Control Center EMS Solutions for the Grid of the Future

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A Historical Perspective –
The Nov 1965 Blackout… Some Beneficial Outcomes..

1. Public awakened to our dependence on electric power
   a) Support for new national initiatives

2. Universities re-energized in power systems programs

3. New government R&D funds for power systems research
   a. Extensive studies on identifying blackout cause & recommendations to prevent future blackouts

Also, concurrently:

Advent of the affordable digital computer

• Large, complex mathematical problems became easier to solve!
And, the Birth of the Modern EMS Control Center!

Thanks to the serendipitous & fortunate nexus of 3 events:

1. Greater R&D funding for power systems
2. More students in electrical power engineering
3. The birth of affordable digital computers
Thoughts to ponder…

““The interconnected electric power grid is one of the most complex real-time, engineering machines in existence today!”

- Millions of components need to work together to supply electricity from source to customer, 7x24!

Operating the power grid is not rocket science…”

“It is much more than that!!“ - Terry Boston, PJM

Today, We are adding even more complexity to this already complex machine:

Variable renewables, DR, DG, PV, PHEV, electronic loads, lower inertia generation, etc…

“Na práctica .. a teoría é ontra” or "In real-life…the theory is different"

- Savu Savulescu
Major Sources of Grid Vulnerability

- Natural calamities
- Line Overloads – excessive sagging
- Equipment & Protection failures
- Breaks in communication links
- Faults
- Human errors
- Inadequate security margin
- Gaming in the market
- Sabotage or intrusion by external agents
- Missing or uncertain information
Some challenges of grid management

Vulnerability assessment is a computationally intensive process

Assessments need to be continually repeated

On-line assessment is a challenge

Measurements and operating conditions are noisy

Available tribal knowledge is based on past real-life experiences
The Reality We Face….

‘Blackouts will occur again in the future’….

– Our power grid is too complex to make it fail-safe!
## Timeline of high impact blackouts - worldwide

<table>
<thead>
<tr>
<th>Date</th>
<th>Region</th>
<th>Duration</th>
<th>People affected</th>
<th>Initiating Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-Nov-65</td>
<td>NE US, NYC</td>
<td>14 hours</td>
<td>25M</td>
<td>Faulty substation relay</td>
</tr>
<tr>
<td>13-Jul-77</td>
<td>NYC</td>
<td>25 hours</td>
<td>8M</td>
<td>Lightning</td>
</tr>
<tr>
<td>1-Mar-89</td>
<td>Quebec &amp; NY State</td>
<td>9 hours</td>
<td>6M</td>
<td>Geomagnetic storm</td>
</tr>
<tr>
<td>11-Mar-99</td>
<td>Sao Paolo, Brazil</td>
<td>5 hours</td>
<td>97M</td>
<td>Lightning</td>
</tr>
<tr>
<td>14-Aug-03</td>
<td>NE US (8 states), Canada</td>
<td>upto a day</td>
<td>50M</td>
<td>Line overload problems</td>
</tr>
<tr>
<td>28-Sep-03</td>
<td>95% of Italy, Switzerland</td>
<td>18 hours</td>
<td>55M</td>
<td>Line fault</td>
</tr>
<tr>
<td>12-Jul-04</td>
<td>Greece</td>
<td>varied</td>
<td>7M</td>
<td>Heavy Load conditions</td>
</tr>
<tr>
<td>1-Aug-05</td>
<td>Indonesia</td>
<td>5 hours</td>
<td>100M</td>
<td>Grid imbalance</td>
</tr>
<tr>
<td>1-Nov-06</td>
<td>Germany, France, Italy, Spain</td>
<td>varied</td>
<td>10M</td>
<td>Line switching error</td>
</tr>
<tr>
<td>1-Feb-08</td>
<td>Chenzou, China</td>
<td>2 weeks</td>
<td>4M</td>
<td>Winter storms</td>
</tr>
<tr>
<td>10-Nov-09</td>
<td>Brazil &amp; Paraguay</td>
<td>3 hours</td>
<td>67M</td>
<td>Storms</td>
</tr>
<tr>
<td>10-Jul-12</td>
<td>India North</td>
<td>24 hours</td>
<td>370M</td>
<td>Over-withdrawals, line overloads</td>
</tr>
<tr>
<td>31-Jul-12</td>
<td>India - 3 regions</td>
<td>several hours</td>
<td>620M</td>
<td>Over-withdrawals, line overloads</td>
</tr>
</tbody>
</table>
The Solution being sought.....

How to contain an Initiating event to prevent a Cascading, Uncontrolled spread across the entire grid!

And more importantly: How to Restore power to customers ASAP!
Energy Control Centers – Energy Management Systems -EMS

• ~50 years of Control Center evolution

• Tomas Dy-Liacco – “Father of the Modern Energy Control Center!”

• EMS manages the ‘physical flow’:
  – Operate the electric grid within safe limits
  – ‘Prevent Blackouts’
  – Automatically adjust generation to demand
  – Identify risks; take preventive action
  – Expedite restoration
Power System Grid Operating States – First postulated by Tom Dy-Liacco.

Secure

System intact

Restorative

Resynchronization

Alert

Preventive Control

Emergency

Heroic Action

A-Secure

Insecure

Violation of inequality constraints

In extremis

Cut losses, Protect Equipment

Normal

Objective: Load tracking, cost minimization, system coordination

E = Demand is met
I = Constraints are met

System not intact

Focus is on: Steady State Grid Operation!
EMS – 60’s & 70’s
Analog, hardwired

Power System
(Generators and Tielines)

Analog

SCADA and Load Frequency Control

Analog Computer

Operator Terminal
Grid management Yesteryear - circa 1960 –
Analog, hardwired systems
EMS – 80’s and 90’s – Digital

Study mode / Modeling/ Archiving

Real-Time Applications
- Generation Applications
- Transmission Applications
- Training Simulator

Database & Development Environment

Operating System – Digital Computer

Data Acquisition

Operator Console

Power System (HV substations)
A Modern EMS Control Center
Control Centers’ goal – Balancing Reliability and Economics

But...
Reliability Always Trumps Economics
Today’s grid’s - ‘Smart’ automated capabilities

• System-wide ‘Smarts’:
  1. EMS with operator actions
  2. EMS with Automatic generation Control (AGC)
  3. Automatic under/over voltage frequency shedding
  4. Special grid protection schemes, etc

• Regional ‘Smarts’:
  1. EMS with Volt-Var Control (VVC)
  2. Automatic under/over voltage load shedding

• Equipment ‘Smarts’:
  1. Relays for protection of individual power equipment:
     • Isolation of transformers, lines, generators, etc
The Grid of Future – Smart Grid Evolution

- Facilitate integration of Renewable Energy
- Electricity Markets
- Customer participation
- Distributed Generation
- Demand Response
- Cyber Security
- ‘Big Data’ Management
Power System Grid Operating States

Secure
- Normal
  - Objective: Load tracking, cost minimization
  - E = Demand is met
  - I = Constraints are met

Insecure
- Alert
  - Preventive Control
  - E I
  - Violation of inequality constraints

A-Secure
- Emergency
  - Heroic Action
  - System not intact

Restorative
- Resynchronization
  - System not intact

Focus is changing to:
- Steady State Grid Operation + Dynamic Grid Operation!
Emerging Smarter Grid Technologies & Solutions

- Advanced Sensing & Measurement
- Smart Meters
- Phasor Measurement Units (PMUs)
- Integrated Communications
- Advanced Components and Controls
- Improved Decision Support systems
- Advanced Visualization technologies
- Low Carbon emission technologies
Today’s changing Grid Monitoring landscape

**Synchrophasor** PMU measurement devices are being deployed aggressively worldwide
- By 2013, will be a five-fold increase across US – over 1000 PMUs deployed
- China has over 1000 PMUs installed
- Other countries are also deploying PMUs

**Each PMU provides 10-12 separate sub-second measurements**
- Measurements include voltages, currents and frequencies
- Augments traditional 2-4 second SCADA

**Real-time grid measurements will be 60 to 120 times faster**
- Today 2-4 measurements/sec rate
- Tomorrow 30-60 samples/second rate
What is Synchrophasor Technology?

Phasor Measurement Units (PMUs)

- Next generation measurement technology.
  - voltages, currents, frequency, frequency rate-of-change at sub-second rates
- Higher resolution scans (e.g. 30-60 samples/second).
- Precise GPS time stamping.
### SCADA data - today
- Refresh rate 2-5 seconds
- Latency and skew

### Phasor data (PMU) - tomorrow
- Refresh rate 30-60 samples/sec
- Time tagged data, minimal latency

<table>
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<tr>
<th>Earlier Information for Better Decisions</th>
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</table>

#### Freq change means:
- Sudden Gen-Load MW imbalance somewhere in the grid

#### Angle-pair change means:
- Sudden MW change in a specific location of the grid

**X-ray**

**MRI**
DOE and NERC are working together closely with industry to enable wide area time-synchronized measurements that will enhance the reliability of the electric power grid through improved situational awareness and other applications.

“Better information supports better - and faster - decisions.”
As PMUs grow relative to SCADA..

The utility industry will benefit with a unprecedented grid view:

- A time-synchronized snapshot of grid conditions, at a sub-second rate
Holistic Grid Security Analysis

Traditional **MODEL-BASED** Analysis

Other EMS Applications

**EMS**

- SCADA & Alarms
- State Estimator
- Small-Signal Stability
- Transient & Voltage Stability
- Island Management

WAMS Alarms

State Measurement

Oscillation Monitoring

Stability Monitoring & Control

Island Detection, Resync, & Blackstart

New Applications

**PMU MEASUREMENT-BASED** Analysis

**PhasorPoint**

Control Center - PDC
Integrated “measurement-based” & “model-based” Stability Analysis….

**Synchrophasor Applications**
- PMU Measurement-based analysis
  - PhasorPoint
- Model-based analysis:
  - Corrective actions based on ‘what-if’ analysis

**Dynamic Security Assessment**
- Monitor
- Grid Operating Point
- EMS Limit
- New Limit
- True Limit

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Western Interconnection
August 10th, 1996 Blackout

*Dynamic models predicted stable system when the system was in fact unstable.*

PMU provide necessary dynamic data to calibrate dynamic power system models.
August 14th, 2003 Blackout Timeline
Monitor wide area grid stress
Monitor ‘angular separation’ as an indicator of increased grid stress due to:

- increased transmission path loading between ‘Sources’ & ‘Sinks’ of power
- sudden events such as line outages (i.e. weakening of the grid)
Small Signal Oscillation Visualization - e-terravision

Modes shapes, amplitudes, damping, frequency, etc

Real-time alerts on poorly damped oscillations

Track oscillatory stability in real-time.

Identify regions where inter-area oscillations are observable
Voltage Stability Assessment - e-terravision
Voltage Contours, MW Margins, Weak Elements, Remedial Actions

Identify weak elements (i.e., regions most prone to voltage instability)

MW Transfer Margins

Control Recommendations
I have a fully functional EMS.
Tell me, why do I need Synchrophasor WAMS?

- Observability of the grid - **beyond your SCADA system**
  - Disturbances, oscillations, islanding, angles diverging, overloads, etc
- Detect **undamped grid oscillations** that may lead to a blackout
- Monitor **diverging voltage angles** that may lead to a blackout
- Monitor **low voltage regions & reactive margins** to prevent instability
- **Maximize MW capacity** across existing congestion corridors
- **Immediate online replay of a recent disturbance**
- **Faster forensic, post-event analysis** and detailed event re-creation
- **Detection of islanding** in the grid; assist in **re-synchronization**
  - ‘Synchrocheck relay’ for the grid
• 99 projects selected from 400+ applications designed to accelerate US grid modernization:
  • Started 2009 end 2013/14

• Objectives to improve:
  • Grid flexibility, reliability, efficiency, affordability & resilience

• $7.8B total funding with $3.4B from 2009 ARRA stimulus bill and $4.4B from private sector
  • Nearly 80 percent of authorized funds have been spent

• 4 Analysis reports were issued in Dec 2012 (smartgrid.gov)
  • Electricity demand reduction, O&M savings from advanced metering, reliability improvements from DA, Controls for Voltage and Reactive power management

• 5th report on Synchrophasor Applications will be issued in late 2013
Local, Device protection predominantly:
- Transformers, lines, bus structures, generating units, etc

System-wide, Grid protection:
- AGC: Automatic Generation Control
  - A pioneering Smart-Grid application since the ‘70s!
- Automatic load-shedding – frequency and voltage deviations
- Remedial action schemes (RAS), special protection schemes (SPS) or System Integrity Protection schemes (SIPS), etc.
Grid Protection, In the Future:

- Develop protective control schemes that dynamically adapt to current power system conditions, to preserve the integrity of the “grid” as an entity.

- Tightly integrate fast sub-second measurements with fast sub-second controls (FACTS, HVDC, etc)
Smart Grid Challenges

Wide Area Management Systems (WAMS)

Increasing phasor-based WAMS market penetration

Delivering new real-time insights into:
  − Grid stability and optimisation

Utilities are now looking for/need:
  − Further leverage of investment in WAMS
  − Automatic WA control solutions for stability & optimisation
  − WA control oversight/co-ordination – Layered Intelligence

‘Human-in-the-loop’ alone is not sustainable
  − Increasing complexity and dynamic uncertainty

Automatic control essential
  − Improve stability, optimise network transfers
Benefits of Phasor-based Wide-Area Control

Improved system security

Increased network use

Simplified and robust schemes
  - Fewer measurement requirements
  - Reduced communications channels

Responds to direct measures of system stress

Low maintenance
  - Easy to manage topology changes
  - Phase angle approach easier to test

Generic approach supporting wide range of applications

Basis for control layers – Layered Intelligence
  - Reduces complexity
Timeframe for Stability Issues

**Protection**
- 16-200ms Equipment Protection
- 200-600ms Wide Area Defence

**Automated Wide Area Control**
- 0.6-3s Automated Trip
- 3-15 seconds Automated Dispatch

**Control Room EMS/WAMS**
- 15 minutes Operator Dispatch
- Human Response

**Stability Issues**
- Frequency Stability
- Oscillatory Stability
- Long-Term Voltage Stability
- Short-Term Voltage Stability
- N-x Transient Stability
- Transient Stability
- Local & Differential Fault Protection
Grid Control transitional approach

“Think Globally – Act Locally!”
From the July 2001, Wired magazine

“The best minds in Electricity R&D have a plan:
Every node in the power network of the future will be
Awake,
Responsive,
Adaptive,
Price-smart,
Eco-sensitive,
Real-time,
Flexible,
Humming….
and interconnected with everything else.”

A Decade Later…..
We are finally gaining Traction!
WAMS: “Wide Area Monitoring System”
The new heartbeat of the grid!

- Offline Analysis
- Root Cause Analysis
- Modelling
- Post-Event
- Generator & ISO Compliance
- Dynamic Security Assessment
- State Estimation Contingency Analysis
- EMS
- Synchrophasor Analytics
- Substation Automation
- Wide Area Controls
- Local Controls
- Distribution
- DMS
- Demand Response
- Distributed Generation
- New Smart Grid Applications

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Thank you!

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