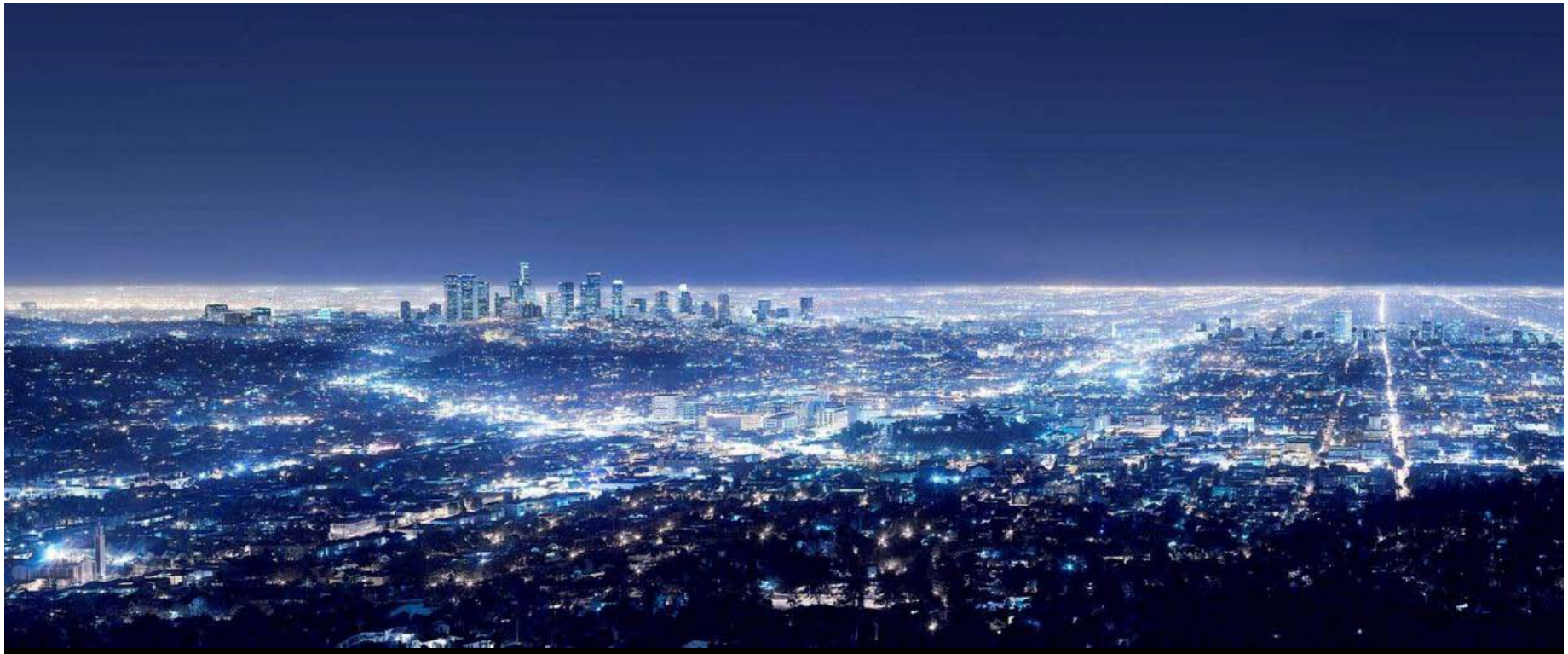

Texas A&M Relay Conference, April 09, 2013

Application of Distance Multifunction IEDs in An Utility Distribution Network

Application of distance multifunctional IEDs in an utility distribution network

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  Yordan Kyosev – EPCOR
  Peter Fong – Sequence Instrument Inc.
  Jack Chang – ABB Inc.

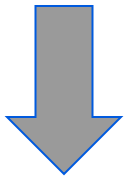
- Speaker: Jack Chang, Regional Technical Manager

Backgrounds

- EPCOR Utilities Inc. (Edmonton, Alberta, Canada) initiates a capital project to replace aging feeder relays in their 15 KV network
- Existing relays consist of overcurrent and auto-reclosing
- Each feeder (17 total) → short express cable with aerial sections
- High SC level near substations (15 kA @ 15KV, 3P, sym)
- Fuse burning approach so OC (51P,N) elements take time to operate near the substation due to coordination
- arc flash, damages to cable, loss life to transformers
- Block AR for cable faults more reliably
- Concerns of OC sensitivity on fallen conductors (safety)
- Require accurate impedance data (especially the cable)

EPCOR's Requirements

- A sensitive means of fault detection with constant reach regardless of source impedance
- Multiple measurement zones with different time delay
- Different setting groups or protection element during hot line work
- Comprehensive events and disturbance capability
- Accurate fault locator algorithm
- Modern substation automation protocols (eg. IEC61850)
- ***Cost must be competitive to a feeder OC relay***



Modern Numerical Distance IEDs with OC backup

- But, online monitoring of operation is required before releasing the new 21 functions to tripping

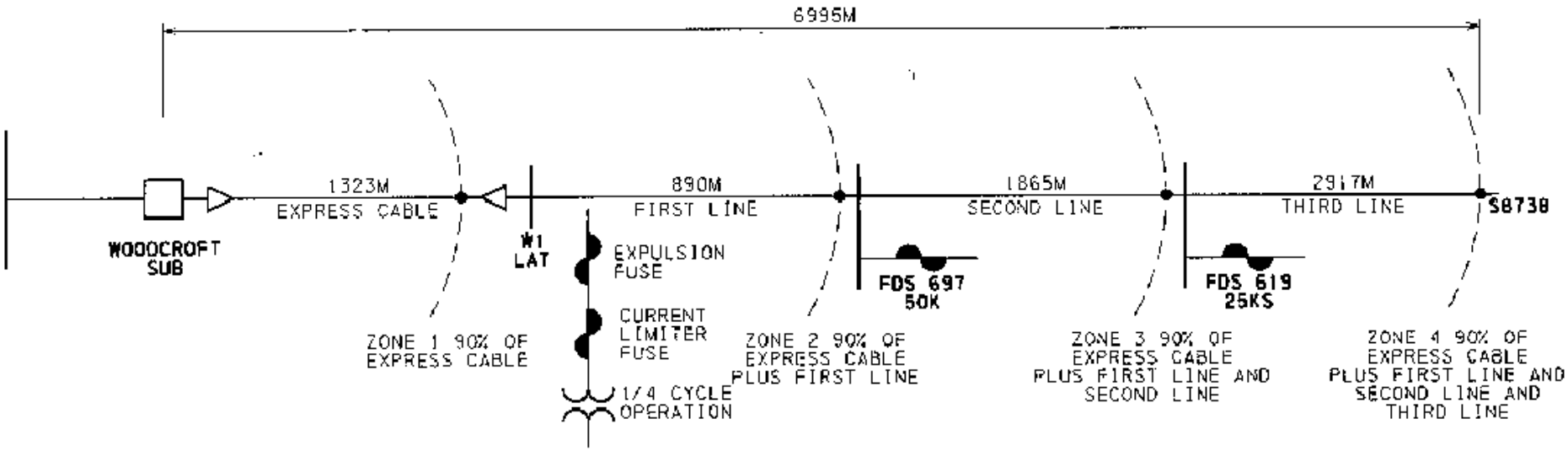
Over-Current Characteristics

- Less expensive
- Inherently non-selective and non-directional
- Mainly used on radial feeders with one way power flow
- Sensitivity varies with source impedance (reach is not constant, hard to set instantaneous operation)
- Hard to coordinate with neighboring devices in mesh networks (required directional sensing)
- Could be made selective and directional with a polarizing source (voltage) and communication infrastructure
- Distance protection

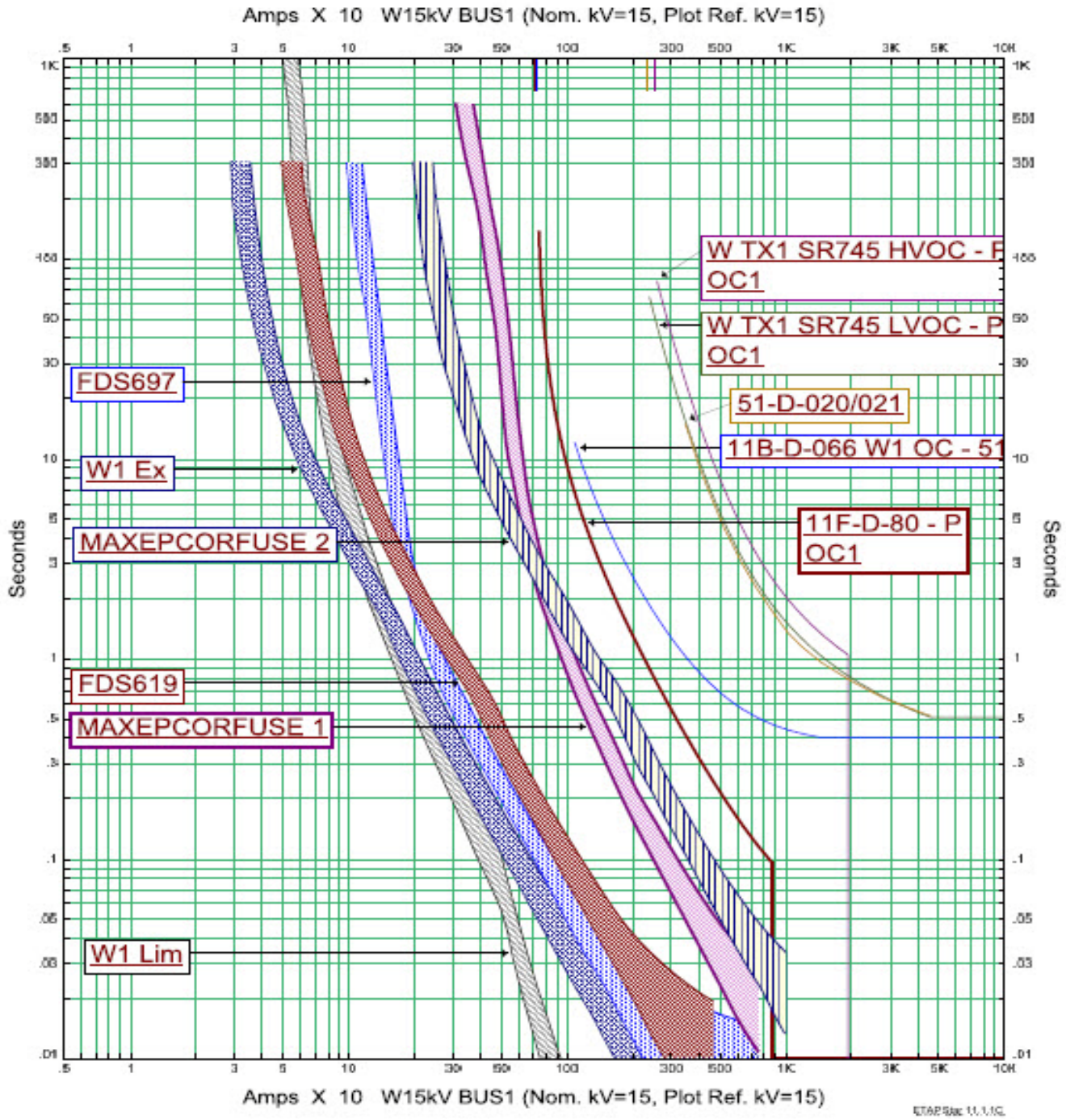
Distance Characteristics

- Require both voltage and current inputs to determine fault locations (not a disadvantage cost wise anymore)
- “Reach” settings based on positive sequence transmission line impedance.
  - Not influenced by different source impedance, fixed reach
  - Greater instantaneous trip zone coverage and security
- Phase and ground faults protection
- Non-selective, but directional in nature. Require communication system to be selective
- Greater sensitivity (handled load encroachment)
- Easier setting calculations and coordination
- Multi-terminal line applications

Sample Feeder Single Line



- Multiple sections
- Tapped transformers protected by high-speed current limiting fuses from First Line Section
- Multiple line branches after First Line
- Maximum 4 – 5 feeder sections
- Ideal for modern 5-zone numerical distance IED applications


Amps X 10 W15kV BUS1 (Nom. kV=15, Plot Ref. kV=15)
Seconds
W TX1 SR745 HVOC - P
OC1
W TX1 SR745 LVOC - P
OC1
51-D-020/021
11B-D-066 W1 OC - 51
11F-D-80 - P
OC1
FDS697
W1 Ex
MAXEPCORFUSE 2
FDS619
MAXEPCORFUSE 1
W1 Lim
Amps X 10 W15kV BUS1 (Nom. kV=15, Plot Ref. kV=15)

Project Scope

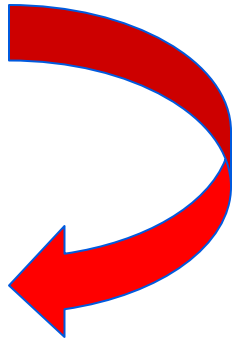
- Product evaluation + procurement
- Cable impedance measurement
- Protection Implementation
- FAT + Commissioning
- Remote Monitoring

Product Evaluation + Procurement

- Functional testing 5 selected vendor products
- Focus on:
  - quad characteristics
  - setting sensitivity
  - fault location accuracy
  - broken conductor algorithm
  - cost advantage
  - disturbance handling

Product Evaluation + Procurement (2)

DESCRIPTION					TRIP	RECLOSE	RECLOSE OP CORRECT	TRIP INDICATION
NAME	PHASE	REACH	Z-FAULT	HLT				
EXPRESS CABLE FAULT	A-N	50.00%	0	OFF	OK	NO	OK	ZONE 1
EXPRESS CABLE FAULT	3 PH	25.00%	0	OFF	OK	NO	OK	ZONE 1
EXPRESS CABLE FAULT	B-C	75.00%	0	OFF	OK	NO	OK	ZONE 1
GRID FAULT	3 PH	25.00%	0	OFF	OK	YES	OK	ZONE 2
GRID FAULT	C-N	90.00%	2	OFF	OK	YES	OK	ZONE 3
GRID FAULT	A-B	75.00%	15	OFF	OK	YES	OK	ZONE 3

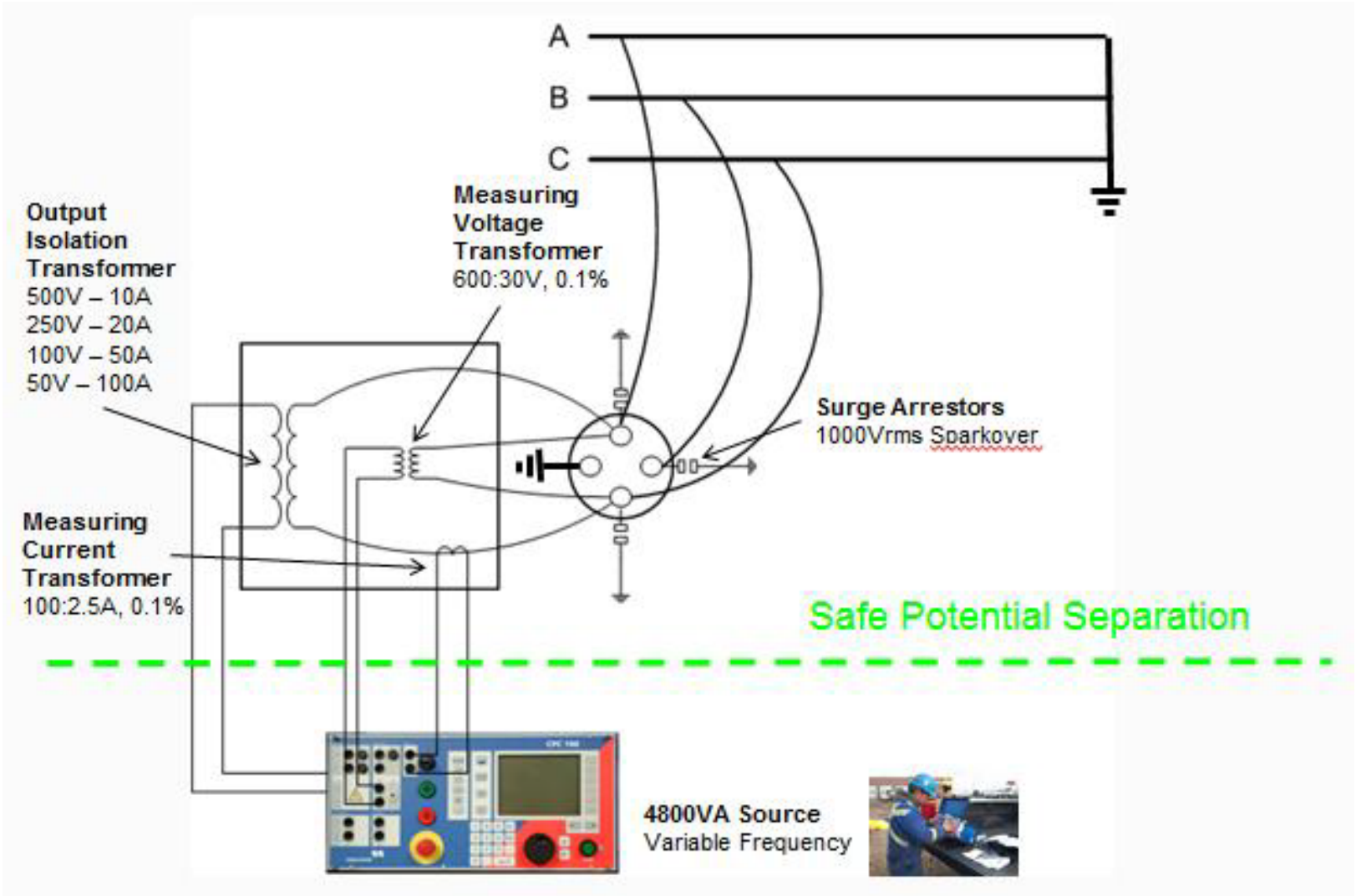


TRIP PHASE INDICATION	FAULT LOCATION	TRIP TIME (ms)	RECLOSE TIME (ms)	WAVEFORM CAPTURE
A-N	0.62%	26.4	-	OK
A-B-C	0.43%	28.5	-	OK
B-C	1.31%	43.5	-	OK
A-B-C	24.94%	60.9	3027	OK
C-N	89.00%	2025	3026	OK
A-B	72.72%	2031	3031	OK

Cable Impedance Measurement

- The 90% Zone 1 reach setting requires accurate cable impedance data
- Z1 and Z0 are typically calculated with conductor geometric data and assumption of ground return for cables→ prone to errors over 20% sometimes
- Ground compensation factor (Kn) can be erroneous
- Accurate cable impedance can be measured by primary injection technique
- Single phase Current injected at 40Hz and 80 Hz
- Z1 & Z0 impedance calculated at the same frequency. 60Hz values are interpolated
- Correct Kn factor for ground compensation can be calculated

Cable Impedance Measurement (2)



Protection Implementation
Distance Functions

- Up to 4 distance measuring zones (ph + gnd) loops and one supervisory zone are applied
- Quadrilateral characteristics
- Resistive reach set to 2 times reactive reach for phase loops. Ground loops set 2 times more sensitive
- Zone picked up configured as SCADA alarms
- Not all zones enabled to trip at this moment. Behavior is being monitored online to ensure security and increase confidence
- Used as a tool to learn dynamic load profile

Protection Implementation
Zone 1 Distance

- Protect the express cable
- Instantaneous operation must block auto-reclosing
- 90% vs 110% reach (EPCOR operators demand reclosing for entire aerial sections to maintain service continuity)
- Accurate cable impedance (Z1, Z0) – measurement required
- Tripping enabled

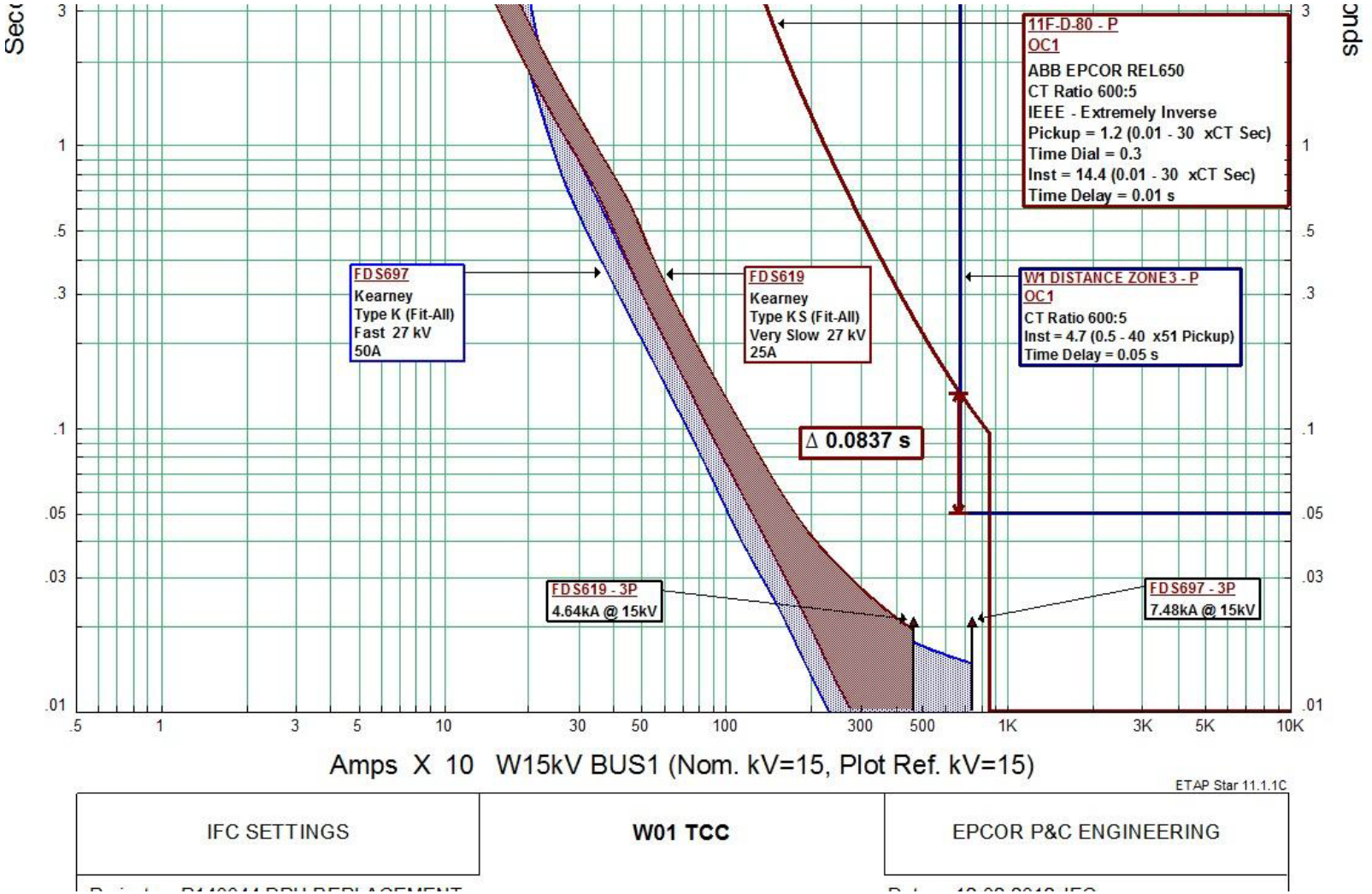
Protection Implementation
Zone 2 Distance

- Protect faults up to the first branch fuse
- Pad-mounted transformer taps (protected by high speed current limiting fuse)
- Initiate auto-reclosing (single-shot only)
- Coordination is not a concern. Time delay 33 millisec to avoid racing with Zone 1 (which blocks 79)
- Reduce fault clearing time compared to OC
- Tripping not enabled at this moment. behavior monitored

Protection Implementation
Zone 3 Distance

- Protect all previous sections plus 90% of Second Line (up to 2nd branch fuse)
- Coordination with branch fuse is required
- Gain speed over OC (51) element (EPCOR owns relay and fuse)
- Initiates auto-reclosing
- Depending on length of Second Line, might not always be enabled (Requirement: length > 20% of previous sections)
- Tripping not enabled at this moment. behavior monitored

Protection Implementation
Zone 3 Distance



Protection Implementation
Zone 4 Distance

- Protect to the end of the feeder
- Very sensitive resistive reach (15 ohm for phase loops, 30 ohms for ground loops)
- Operation blocked when OC picks up. Ensure coordination with fuses. Operate only on low fault current
- >5.0 sec operation delay (coordination)
- Alarms to SCADA when picked up
- Serve as a circuit trouble annunciator (eg. fallen conductor).
- Tripping not enabled at this moment. behavior under load is being monitored.

Protection Implementation
OC Functions (50 P,N + 51 P,N)

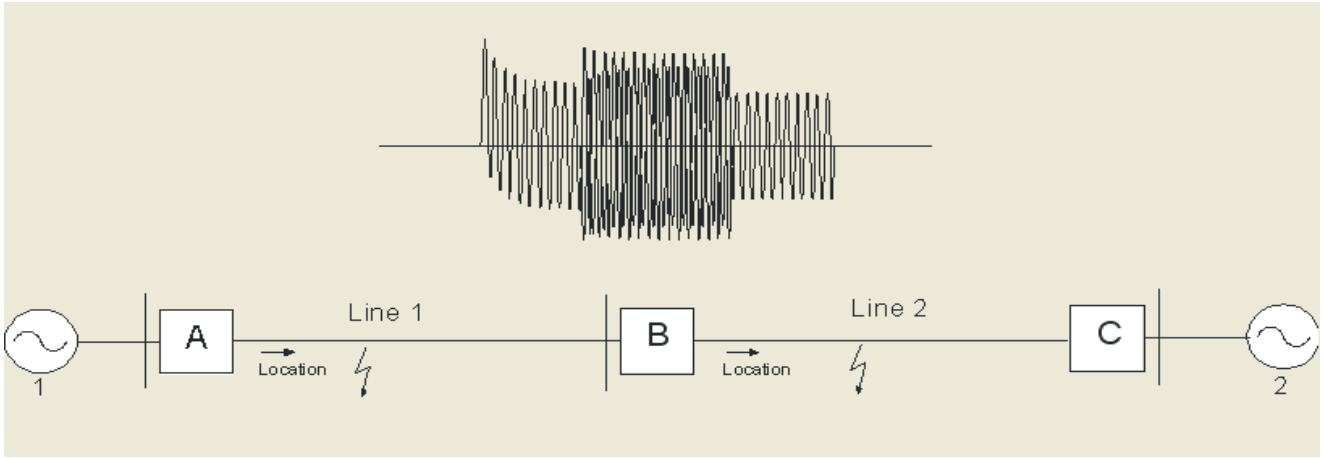
- Backup protection to distance zones 1 – 3
- 50 P,N set up to only protect the express cable when applicable (eg. Length of cable and source impedance). Block auto-reclosing
- 51 P,N picked up blocks Zone 4 operation. 51P,N operation initiates auto-reclosing
- Tripping at all times

Other Applications

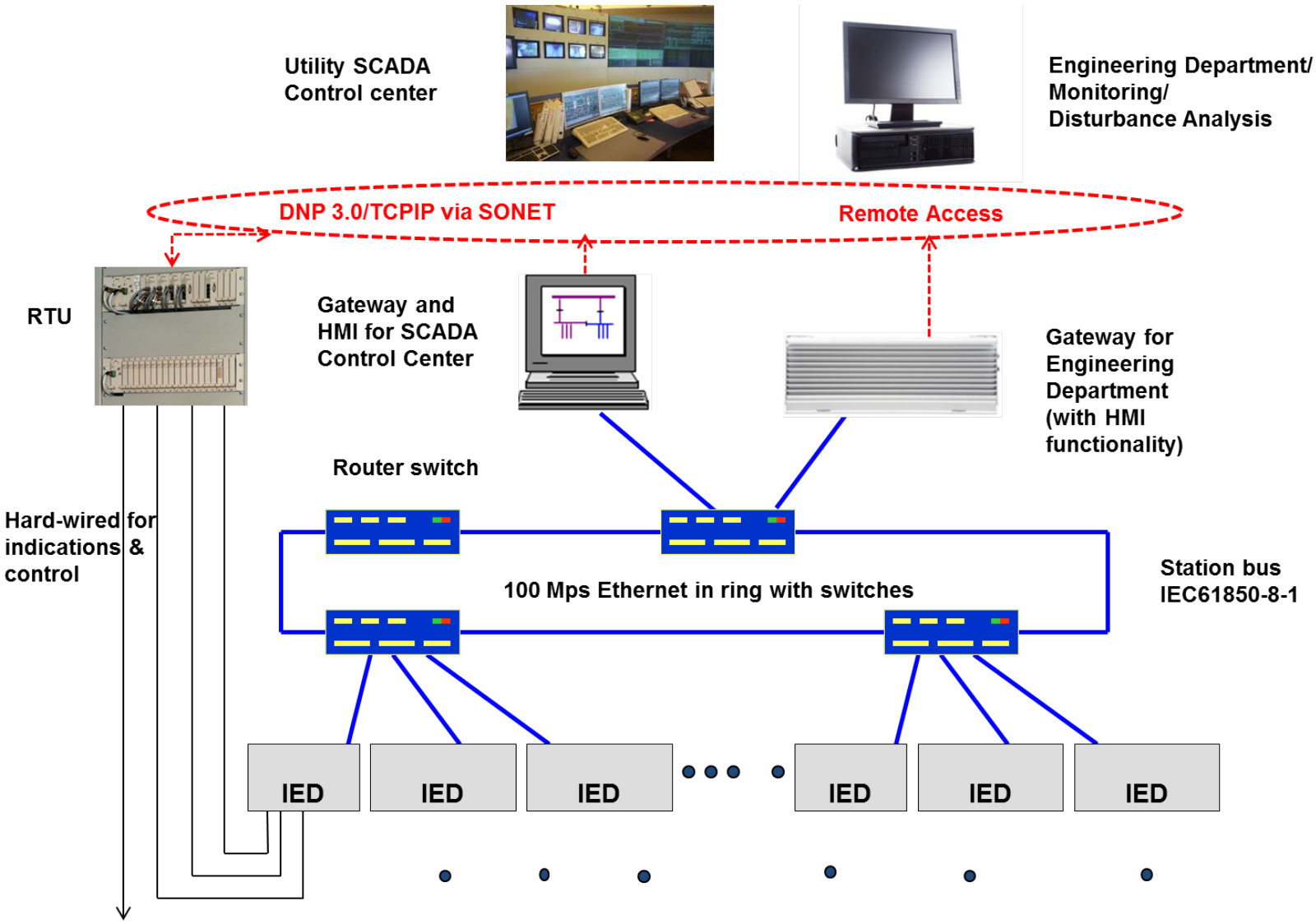
- Hot Line Mode: switch on a dedicated 50 P,N element with sensitive pick up set point (matching 51P) and block auto-reclosing
- Switch-on-to-fault: non-directional Zone 2 P,N picked up to trigger. Reduce arc-flash energy near substation due to high fault current and wrongful energization
- Broken conductor algorithm: measures current in three phases and picks up for large differences. Alarms only.
- Fault locator algorithm: impedance based
- Local annunciation: programmable LED + front IED display showing SLD, BKR status and selector switch (79, HLT) positions
- SCADA communication (IEC 61850 GOOSE + Client/Server)

FAT and Commissioning

- Initial product evaluation and FAT after engineering are performed in the EPCOR test lab
- A two-section feeder model with correct source/line impedances were created using the Network Simulation Software of the test equipment
- Secondary injecting voltage/current automatically mimicking the real-time network condition
- Verifying relay settings, local annunciation, functional operation under different network conditions
- Advanced test modules were used to verify 50, 51, and 21 characteristics.



Substation Automation and Online Monitoring



Substation Automation and Online Monitoring (2)

- Two standard substation gateways (1x RTU, 1x data concentrator + HMI). A third gateway under planning for the purpose of system disturbance analysis and monitoring
- RTU (hardwired and DNP slave)
  - Most critical information (eg. protections operated, relay failures, breaker status)
  - Apparatus control commands including HLT
- Standardized Data concentrator + HMI (61850 client/server + DNP slave)
  - Collect same RTU information via 61850
  - Other alarm points (TCM, MCB open etc)
  - Analog measurement (S, P, Q, V, I, freq)
  - Fault location estimation
  - No control

Substation Automation and Online Monitoring (3)

- Generic Object Oriented Substation Events (GOOSE)
  - Any protection operation in an IED would publish GOOSE
  - Subscribed by IEDs in other bays to trigger DFR
  - Aid substation wide post disturbance analysis (eg. Sympathetic tripping)
  - No protection grade of applications were implemented
- Engineering data concentrator and HMI (61850 client/server and secure remote access)
  - Collect same information as standard gateway
  - Plus detailed information of protection functions as needed
  - Recreate IED front faceplate (inc. LEDs, PB status)
  - Disturbance recording (Comtrade)
  - Used to learn system behavior and improve system modeling and relay settings

Conclusions

- Joint efforts among EPCOR engineers, contractors and vendors
- Apply both distance (21) functions and conventional OC (50, 51) functions for distribution feeder protection
- Benefits of applying multifunctional distance IEDs:
  - Improve operation speed, reduce equipment damage and enhance personnel safety near the substation
  - More constant and selective fault coverage (auto-reclose blocking)
  - Sensitive detection of high-resistive faults and circuit troubles
  - Multiple instances of protection functions and setting groups aid applications under different operating conditions
  - Variety of local annunciation options
  - Embedded SCADA communication for efficient post events analysis and real-time system state monitoring

Questions