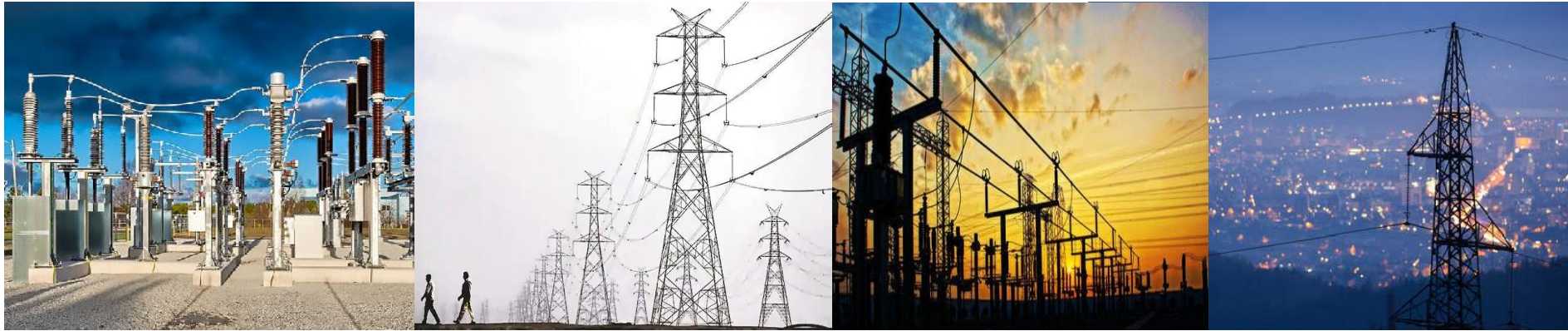# Tests & Measurement in Power Utilities

IEC 61850 is a Power Grid a standard was that defines a set of Ethernet-based protocols to be used by power devices to exchange data, send commands, measure values and get synchronized

.

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Telecom

ALBEDO a global <u>manufacturer</u> of <u>Testers</u> & <u>Timing</u> appliances

ICT electronics (1983-2000)

Trend (2001-2009)

ALBEDO telecom (2010 - today)

As result of the convergence process in the **Power Grid,** a new standard was released, the **IEC 61850**, that defines a set of Ethernet-based protocols.

The IEC 61850 objective is to facilitate the interoperability (between devices and systems), ease of configuration (allocation of functions to devices), long term stability (layered, object-model based design), and reliability (lossless network architectures) to replace wire communications.
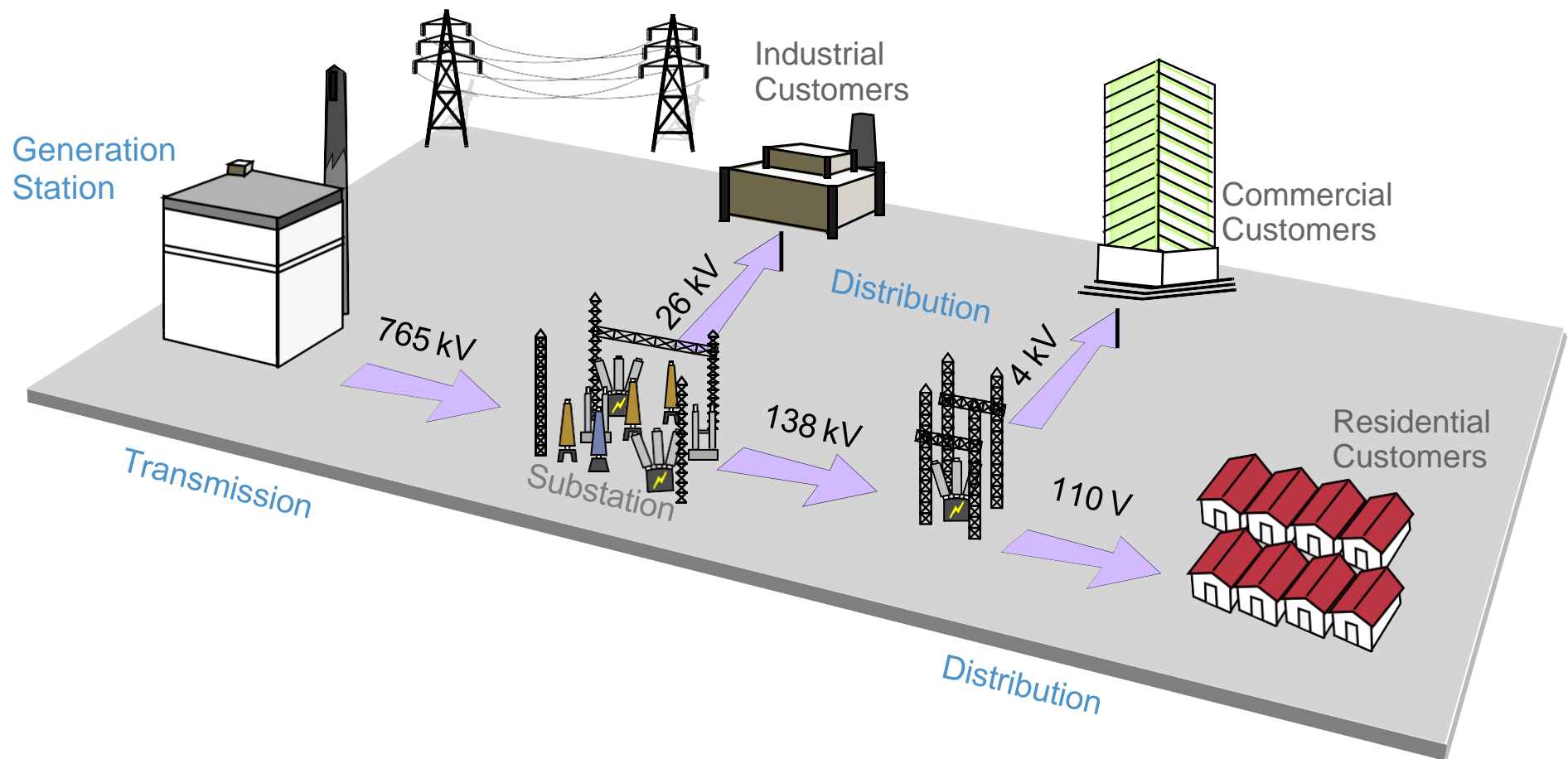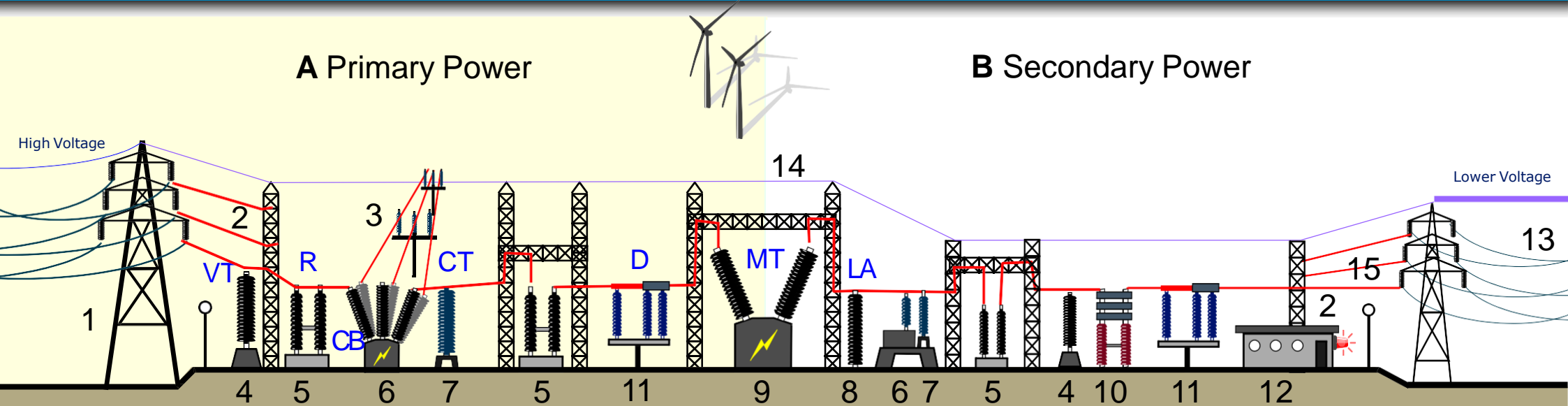
The basic architecture of electricity transmission and distribution changed very little during the first 100 years. However, in recent decades, the concept of **Smart Grid** emerged thanks to the massive use of digital technologies to increase efficiency, resilience and quality of the service.

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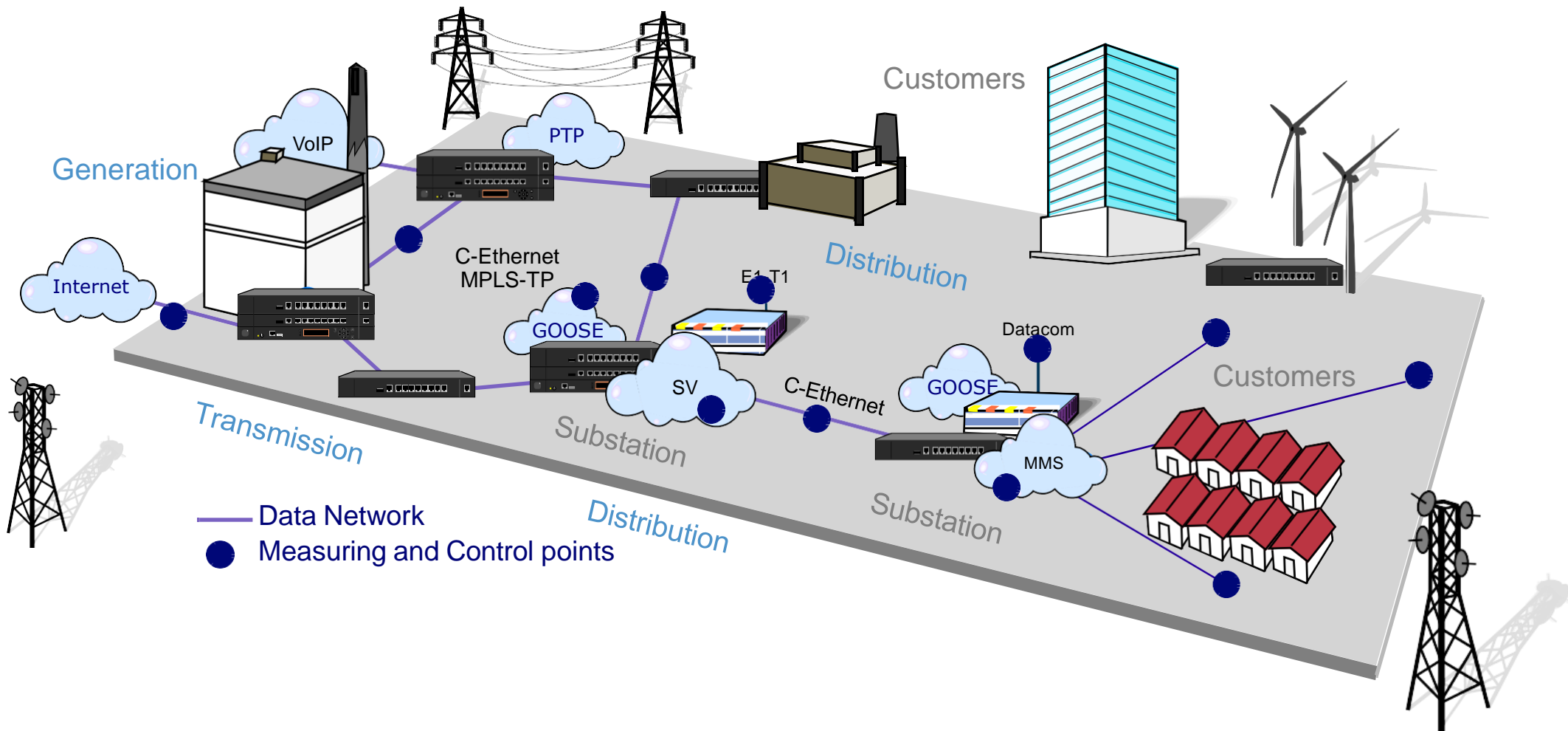
Smart Grid require a **Telecom Data Network** to communicate all the elements of the Power System, including Generation plants, Substations and Customers in order to increase the efficiency, resilience and quality of the power grid, while allowing advanced management.

A Primary Power

B Secondary Power

High Voltage

Lower Voltage

14

3

2

R

VT

CT

D

MT

LA

15

1

2

CB

13

4   5   6   7   5   11   9   8   6 7   5   4 10   11   12

1.Primary Power (PP), 2.Feeder, 3. Busbar, 4.Voltage Transformer (VT), 5.Relay (R), 6.Circuit Breaker (CB), 7.Current Transformer (CT), 8.Lightning Arrester (LA), 9.Main Transformer (MT), 10. Capacitors (C), 11.Disconnector, 12.Control Shelter, 13.Secondary Lines, 14. Ground, 15. Overhead Lines
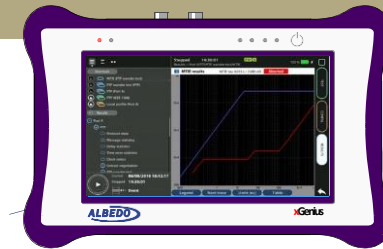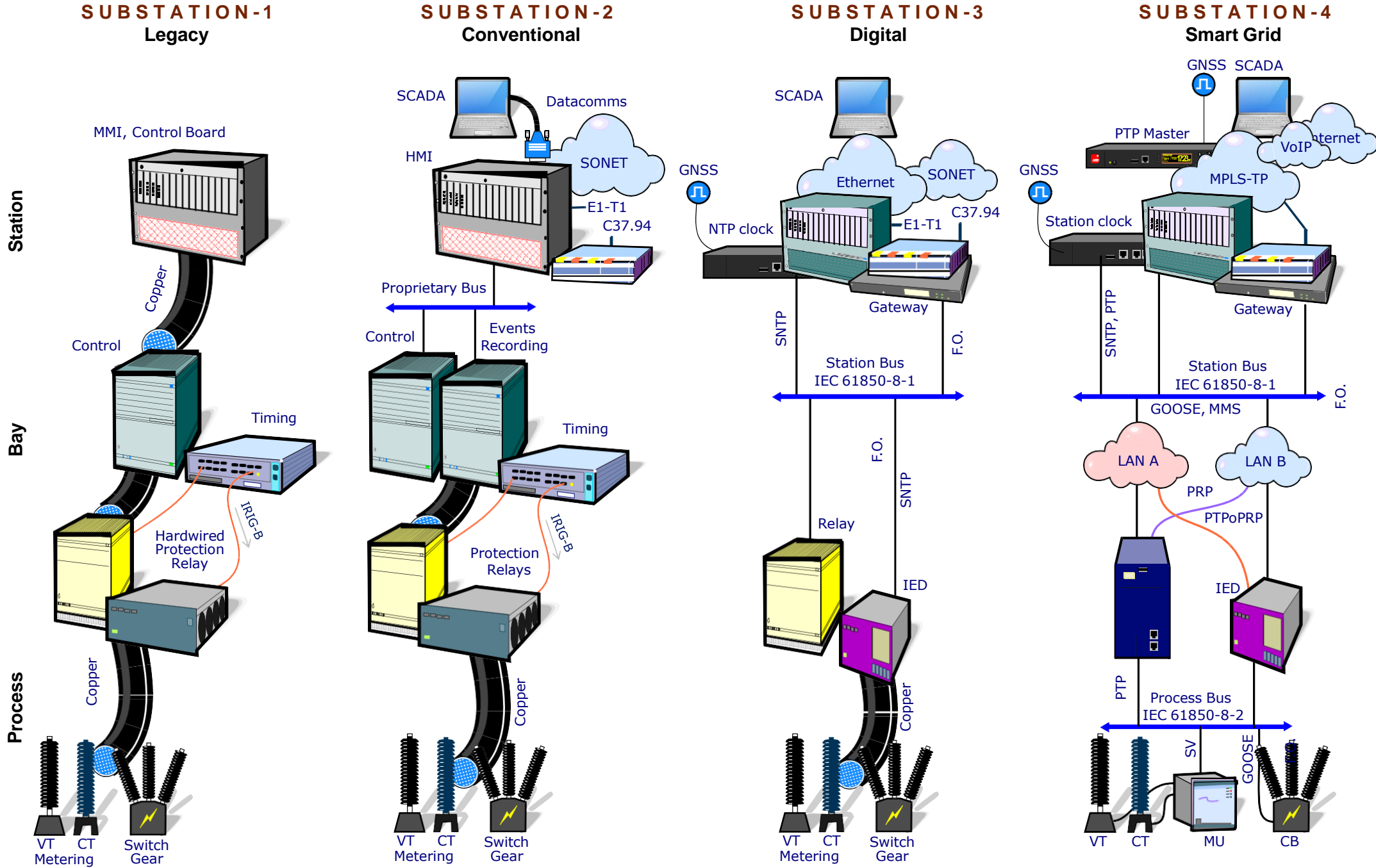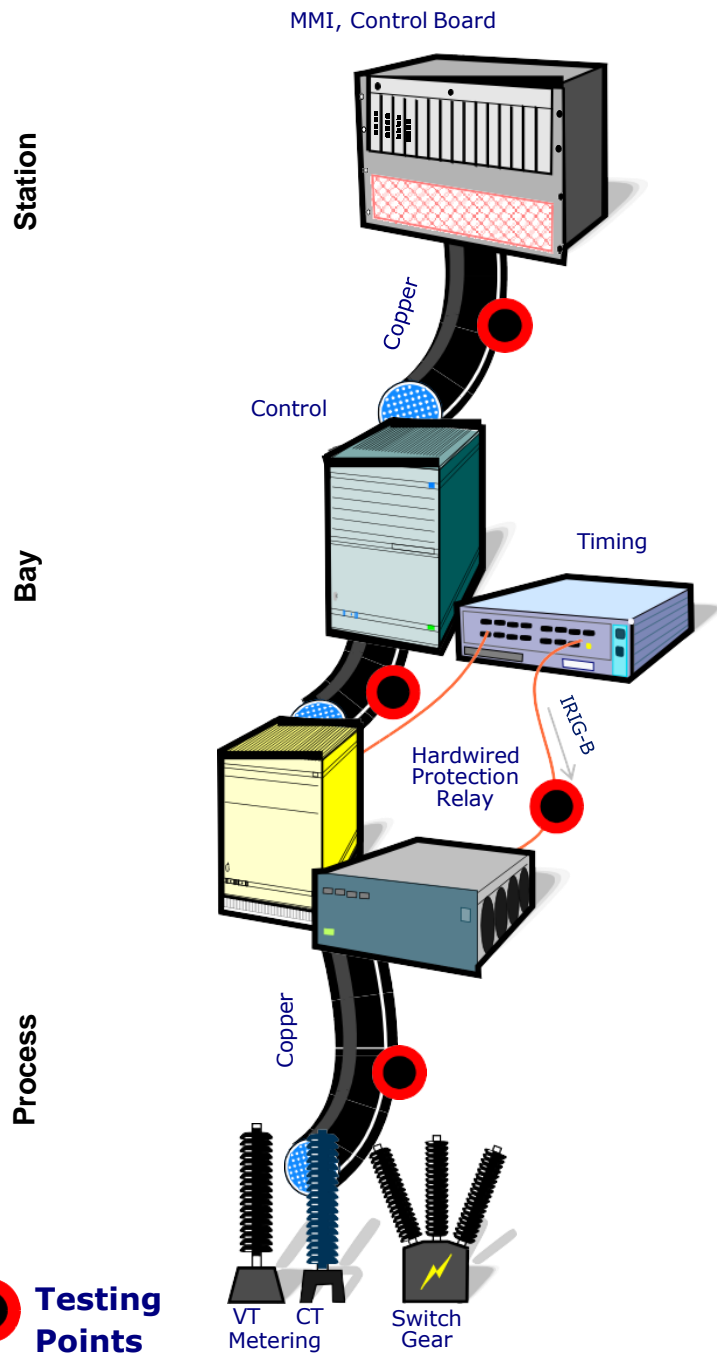
The **Primary Power** manages the high voltages lines coming from Generation while the secondary the lower voltages distributed to Industrial and residential consumers.

Zeus is powerful and self-contained tool ideal for engineers to set up, troubleshoot and maintain all Digital Communications deployed in Substations.

SUBSTATION-1
Legacy

SUBSTATION-2
Conventional

SUBSTATION-3
Digital

SUBSTATION-4
Smart Grid

Station

Bay

Process

MMI, Control Board

Copper

Control

Timing

Hardwired Protection Relay

IRIG-B

Copper

VT Metering   CT   Switch Gear

SCADA   Datacomms

HMI   SONET

E1-T1
C37.94

Proprietary Bus

Control   Events Recording

Timing

Protection Relays

IRIG-B

Copper

VT Metering   CT   Switch Gear

SCADA

GNSS

Ethernet   SONET

NTP clock   E1-T1
C37.94

Gateway

SNTP   F.O.

Station Bus
IEC 61850-8-1

F.O.

SNTP

Relay   IED

Copper

VT Metering   CT   Switch Gear

GNSS   SCADA

PTP Master   VoIP   Internet

MPLS-TP

GNSS

Station clock

Gateway

SNTP, PTP   F.O.

Station Bus
IEC 61850-8-1

GOOSE, MMS

LAN A   LAN B

PRP

PTPoPRP

PTP   IED

Process Bus
IEC 61850-8-2

SV   GOOSE

VT   CT   MU   CB

MMI, Control Board

Station

Copper

Control

Bay

Timing

Copper

IRIG-B

Hardwired
Protection
Relay

Process

VT
Metering

CT

Switch
Gear

**Testing
Points**

What to Test

1. Serial communication: RS-232, RS-422, V.35, V.36
2. IRIG-B: timing accuracy
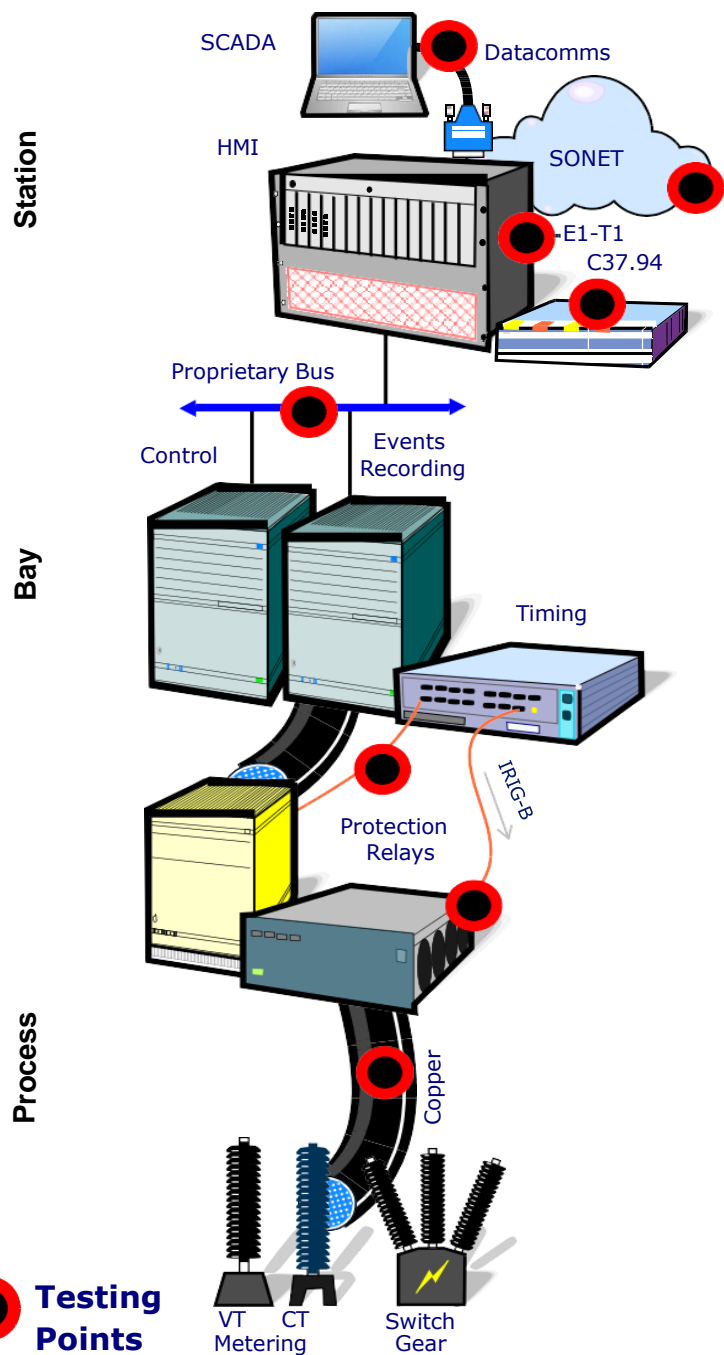3. E1/T1: voice [and timing]

Objectives

Installation & maintenance of:

- Serial communications
- Timing quality
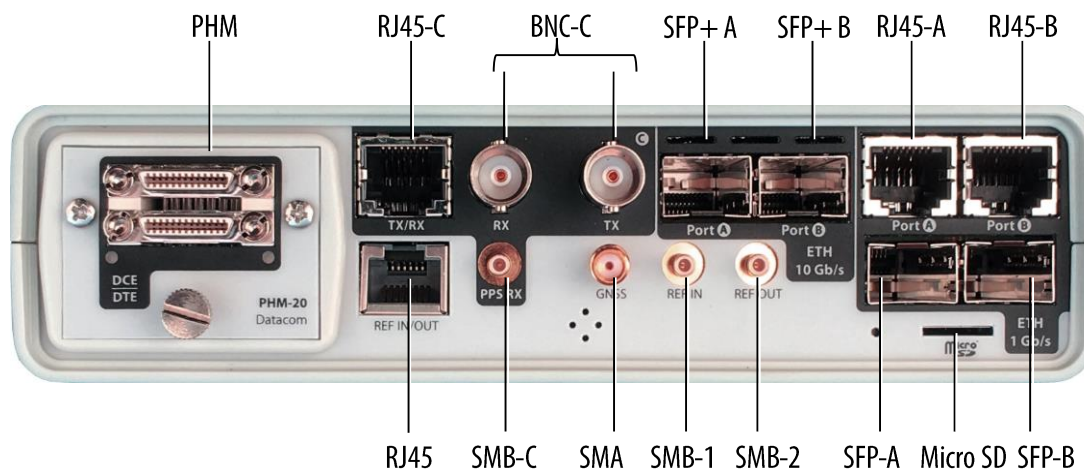- Voice circuits

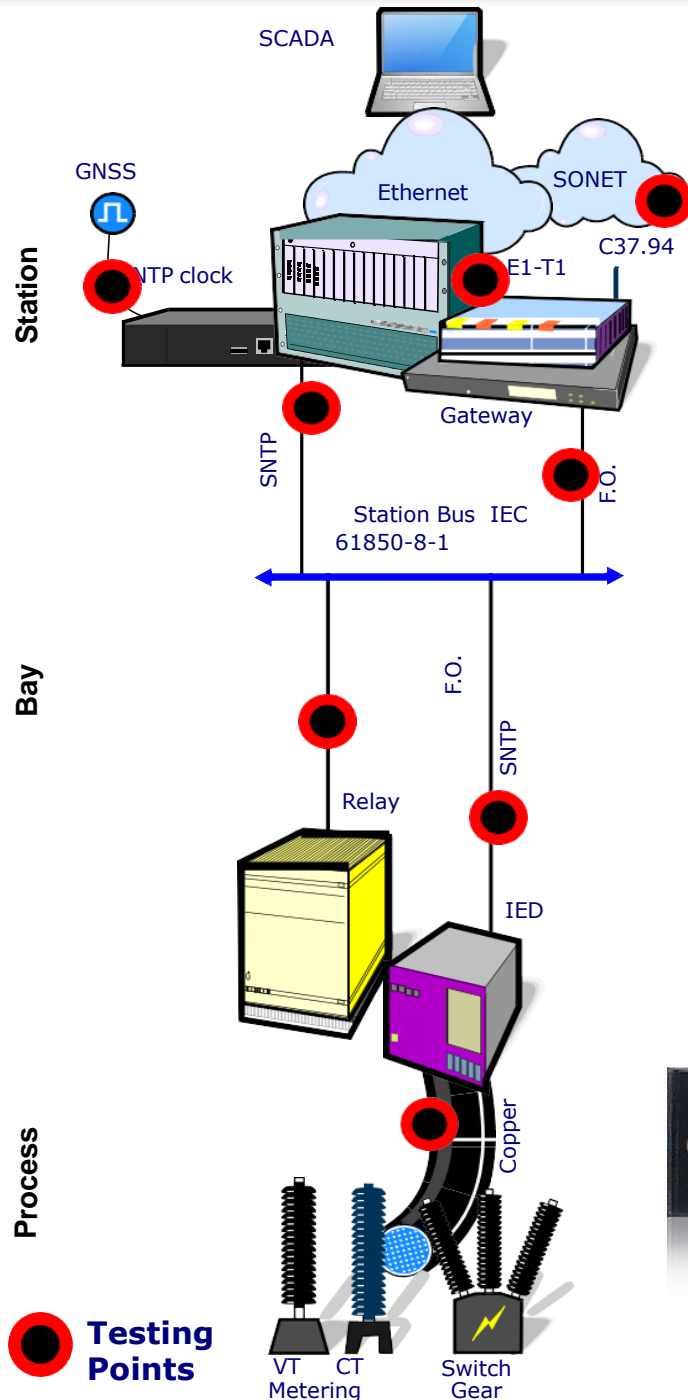*Serial Data Communication cables and interfaces*

What to Test

1. Serial communication data: RS-232, RS-422, V.35, V.36
2. IRIG-B: timing
3. E1 / T1: pulse, voice, data
4. C37.94: one-way / two-way delays, event emulations
5. Teleprotection: One-way delay
6. Ethernet capacity/quality: RFC 2544, eSAM, etc.

Objectives

- Check and adjust teleprotection based on C37.94
- Check the quality of the Ethernet network

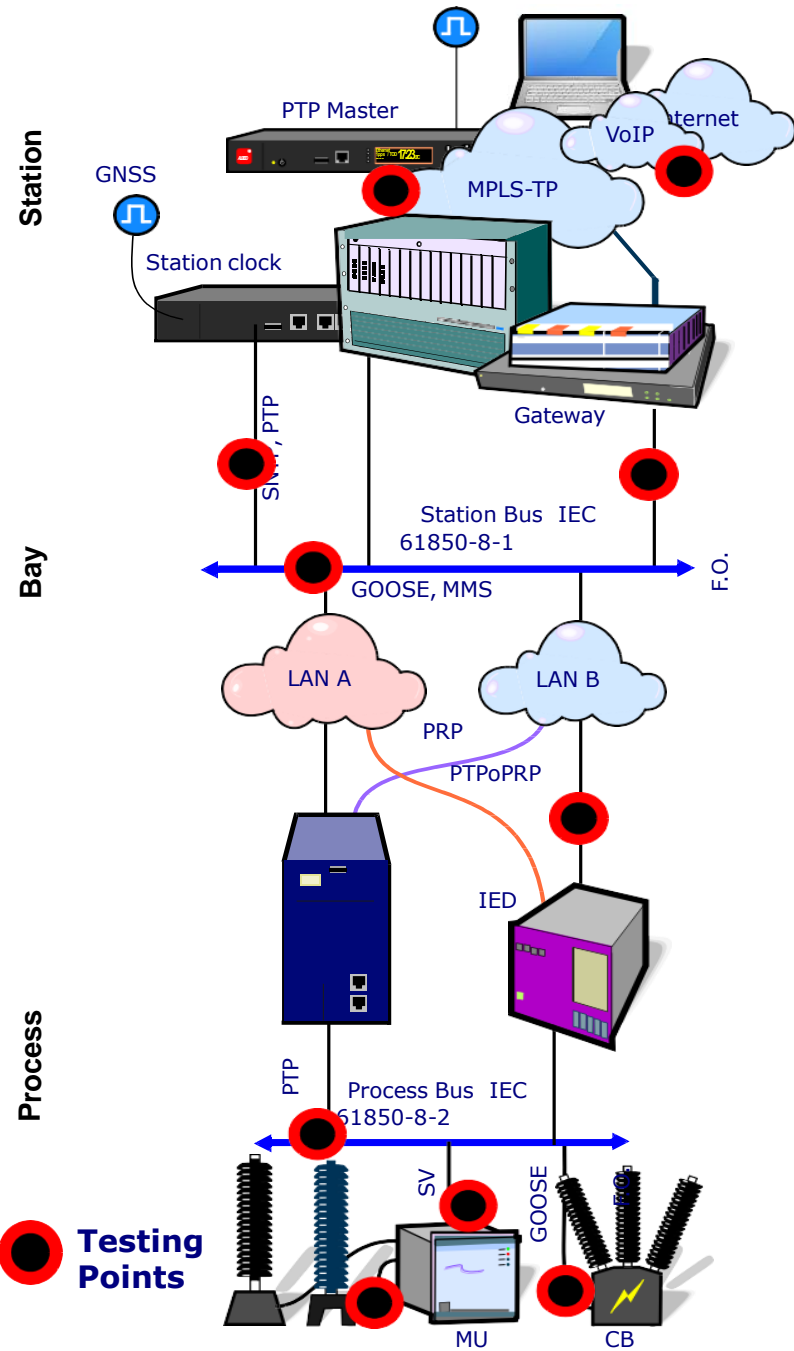*xGenius testing interfaces*

What to Test
1. Serial communication data: RS-232, RS-422, V.35, V.36
2. IRIG-B: timing
3. E1 / T1: pulse, voice, data
4. Ethernet: RFC 2544, eSAM, etc.
5. IP: ping, trace route
6. Fiber Optic: Power, OTDR
7. NTP: message, delays, jitter, TE
8. Teleprotection: C37.94, One-way delay, Quality

Objectives
- Check the teleprotection times C37.94
- Check and adjust IRIG-B and NTP synchronisms
- Check the quality of the Ethernet network
- Install and maintain fiber optics
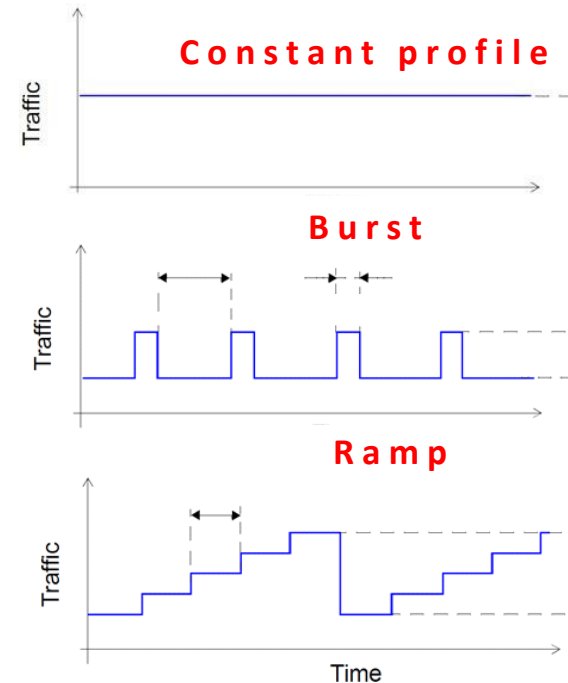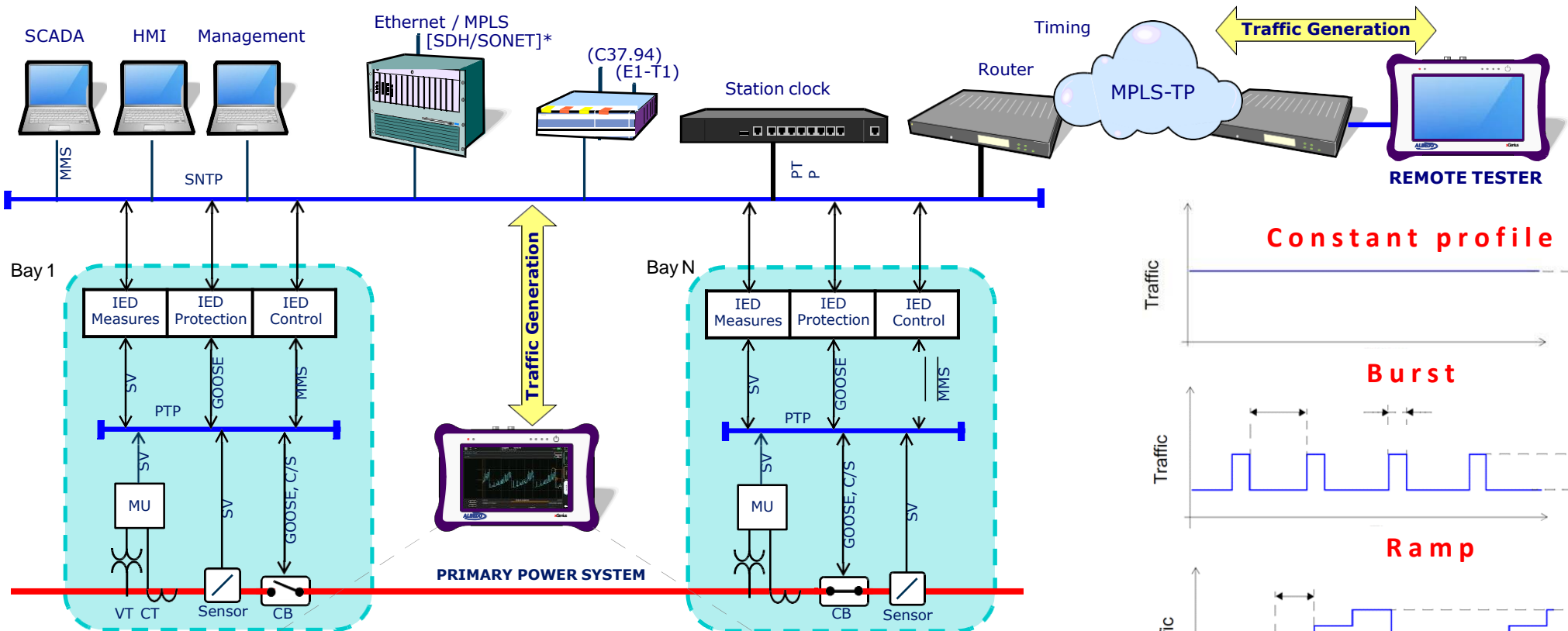
Net.Time a PTP/NTP clock

What to Test

1. Serial communication data: RS-232, RS-422, V.35, V.36
2. IRIG-B: time
3. E1 / T1: pulse, voice, data
4. C37.94: delays, event emulations
5. Teleprotection: Unilateral delay
6. Ethernet: RFC 2544, eSAM, etc.
7. IP: ping, tracking route
8. MPLS-TP
9. Fiber Optic: Power, OTDR
10. NTP: message, delays, jitter, TE
11. PTP: Wander, PPS, TE
12. GOOSE: analysis / capture / decoding
13. SV: analysis / capture / decoding
14. MMS: analysis / capture / decoding
15. Master / slave clock emulation
16. IEC-61850: delay of protocols

Objectives

- Guarantee the interconnection between different manufacturers
- Interconnection of new and old PTP-NTP-IRIG-B synchronism
- Install and develop new protocols like GOOSE

Objectives

- Check Eth/TCP/IP: RFC2544, RFC6349, Y1568
- Detect congestion points and error causes

Latency trace

Type	Message	Protocol	Layer	BWidth	Delay	Priority	Bus	Model	Application
1A	Trip	GOOSE	L2 - Multicast	Low	< 3 to 10ms	High	Process	Publisher	Protection
1B	Other	GOOSE	L2 - Multicast	Low	< 20 to 100ms	High	Process	Publisher	Control
2	Med Speed	MMS	L3 - IP/TCP	Low	< 100 ms	Medium Low	Process & Station	Client/Server	Data collection
3	Low Speed	MMS	L3 - IP/TCP	Low	< 500 ms	Medium Low	Process & Station	Client/Server	Data collection
4	Raw Data	SV	L2 - Multicast	High	< 3 to 10ms	High	Process	Publisher	Analysis, Protection
5	File Transfer	MMS	IP/TCP/FTP	Medium	< 1000 ms	Low	Process & Station	Client/Server	Management, Data
6	Timing	PTP	L2 - PTP	Low	Protection < 0,1 to 3ms Transformers ±1 to ±25us	Medium High	Process & Station	Unidirectional	Timing, IED, Synchrophasors
7	Command	MMS	L3 - IP	Low	< 500 ms	Medium Low	Station	Client/Server	Cconfiguration

IEC-61850 protocols to synchronize, configure, manage, control, protect, measure and data collection.

SUBSTATION-1

SUBSTATION-2

IED

Latency < 2 ms   Latency < 10ms   Latency < 2 ms
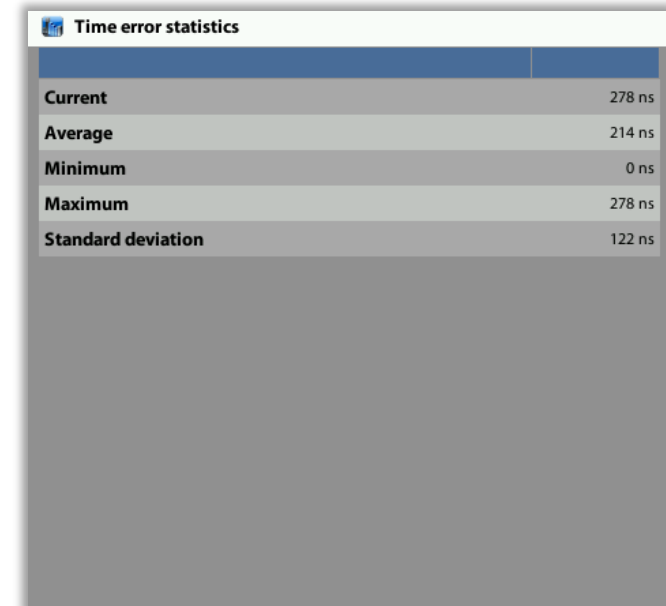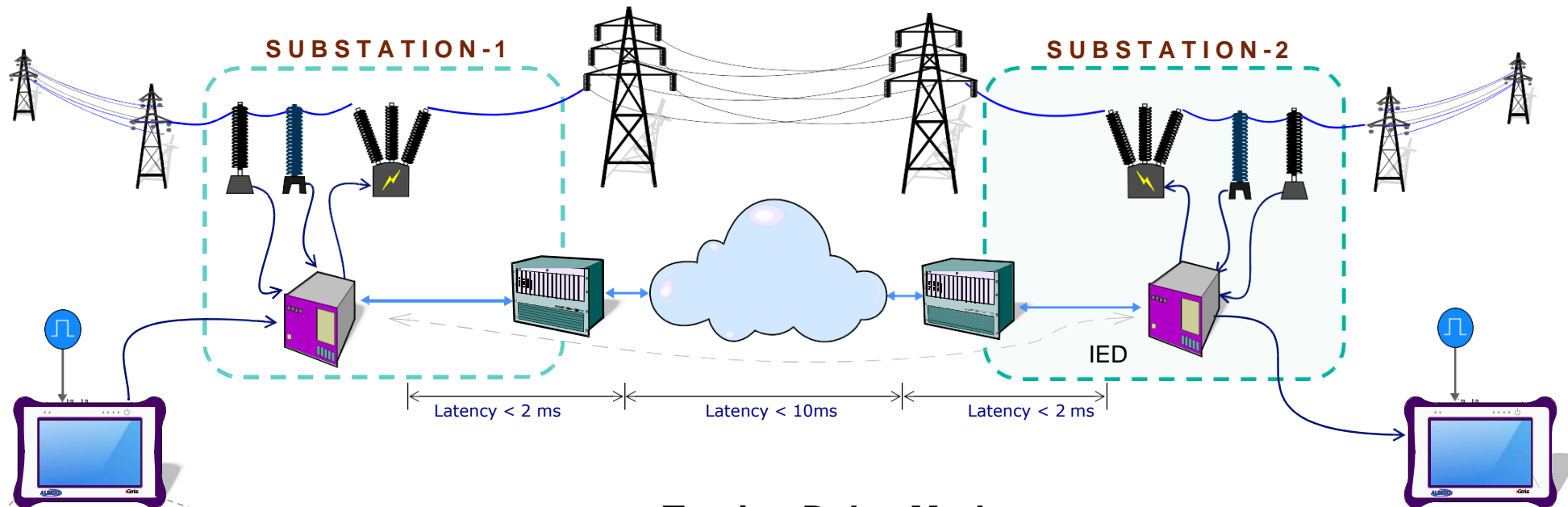
Testing Delay Modes
- Bidirectional Delay (Round Trip Delay)
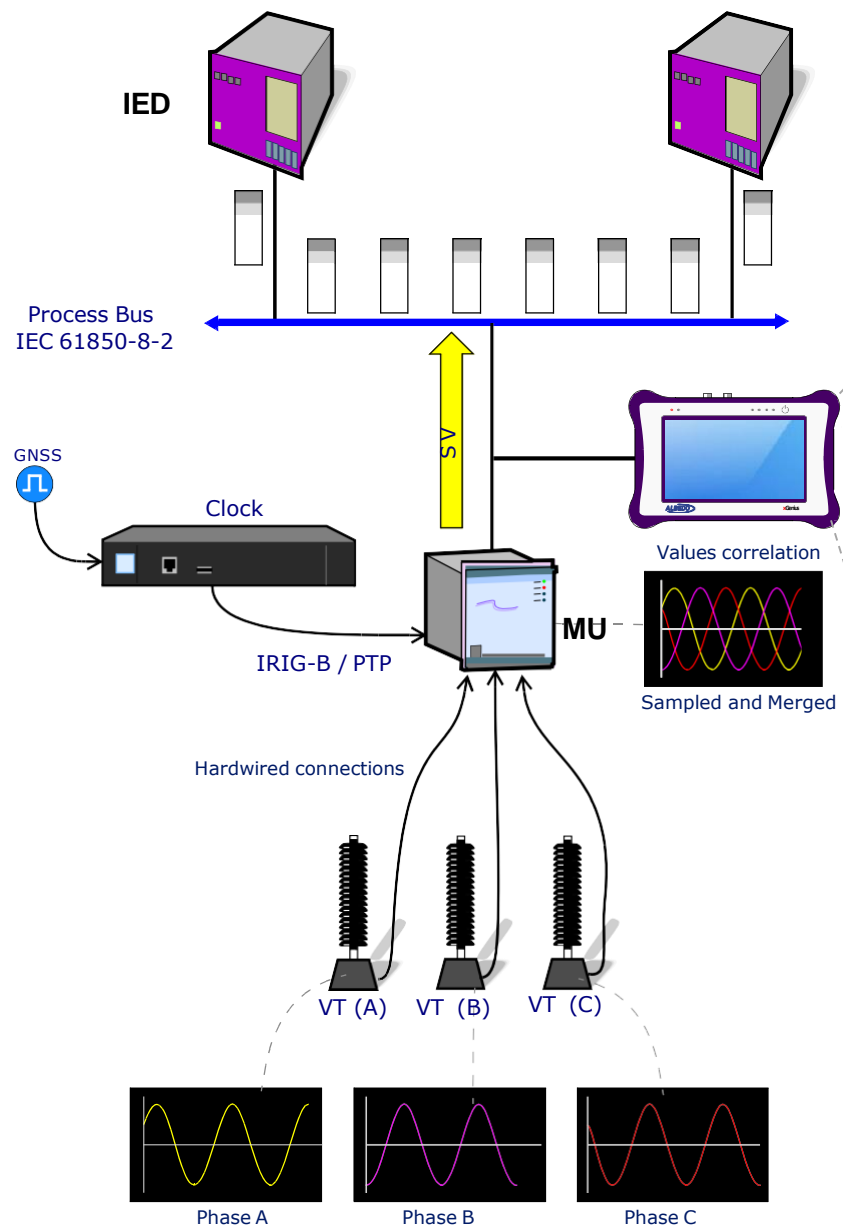- One way delay with GNSS or ToD help

Latency results
- Bidirectional Delay or Round Trip Delay (RTD)
- One Way Delay Forward and Reverse Path
- Asymmetry with min. / max records
- Patch cord delay compensation
- PASS / FAIL indication

Objectives
- Bidirectional Delay or Round Trip Delay (RTD)
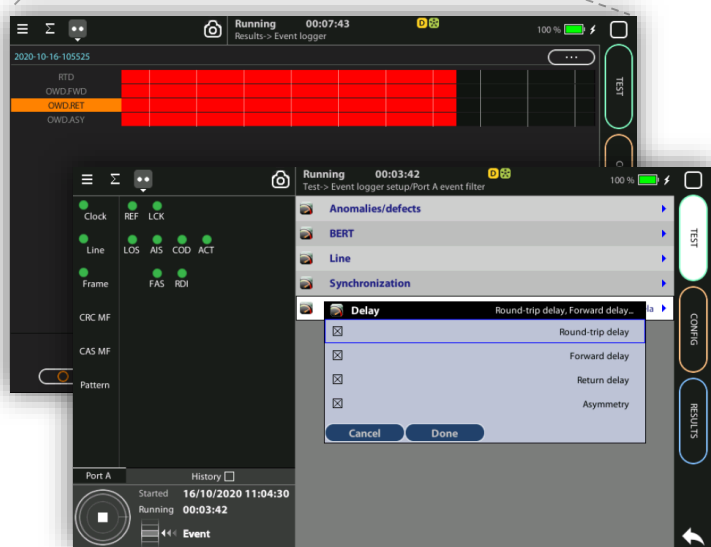
A **Merging Unit** (MU) digitalizes the analog measurements provided by current and voltage transformers (CT / VT) transmits the information using the Sampled Values (SV) protocol at a predefined bit rate.

IED

Process Bus
IEC 61850-8-2

GNSS

Clock

SV

IRIG-B / PTP

MU

Values correlation

Sampled and Merged

Hardwired connections

VT (A)   VT (B)   VT (C)

Phase A   Phase B   Phase C

State	Finished
Status	Idle
Packets stored	130
First capture at	05/12/2019 15:31:37
Last capture at	05/12/2019 15:31:37
Usage (%)	0

Objectives

- Detect SV transmission faults
- Facilitate interconnection between manufacturers
- Verify and adjust the latency of SV samples

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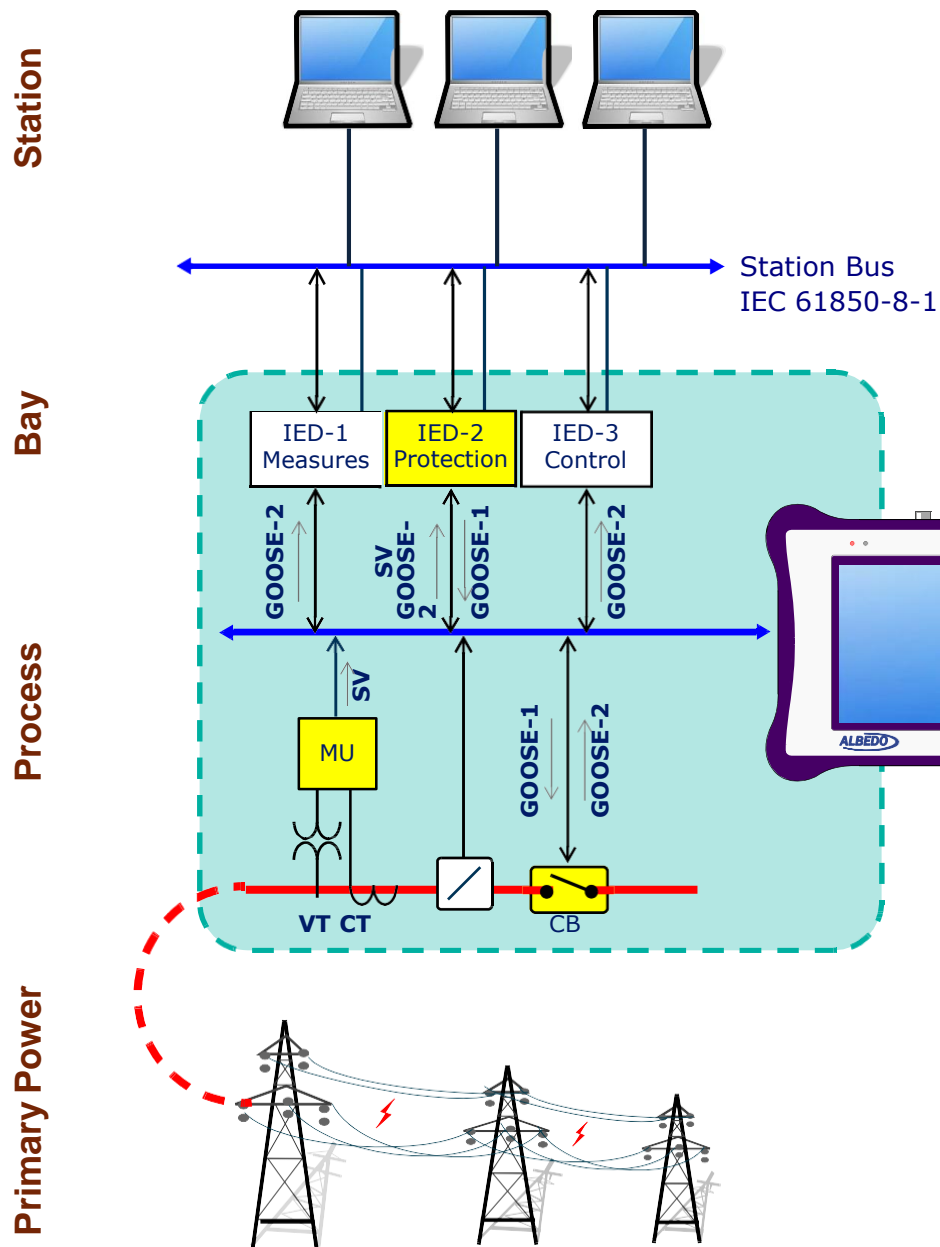
GOOSE is a messaging system used by IEDs and mission-critical applications to tell about substation events: commands, alarms, indications, measurements
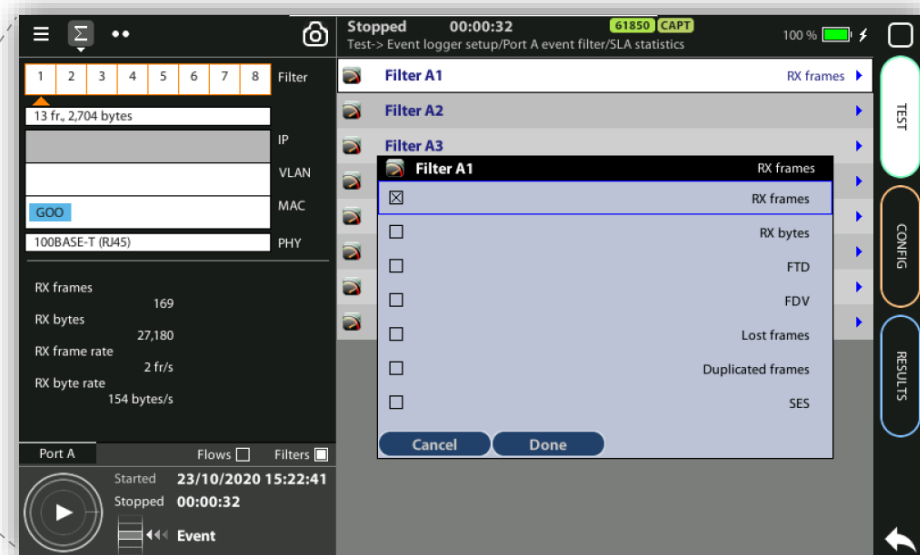
Objectives
- Decoding of faults in GOOSE protocol
- Facilitate interconnection between manufacturers
- Verify and adjust the latency of GOOSE packets

Capture buffer

Memo Ocupation

Time Stamps

Delay Analysis

IEC 61850 Capture

Frame structure

Decodification

Summary of the Frame structure

Supports **DNS, DHCP, GOOSE, SV, NTP, PTP** protocols

- Captures in pass-through and end-point modes
- High resolution hardware time stamp
- Synchronized captures (GNSS, IRIG-B, 1PPS / ToD)
- Package-by-package delay analysis
- Export to PCAP and PCAPng

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IRIG - Xabc

Rate
A: 1000 PPS
> **IRIG-B: 100 PPS** <
D: 1 PPM
E: 10 PPS
G: 10000 PPS
H: 1 PPS

Coding
0: BCD, CF, SBS
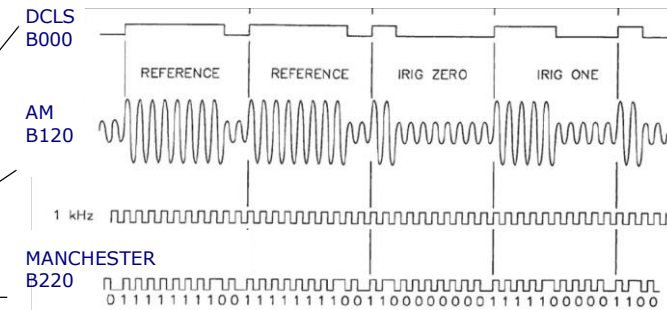1: BCD, CF
2: BCD
3: BCD, SBS
4, 5, 6, 7: others

Carrier
0: No carrier (DCLS)
1: 100 Hz
2: 1 kHz
3: 10 kHz
4: 100 kHz
5: 1 MHz

Modulation
0: Unmodulated DCLS
1: AM (Amplitude Modulated)
2: Manchester Modulated

BCD
0000 = 0
0001 = 1
0010 = 2
0011 = 3
0100 = 4
0101 = 5
0110 = 6
0111 = 7
1000 = 8
1001 = 9

BCD - Binary Coded Decimal, coding of time (HH,MM,SS,DDD)
SBS - Straight Binary Second of day (0….86400)
CF - Control Functions depending on the user application

IRIG SAMPLES: B000, B120, B220

DCLS B000
AM B120
1 kHz
MANCHESTER B220

REFERENCE   REFERENCE   IRIG ZERO   IRIG ONE

0 1 1 1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 0 0

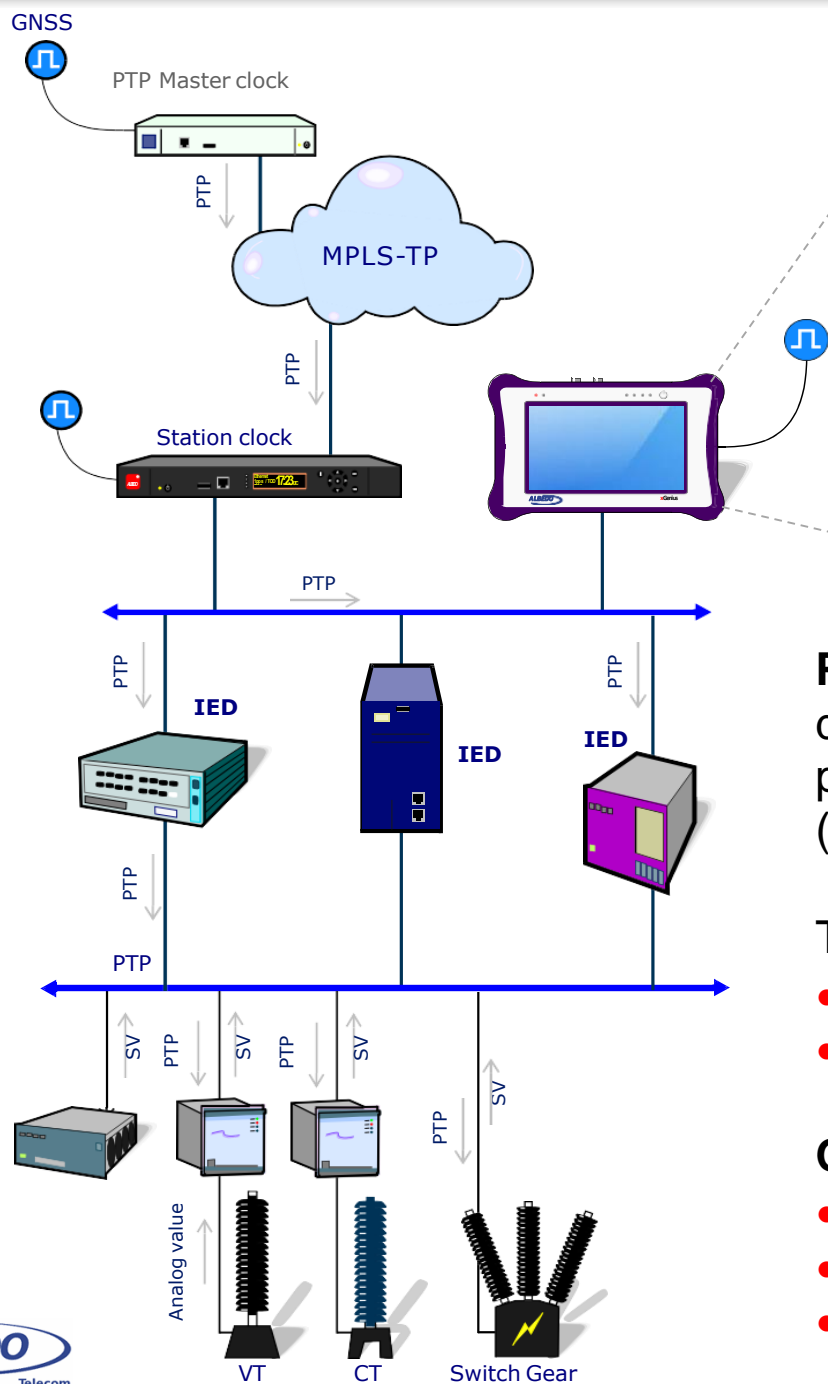| Input IRIG-B status	Synchronized to Irig
Modulation	Pulse width code (0) ▶
Frequency	No carrier (0) ▶
Coded Expression	BCDtoy, CF, SBS (0)
Gain	0 dB ▶
Level	3.3 V ▶
Impedance	50 Ohm ▶
Input reference delay	0 ns ▶

IRIG-B
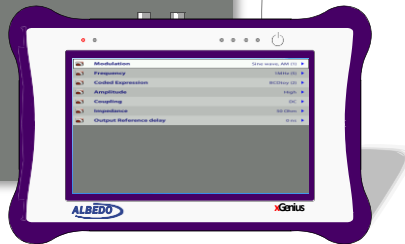
IRIG-B sends a timing signal every second at 100 pulse/sec rate therefore the 100 is the number of bits of each frame. IRIG-B info includes Year, Day, Hour, Min, Sec.
- AM modulated clock reference input and output
- Unmodulated (DCLS) i/o over RS-422 / RS-485 or TTL
- Manchester encoded IRIG-B input and output

Test & Measurement
- Analysis of the received IRIG-B structure

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Precision Time Protocol (IEEE 1588) with **Power Profile** defined in IEEE C37.238 address the requirements of the power industry in terms of accuracy, continuous operation (24/7) and deterministic failure behavior.

Testing PTP with xGenius / Zeus
- Master / Slave: emulation modes
- Frequency & Phase testing

Objectives
- Migration to PTP protocol from NTP or IRIG-B
- Check accuracy, holdover, GNSS, PPS and identify faults
- Facilitate interconnection of time sources and GPS back up

Built in TE chronograph

Tests between PTP master to client clocks

- Time Error (TE) Test
- Bidirectional TE and max | TE |
- Low frequency TE, cTE + dLTE
- High frequency TE
- Delay asymmetry
- Delay between Master PTP and customers

Metrics of Wander

- TIE
- MTIE
- TDEV
- Tables and Graphs

TE analysis (PASS/FAIL)

Objectives

- Monitor the PTP clock
- Determine if Time Error is in range
- Verify the holdover and recovery times

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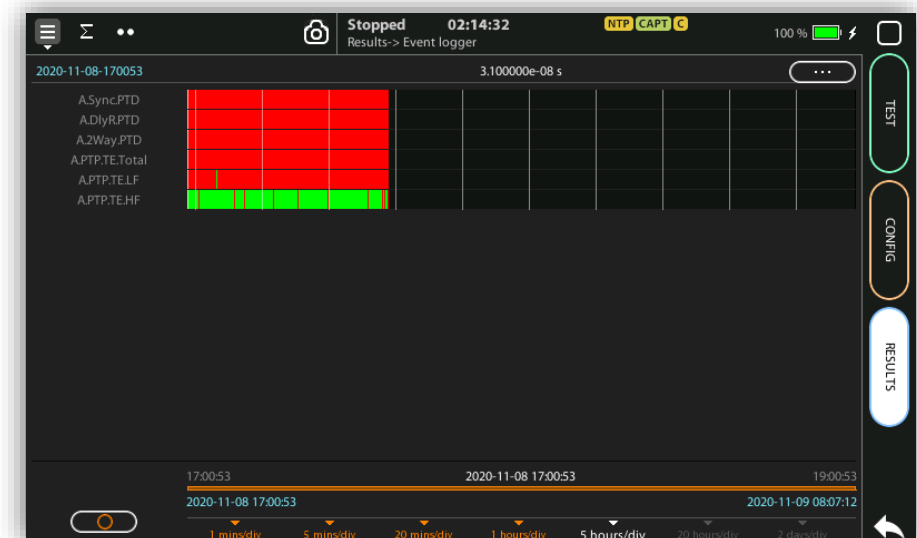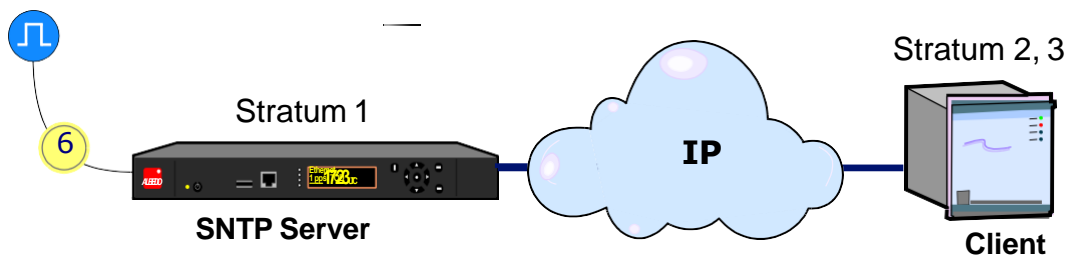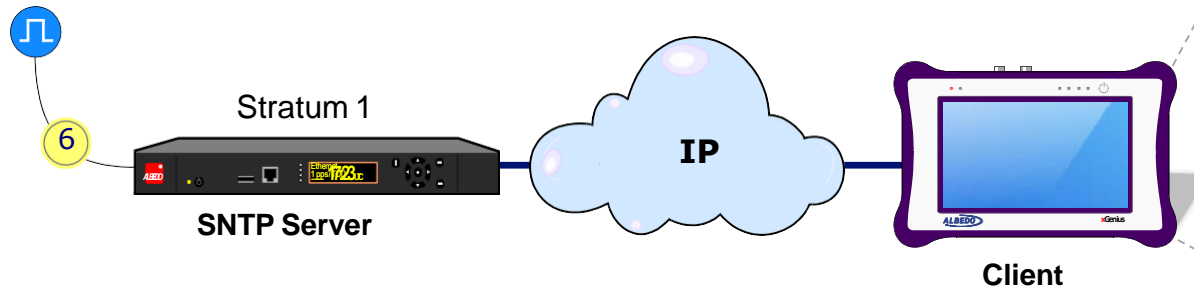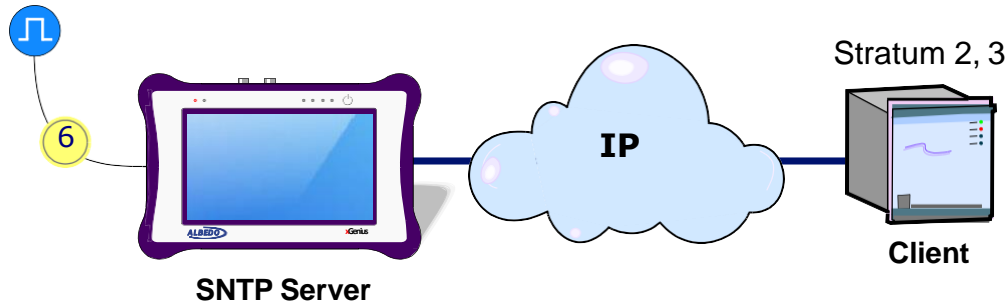
Offset: difference between clocks

Offset = 5'
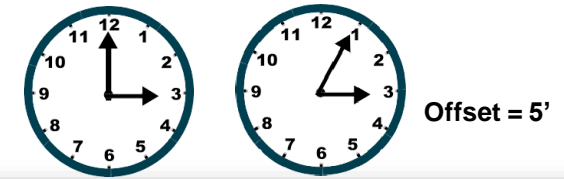
Zeus / xGenius testing features

- NTPv3 / v4 server and client emulation
- Traffic filtering, classification, analysis
- NTP delay and asymmetry
- Statistics of Time Error (TE)

Objectives

- Monitor the PTP clock
- Analyze time error tolerances
- Verify the holdover and recovery times

| 1 | 1 | ... | 0 | Alignment Bits |
| a₁₇ | b₁₇ | c₁₇ | d₁₇ | Channel CAS Bits |

A Remote Alarm Indicator

E CRC-4 Error Signaling Bits — Channel Bytes

C₁ C₂ C₃ C₄ CRC-4 Bits — S Spare Bits
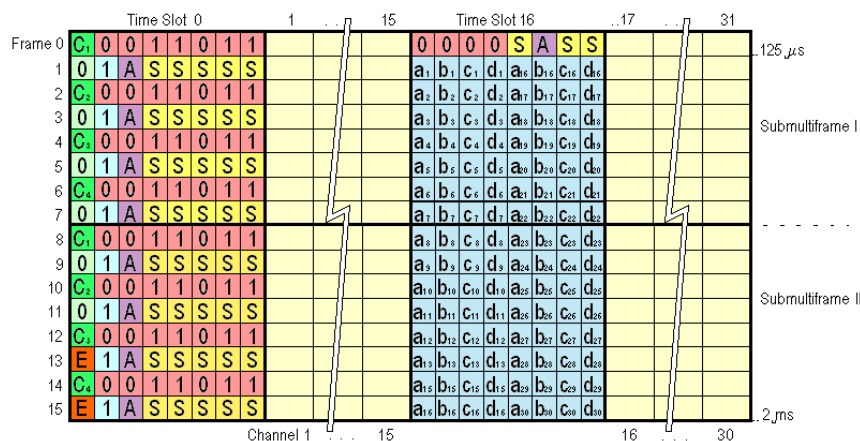
Analysis / Generation

- E1 / T1: frame / unframed with / without CRC
- Overheads: display and edition
- CAS analysis
- Pulse Mask
- Channel map: Busy / Free, Drop / Insert of 64 kb/s

Measurements

- BER
- Line / Freq
- Errors / Alarms
- G.821, G.826, M.2100
- VF: tone generation / analysis
- Attenuation, Freq, Freq. deviation, Level, Peak codes
- E1 / T1 in sync

Analysis / Generation

- Jitter analysis: Peak to peak, RMS, hits, count (.1 at 100kHz)
- Wander: With mask (1µHz to 10Hz)
- Wander: 10 MHz, 2048 kHz, 1544 kHz, 1pps

Synchronization **SyncE**

Port A (Tx)

Port B (Rx)

$f_o = f_i + 10$ ppm

f_i
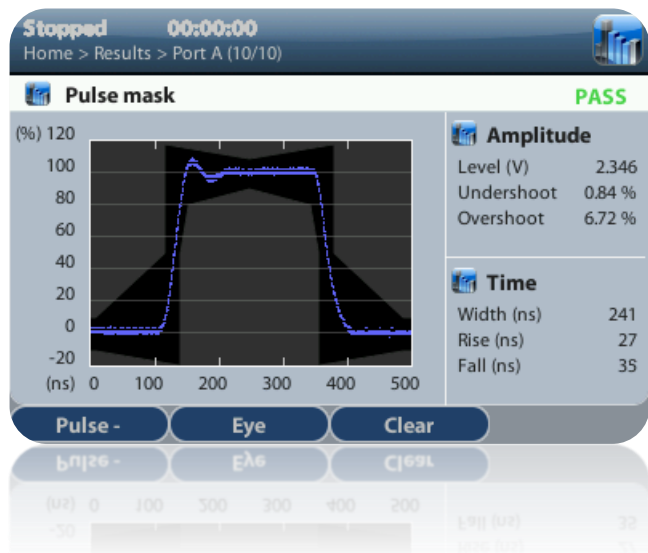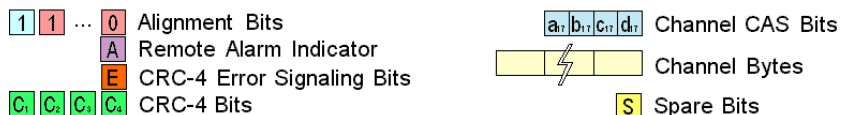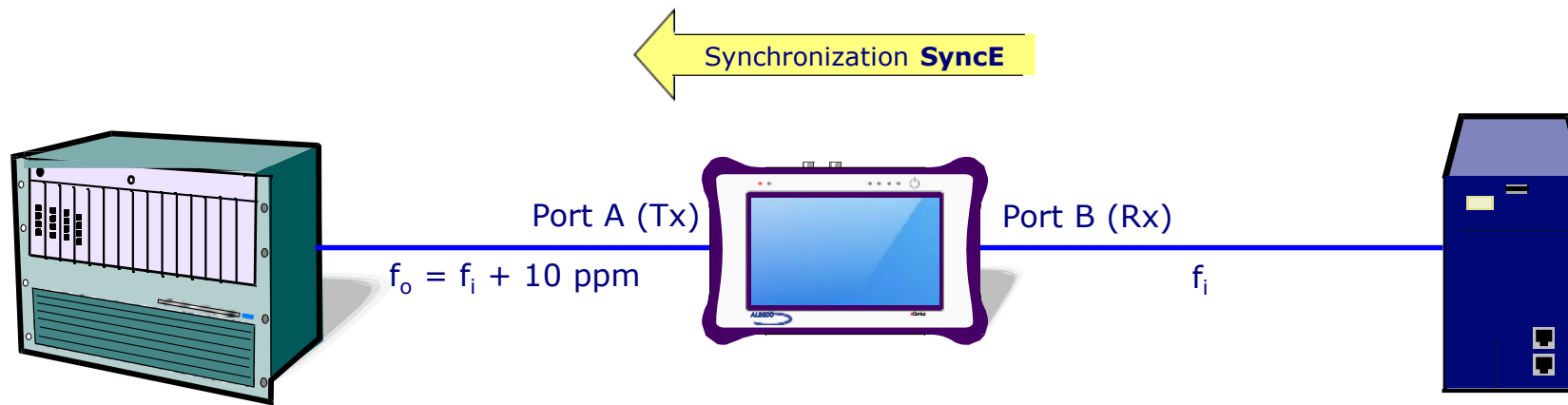
Testers have a set of tests to ensure SyncE

Quality tests

- Synchronism according to ITU-T G8261, G8262, G8264 standards
- Check Line Frequency (MHz), offset (ppm), drift (ppm / s)
- Analysis / Generation of ESMC and SSM messages
- SSM counter & speed

Wander analysis

- SyncE TIE, MTIE and TDEV measurement
- SyncE Wander generation

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Based on hot pluggable modules

- V.24 / V.28, X.12 / V.11, X.21 / V.11, V.35, V.36 / RS-449, EIA-530 / A
- Data, Stop, Parity, inter word gap
- DTE / DCE emulation, Full duplex monitor

Inserting events

- Pattern: TSE, Slip, LSS, All 0, All 1
- Asynchronous interfaces: FRM, PRTY

Modes

- Anomalies: single, rate
- Defects: continuous
- V.24/V.28, X.12/V.11, X.21/V.11, V.35, V.36/RS-449, EIA-530/A

C37.94 Testing **Operation modes**

- Endpoint emulation
- Intrusive pass-through
- Monitoring
- Loopback

SUBSTATION 1

SUBSTATION 2

High Voltage

Power Relay

Power Relay

GPS

GPS

C37.94 Errors, Alarms
G.821 performance
Frame/Unframed BER
Frequency (Hz, ppm, max)
One-Way delay (GPS)
Round Trip Delay
Optical Power

Fiber Optics
IEEE C37.94

Fiber Optics
IEEE C37.94

TDM

Delay statistics

	Current	Average	Range	Std. dev.
Offset (theta)	0.278 μs	0.278 μs	0.003 μs	0.000 μs
Delay (delta)	0.954 μs	0.954 μs	0.000 μs	0.000 μs
Delay (forward)	0.697 μs	0.697 μs	0.002 μs	0.000 μs
Delay (return)	0.140 μs	0.140 μs	0.005 μs	0.001 μs
Asymmetry	0.557 μs	0.557 μs	0.000 μs	0.001 μs
Jitter (psi)	0.278 μs			

What to **measure/emulate/verify**

- Performance: BERT, G.821
- Analysis / generation: of events
- Optical power & frequency measurement
- Asymmetry: One-way / round-trip delay,
- Jitter and wander analysis

Objectives

C37.94 activation, verification & troubleshooting

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Configure / Monitor / Troubleshoot / Results

S U B S T A T I O N - 1

S U B S T A T I O N - 2

S U B S T A T I O N - n

Internet

IP/MPLS

Ethernet / IP

PTP/NTP

NTP

PING / GOOSE
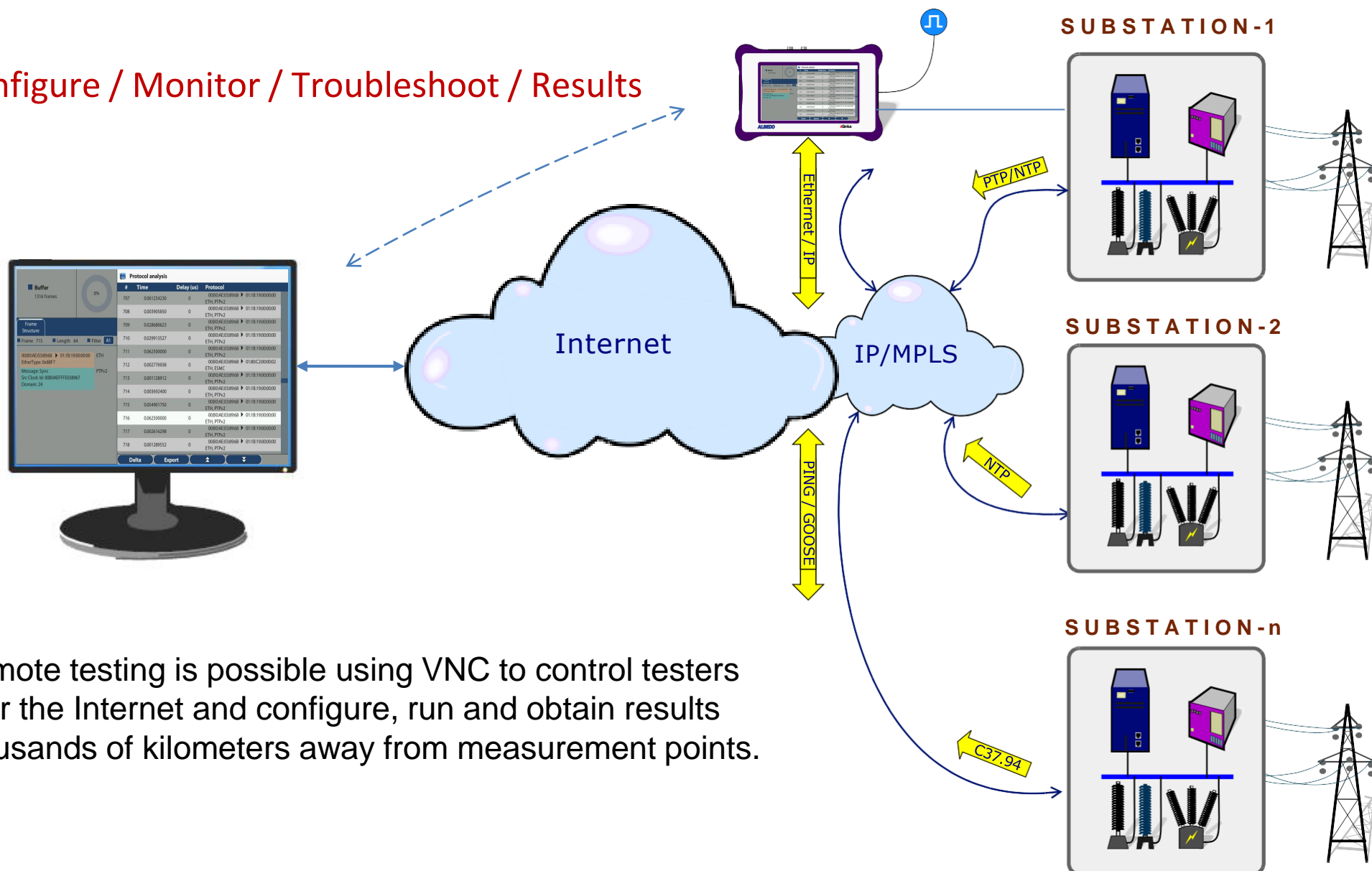
C37.94

Remote testing is possible using VNC to control testers over the Internet and configure, run and obtain results thousands of kilometers away from measurement points.

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Test & Monitor points

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE

G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
k -100BASE-T
L - IRIG-B
M - GbE
N - Round Trip Delay
O - PTP Power / Telecom
Q - GOOSE offset
R - PTP wander
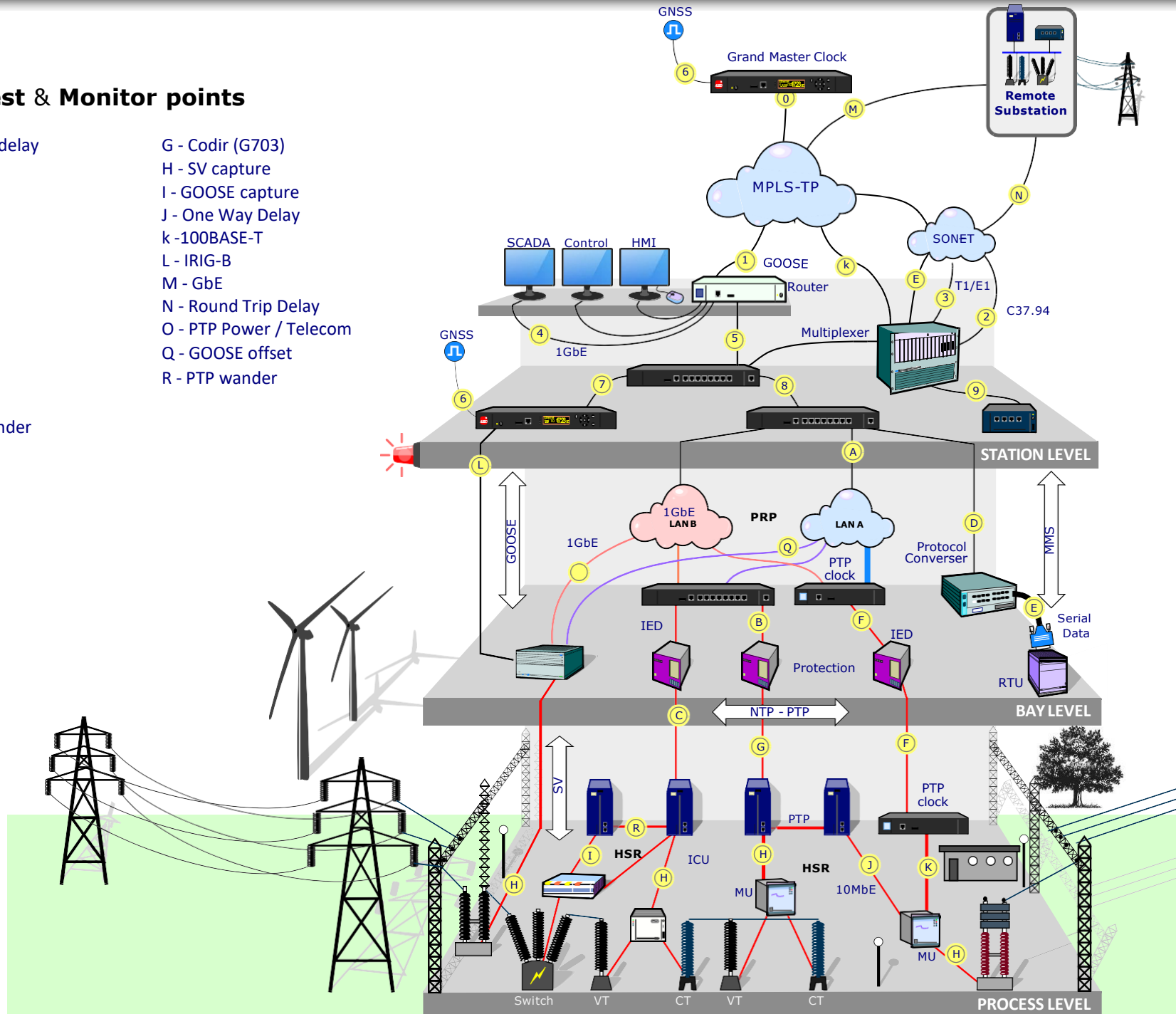
Testing point at **Station** level

Test & **Monitor points**

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE
G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
k -100BASE-T
L - IRIG-B
M - GbE
N - Round Trip Delay
O - PTP Power / Telecom
Q - GOOSE offset
R - PTP wander

GNSS

Master PTP Clock

Remote Substation

MPLS

SONET

SCADA   Control   HMI

Router

GNSS

1GbE

T1/E1

C37.94

Station Clock

Switch

Switch

Multiplexer

GOOSE

STATION LEVEL

Test & **Monitor points**

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE
G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
k -100BASE-T
L - IRIG-B
M - GbE
N - Round Trip Delay
O - PTP Power / Telecom
Q - GOOSE offset
R - PTP wander

Test & **Monitor points**
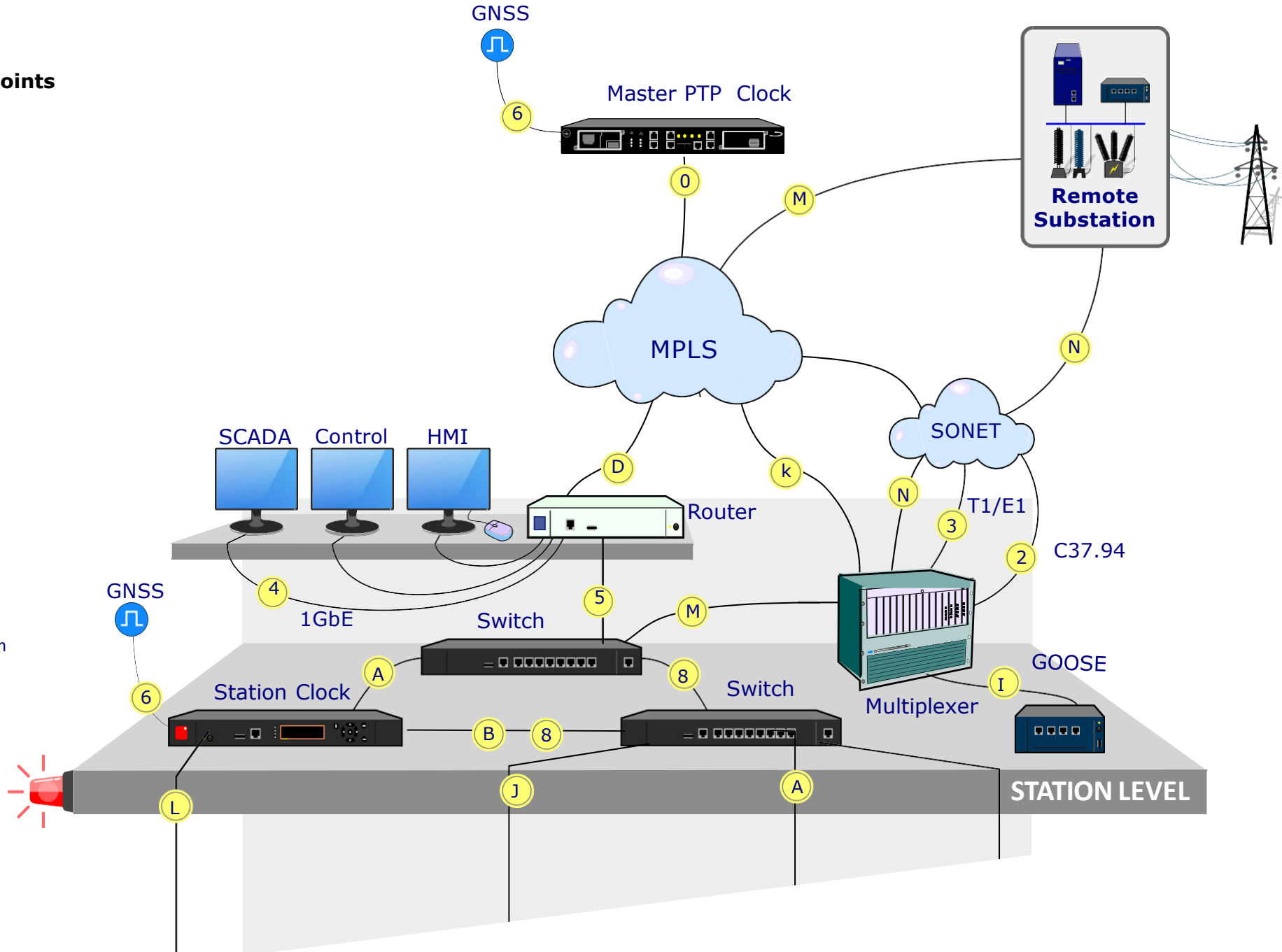
1 - GOOSE delay
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MU
IED
IED
IED
RTU

NTP - PTP

BAY LEVEL

C
G
F

SV

IED
IED
IED
IED

PTP clock

PTP

R
I
HSR
J
ICU
H
H
J
K
MU
10MbE
MU
MU

4
H

Switch
VT
CT
VT
CT
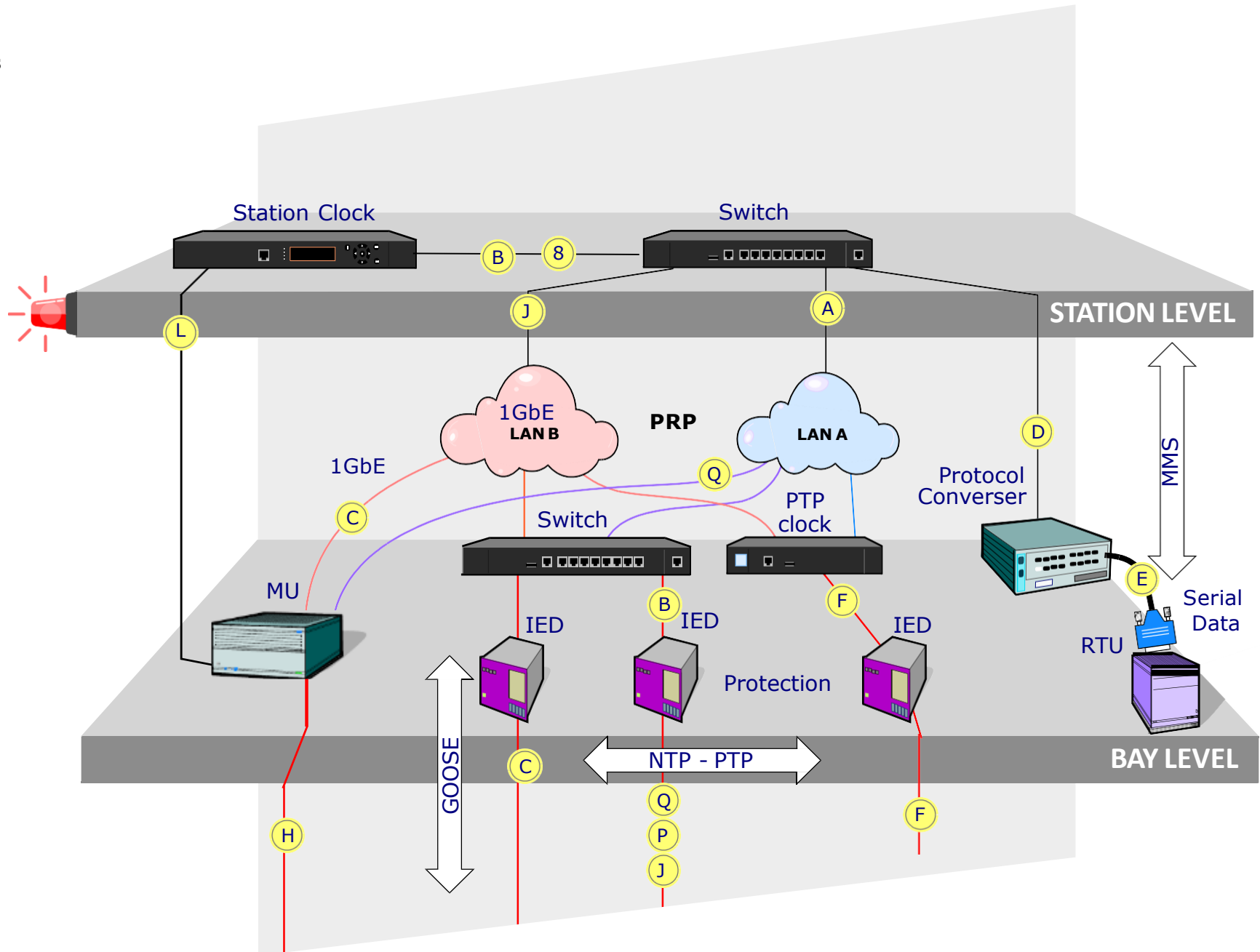
PROCESS LEVEL

Net.Time Power is a synchronization node, compliant with IEC 61850, that supports PTP over PRP and multiple clock options such as NTP, SyncE, 1PPS, ToD, IRIG-B, etc. to satisfy all timing needs in substations. It also includes Power and Telecom PTP profiles and Rubidium oscillator. Net.Time simplifies the provision of timing facilitating the integration of the installed plant for perfect control, protection and data acquisition.

Zeus

xGenius

ALBEDO testers provide deep insights to design, install, maintain, troubleshoot and engineer communications infrastructures of the Smart Grid. The unit is able to test Ethernet/IP, PTP, GbE, IRIG-B, T1/E1, G703, C37.94 and GOOSE, SV and MMS protocols. One-way-delay tests, assisted by GPS, is possible at all interfaces. Zeus has a set of programmable filters to capture live data traffic at wire-speed. You can now analyze GOOSE, SV, MMS and other protocols to decode and save in PCAP format or calculate delays from local or remote substations.

WAN

MPLS
SyncE
E1/T1

GOOSE / SV
TCP / IP

PTP / SNTP
IRIG-B / PPS

IEC 61850

Substation

C37.94
OWD

Teleprotection
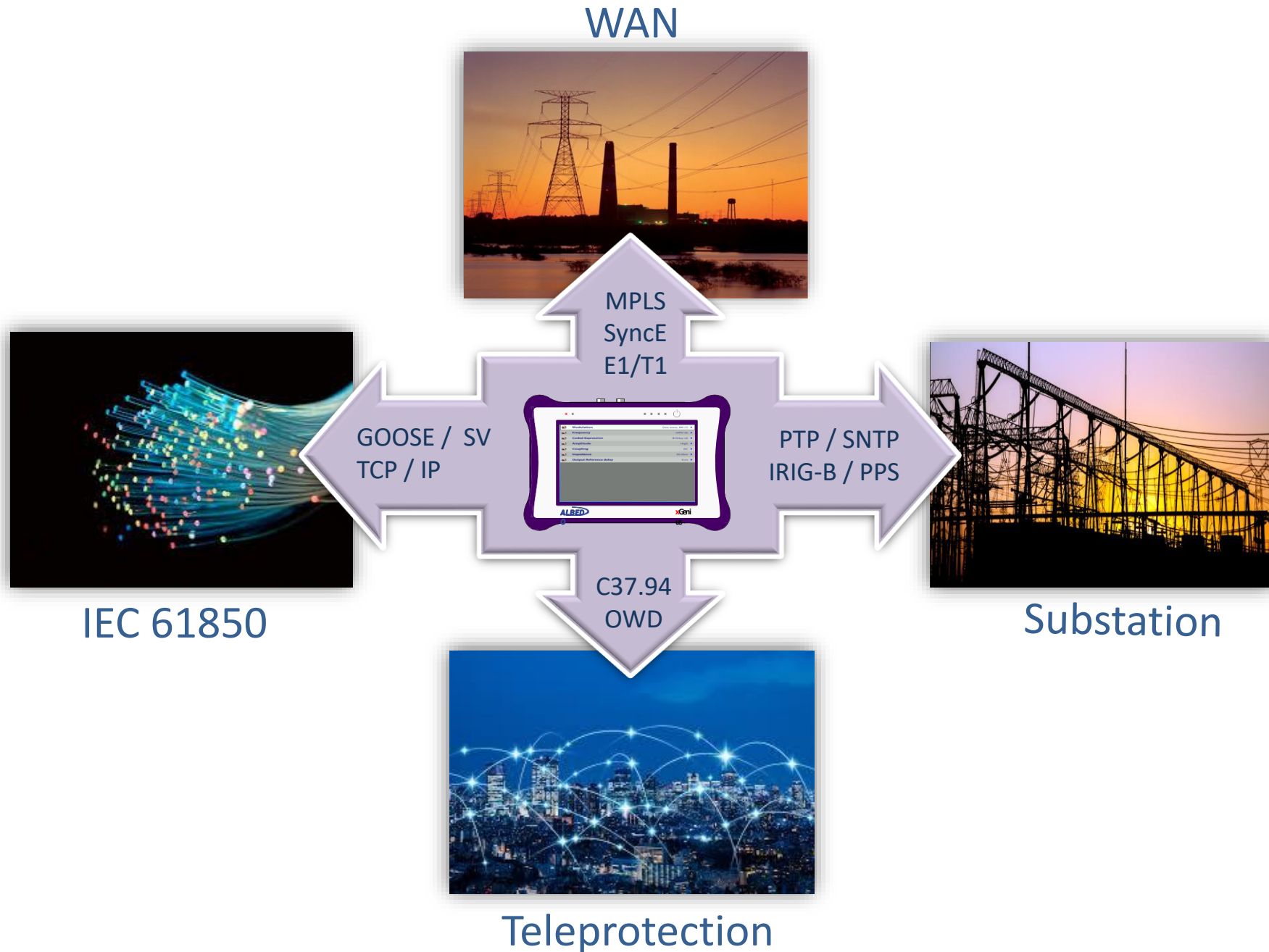
AAA: Authentication, Authorization, and Accounting

ACL: Access Control List

AP: Access Point

Busbar: Metallic strip or bar, typically housed inside switchgear, panel boards, and busway enclosures for local high current power distribution **C37.94**: TDM interface devoted for teleprotection

CB: Circuit Breaker designed to close or open electrical circuit under normal or abnormal conditions. It operates on relays command.

CBWFQ: Class-Based Weighted Fair Queuing

CG: Connected Grid

CID: Individual configuration of each IED

CIP: Critical Infrastructure Protection

CLI: Command-Line Interface

CorpSS: Corporate Substation

CT: Current Transformer, used for measurement of current, if too high to apply directly to measuring instruments, a CT produces a proportional current which can be measured and recorded, CT are used in metering and protective relays

DAN: Doubly Attached Nodes implementing HSR or PRP

DAU: Data Acquisition Unit

Disconnector: isolates physically and visually the lines

DMZ: Demilitarized Zone

DCB: Directional Comparison Blocking

DCS: distributed control systems

DSC: Differentiated Services Code Point

ESP: Electronic Security Perimeter

Feeder: Transmits power to the distribution points

GM: Grandmaster

GNSS: Global Navigation Satellite System

GOOSE: Generic Object-Oriented Substation Events is a control model defined as per IEC 61850 which provides a fast and reliable mechanism of transferring event data over entire electrical substation networks. When implemented, this model ensures the same event message is received by multiple physical devices using multicast or broadcast services

HMI: Human Machine Interface

PTP: Precision Time Protocol

RedBox: Redundancy Box

Relay: is automatic device which senses an abnormal condition of electrical circuit and closes its contacts and complete the circuit breaker trip.

REP: Resilient Ethernet Protocol

RCT: Redundancy Control Trailer

RTU: Remote Terminal Unit

SA: Substation Automation

SAN: Singly-Attached Node

Secondary Lines: lower voltage side at the substation

SCADA: Supervisory Control And Data Acquisition, transmits and receives data from events of controls, measuring, safety and monitoring. Power system elements can be controlled remotely over. Remote switching, telemetering of grids showing voltage, current, power, direction, consumption in kWh, synchronization.

SCD: Substation Configuration Description **SCL**: Substation Configuration Language **SNTP:** Simple Network Time Protocol

Station Bus: Connects the entire substation and helps provide connectivity between central management and individual bays

STP: Spanning Tree Protocol

SV: Sampled Values, is a method to read instantaneous values such as currents, voltages, impedances, etc. from CTs, VTs or digital I/O and then transmitted to make them are available for those IED subscribed.

Switchgear: combination of switches, fuses or CB to control, protect and isolate electrical equipment

SyncE: Synchronous Ethernet

TLV: Type, Length, Value

VT: Voltage Transformer (see CT)Potential Transformer, gives the reference voltage to the Relay for Over-voltage or Under-voltage Protection

UCA IuG: Utility Communications Architecture International Users Group

VDAN: Virtual D

HQoS: Hierarchical Quality of Service

HSR: High-Availability Seamless Redundancy

IA: Industrial Automation

ICS: Industrial control systems

ICU: Intelligent Control Unit

IEC: International Electrotechnical Commission

IEC 61850: Standard defining communication protocols for intelligent electronic devices at electrical substations

IED: Intelligent End Device, microprocessor-based controllers of power system equipment, such as circuit breakers, transformers and capacitor banks to enable advanced power automation.

IRIG: Inter-Range Instrumentation Group

ISE: Identity Services Engine

L3VPN: Layer 3 Virtual Private Network

LA: Lightning Arrester protects the power grid from electric storms

MQC: Modular QoS Command-Line Interface

MMS: Manufacturing Message Specification, messaging system for exchanging real-time data and supervisory control information. Allows client such as SCADA, an OPC server or a gateway to access all IED objects **MPLS**: Multi-protocol Label Switching

MU: Merging Unit connected to the process bus converts analog data(ie. volts, currect...) into digital information

NERC: North American Electric Reliability Corporation

NIST: National Institute of Standards and Technology

NMS: Network Management System

OAM: Operations and Maintenance

PCP: Priority Code Point

PIOC: Instantaneous overcorrent Protection

PLC: Programmable Logic Controller

PMU: Phasor Measurement Unit

POTT: Permissive Overreaching Transfer Trip

PP: Primary Power

Process Bus: Connects primary units and control equipment to the IEDs

PRP: Parallel Redundancy Protocol

PRTC: Primary Reference Clock

PT: see VT

T-GM: Grand Master PTP

T-BC: Boundary Clock

T-TSC: Slave Clock

That' all

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in Test we Trust