DIGITAL SUBSTATION. STANDARD IEC 61850, MOSCOW, JULY 2019

Digital Substation Experiences

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ABB

Contents

Architecture examples

Process bus architecture

Station wide PRP process bus for main 1 and main 2

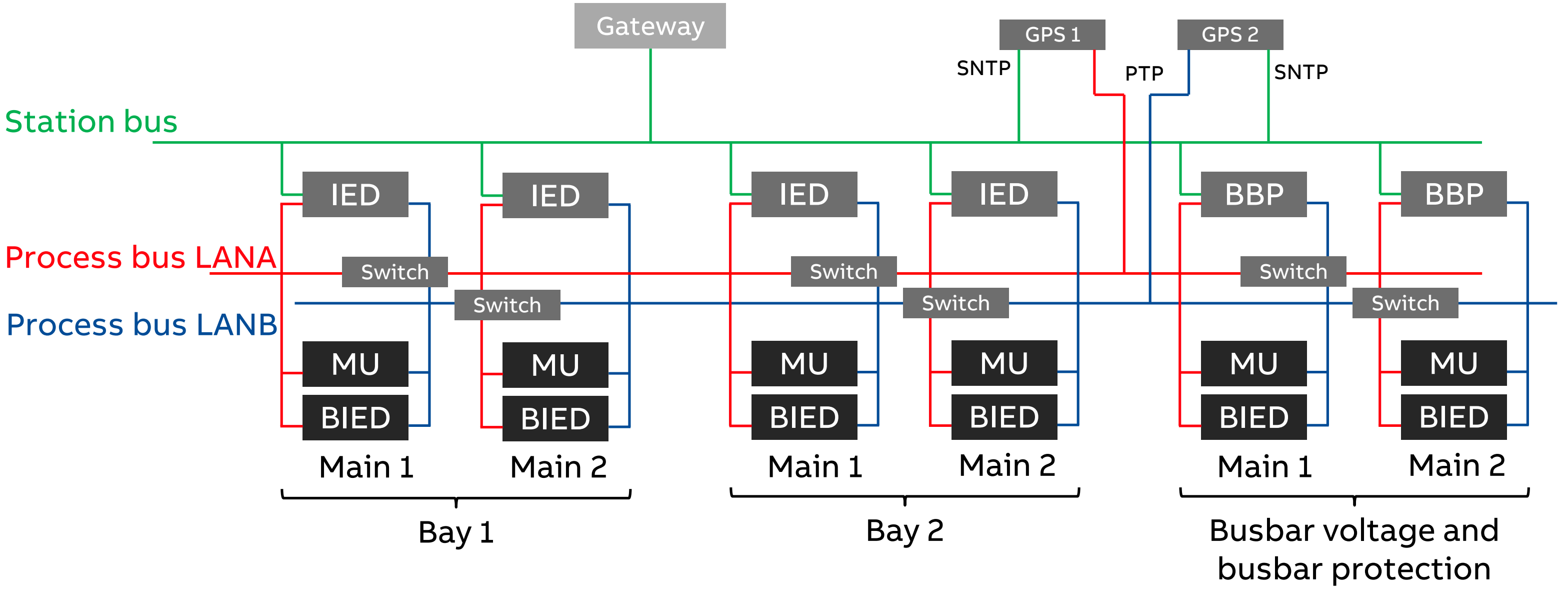
Advantages and disadvantages

Advantages

- Flexible process data exchange between feeders
- Flexible process data exchange between main 1 and main 2 protection
- Ethernet switches provide connectivity for analyzing and simulation tools (VLANs, MAC address filtering… to be considered)

Disadvantages

- Higher costs due to Ethernet switches
- Dataflow management with VLANs or MAC Address filtering required



Oborniki Slaskie digital substation installation - Poland

110kV FOCS and SAM600 installation

Digital devices

- 5 x FOCS fiber optic current sensor, redundant
- 10 x SAM600 MU systems (for conv VTs)
- 12 x REF620 as binary process interface
- 4 x REF615 feeder terminals as P&C and MU for transformer diff. protection
- 13 x 670 series protection and control IEDs (RED, RET, REB, REC)
- Station level with redundant GPS (PTP), gateways and HMIs

Outdoor panel

Protection panel

ABB

Oborniki Slaski

PRP process bus

System architecture

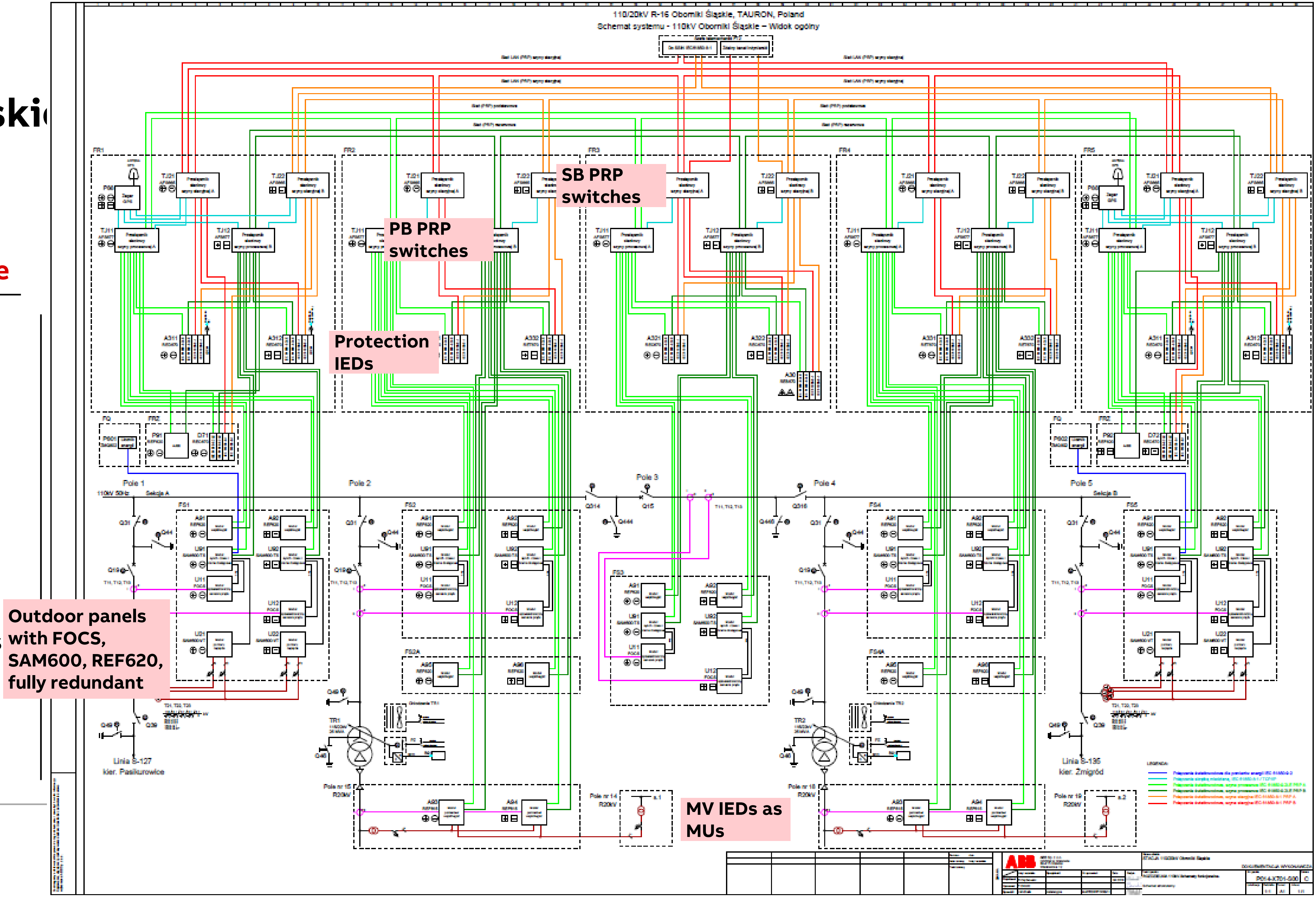
PRP station bus

Station-wide PRP process bus, common for main 1 and main 2

2 bay control IEDs for entire substation

Redundant GPS clocks (PTP) with connection to station and process bus

MV feeder terminals as MUs for transformer diff protection (low voltage side)



Process bus architecture

HSR rings per bay and main protection, separate station-wide rings for BBP

Advantages and disadvantages

Advantages

– Separate bay HSR rings for first and second main protection provide perfect separation

– No disturbances between feeders or main 1/2 protection during service and maintenance

– No dataflow management required in bay rings

– Substation size has no impact on bay HSR ring performance

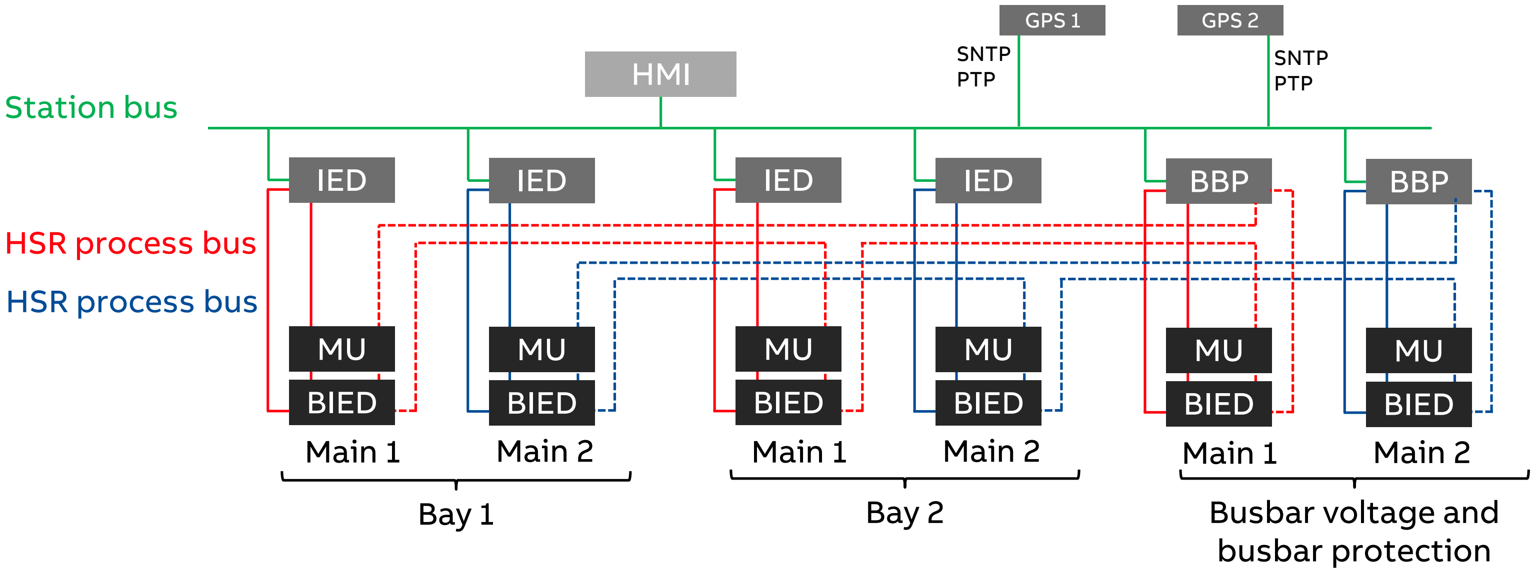
– No Ethernet switches on process bus

Disadvantages

– Connection between 1st and 2nd main protection only through station bus

– Process data exchange between feeders is limited

– PTP on process bus is critical and may require redundant station bus communication



- Busbar voltage distribution through station wide rings through bay MUs or through station bus.
- MUs in bays forward BB voltage from station HSR ring to bay HSR rings
- PTP boundary clock function in IEDs for synchronization of process busses

Langedalen digital substation - Norway

110kV AIS substation with FOCS and SAM600

FOCS, SAM600 and 670 series IEDs

Complete substation with fiber optic current sensors, merging units, breaker IEDs and IEC 61850 process bus.

- redundant FOCS fiber optic current sensors
- SAM600 merging units and breaker IEDs
- 670 series protection and control IEDs with process bus
- HSR process bus ring

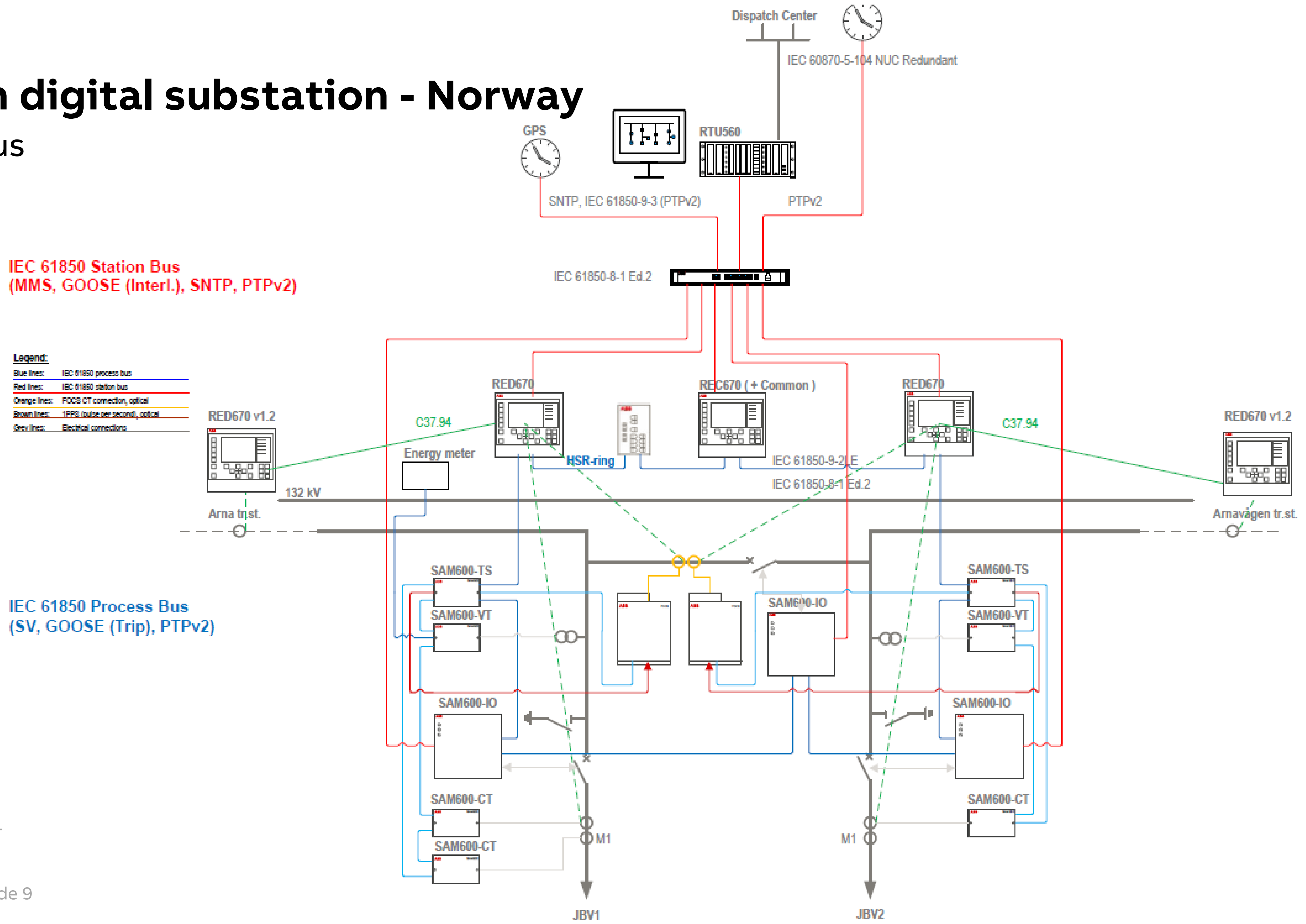
Customer:
BKK

Year of commissioning:
Dec 2018

Voltage level:
132kV

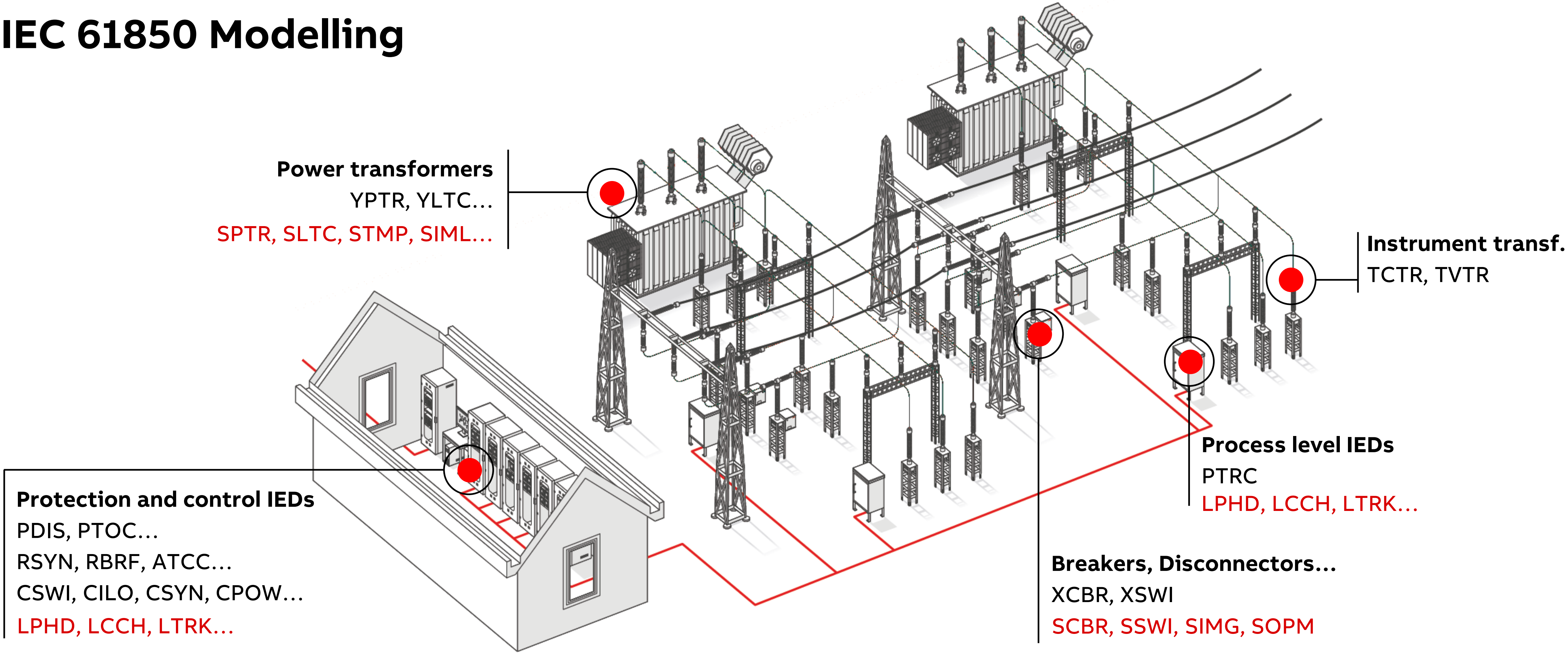
Langedalen digital substation - Norway

HSR process bus



IEC 61850 logical node modelling

IEC 61850 Modelling



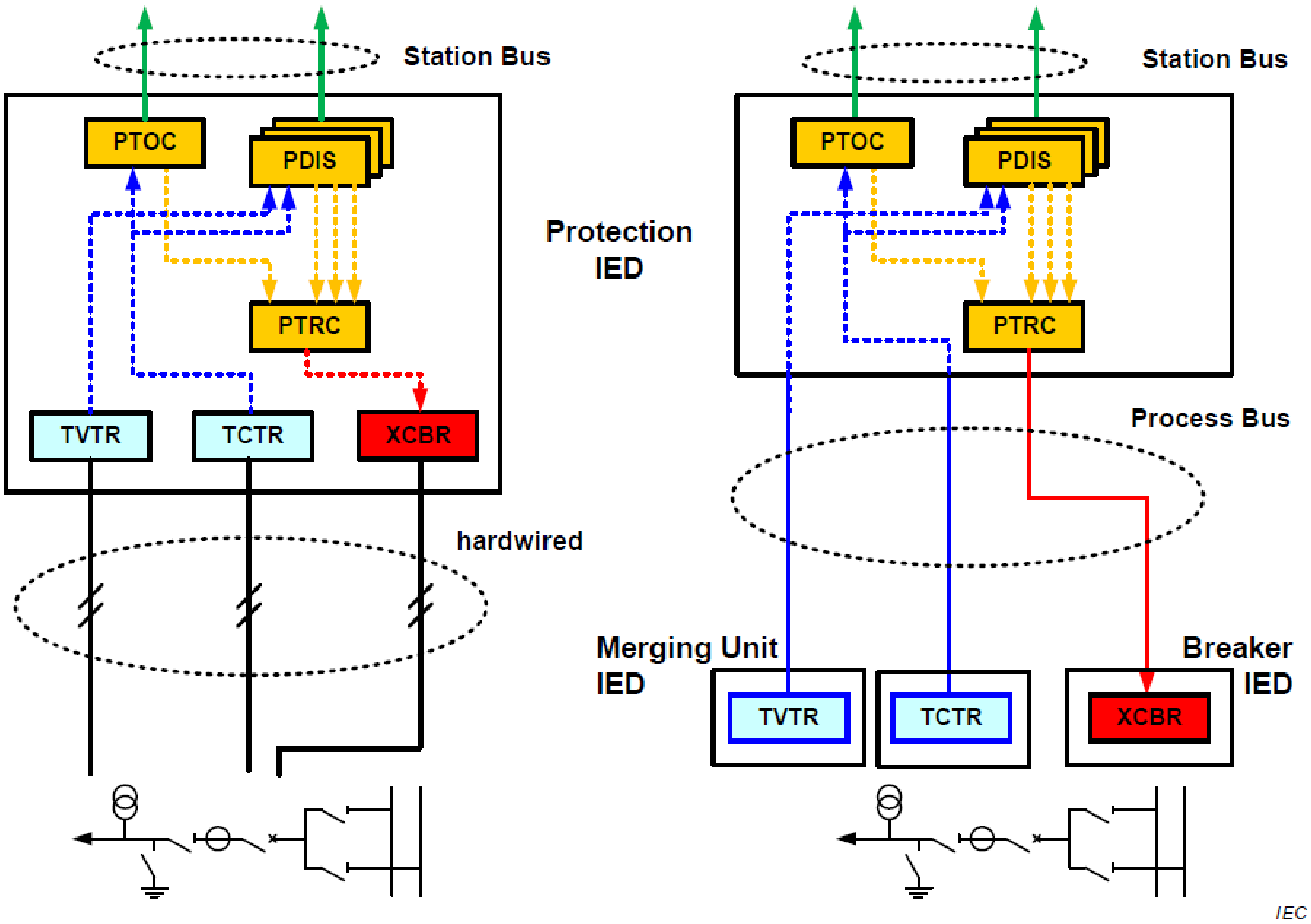
Consistent application for protection, control and maintenance

Logical Node modelli

Protection

LN modelling

Bay protection (left: without process bus, right: with process bus)



IEC TR 61850-7-500, Figure 24

IEC 61850 modelling

Example

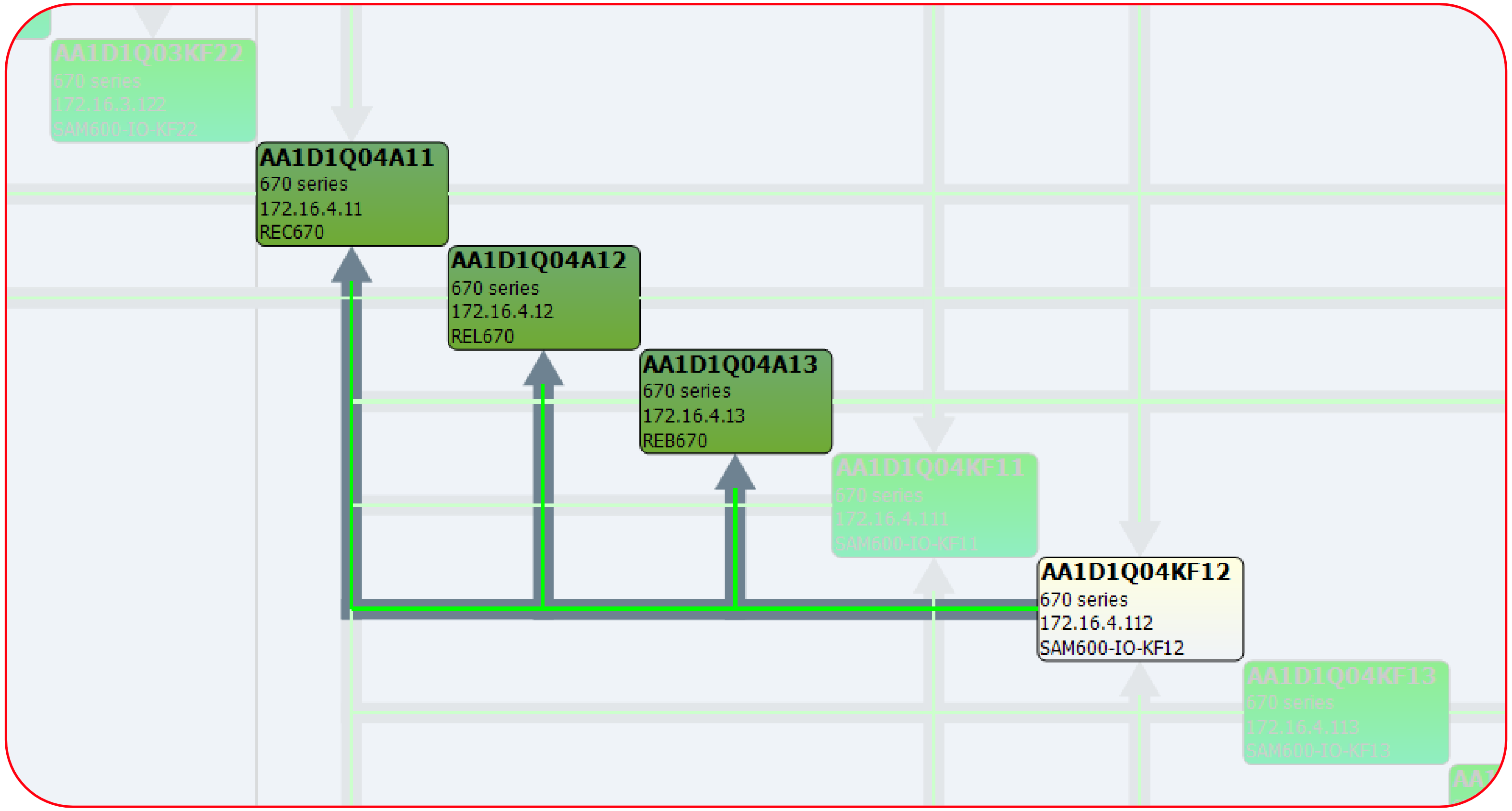
GOOSE SCU to IEDs

Graphical dataflow representation from an SCD file of a digital substation

The boxes, diagonally, represent IEDs and SCUs

Horizontal and vertical lines are GOOSE connections

The highlighted arrows indicate the GOOSE communication from an SCU to the protection and control IEDs of one feeder.

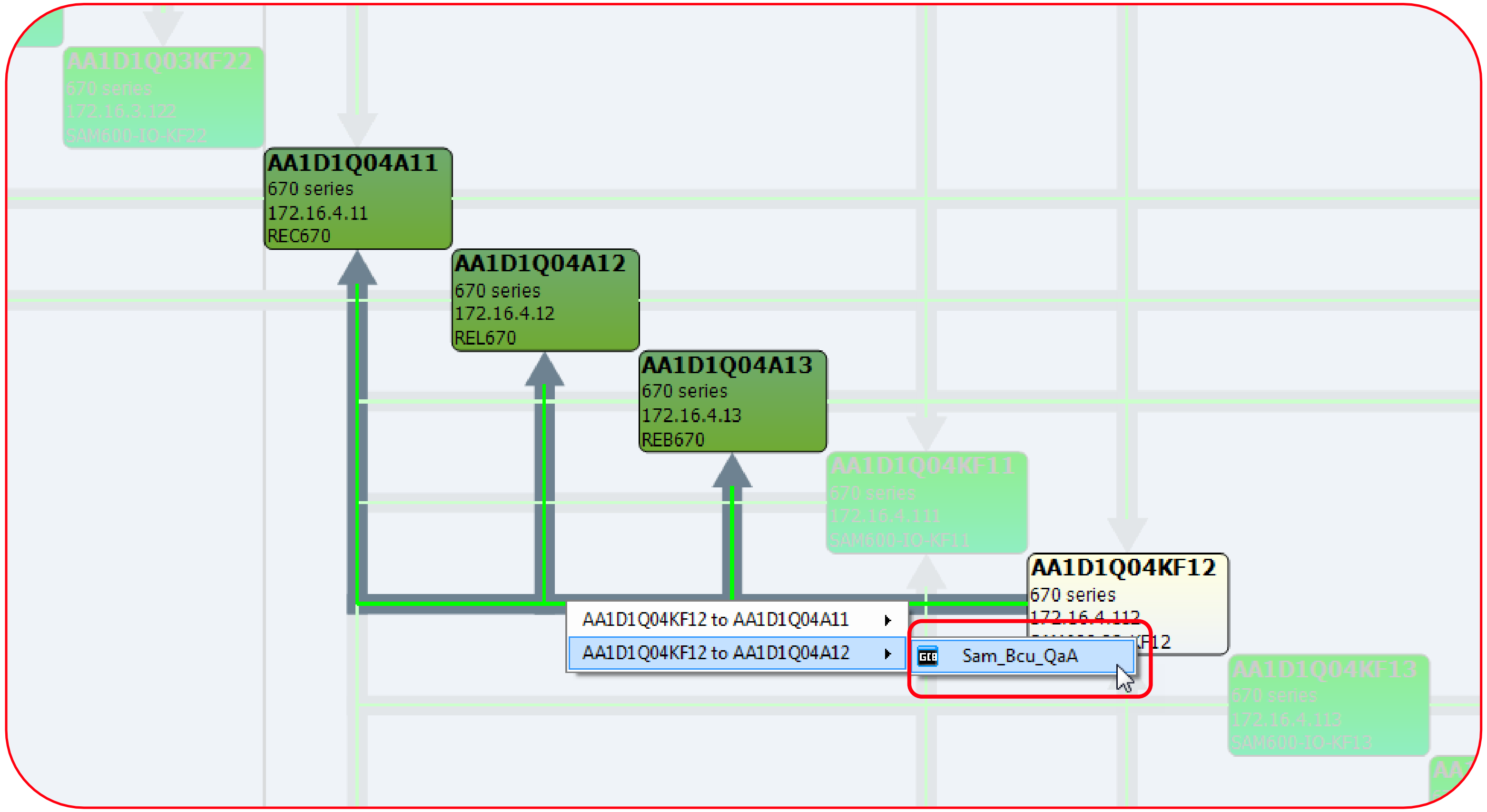


IEC 61850 modelling

Example

Transmitted dataset

Right-click on the connections unveils the transmitted datasets



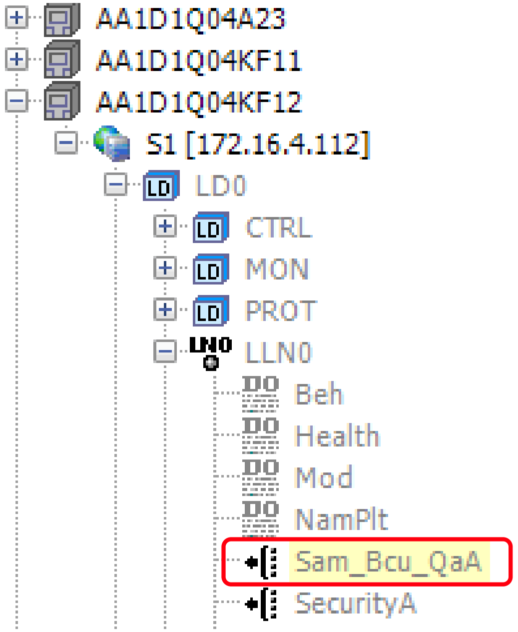
IEC 61850 modelling

Example

Dataset content

IEC 61850 modelling gives clear insight of the dataset content.

Adhering to correct modelling in SCUs, MUs and IEDs enables efficient engineering, testing and maintenance.



Element	Description
AA1D1Q04KF12CTRL/SXCBR1.Beh.stVal	Behaviour parameter for 61850
AA1D1Q04KF12CTRL/SXCBR1.Beh.q	Behaviour parameter for 61850 Quality
AA1D1Q04KF12CTRL/SXCBR1.Loc.stVal	Indication that the function is in local mode
AA1D1Q04KF12CTRL/SXCBR1.Loc.q	Indication that the function is in local mode
AA1D1Q04KF12CTRL/SXCBR1.LocKey.stVal	Indication that the function is in local mode
AA1D1Q04KF12CTRL/SXCBR1.LocKey.q	Indication that the function is in local mode
AA1D1Q04KF12CTRL/SXCBR1.OpCnt.stVal	Operation counter value
AA1D1Q04KF12CTRL/SXCBR1.OpCnt.q	Operation counter value Quality
AA1D1Q04KF12CTRL/SXCBR1.Blk.stVal	Block parameter for 61850
AA1D1Q04KF12CTRL/SXCBR1.Blk.q	Block parameter for 61850 Quality
AA1D1Q04KF12CTRL/SXCBR1.CBOpCap.stVal	Breaker operating capability 1 = None, 2 =
AA1D1Q04KF12CTRL/SXCBR1.CBOpCap.q	Breaker operating capability 1 = None, 2 =

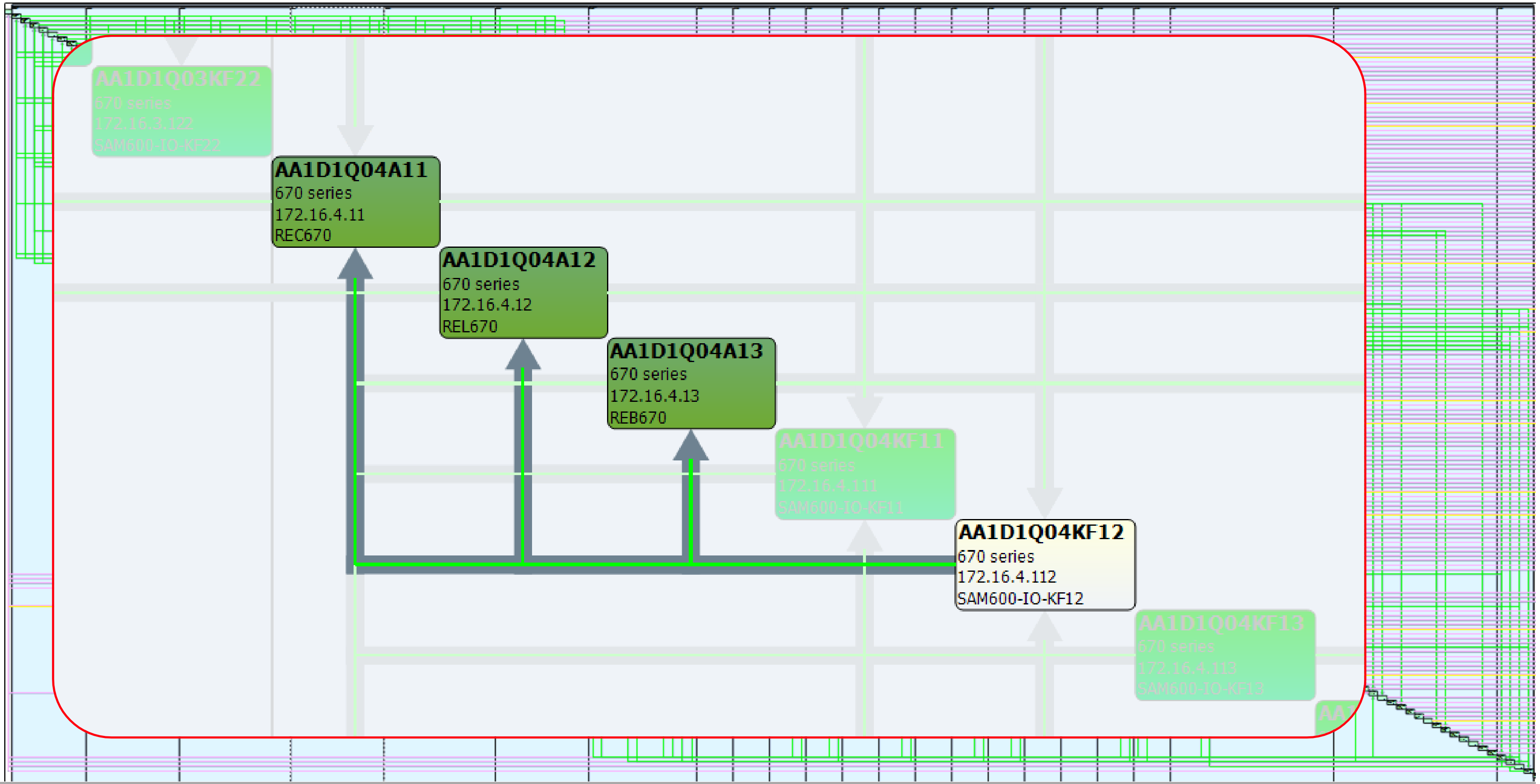
IEC 61850 LNs enable efficient engineering and testing

IEC 61850 modelling

Example

The real system

- 80 + SCUs
- 70 + MUs
- 90 + IEDs

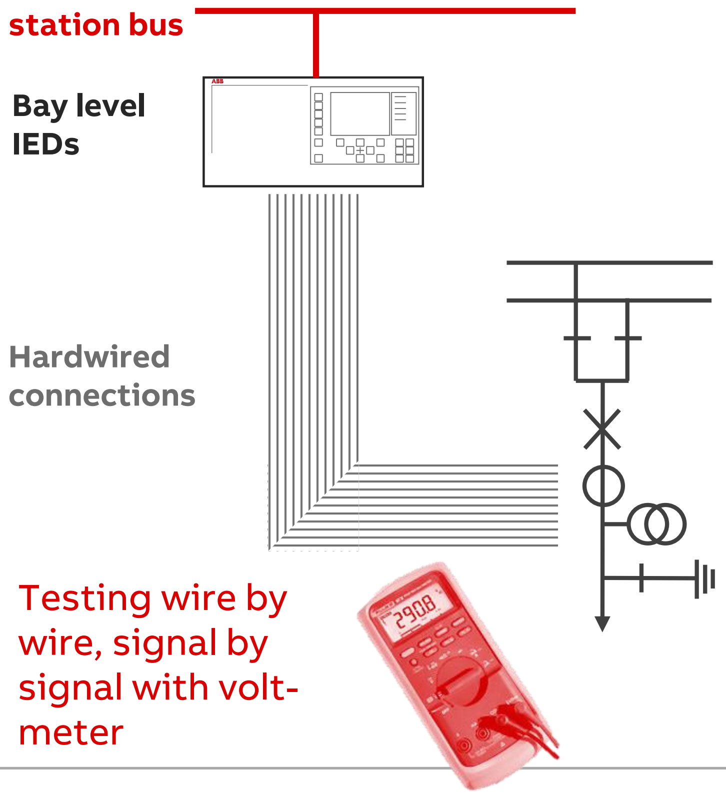


Imagine this would be done with general purpose GGIO…

IEC 61850 modelling

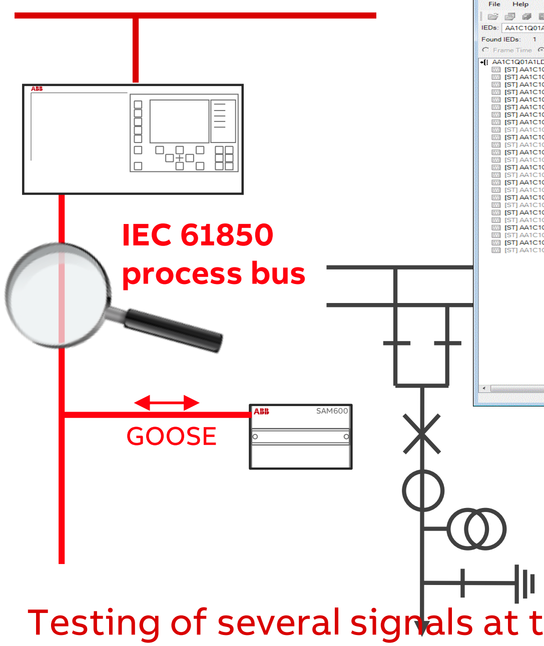
Enable efficient testing

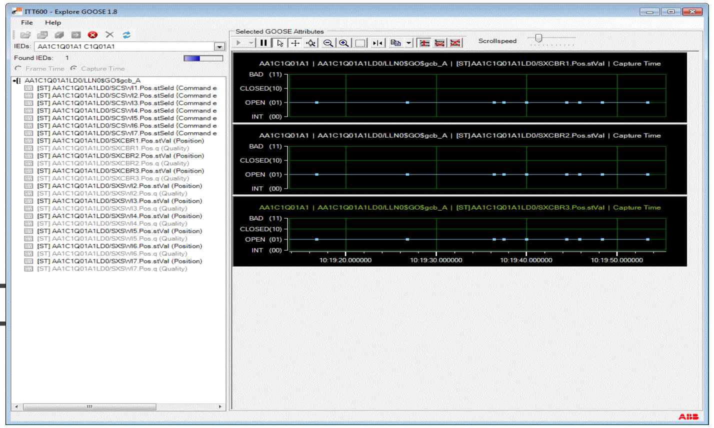
Hardwired signal exchange



Testing wire by wire, signal by signal with volt-meter

IEC 61850 GOOSE signal exchange

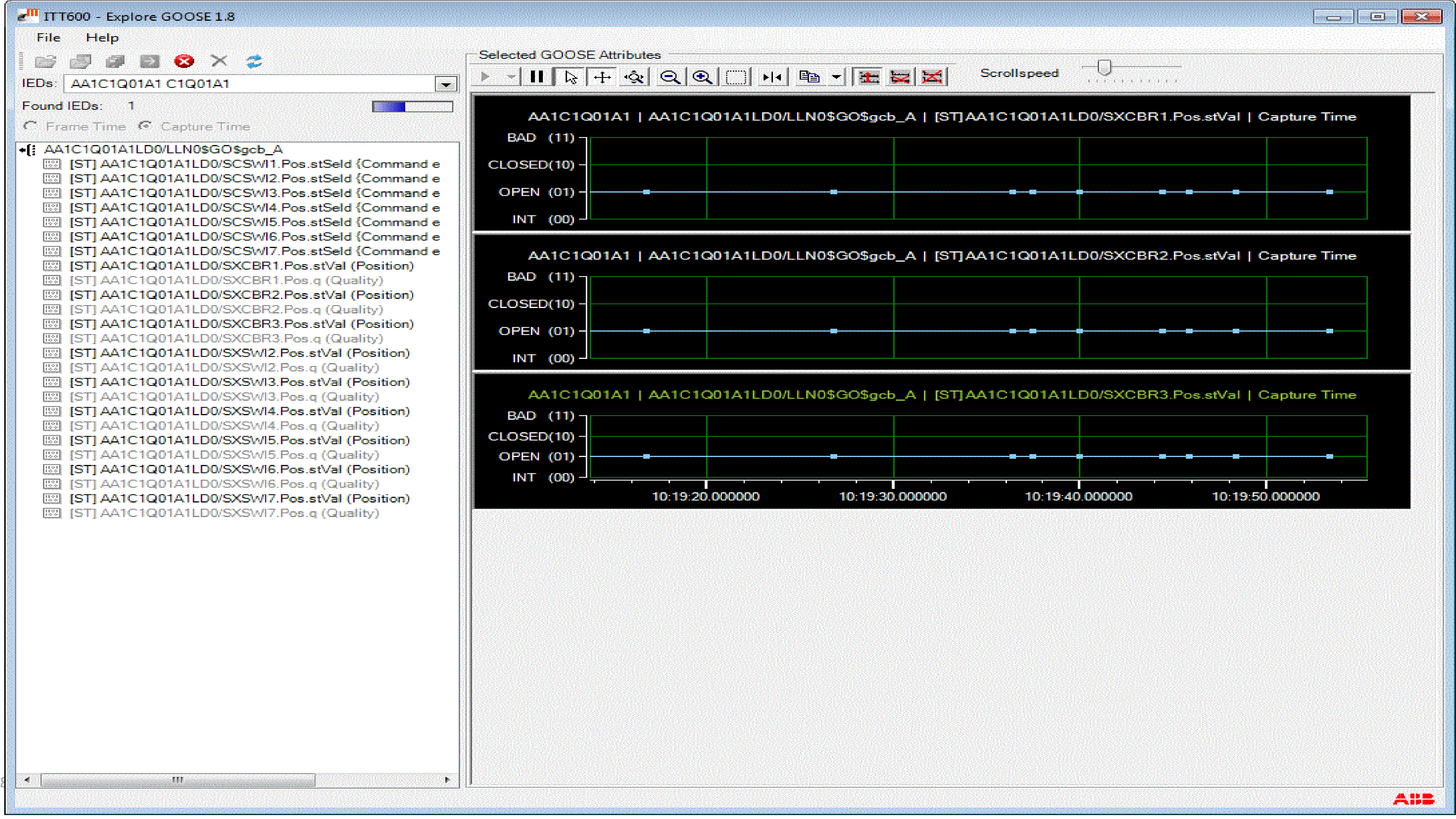




Testing of several signals at the same time

Time measurement between status changes

Recording for offline analysis


ITT600 - Explore GOOSE 1.8
File
Help
IEDs: AA1C1Q01A1 C1Q01A1
Found IEDs: 1
Frame Time
Capture Time
AA1C1Q01A1LD0/LLN0GOgcb_A
[ST] AA1C1Q01A1LD0/SCSWI1.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SCSWI2.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SCSWI3.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SCSWI4.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SCSWI5.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SCSWI6.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SCSWI7.Pos.stSeld (Command e
[ST] AA1C1Q01A1LD0/SXCBR1.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXCBR1.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXCBR2.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXCBR2.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXCBR3.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXCBR3.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXSWI2.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXSWI2.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXSWI3.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXSWI3.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXSWI4.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXSWI4.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXSWI5.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXSWI5.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXSWI6.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXSWI6.Pos.q (Quality)
[ST] AA1C1Q01A1LD0/SXSWI7.Pos.stVal (Position)
[ST] AA1C1Q01A1LD0/SXSWI7.Pos.q (Quality)
Selected GOOSE Attributes
Scrollspeed
AA1C1Q01A1 | AA1C1Q01A1LD0/LLN0GOgcb_A | [ST] AA1C1Q01A1LD0/SXCBR1.Pos.stVal | Capture Time
BAD (11)
CLOSED(10)
OPEN (01)
INT (00)
AA1C1Q01A1 | AA1C1Q01A1LD0/LLN0GOgcb_A | [ST] AA1C1Q01A1LD0/SXCBR2.Pos.stVal | Capture Time
BAD (11)
CLOSED(10)
OPEN (01)
INT (00)
AA1C1Q01A1 | AA1C1Q01A1LD0/LLN0GOgcb_A | [ST] AA1C1Q01A1LD0/SXCBR3.Pos.stVal | Capture Time
BAD (11)
CLOSED(10)
OPEN (01)
INT (00)
10:19:20.000000
10:19:30.000000
10:19:40.000000
10:19:50.000000

Precise time synchronization

Time synchronization

Synchronization of sampling

Sample count based on time synchronization

The time synchronization is used to synchronize the sampling of analogue values

It enables synchronous sampling by different physical devices

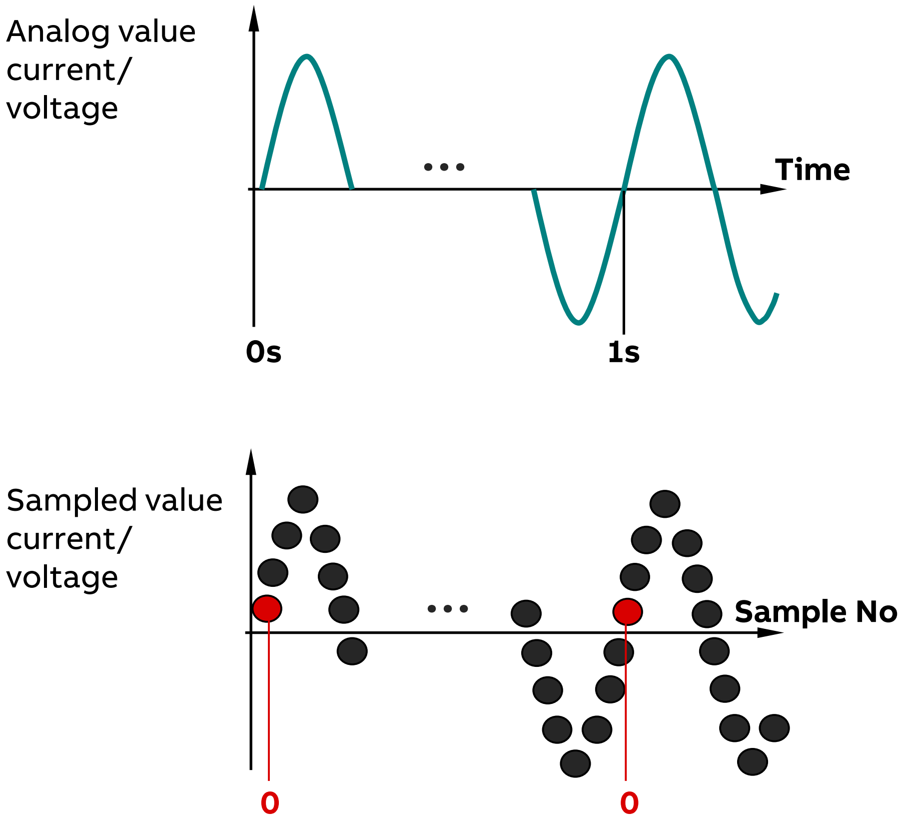
Reference to absolute time is not always required

Synchronization on process level can be separate from station level

The need to synchronize depends on the application

IEC 61850 specifies for synchronization:

- Phasor measurement applications: 1µs
- Protection applications: 4µs



The foundation of digital substations

Precise time synchronization

Increased accuracy

Processing of real-time data from different sources requires that the acquisition is synchronized.

Accuracy need changed from 1 Millisecond to 1-4 Microseconds

Time synchronization class	Accuracy [μs] Synchronization error	Application
TL	> 10 000	Low time synchronization accuracy – miscellaneous
T0	10 000	Time tagging of events with an accuracy of 10 ms
T1	1 000	Time tagging of events with an accuracy of 1 ms
T2	100	Time tagging of zero crossings and of data for the distributed synchrocheck. Time tags to support point on wave switching
T3	25	Miscellaneous
T4	4	Time tagging of samples respectively synchronized sampling
T5	1	High precision time tagging of samples respectively high synchronized sampling

Comparison SNTP / PTP / IRIG-B

Feature	SNTP	PTP	IRIG-B
Architecture			
Supported topologies	Any	Any	Only star or daisy chain
Communication infrastructure	IEC 61850 Network is used	IEC 61850 Network is used	Separate Network required
Supported by IEC 61850 compliant devices	Yes	Yes	Limited
Supported by Ethernet switches and routers	Yes	Yes, if PTP capable	No
Support of multiple time masters	Yes (limited number of masters)	**Yes (“unlimited number”, BMCA*)**	No
Redundant Connection to IEDs	Yes (PRP, HSR)	Yes (PRP, HSR)	No
Interoperability			
According IEC 61850 Standard	Yes	Yes	No
Accuracy			
Time synchronization accuracy	1 ms	1 µs	100 µs
Time stamp resolution at the IED	1 ms	1 ms	1 ms
Availability and Supervision			
Supervision	All connections supervised	All connections supervised	only indirectly via IEDs
Availability	High, by using multiple time master	**Highest (BMCA*)**	low, only single time master
Economics			
Fiber optical cables and cabling costs	Low, no separate network required	Medium, PTP capable switches	High, separate network required
	Insufficient for synch of sampling		**unreliable**

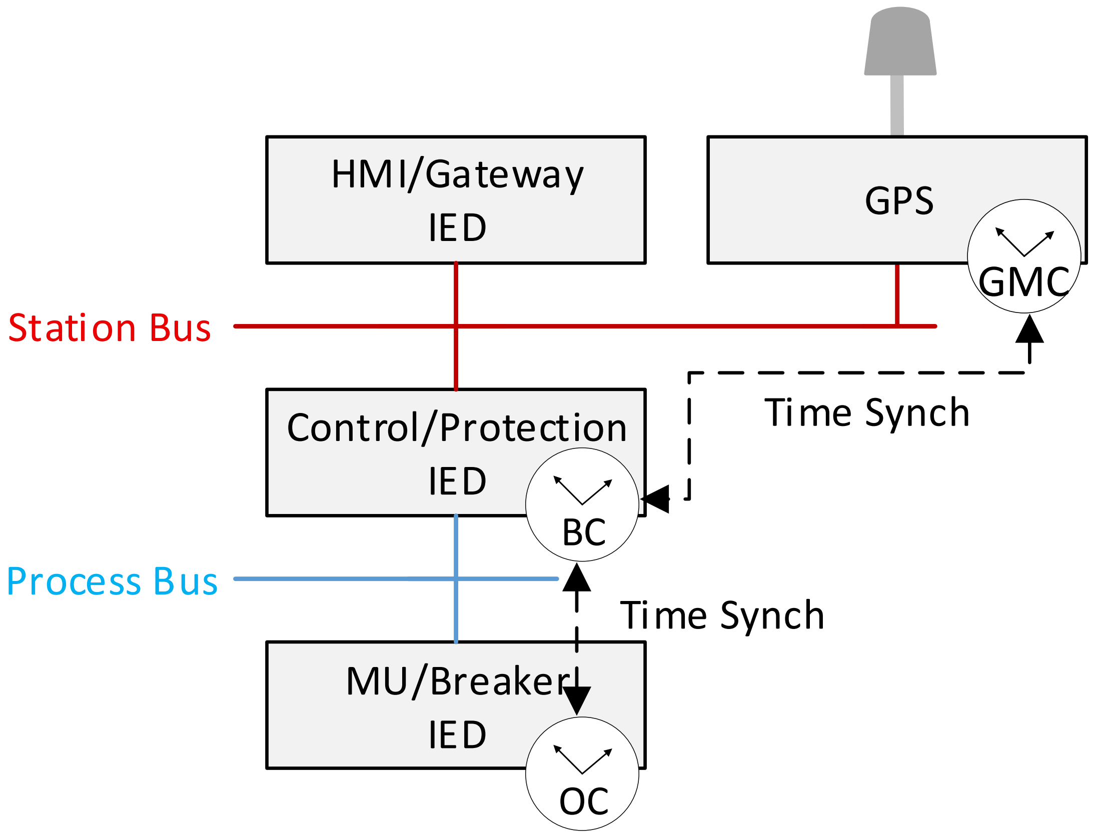
*BMCA: Best Master Clock Algorithm, automatically selects best available master to synchronize the system

Time synchronization architecture

Separate station- and process bus

Boundary clock (BC) in IEDs

- A basic architectural principle in digital substations is the full physical separation of the station bus from the mission critical real-time communication carrying IEC 61850 GOOSE and sampled values data on the process bus.
- This principle guarantees highest performance for GOOSE and SV, simplifies maintenance and allows for building separate security zones.
- As time synchronization of the merging units is crucial, the time from GMCs typically connected to the station bus needs to be bridged through the network to the process bus devices.



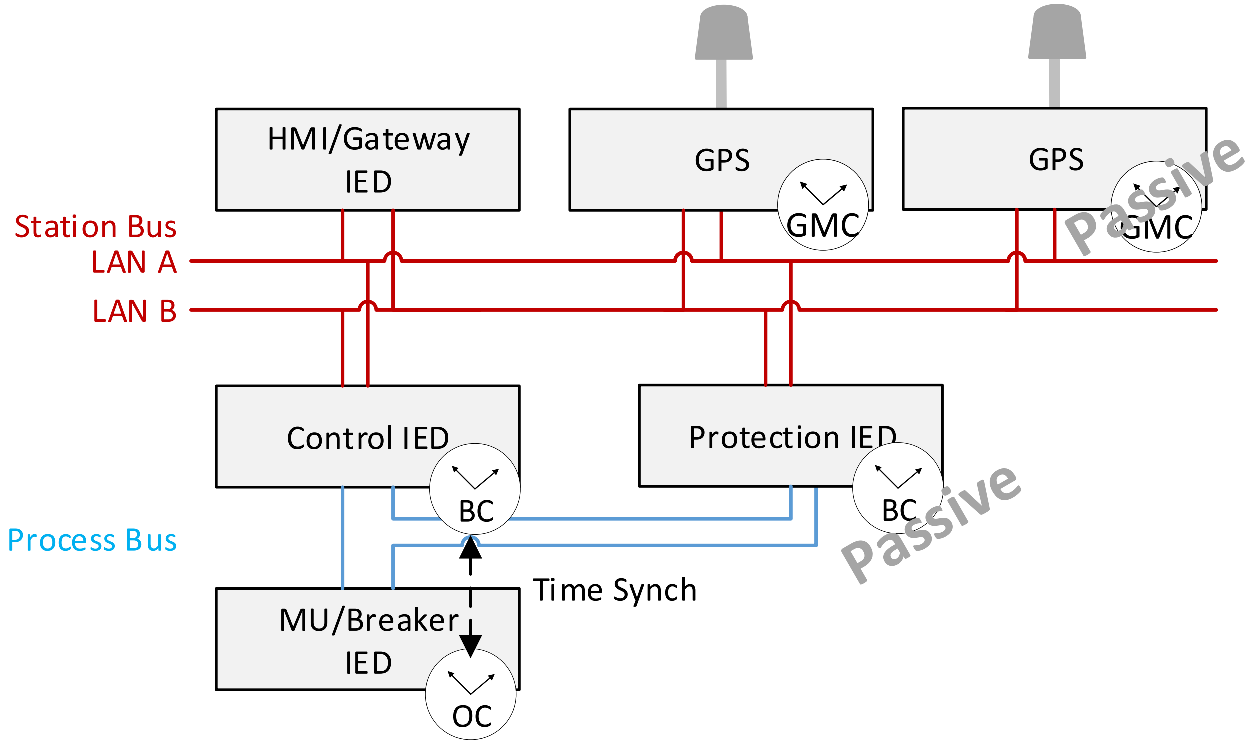
Time synchronization architecture

Redundant clocks

Redundant clocks and networks

To avoid this single point of failure it is recommended to have redundant GPS clocks connected to same network.

In the case that the network is designed as PRP, the two GPS clocks are connected as double attached nodes.



Time synchronization architecture

Principles for robust system design

As many functions depend on the precise time synchronization, there are a few useful principles that should be followed, to achieve high system availability:

- Redundant GPS clocks or other type of GMCs
- Redundant communication networks (HSR or PRP) for transmission of process data and PTP synchronization
- Redundant protection systems, with dedicated process and bay device for first and second main protection
- Protection and control IEDs that are capable to become time master with best master clock algorithm
- Protection and control IEDs acting as boundary clocks between station and process bus
- Graceful degradation of application functions in case of time synch failures, resulting in blocking of protection functions that depend on consistent synchronization only

Digitalization beyond substation boundaries

Real-time communication between substations

GOOSE and Sampled Values across substations

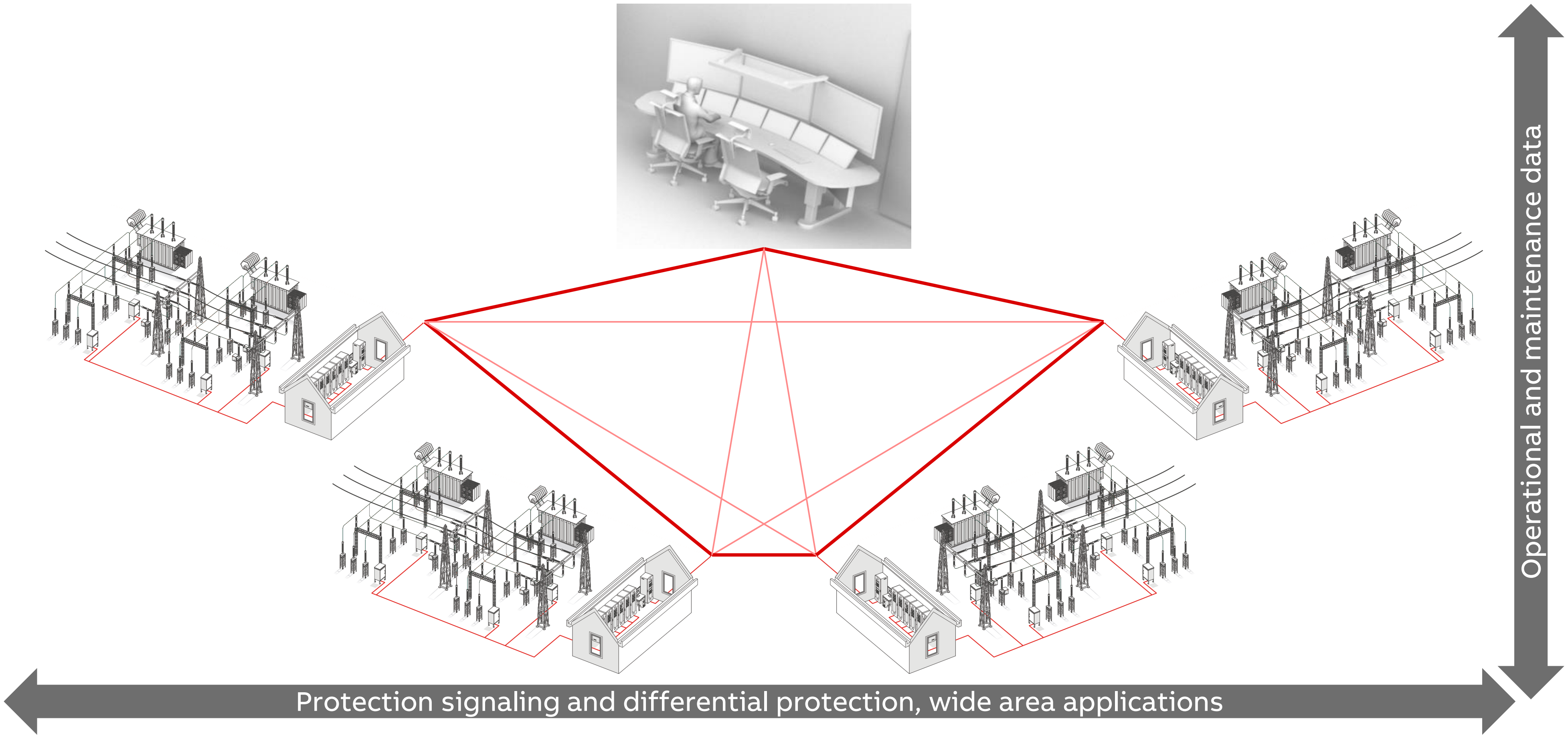
Unseen opportunities

Digital substations, embedded in a digital utility communication network

– Maintenance and operation data from sensors to board room

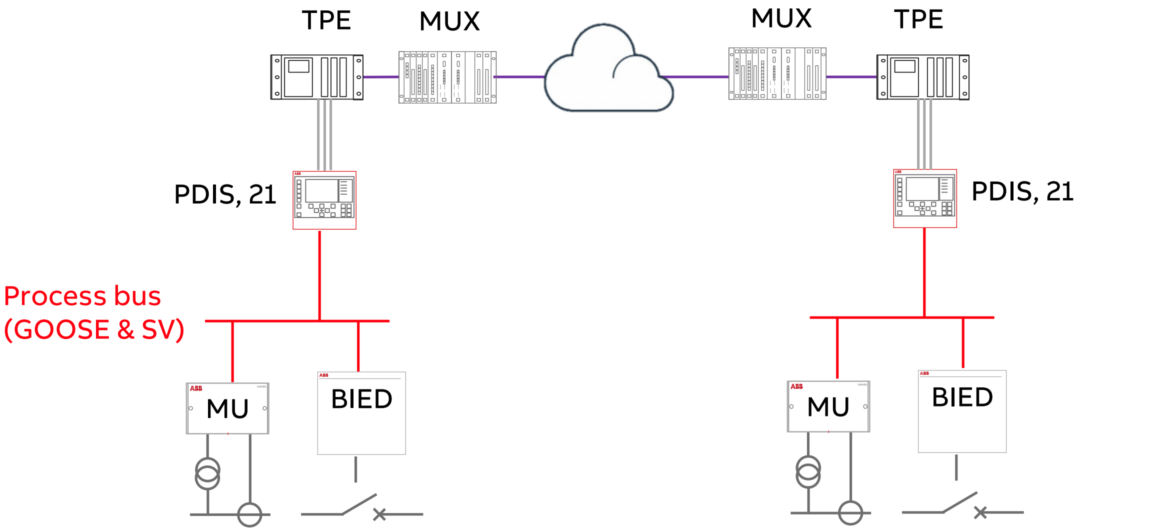
– Real-time GOOSE and SV communication between substations

Integration and system-wide connectivity adds value to digital substation data

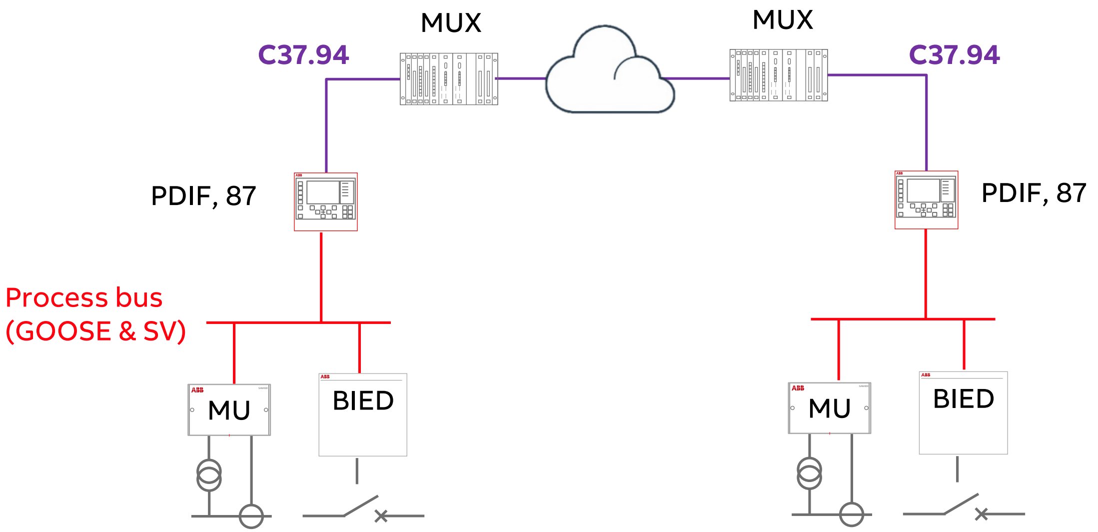


Digital substations with conventional line protection

Distance protection



Differential protection

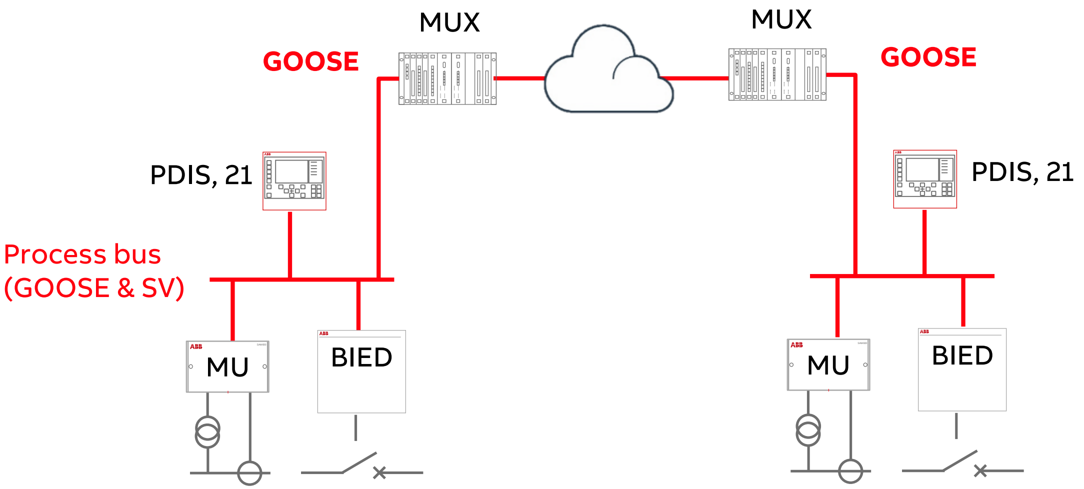


Protection IEDs act as "protocol converter" between IEC 61850 and wires or C37.94

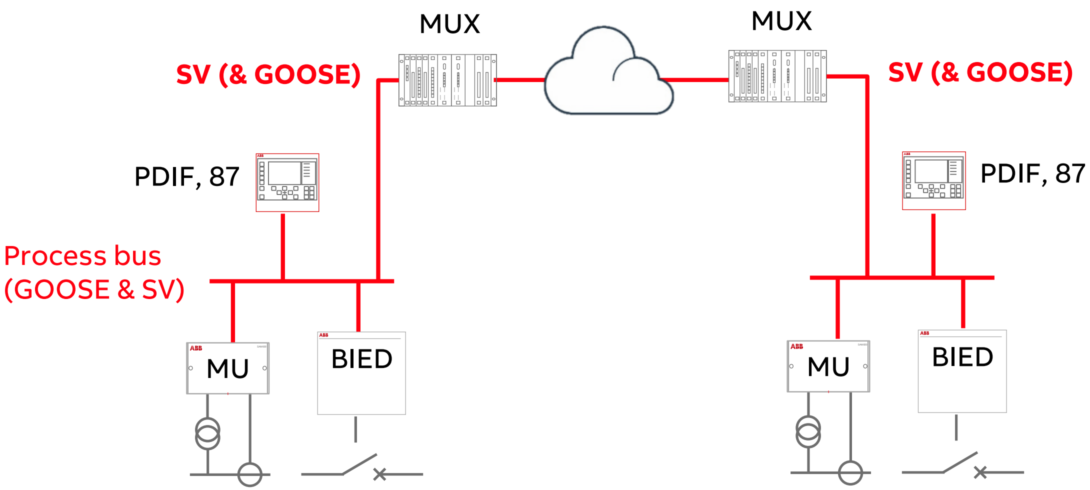
Digital substations with digital line protection

ABB FOX612/615 MUX with IEC 61850 GOOSE and Sampled Values

Distance protection



Differential protection



Increased performance and flexibility with simpler system design

Comparison

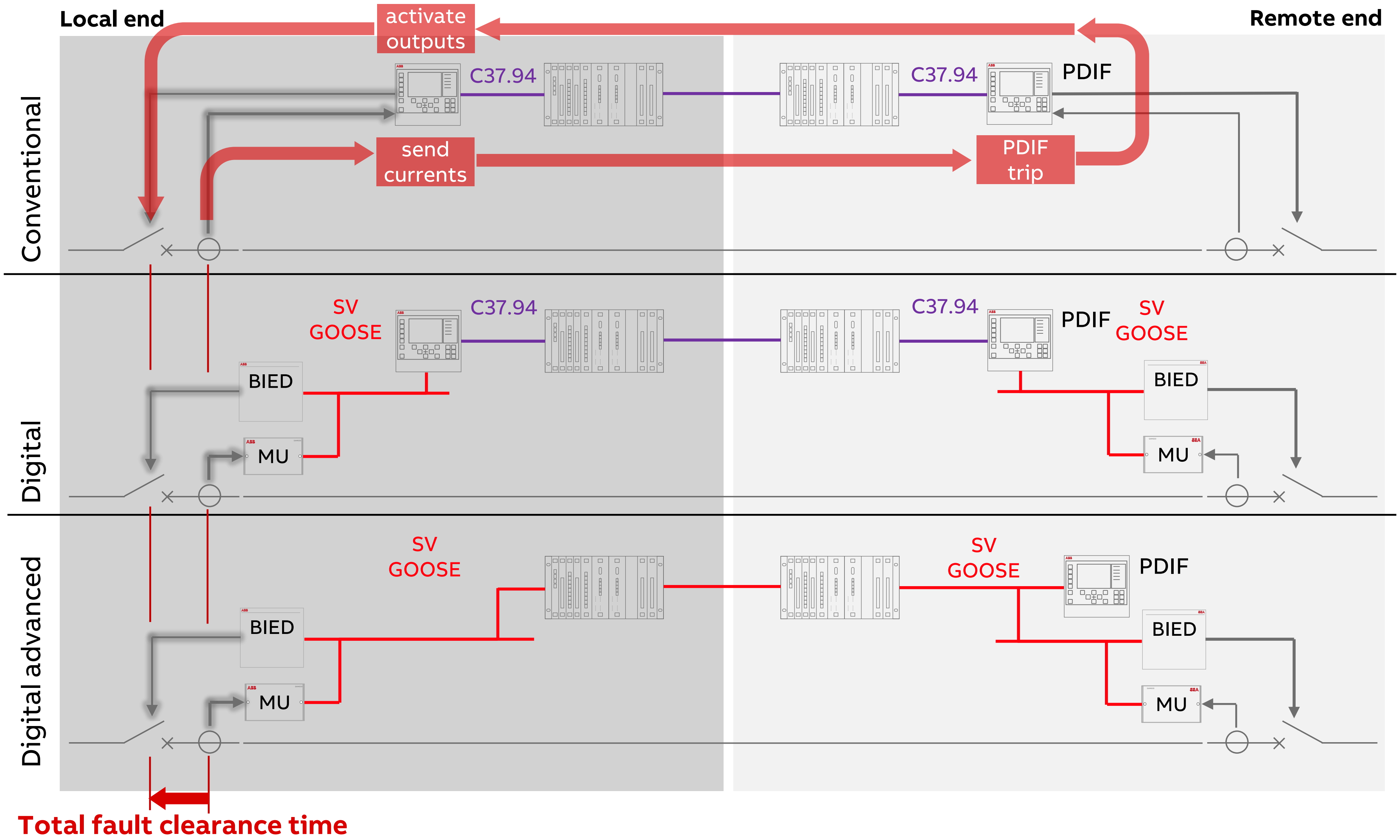
Line differential

Comparison of 3 scenarios:

– **Conventional** with C37.94 between PDIF IEDs

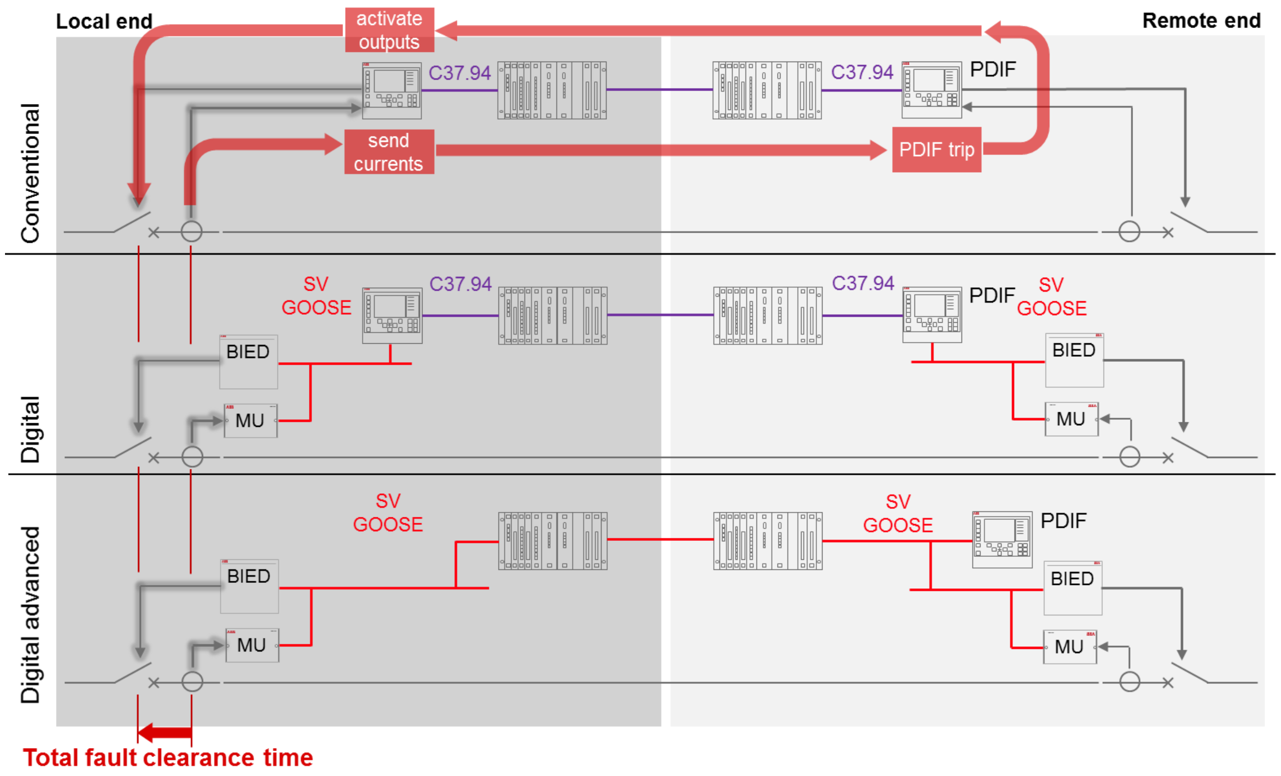
– **Digital** with MUs, sampled values & GOOSE but C37.94 between IEDs

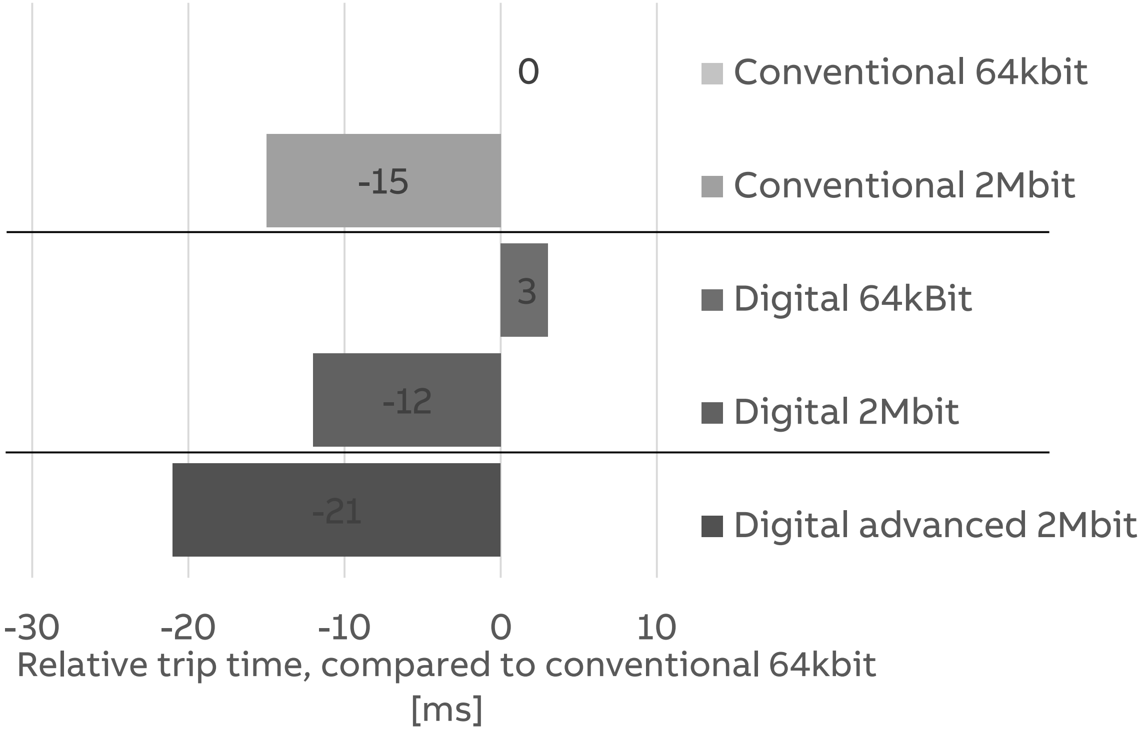
– **Digital advanced** with sampled values and GOOSE directly between process and remote end IED



Digital substations with digital line *differential* protection

Analysis of fault clearance time





- Conventional setup with 2Mbit LDCM instead of 64kbit gives 15ms time reduction
- Digital setup with conventional communication is slightly slower (delay time of MU + communication + delay time of BIED)
- SV and GOOSE based communication directly from MU and to BIED gives time reduction of >20ms

Real-time analog and binary data across substations

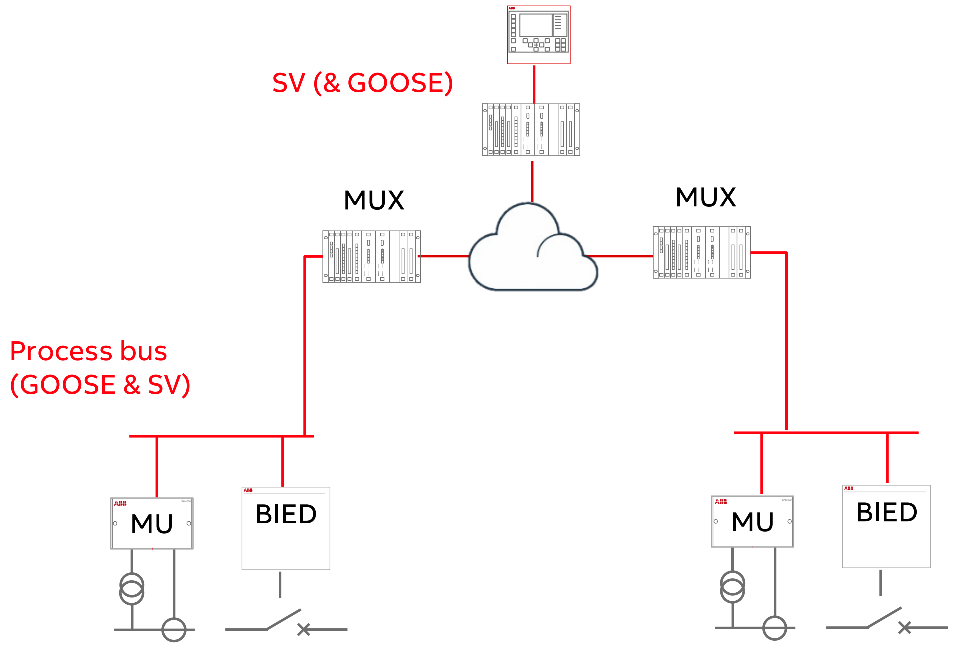
IEC 61850 GOOSE and Sampled Values

New application possibilities

Being able to distribute real-time measurements and commands across wide area networks, opens unseen opportunities

For example

- Automatic voltage regulation
  by using remote measurements to optimally adjust tap-change settings
- Integration of renewable generation
  share measurements between grid connection points and remote generation locations, e.g. off-shore wind turbines
- Power System Protection Scheme (PSPS) or Remedial Action Scheme (RAS)
  using real-time measurements to perform system wide protection functions
- …



ABB