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Practical Backup Fault Protection with Synchrophasors

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Industry roadmap for synchrophasor apps

Udren-Novosel Chapter 6 – PACWorld Conference 2010

- WAMS gathering, visualization, archiving.
- Use real data to tune models. Dynamic, generators, loads…
- Model secondary system (P&C) behavior.
- Develop & validate high-speed real time control algorithms.
- Expand PMU & controller infrastructure – coverage, availability, latency, redundancy, security.
- Try control functions open-loop.
- Build practical PoC labs and installations.
- Close the loop and enter the WAMPACS era!

We know it will happen.

It takes big investment. It takes time!

What is holding up P&C functions?

- Risk aversion for closed-loop control functions.
- What did we fail to predict?
- Long validation and trial period.

Meanwhile:

- PMU infrastructure being installed.
- Business case goes <u>beyond</u> just making system operators aware of their situation.
- *We all think* - if we build it [*PMU network*], the applications will come, and they will work, because...

Synchrophasor measurements are simple & robust - like an airplane wing.

Closed loop application we can do *now*

Wide-area current comparison backup fault protection based on Kirchoff's Law

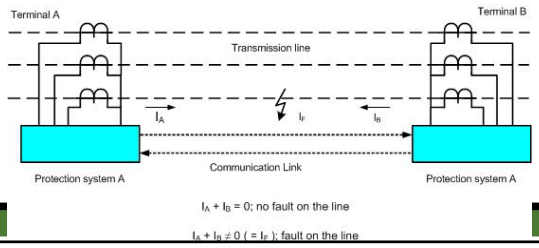
- Simple at its core.
- We already thought of it (IEEE PSRC WG C14 Report 2009-12).
- Like an airplane…full implementation of a simple concept is not so simple.

The point:

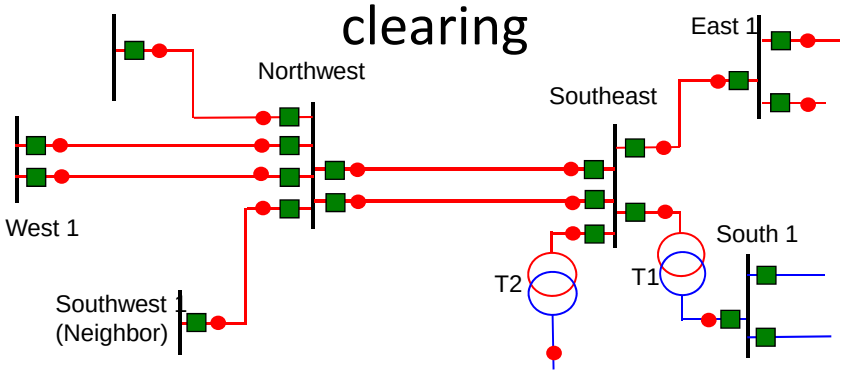
- We have what we need to make a practical application *today*.

Basic principles

- PMUs on lines at a voltage tier, and at transformer boundaries.
- Primary protection is pilot/unit operating directly among terminals as we do today.
- Nested differential zones covering multiple lines & stations.
- Time delayed backup in layers.
- Predictable measurement times and precise dynamic remote zone boundaries = reduced backup time delays.
- Disconnect only what is needed to isolate any fault, even after relay and breaker failures.



Multiple strategies for fault clearing



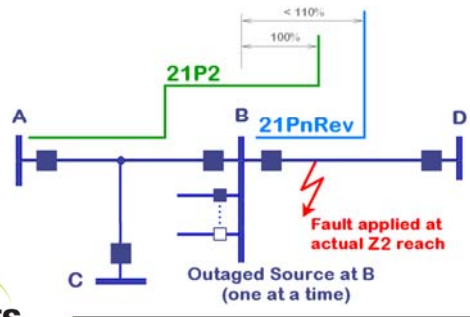
- Duplicate primary protection in PMU relaying system.
- Breaker failure detection & tripping.
- Remote backup – adjacent zone tripping.
- Non-PMU backup relays are set for safety net protection.

More basic principles

- Processing can be centralized or distributed.
- IEEE C37.118-2005 or C37.118.1-2011 /P or M class phasors – individual phase currents (and voltages).
  - Binaries - breaker state, PMU status, test modes, quality, time lock…
- Communications latency of 50 to 100 ms is adequate.
  - Faster improves operation and opens options.
- Downward control path to trip breakers.
- Will be able to achieve overall wide area protection response of 100 – 120 ms in the near future – way faster than needed here.

Overcomes distance backup problems - 1

- High cost of maintaining coordination of distance elements
  - Constantly changes - needs to be repeated over time.
- Vulnerable to errors from old or bad physical system data.
- Some miscoordination is hard to fix – we accept overtrips that could cause trouble.



Overcomes distance backup problems - 2

- Loadability limits, NERC PRC-023.
- Tripping for swings – split at bad locations.
- Outage and reconfiguration problems.
- New energy sources – low fault current contribution.
  - PV & Solar
  - Dc inverter wind
  - Dc tie interface
  - Battery storage system interface

- We are retiring/losing coordination expertise.

Overcomes distance backup problems - 3

- Inherent self-monitoring across entire backup protection system.
- Redundancy with specific outage alarms for action.
- Free of periodic maintenance need (even for NERC)

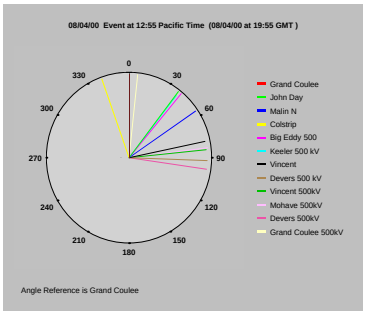
We always know the operational state and exact coverage of all backup protection functions at all times.

Overcomes distance backup problems - 4

Immune to misoperation on heavily loaded/stressed system.

- No NERC loadability studies or documentation.
- No trips on stable (or unstable) swings.

Use voltage phasors from the same PMUs and data streams for precise control of out-of-step protection trips and islanding strategy.

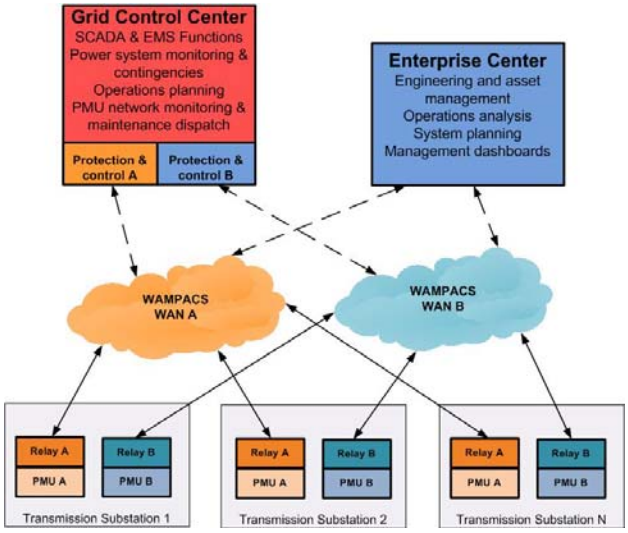


Phasor communications are critical

Communications channels for synchrophasors require most of the reliability/availability focus

- 99.95% channel availability is typical – compared to 99.999% for a typical relay/PMU.
- Simultaneous evaluation of multiple layers provides some inherent backup.
- For critical backup - PMU & isolated communications redundancy for no single point of failure.

Redundant wide area architecture



New wide area comms networks

- SONET TDM – C37.118-2005; C37.118.2-2011.
- Utilities are installing Ethernet packet networks.
- Dealing with external service providers

Harris Corp. model for FAA air traffic control communications:

- N-redundant cyber secure communications – widely separated paths.
- WDM on fibers there for other users – Harris' & others.
- Reliable & successful for mission critical continental wide area applications.
- Adopted by WECC for WISP program.
- AT&T, Verizon, others offering this model.

Cyber secure phasor streaming

IEC 61850-90-5 fits 61850 principles, but view it as a separate service just for this use.

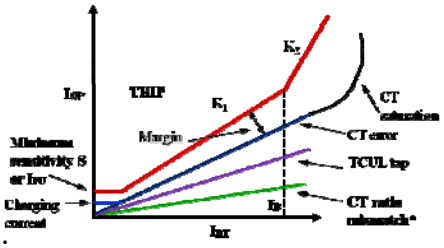
- Sampled Value (SV) or GOOSE publish/subscribe *across the Ethernet WAN – Routable SV (R-SV) and Routable GOOSE (R-GOOSE) services.*
- Adds layer 3 transport – UDP/IP unicast/multicast (*unconfirmed* efficient stream of data packets – not TCP/IP)
- Subscribers can search for publishers, & manage WAN routes dynamically using Internet Group Management Protocol (IGMP) V.3, *a standard IT router service*.

Cyber secure phasor streaming

- New in 61850-90-5 - *a big deal* – end-to-end authentication in each packet!
  - *IT standard* SHA-256 authentication hash code - computed in real time.
  - Needs new PMU or relay processors to compute authentication hash code for every packet, authenticate incoming packets.
  - *IT standard* Group Domain of Interpretation (GDOI) security key distribution/management.
- Packet encryption specification (can be done in router or in PMU/relay).
- Security needed for *all* important functions.

Application design topics

- CT saturation; shunt reactance of system
  - Differential relay designs give us the tools.
  - Saturation evidence in remote measurements.
- UPC or FACTS devices in zone.
  - Transfer charge among phases.
  - Known operating state.
  - Signature measurements.
- Shunt reactors or capacitors - same as FACTS.
- Dead battery station with transformer – reduce security margin.
  - Alarmed when battery fails, not at time of fault.



Conclusions

- WAMPACS infrastructure can handle current comparison backup relaying.
- Not dependent on model refinement – overcomes bad models.
- Secure on stressed power systems.
- Demonstrate at no risk, on existing PMU deployments.