Evolution of Energy Control Centers

Energy Management Systems - EMS

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Greatest Engineering Achievements:
Of the 20th Century

20. High-performance materials
19. Nuclear technologies
18. Laser and fiber optics
17. Petroleum and petrochemical technologies
16. Health technologies
15. Household appliances
14. Imaging
13. Internet
12. Spacecraft

11. Highways
10. Air conditioning and refrigeration
  
9. Telephone
8. Computers
7. Agricultural mechanization
6. Radio and television
5. Electronics
4. Water supply and distribution
3. Airplane
2. Automobile

#1. Electrification

» As voted by the US National Academy of Engineers
Overview of the Electric System

Basic Structure of the Electric System

Color Key:
Blue: Transmission
Green: Distribution
Black: Generation

Generating Station
Generator Step Up Transformer
Transmission Customer 138kV or 230kV
Transmission Lines 500, 345, 230, and 138 kV
Substation Step-Down Transformer
Primary Customer 13kV and 4 kV
Secondary Customer 120V and 240V
Subtransmission Customer 26kV and 69kV
Figure 1: The U.S. electricity business value chain in 2002 (source: Cambridge Energy Research Associates)
North American Electric Power Industry

- More than 3000 Electric Utilities
- 2000 Independent Power Producers
- 100 Related Organizations
- 120 Million Residential Customers
- 16 Million Commercial Customers
- 700,000 Industrial Customers
- 700,000 Miles of High-Voltage Transmission Lines - Owned by 200 Organizations - Valued at $160 billion
- 5 Millions Miles of Medium Distribution Lines - 22,000 Substations - Owned by 3,200 Organizations – Valued at $140 billion
World at Night
The Beginnings of the Energy Management System
“The Big Bang”
1965 Blackout of the Northeast US

- Lasted over 13 hours for many…
- 30 million people, 80,000 sq. mi.
- Billions of $ in lost business
- A wake-up call to US public
- Resulted in creation of:
  - NERC (North American Reliability Council)
    - In 1968: Developed reliability standards for regions and relied on peer-pressure and mutual respect for ‘soft’ enforcement
    - In 2006, has applied to become the FERC-endorsed Electricity Reliability Organization (ERO) to impose ‘hard’ Mandatory Reliability Standards with consequential penalties.
  - EPRI (Electric Power Research Institute)
    - Centralized, pooled R&D for electric utilities
**Power System Grid Operating States**

- **Secure**
  - Normal
    - Objective: Load tracking, cost minimization, system coordination
  - Restorative
    - Resynchronization
  - Alert
    - Preventive Control
  - Emergency
    - Heroic Action

- **Insecure**
  - In extremis
    - System not intact
    - Cut losses, Protect Equipment
  - Emergency
    - System intact
    - Heroic Action

**E** = Demand is met  
**I** = Constraints are met

L. Fink, K. Carlsen, IEEE Spectrum, March 1978
Sources of Grid Vulnerability

- Natural calamities
- Component failures
- Protection and control 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
Challenges

- Vulnerability assessment is computationally intensive process
- Assessments need to be continually repeated
- On-line assessment is a challenge
- Measurements and operating conditions are noisy
- Available knowledge is in historical examples
Widespread Disturbances

March 8, 2004

Compliments of Terry Boston, TVA
Major Interconnections and Reliability Councils

Courtesy: NERC
“Blackouts will occur again in the future”….

- Our power grid is too complex to make it fail-safe!
- In the past decade:
  - Investment in generation far exceeded transmission….
  - Making it more of a barrier to transfer energy….
  - **Means More Congestion**….

**Our challenge is:**

- **To Prevent the Cascading, Uncontrolled Spread** of an initiating blackout!
- And more importantly: **To Restore power** to affected customers ASAP!
The Big Challenge!

- Electricity as a Commodity **Cannot be Stored!**

- Electricity Demand **changes from instant to instant**

- Supply needs to change instantaneously to meet Demand…

- If supply does not equal demand, **Frequency goes off-normal** (not 60Hz)… which results in:
  - Protective relay trips of generating units, loads, etc.
  - Potential for a cascading blackout..
  - And your electric alarm clocks would not keep correct time!

😊
Electric Utilities Ultimate Goal – Balancing Reliability and Economics
EMS capabilities have evolved over the past five decades (since the 1965 blackout)

EMS manage the flow of electricity in the grid.

- Operate the electric grid within safe limits
- Operate the system reliably – “Prevent Blackouts”
- *Keep the Lights On!!*
- Automatically adjust generation to follow Instantaneous customer load changes *(Remember, Electricity Cannot be Stored....)*
- Identify potential risks and take preventive action
- Expedite restoration of customers after an emergency
EMS – 60’s & 70’s Analog, hardwired

Power System
(Generators and Tielines)

SCADA and Load Frequency Control

Analog Computer

Operator Terminal
EMS – 80’s and 90’s Digital

Study mode / Modeling / Archiving

Real-Time Applications

- Generation Applications
- Transmission Applications
- Training Simulator

SCADA

Database & Development Environment

Operator Console

Data Acquisition

Power System

(HV substations)
EMS Control Centers

Control Systems dedicated to the management of energy networks
Control Center Operator
Mapboards and Stripcharts
EMS Applications - 1

- **Supervisory Control and Data Acquisition (SCADA)**
  - Monitor physical system conditions in real time (2-4 sec)
  - Perform supervisory controls
  - Exchange data with external functions

- **Generation Scheduling & Dispatch**
  - System load forecast (SLF)
  - Generation/Interchange scheduling
  - Real-time economic dispatch (ED) & reserve monitoring
  - Real-time automatic generation control (AGC)
EMS Applications - 2

- Transmission Grid Management
  - State Estimation (SE) for real-time transmission system
  - Network Security Analysis: real time contingency analysis (CA) for N-1 system security
  - System Optimization: remedial actions, volt/var control

- Dispatcher Training
  - Dispatcher Training Simulator (DTS) of historical and hypothetical scenarios

- Others Business Functions:
  - Energy accounting,
  - Modeling and database management
EMS Analysis Tools

- **Fiscal Brain**
- **Proactive Brain**
- **Analytical Brain**
- **Reactive Brain**
- **Eyes**

**DSS**
- DTS
- 30 min

**SE & CA**
- 60 sec

**AGC**
- 4 sec

**SCADA**
- 2 sec

**Market System Tools**
EMS Views of the Grid

- **Asynchronous, Uncorrelated, Telemetry view**
  - **Existing system-wide view**
  - **Generation, Ties**
    - **Energy Balance (Freq) view**
  - **System-wide, correlated**
  - **What is coming up next**
    - **Future system-wide view**

- **SCADA**
- **AGC**
- **SE & CA**
- **DSS**
- **DTS**
Current New Influences

- **Types of Customers**
  - Central markets (ISOs, RTOs, etc)
  - Market Participants (Gencos, retail, traders)
  - Network & Operations planning
  - Distribution management

- **Mandates from FERC**
  - RTOs (very large networks, UI, robustness)
  - Transmission planning & Congestion management

- **Technologies & Tools**
  - Software advances:
    Artificial Intelligence, optimization engines, visualization engines, integrated development/UI environments, Desktop applications
  - Economical communication and standardized device protocols
  - Web-enabled IT systems
  - New types of synchronized, fast measurements
Current Challenges

New Constraints:

Resulting in greater uncertainty in operation!

- Aging of operators – Lower skill level and experience
  - 50% eligible for retirement by 2010…
- Aging transmission system infrastructure; Low new investment
  - Increased congestion; Restricting operating limits
  - Deferred maintenance; lack of integrated system planning.
- Deregulated environment – Less predictable system loading
  - Exchange of data RTOs; Market driven scheduling/operation
- Cyber security threat (Intrusion, Viruses)
  - Authorization / Authentication of Users; Protection against attacks
- Terrorism threat (Physical security)
  - Protection of sites; Protection of data
- Financial auditing threat (Sarbannes – Oxley)
Current Challenges (contd)

- Are US R&D Budgets for Electricity R&D enough?

- “US annual budget for Electricity R&D is less than what we spend on R&D for pet food”
  (Nora Brownell, FERC Commissioner, EPAct mtg, Feb 2nd, 2006)
Evolution of Network Model Sizes

1989: 1,200 buses (Original EMP Test Model)
1990: 4,200 buses
1991: 2,000 buses
1992: 8,000 buses
1993: 3,000 buses
1994: 6,000 buses (WECC 161 KV & above)
1995: 8,000 buses (reduced ECAR)
1996: 5,000 buses
1997: 11,000 buses (PSSE Bus/Branch replaced by detailed breaker for MISO Area)
1998: 2,500 buses Dec 04 (42,000 buses used for FAT/SAT)
1999: 3,000 buses
2000: 5,000 buses
2001: 32,000 buses
2002: 1.5M feeders Distribution
2003: 23,000 buses Mar 05 (Eastern Interconnect Breaker Model 73,000 buses)
2004: 2,000 buses
2005: 1,400 buses
2006: 3,000 buses

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EMS SG Overview, Giri
Operators’ Needs Evolving
More Information, Less Data

Operators see Data
They need Information

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EMS SG Overview, Giri
Visualization
The problem

Huge volume of data
Situational Awareness...
Handling a deluge of data…

- Miller’s **Magical Number Seven**, plus or minus two (Miller, 1956)
  - Operators can only handle 7 (plus/minus 2), ‘chunks of information’

- Hence, although “a picture is worth a thousand words”
  - The “correct picture” is worth a **million words!!**
Integrated SCADA & GIS Displays
Voltage Stability – Locations & Controls

VSAT Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Source</th>
<th>Sink</th>
<th>Transfer Size</th>
<th>Size of Limit</th>
<th>Last Run</th>
<th>Next Run</th>
<th>Status</th>
<th>Limiting Contingency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario1</td>
<td>Area1</td>
<td>Area2</td>
<td>500</td>
<td>85%</td>
<td>00:12:34</td>
<td>00:13:04</td>
<td>Pending</td>
<td>LAKEVIEW-RICHVIEW,345</td>
</tr>
<tr>
<td>Scenario2</td>
<td>Area21</td>
<td>Area3</td>
<td>500</td>
<td>10%</td>
<td>13:23:35</td>
<td>00:23:35</td>
<td>Idle</td>
<td></td>
</tr>
</tbody>
</table>

Violation Type: Thermal

Map with various locations including CHENAUX, MTOON, STRATFRD, MTOWN, JVILLE, PICTION, MITCHELL, PARKHILL, WVILLE, and BVILLE.
Where are the VAR sources?
Oscillation Modes & Damping
Fault Location Overlay

105

Branch: JENNINGS - SCOTT 69 kV
(18.1,18.2,44.0,45.0,212.0,662.0)
Section: TEJAS CO (L-44) TAP-EGAN

Line Damage: Conductors touching each other
Vegetation Damage:
Disturbance Location Overlay


08/02/2008 14:03:17.123456 AG
Look-ahead Visualization, Projection…

System State Trajectory

Preventive Action

With Preventive action

Without Preventive action

Look ahead Analysis

History

Present Time

Time
The full energy value chain will be impacted

Energy management MUST be smarter at all levels

- Generation
  - Renewable Energy Sources
  - Flexible generation

- Grids
  - Renewable Energy Sources integration
  - Storage integration
  - Increased stability and quality issues
  - New interconnections
  - Demand-side management / Meter Data management

- Consumption
  - DG integration
  - Smart meter
  - Electric vehicle
ALSTOM Smart Grid Initiatives

Smart Dispatch
- Generation Portfolio Management including renewable
- Full Integration of pricing and demand/supply principles to manage the grid
- Demand response management

Smart Transmission Grids
- On-line Asset Management
- On-Line Stability Analysis & Defense Plans
- Power Electronic Controls (HVDC, FACTS, SVC...)

Smart Distribution Grids
- Automatic Meter Management System
- Integrated Distributed Management Systems
- Renewable and load management integration

Smart Substation
- Substation Protection & Control Architectures
- Self-adaptive Defense Plans
- Secondary Distribution Applications

Visualization, Situation Awareness and Decision Support Tools
System Architecture including Common Information Model
Secure, deterministic and reliable data communication
DOE Smart Grid Investment Grants (SGIG)

$3.4B total to over 100 awardees:

- Notification October 2009
- DOE contracts signed in the past month
- 3 year duration
- 50% cost sharing

$200M+ related to synchrophasor (PMU) deployments

- Deployment of additional ~700 PMUs in next 3 years
What is SynchroPhasor Technology?

**Phasor Measurement Units (PMUs)**

- Next generation measurement technology.
  (voltages, currents, frequency, frequency rate-of-change, etc)
- Higher resolution scans
  (e.g. 30 samples/second).
  - Improved visibility into dynamic grid conditions.
  - Early warning detection alerts
- Precise GPS time stamping.
  - Wide-area Situational Awareness.
  - Faster Post-Event Analysis.

“MRI quality (3-D color) visibility of power system, compared to X-ray (2-D b/w) quality visibility of SCADA” – Terry Boston (PJM)
<table>
<thead>
<tr>
<th>SCADA data</th>
<th>Phasor data (PMU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refresh rate 2-5 seconds</td>
<td>Refresh rate 30 samples/sec</td>
</tr>
<tr>
<td>Latency and skew</td>
<td>Time tagged data, minimal latency</td>
</tr>
<tr>
<td>‘Older’ legacy communication</td>
<td>Compatible with modern communication technology</td>
</tr>
<tr>
<td>Responds to quasi-static behavior</td>
<td>Responds to system dynamic behavior</td>
</tr>
<tr>
<td><strong>Freq change means:</strong></td>
<td><strong>Angle-pair change means:</strong></td>
</tr>
<tr>
<td>Sudden Gen-Load MW imbalance</td>
<td>Sudden MW change in a specific location of the grid</td>
</tr>
<tr>
<td>somewhere in the grid</td>
<td></td>
</tr>
<tr>
<td>X-ray</td>
<td>MRI</td>
</tr>
</tbody>
</table>

*Courtesy EIPP, NASPI*  PMUs measure voltages & currents - magnitudes & angles

*Earlier Information for Better Decisions*
Synchrophasor measurement devices are being deployed aggressively in the US and globally

- By 2012, will be a five-fold increase in PMUs across US – over 1000 PMUs deployed
- Each PMU provides 10-12 separate sub-second measurements
- Measurements include voltages, currents and frequencies
- Augments traditional 2-4 second SCADA

Facilitates wide-area monitoring systems (WAMS) and future wide area control (WAC) - self-healing grid

This is the next SCADA frontier – “fast, sub-second measurements and fast, automated controls”
Synchrophasor Impact on Grid Operations

“An Unprecedented Transformational Change to help operate the grid More efficiently, reliably and to facilitate integration of Green energy resources”
EMS Integrated with SynchroPhasor Solutions

Phasor Data Concentrator (PDC)

Real-Time Controls

IEC 61850

Damping control

FACTS

PMUs

Dynamic Security Assessment
- Transient Stability Analysis
- Small Signal Stability Analysis
- Voltage Stability Analysis

Energy Management System (EMS)
- Improved State Estimation
- Grid Security Assessment
- SynchroPhasor State Estimator

SynchroPhasor Applications Framework (PhasorPoint)
- Oscillatory Stability Monitoring
- Disturbance Detection
- Composite Events
- Islanding/Restoration/Blackstart
- Post-Event Analysis, Baselining

PMU based Information/Alerts (few seconds)

PMU Data (1 per second)

PMU Data (30-60 per second)

SE snapshot (1 per min)

Wide-Area Advanced Visualization

e-terra

e-terra

e-terra

e-terra

Communication Network (NASPInet Vision)

GOAL: Develop an “industry grade” secure, standardized & distributed data communications infrastructure to support SynchroPhasor applications in North America.

By 2015, Almost all utilities, TOs & ISOs will have the opportunity to tap into real-time PMU data from across the North America

Truly an interdisciplinary problem requiring power engineering, communications, data management & systems integration expertise.
A sudden disturbance causes a traveling wave that can be detected by PMU data across the grid:

Use PMU and to triangulate & precisely locate the origin of the disturbance

Source: VirginiaTech FNET
Oscillatory Stability Management

Simultaneous multi-oscillation detection and characterisation direct from measurements

Measured P / f / δ

Mode Frequency

Mode decay time

Exp(-t/τ)

Mode Amplitude

Mode Phase

For each oscillation detected, alarm on:
mode damping and/or
mode amplitude for

Operations

Early warning of poor damping (two level alarms)
Unlimited oscillation frequency sub-bands
Individual alarm profiles for each sub-band

Planning & Analysis, Plant Performance

Fast Modal Analysis: Alarms

Trend Modal Analysis: Analysis

Dynamic model validation

Damping controller performance assessment

Post-event analysis

Wide area mode alarms
Mode locus plot with alarm thresholds

Dynamic performance baselining
Oscillation Source Location

Mode Power Path
Identify contributions from regions
Uses only PMU data
All region boundaries monitored
“Regions” can be any size

1. Select regional contribution
2. Identify local contribution
3. Action guidelines

Auto-Report
Today:

Schemes to protect grid reliability…

► Local, Device protection:
  ≡ Transformers, lines, bus structures, generating units, etc

► System-wide, Grid protection:
  ≡ AGC (maintains system frequency) – one of the first ‘smart grid’ applications - since the ‘60’s…
  ≡ Remedial action schemes (RAS), special protection schemes (SPS), etc.

Drawbacks are:
  ● Logic is fixed and does not adapt to current conditions
  ● Are conservative by design; have to work for a wide range of 7/24 operating conditions
Tomorrow:
“Adaptive Wide Area Control”
To intelligently protect the entire power grid

- Interconnection-wide protective control schemes that dynamically adapt to current power system conditions, and issue fast controls automatically, to preserve the integrity of the entire grid entity.
The Grid of the 21st century: towards a bi-directional flow of energy and information

A “Smarter” network

From a traditional top-down network...

- Centralized generation
- Centralized consumption

... to a meshed network integrating all modes of generation and consumption safely and efficiently

- New elements impacting the network
  - Renewable Energy
  - Energy Storage
  - Micro Grid
  - Smarter Homes
  - Electric Vehicles

- New solutions to be developed
  - Smarter Data Management
  - Smarter Equipment

Alstom Grid – Press conference – 8 June 2010– P 23
Future Vision of the Energy Ecosystem

An Energy Ecosystem Driven by Innovation

Tomorrow's Weather: Sunny, windy, and warm.
Thank you…