IEC 61850 – The Digital Power System

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Agenda

IEC 61850 and the Digital Substation

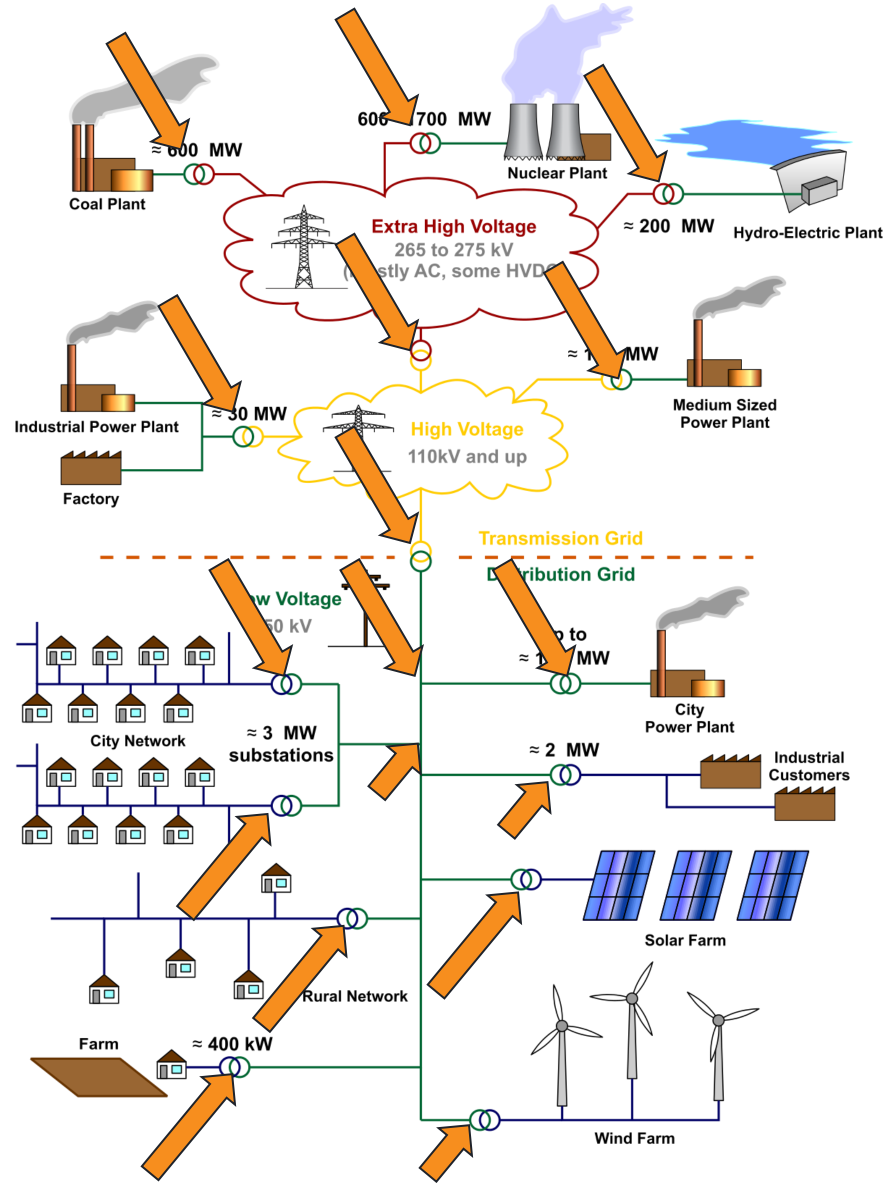
- What is Substation Automation?
- High-Level Review of IEC 61850 and Digital Control
- Communication
- Data Model
- Engineering and Testing Process
- Benefits/risks

Future IEC 61850 Applications

IEC 61850 – Substation Automation

What is a substation?

“A node on the electric grid where power is transformer, flow controlled, and monitored”



IEC 61850 – Substation Automation

What is automation?

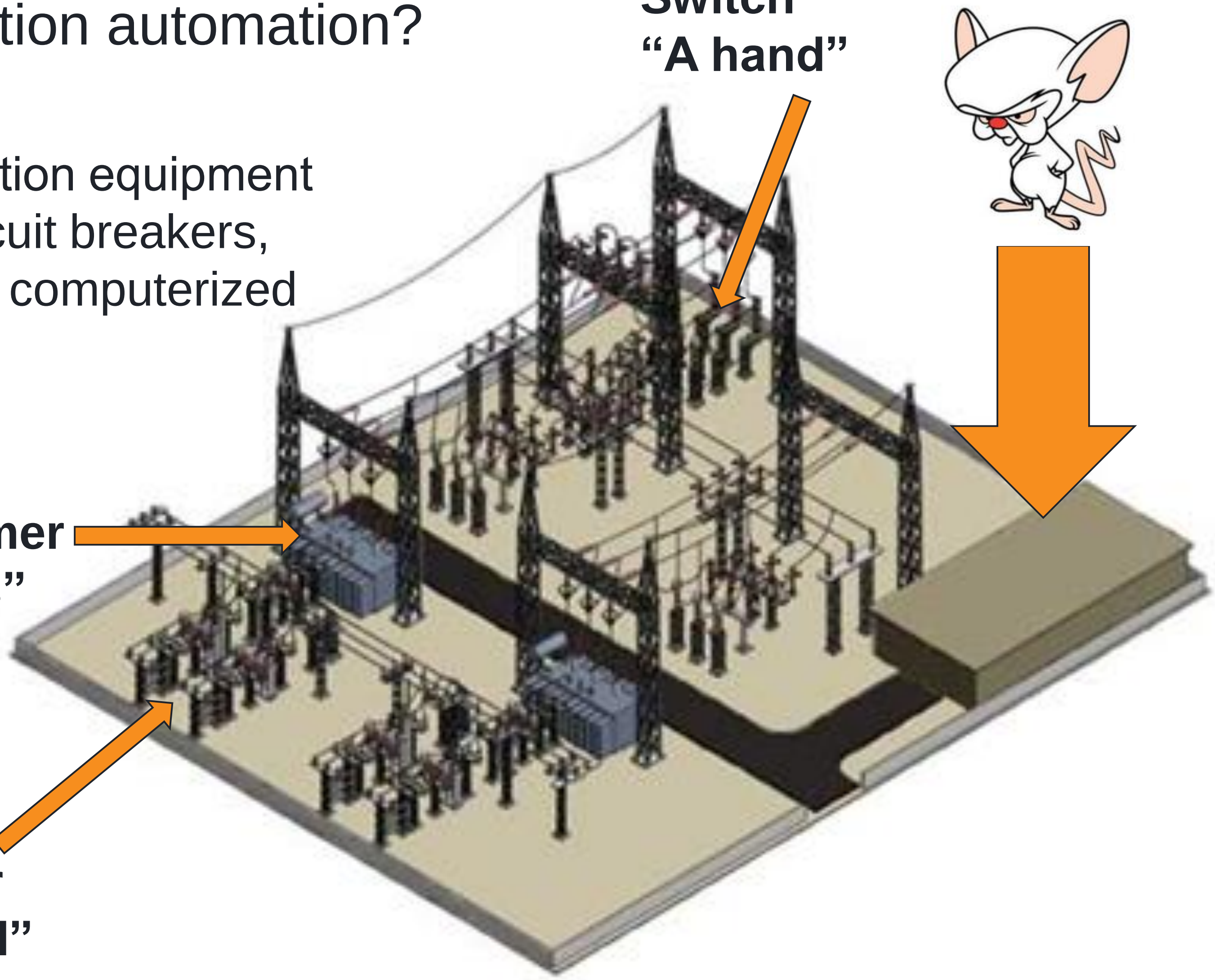
"The use of computers and machines to control mechanisms with <u>minimal</u> human guidance"

IEC 61850 – Substation Automation

What is substation automation?

“Control of substation equipment (transformers, circuit breakers, switches) through computerized system”

Switch
“A hand”



Transformer
“The legs”

Circuit
Breaker
“A hand”

IEC 61850 – Substation Automation

IEC 61850 is a standard for substation automation communication

aka – how does "the brain" communicate

<u>Goals of IEC 61850</u>

- A communication protocol designed to model the entire station

"Defines the rules of engagement for communication in a substation"

- Promotion of high inter-operability between systems from different vendors

"Vendor agnostic – same rules regardless of the manufacturer"

- A communication protocol that can be made future proof

"Network based – similar to an office computer network"

- Define testing required to ensure equipment conforms to the standard

"How are you sure that everyone is playing by the same rules"

IEC 61850 – Substation Automation

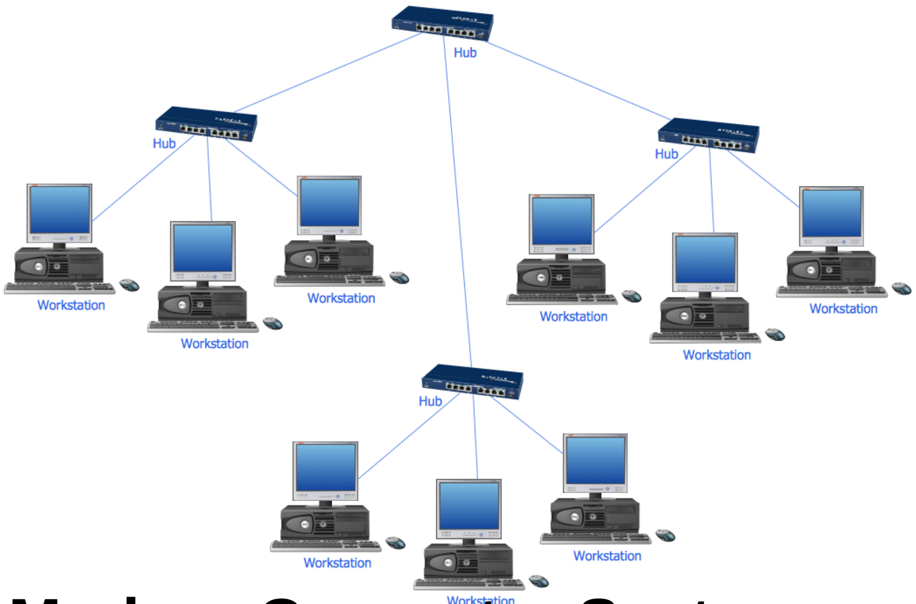
The Premise

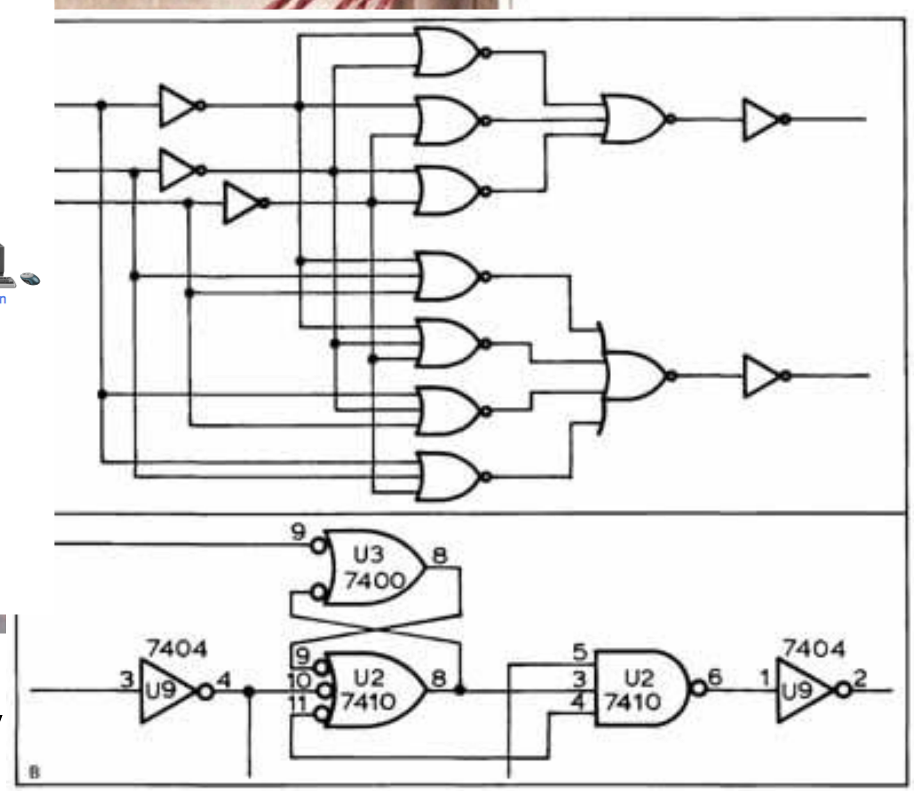
- Non-propriety, secure, and reliable network communication within a electric substation

Network Based Communication

- Analog (CT/PT) and discrete signals (contacts/trip/close) are transmitted over IT-based networks
- Communication paths “wiring” and logic is defined in software in lieu of physical wiring

IEC 61850 – Substation Automation





Modern Computer System

-Digital logic made possible by common programming languages

-Standards enable off-the-shelf products

Original Computer

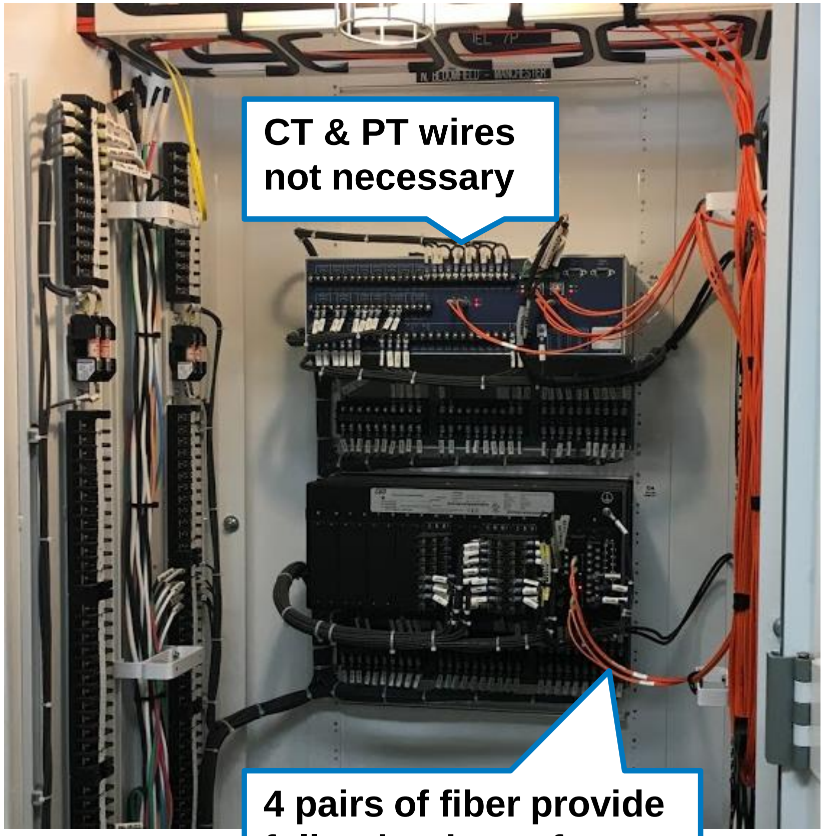
-Wired logical connections

-Custom design

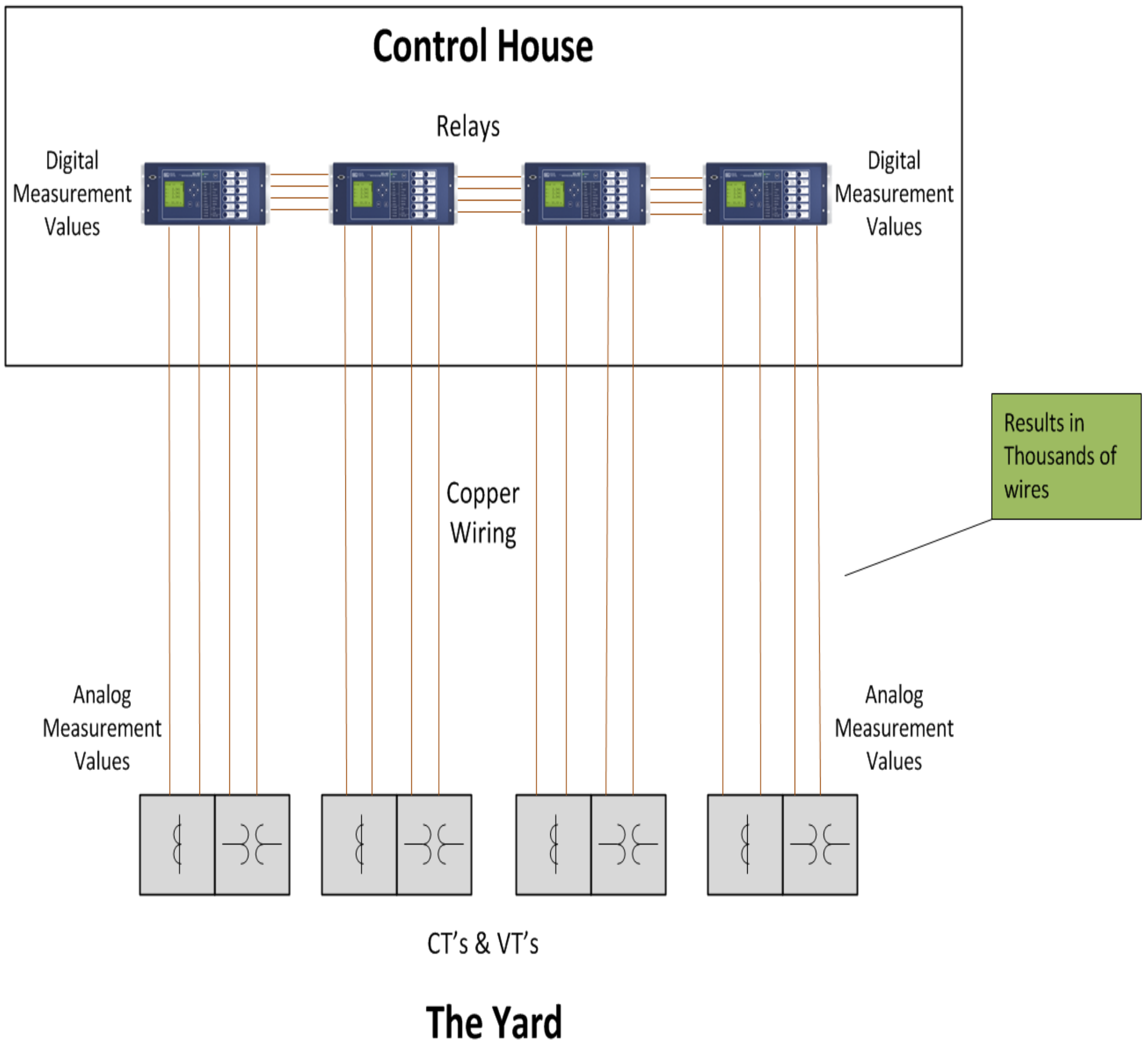
Conventional vs. IEC 61850 Station

Example of a recently constructed control panel

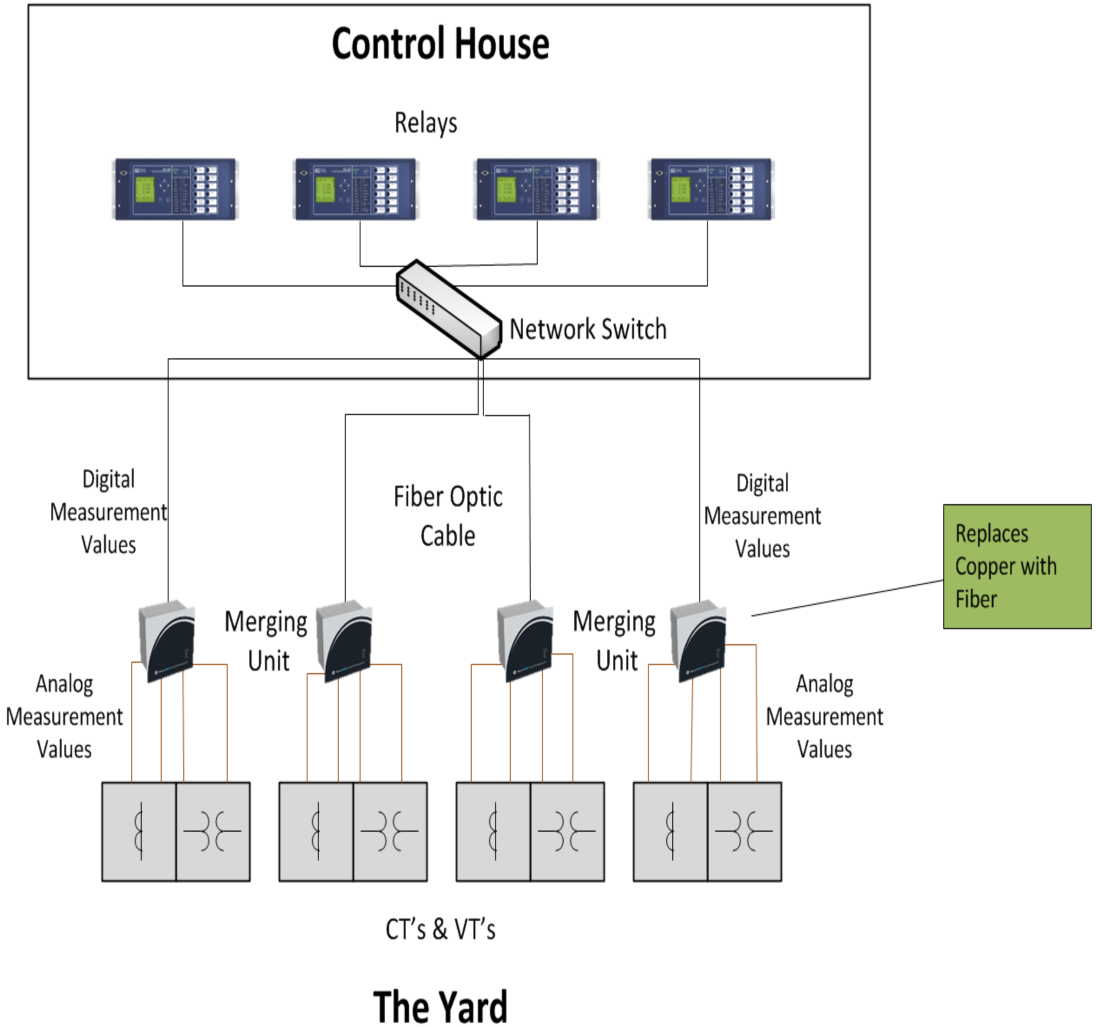
Relay panel with partial 61850 installation



Conventional Substations

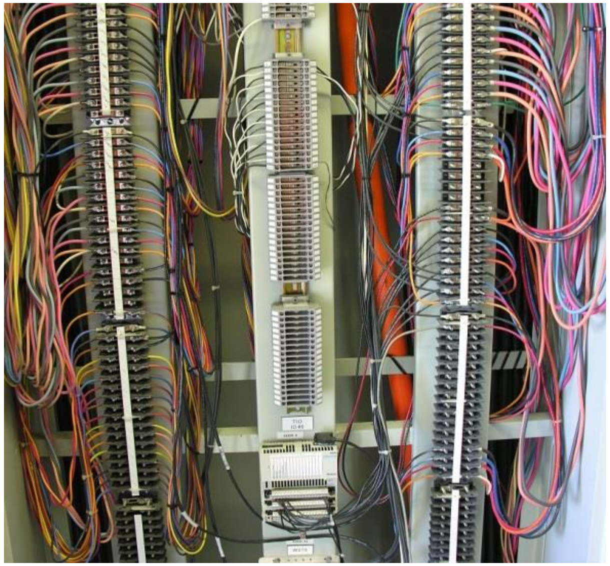


An IEC 61850 Approach



Wiring Comparison

Conventional



- Labor intensive and expensive wiring
- Limited performance and data transmission capabilities

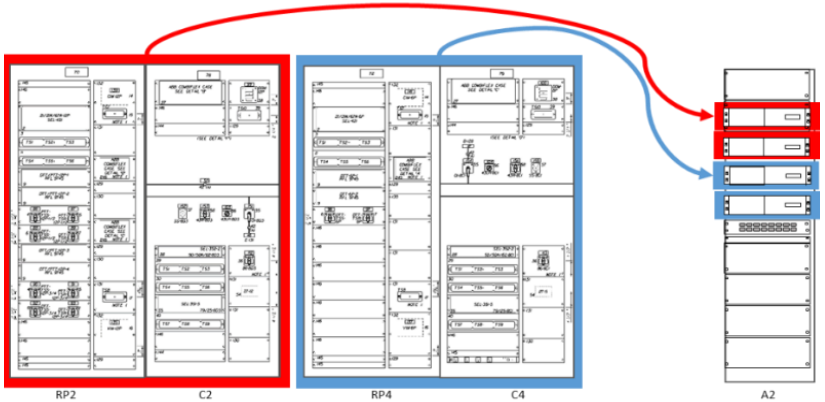
IEC 61850

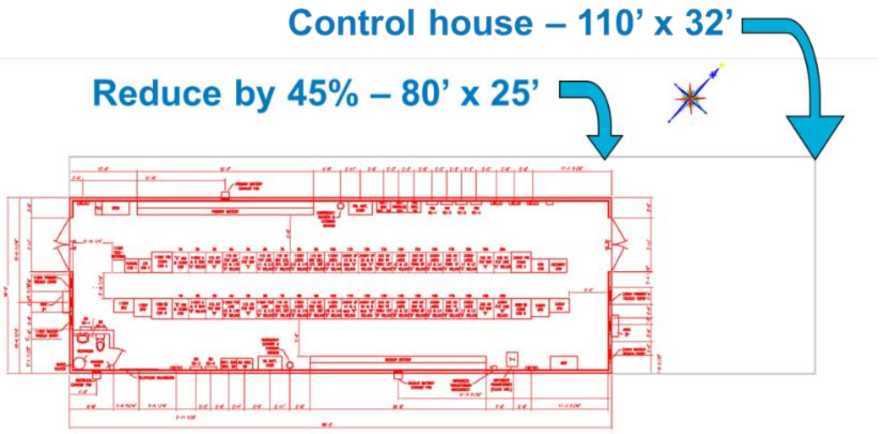
- Simplified and cost-effective
- Enhanced performance and data transmission capabilities

IEC 61850 – Digital Control System

Digital Control/Protection System

- Control is performed over network through digital devices (HMIs, relays, etc.)
- Test switches are not needed in the control house as voltages and currents are converted to digital signals in the yard
- Panel reduction and therefore control house size reduction

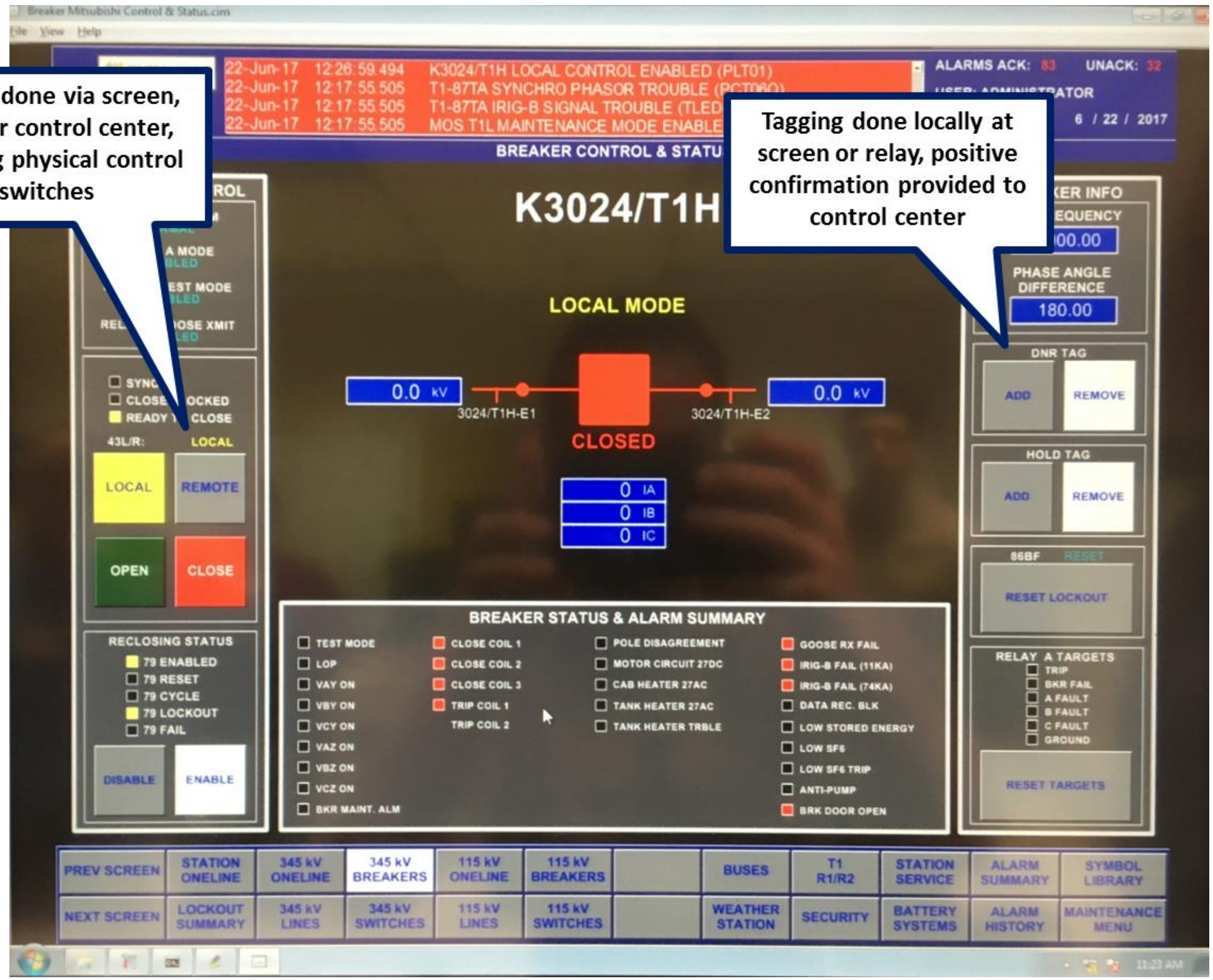




Digital Control System Example

Control done via screen, relay, or control center, reducing physical control switches

Tagging done locally at screen or relay, positive confirmation provided to control center

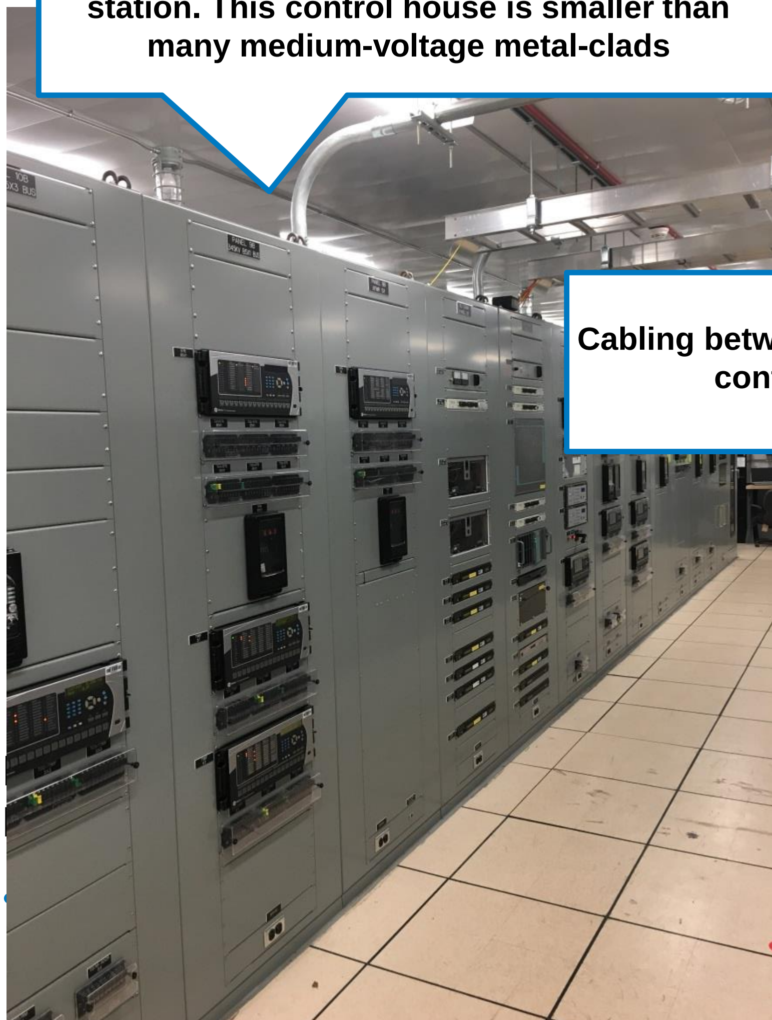


In-Use Digital Control System

- Breaker Control Screen

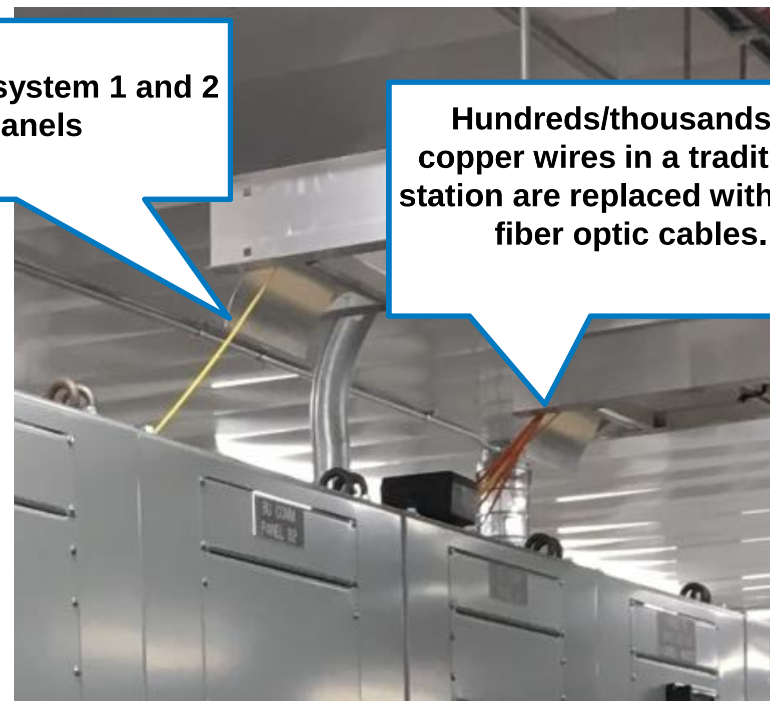
IEC 61850 System Example

System 1 relay package for a 345 kV switching station. This control house is smaller than many medium-voltage metal-clads



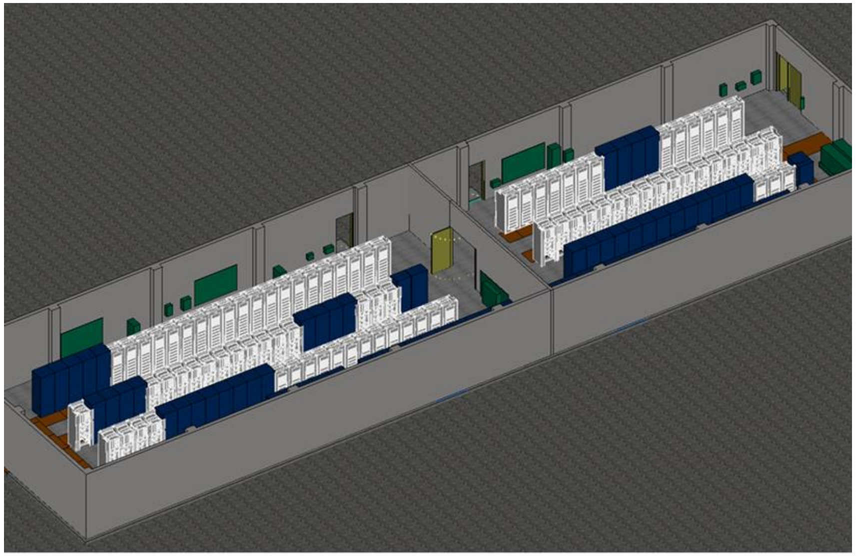
Cabling between system 1 and 2 control panels

Hundreds/thousands of copper wires in a traditional station are replaced with a few fiber optic cables.



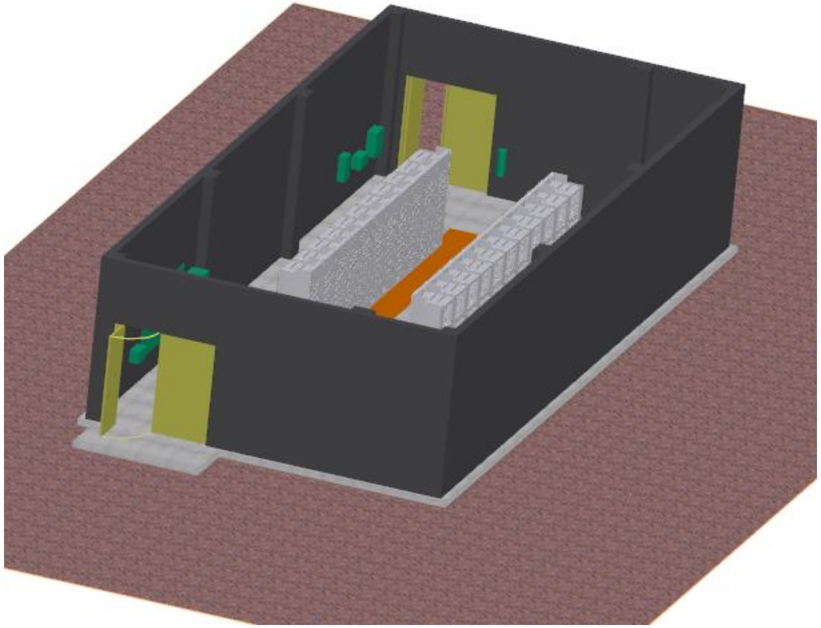
IEC 61850 – Substation Automation

Recently constructed 345kV control house



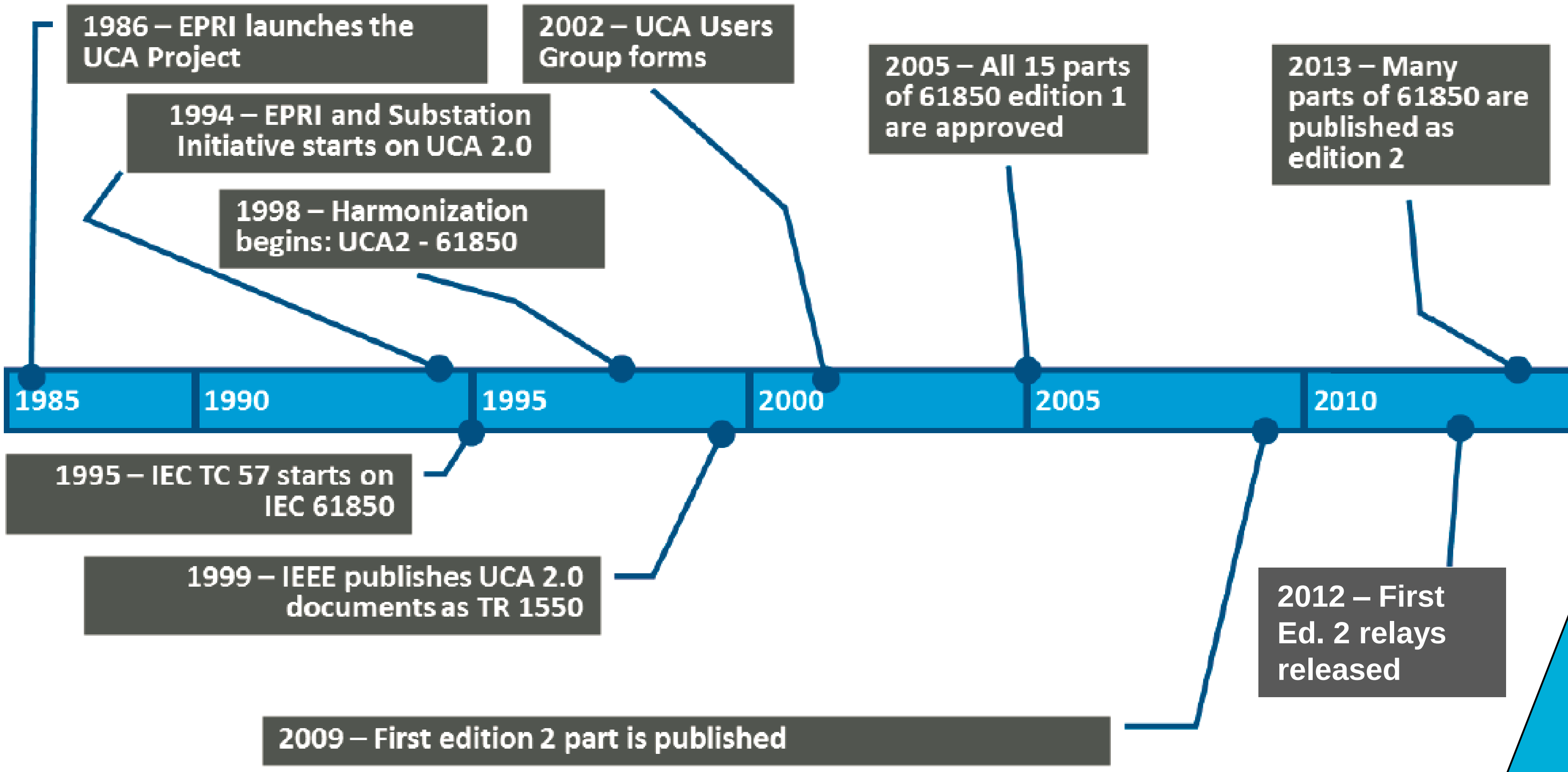
158’-4” x 41’

Same 345kV control house using IEC 61850



~60’’ x 30’

IEC 61850 – Substation Automation History



Today there are 28 separate documents under IEC 61850 alone, along with supplemental material from IEEE and CIGRE

IEC 61850 – Substation Automation

- What makes IEC 61850 different from other standards:
  - <u>Data mapping of **electric substation** equipment</u>
  - <u>Engineering and testing processes are built into the standard</u>
  - Communication protocols
    - GOOSE - Fast Transfer
    - SMV - Sampled Data
    - MMS – Reporting
  - Each packet has:
    - Quality
    - Time sync
    - Test/Simulation

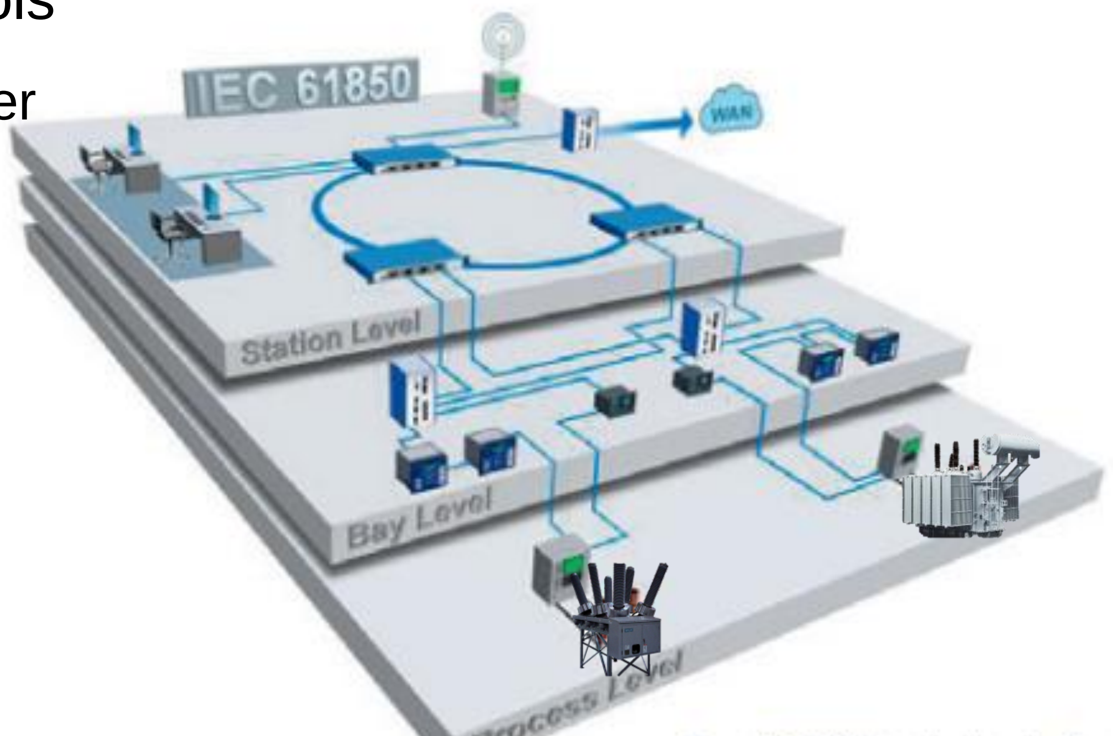


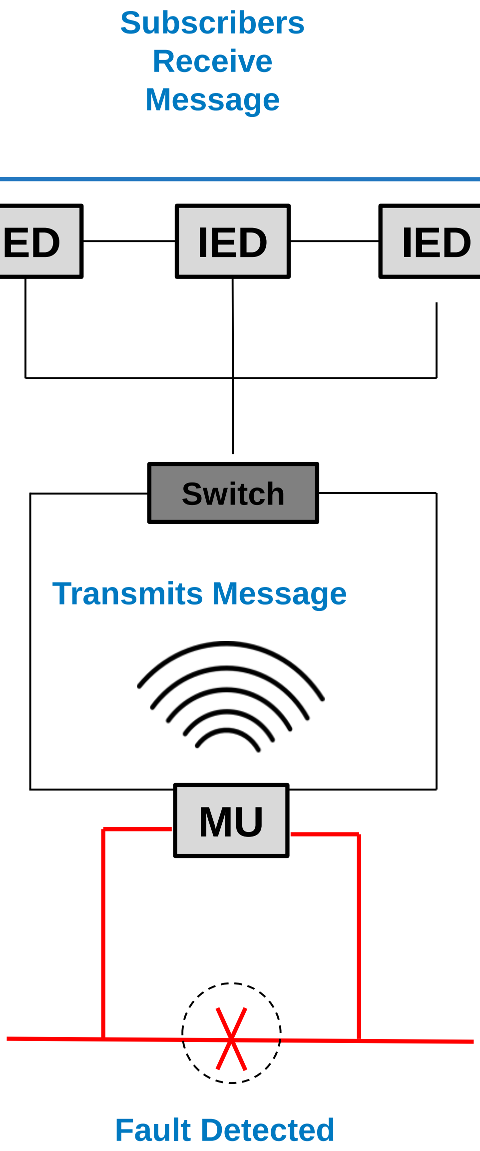
Figure: IEC 61850 Substation Automation Syste

Communication

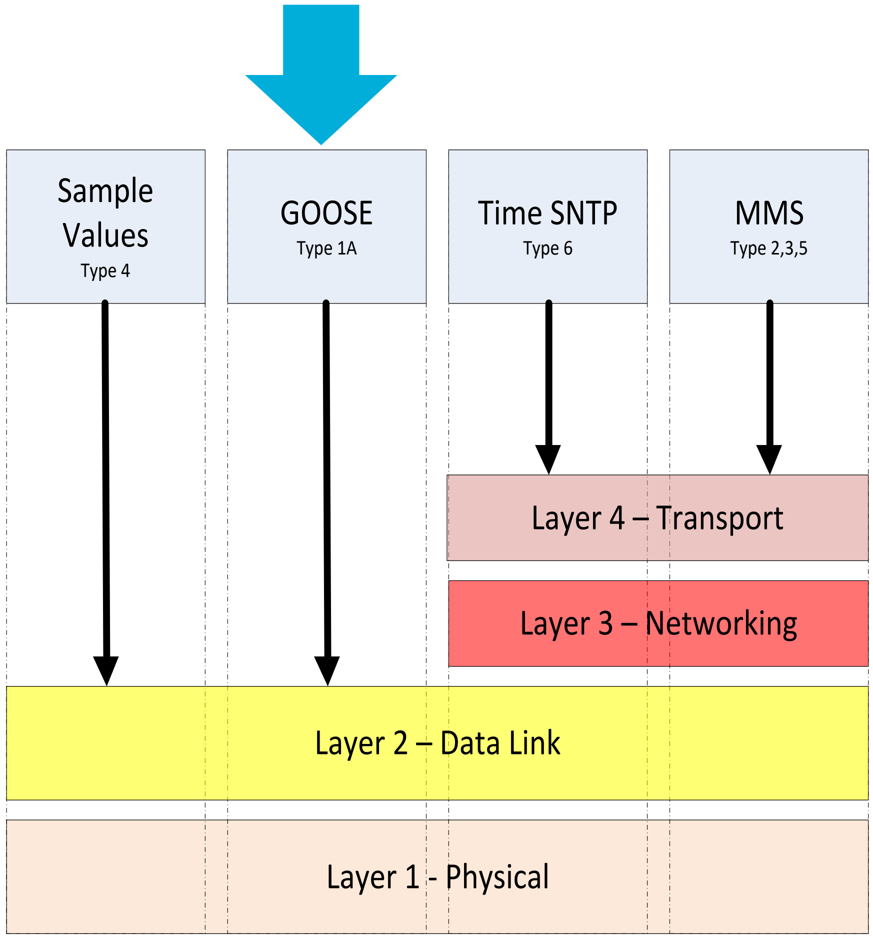
Dial "61850" for help

GOOSE Messaging

- Generic Object-Oriented Substation Event
  - Device to multi-device communication
    - IED transmits message
    - Devices subscribe to message
  - Event-driven message
  - Message sent repeatedly every predetermined interval (~ms)
  - Contains a dataset
    - Think of an “Envelope” not just a “point”

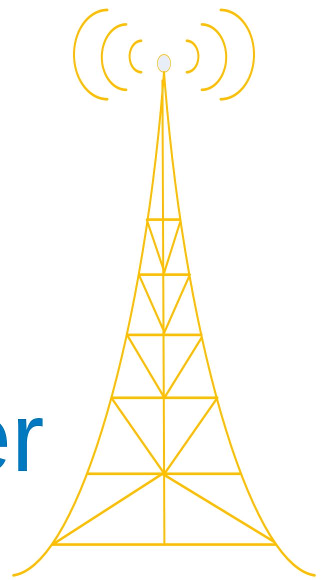


GOOSE – Layer 2

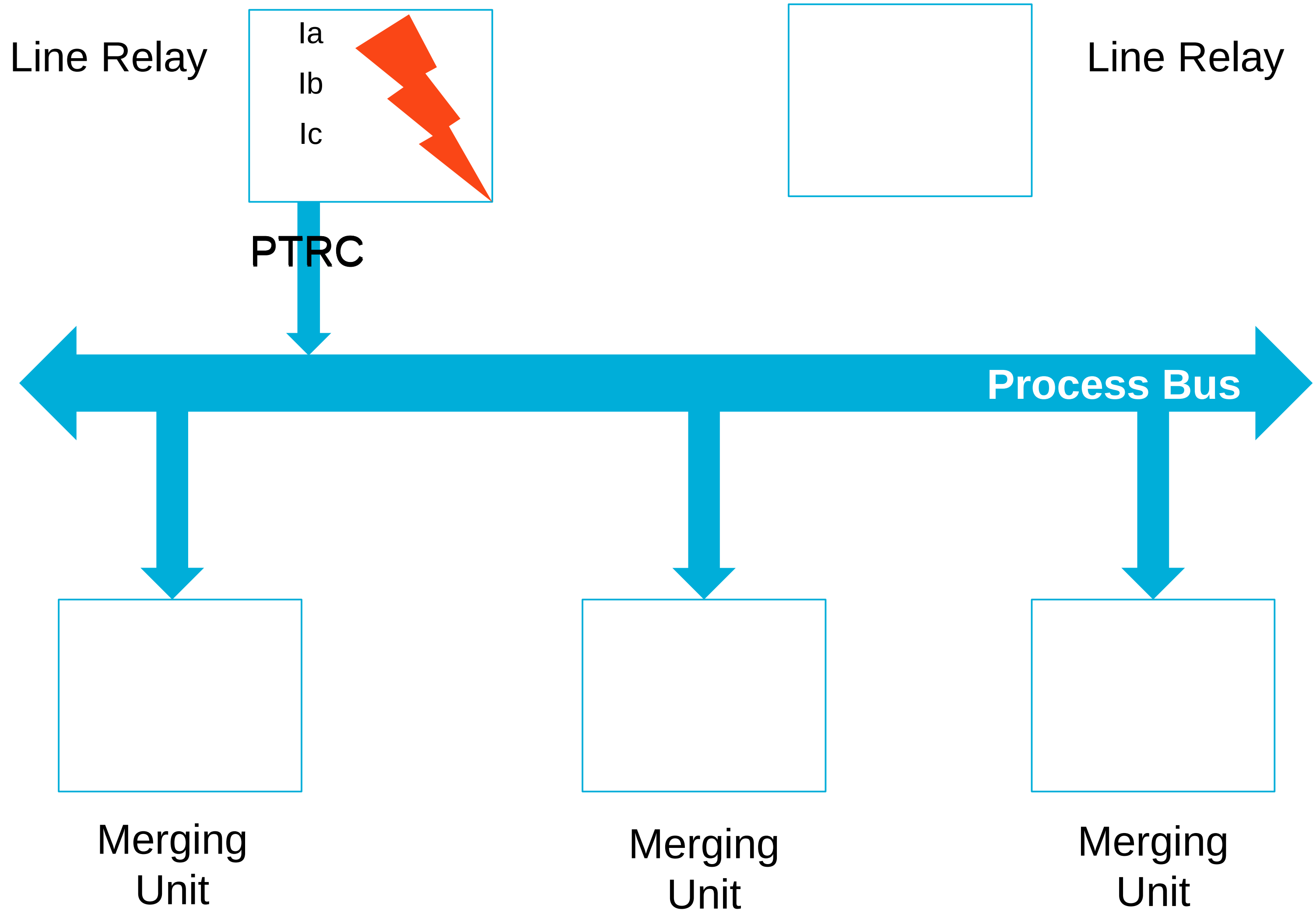


Publisher-Subscriber Model

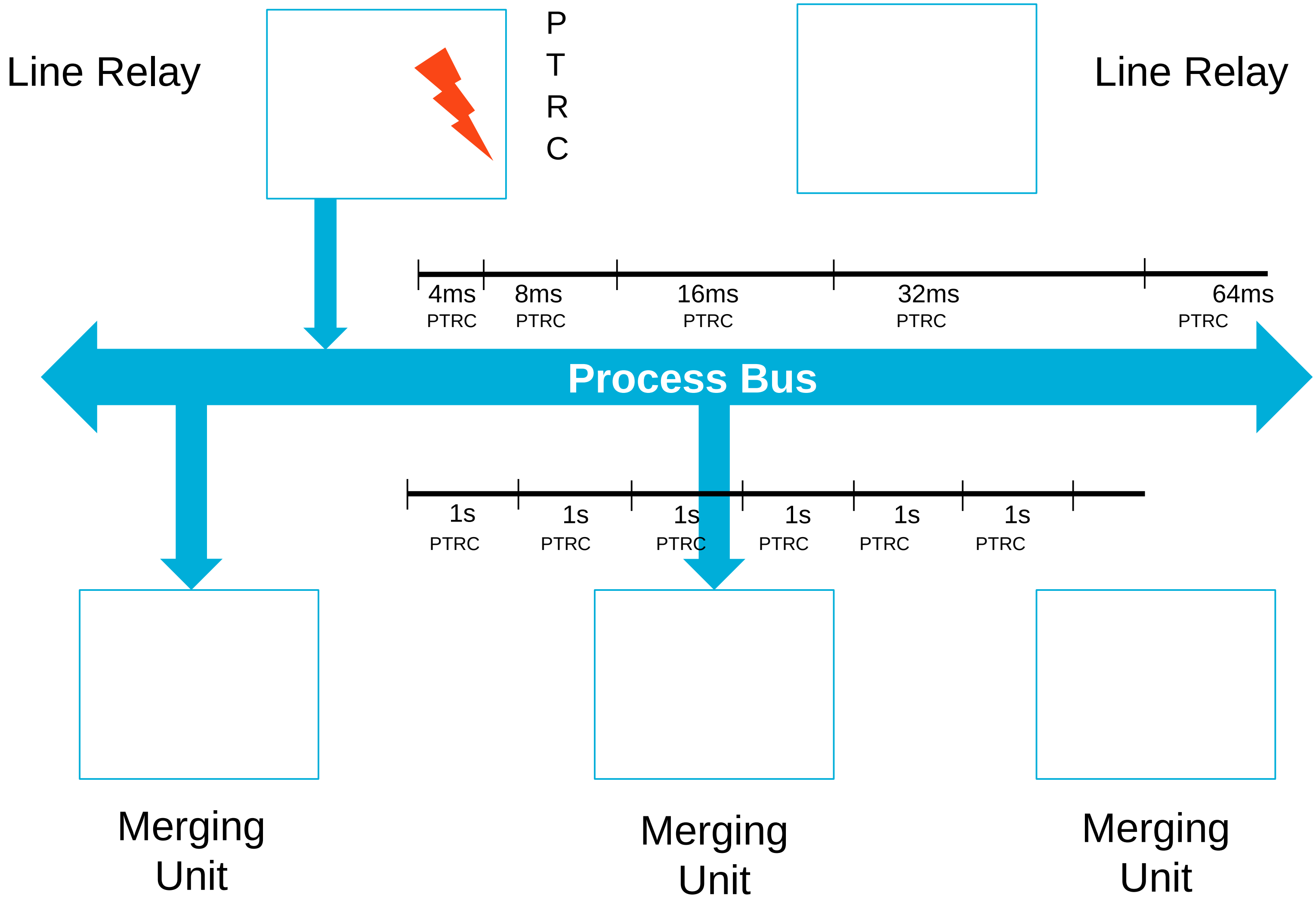
- Messaging pattern to categorize and filter data
  - Publisher – <u>sends</u> data to a network
  - Subscriber – <u>subscribes</u> to a specified type of data



GOOSE – An Event-Driven Message

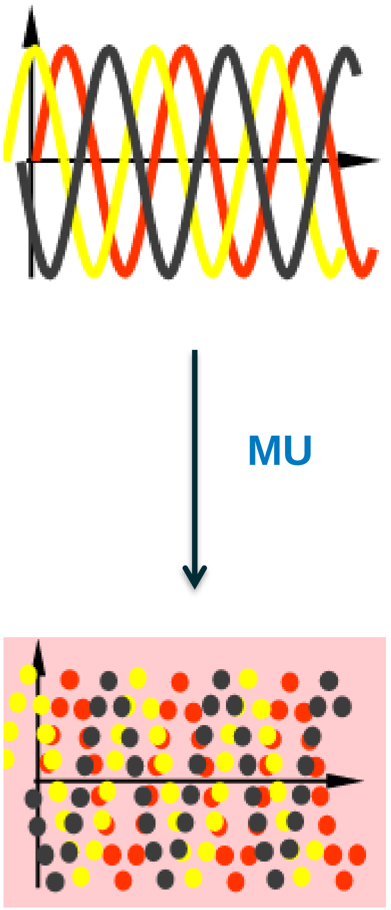


GOOSE on the Process Bus

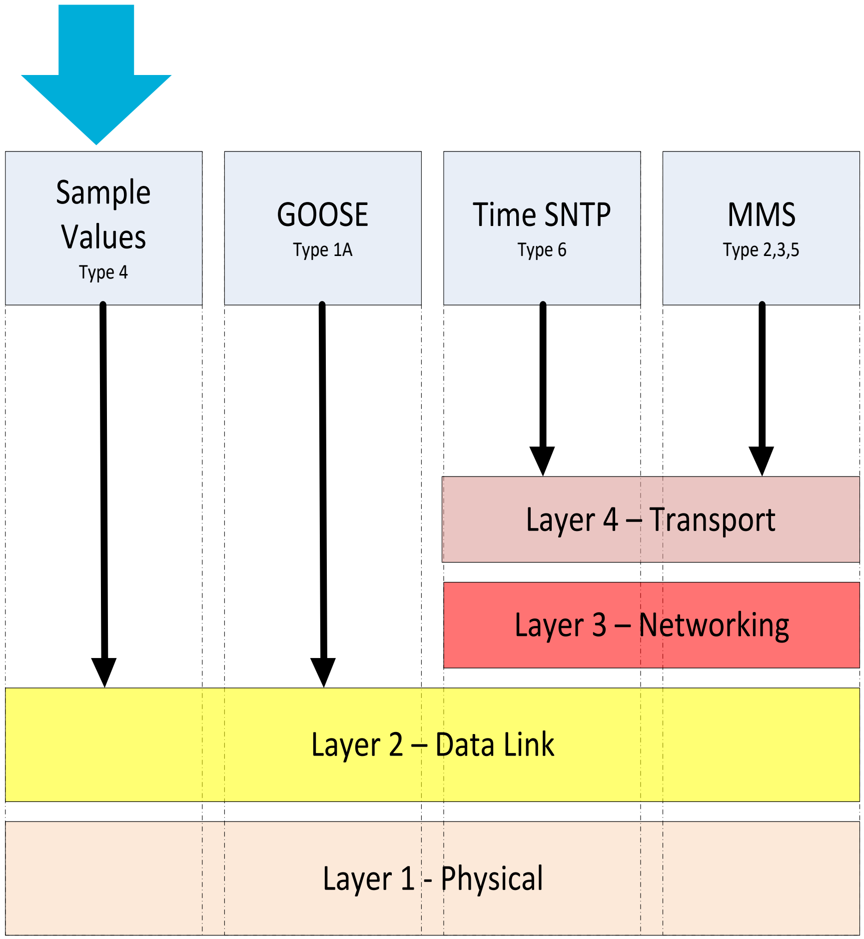


Sampled Values

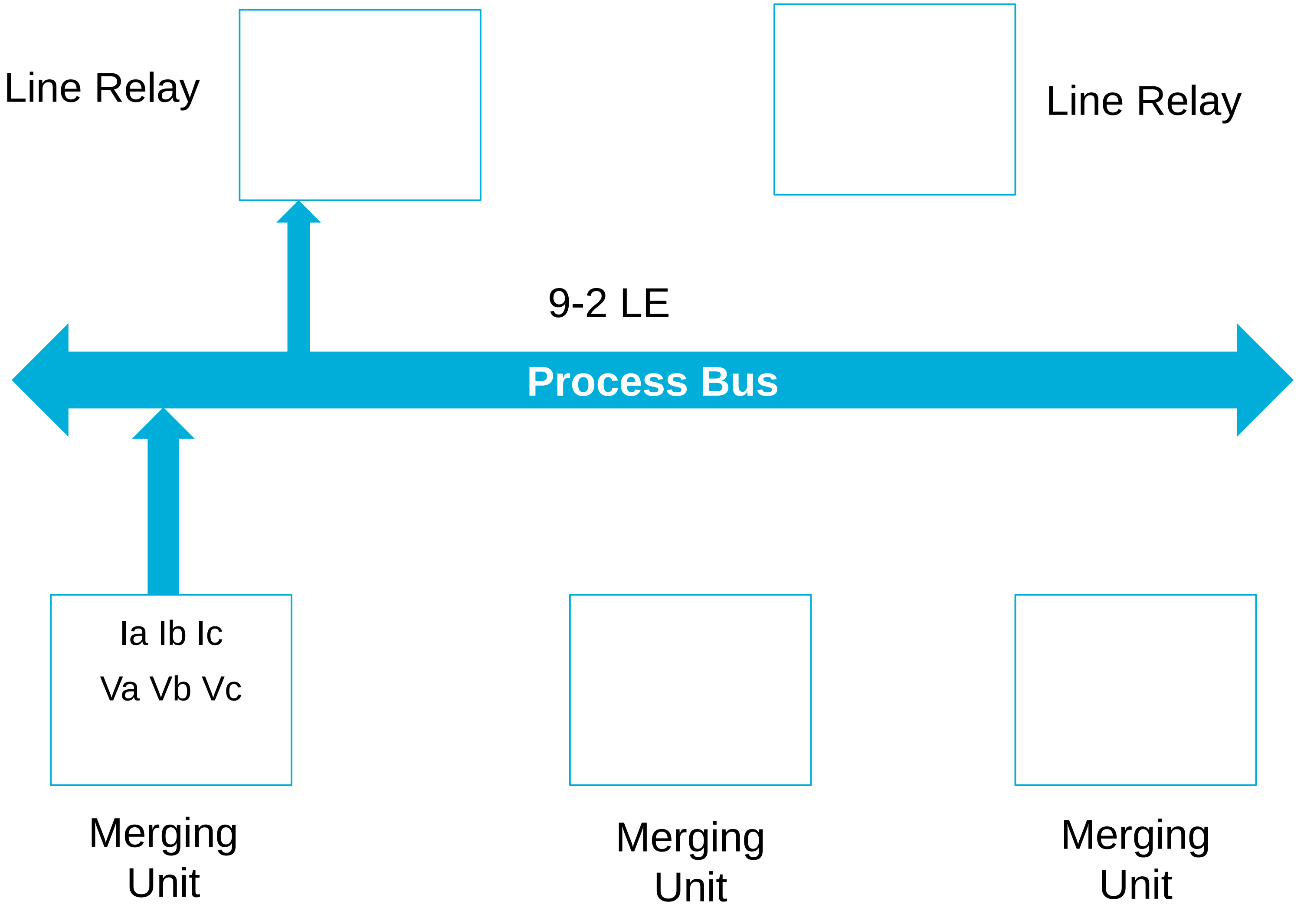
- Time-Sampled Data from CTs & VTs
- Sent from merging units to relays
- Multicast messages sent over Ethernet
- For protection – 80 samples per cycle with 4 currents and 4 voltages in the stream, 256 samples/cycle for metering/fault analysis
- Addressed in IEC 61850 9-2 (clarified in 9-2LE)



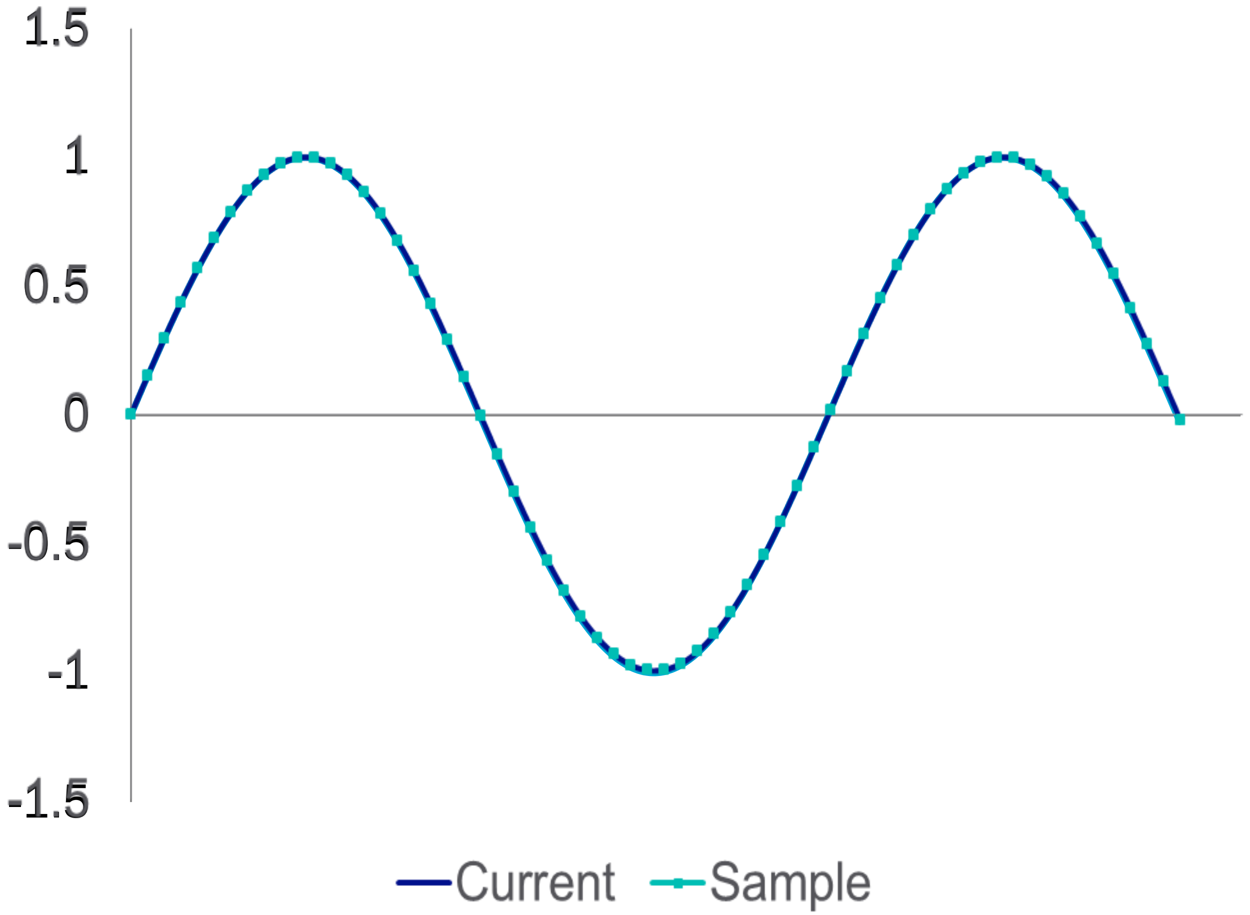
Sampled Values – Layer 2



Sampled Values On The Process Bus



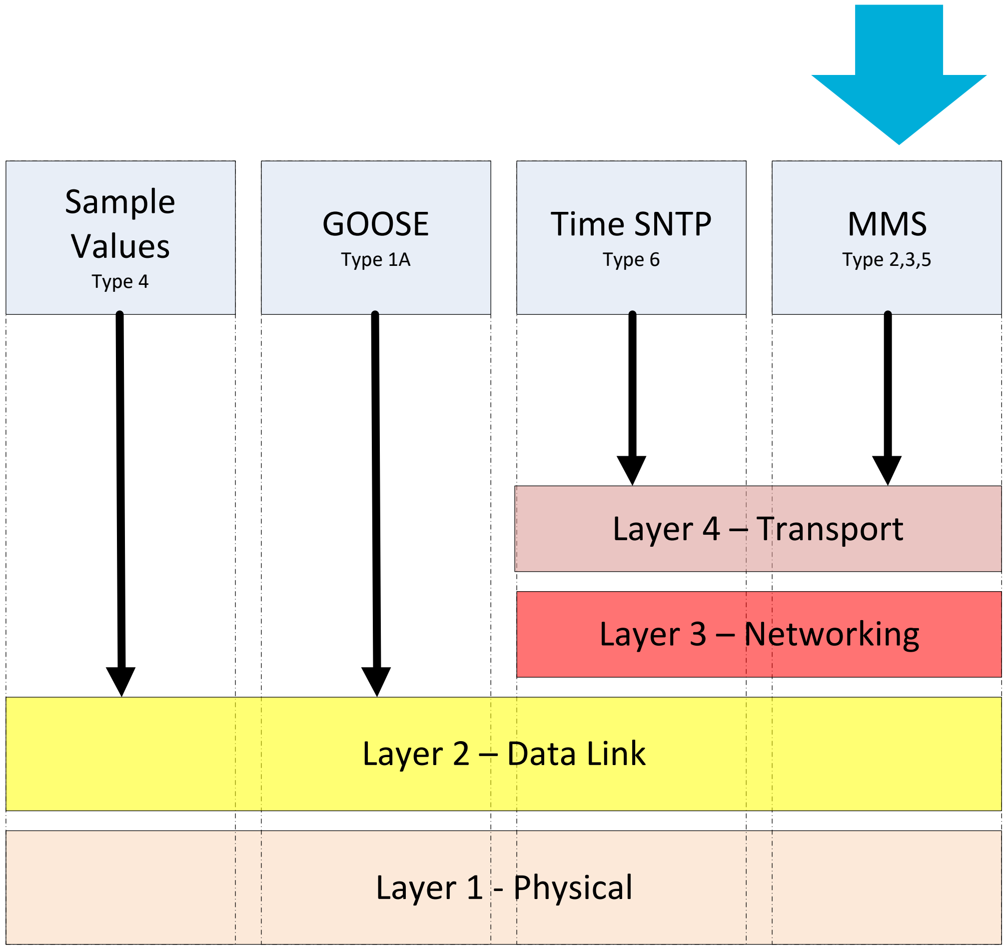
Current Vs. Sample



MMS Reporting

- Manufacturing Message Specification
  - Client-server communication
  - Real-time process data and supervisory control
  - Less “critical” data compared to GOOSE and SMV
  - Device-to-device communication over network
  - Originated in ISO 9506, prior to IEC 61850

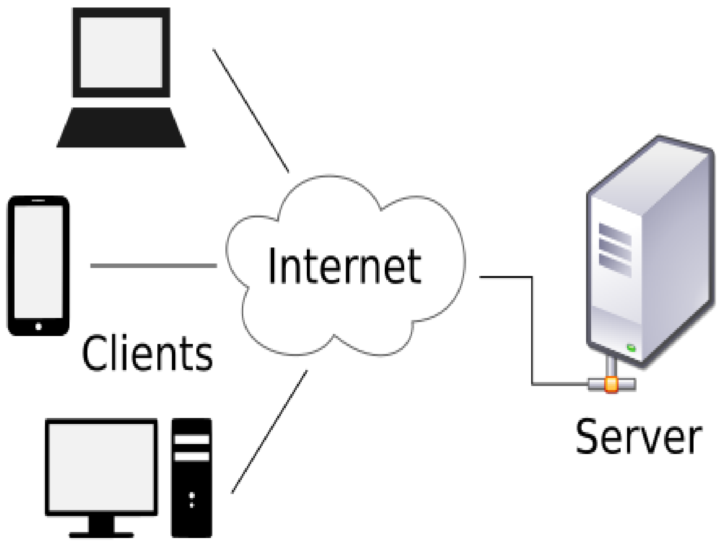
MMS – Layer 4



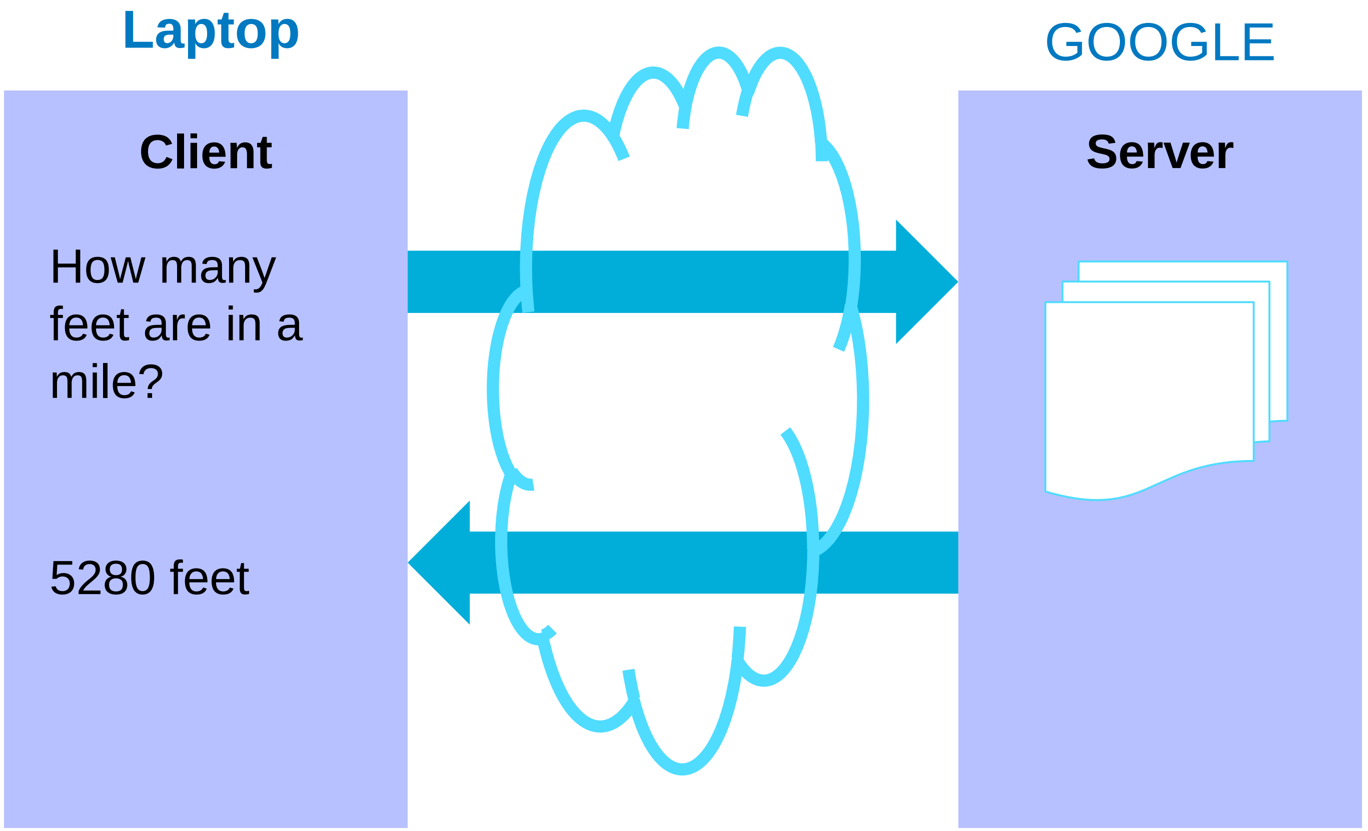
Sample Values
Type 4
GOOSE
Type 1A
Time SNTP
Type 6
MMS
Type 2,3,5
Layer 4 – Transport
Layer 3 – Networking
Layer 2 – Data Link
Layer 1 - Physical

Client-Server Model

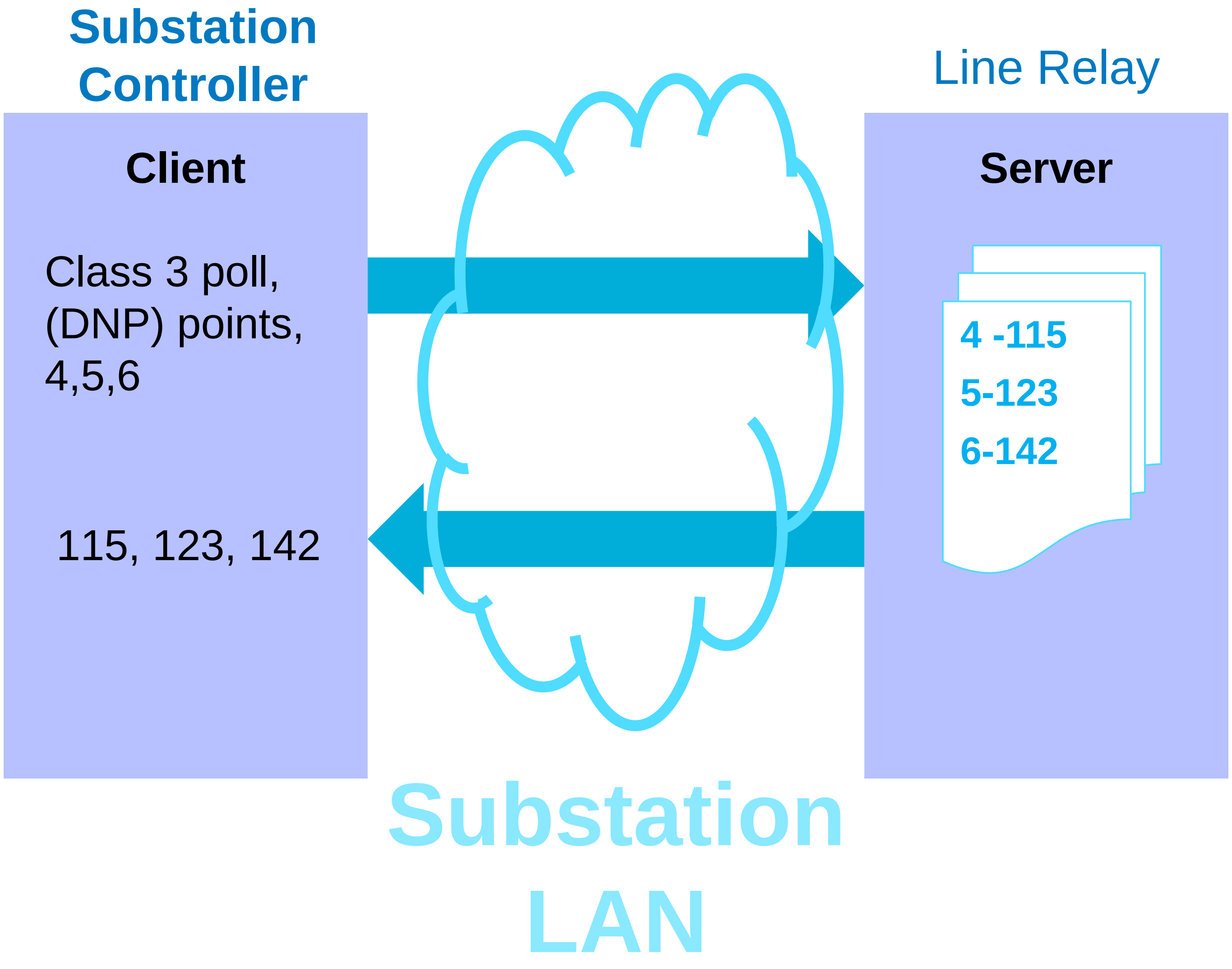
- Communication structure for a network system
- Client – the requestor/initiator
- Server – the provider/servicer
- Request/Response messaging pattern
- IEDs act as clients to other IEDs to obtain data



An Everyday Example



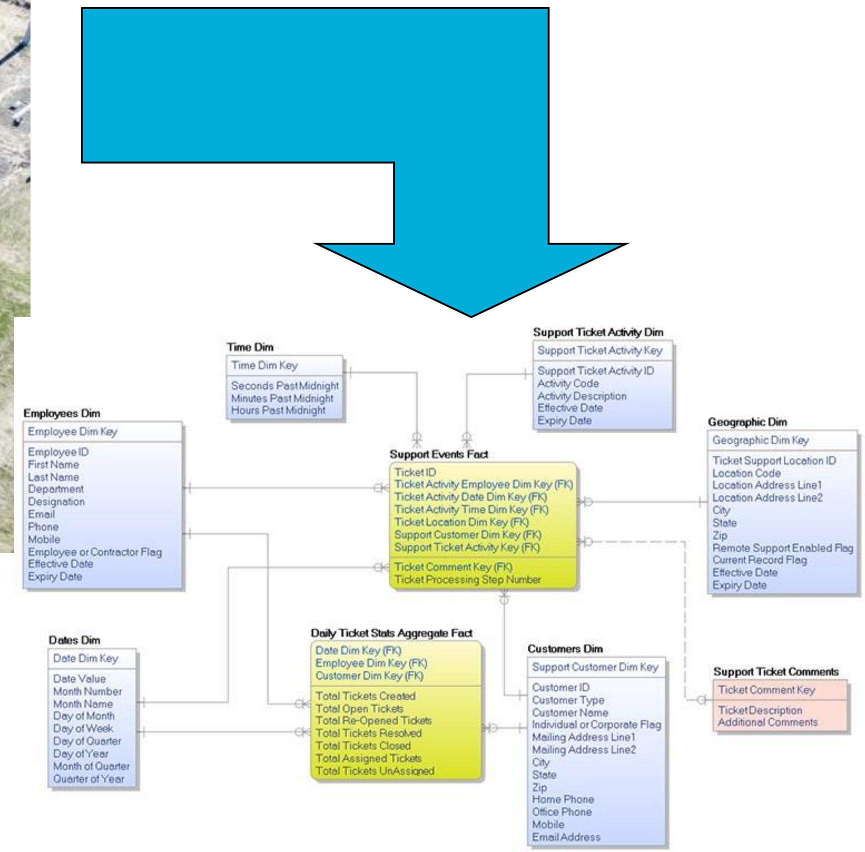
In A Substation Environment



MMS Operation

- Type 1 – Fast messages
- Type 1A – Trip
- ➡ Type 2 – Medium speed messages
- ➡ Type 3 – Low speed messages
- Type 4 – Raw data messages
- ➡ Type 5 – File transfer functions
- Type 6 – Time synchronization messages

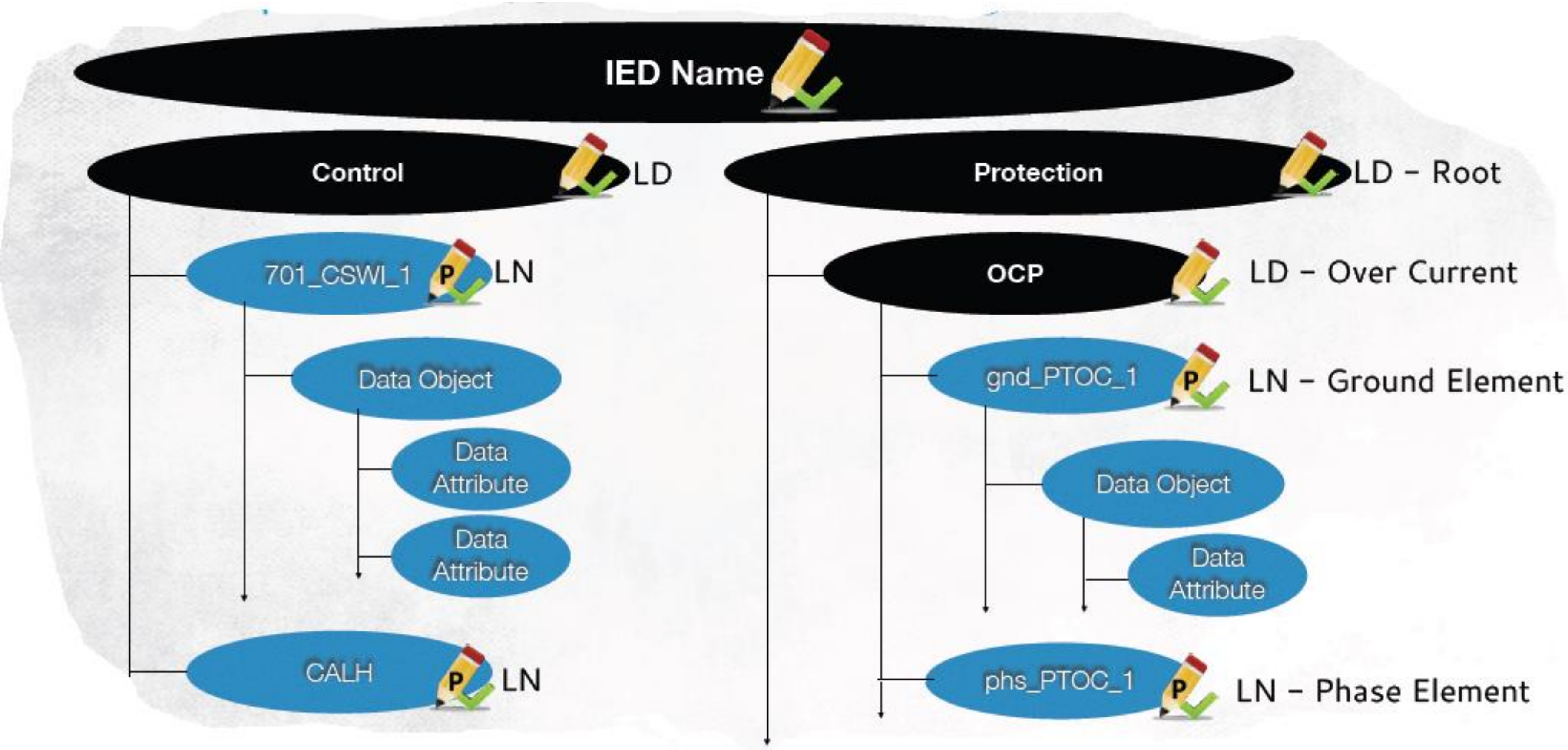
Data Map



Time Dim
Time Dim Key
Seconds Past Midnight
Minutes Past Midnight
Hours Past Midnight
Support Ticket Activity Dim
Support Ticket Activity Key
Support Ticket Activity ID
Activity Code
Activity Description
Effective Date
Expiry Date
Employees Dim
Employee Dim Key
Employee ID
First Name
Last Name
Department
Designation
Email
Phone
Mobile
Employee or Contractor Flag
Effective Date
Expiry Date
Support Events Fact
Ticket ID
Ticket Activity Employee Dim Key (FK)
Ticket Activity Date Dim Key (FK)
Ticket Activity Time Dim Key (FK)
Ticket Location Dim Key (FK)
Support Customer Dim Key (FK)
Support Ticket Activity Key (FK)
Ticket Comment Key (FK)
Ticket Processing Step Number
Geographic Dim
Geographic Dim Key
Ticket Support Location ID
Location Code
Location Address Line1
Location Address Line2
City
State
Zip
Remote Support Enabled Flag
Current Record Flag
Effective Date
Expiry Date
Dates Dim
Date Dim Key
Date Value
Month Number
Month Name
Day of Month
Day of Week
Day of Quarter
Day of Year
Month of Quarter
Quarter of Year
Daily Ticket Stats Aggregate Fact
Date Dim Key (FK)
Employee Dim Key (FK)
Customer Dim Key (FK)
Total Tickets Created
Total Open Tickets
Total Re-Opened Tickets
Total Tickets Resolved
Total Tickets Closed
Total Assigned Tickets
Total Tickets UnAssigned
Customers Dim
Support Customer Dim Key
Customer ID
Customer Type
Customer Name
Individual or Corporate Flag
Mailing Address Line1
Mailing Address Line2
City
State
Zip
Home Phone
Office Phone
Mobile
Email Address
Support Ticket Comments
Ticket Comment Key
Ticket Description
Additional Comments

IEC 61850 – Data Map

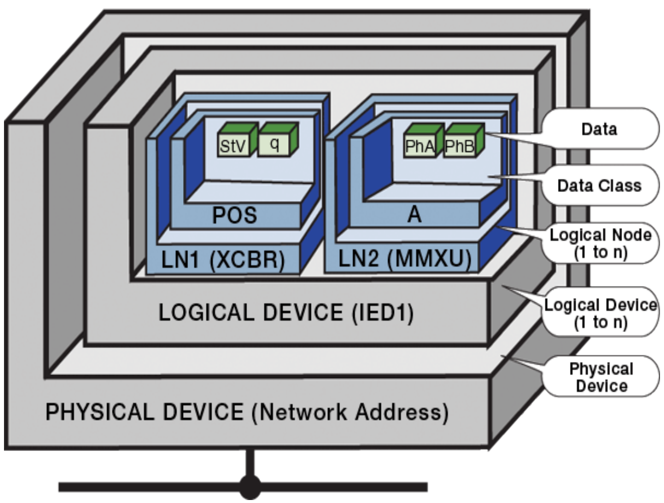
- What is the IEC 61850 data map:

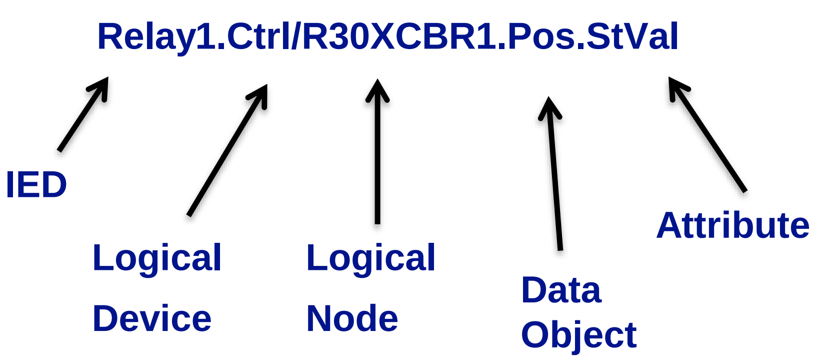


IEC 61850 – Data Map

LN Application – Circuit Breaker Status

- The interface to a circuit breaker can be modeled as the logical node XCBR
- This Logical Node XCBR has a data object POS (breaker position)
- Within the data object, there is a data attribute called stVal (status value)





IEC 61850 Data Mapping – XCBR Example

XCBR class				
Data object name	**Common data class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.		
Data objects				
Descriptions				
EEName	DPL	External equipment name plate		O
Status information				
EEHealth	ENS	External equipment health		O
LocKey	SPS	Local or remote key (local means without substation automation communication, hardwired direct control)		O
Loc	SPS	Local control behaviour		M
OpCnt	INS	Operation counter		M
CBOpCap	ENS	Circuit breaker operating capability		O
POWCap	ENS	Point on wave switching capability		O
MaxOpCap	INS	Circuit breaker operating capability when fully charged		O
Dsc	SPS	Discrepancy		O
Measured and metered values				
SumSwARs	BCR	Sum of switched amperes, resettable		O
Controls				
LocSta	SPC	Switching authority at station level		O
Pos	DPC	Switch position		M
BlkOpn	SPC	Block opening		M
BlkCls	SPC	Block closing		M
ChaMotEna	SPC	Charger motor enabled		O
Settings				
CBTmms	ING	Closing time of breaker		O

This is the breaker position (52a or 52b)

IEC 61850 Data Mapping – Sample of LN

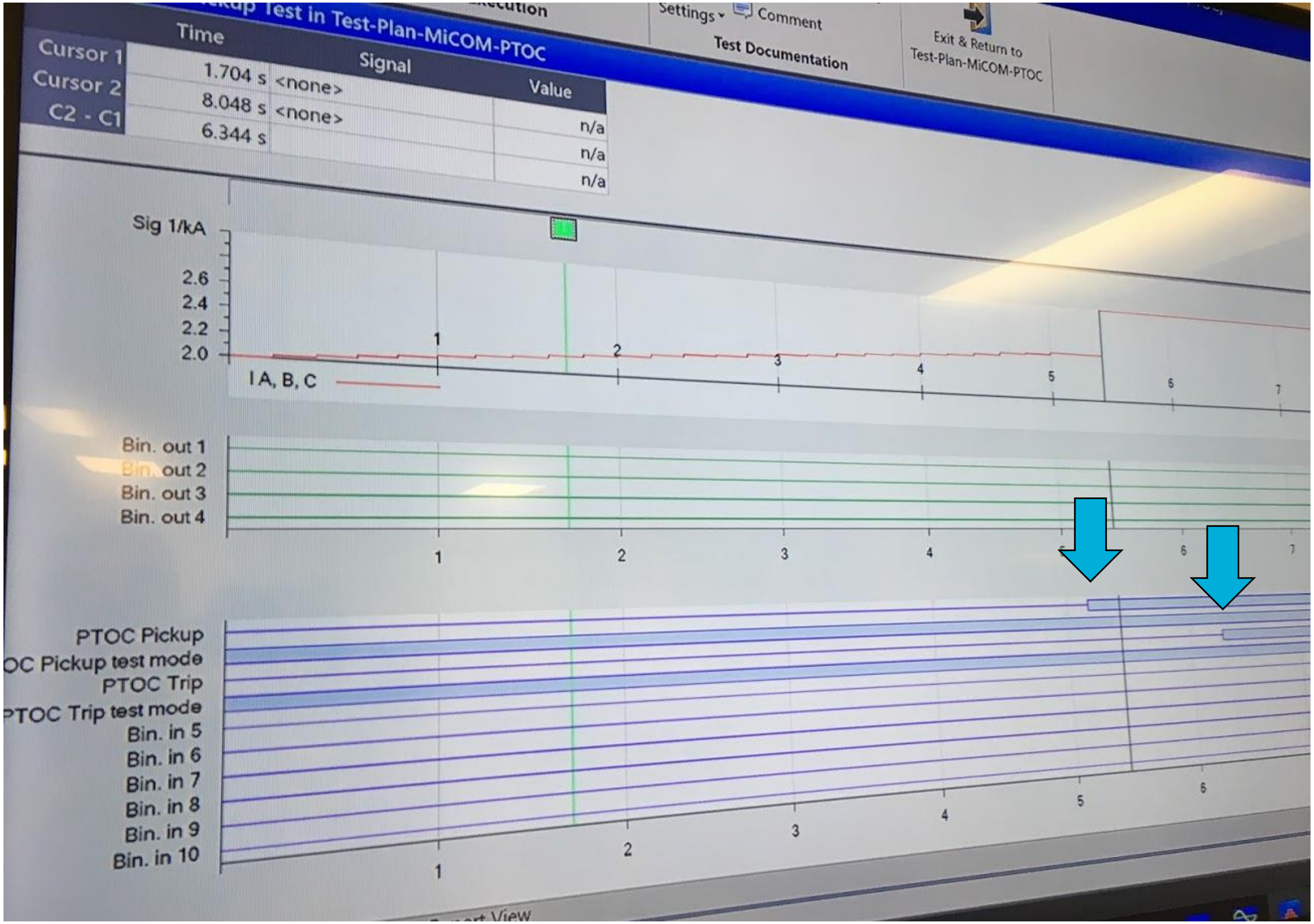
Functionality	IEEE	LN Function	LN Class	LN class naming
Transient earth fault protection		PTEF	PTEF	Transient earth fault
Sensitive directional earth fault	(37) (67N)	PSDE	PSDE	Sensitive directional earth fault
Thyristor protection		PTHF	PTHF	Thyristor protection
Protection trip conditioning		PTRC	PTRC	Protection trip conditioning
Checking or interlocking relay	3	CILO	CILO	Interlocking
Over speed protection	12	POVS		
Zero speed and under speed protection	14	PZSU	PZSU	Zero speed and under speed
Distance protection	21	PDIS	PDIS	Distance protection
			PSCH	Protection Scheme
Volt per Hz protection	24	PVPH	PVPH	Volts per Hz
Synchronism check	25	RSYN	RSYN	Synchronism-check
Over temperature protection	26	PTTR	PTTR	Thermal overload
(Time) Under voltage protection	27	PTUV	PTUV	Under voltage
Directional power / reverse power protection	32	PDPR	PDOP	Directional over power
			PDUP	Directional under power
Undercurrent / under power protection	37	PUCP	PTUC	Under current
			PDUP	Directional under power
Loss of field / Under excitation protection	40	PUEX	PDUP	Directional under power
			PDIS	(Distance) impedance
Reverse phase or phase balance current protection, Negative sequence current relay	46	PPBR	PTOC	Time overcurrent
Phase sequence or phase-balance voltage protection, Negative sequence voltage relay	47	PPBV	PTOV	Overvoltage protection
Motor start-up protection	48, 49, 51LR66	PMSU	PMRI	Motor restart inhibition
			PMSS	Motor starting time supervision
Thermal overload protection	49	PTTR	PTTR	Thermal overload
Rotor thermal overload protection	49R	PROL	PTTR	Thermal overload
Rotor protection	49R	PROT	PTTR	Thermal overload

IEC 61850 Data Model and Test- Example

PTOC class				
Data object name	**Common data class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2, Clause 22.		
Data objects				
Status information				
Str	ACD	Start		M
Op	ACT	Operate	T	M
Controls				
OpCntRs	INC	Resettable operation counter		O
Settings				
TmACrv	CURVE	Operating curve type		O
TmAChr33	CSG	Multiline curve characteristic definition		C
TmASt	CSD	Active curve characteristic		O
StrVal	ASG	Start value		O
TmMult	ASG	Time dial multiplier		O
MinOpTmms	ING	Minimum operate time		O
MaxOpTmms	ING	Maximum operate time		O
OpDlTmms	ING	Operate delay time		O
TypRsCrv	ENG	Type of reset curve		O
RsDlTmms	ING	Reset delay time		O
DirMod	ENG	Directional mode		O
NOTE TmAChr33 refers to the attribute TmACrv.setCharact = 33 etc.				

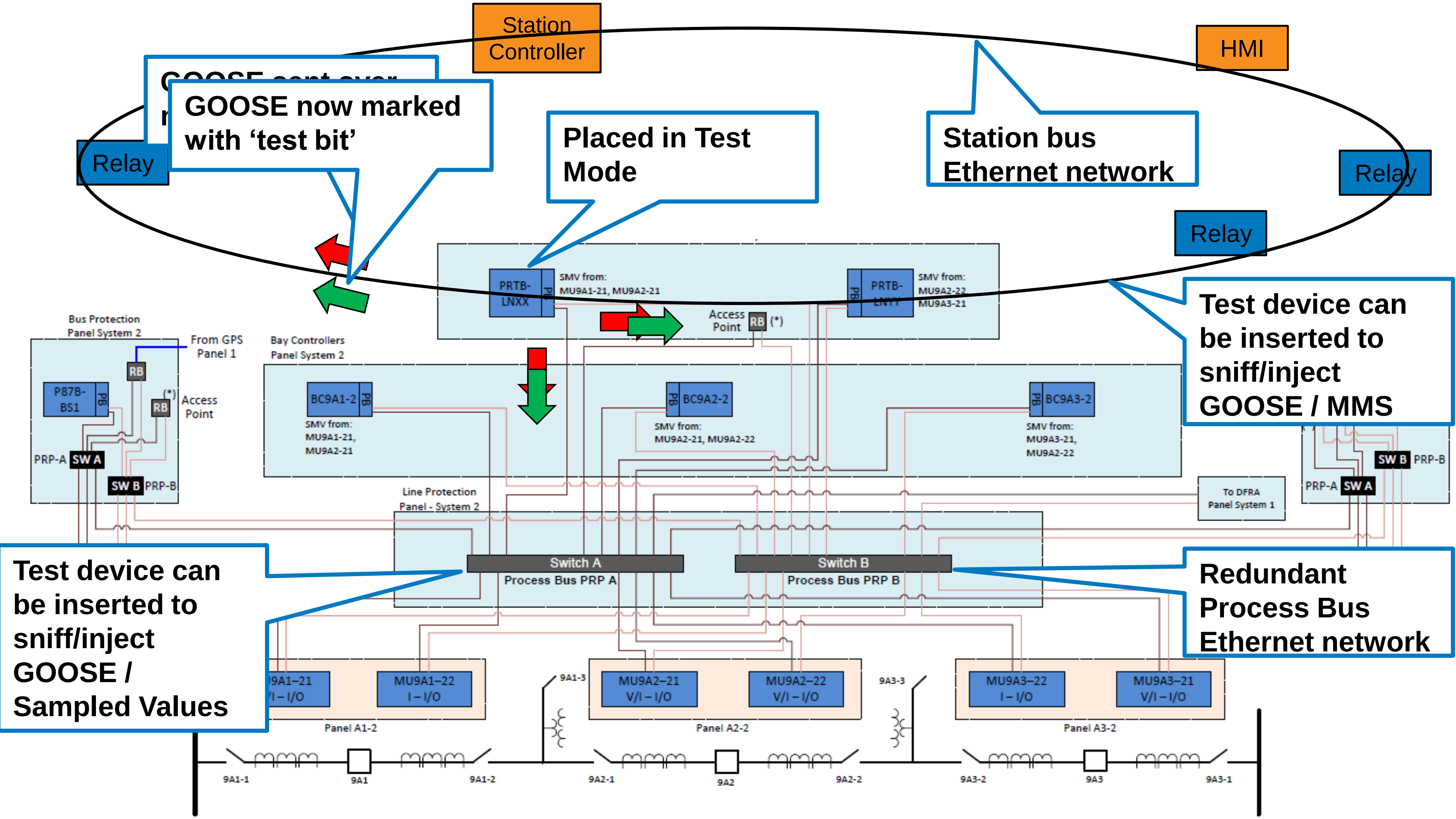
The only value which is typically available in a conventional station

IEC 61850 Data Mapping - Example



IEC 61850 Testing - Example

IEC 61850 Testing Process



IEC 61850 – Benefits

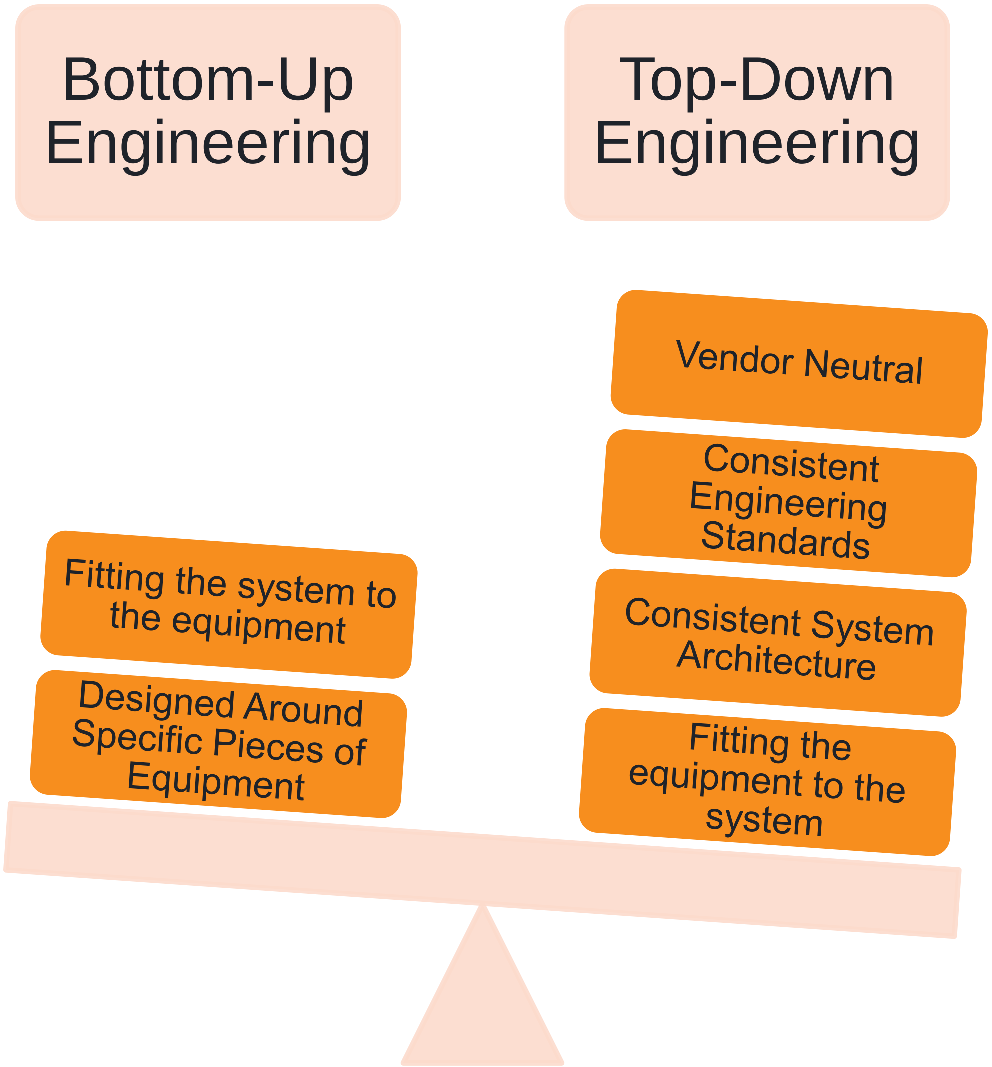
Interoperability	Non-propriety common communication language
	Common platform for protection, control, asset management systems
Design Standardization	Shorter construction window as ***system can be designed, modeled, and tested in advance***
	Designs are easily reproducible
Flexibility	Data is available over the network, modifications can be done via settings rather than physical changes
	System can be easily expanded
Digital Control System	Reduced control building size
	Reduced physical wiring
Increased System Visibility	Optimizing on-site maintenance
	Easier access to more asset data
Safety	Electrical hazards are remote from operator terminals
	Enhanced tagging control

IEC 61850 File Types and Engineering Process

- The logic that used to be constructed with devices wired in parallel or series is now done via digital programming
- There are various files types, a couple examples:
  - ICD – IED Configuration Database
    - Configuration for a single relay or merging unit
  - SCD – Substation Configuration Database
    - Configured file for entire substation
  - SSD – Substation Specification Database
    - Generic configuration file for the entire substation, can include logic, communication, protection elements, etc.

Engineering Process

- What is a top-down approach?
- Focus on the system objectives not equipment limitations
- Possible because IEC 61850 defines the data map for a substation



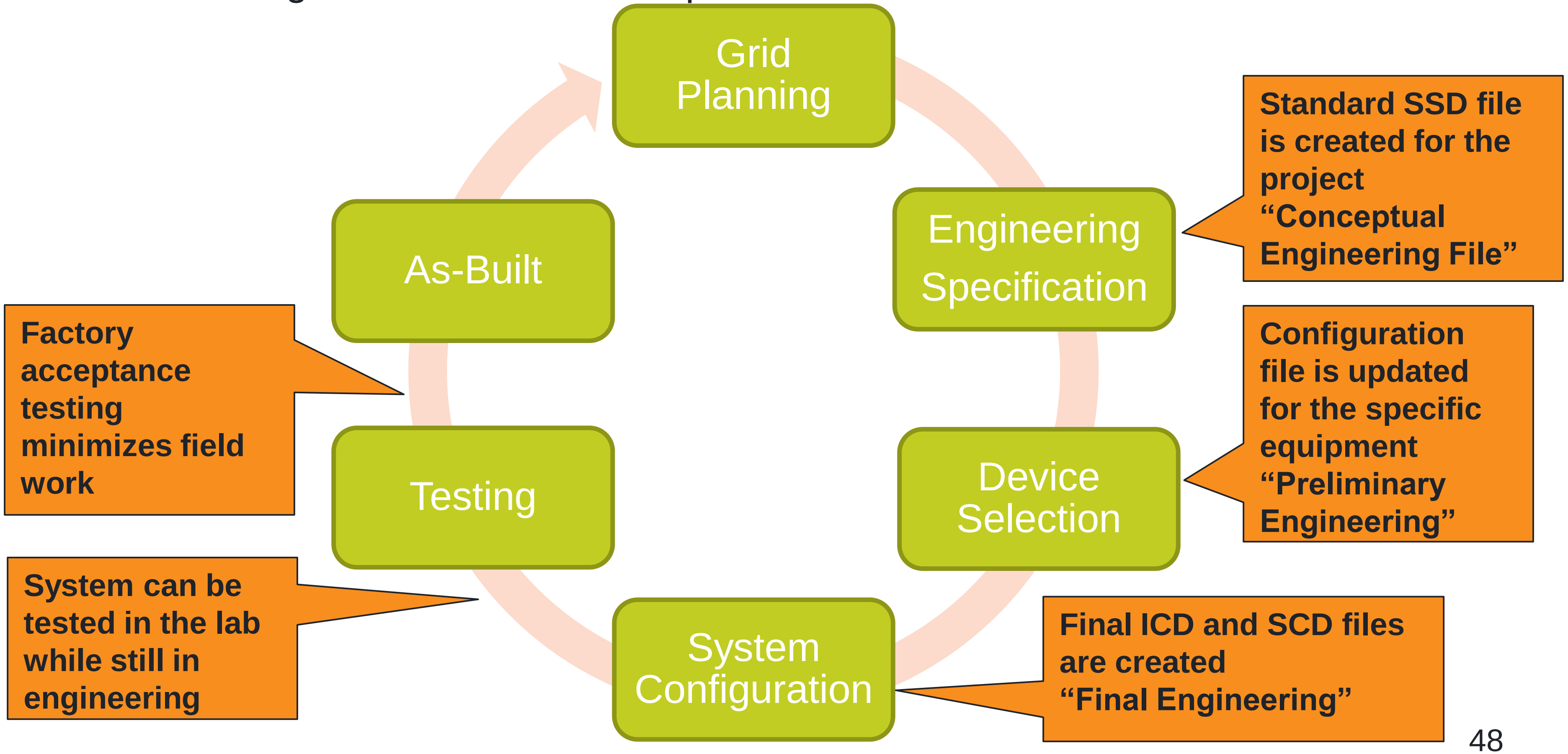
Engineering Process

Top-Down vs. Bottom-Up Engineering

- Goal of using a Top-Down design:
  1. Standardized engineering process
  2. Repeatability
  3. Vendor inter-operability
- Reality:
  1. Mix of top-down and bottom-up
  2. Standards based on top-down approach, but of the system will need to be customized based on equipment limitations

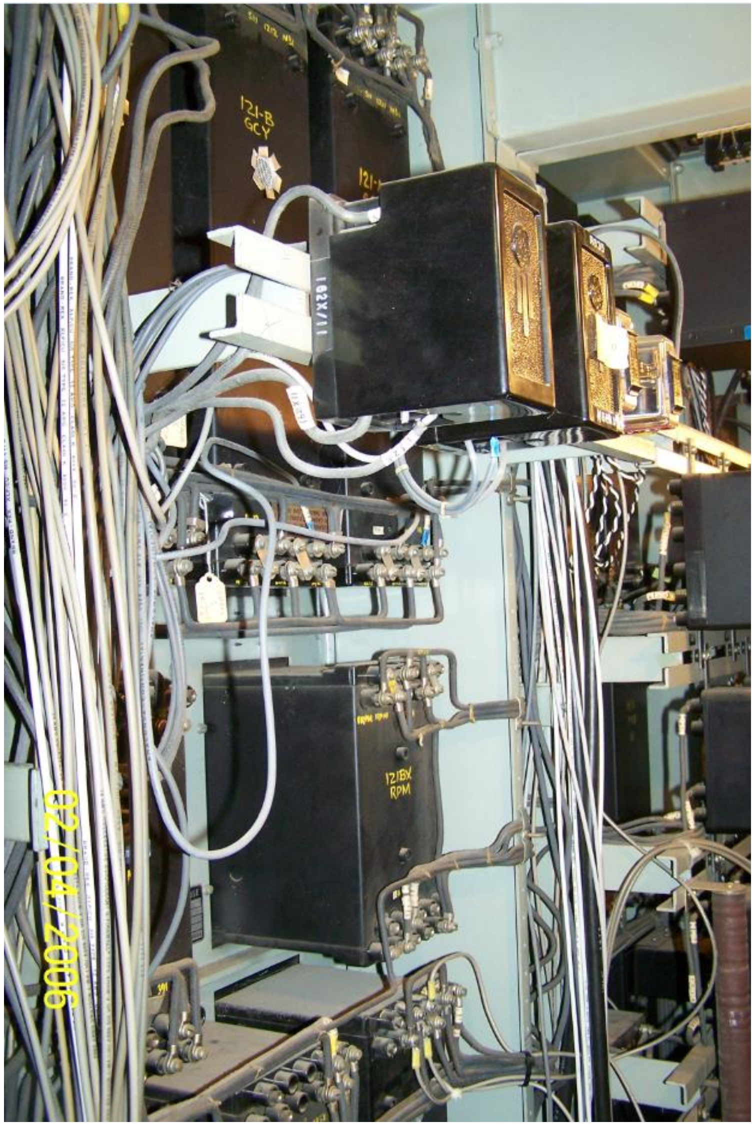
Engineering Process

- Standard and Portable Design
  - National Grid's goal is to create general standards around IEC 61850
  - The design will be tailored for specific installations



IEC 61850 – Substation Automation

- Why would we want to change the status quo?
  - Decreased capital cost
  - Smaller footprint
  - Increased flexibility and visibility
  - Proactive condition-based maintenance and remote access



IEC 61850 – Benefits

Interoperability	Non-propriety common communication language
	Common platform for protection, control, asset management systems
Design Standardization	Shorter construction window as system can be designed, modeled, and tested in advance
	Designs are easily reproducible
Flexibility	Data is available over the network, modifications can be done via settings rather than physical changes
	System can be easily expanded
Digital Control System	Reduced control building size
	Reduced wiring
Increased System Visibility	Optimizing on-site maintenance
	Easier access to more asset data
Safety	Electrical hazards are remote from operator terminals
	Enhanced tagging control

IEC 61850 – Risks

Cyber-Security	Network connectivity, all devices connected to the network are potentially accessible
	The network can be a single point of failure if not properly designed
	Patch management requirements are greatly increased
New Technology	Some concepts are not fully proven in the field
	Not all vendors offer compatible products
	Limited available workforce
Engineering & Operational Learning	New standards and work methods are required
	Cross discipline skillsets are not available for example, most protection engineers are not familiar with VLANS or MAC addresses

IEC 61850 – Substation Automation

In Summary…

- Packet-based network communication for electric power systems
- Reduced control house size, reduced wiring, standardized design, reduced operational costs
- IEC 61850 considers the entire system lifecycle; engineering, construction, operations
- Potential new challenges that have to be addressed
  - Coordination between engineers and operations is critical

IEC 61850 – Substation Automation

1.) What were the standard committee's goals in the development of the IEC 61850 standard?

- Answer:
  - Data mapping of the entire substation;
  - Future-proof communication;
  - Vendor interoperability;
  - A common means of storing data,
  - Defining testing for conformance to the standard

IEC 61850 – Substation Automation

2.) What are some of the advantages in transitioning to an IEC 61850 digital substation?

- Answer:
  - Interoperability
  - Design standardization
  - System flexibility
  - Reduced capital costs
  - Reduced operational costs
  - Increased system visibility
  - Enhanced safety

3.) What are the risks with digital substations?

- Answer:
  - Cyber-security
  - New technology
  - Engineering and operational learning curve

IEC 61850 – Substation Automation

A couple questions

4.) How are the potential risks with digital substations being mitigated?

- Answer:
  - Design with security in mind
  - Compartmentalized networks
  - Extensive collaboration between engineering and operations

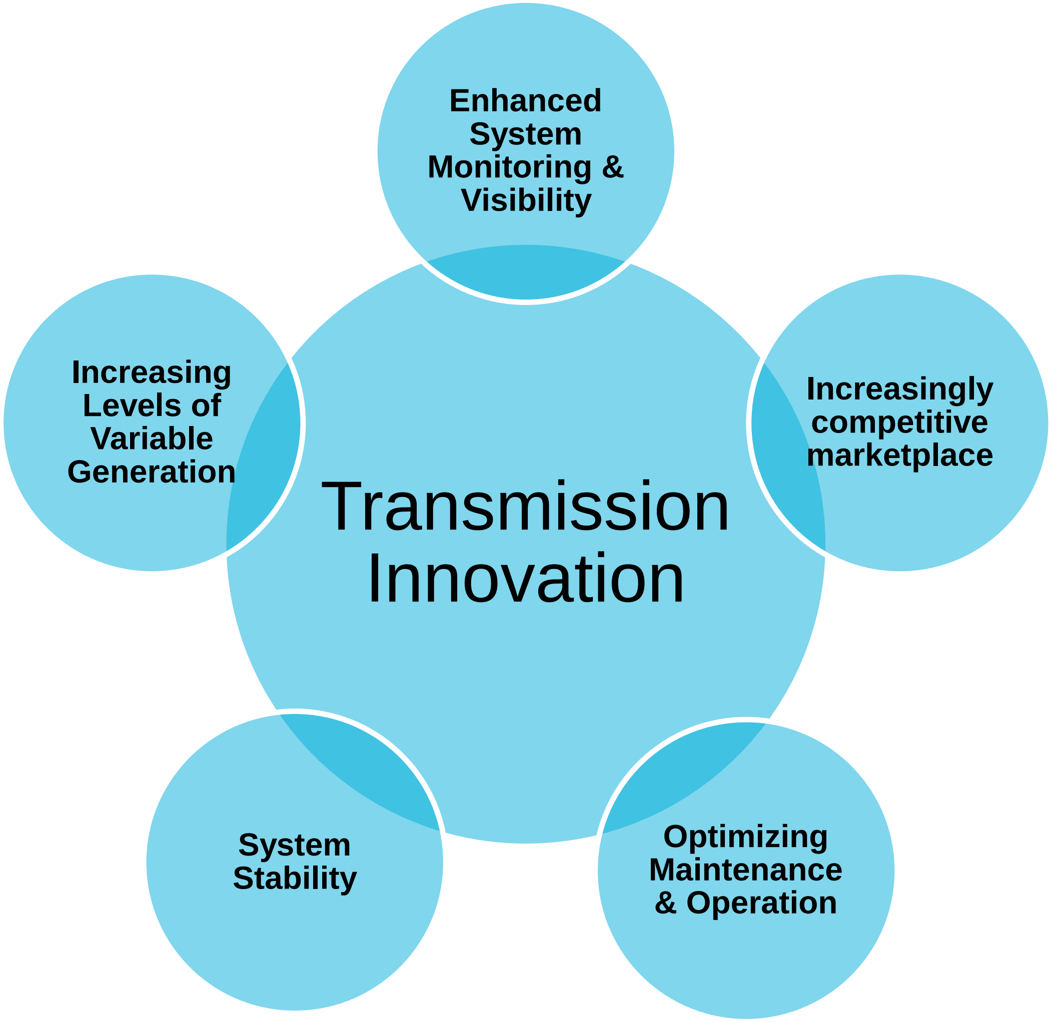
IEC 61850 – Substation Automation

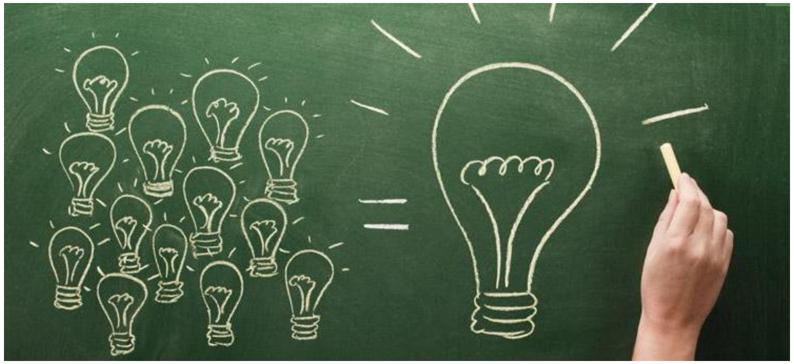
A couple questions

5.) Does IEC 61850 have a technical, commercial, or organizational impact?

- Answer:
  - All of the above! To fully realize the benefits, transitioning to a digital substation requires complete organizational buy-in

Transmission Innovation – Future of IEC 61850





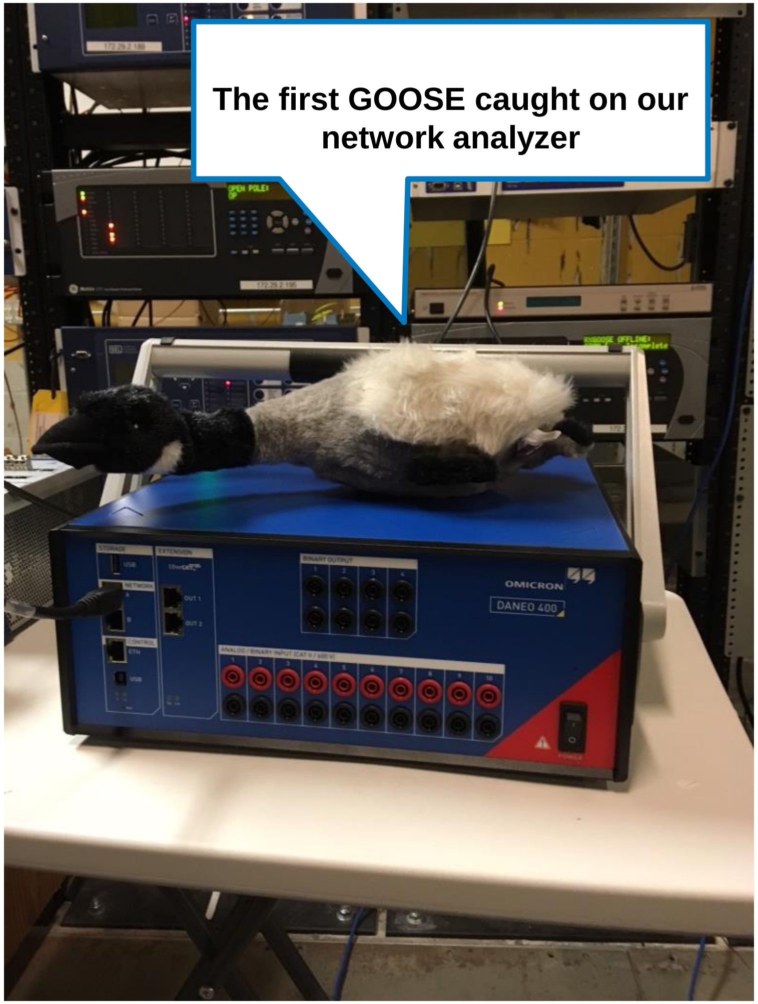
IEC 61850 and the Future

- Flexibility to support the rapidly changing power industry
  - More than one utility is using IEC 61850 to support dynamic relay settings
    - Settings will adjust based on system conditions –

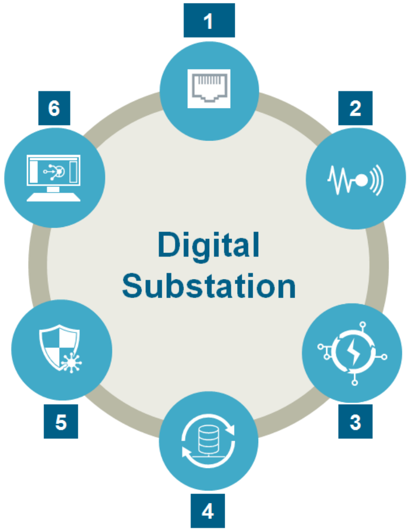
- Automatically generated HMI screens

- Software based design

Thank You



1. Ethernet-based communication on IEC 61850
2. Digitalization of analog protection elements
3. Asset management support
4. Integrated engineering
5. Cyber Security - Prerequisite of any digital substation
6. Network control support



IEC 61850 – Terminology

HMI

Gateway

Relay

Bay Controller

Merging Unit