Physical Grid Vulnerabilities

NRC Workshop on the Resiliency of the Electric Power Delivery System in Response to Terrorism and National Disasters

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Geographic Reach

- Localized attacks similar to common contingencies.
  - Unplanned line/generator outage
  - N-1, N-2 reserve protocols
  - Restoration procedures well documented
- Wide-area assaults more difficult to anticipate/remediate
  - Katrina
  - 1965/2003 blackouts

Restoration/Repair Challenges

- Limited scope
  - Restoration rapid.
  - Time available for repair.
  - Exception may be under-street metropolitan cables.
- Wide-area affected
  - 1965/2003 need was restoration, not repair.
  - Katrina required repair.
    - Restoration on order of weeks/months
    - Repair on order of years

The Transformer Problem

- Large transformers no longer manufactured in U.S.
- Lead times on order of years.
- Spares and suitability are limited.
- Transport requires unique equipment, detailed routing, and is slow.

Unit Transformer on a Schnabel Car

Source: Consumers Power

Another Schnabel Car Example

Source: Raimond Spekking

Stator Being Loaded on Schnabel Car

Source: Carl Youman

Operational Intrusion

- System collapse
  - Scope can be limited.
    - New technology (e.g., synchrophasor network).
    - New system topology (e.g., islands with dc interties).
- Physical damage
  - Due to misoperation of relays/generators/SCADA systems.
- Prevention responsive to cybersecurity measures.

Physical Intrusion

- NERC audits.
- Can be uncoordinated and limited.
  - Most likely in dispersed parts of system
    - Lines, substations.
  - Treated as single contingency.
  - Propagation circumscribed.

Physical Intrusion (cont'd)

- Can be coordinated and widespread
  - Communication and action protocols critical.
  - Rapid identification of event.
  - Creates human and equipment resource problem.
  - Extensive and prolonged social disruption.
  - Most debilitating if transformers involved.
  - Greatest vulnerability is multiple substations.

50 kV/10 kV Substation
(Innsbruck)

Source: www.e-architect.co.uk

Substation/Switchyard

Source: www.rtcmagazine.com

Switchyard

Source: www.firstelectricnewspaper.com

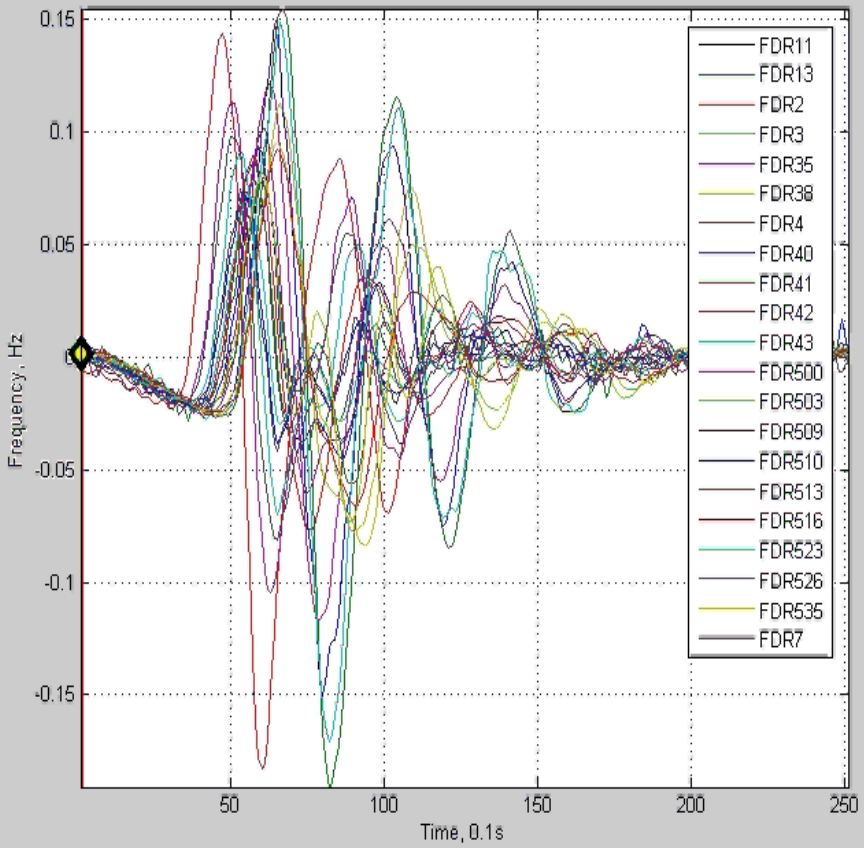
Terrorism by Electromagnetic Pulse

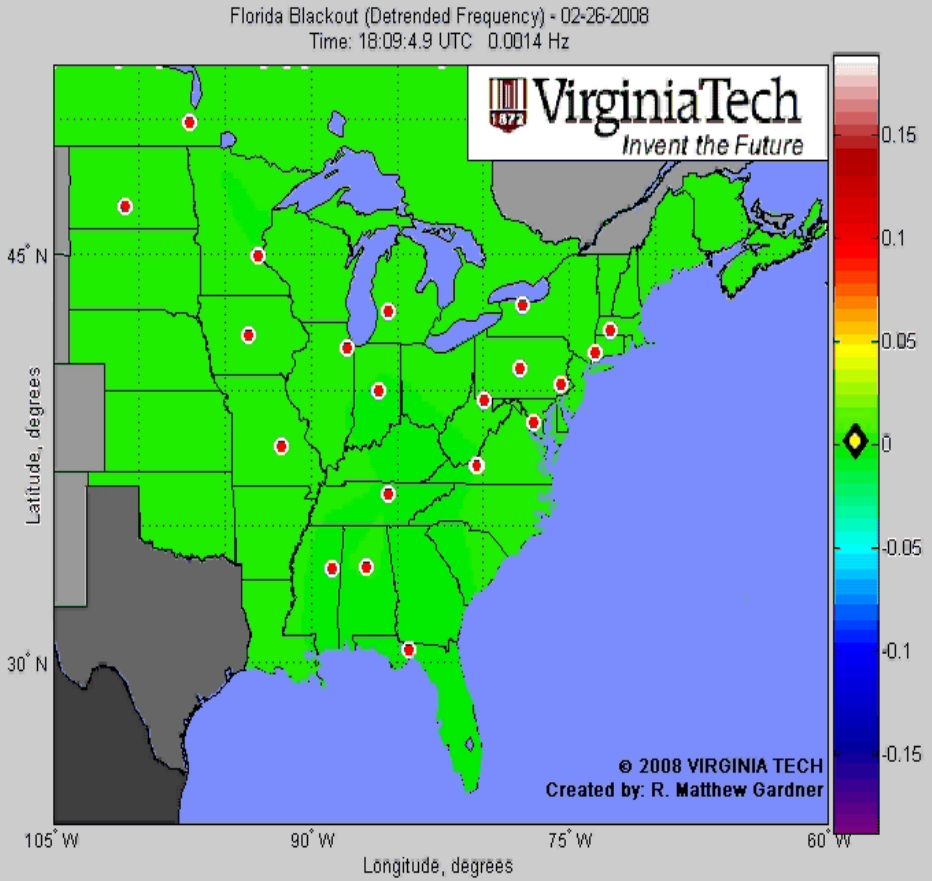
- EMP has potential for massive disruption.
  - Electronics vector of high vulnerability.
    - Loss of sensing, data exchange, control, SCADA.
    - Loss of infrastructure, e.g., transport, fuel.
  - Large quasi-dc fields can cause extensive heavy equipment damage.
- Potential demonstrated by geomagnetic storms.
  - Solar flares.
  - Causal but limited damage.

Sequence of 1989 HQ GMD Event

- 02:44:17 Tripping of static VAR compensator CLC 12 at Chibougamau.
- 02:44:19 Tripping of static VAR compensator CLC 11 at Chibougamau.
- 02:44:33 to 02:44:46 Shutdown of the four SVCs at the Albanel and Nemiscau substations.
- 02:45:16 Tripping of static VAR compensator CLC 2 at La Verendrye.
- 02:45:24.682 Tripping of line 7025 at the Jacques Cartier substation.
- 02:45:24.936 Tripping of line 7044 at the La Verendrye substation.
- 02:45:24.948 Tripping of line 7016 at the La Verendrye substation.
- 02:45:24.951 Tripping of line 7026 at Chamouchouane substation.
- 02:45:24.978 Tripping of line 7045 at the Grand-Brule and La Verendrye substations.
- 02:46:00 HQ system down.

The 2008 Florida Blackout





Mitigation Approaches

- Reserve capacity
- Spares
- Hardening of electronics
- Perimeter security
- Islanding thru dc interconnects

Conclusions

- Geographically limited intrusion:
  - manageable.
- Wide-area operational intrusion:
  - responsive to cybersecurity measures.
- Wide-area physical intrusion:
  - Approach is response vs. prevention.
  - Standard communication network and protocols essential.
  - Situational awareness and response through synchrophasor network could mitigate damage.

Loaded Stator

Source: Carl Youman