Synchro-Waveform Recordings: what is next?

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Panel: Synchro-waveforms Data Analytics and Data-Driven Applications
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Outline

Status (transmission):

- SW have limited use today
- IBR deployment requires SW data

Unresolved infrastructure issues

- How to acquire, communicate and manage SW
- How to integrate SW measurements

Open application issues:

- Causes of inverter tripping
- Causes of relay misoperation

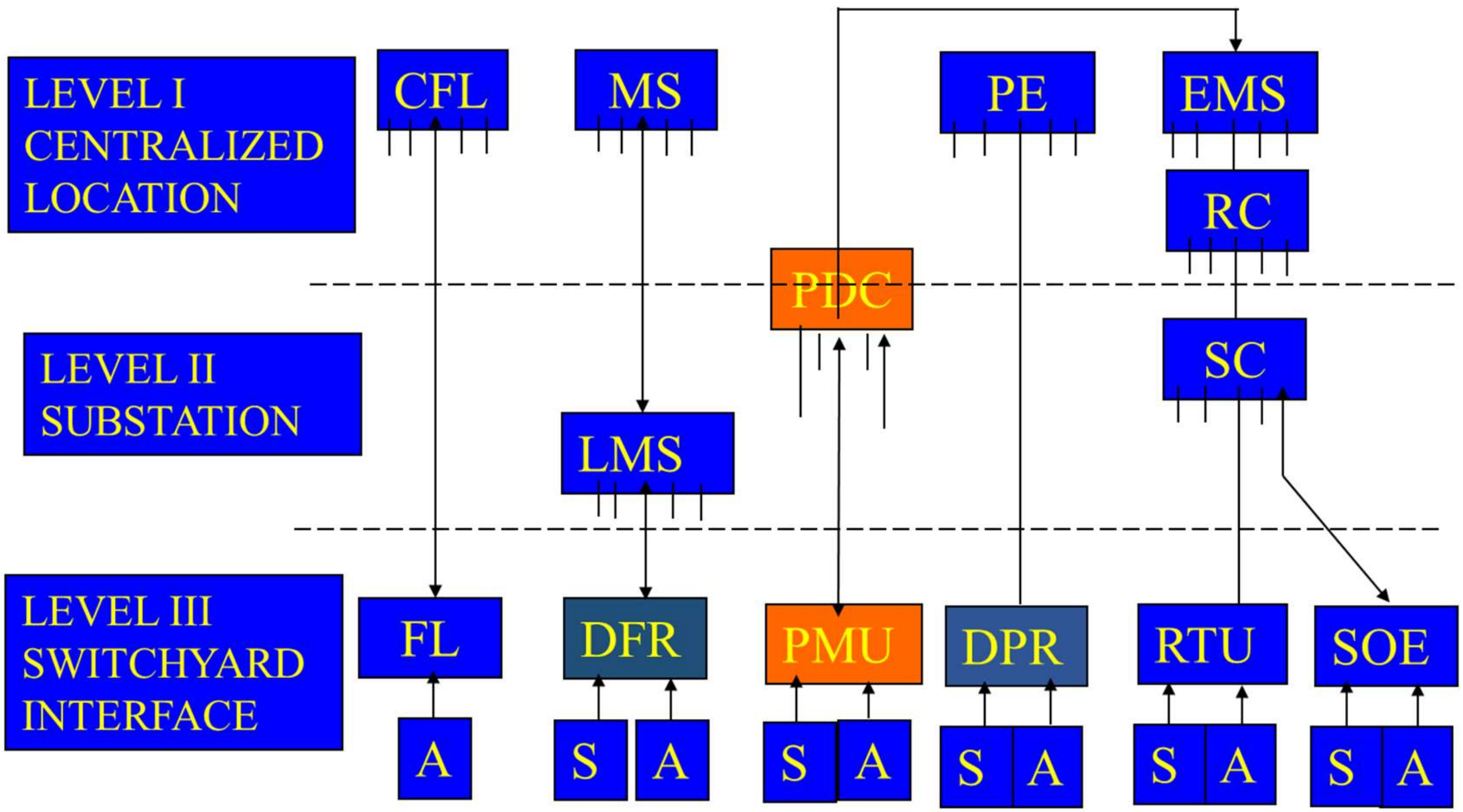
What is next:

- How to use such (integrated) data in decision making
- How to automate decision making

Q/A

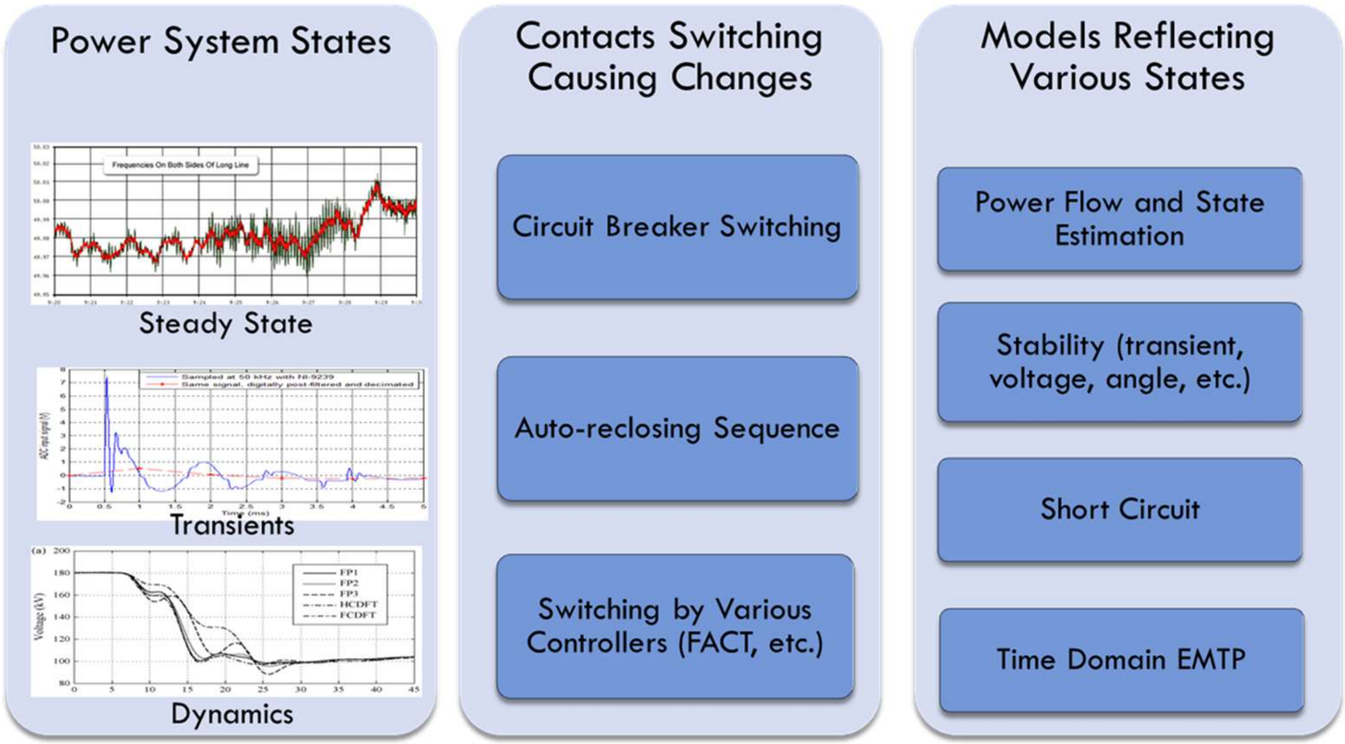
Status: Transmission

Terminology:
Point on wave (PoW)
SynchroWaveform (SW)



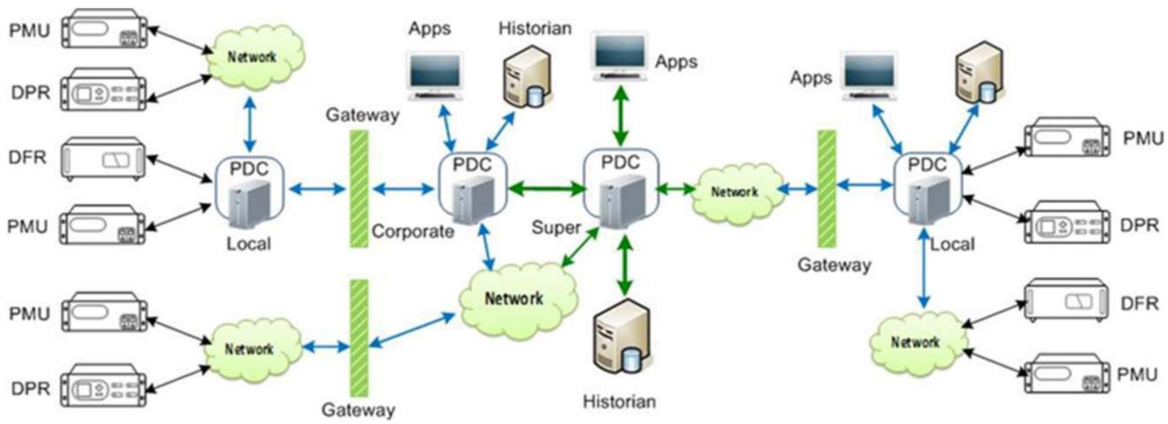
Status: Transmission

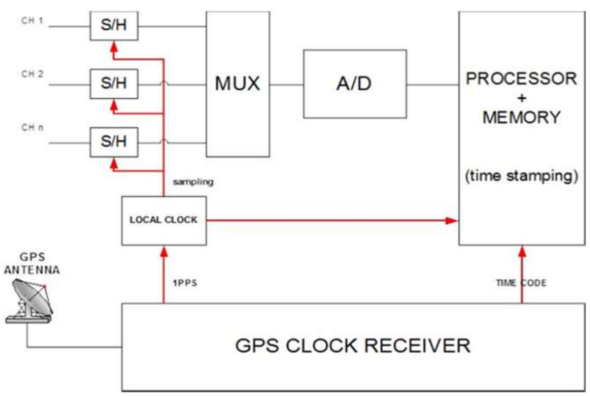
IBR deployment requires SW data



Unresolved Infrastructure Issues

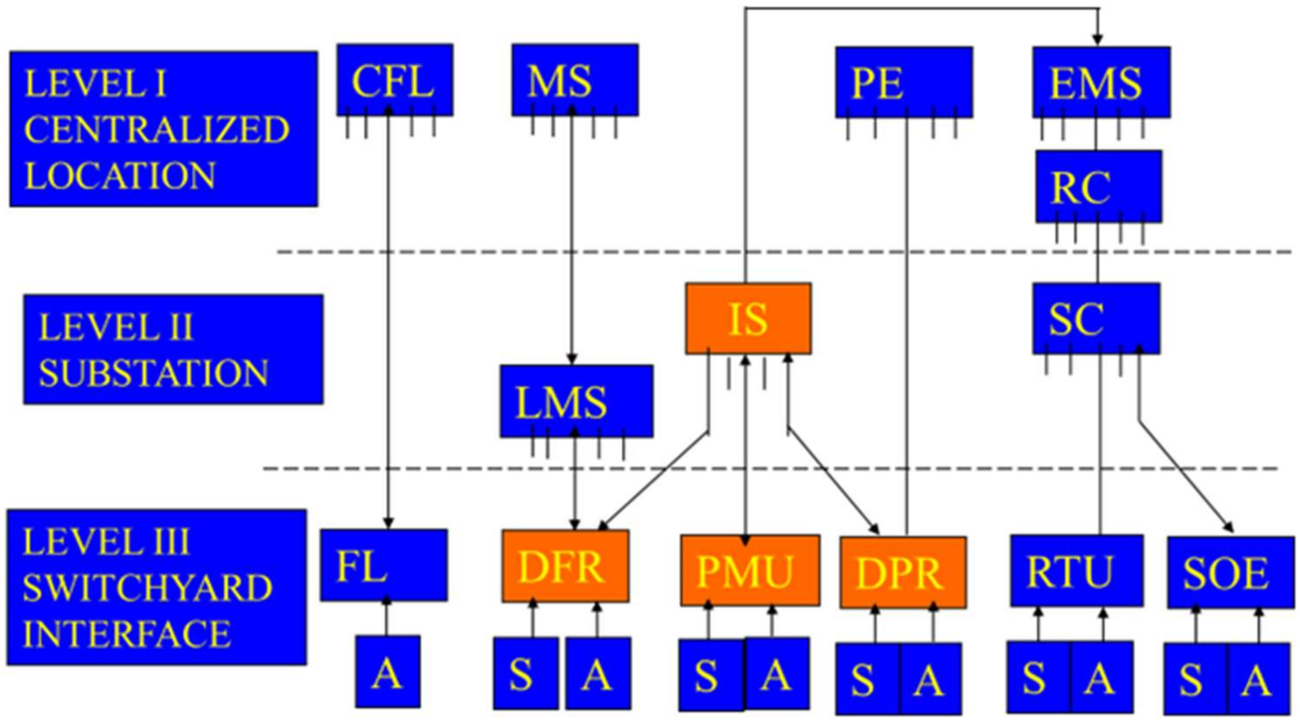
How to acquire, communicate and manage SW Data





Unresolved issues

How to integrate SW measurements



M. Kezunovic, A. Abur, A. Edris, D. Sobajic, “Data Integration/Exchange Part II: Future Technical and Business Opportunities,” IEEE Power & Energy Magazine, pp 24-29, May/June 2004

Open application issues

Causes of inverter tripping

- **Inverter Instantaneous AC Overcurrent Tripping.** During the fault, the phase and magnitude of inverter terminal voltage changed rapidly. As the inverter attempted to respond to this change, inverter ac current was driven above its rating and on instantaneous ac overcurrent exceeding the trip threshold.
- **Passive Anti-Islanding (Phase Jump) Tripping.** inverters did not trip on PLL loss of synchronism since many of those protections had been disabled; however, the inverters from this same manufacturer tripped on passive anti-islanding function, which misinterpreted the grid phase angle shift upon fault recovery as an islanding signature
- **Inverter Instantaneous AC Overvoltage Tripping.** Inverter overvoltage conditions occur upon fault clearing. Terminal voltage is depressed during the fault and then rises very rapidly at fault clearing. At the time of fault clearing, the inverter ac current recovers and inverter injects a significant amount of reactive current. The large injection of reactive current, based on measurements taken during fault conditions, and the near-instantaneous recovery of terminal voltage results in high inverter terminal voltage conditions and the inverters subsequently tripped
- **Inverter DC Voltage Unbalance Tripping.** Unbalanced (negative sequence) voltage on the ac side of the inverter can cause a ripple on the dc bus that must be managed by inverter inner control loops. If these loops are not sufficiently fast enough to respond to grid fault events, the dc-side ripple may surpass the trip threshold and cause inverter tripping for ac-side faults.
- **Feeder Underfrequency Tripping.** Feeder protective relaying was configured with underfrequency trip settings of 57.5 Hz with an instantaneous (0.0sec) timer. Instantaneously measured frequency was the primary contributor to erroneous widespread solar PV tripping

Y. Li, Y. Gu, T. C. Green, "Revisiting Grid-Forming and Grid-Following Inverters: A Duality Theory," arXiv: 2105.13094v3, 27 Jan 2022

Open application issues:
Causes of relay misoperation

- **Power Swing Protection**: Increased rate of change of swing impedance due to fast IBR controls & reduced inertia. Changed swing impedance trajectory due to IBR dynamics.
- **ROCOF Protection**: Increased Rate-of-change-of-frequency (ROCOF) due to reduced system inertia under IBRs
- **Negative Sequence quantities-based protection**: Low I2 contribution of IBRs, depending on IBR type & control scheme. Changed I2 power factor due to IBR controls.
- **Fault Identification Logic**: Changed I2 power factor due to IBR controls.
- **Communication Assisted Protection**: The changed I2 power factor may lead to misoperation of the directional element; the impacted relay communicates an incorrect permissive trip/block signal to the remote relay causing an incorrect trip decision.
- **Line Distance Protection**: Low fault current amplitude due to IBRs may lead to lack of enough supervising current, thus leading to failure to trip. Dynamically varying source impedance (and angle) of IBRs may cause unpredictable and inconsistent dynamic expansion of mho circle, thus leading to reduced reach accuracy and risk of over- or under-reach.
- **Memory Polarized Zero Sequence Directional Element**: Faster IBR controls and reduced inertia may cause a shift in the phase angle of the short-circuit voltage with respect to that of the memory voltage, leading to an incorrect directionality decision.
- **Line Current Differential Protection**: The lower fault current amplitude and dynamically changing phase angle may cause an LCD relay to encounter different current flow patterns compared to SGs, thus causing it not to pick up an internal fault.
- **Phase Comparison Protection**: The dynamically changing phase angle under IBRs may produce a spurious shift in the phase angle of line terminal currents, potentially causing PC misoperation (internal fault not detected)

A. Haddadi, E. Farantatos, I. Kocar, U. Karaagac, "Impact of Inverter-based Resources on Protection," Energies 2021, 14, 1050

What is next

How to use such (integrated) data in decision making

- ***Time scale***: Operations, planning, protection, asset management
- ***Spatial scale***: Local events, system-wide events
- ***Monitoring***: Open loop
- ***Control***: Closed loop through an operator or through a controller
- ***Protection***: Closed loop (automatic control)
- ***Processing***: Local (substation), remote (control center), cloud
- ***Storage***: Time-window of interest, "continuous"
- ***Recording***: Triggering or streaming
- ***Sparsity***: low density, high density
- ***Placement***: substation, IBR controller
- ***Correlation***: no correlation, correlation with other SW data, and correlation with other types of recorded data

H. Mohsenian-Rad, M. Kezunovic, F. Rahmatian "Synchro-waveforms in Wide Area Monitoring, Control, and Protection," IEEE Power and Energy Magazine, 2024

What is next

How to automate decision making

Data integration, wrangling, cleansing:
- Use of signal processing to detect bad data and extract features
- Use of data labeling to determine association between the recordings and events
- Use of ML/AI to learn from historical data to develop data models for event analysis

Data analysis to determine cause-effect:
- Run simulations and compare to SW recordings to calibrate models
- Replay SW into the relays and IBR controllers to understand responses
- Correlate SW recordings to other field recordings and simulations of power system events to understand contingencies

Personnel preparedness:
- Create hands-on education and training facilities
- Provide tools for SW data handling
- Develop business cases for the use of SW data

Conclusions

Q/A

- Why the SW recordings are important: they reveal dynamics between power system, controllers and protective relay
- Why SW recordings require recording infrastructure improvements: They need new sensors, communication approaches, and processing
- Why the analysis of SW recordings needs to be automated: the data volume is overwhelming, and the analysis may be beyond users' manual processing
- Why end user needs to better understand the potential benefits: SW recordings can reveal certain power system properties that cannot be understood otherwise
- Who may use SW: Utilities (planning, operations, relaying, maintenance), Consultants (IBR interfacing requirements and performance), and vendors (equipment certification)
- What is missing: standards, practical use cases, utility deployments, vendors offerings, research to answer why and where SW are indispensable