Protection and Testing Considerations for IEC 61850 Sampled Values-Based Distance and Line Current Differential Schemes

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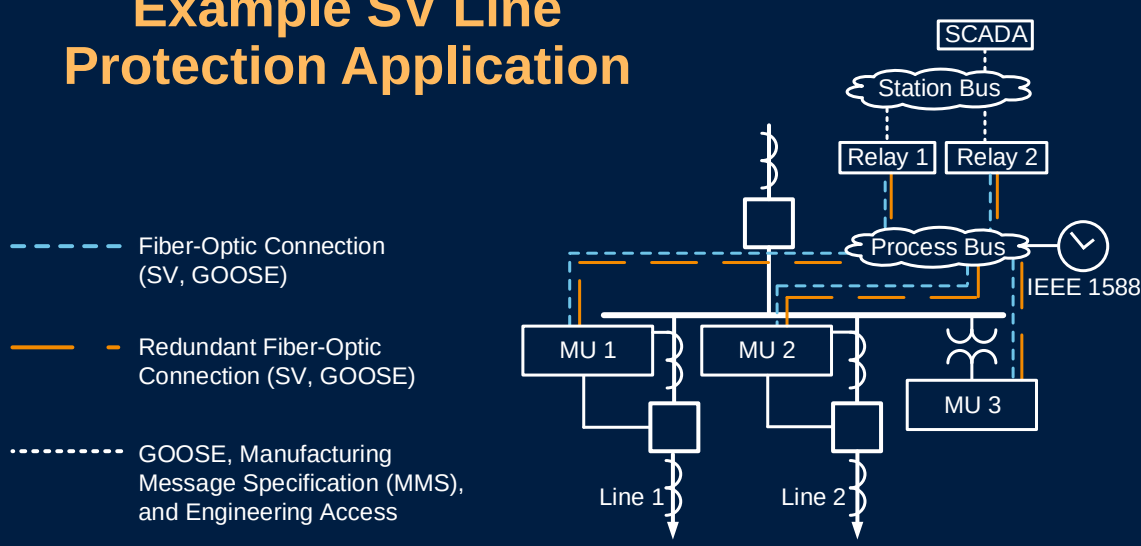
Teaching Effects of Sampled Values (SV) on Protection Applications

- Discuss impacts of IEC 61850-9-2 SV communications on line protection
- Show testing procedure used to compare SV and traditional relays
- Discuss performance results

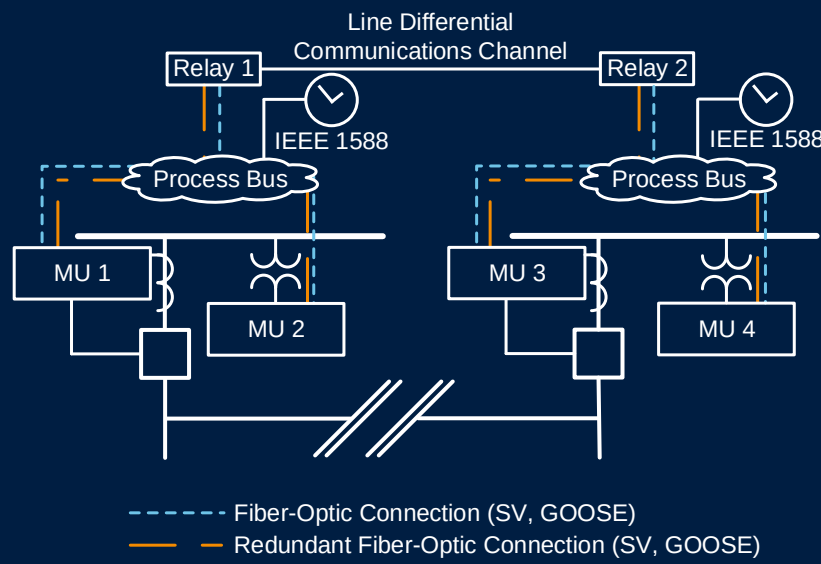
IEC 61850-9-2 at a Glance

- Digital communications replace copper wiring
- Data from multiple merging units (MUs) are aligned based on high-accuracy time source (e.g., IRIG-B or IEEE 1588 PTP)
- Protocol features include
  - MUs and subscribers
  - 80 samples per power system cycle (4.8 kHz)
  - 1 waveform sample per channel, per message
  - 4 voltages and 4 currents per stream (A, B, C, N)

Example SV Line Protection Application



Example SV Line Differential Protection Application



SV Dominates Bandwidth Usage

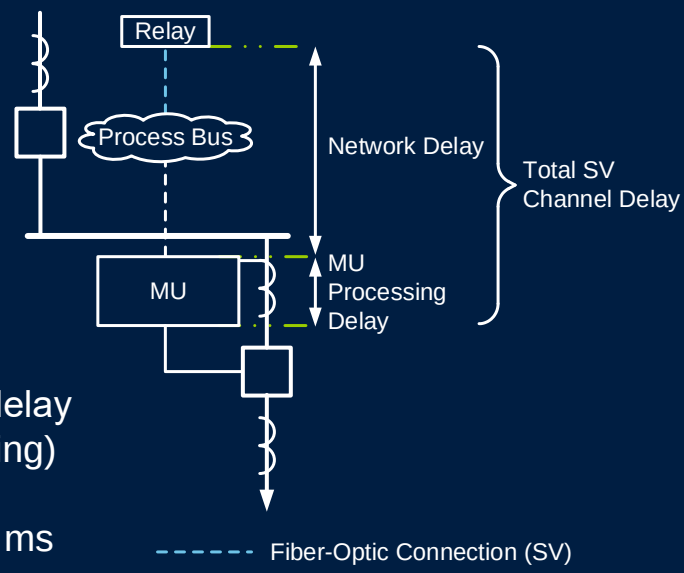
- SV (one stream at 4.8 kHz): 5.760 Mbps
- GOOSE (40 messages per second): 0.075 Mbps
- PTP (4 messages per second): 0.004 Mbps

How Much Delay Does SV Introduce?

SV channel delay =
MU delay + network delay

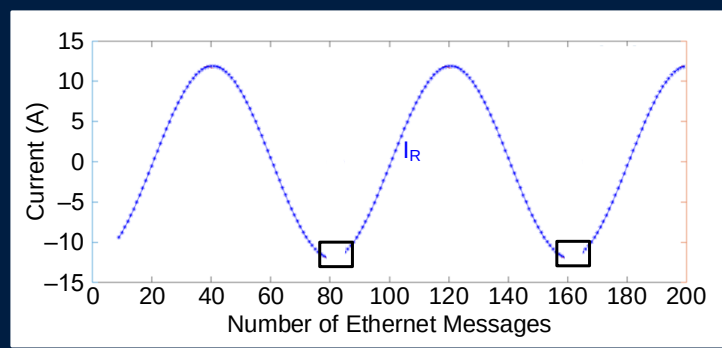
Relay wait time ≥ SV channel delay
(ensures deterministic processing)

Relay wait time is typically 1–2 ms



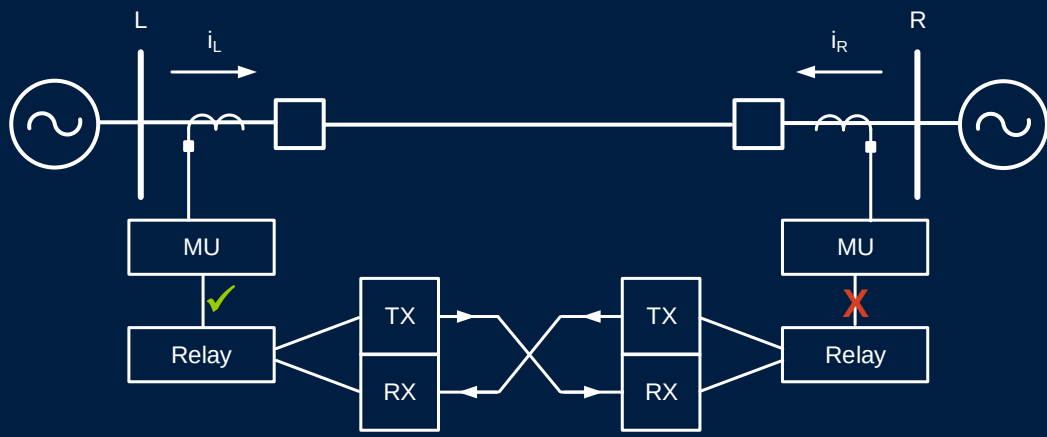
Relays Must Respond Correctly to SV Packet Loss

- Protection dependability cannot be guaranteed
- Protection security must be maintained when data are lost
- If only a few packets are lost, data can be interpolated

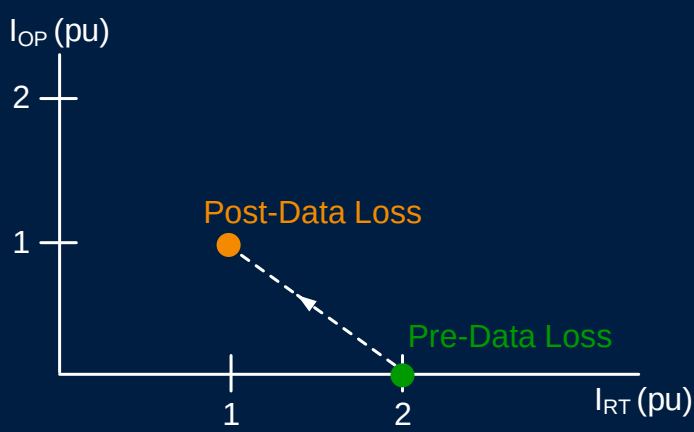


SV Line Differential Scheme

What Happens if Data Are Lost at Only One End?

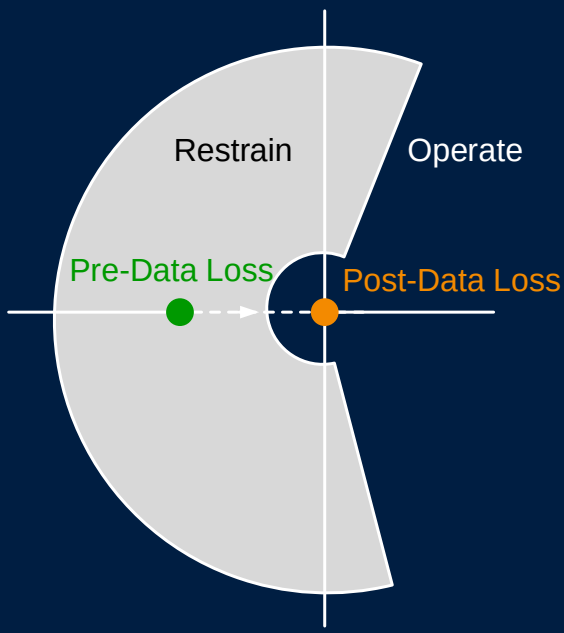


Percentage Line Differential Protection Must Be Secured When SV Data Are Lost



Slope check passes (I_{OP} / I_{RT} = 1)

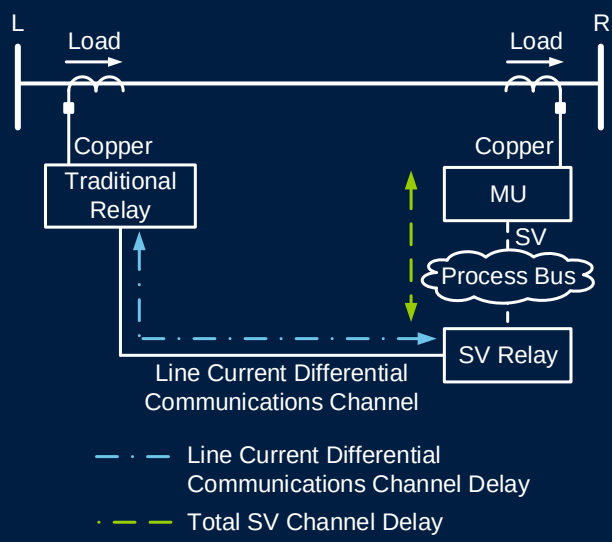
Relay potentially trips if operating current exceeds minimum threshold



Alpha Plane Line Differential Protection Must Be Secured When SV Data Are Lost

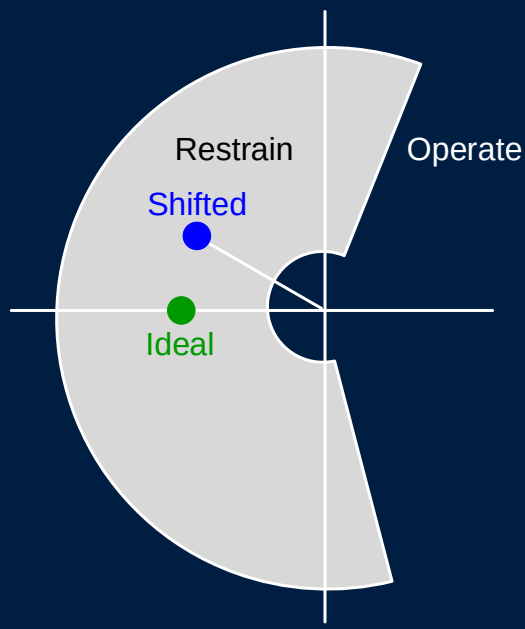
Data loss at one end causes Alpha Plane to enter operating region

Hybrid Line Differential Applications Pose Extra Challenges



SV relay data acquisition path has extra 1–2 ms delay

≈30 electrical degrees of alignment error, if not compensated



SV Relay Must Correct for SV Delay for Alpha Plane to Plot Correctly

Relay still restrains under load

Less margin for CT errors, channel asymmetry, etc.

Solutions for Line Differential Applications

SV Relay

- Block differential element upon loss of SV data
- Send blocking signal to remote relay over line current differential communications channel
- Compensate for extra data acquisition delay when traditional relay is on other end of line

Distance and General Protection
Effects of SV Voltage Data Loss

- Voltage data loss is similar to loss-of-potential (LOP), although three-phase data loss is most likely
- Distance elements and directional elements are blocked (desirable)
- LOP alarm is undesirable (no VT fuse actually blown)
- Undervoltage and overvoltage elements can misoperate if not supervised

Solutions for SV Voltage Data Loss

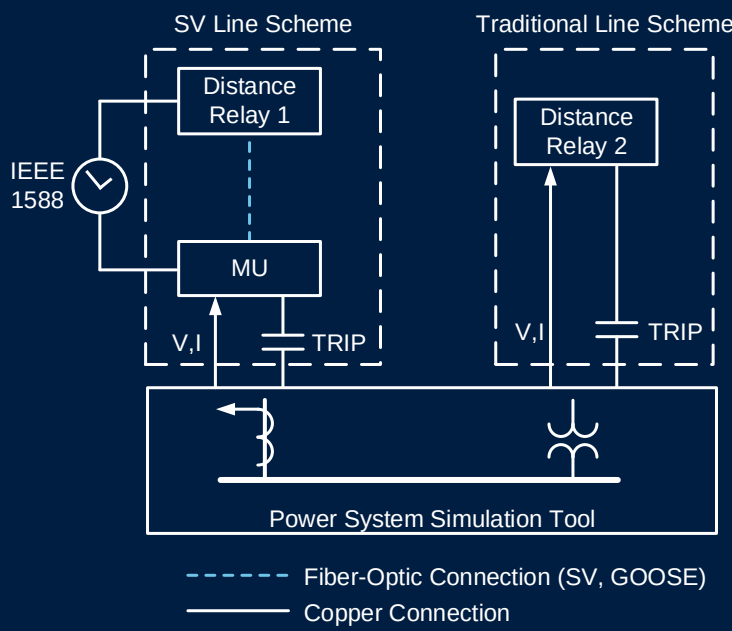
- Relay should block distance and directional elements
- Relay should not issue LOP alarm, but should instead assert dedicated SV status Boolean quantities
- SV status bits in torque control equations supervise undervoltage and overvoltage elements
- Relay should continue to block protection for >1 cycle upon data restoration to allow filters to settle

Distance and General Protection
Effects of SV Current Data Loss

- Dependability of distance elements is compromised
- Open-phase and open-pole logic may falsely operate if not supervised
- Negative-sequence and zero-sequence overcurrent elements may misoperate if not supervised

Solutions for SV Current Data Loss

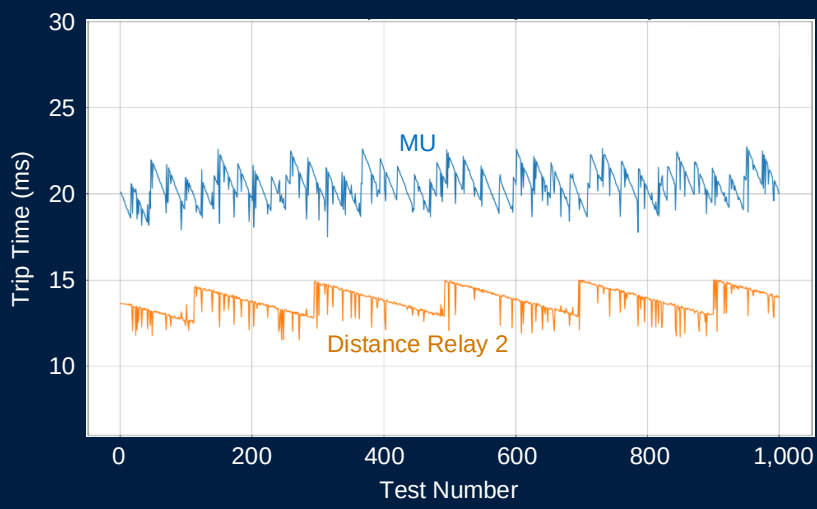
- Freeze open-phase and open-pole logic at their previous states
- Supervise negative-sequence and zero-sequence overcurrent elements with SV status bits in torque control equations
- Continue to block or freeze protection for >1 cycle upon data restoration to allow filters to settle



Closed-Loop Testing Benchmarks SV Relay Performance

SV relay trips breaker through MU via GOOSE

SV and GOOSE Delays Affect SV Relay Trip Speed



SV delay of 1–2 ms

GOOSE delay of 4–5 ms going from relay to MU

Understand Your System to Engineer Reliable Protection Schemes

- SV systems require high-accuracy time and robust communications networks
- Network needs to be able to handle traffic (SV + GOOSE + PTP)
- Effects of SV data loss are mitigated by relay design and user settings
- SV relay trip speed is impacted by SV and GOOSE delays