System

SVC
tripped

Lines
tripped

Transformer
damaged



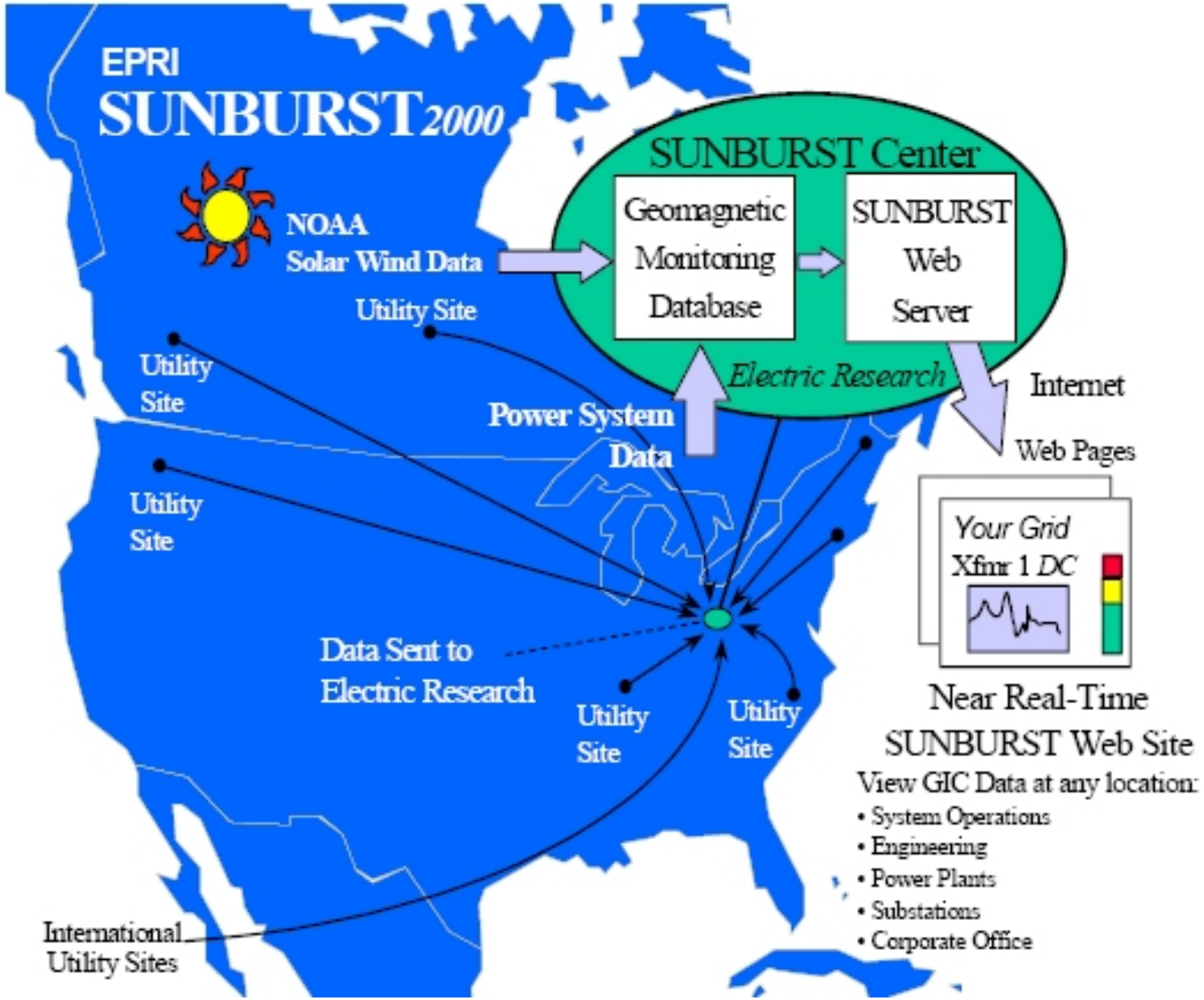
Past Manitoba Hydro Projects

1) Electric Power Research Institute (EPRI) SUNBURST Program

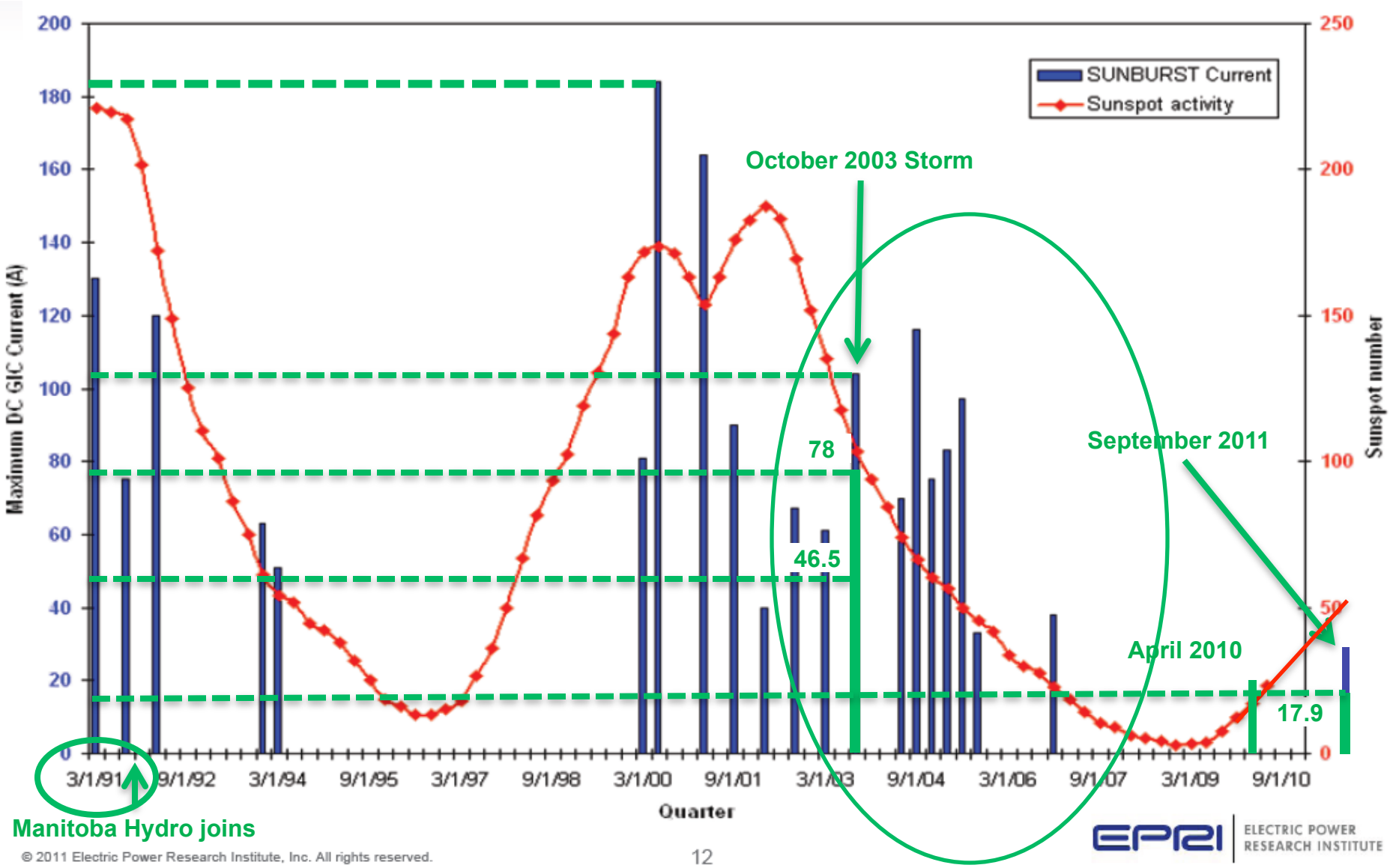
2) In-House Software and Analysis

3) Equipment GIC Specifications

4) 2007-08 Finnish Meteorological Institute R&D Project


EPRI
SUNBURST2000
NOAA
Solar Wind Data
SUNBURST Center
Geomagnetic Monitoring Database
SUNBURST Web Server
Electric Research
Internet
Web Pages
Utility Site
Utility Site
Utility Site
Power System Data
Your Grid
Xfmr 1 DC
Data Sent to Electric Research
Utility Site
Utility Site
International Utility Sites
Near Real-Time SUNBURST Web Site
View GIC Data at any location:
• System Operations
• Engineering
• Power Plants
• Substations
• Corporate Office

SUNBURST: Maximum transformer GIC DC neutral currents over the past two solar cycles



EPRI ELECTRIC POWER RESEARCH INSTITUTE

Past Manitoba Hydro Sponsored Projects: 2) In-House Software and Analysis

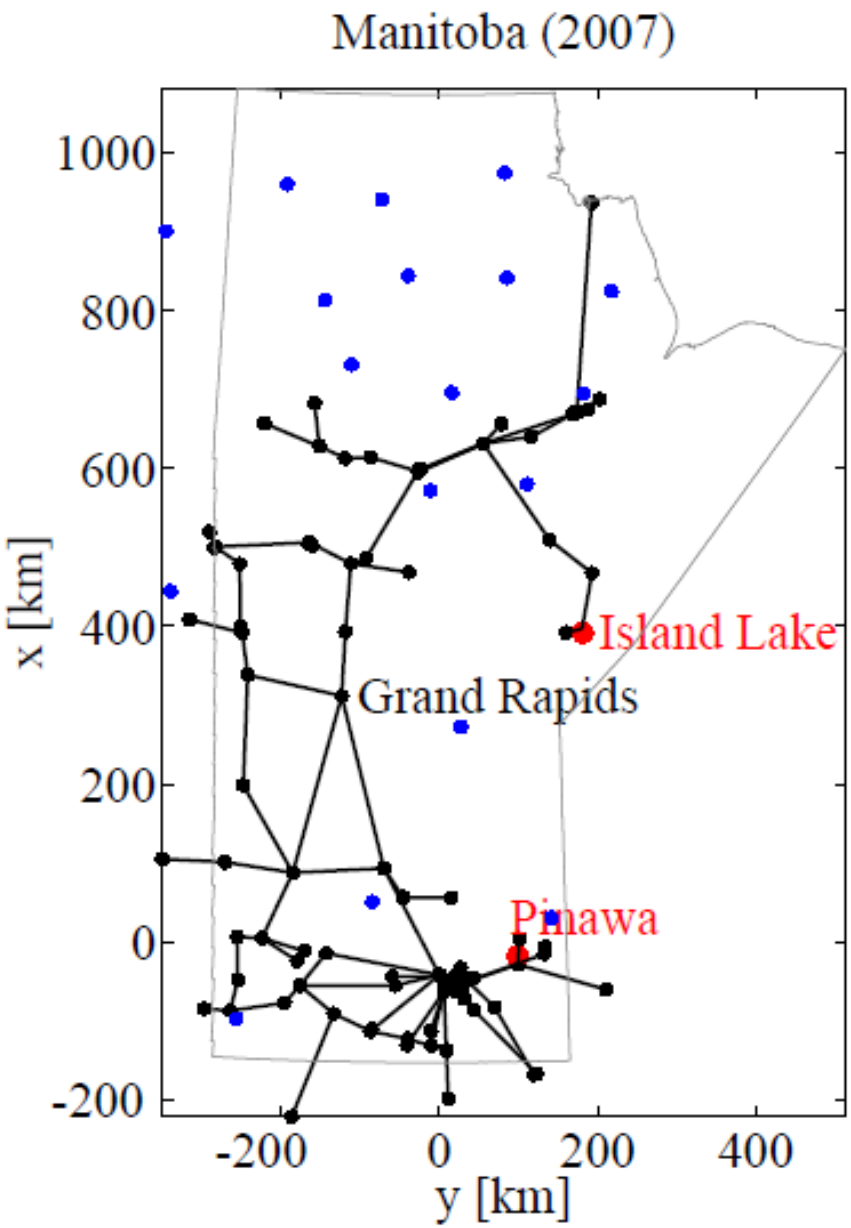
- 1994 Development of Software for Geomagnetically Induced Current (GIC) Calculations.
  - Natural Resources Canada
  - Finnish Meteorological Institute
  - System Planning Department
    - Supported the claim that changes to the system will move the GIC from one station to another.
    - After Series compensation of the 500 kV line this study indicated Ridgeway Station has the largest GIC.
  - Did not utilize an actual E field rather a hypothetical one.

Past Manitoba Hydro Sponsored Projects: 3) Equipment GIC Specifications

- System Planning Department Specified GIC withstand capabilities for critical equipment.
  - Forbes SVC
    - Extensive testing of SVC controls at IREQ
  - Riel Sub-Station
    - Transformer
    - Shunt and neutral Reactors
    - CT's
    - Circuit Breaker
  - SVC (Ponton & Birchtree)
    - Transformer
      - 100 A dc for up to 1 minute.
      - 30 A dc for up to 30 minutes.
    - Factory Acceptance Tests (Second Harmonic Distortion)
      - » Measurement devices.
      - » Protection.
      - » Synchronization.

Past Manitoba Hydro Sponsored Projects: 4) 2007-08 Finnish Meteorological Institute R&D Project

- Assessment of geomagnetic activity levels and the related geoelectric field and GIC in Manitoba for the last solar cycle.
  - Statistics of the magnetic flux.
  - Statistics of the modelled geoelectric field.
  - Statistics of the modelled GIC in the Manitoba Power system.
  - Detailed analysis of the large magnetic storm on 29-30 October 2003


Manitoba (2007)
1000
800
600
400
200
0
-200
x [km]
-200
0
200
400
y [km]
Island Lake
Grand Rapids
Pinawa

FMI Findings

1. Average Electric field values increase from the south to the north.

2. No clear geographic rule of how electric field magnitudes vary as a function of latitude.

3. East component electric field is on average larger than the north component.

4. Largest electric field has no preferred direction.

5. Large fields can be experienced anywhere in Manitoba.

FMI Findings

1. GIC maximum does not necessarily correspond to sunspot number.

2. Large GIC can be occur at all latitudes.

3. Higher activity can be expected during the spring and autumn equinoxes.

4. The time of daily maximum for GIC is around midnight.

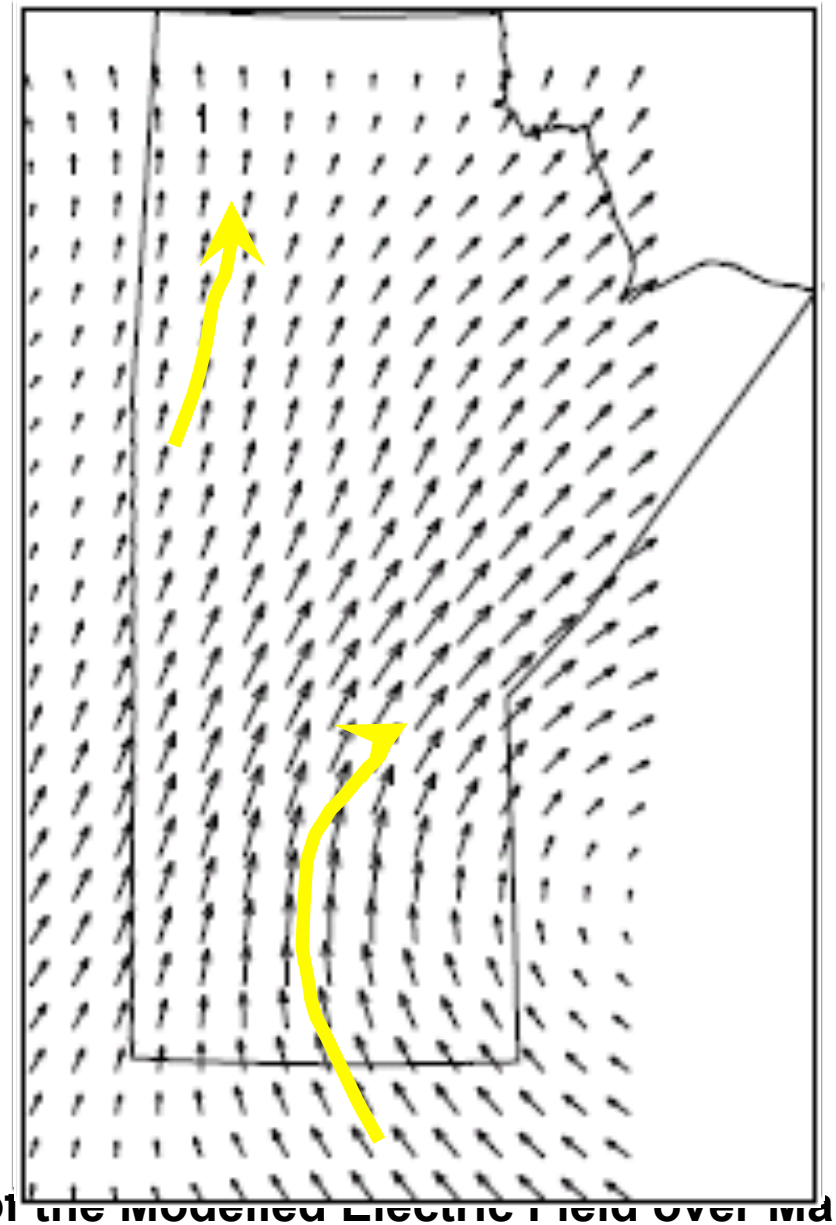
5. A secondary source of GIC are pulsations which typically occur in the morning (preceded by substorms).

6. For the last solar cycle the maximum GIC occurred on October 30, 2003

Top 17 Simulated Transformer GIC for Last Solar Cycle

Station	# Parallel Transformers	Approximate GIC
Ridgeway*	2	78
Silver	2	55
Richer	1	53
Vermillion	2	52
Reston	2	51
Cornwallis	3	49
Overflowing River	2	48
Cliff Lake	3	45
Grand Rapids**	4	40
St. Leon Wind	1	38
Rapid City	1	37
Birtle South	2	36
Inco	4	34
Ponton	1	33
Letellier	2	31
Rosser	4	28
Ashern	2	23

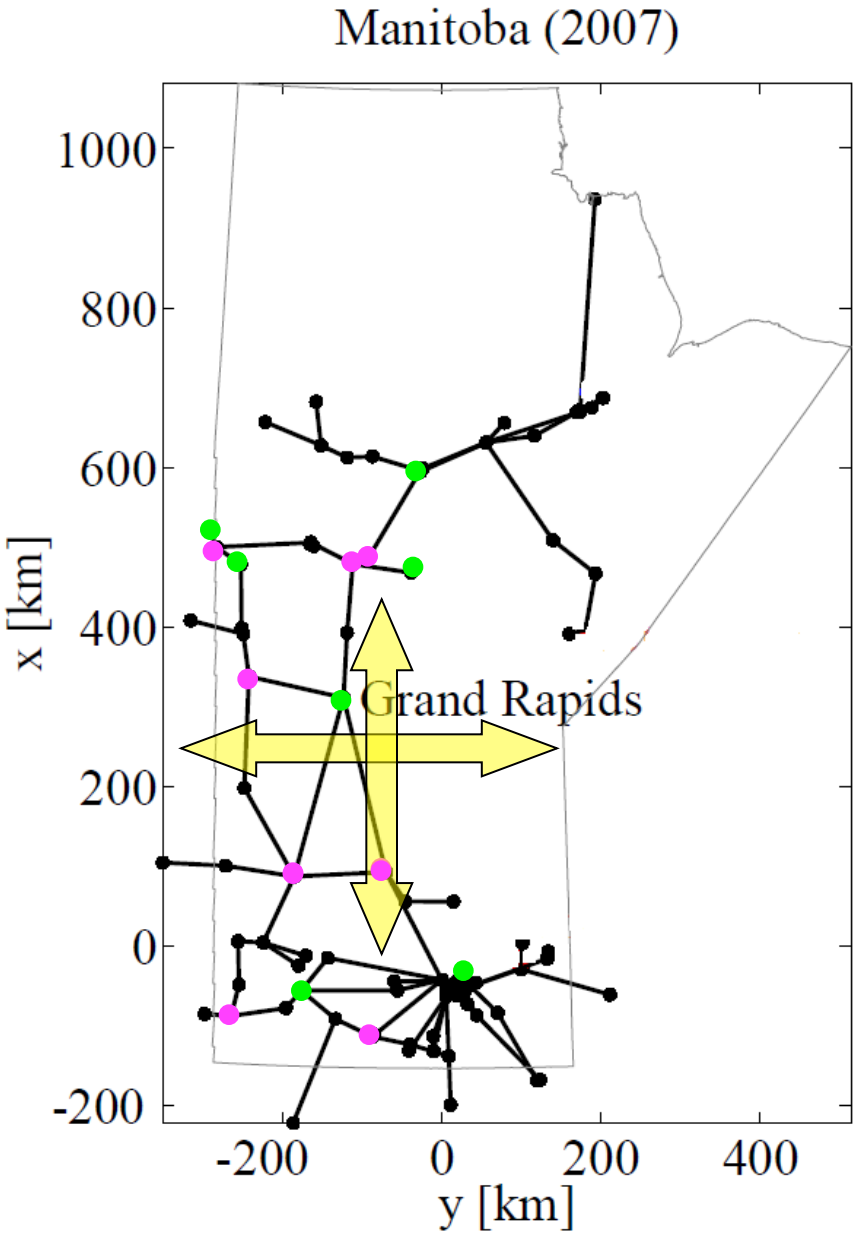
07:27:40



V_{max} = 1.9 V/km
V_{max} = 3.3 V/km
V_{max} = 3.1 V/km
V_{max} = 2.6 V/km
V_{max} = 3.1 V/km
V_{max} = 2.1 V/km

Snapshots of the Modelled Electric Field over Manitoba on September 29, 2003

Hypothetical Map of GIC Direction



GIC Direction:

- In to Ground
- Out-of-Ground

Present Projects

1) Natural Resources Canada R&D Project

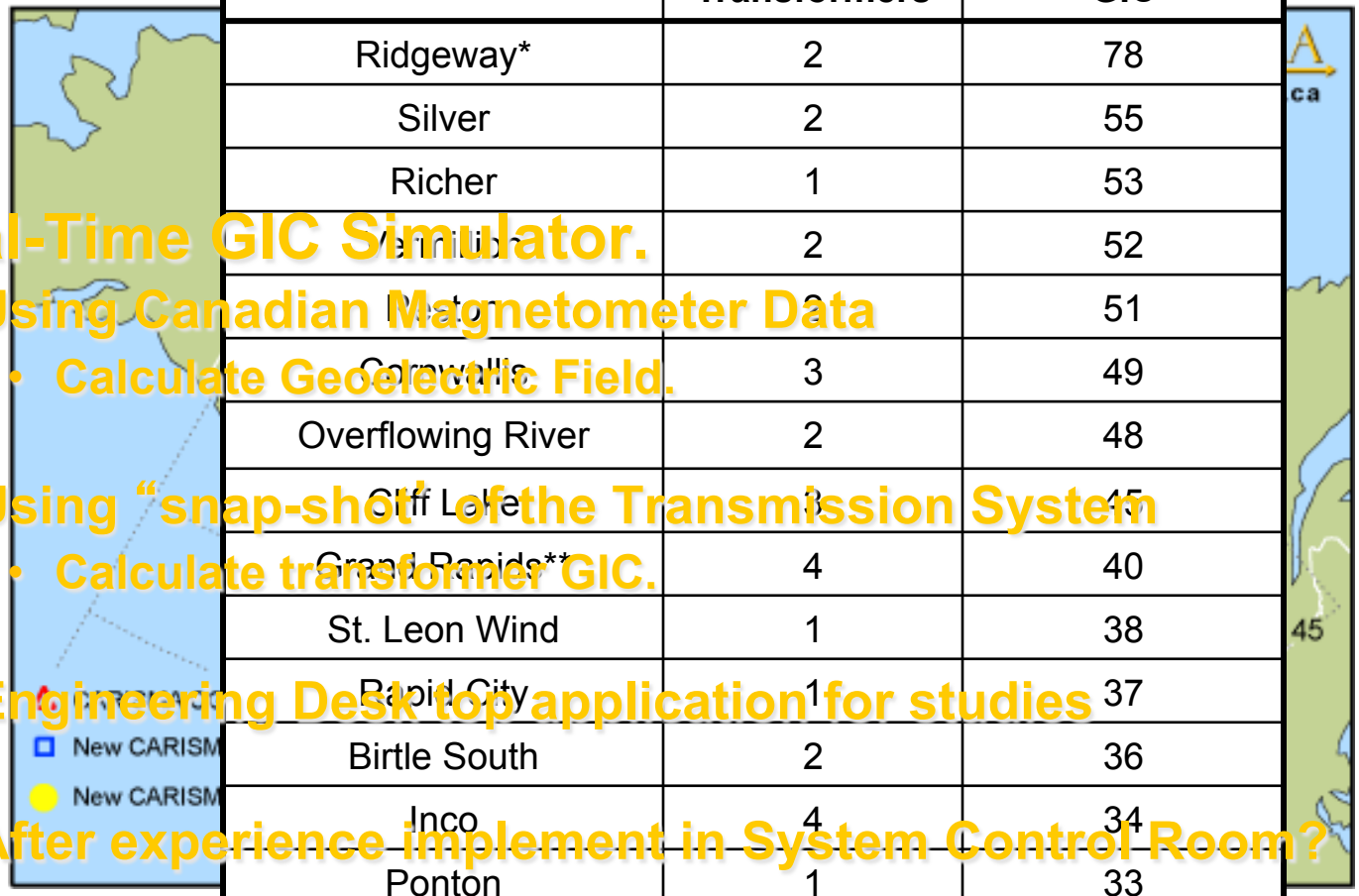
2) GIC Monitoring

3) System Planning High Level GIC Assessment

4) Standing Emergency Operating Procedure for GIC

Present Manitoba Hydro Sponsored Projects:

1) Natural Resources Canada R&D Project:



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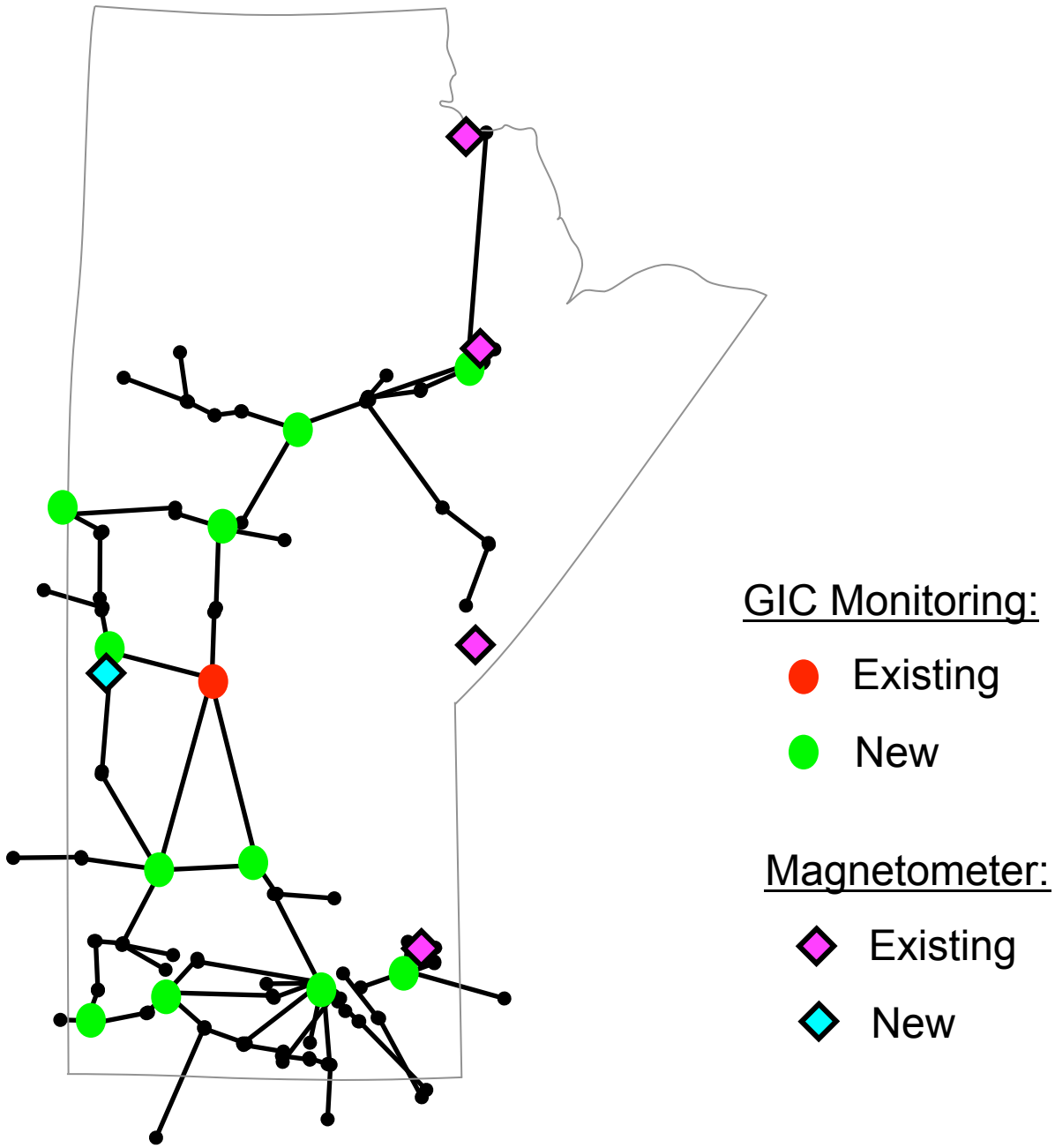
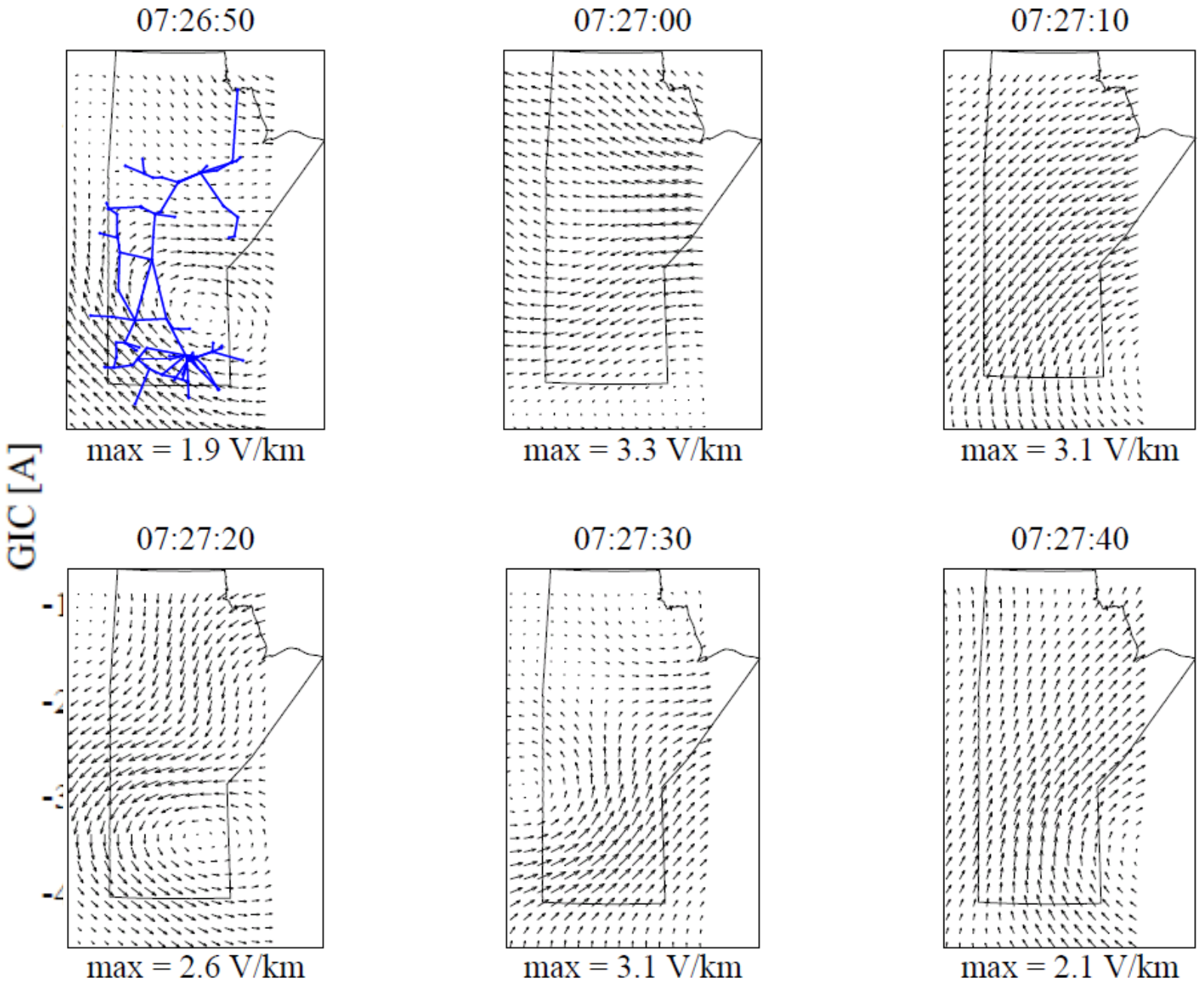
Rapid City	1	37
Birtle South	2	36
Inco	4	34
Ponton	1	33
Letellier	2	31
Rosser	4	28
Ashern	2	23

- **Real-Time GIC Simulator.**
  - **Using Canadian Magnetometer Data**
    - **Calculate Geoelectric Field.**
  - **Using "snap-shot" of the Transmission System**
    - **Calculate transformer GIC.**
  - **Engineering Desk top application for studies**
  - **After experience implement in System Control Room?**

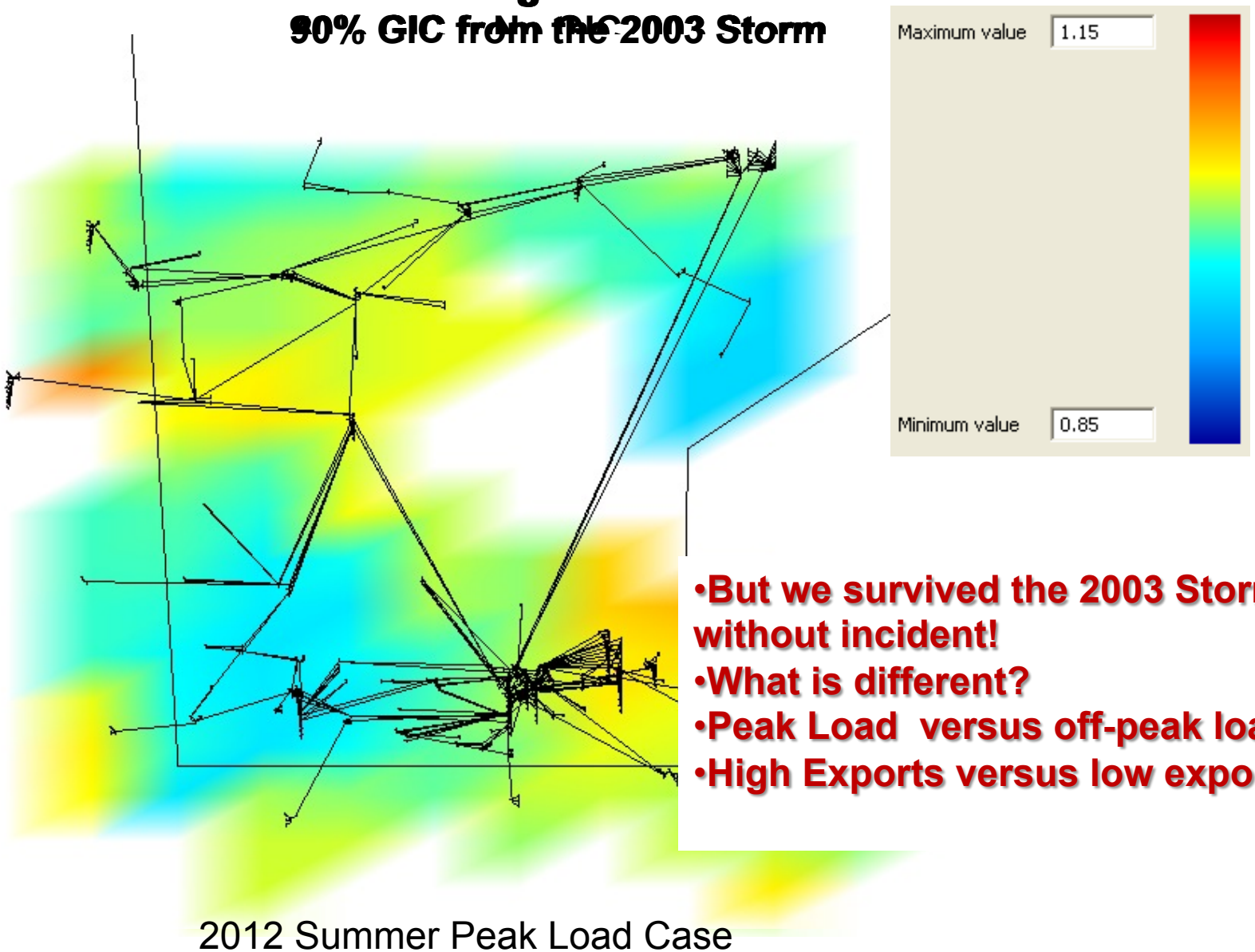
Present Manitoba Hydro Sponsored Projects:
2) GIC Monitoring

- Identify existing power system meters which can be utilized for GIC measurements.
  - Transformer neutral currents.
  - Transformer MVAR losses.
  - Develop GIC metering specification.
- Identify critical stations to add GIC monitoring.
- Sponsor Natural Resources Canada to install a magnetometer at one of our GIC monitoring sites?


GIC Monitoring:
Existing
New
Magnetometer:
Existing
New

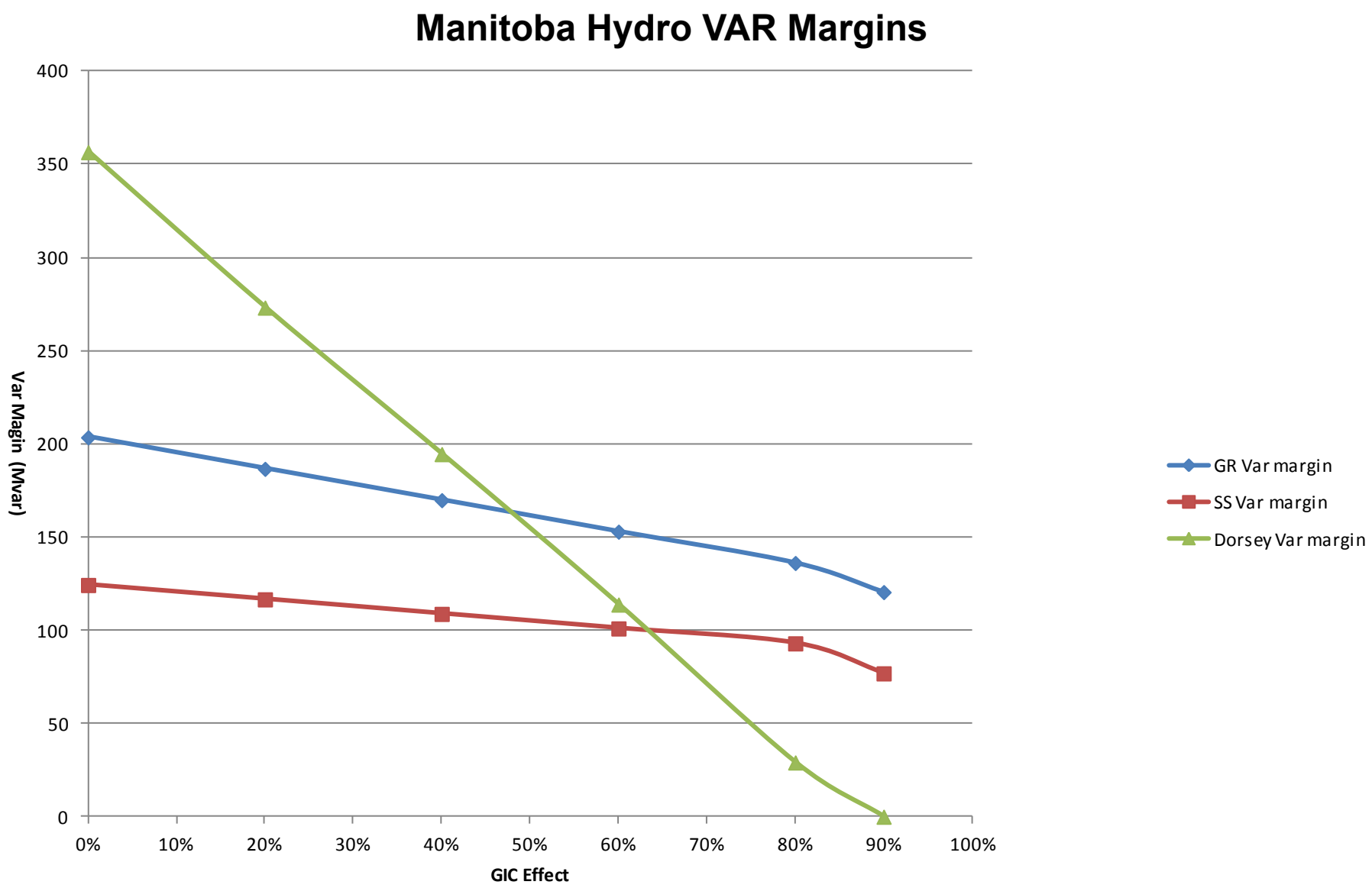

07:26:50
07:27:00
07:27:10
max = 1.9 V/km
max = 3.3 V/km
max = 3.1 V/km
GIC [A]
07:27:20
07:27:30
07:27:40
max = 2.6 V/km
max = 3.1 V/km
max = 2.1 V/km

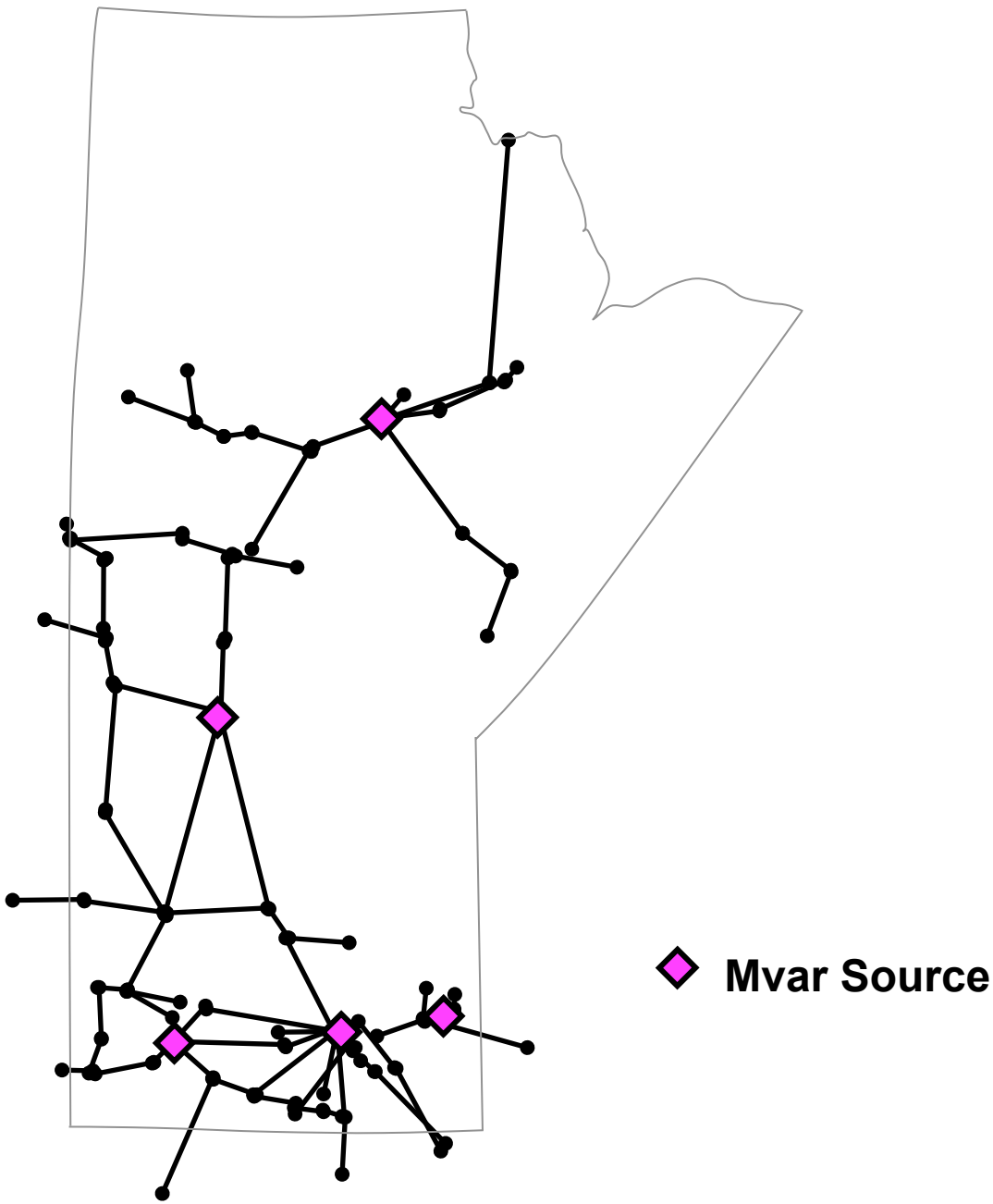
Voltage Profile
90% GIC from the 2003 Storm



- But we survived the 2003 Storm without incident!
- What is different?
- Peak Load versus off-peak load.
- High Exports versus low exports.

2012 Summer Peak Load Case
Manitoba Exporting Power to its neighbours


Manitoba Hydro VAR Margins
400
350
300
250
200
150
100
50
0
Var Magin (Mvar)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
GIC Effect
GR Var margin
SS Var margin
Dorsey Var margin


Mvar Source

Emergency Operating Procedure

- System Control Department has a standing Emergency Operating Procedure for GIC Events. Some actions include:
  - Monitoring of reactive power security margins,
  - Reducing loading on interconnection tie lines and other internal critical transmission lines if the security margins are being depleted,
  - Bringing on equipment capable of synchronous condenser operation.

Thank you