WAMS/WAMPAC concepts and implementations in practice

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Presentation outline

• WAMS: Why and what we can do with it?
• Commonly used real-time analysis and detection functions based on WAMS
• WAMPAC
• WAMPAC communication issues and time delays
• WAMPAC in action
• Conclusions
WAMS: Why?

• WAMS system is the only standardized system currently available for permanent monitoring of the power system dynamics
  - Cyclic data receiving with 50(60) / 200(240) samples/sec
  - Time tagged data with time accuracy of 1 µs
  - Wide area time synchronized overview and analysis of event data

• Expectation of increasing the dynamical problems in the future
  - To build a new overhead line can be a big problem ⇒ maximization of power transfer over existing lines
  - Renewable energy sources which are not deterministic
    ▪ Photovoltaic
    ▪ Wind farms

• Electricity market liberalization
  - Power transfer on long distances
  - Electricity market without consideration of the technical limitations of power systems
WAMS: What we can do with it?

• Better information for operator in control room
  – Automatic detection in case of oscillations and informing operator where and what kind are they
  – Faster and more precise stability problems localization
  – Overview in case of power system splitting
  – Help at power system restoration

• Post mortem analysis
  – Faster understanding and identifying of event dynamic behaviour

• Improvement of different settings of devices installed in a power system
  – PSS settings
  – Protection devices

• Improvement of power system models
Commonly used real-time analysis and detection functions based on WAMS

• Low frequency oscillation monitoring
  - Inter-area oscillations
  - Local oscillation

• Voltage monitoring
• Frequency monitoring
Reasons for inter-area oscillations:

- Unexpected opening of a transmission line
- Higher power exchange between countries as planned
- Outage of bigger power plant
- Etc.
On 1st December 2016, at 11:18 CET, an unexpected opening of a line in the French system (on the western 400 kV interconnection corridor with the Spanish system) triggered an oscillatory incident in Continental Europe electricity system (CE).
Case: Central Europe Inter-area oscillations of 1st December 2016

- Oscillation frequency: 0.15 Hz
- Measurements from:
  - Ljubljana (SI)
  - Bucharest (RO)
  - Magdeburg (DE)
  - Stuttgart (DE)
• The biggest amplitude of the oscillation was registered on the Iberian Peninsula.
• 3 minutes after the reduction of the Spain to France schedule exchange from 2.250 MW to 1.000 MW, agreed by REE and RTE operators, the oscillations were totally damped.
• These oscillations lasted for about five minutes (11:18 to 11:23 CET).
• Conclusions:
  − The event demonstrates that coincidence and combination of different factors can influence the system stability.
  − Power transport over long distances together with too high impedance can cause a low system damping with respect to inter-area oscillations and should, therefore, be treated carefully.
  − Aspects such as HVDC influence and PSS settings across the CE system will be further investigated
  − It is also important to note that prompt coordination between the TSOs played a vital role in the mitigation of the transient.

Reasons for local oscillations:

• Power plants
  - Non-optimal settings or malfunction of the generator governor and excitation system
  - Incorrect setting of power system stabilizers (PSS)
  - Incorrect settings of joint controller

• Big consumers like iron/steel factories
Case: Undamped oscillations in Slovenia when initial test on a new generator was performed

- The frequency of oscillation was 1.2 Hz.
- Power oscillation: The highest oscillation (40%) in substation Maribor. In other locations the power oscillated less than 20% of operation power.
- Frequency oscillations: The highest in Maribor: 10 mHz other locations around 4.5 mHz

Source: T. Babnik, U. Gabrijel, B. Mahkovec, M. Perko, G. Sitar: "The road from WAMS to WAPCS", CIGRE Study Committee B5 Colloquium, October 19-24, 2009, Jeju Island, Korea, PS3-304
Case: Un-damped oscillations in Slovenia when initial test on a new generator was performed

• Conclusions:
  – Cause of oscillations: the voltage regulator and the excitation system as a whole were not working properly.

• Changes in Slovenian TSO Grid code:
  – When initial tests on a new generator are performed a mobile PMU unit must be installed for the testing period.
  – If some problems are detected the generator must be switch off immediately.
Case: Un-damped oscillations caused by steel factory

- When the arc furnace operates in the factory, it causes low frequency oscillations of 1.8 Hz
- The amplitude of the oscillation on active power is between 1.5 to up to 4% of the operation power


Source: ELES Web page: https://www.eles.si/obratovanje-prenosnega-omrezja
Case: Un-damped oscillations caused by steel factory - Influence of PSS

- Suppression of oscillation with PSS in operation
- Power plant has two generators:
  - 1 generator has PSS in operation
  - 2 generator PSS is not in operation
- PSS suppressed oscillations up to 75%
- PSS is PSS2B type covering frequencies 0.5 to 2 Hz
• Conclusions:
  - Load can cause local oscillations and can have a big influence on smaller generator units
  - It would be useful to dynamically control PSSs
Voltage and frequency monitoring

Voltage monitoring:
- Supervision of voltage profile
- Voltage phase angle monitoring

Frequency monitoring:
- Supervision of power system frequency if it is within specified limits
- Supervision of fast frequency changes caused by bigger generation /load outages
- Islanding detection
Synchronization assistance

- Detects the conditions when circuit breaker can be switched on
- Automatic
  - When the phasor is inside the synchro-check zone command is sent automatically to the SCADA system or bay computer
- Manual
  - Operator based on graphical visualisation of phasors manually trig the command by SCADA system
WAMPAC: Communication connectivity

- **SCADA/EMS**
  - IEC 60870-5-101/104
  - DNP 3.0
  - ICCP/TASE 2
  - IEC 61850
  - OPC-UA

- **PMUs/PDC**
  - IEEE C37.118
  - IEEE 1344
  - IEC 61850-90-5

- **PDCs**
  - IEEE C37.118
  - IEEE 1344
  - IEC 61850-90-5

- **PDC Exchange**

- **Visualisation**

- **SCADA Exchange**

- **Monitoring**

- **Control**

- **IEDs**
  - IEC 60870-5-101/104
  - DNP 3.0
  - IEC 61850

- **GPS**
WAMPAC: Time delays

PMU->PDC->SA
- PMU to PDC
- PDC processing
- PDC to Substation automation
- Substation automation processing

PMU->PDC->SCADA->SA
- PMU to PDC
- PDC processing
- PDC to SCADA
- SCADA processing
- SCADA to Substation automation
- Substation automation processing
WAMPAC: Communication issues

- Time delays
- Communication reliability
WAMPAC: Implementation cases

• Inter-area WAMPAC systems:
  − Solving the inter-area oscillation problems

• Regional WAMPAC systems:
  − Based on time synchronized data scenarios activation for regional problems solving
  − RAS (Remedial Action Schemes)/SIPS (System Integrity Protection Schemes)

• Automated decision-making systems based on WAMS data for increasing the reliability of the power system
WAMPAC: Acceptable reaction times

- **Oscillation problems:**
  - Progressively growing oscillations: reaction 10 periods (10s+)
  - Low damped oscillations with high magnitudes: reaction 10 periods (10s+)
  - Dynamic PSS control: reaction app. 10 periods (10s+)

- **Main line outages:**
  - Generation shedding
  - Fast power direction changes: reaction 400-500ms

- **Generation outages:**
  - Load shedding: reaction 400-500ms

- **Voltage problems:**
  - Compensation unit control: reaction 1s
• Central America Event: March 17, 2017; Separation of SER
  - Explosion of CT in Panama substation caused disconnection 340 MW of load.
  - Power flow from Panama to the rest of SER increased from 75 MW to 417 MW.
  - Consequences: overload and disconnection of lines in SER.
  - The restoration of the SER systems took app. 1 hour and 30 minutes to reconnect all the countries.

Source: https://www.geni.org/globalenergy/library/national_energy_grid/panama/panamanationalelectricitygrid.shtml
• In case of power flow increasing in Costa Rica direction automatic disconnecting power plants with WAMPAC control
• PMUs monitors all three 230 kV cross-border lines between Panama and Costa Rica and send the measurements to the central WAMPAC system installed in Panama city control centre.
• In the WAMPAC is implemented the scenarios for regional power transfer stabilisation.
• If WAMPAC recognize the critical situation then automatically send the command for generation reduction to the power plant close to the border with Costa Rica.
• Situation must be solved in 400ms.
WAMPAC operation: February 2\textsuperscript{nd} 2018:

- Evolving short circuit on transmission line Chorrera - El Higo.
- Two consecutive unsuccessful attempts of line closure were performed. Transients caused with re-closure attempts of the line caused the loss of load of approximately 230 MW.
- The frequency increased over 60.1 Hz and total interconnection active power increase over 200 MW.
- These changes fulfilled conditions for the activation of the “Generation Disconnection Scheme” resulting in the disconnection of generators of the Fortuna HPP.

Source: CIGRE Study Committee B5 Colloquium, Tromsø, Norway, 24th – 28th June 2019, paper B5\_110\_2019
Technical conclusions

- WAMS technology is in operation already for 15 years and it became the common accepted technology in control centres and for post-mortem analysis.
- In EU is PMU data exchange more than 10 years common practice. It servers for faster understanding of wide area dynamic phenomena.
- WAMPAC technology became with new and more reliable communication infrastructure acceptable solution also for the control purpose.
- Expected dynamic problems will WAMPAC, as a solution with a small investment costs, enforced as acceptable solution in the future.
Economical conclusions

• Already available technology and equipment without additional investment:
  − Synchro-phasor data based on IEEE C37.118 is already integrated in protection equipment.
  − Digital statuses based on GOOSE messages can be mapped in IEEE C37.118
  − Control commands can be send directly from WAMPAC system to already installed devices in substations by standard protocols.

• Solution preparation and configuration:
  − A useful solution can be obtained by internal analytical TSO department in a short time
  − Based on analysis of past events procedure preparation for control action scenarios
  − Testing of scenarios with simulations
  − Internal departments for configuration of the central WAMPAC system
  − Using of TSO internal knowledge and experiences usually gives the best solutions

• Risks because of communication unreliability:
  − If the solution operates in 9 out of 10 cases, the system is improved by 90% with a minimal financial investment.

• Implementation time window:
  − If equipment and internal knowledge already exist the solution is available practically immediately.
Thank you