SYNCHROPHASOR APPLICATIONS
EXISTING AND FUTURE APPLICATIONS

Galina S. Antonova, Technical Sales Engineer
Agenda

Introduction
Phasor-enhanced state calculator
Power system stability applications
Fault location application
Wide-area control applications
IEEE Guide on use of synchrophasors for protection and control applications
Synchrophasor projects:
  - North American Synchrophasor Initiative (NASPI)
  - Western Interconnection Synchrophasor Program (WISP)
Ways to learn:
  - PG&E Synchrophasor proof of concept facility
Synchrophasor-based applications

WAMS
Coordinated measures based on dynamic view for monitoring, protection and control of power systems

Object Protection
Direct local actions by on-line status information

SCADA / EMS
Monitoring at SCADA/EMS cycle rates actions initiated by long-term phenomena
Phasor-Enhanced State Estimator
Benefits are increased observability, redundancy, accuracy, and bad data detection capability.

The application of a sufficient number of PMUs across the system will improve the State Estimation solutions to the point they will be called state calculations.
Power System Stability Constraints

Loadability of (AC) transmission lines are limited by

- Thermal constraints
- Voltage constraints
- Dynamic angle constraints
  - Oscillatory stability
  - Transient stability
- Steady-state angle constraints

WAMS Applications provide a way of monitoring the proximity to the stability limits and constraints
Power System Stability Applications

- Thermal Stability
  - Frequency Stability
    - Oscillatory
    - Ambient
  - Transient
  - Steady-state

- Rotor Angle Stability
  - Transient

- Voltage Stability

- Islanding
  - Detection
  - Intentional

- WAMS
  - Target Phenomena

- LTM
- PDM
- POM
- PAM
- VSM
PSGuard: Wide-Area Monitoring System

PSGuard Applications

- Phase Angle Monitoring
- Voltage Stability Monitoring
- Line Thermal Monitoring
- Event Driven Data Archiving
- Power Oscillation Monitoring
- Power Damping Monitoring
- SCADA/EMS integration
- Communication gateway
Voltage Instability Predictor

\[ Z_{\text{APP}} = \frac{V}{I} \]

\[ Z_{\text{EQ}} = \frac{V_{\text{EQ}} - V}{I} \]
Voltage Instability

$V_{\text{EQ}}$  

$V_R$  

$Z_{\text{EQ}}$  

$P_D$  

$I$  

$Z_{\text{APP}}$  

No Load  

$P_D = 0, V_R = 1.0$  

Line 2 Out  

Load  

Line 1 Out  

$P_{\text{MAX}}$  

UNSTABLE  

Three Phase Fault  

$P_D = 0, V_R = 0$  

Power Delivered, $P_D$ (pu)  

Receiving Bus Voltage, $V_R$ (pu)
Voltage Stability Monitoring (VSM) Principle

Assessment of distance to Point of Maximum Loadability, PML
- Identify network equivalent
- Stay on top section of PV Curve!
- Trigger emergency actions when Power Margin too small
- Patented Method
Voltage Stability Monitoring (VSM) Application

PMU measurements from both ends of the line are used.
Voltage Stability Monitoring (VSM) User Interface
Line Thermal Monitoring (LTM) Application

Transmission Line Thermal Monitoring

\[ V_S \rightarrow I_S \rightarrow R \rightarrow \frac{X_C}{2} \rightarrow I_R \rightarrow V_R \]

Compute average conductor temperature to provide
- Real-time assessment of loadability
- Early warnings in case of overload
- Available line capacity
- Indirect estimation of line sagging
Field results correlate increased power transfer from 950 MW to 1150 MW leads to an average temperature increase from 46°C to 49°C over 30 min.
Line Thermal Monitoring (LTM) User Interface
Ambient and Transient Power Oscillation Monitoring

- PDM: determining modes and characteristics based on ambient variations
- POM: detecting transient oscillations

![Frequency vs. Time Graph](image-url)
Power Oscillation Monitoring (POM) Application

- Detection of power swings in a high voltage power system.
- Algorithm is fed with the selected voltage and current phasors.
- Detection of the various swing (power oscillation) modes.
- Quickly identifies the amplitude and frequency
- Negative damping identification
Power Oscillation Monitoring (POM) Use Interface
Power Damping Monitor (PDM) Application

Determine in real-time from ambient oscillations

– Modal frequencies and damping
– Phase in each measurement signal
– Modal activity

Challenge
– Ambient noise small
Power Damping Monitor (PDM) User Interface

System Information
- Line A
- Line B
- Interface Manager
- Line Test
- Line FCA
- Line FCA Location
- Voltage Phase Monitoring

Legend:
- 220kV
- 400kV
- Other

Location A
- 138kV
- 130kV
- 48kV
- 0.8MVA

Location B
- 138kV
- 130kV
- 48kV
- 0.8MVA

Location C
- 138kV
- 130kV
- 48kV
- 0.8MVA

Location D
- 138kV
- 130kV
- 48kV
- 0.8MVA

Location E
- 138kV
- 130kV
- 48kV
- 0.8MVA

Location F
- 138kV
- 130kV
- 48kV
- 0.8MVA

System Monitoring Center (SMC)
- Alarm and status viewer to be acknowledged by the Operator
- User-friendly process navigation based on customer’s single-line diagram

65.48%
62.20%
-26.83%
Power Damping Monitor (PDM) Example

East-west mode - ~0.13 Hz
North-south mode - ~0.25 Hz
Former east-west mode - ~0.17 Hz
Power Damping Monitor (PDM) Output

- Results for October 25, 2011 event
  - 14:30 - 14:59 CET during fault
  - 15:00 – 15:30 CET post fault

- Trip reduced damping of the former east-west mode by 10%

- PDM reported around 60% damping of the east-west mode before and disturbance (nearly unaffected)
Phase Angle Monitoring (PAM) Principle

Phase Angle Monitoring

Phase angle difference ($\delta$) is indicative of:
- Relation between grid strength and power transfer

Abnormal values of the phase angle difference is indicative of:
- Unusual power transfer
- Line trips
- Abnormal voltage levels
Phase Angle Monitoring (PAM) User Interface
Angular Differential Protection Example

Source: E. Martinez Angular Difference Protection Scheme, Conference on Actual Trends in Development of Power System development and Automation, Sept 2009, Moscow, Russia
Angular Differential Protection Example
Integrating SSO and PMU Functionality

SSO = Subsynchronous Oscillations

Filter 1 → OV (59) → AND → V1_59_Trip
Filter 2 → OV (59) → AND → V2_59_Trip

Supersynchronous

Subsynchronous

To SSO Mode X detection

Measurements V, F, etc

SSO Mode 1 detection

SSO Mode 1 reporting

SSO_Trip

PMU data

DFR report

PMU report

f1 V1
f2 V2

©ABB
Simulation model and system

Measurements and SSO Filters

Action (Alarm mitigation or protection)

Typical SSO Parameters (V, I, F)

Streaming SSO Oscillography Points (typical)
Configuration and SSO Filter Output

Steady State Operation
SSO Oscillography (filter output)

Steady state operation
Simulation: Overvoltage

Measurements and SSO filters
Determining fault location using synchrophasor measurements

- One of possible fault location technologies described by IEEE C37.114 Fault Location Guide.
- Relies on negative sequence current and voltage measurements from 2 ends (a two-terminal method)
- Different algorithms and impedance matrixes used for different faults
- Dependent on time synchronization and communication
- Down to 2% accuracy in fault location were demonstrated
- Testing performed at PG&E synchrophasor proof of concept facility
Wide-Area Control Applications

Wide Area Power oscillation
Damping control WA-POD
Choose feedback signals from any PMU equipped substation
Coordinated POD action from several actuators (SVC, FACTS, Generators)

Prototype WACS implemented and tested
– PMU-PCU400 PDC-MACH2 control system
– Wide Area Power Oscillation Damper (POD) with local signal based POD as backup
Deployed in 2010
2004: Increasing capacity with SVC

- Increasing capacity with SVC
- Region with generation surplus
- Increasing maximum transmission capacity for active power
- SVC: static var compensation
2004: FACTs for Power Flow Control

- switched series compensation (SC) new 2004
- thyristor controlled series compensation (TCSC)*
- dynamic flow control (DFC)* vision

* fast control
2004 vision: combining intelligent solutions

Step 1:
- system analysis
- free capacity available
- temporary overload acceptable

Step 2:
- increase reactance of overloaded line
- stable situation
Nordic Power System

Interconnected power systems
– Finland
– Sweden,
– Norway,
– East Denmark
– West Denmark
– Iceland (isolated)

Recently installed in Norway
– PMUs (locations R, F, K, H)
– SVCs (locations H, T, V)
Wide-area Power Oscillation Damper Control

PMUs streaming synchrophasors
- Nedre Røssåga
- Kristiansand

SVC is located at Hasle
- PDC
  - receives voltage phasors
  - extracts voltage phasor angle
- ABB Mach2 Controller
  - Local control
  - WAPOD Control
  - Switch-over logic

Wide-area Monitoring and Control System

SVC Control Implementation

Field Test Results: Switching 420kV Hasle-Tegneby

SVC at Hasle (4 x 90 Mvar TCR)

WAPOD Field Tests:
Completed on 2011-11-15

North American Synchrophasor Initiative

Phasor Measurement Units in North American Power Grid

Source: NASPI, April 2010
North American Synchrophasor Initiative 6

Phasor Measurement Units in North American Power Grid

Source: NASPI October 2013
North American Synchrophasor Initiative

Phasor Measurement Units in the North American Power Grid

Source: NASPI March 2015

Legend
- PMU Locations
- Transmission Owner Data Concentrator
- Regional Data Concentrator

With information available as of March 9, 2015
Western Interconnection Synchrophasor Program
Western Interconnection Synchrophasor Program

- 244 Substations with PMUs
- Sampling Rate 30-120 sps
- Installation Rate:
  - 2011 Q3: 22
  - 2011 EOY: 38
  - 2012 EOY: 267
  - 2013 Q1: 362

Source: WECC WISP Western Interconnection Synchrophasor, Vickie VanZandt NASPI Work Group Meeting October 2011
Harris Corporation Network to Provide the Communication Infrastructure for Enhancement of Reliability in the Western Interconnected Electric Grid for Western U.S., Canada, and Northern Mexico

**Highlights**

- Wide area network to support the Western Electricity Coordinating Council and other participating electric utility organizations
- Key infrastructure component in implementing real-time vulnerability detection in western region’s electric grid
- Enables utilities to have better visibility into the condition of the power system and take timely actions to mitigate widespread electrical outages

**MELBOURNE, FL, July 14, 2011** — Harris Corporation (NYSE:HRS), an international communications and information technology company, has been awarded a five-year contract to provide a wide-area network that will help detect and assist in avoiding or mitigating regional electrical system disturbances in a service area that extends from Canada through 14 western U.S. states and northern Mexico.

The private network will enable the Western Electricity Coordinating Council (WECC) Reliability Coordinator, and other participating entities, to detect and take timely actions to mitigate the risk of impacts such as oscillations, grid instability and ultimately, widespread system blackouts.
PG&E Synchrophasor Proof-of-Concept Facility (POC) is a smaller scale synchrophasor system used to **test**, **validate**, and **demonstrate** various functions and interoperability before field deployment.
PG&E synchrophasor proof-of-concept architecture

Source: Grid monitoring and situational awareness: PG&E synchrophasor proof-of-concept project presentation at ABB APW 2013
Synchrophasor applications for protection

IEEE PSRC Report on use of Synchrophasors for Protection Applications

Present applications
- Wide-area frequency monitoring
- Power swing detection
- Load shedding
- Automatic generator shedding
- Distributed generation anti-islanding
- Line reclosing selectivity
- Distance to fault

Future applications
- Bus differential relaying
- Line differential relaying
- Distance function
- Line backup protection
Conclusions

Synchrophasor measurements have been used for various power system applications:
- Power system stability applications
- Wide area control and protection applications

Synchrophasors dependency on time synchronization and communication present challenges.

Research and development lead to growing use of synchrophasor for enhancing power systems.