PSGuard
Wide Area Monitoring, Protection and Control

Applications

Dr. Joachim Bertsch & C. Carnal
PSGuard system & applications

PSG modules / packages

Advanced control
Control action recommendation
Fault location monitoring
Power oscillation monitoring
Voltage stability monitoring
Event driven data archiving
Line thermal monitoring
Phase angle monitoring
Basic monitoring
Data storage and export
Advanced monitoring

Basic platform

PSG 870
PSG 850
PSG 830

Wide Area Protection & Control
Wide Area Monitoring
Wide Area Measurement

Communication System

PMU Station 1
PMU Station 2
PMU Station 3
PMU Station 4
PMU Station n

GPS system accuracy <1μs

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Connectivity

Features:

• Wide area measurement and phase data viewing
• Acquisition of phasor data from new and already installed PMU
• Processing and central data display
• Checking the validity of the acquired data
• Monitoring of the communication links to the PMU
Benefits:

• Proper and secure data acquisition as the base for real-time processing
• Base for short term system reaction
• High system security by data quality verification
• Integration according common standards (IEEE1344)
Basic monitoring
Basic monitoring

Features & benefits:

• Process oriented navigation
• Historical data and trending facility
• Integrated system base for advanced applications
• Precise system data information in real-time
Basic monitoring

provided views for monitoring

Phasor information

Easy navigation

History view
Basic monitoring: Customer specific view
Basic monitoring: Customer specific view

PSGuard
PSG830 Wide Area Monitoring

PSGuard applications
• Line thermal monitoring
• Voltage stability monitoring
• Phase angle monitoring

Component values (e.g. phase angle, voltage)

System abnormal status, early warning and emergency alarm

Power values (P, Q, S) and direction

Application button showing the monitored value and an alarm (red) on phase angle
US - NERC recommendations : Basic monitoring

Blackout Cause Group 3
Reliability Coordinator Ineffective Diagnostics

- Reliability Coordinator (MISO for FE)
  - State estimator failed due to a data error.
  - Flowgate monitoring tool didn’t have real-time line information to detect growing overloads
  - Operators couldn’t easily link breaker status to line status to understand changing conditions.
  - Did not declare emergency or take any action

- PJM & MISO ineffective procedures & wide grid visibility to coordinate problems affecting their common boundaries
US - NERC recommendations: Basic monitoring

NERC Technical Initiatives - 2

- Time-synchronized measurements for disturbance analysis and operations
- Reevaluate system design, planning and operating criteria
- System modeling and data exchange standards
Data storage and export
Features & benefits:

• Data processing and storage
• Navigation through historical data
• Trending facility
  • Power system analyses independent from PSGuard
  • Proper base for investment planning
FirstEnergy Computer Failures

- 14:14 Alarm logger fails and operators are not aware
  - No further alarms to FE operators
- 14:20 Several remote consoles fail
- 14:41 EMS server hosting alarm processor and other functions fails to backup
- 14:54 Backup server fails
  - EMS continues to function but with very degraded performance (59 second refresh)
    - FE system data passed normally to others: MISO and AEP
    - AGC function degraded and strip charts flat-lined
- 15:08 IT warm reboot of EMS appears to work but alarm process not tested and still in failed condition
- No contingency analysis of events during the day including loss of East Lake 5 and subsequent line trips
Advanced monitoring & State calculator
Features & benefits:

• Topology detection
• Islanding recognition

Precondition for:

• Dynamic network parameter calculation
• State calculation
Advanced monitoring & State calculator

- Voltage and current phasor measurements by PMUs
- Goal – computation of all remaining unknown voltages and branch currents
MISO State Estimator and Reliability Analysis

- MISO state estimator and contingency analysis ineffective from 12:37 to 16:04
  - State estimator not solving due to missing information on lines out in Cinergy then DPL
  - Human error in not resetting SE automatic trigger
- Using Flowgate Monitoring tool to monitor conditions on previously identified critical flowgates
Blackout Root Cause Group 1
FirstEnergy Lack of Situational Awareness

- Did not ensure a reliable system after contingencies occurred because it did not have an effective contingency analysis capability
- Did not have effective procedures to ensure operators were aware of the status of critical monitoring tools
- Did not have effective procedures to test monitoring tools after repairs
- Did not have additional high level monitoring tools after alarm system failed

No awareness of risk-level
Event driven data archiving
Event driven data archiving

Benefits:

- Automatic recording and storing of the grid disturbance data based on the specified triggering conditions

- Valuable for root cause analysis as it enables the user to have a clear view of activities preceding and following an event.

- Improve network planning

- Input data for calibration and verification of the dynamic models of the network

- Improve network behavior analysis and identification of the specific network properties for the network reinforcements and extensions

- To comply with future UCTE requirements for studying UCTE-wide disturbances
Phase angle monitoring
Benefits:

• Providing operators with a real-time information about the voltage phase angle deviations

• Improve voltage control

• Improve system stability, security and reliability

• Operate safely power carrying components closer to their limits

• Provide improved power system observability

• Provides crucial information for the successful reclosing of the transmission lines in important corridors
RECOMMENDATIONS AND CONCLUSIONS

...  

- After the first contingency, although the foreseen countermeasures for returning the system to a secure state were available from a purely technical point of view, human, technical and organisational factors prevented the system from returning to a secure state.

...  

R2: UCTE is reviewing its rules and introducing the Operation Handbook: the policies 3 and 5 on security assessment should specifically take care of the following issues:
  - harmonise criteria for compliance with the N-1 principle;
  - determine criteria for the time delay to return the system to N-1 secure state after a contingency;
  - include issues such as phase angle and voltage stability into the standard short term contingency analysis;
  - define clear guidelines for sharing of tasks to be performed, taking into account the perimeter of each control centre.

...  

R7: As a support tool for dynamic analysis and monitoring of the UCTE system, accelerate the ongoing Wide Area Measurement System (WAMS) installation program.
Swiss grid utility: PSGuard project

Diagram showing a network of PMUs (Phasor Measurement Units) connected to a PSGuard Workstation, with GPS satellite and geographic locations marked as FRANCE, GERMANY, AUSTRIA, ITALY.
## Swiss grid utility: Phase Angle monitoring

![Phase Angle Difference](image)

### Phase Angle Difference

<table>
<thead>
<tr>
<th>Location 1</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bassecuit - Lavorgo</td>
<td>17.00 [°]</td>
</tr>
<tr>
<td>Bassecuit - Scazza</td>
<td>15.00 [°]</td>
</tr>
</tbody>
</table>

### Map

- **Scazza**
  - 650.0 [MW]
  - 120.0 [MVAR]

- **Lavorgo**
  - 800.0 [MW]
  - 100.0 [MVAF]
• Strong relation of load of line and phase angle difference between the voltage at the ends
• 100 MW approximately corresponds to 1 degree
• Supervision of n-1 criteria
1.) The concept of the ABB PMUs RES521 is very user-friendly. It is easy to set the parameters from remote using our central PSGuard workplace in Laufenburg. This means low installation costs, especially when it comes to extensions. Additionally, the accuracy of the frequency measurement is with 1 mHz 10 times higher as indicated in the product specification. Using ABB’s PSGuard system we can better and faster trace the dynamic changes in the Swiss high voltage transmission grid. This is of utmost importance, as grid operators win time to take the right decisions under critical operating conditions.

2.) The ABB PSGuard Phase Angle Monitoring module supervises the loading of the Swiss transmission corridor to Italy. There is a direct correlation between the voltage phase angle and the transmitted power. The voltage phase angle difference between the northern and the southern border of Switzerland reflects directly the loading of the corridor. Therefore it provides an useful additional information for our operators as well as for the protection engineers.

Dr. Walter Sattinger,
Project Manager PSGuard WAMS Introduction
ETRANS / Swiss Grid Coordinator

3.) The results of the Line Thermal Monitoring provide additional accuracy in determining the mean current line temperatures if PMUs are installed on both ends of a line. This opens interesting new possibilities to verify the average line temperature during operation.

Mr. George Bossert
Head of Dispatching
ETRANS / Swiss Grid Coordinator
Line thermal monitoring

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Features & benefits:

• Conductor average temperature calculation

• Real-time assessment of thermal limits based on measured and design parameter of the line

• Assessment of transmission line loadability
  • Safe temporal enhancement of transmission capacity
  • Dynamic thermal limit adaptation
  • Collapse prevention: early warning in case of overload
  • Usage of existing transducers / (PMUs)
  • Indirect estimation of line sagging
Determine Active and Reactive power losses on the monitored Line
The changes in the average line temperature are estimated using only the electrical quantities measured by PMU.

- Increase of power transfer 950 MW to 1150 MW -> temperature increase from 46 degrees to 49 degrees in 30 min.
Line thermal monitoring

- Transfer limit of a line could also be a matter of thermal limit
- Thermal limit usually assumed very conservative i.e. high air temperature, no wind
- Often weather conditions are much better and therefore more transmission will be possible
- Precondition: installation of on-line temperature monitoring!
- PSGuard offers this application, without additional hardware investments
Line thermal monitoring

- Dynamic calculation of actual line-parameter:
  i.E. \( \Delta T = -30 \, ^\circ\text{C} \rightarrow I \Delta RI > 10\% \) (400-kV-line)

- Electrical limit: \( \Delta P_{\text{max}} > 6,5 \% \)
Line thermal monitoring

As Phasors (magnitude & phase) synchronized with the Global Positioning System (GPS)

Measurement of:
- Current
- Voltage
Line thermal monitoring

- Dynamic calculation of actual line-parameter: i.E. \( \Delta T = -30 \, ^\circ C \rightarrow I \Delta RI > 10\% \) (400-kV-line)

- Electrical limit: \( \Delta P_{\text{max}} > 6,5 \% \)

\[
\begin{align*}
R + jX_L & \quad \text{Load} \\
\begin{array}{c}
I_1 \\
\text{u}_1 = \text{const}
\end{array} & \quad \begin{array}{c}
R+jX_L \\
\text{jX}_C
\end{array} & \quad \begin{array}{c}
\text{jX}_C \\
\text{u}_2
\end{array} & \quad I_2 \\
\text{s} = p + jq
\end{align*}
\]
Line thermal monitoring

\[ I_1 = V_1 \cdot Y_s + (V_1 - V_2) \cdot Y \]
\[ I_2 = V_2 \cdot Y_s + (V_2 - V_1) \cdot Y \]

- \( V_1 \) phasor of the voltage \((V_{1\text{real}} + j*V_{1\text{imag}})\) at the line end 1
- \( V_2 \) phasor of the voltage \((V_{2\text{real}} + j*V_{2\text{imag}})\) at the line end 2
- \( I_1 \) phasor of the current \((I_{1\text{real}} + j*I_{1\text{imag}})\) injected into end 1
- \( I_2 \) phasor of the current \((I_{2\text{real}} + j*I_{2\text{imag}})\) injected into end 2
- \( Y \) line admittance
- \( Y_s \) line shunt admittance
$$R = R_0 + \alpha \cdot (T - T_0)$$

$$T = \frac{(R - R_0)}{\alpha} + T_0$$

$T$ Line Temperature

$R_0, T_0, \alpha$ Constants of the line
US – NERC recommendations: Line thermal monitoring

Effects of Ambient Conditions on Ratings

- 38' Height @ 5 MPH Winds
- 36' Height @ 0 MPH Winds
- 34' Height @ Emergency Rating

Distance: 800'
Voltage stability monitoring

- Features & benefits:
  - Contingency detection
    - Early warning against voltage collapses
  - Prediction of power system status after each contingency
    - Early fault recognition
    - Avoid spreading of failures
    - Immediate stop of cascading effects
    - Preserves transmission capacity
Voltage stability monitoring

- Online calculation of power margin towards voltage stability limit
- Online & real-time calculation of available transmission capacity
  - Secure operation of the transmission system even under congested conditions
  - Safe temporal enhancement of line transmission capacity
  - Dynamic thermal limit adaptation
  - Protection against uprising voltage instabilities
Voltage stability monitoring

Contingency, ie. line trips

Active Power

Detection Time

Power-margins

10 % 20 %
Voltage stability monitoring

Active Power

Detection Time

140 sec to new stable status

Power-margin

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Voltage stability monitoring: Prediction of stable status

Active Power

Detection Time

Power-margine

PSGuard prediction

140 sec to new stable status

20 s
Transient Voltage Stability Indicator

Voltage stability monitoring: benefit for operation

Active Power

Detection Time

20 s

PSGuard: 120 sec security gain

140 sec to new stable status

Power-margain

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**Objectives**
- Assess distance to Point of Maximum Loadability, PML (in MWs)
- Stay on top section of PV Curve!
- Trigger emergency actions when Power Margin too small

**Approaches**
- Under voltage load shedding (classical)
- **Voltage Stability Monitoring of corridor using PSGuard**
Conventional solution: Under voltage load shedding

- Shed load when $V < V_{\text{shed}}$

- Local measurements

  but

- Difficult to tune shedding voltage

- Does not give information about distance to Point of Maximum Load ability PML
Voltage stability monitoring by PSGuard

- Parameters calculated from a single set of PMU measurements at two sites
  - T-equivalent of corridor determined directly
  - Thevenin source calculated from assumption $Z_g = \text{known}$
  - Reliable parameter calculation

- Rapid response in real-time
- Dynamic power margin analytically determined
- Precondition: Wide Area Monitoring system like PSGuard
Voltage stability monitoring by PSGuard

Line transfer limit adapted to real-time load characteristic!
Voltage stability monitoring

- Area to assess is enclosed by two transfer cuts
- Measurements at either side
  - "Representative voltage" and sum of currents
- Calculated Quantities
  - Approximate Power Margin (MW)
  - Feeding equivalent voltage source
  - Impedance margin
Voltage stability monitoring

<table>
<thead>
<tr>
<th>Voltage Measurements</th>
<th>Current Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMU no</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
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<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

System Monitoring Centre

TCP/IP Network

cut 1
cut 2
PSGuard - Voltage Stability Monitoring

Early warning

Emergency alarm
PSGuard - Voltage Stability Monitoring

Configurable early warning threshold

Configurable emergency alarm threshold

Actual load

Point of maximal loadability

Continuous calculation of P/V curve characteristics
Violations of NERC Reliability Standards

- FE did not return the system to safe operating state within 30 minutes (OP-2)
- FE did not notify others of impending emergency (OP-5)
- FE did not have effective monitoring capability (OP-5)
- FE did not adequately train operating personnel for emergency response (OP-8)
- MISO did not notify others of impending emergency (OP-9)
US – NERC recommendations: Voltage stability monitoring

NERC Technical Initiatives - 1

- Operator and reliability coordinator emergency response training
- Reactive power and voltage control
- Cascade mitigation
- Reliability coordinator and control area functions, authorities, and requirements
- Real-time operating tools
- Restoration review
Power oscillation monitoring
Power oscillation monitoring

Features & benefits:

• Detection of oscillation
• Assessment of power system damping
• Oscillation monitoring
  • Increased power transfer at defined security
  • Early warning to avoid power system collapse
**Bottleneck in transmission corridor**

Limit due to concerns about power oscillations,

The origin, amplitude, frequency, usual duration and damping of oscillations are not known.

-> **PSGuard provides this information**

-> **Oscillations are known and generation settings can be adapted exactly according current situation**
Frequency stability monitoring
Frequency stability monitoring

Features & benefits:

• Based on real-time snapshots of phasors (dynamic values)

• Prediction of power system status (frequency) after each contingency, enabling to recognize collapses at early stage and initiating countermeasures

• Detection of disproportion between consumed and generated power in real-time
  • Fast reactions to sudden power shortage helping to stabilize the power system and avoid blackouts
Frequency stability monitoring
US – NERC recommendations: Frequency stability monitoring

Frequency in Ontario and New York

Frequency Separation
Interior Ontario and Northern New York

- Northwest Ontario stays with Manitoba
- Beck re-separates from Interior Ontario System
- Beck and St. Lawrence stay separated from Interior Ontario but connected to New York State
- Beck reconnects to Interior Ontario System
- Beck and St. Lawrence separate from Interior Ontario System
Advanced control
Advanced control

Features:

• Evaluating and performing the most suitable actions based on information from stability assessment applications

• Automatic actions for system protection

• Automatic action for transmission corridor optimization

• Dynamic set point determination for FACTS / Wide Area control
Advanced control

Features & benefits

• Continuous display of relevant information
• Operator warning & alarm generation
• Suggestion of most suitable operation to come out of prevailing emergency cases
• Operator guidance by suggesting control actions to keep power system in safe and stable position
  • Fast and appropriate reactions to disturbances by the operator
Corrective Actions - FE

- Voltage criteria and reactive resources
- Operational preparedness and action plan
- Emergency response capabilities and preparedness
- Control center and operator training
PSGuard: Ready to protect your transmission capacity

Contact us: wide.area@ch.abb.com