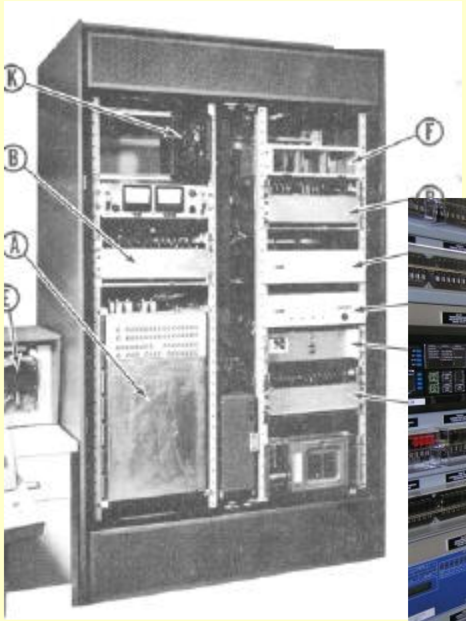
Digital Protection – Past, Present, and Future



Eric A. Udren

Quanta Technology, LLC

Pittsburgh, PA

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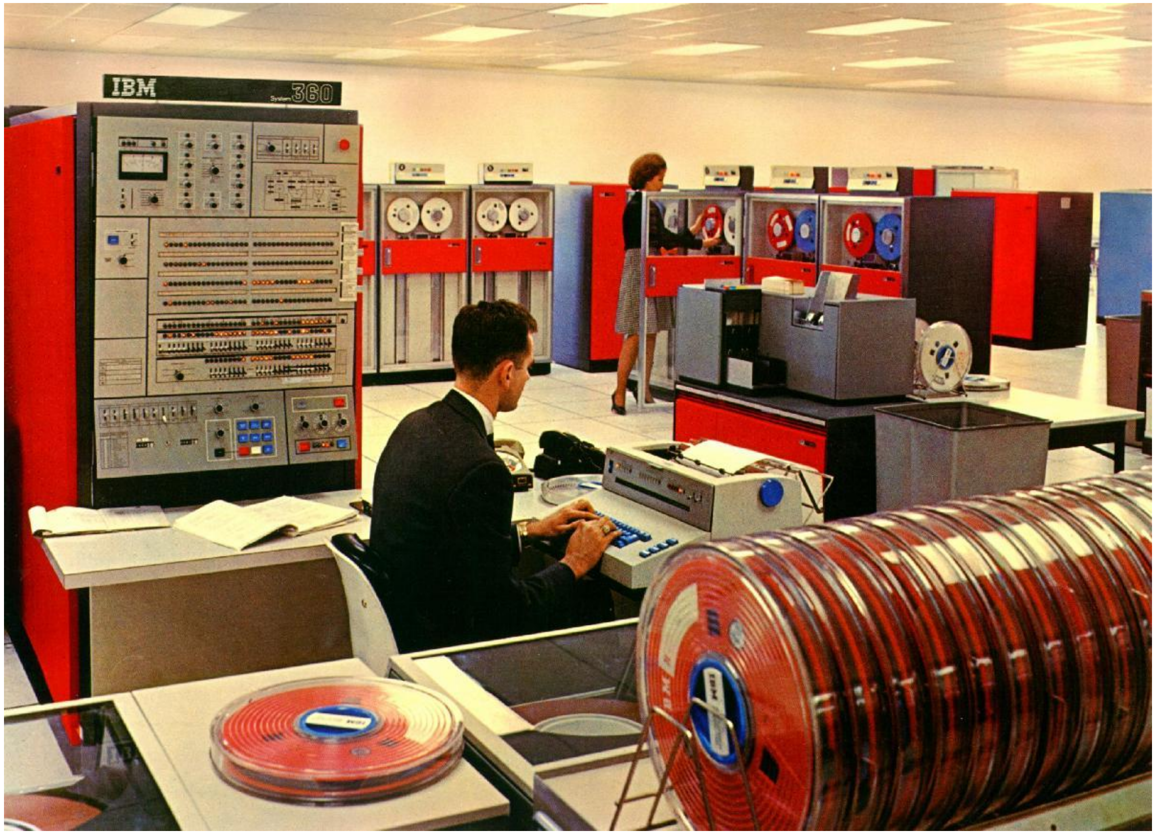
eudren@quanta-technology.com

Era of the invention of the digital relay

Late 1960s – mainframe enterprise computers

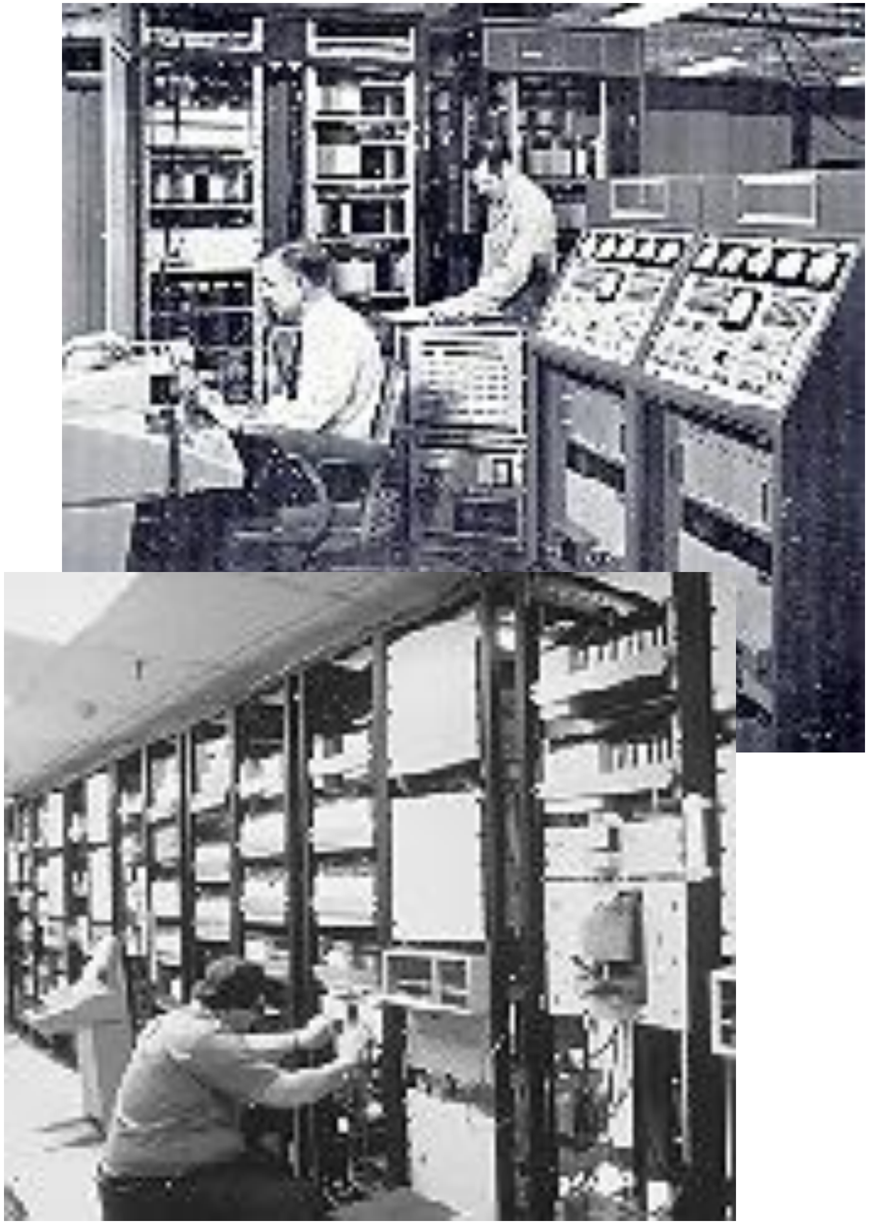
- Centralized processing.
- Office environment.
- A lot of support resources.



The first industrial minicomputers

Westinghouse P50 industrial computer

- The first industrial programmable computer system.
- Product for the factory floor.
- Power plant applications.
- Following generations – P250, P2000
- 1970s – dozens of minicomputer makers



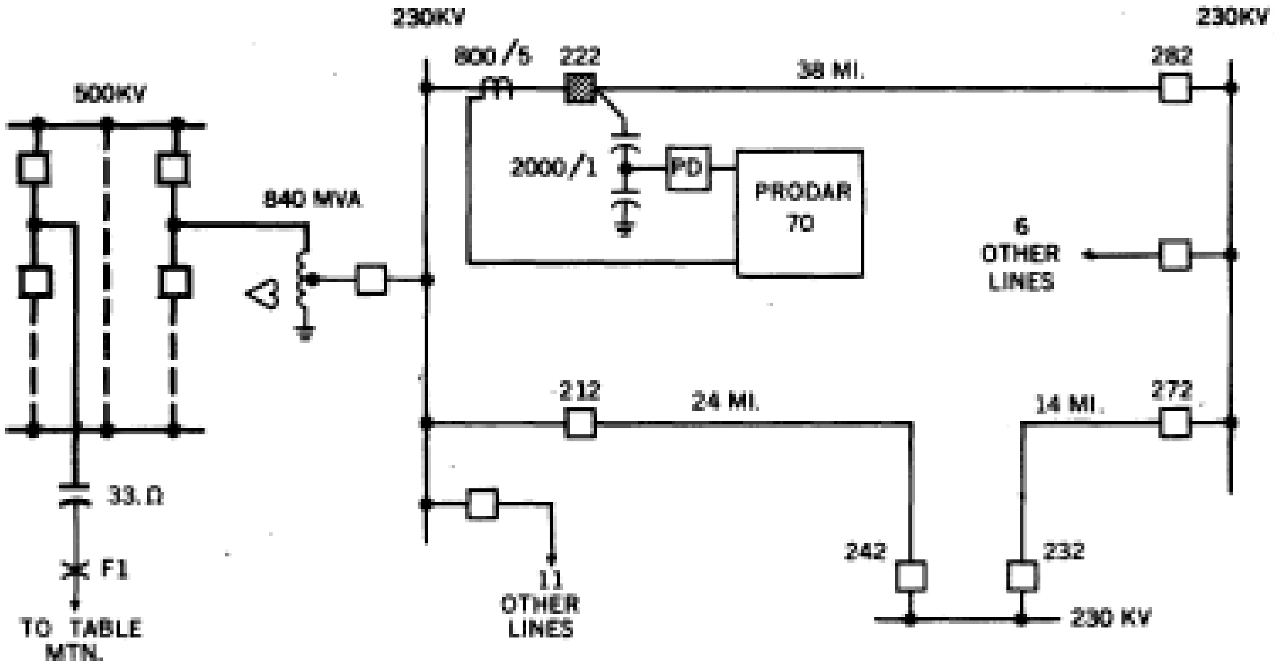
Conception of digital relaying

G.D. Rockefeller, "Fault Protection with a Digital Computer,"
IEEE Transactions on Power Apparatus and Systems, April 1969.

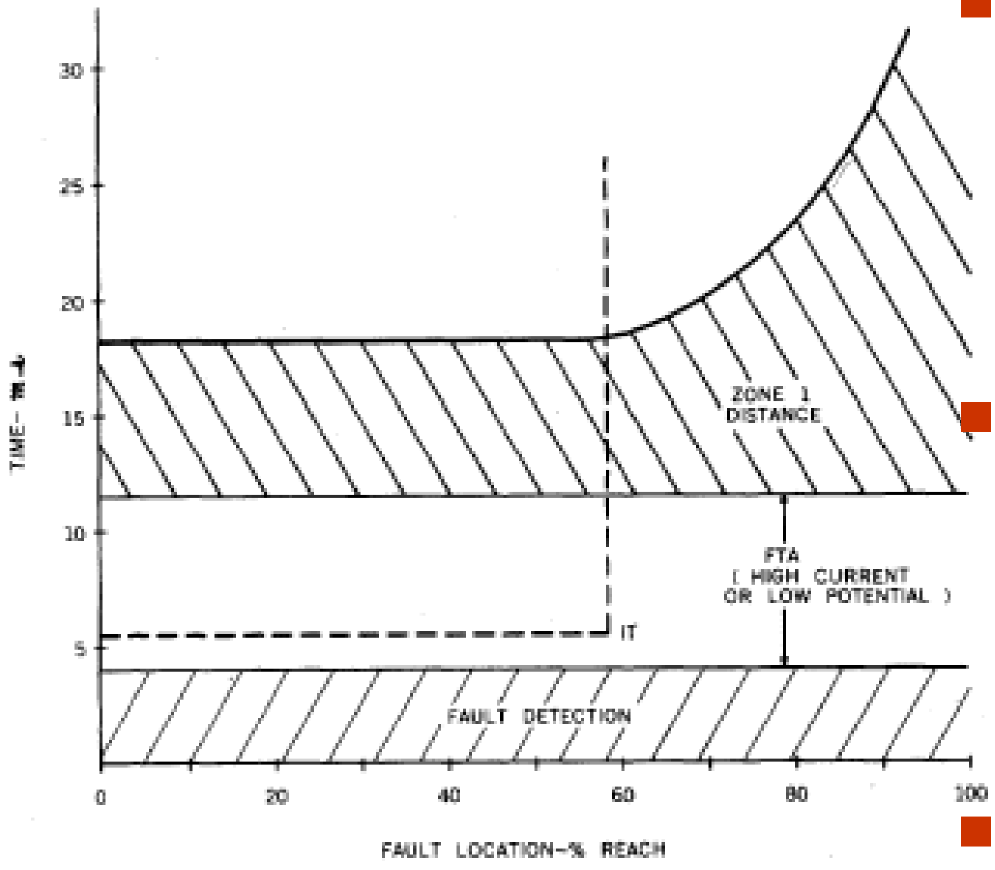
- Work at Newark College of Engineering (now NJIT), 1967-69.
- Concept of sampling voltages and currents, perform math on the individual sample values.
- Concept of a single substation computer for all protection.
- Tried to use the computers we had – not like the isolated zones of protection we had (and have)…
- Meanwhile…George was campaigning for development funds at Westinghouse Relay Division.

Prodar 70 installation and service

- PG&E Tesla Substation 230 kV control house, February 1971.
- Connected to protect Tesla-Bellota 230 kV line.
- Memory voltage, series cap line logic (adjacent 500 kV lines).
- Perfect field service until 1977.
- No failures to operate; no false trips; no failures.*
- *"The Noisy Sentinel."*



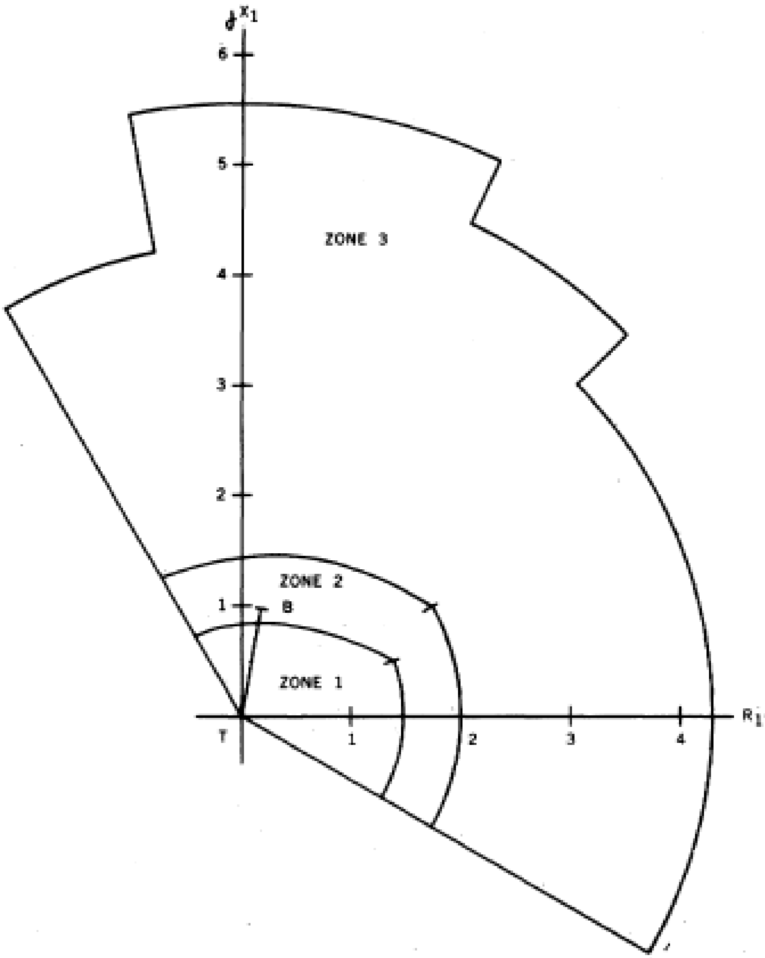
Quite a fast and accurate relay…



Computational methods

- B.J. Mann & I.F. Morrison, “Digital Calculation of Impedance for Transmission Line Protection,” IEEE TPAS ,January 1971.
- B.J. Mann & I.F. Morrison, “Relaying a Three Phase Transmission Line Using a Digital Computer,” IEEE TPAS, March 1971.
- M. Ramamoorty, 1972 – Use of discrete Fourier transform for relaying measurement from data samples.

Never seen before from a relay…



1/ 5/71 PRODAR 70 LOGGING EVENTS AT 18 HR. 41 MIN. 46 SEC.
GROUND FAULT DETECTOR OPERATED; SKCNTR = 30955
FTA FOUND NO SEVERE CONDITIONS,
TIME = 18 MSEC.; SKCNTR = 30969
ZONE 2 GROUND DISTANCE OPERATION, PHASE B,
LAST APPARENT IMPEDANCE - 5.2 OHMS AT 77 DEGREES
TIME = 41 MSEC.; SKCNTR = 30992
ZONE 1 GROUND DISTANCE TRIP, PHASE B,
FAULT APPROX. 76.5 MILES FROM THIS POINT
LAST APPARENT IMPEDANCE - 4.9 OHMS AT 71 DEGREES
TIME = 43 MSEC.; SKCNTR = 30994
EXIT FROM RELAYING LOGIC,
TIME = 87 MSEC.; SKCNTR = 31038
EXTERNAL RELAY OPERATED,
TIME = 428 MSEC.; SKCNTR = 31379
GROUND FAULT DETECTOR OPERATED; SKCNTR = 31510
FTA FOUND LOW LINE-TO-GROUND VOLTAGE, PHASE C,
TIME = 6 MSEC.; SKCNTR = 31512
EXIT FROM RELAYING LOGIC,
TIME = 108 MSEC.; SKCNTR = 31614

RECORD 44 CURRENT MEDIANS:

RESERVED TABLE 1 @ 22B8
IA - 4.22 AMPS.
VA - 98.90 VOLTS
IB - 4.13 AMPS.
VB - 98.68 VOLTS
IC - 4.34 AMPS.
VC - 98.72 VOLTS
IR - 0.16 AMPS.

RESERVED TABLE 2 @ 233D
IA - 4.13 AMPS.
VA - 97.84 VOLTS
IB - 13.65 AMPS.
VB - 95.75 VOLTS
IC - 19.48 AMPS.
VC - 94.31 VOLTS
IR - 6.50 AMPS.

RESERVED TABLE 3 @ 23C2
IA - 4.13 AMPS.
VA - 98.55 VOLTS
IB - 18.34 AMPS.
VB - 89.84 VOLTS
IC - 20.72 AMPS.
VC - 84.17 VOLTS
IR - 6.93 AMPS.

RESERVED TABLE 4 @ 2129
IA - 4.28 AMPS.
VA - 98.63 VOLTS
IB - 4.13 AMPS.
VB - 98.53 VOLTS
IC - 4.31 AMPS.
VC - 98.53 VOLTS
IR - 0.19 AMPS.

Benefits of the first digital relay

- Event record displays - Teletype printer event log with time tags.
- Fault location – in-service accuracy comparable to that of commercial relays 15 to 20 years later.
- Analog value logs and oscillographic records – output via the paper tape punch for separate plotting of oscillographic traces.
- Tailored reach characteristics, load restriction capability
- Self -monitoring of protection system electronics – failure dead-man alarm, held open by active program stimulation, active monitoring of A/D converter subsystem.

Technology demonstration – not cost effective product

More digital relaying trials

- Phadke, Adamiak, et al – minicomputer based relay at AEP, 1970s (& conception of synchrophasors).
- GE PROBE computer relaying system.

Second half of 1970s – Birth and evolution of the first microprocessors

- 1979-80 – Dr. E. O. Schweitzer & colleagues develop efficient computations for 8 bit microprocessor; develop fault locator product with good relaying.
- Focus on cost-effective reliable solution led to massive respected manufacturing business today.
- Information access via data communications.

Digital relays today

- *Most reliable* generation of relays.
- Short technical life, *and getting shorter*.
- Self-monitoring – *easier maintenance*.
- Multifunctional – *how many functions do we want in a box*?
- Flexible and configurable – *thousands of settings*.
- Sophisticated characteristics address difficult protection problems.

Still like electromechanical relays?

- No going back…
- Cost of microprocessor line relays is *between 2% and 4%* of EM panel – get it in a week, not 48 weeks.

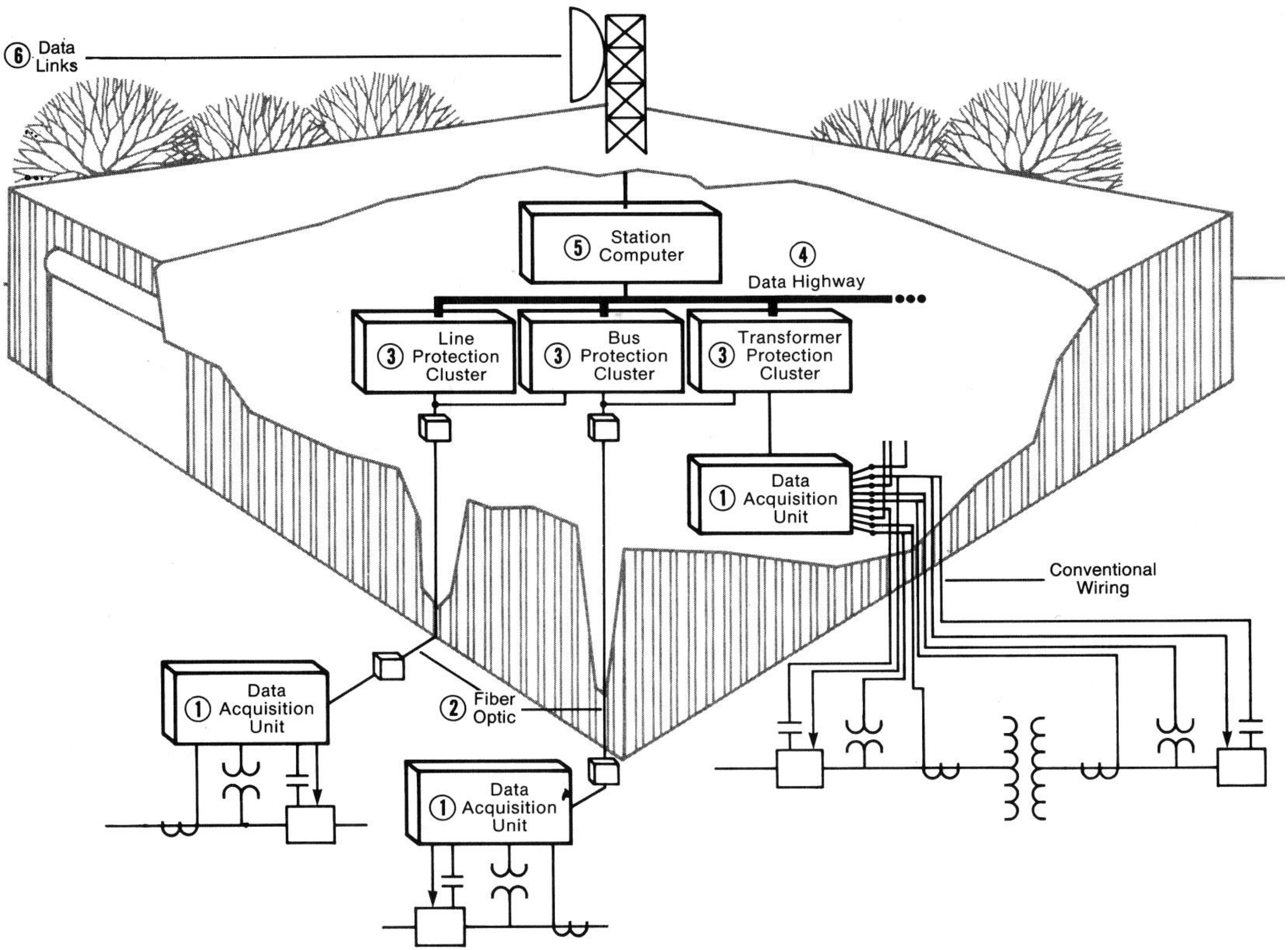
Integrating relays with data communications

- 1970s were the era of office & enterprise data networking.
- Digital relaying was demonstrated and on the way.
- Could they be combined to make a substation protection and control system that gets rid of wiring?

First protection and control system based on network data communications – 1978-86 EPRI WESPAC project

- First full installation at PG&E Deans 500 kV Substation.
- Westinghouse and GE relays interoperated via standard communications.
- Stand alone relays at other utilities.
- Included switchyard data communications…

Integrating relays with data communications



Role of IEC 61850

- 1980s – 1990s – relays, RTUs, IEDs with data communications ports for integration.
- Relays were marginal sources of measurement data.
- Every vendor invented “the best protocol.”
- Protocol locks users into the vendor’s system design.
- Combining product communications was a user headache.
- Users wanted interoperable communications…

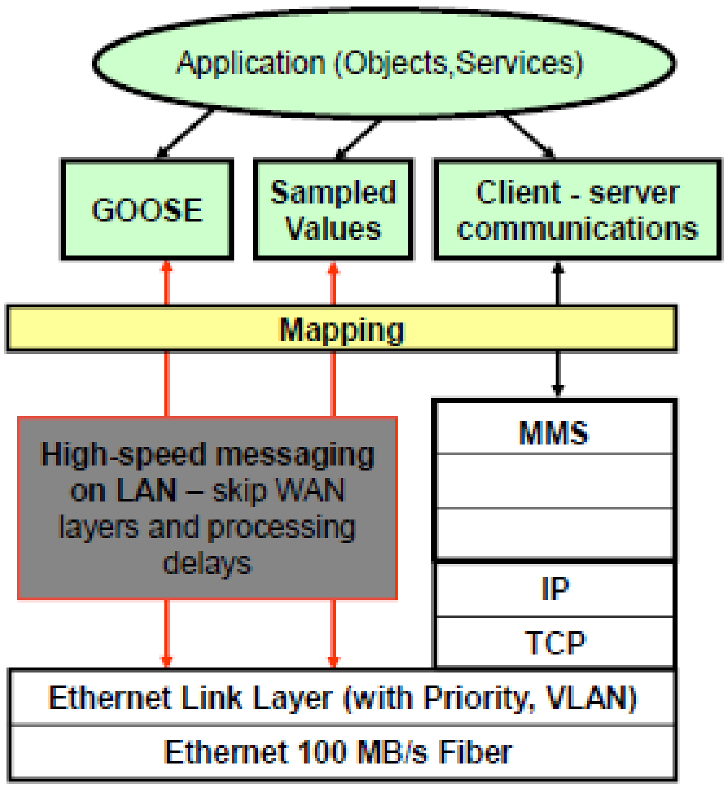
EPRI UCA – 1990-91 (North America)

IEC 61850 – 1995-96 (International – Europe & NA)

***Merged in 2000 into a* single international standard communications system development - IEC 61850**

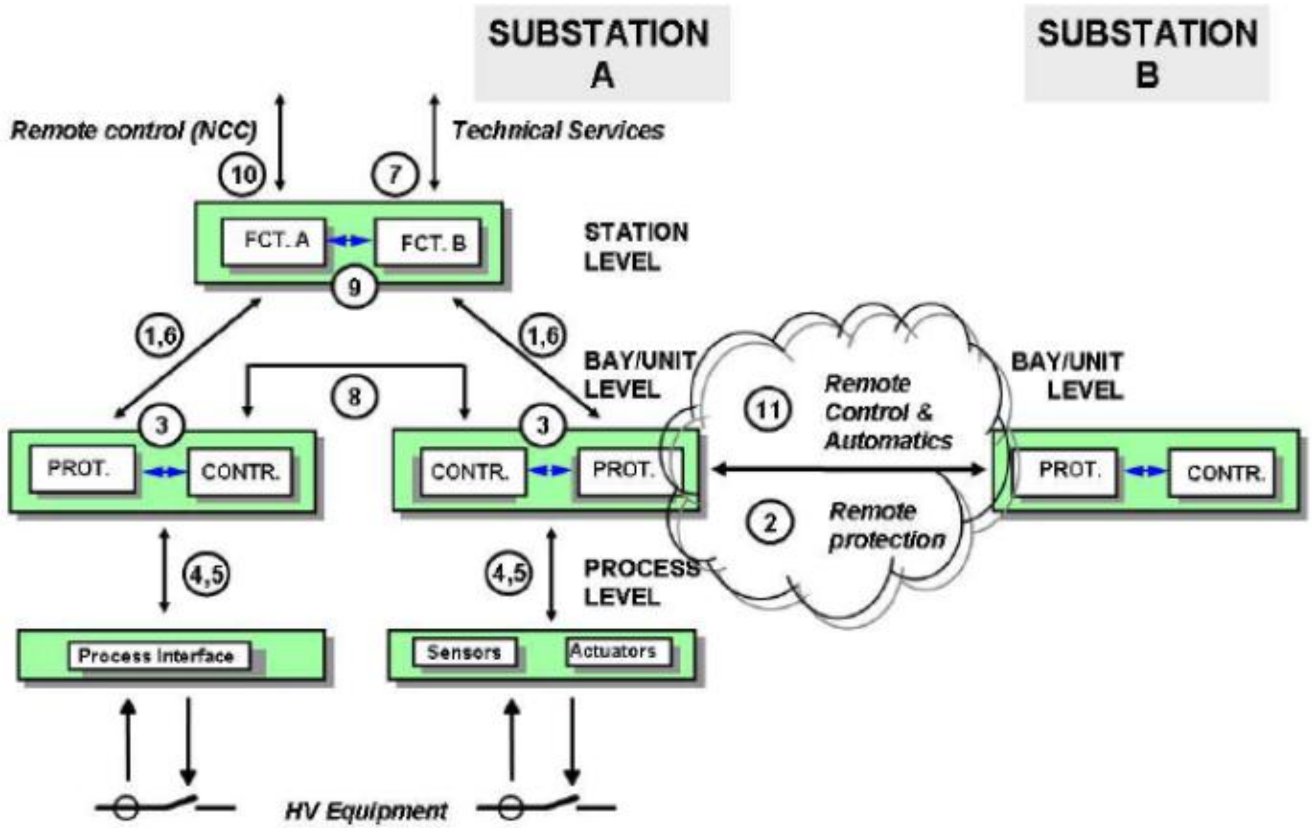
Role of IEC 61850

- A protocol stack – Ethernet, MMS, application.
- Not just a protocol – a definition of *application models* exchanging *standardized data objects – bigger scope*.
- A host of services – not a monolith.
- Support *all* substation communications including high speed control (GOOSE) and switchyard data acquisition (process bus).



Role of IEC 61850

- Expanded from substation to utility enterprise wide communications.
- A single international standard, with some growing pains for North American users…but the only path forward.



Industry roadmap for synchrophasor apps

Udren-Novosel Chapter 6 – PACWorld Conference 2010

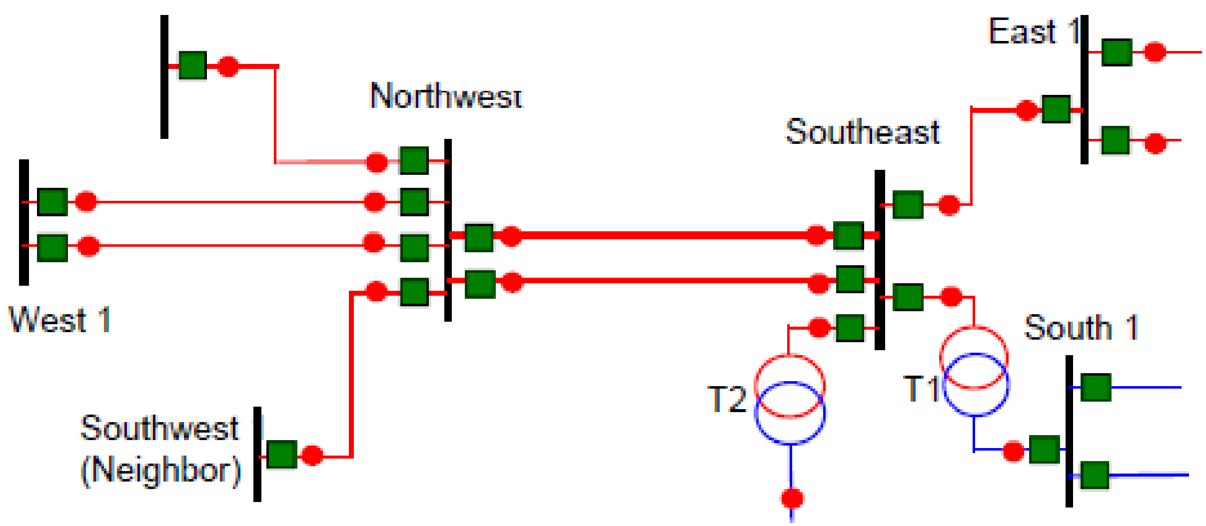
- WAMS gathering, visualization, archiving.
- Use real data to tune models. Dynamic, generators, loads…
- Model secondary system (P&C) behavior.
- Develop & validate high-speed real time control algorithms.
- Expand PMU & controller infrastructure – coverage, availability, latency, redundancy, security.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

Progress reported at this conference!

Closed loop application we can do now

Wide-area current comparison backup fault protection

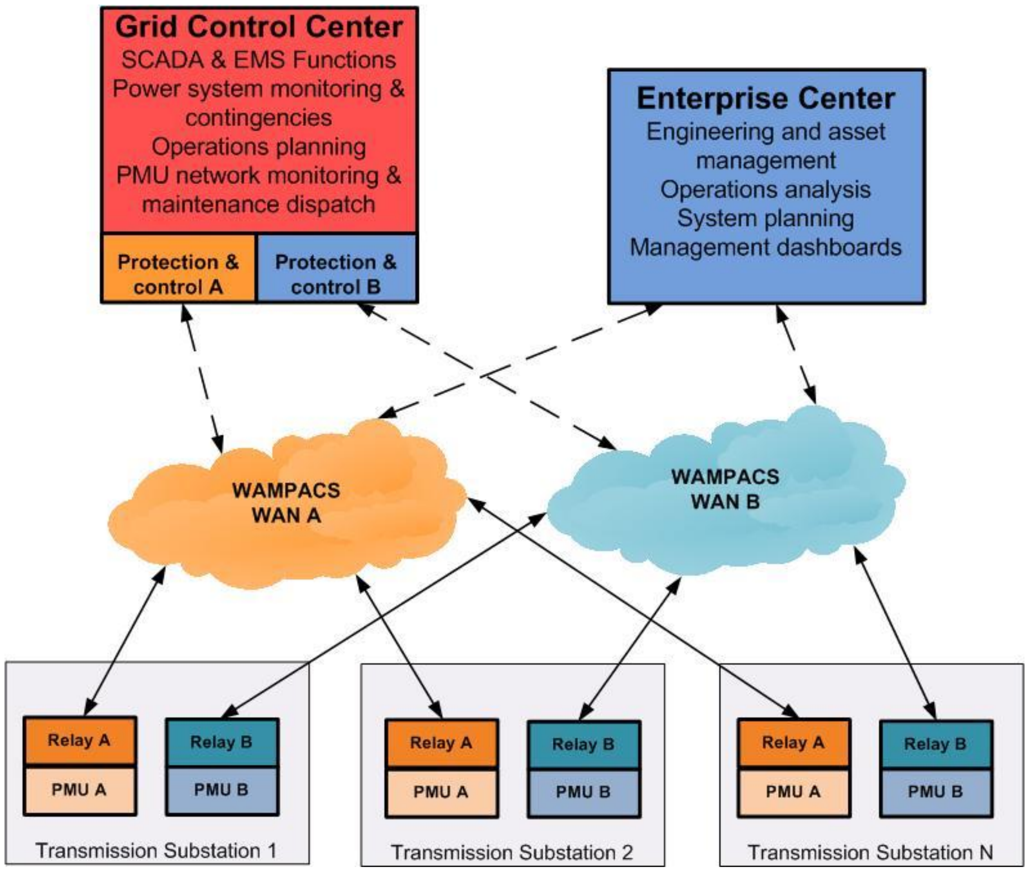
- Simple robust principle - setting-free application.
- Nested differential zones covering multiple lines & stations.
- Predictable measurement times
- Precise dynamic zone boundaries = reduced backup time delays.
- Disconnect only what is needed to isolate any fault, even after relay and breaker failures.



Overcomes distance backup problems

- High cost of maintaining coordination of distance elements
- Some miscoordination is hard to fix – we accept overtrips that could cause trouble.
- No loadability limits.
- No tripping for swings.
  - Use *voltage* phasors for smart splitting.
- Doesn’t care about low fault contributions from power electronic interfaces or DER.
- Self-monitoring with inherent redundancy
  - Actionable alarms point to the problem.
  - Eliminates most NERC protection maintenance requirements.

Conclusion - redundant wide area architecture



- Redundant phasor gathering platform supports wide area protection.
- The same platform that supports all other wide area
- Simple and robust relaying protects the grid of the future.
- Demonstrate at no risk with today's high density PMU deployments.