USE OF SYNCHROPHASOR MEASUREMENTS IN PROTECTIVE RELAYING APPLICATIONS

IEEE Power Systems Relaying Committee

C14 Working Group Report

Presented by Jim O'Brien

Duke Energy

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C14 Working Group

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WG Report

- The objective of the report is to provide protective relaying engineers and the industry with practical information in synchrophasor measurement applications in the protective relaying area.
- The full report is available at http://www.pes-psrc.org/ (Published Reports)
- This summary covers:
  - Background
  - Present Applications
  - Future Applications

What is a Synchrophasor?

- A phasor is a vector consisting of magnitude and angle that corresponds to a sinusoidal waveform at a given frequency.
- A synchrophasor is defined in IEEE C37.118 as “a phasor calculated from data samples using a standard time signal as the reference for the measurement.
- Synchronized phasors from remote sites have a defined common phase relationship.”

Synchrophasor Measurements

- Measuring devices are placed at different locations in a power grid to capture voltage and current waveforms, from which phasors can be calculated.
- Synchrophasors measured across an interconnected power grid will have a common timing reference and thus can be compared directly.

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Synchrophasor Measurements

- In 1994, the IEEE PSRC working group prepared an IEEE paper that discussed synchronized sampling of phasors for relaying and control applications
- In 1995, a standard on synchrophasors was introduced, IEEE 1344
- In 2005, IEEE 1344 was replaced by the IEEE synchrophasor standard C37.118-2005

Synchrophasor Measurements

- C37.118-2005 was split into two standards which were both published in December 2011
- C37.118.1-2011 carries the measurement requirements from the C37.118-2005 and extends them with frequency and rate of change of frequency requirements and adds performance under dynamic conditions for all measurements
- C37.118.2-2011 carries the data communication requirements from C37.118-2005 without significant change, adding a new configuration message and few minor changes for ongoing compatibility

Why Synchrophasor Measurements in Protection?

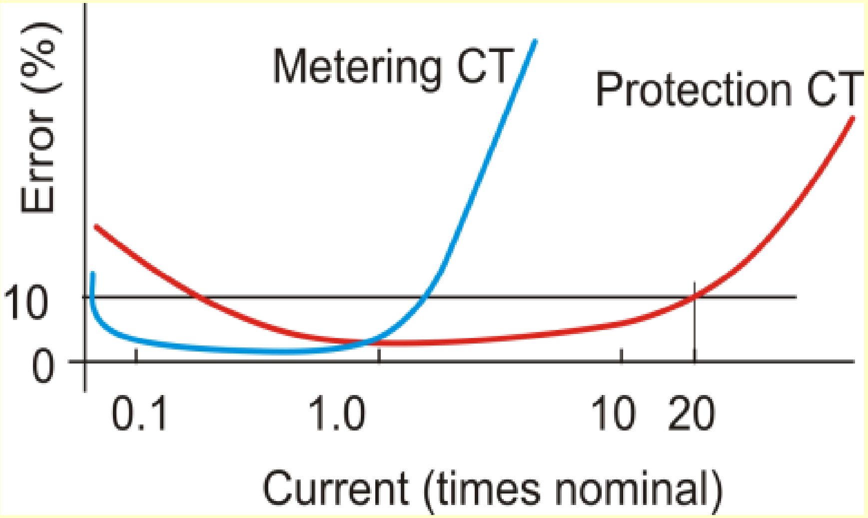
- Time-stamped synchronized measurements represent actual system conditions at any given time and can be utilized in relay protection.
- Tasks associated with visualizing, storing, and retrieving the phasor measurement data are being worked on by the industry.

Why Synchrophasor Measurements?

- Synchrophasor measurements are used in many power system applications, such as wide-area monitoring and situational awareness applications.
- Real time synchrophasor measurements are already applied for system monitoring and can enhance the state estimator in system operations.

Synchrophasor Measurements Considerations

- Current Transformers. If the synchrophasor measurements are used to perform protection function, the PMU should be always connected to a protection CT.



Synchrophasor Measurements Considerations

The synchrophasor measurements' ability to meet the overall protection requirements are affected by:

- Reporting rates and latency
- Jitter
- Intermediate systems (Ethernet switches and routers)

Communications Infrastructure Requirements

Bandwidth requirements vary depending on the data rate and the amount of data being transmitted.

Data rate Frames/s	5 Phasors 1 Analog, (integer)	10 Phasors, 4 Analog, 2 digital, (integer)	10 Phasors, 4 Analog, 2 digital, (floating point)
12	4800 bps	8400 bps	14160 bps
30	12000 bps	21000 bps	35400 bps
50	20000 bps	35000 bps	59000 bps
60	24000 bps	42000 bps	70800 bps

Communications Infrastructure Requirements

- The communications system must be reliable and available continuously.
- Data loss due to errors, dropouts, or unavailability should be 0.1% or less per minute, depending on the application.
- Latency requirements depend on the particular application, so they have to be determined on a case by case basis.

Communications Infrastructure Requirements

Description	Delay
Analog modem using simple, direct modulation at 2400 BPS	8 – 12 ms
Analog modem using complex coding (V.32bis, V.34)	60 – 100 ms
Digital with async SONET	38 – 45 ms
Direct digital, sampled into sync system	18 – 24 ms
Network, 10baseTX, direct with no routers, minimal distance	4 – 8 ms
Network, 10baseTX, over WAN narrowband, 2 routers, 200 mi	17 – 19 ms

Communications Infrastructure Reliability

- Reliability includes the reliability of both the channel and the communications equipment.
- The data stream should be transmitted securely and the recovery of the data stream should be reliable and accounted for in the relaying schemes' logic.
- Reliable communications equipment that meets IEEE 1613 and IEC 61850-3 is designed to survive the substation environment.

Satellite Clock Issues

- Hijacking of satellite clock signal
- Satellite clock signal loss
- Satellite clock signal quality.

Present Applications

- Power Swing Detection
- Load Shedding
- Line Reclosing Selectivity Utilizing Synchrophasors
- Power System Analysis
- Synchrophasor Assisted Black Start
- Distributed Generation Anti-Islanding
- Automatic Generation Shedding
- Communication Channel Analysis
- Verifying Voltage and Current Phasing
- Distance to Fault

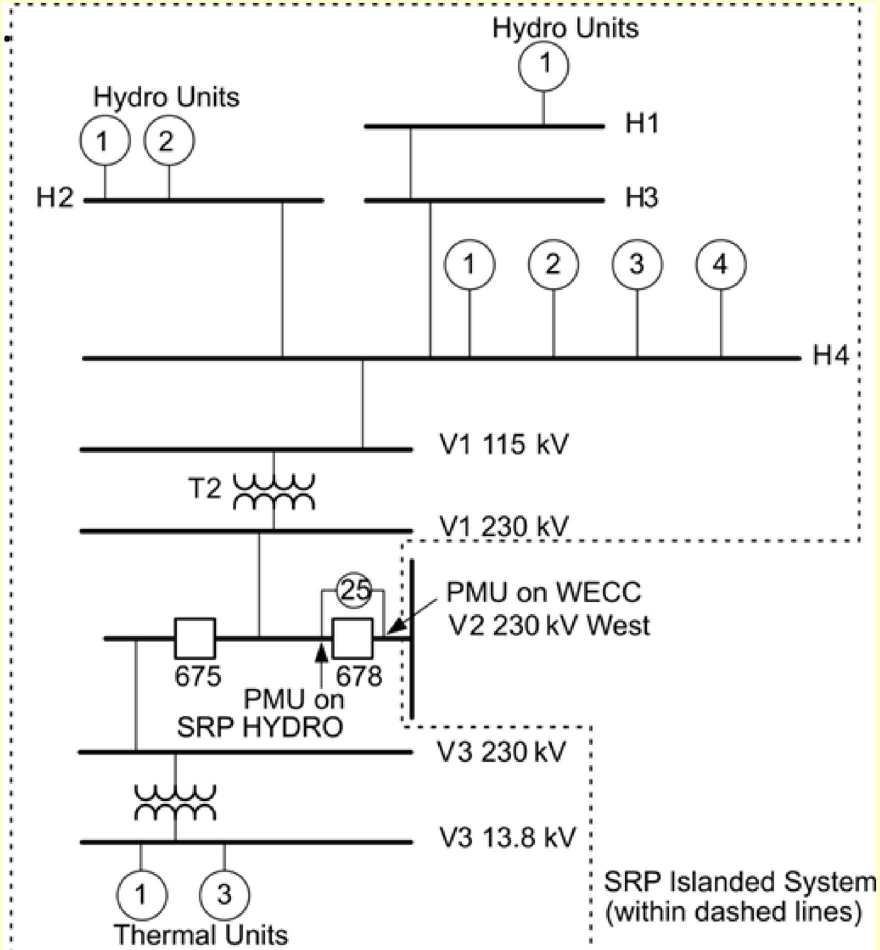
Synchrophasor Assisted Black Start

- Salt River Project (SRP) used synchrophasors as a synchroscope to connnect the SRP and WECC systems.

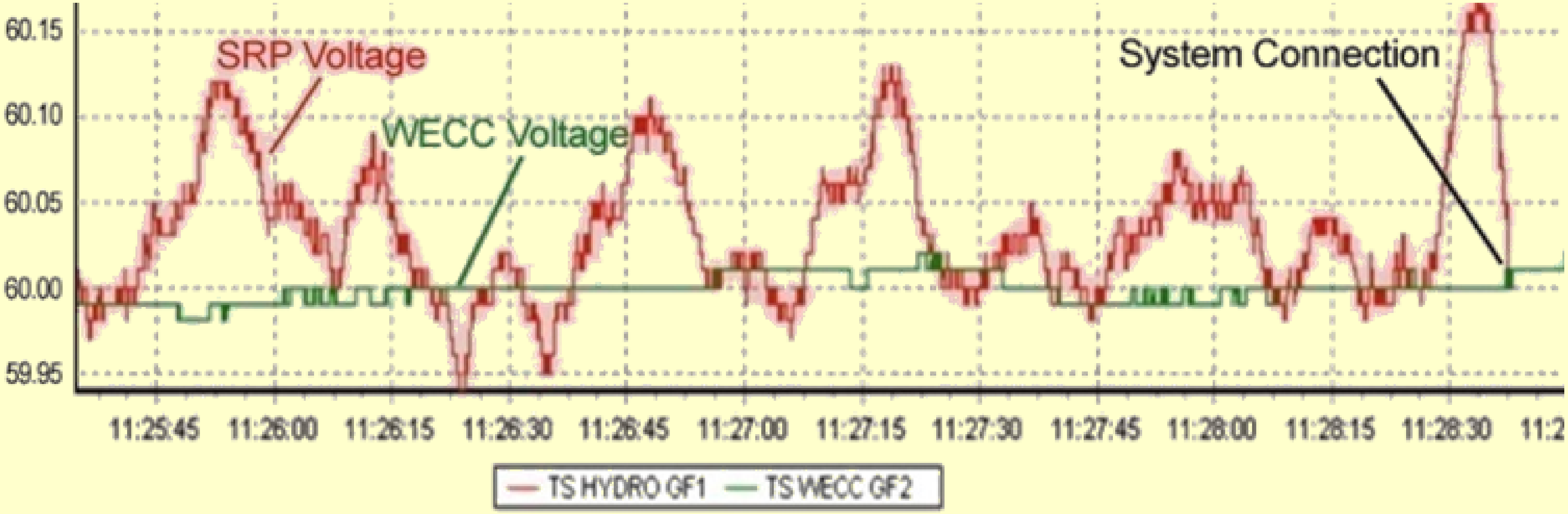
- SRP had two black-start goals: synchronize the thermal and hydro units and synchronize the SRP and WECC systems.

Synchrophasor Assisted Black Start (Cont.)

Figure shows SRP's black-start system. For the purposes of the black-start testing, SRP islanded from WECC at the 230 kV V2 bus via breaker 678.



Synchrophasor Assisted Black Start (Cont.)



Future Applications

- Voltage Instability Predictor
- Loss of Field
- Bus Differential Relaying
- Line Differential Protection
- Negative and Zero-Sequence Line Differential Protection
- Distance Function
- Fine Tuning of Line Parameters
- Distribution Synchronizing

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Future Applications

- Alarms for Encroachment of Relay Trip Characteristics
- New Trends in Adaptive Out-of-Step Protection
- Synchrophasor Application to Controlled Islanding
- Adaptive Voting Scheme
- Real-Time Substation Voltage Measurement Refinements
- Detection of Power System Inter-Area Oscillations
- Synchrophasor-based Line Backup Protection

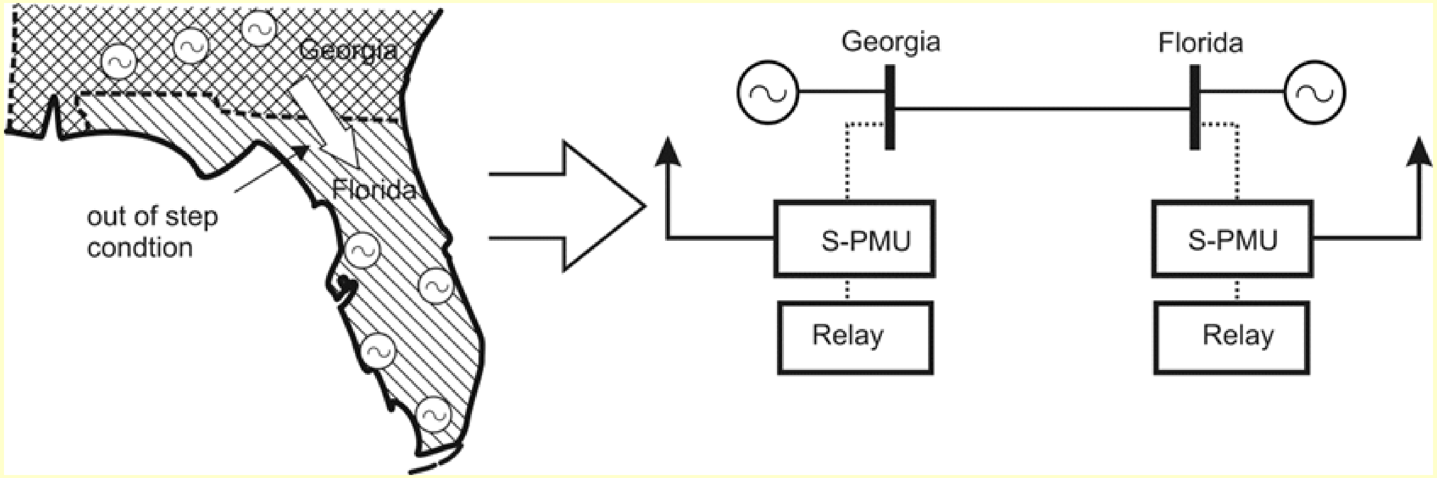
New Trends in Adaptive Out-of-Step Protection

- A group of generators going out-of-step with the rest of the power system is often a precursor to a complete system collapse. Whether a transient will lead to stable or unstable condition has to be determined quickly and reliably before appropriate control action is taken.

- Wide-area time-synchronized measurements of positive-sequence voltage phasors throughout the power system provide a direct path to determining stability using real-time data.

New Trends in Adaptive Out-of-Step Protection

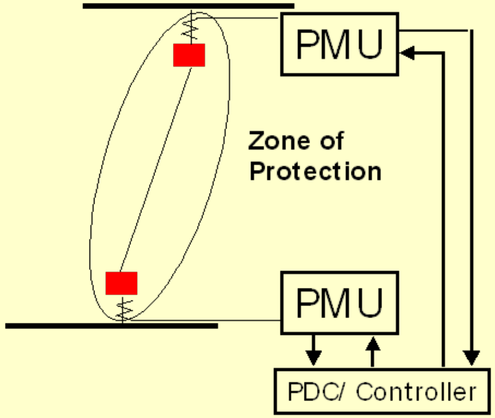
- The concept of adaptive out-of-step protection is shown at the Florida-Georgia interface with the interface modeled as a two-machine system.



Synchrophasor-based Line Backup Protection

- Synchrophasor technology could improve backup protection by helping decide at a PDC/controller location if there is a fault in the protected zone and avoid unnecessary zone 3 tripping on load encroachment.

- Faster detection of failed protection and subsequent correction action increases the stability margin of a power system.



Questions?

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