Steven A. Kunsman, Stefan Meier, Roger Hedding, April 7, 2016

Texas A&M University 69th Annual Conference for Protection Relay Engineers

# Protection and Control System Impacts from The Digital World

# Authors

**Protection and Control System Impacts from The Digital World**

**presented to**

**69th Annual Conference for Protective Relay Engineers**

**Texas A&M University**

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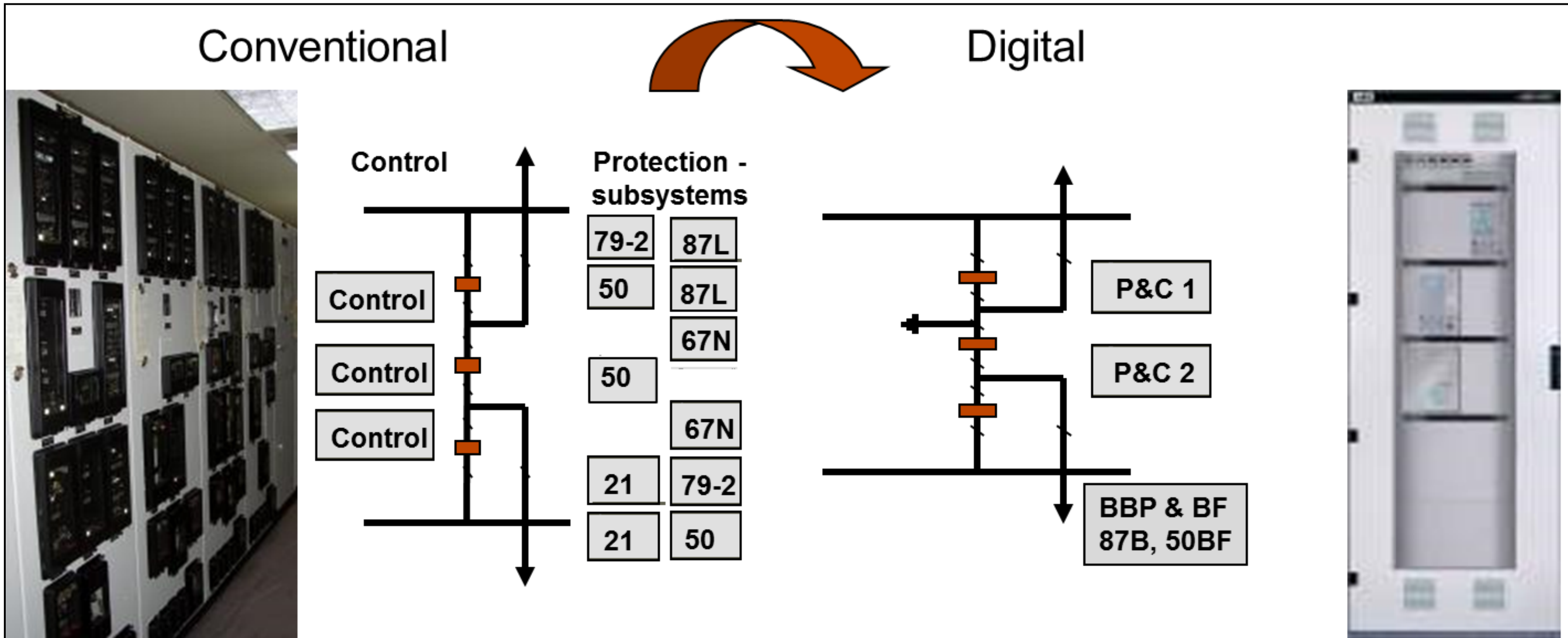
# Background and introduction
## Electro-mechanical versus modern digital system

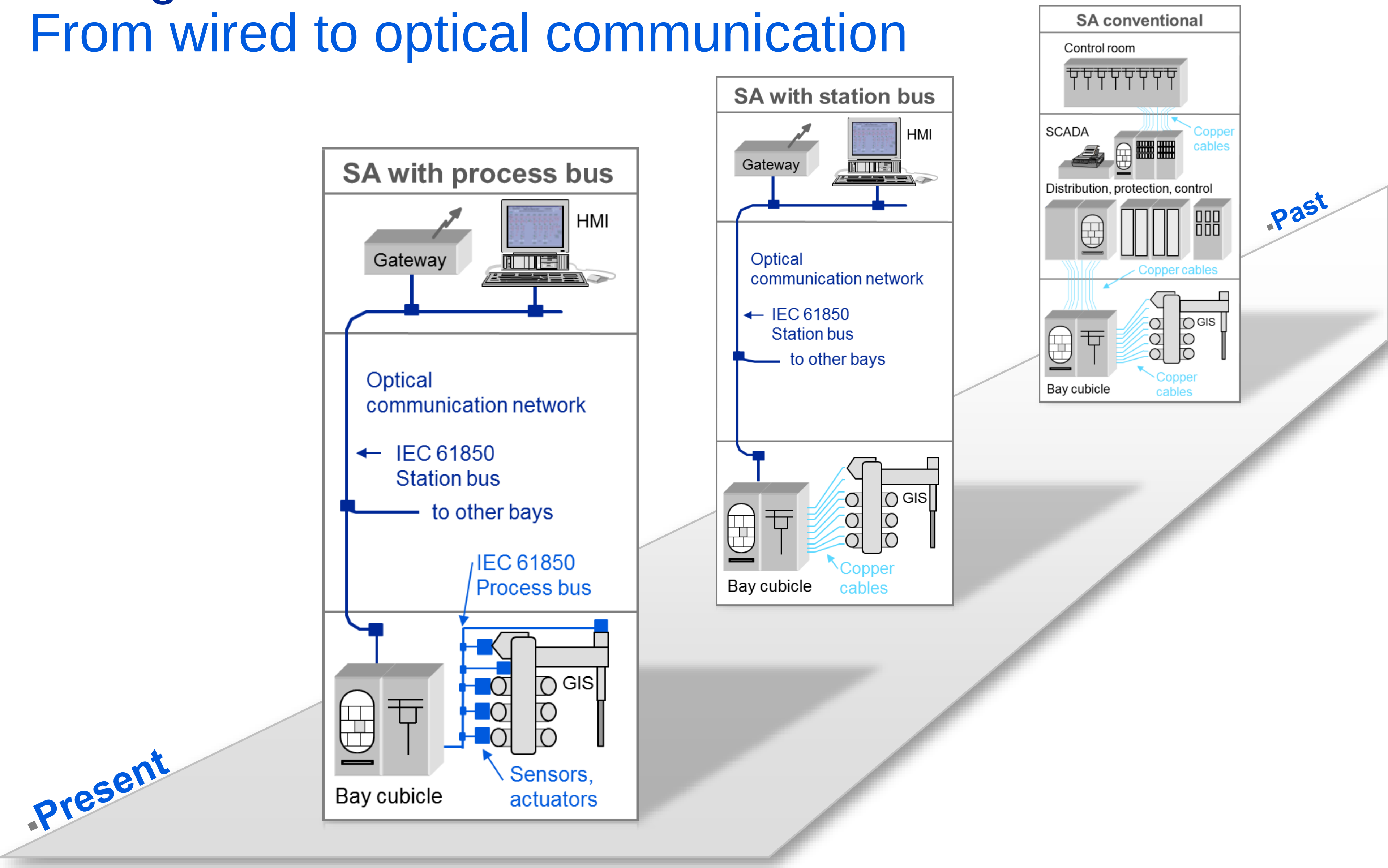



14 protection & control devices (Electro-Mechanical system could add 3 devices per function)

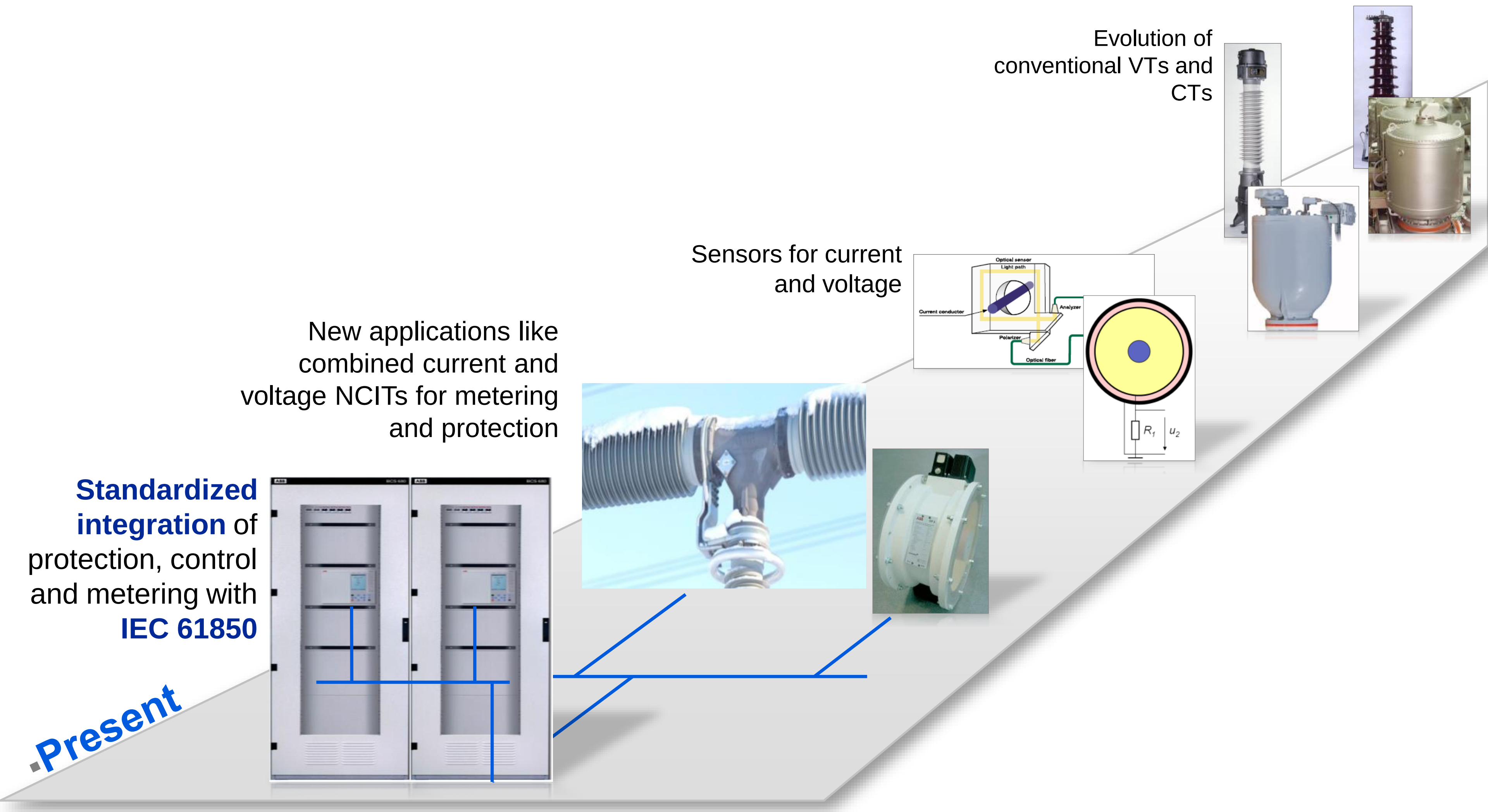
2 protection & control devices including busbar protection/backup

**Advanced protection solution consolidate 3 panels to 1 panel**

# Background and introduction
## From wired to optical communication



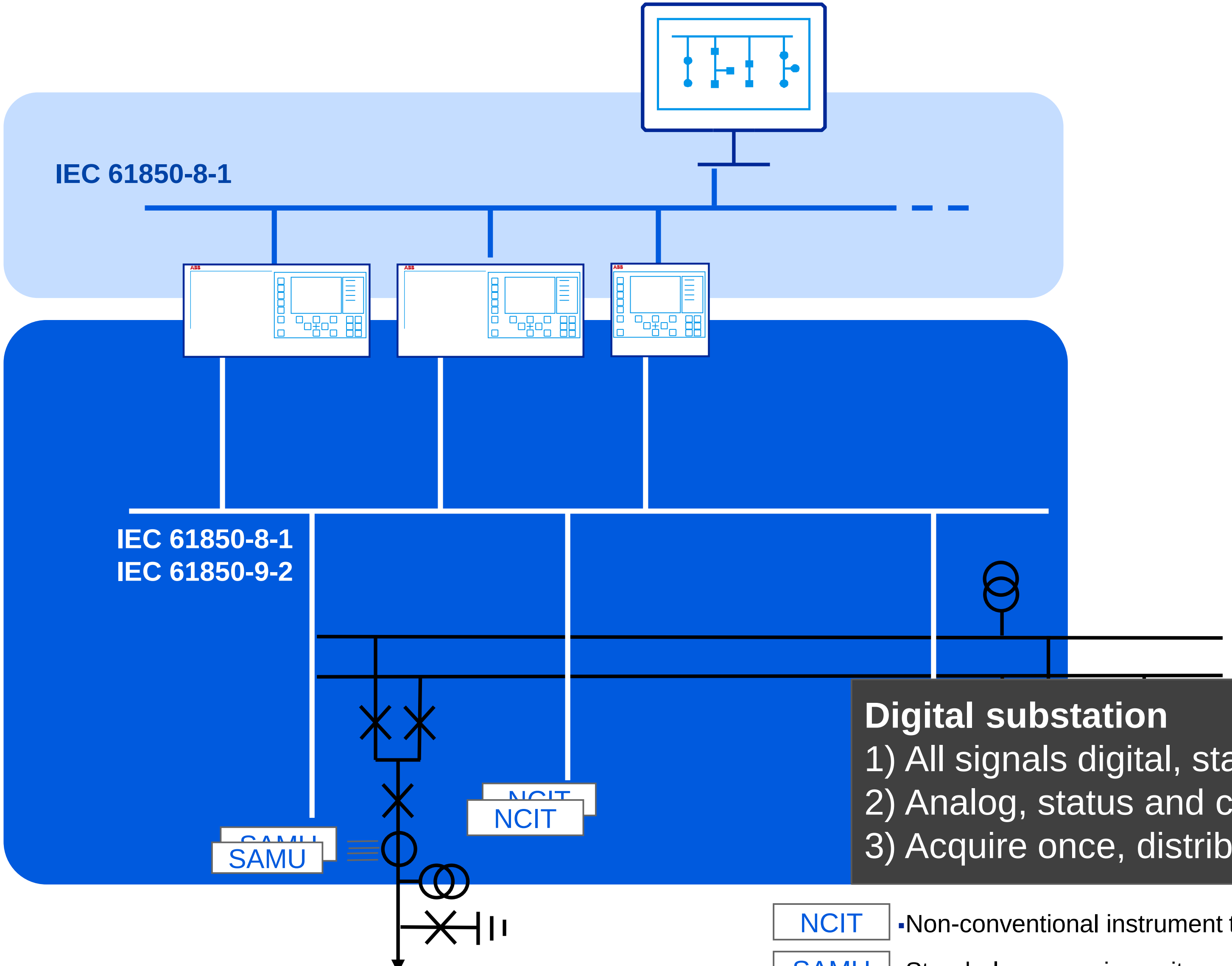
# Background and introduction
## From conventional CTs and VTs to NCITs*




*NCITs = non-conventional instrument transformers

- Background and introduction
- The digital systems
- From copper to process bus
- Fault clearance times of digital substations
- Impacts of non-conventional instrument transformers
- The Digital World opens up Cyber Threats
- Conclusion

# The digital systems
## Digital substation

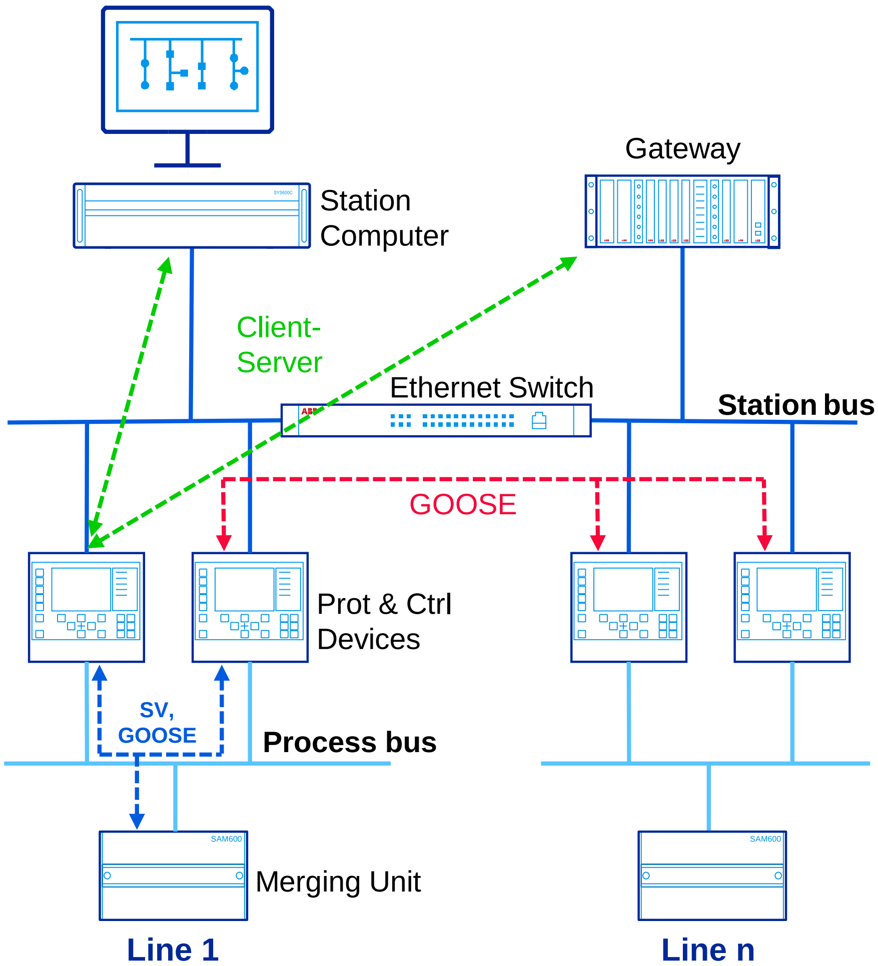



**Digital substation**
1) All signals digital, station and process
2) Analog, status and commands
3) Acquire once, distribute on a bus

NCIT ▪Non-conventional instrument transformers

SAMU ▪Stand-alone merging units

# The digital systems
## Communication services




- Client-Server
  - Reliable point to point sessions for central monitoring and control
  - Commands, reporting, logs, file transfer,…
- GOOSE
  - Real-time data broadcast for station wide applications e.g. interlocking
  - Binary data, indications, commands
- Sampled Values (SV)
  - Real-time data broadcast for collecting measurements from process
  - Sampled analog values

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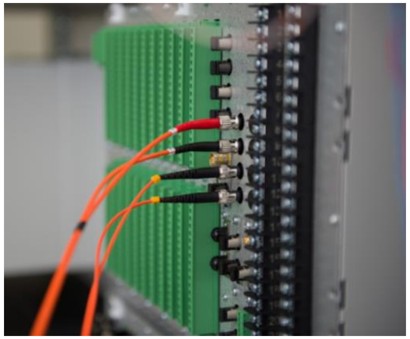
# From copper to process bus
## Less copper


Traditional Copper Wires

Digital Communications

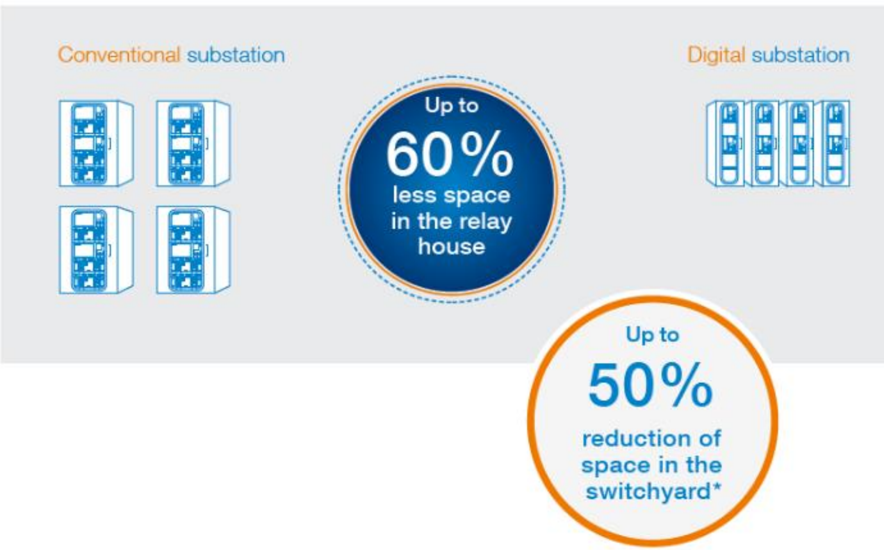


- Reduction in copper cable by up to 80% in transmission level AIS substations
  - By replacing the long stretches of copper by fiber optic cables
  - By replacing horizontal wiring between IEDs with IEC 61850
  - By reducing connections between primary apparatus and process IO modules, as fewer independent connections are required

# From copper to process bus
## Less transport


- More than 30 tons less material to be transported to site for an average sized transmission level substation
  - Weight of the fiber optic cabling is around 90% less than the copper cables it replaces
  - Oil filled CTs replaced by fiber optical current sensors reduces weight around 80%

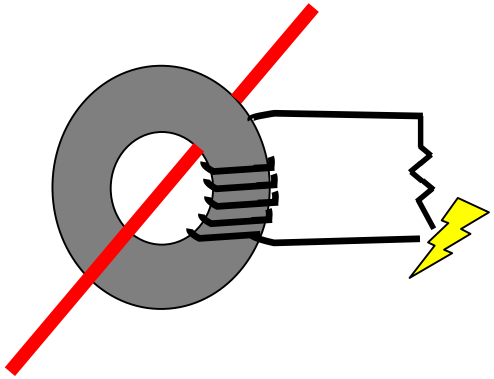
# From copper to process bus
## Less space




- 30 to 60% reduced space for protection and control panels
  - Same number of IEDs require less space due to absence of conventional I/Os and Analog inputs
  - Higher integration of control and protection functionality allows for further space reduction
- Reduction of switchyard footprint by up to 50%
  - By using circuit breakers with integrated disconnecting functionality and optical current transformers

# From copper to process bus
## Enhanced safety – remove risk of open CT circuits

Open CT arcing



**WARNING!!!** The secondary circuit of CTs should never be opened or left open when current is flowing in the primary. If the secondary circuit is open, the primary current will drive the core to saturation, inducing abnormally high and possibly lethal PEAK voltages.

Damage due to CT circuit arcing

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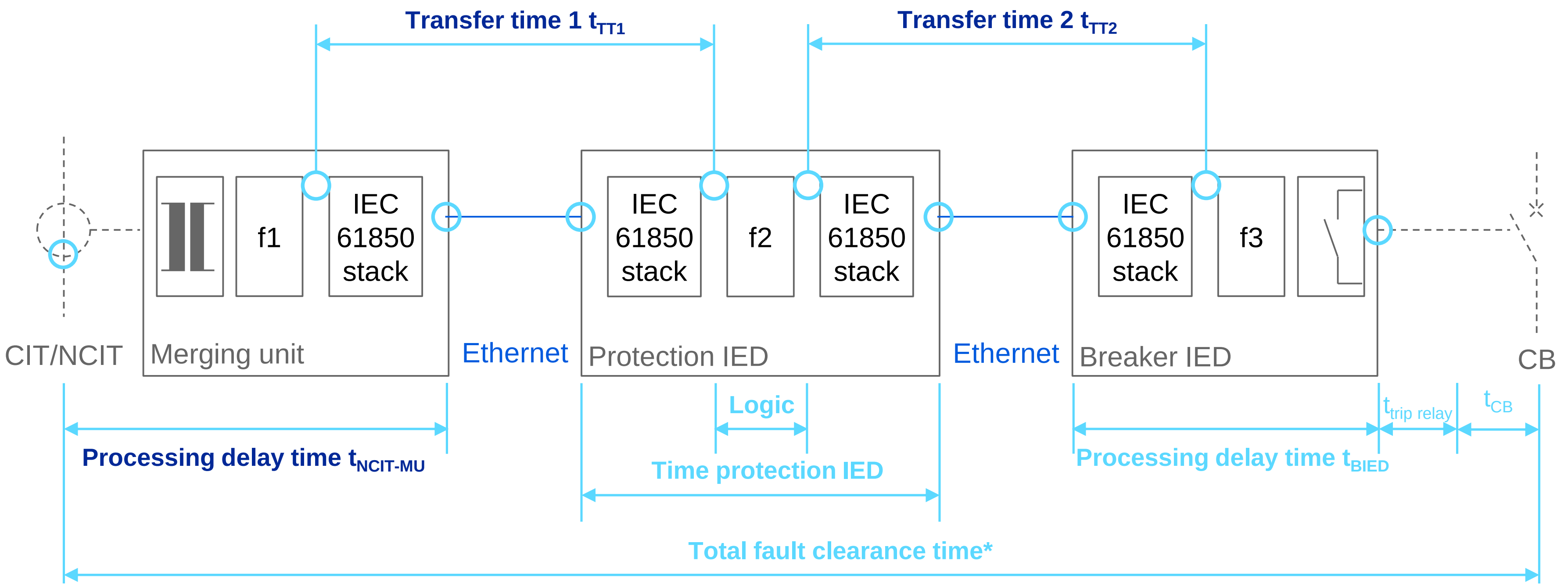
# Fault clearance times of digital substations
## Total fault clearance time, digital system

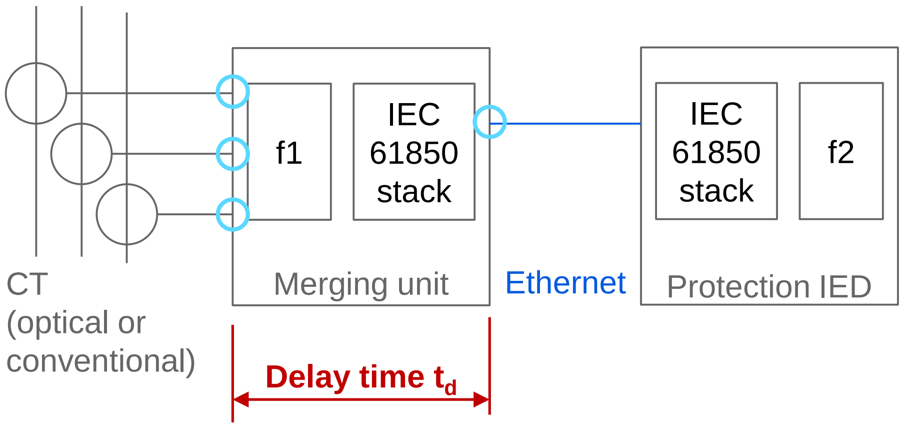



* Total fault clearance time: time from fault inception to clearing of the arc by the circuit breaker

Typically required values for HV and EHV substations: 65 to 80ms (4 power cycles)

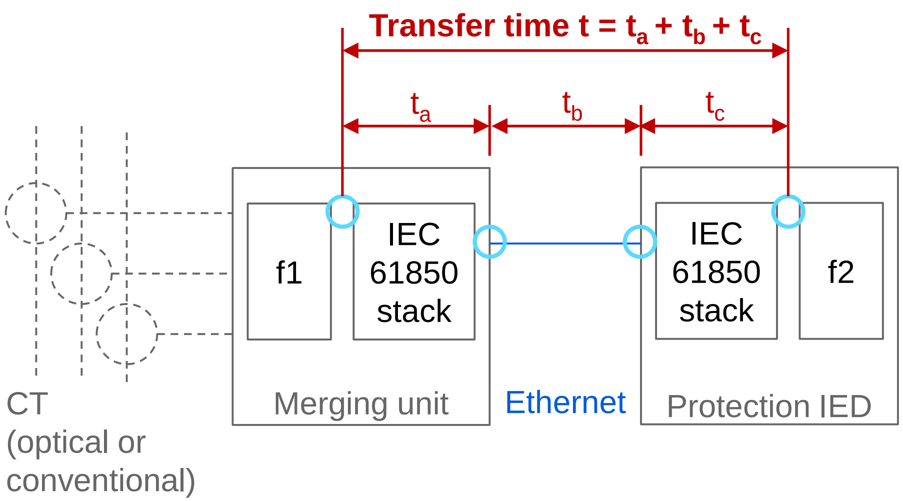
**Dark blue: standardized times**

# Fault clearance times of digital substations
## Standardized value: Merging unit delay time




- IEC 61869-9 will specify the allowed delay time of the merging units:
  Delay time ≤ 2ms
- Time from change on primary side until data is available on Ethernet port of the merging unit
- This time has a direct impact on protection speed

# Fault clearance times of digital substations
## Standardized value: Transfer time

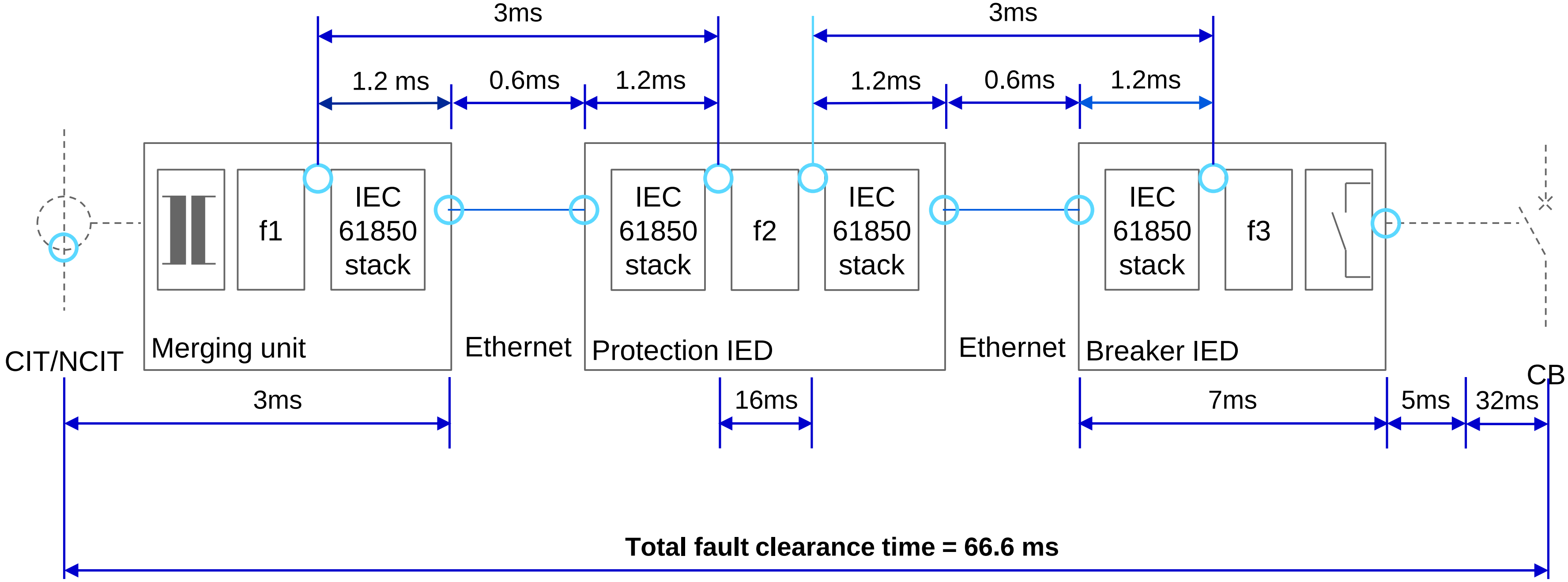



- IEC 61850-5 specifies transfer time class TT6 for sampled values and trip GOOSE
  Transfer time ≤ 3ms
  - Resulting performance classes of devices:
    P1 for GOOSE in bay and process IEDs
    P7 for sampled values in MUs and IEDs
- Transmission time of a message, including communication handling on both sides
- This time has a direct impact on protection speed
- Influenced by
  - Stack processing time in merging unit ($t_a$)
  - Stack processing time in protection IED ($t_c$)
  - Network transfer time ($t_b$)

**Product feature.** Ensured by standardized performance test

**System design.** To be considered during project execution

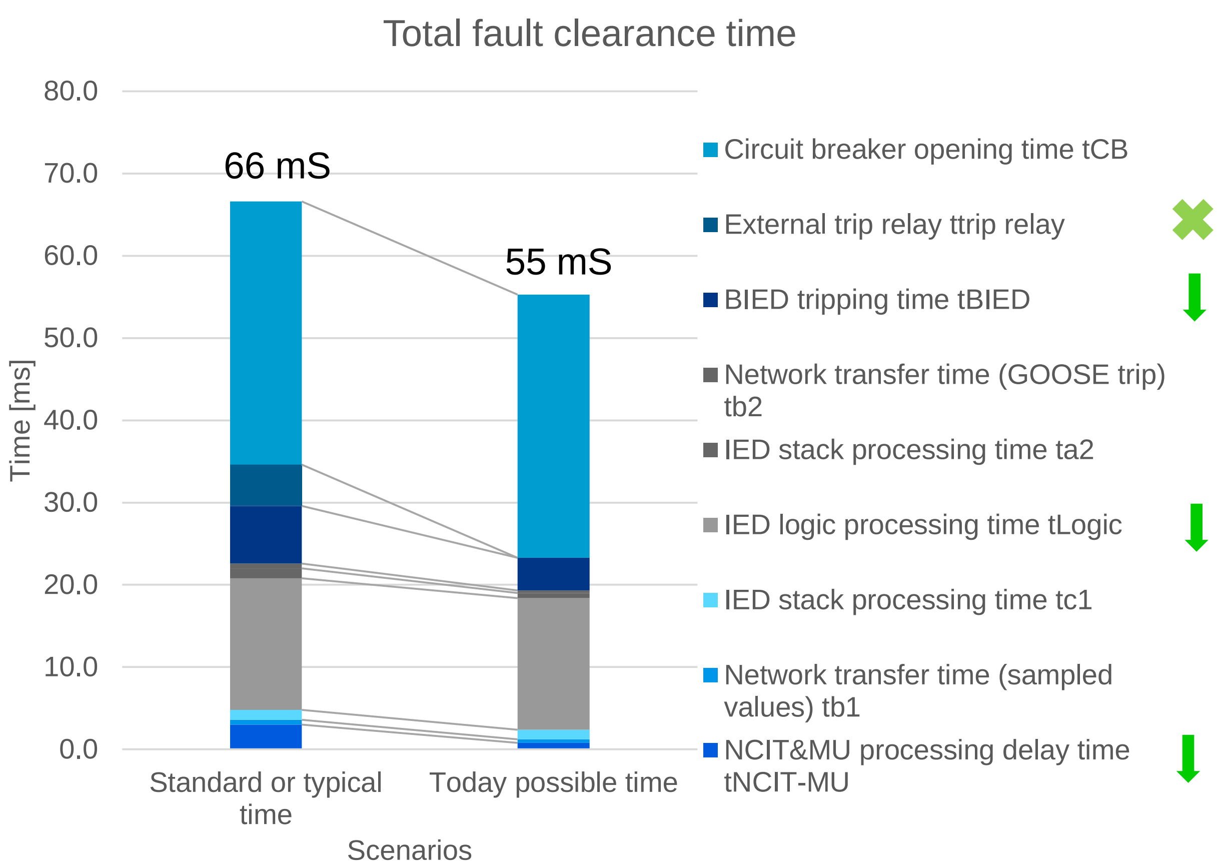
# Fault clearance times of digital substations
## Standard times, BIED with relay output, trip relay




- Achieving 4-cycle total fault clearance time is possible if
  - Components fulfill highest performance classes
  - Ethernet networks have minimal latency

(Even with conservative assumption of 1 cycle for protection function.)

# Fault clearance times of digital substations
## Time with standard and today possible values




- State of the art protection IEDs, NCITs, merging unit and system design
- Standardized performance times can be greatly improved

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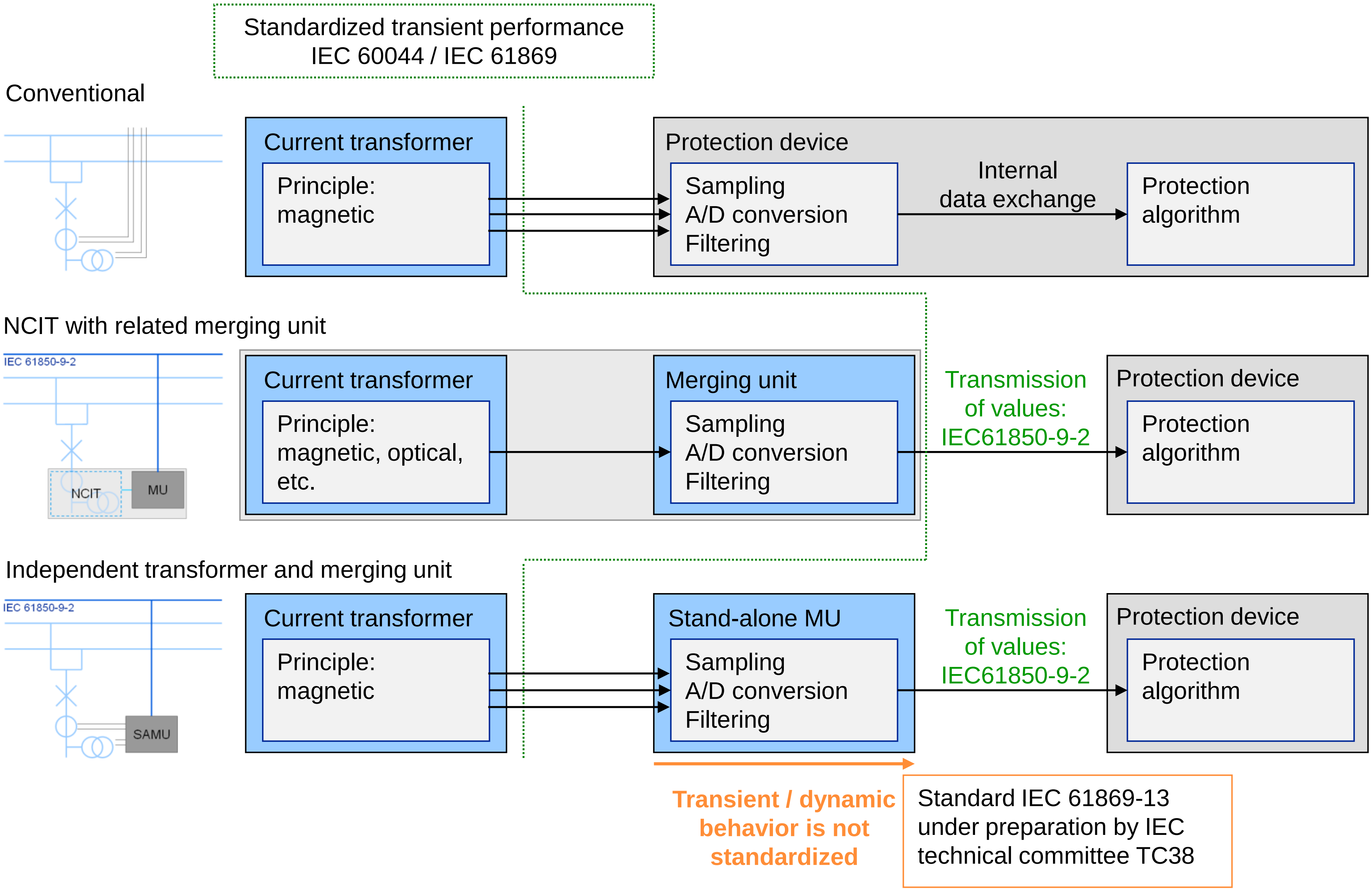
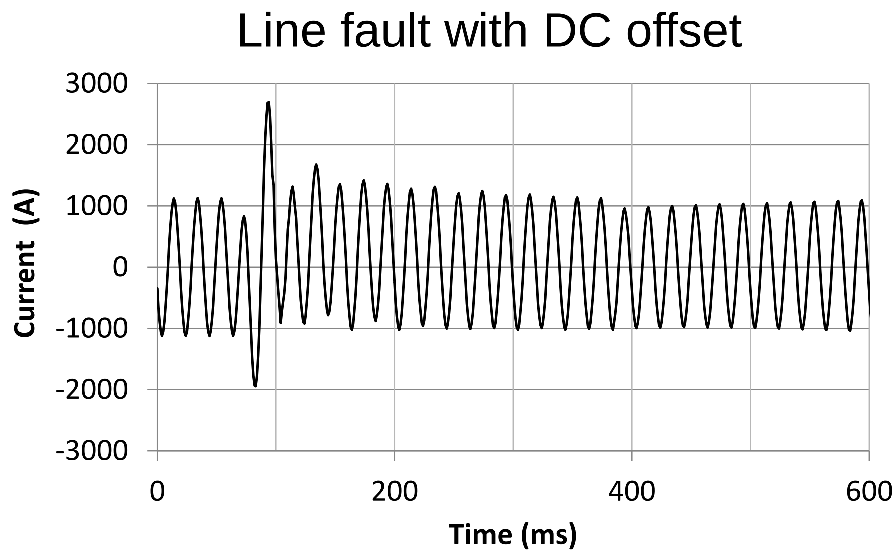
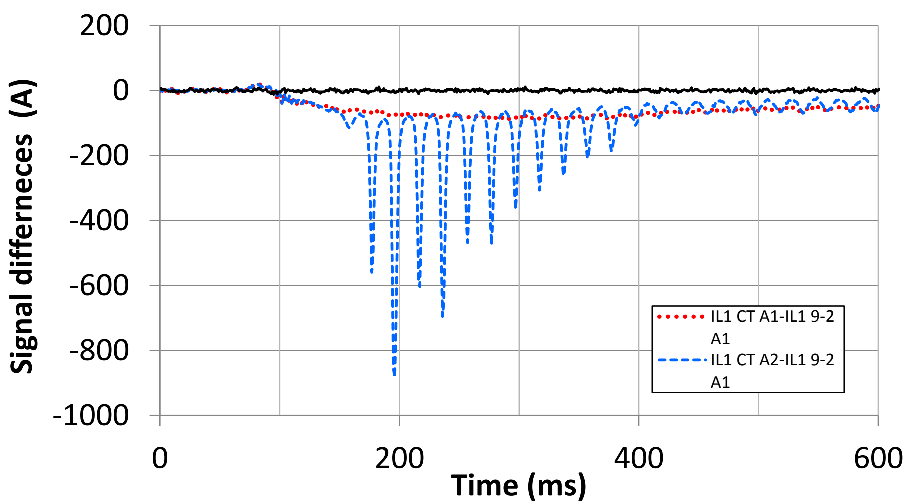
# Impacts of non-conventional instrument transformers
## Transient performance



# Impacts of non-conventional instrument transformers
## Sensor performance vs CTs




**Current vs time (FOCS 1)**




**Signal differences:**

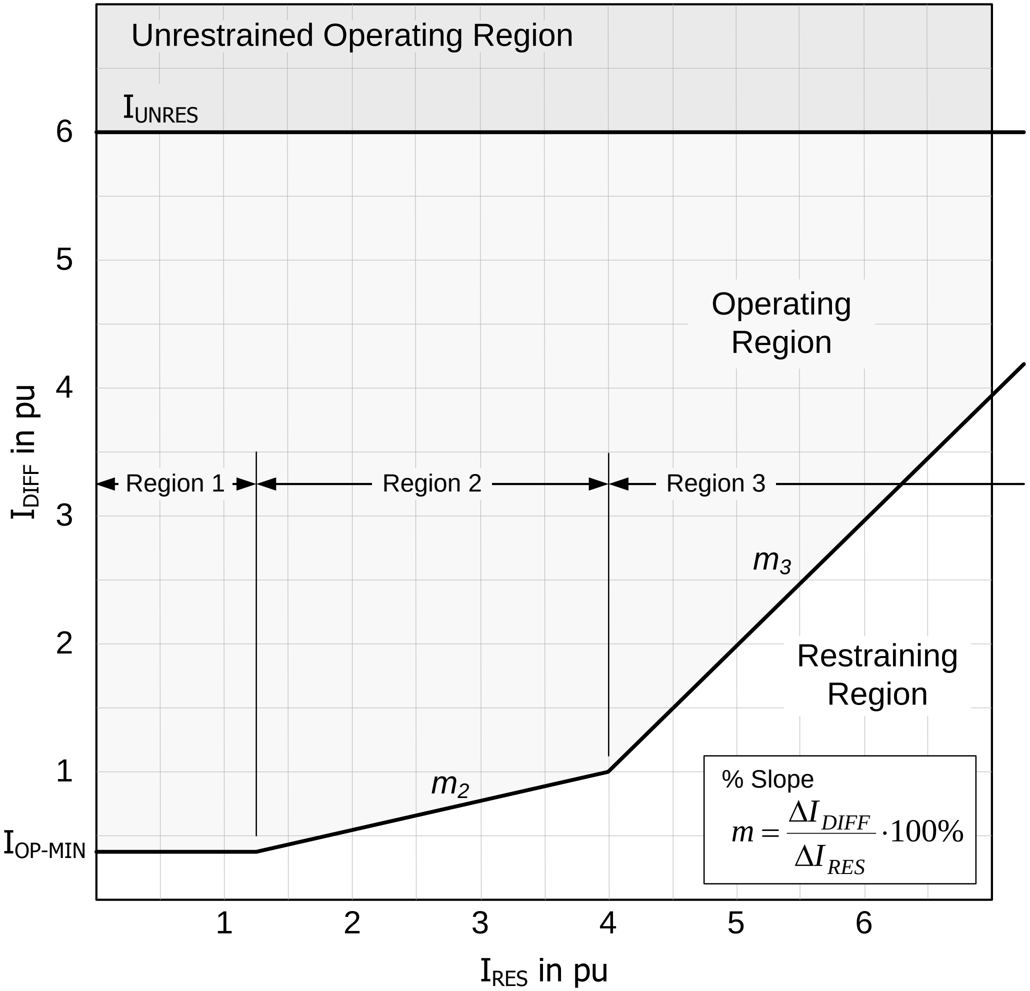
**FOCS 2 – FOCS 1**

**Protection CT – FOCS 1**

**Metering CT – FOCS 1**

Sensor covers metering and protection dynamic range (mA to 100 kA)

# Impacts of non-conventional instrument transformers
## Transformer Differential Protection Application




Reducing the slope setting

- Region 2 due to unequal performance of CT's
- Regional 3 due to CT saturation

# Transformer Differential protection settings
# Error analysis

Example:

CT error = +/- 10%

LTC variation = 10%

Excitation current at rated voltage = 1.4%

Margin = 5%

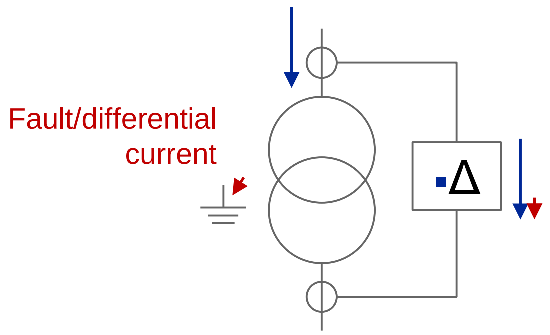
Relay minimum operating current setting:

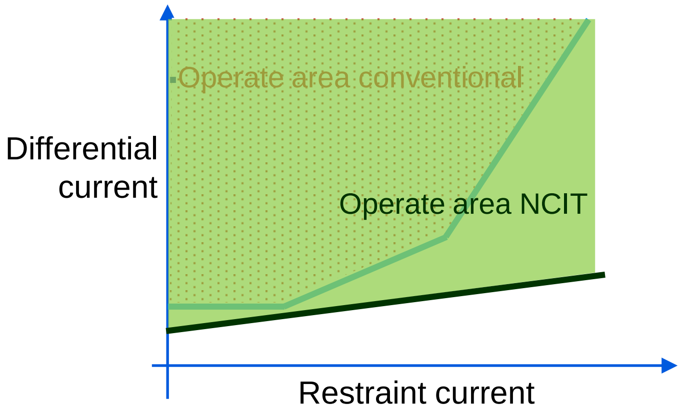
(CT error)@HV side+(CT error)@LV side +LTC + $I_e$ + margin =

0.1+0.1 +0.1+0.02 + 0.05=0.37 pu

Minimizing error can reduce minimum I operate setting by 0.2 PU

# Impacts of non-conventional instrument transformers
## Benefit of sensors not saturating




- Misoperation of current differential protection due to CT saturation needs to be avoided
- Higher absolute current (restraint current) requires a higher differential current to initiate a trip
  - This makes the function stable but loses sensitivity
- As NCITs do not saturate the differential protection can keep sensitivity across entire range
  - Can reduce these slopes to 0 and just have minimum operate setting with a marginal slope for security

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# Cyber Security for Substation Automation
## The Digital World opens up Cyber Threats

- Cyber security has become an issue **by introducing Ethernet (TCP/IP) based communication protocols** to automation and control systems. e.g. DNP 3.0 via TCP/IP or IEC61850
- **Connections to and from external networks** (e.g. office intranet) to substation automation and control systems have opened systems and can be misused for cyber attacks
- **Cyber attacks on substation automation and control systems are real and increasing**, leading to large financial losses
- **Utilities penalties** due to non-compliance with regulatory standards or industry best practices

# Early CIP Committee position on Ethernet

NERC CIP Committee Questions to Vendor Panel (Dec 2007):

**"IEC 61850 (Ethernet based) is wide open communication that does not comply with CIP standards.** There are manufacturers planning to connect substation equipment together using control IED's connected with 61850. How will the 61850 substation of the future maintain compliance?"

**"[We] have determined the best approach for our substation control IED's is to use [non-routable] serial communication.** This removes the need for IP in the substation connected to control IED's, thus keeping the six walls of protection in the control and communication centers. [We] will only purchase control IED's that maintain the secure communication to maintain compliance. What are the manufacturers hearing from other customers with regards to serial or IP communication? Will all of the functions provided via IP communication be available using serial communications? Will serial interfaces continue to be provided for the foreseeable future?"

**"R" in NERC stands for Reliability! Preventing real-time outflow of substation information will only be detrimental to the overall Grid Performance and Reliability**

**We have come a long way since 2007 Airgap is not the solution!**

# The Challenges
## Organizational

### Risk Management

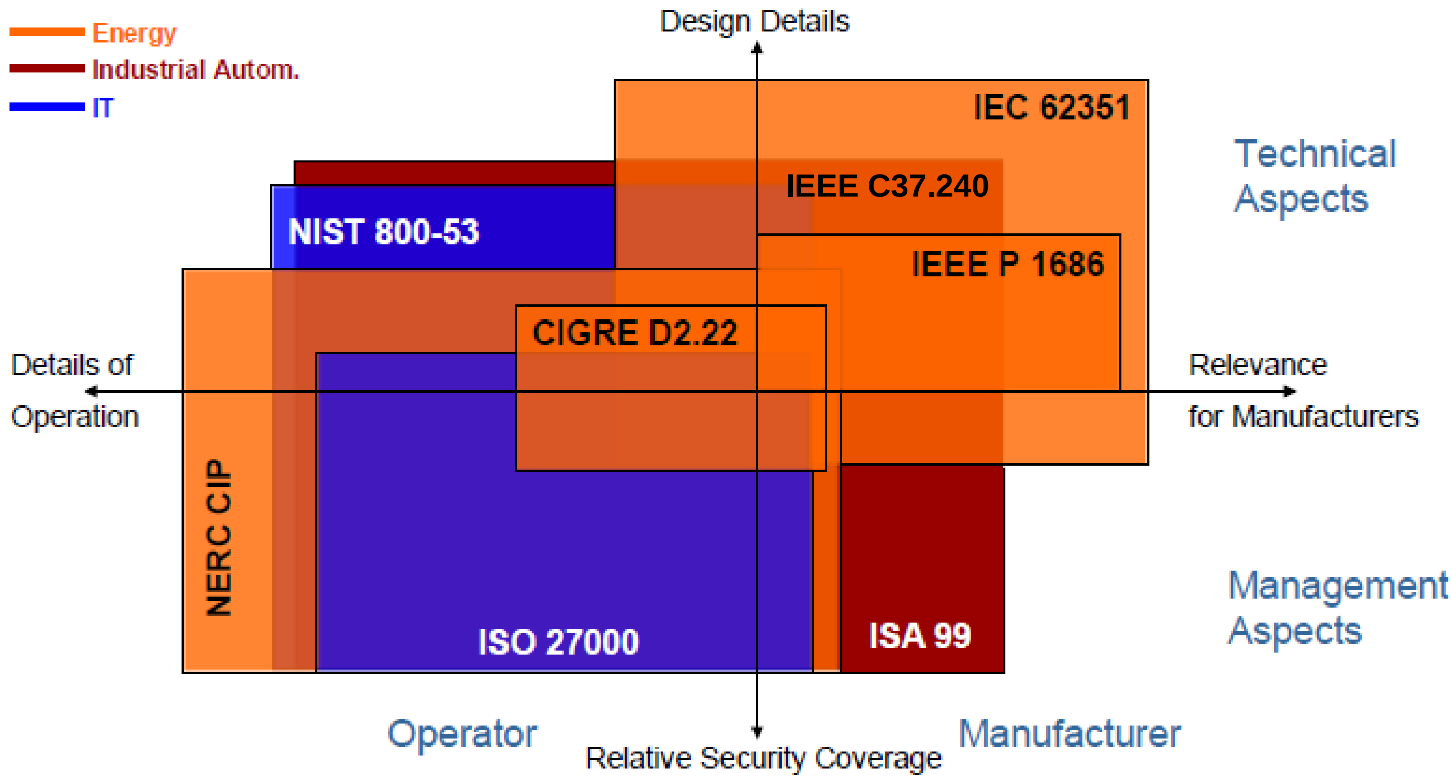

### Awareness


### Competence Management


### Disruptive Changes

Images: www.guardianconsultants.co.uk wegilant.com www.floris-cm.nl blogpool4tool.com

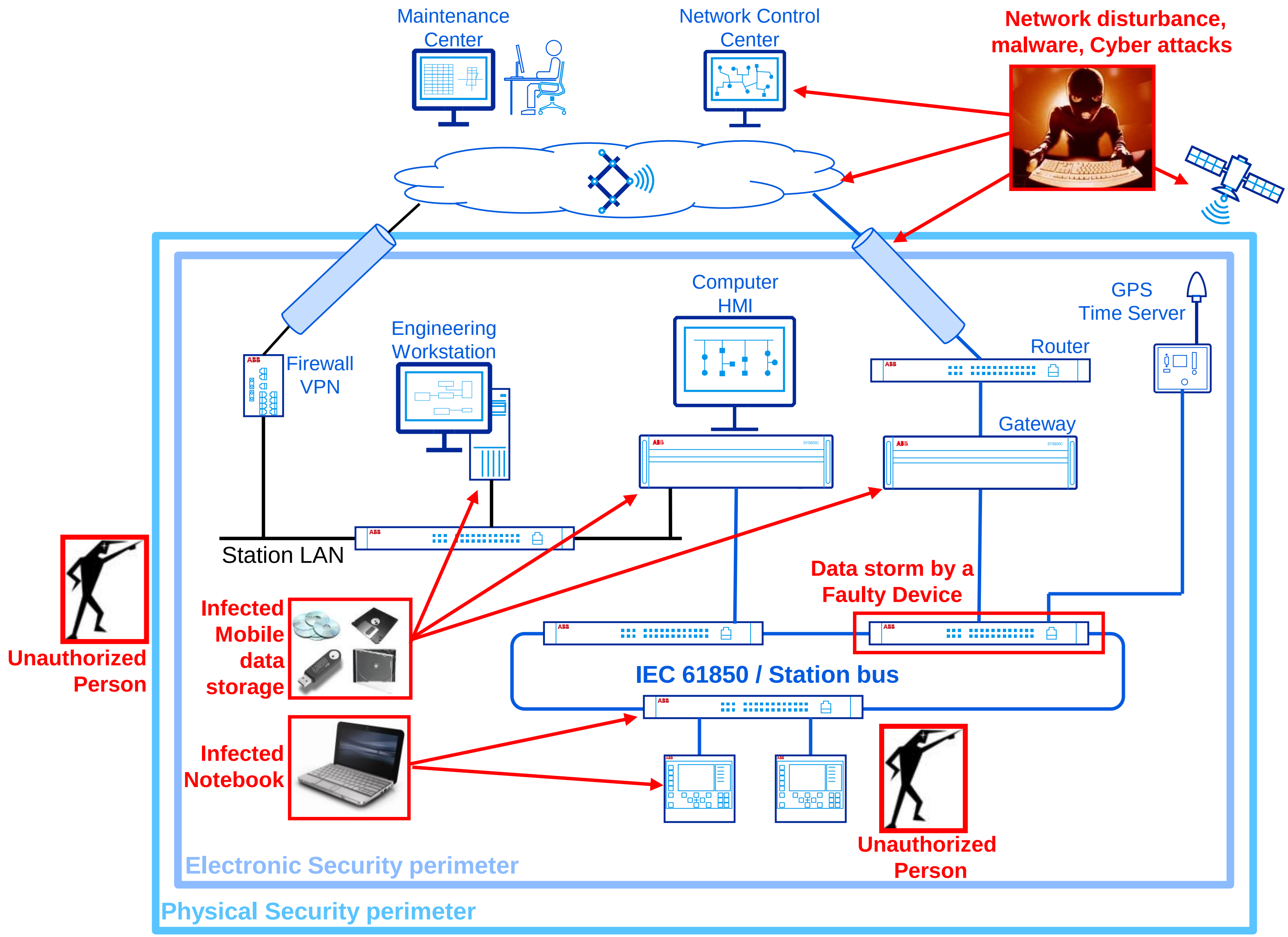
# Cyber Security for Substation Automation
## Standards and their scope



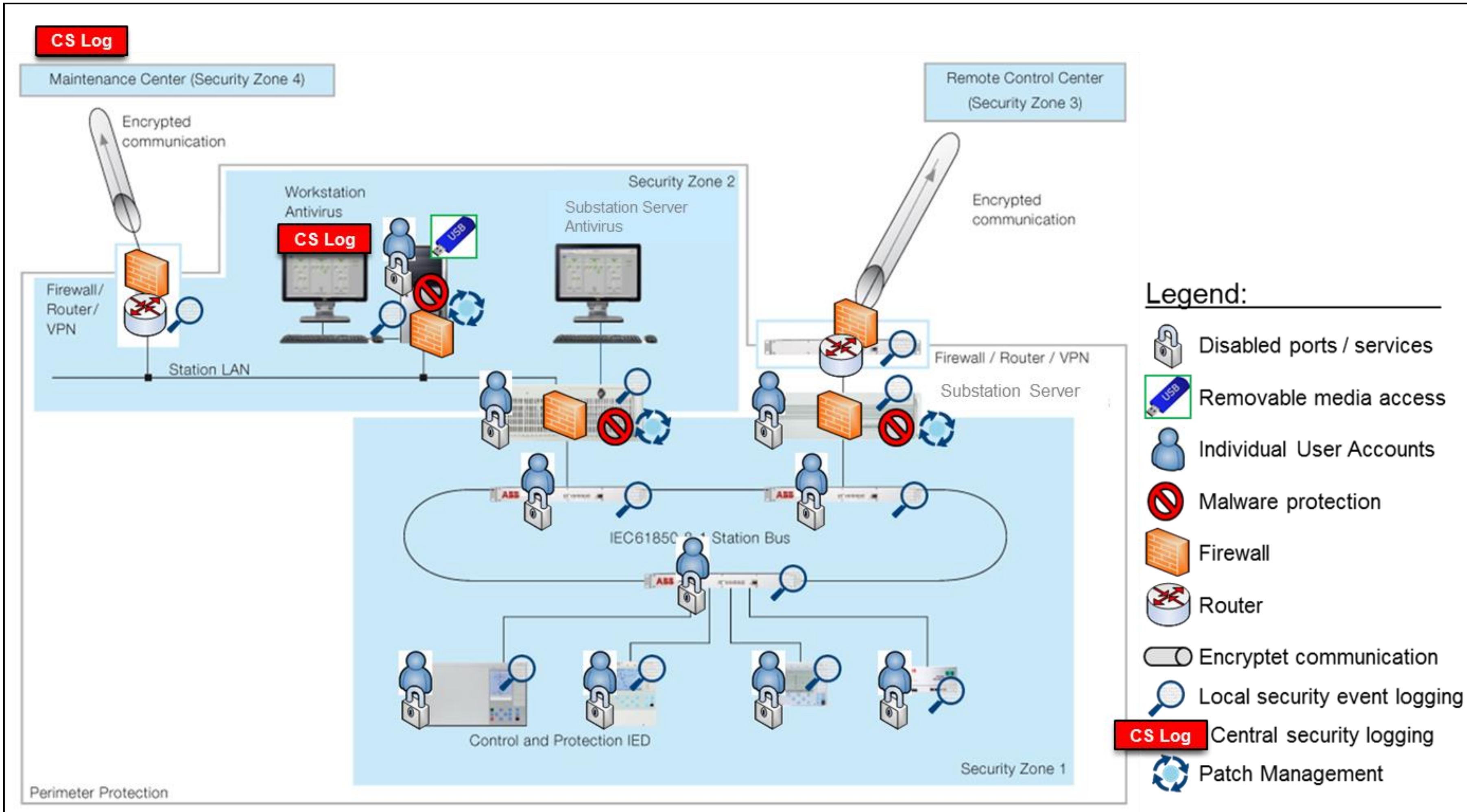

- Graphical representation of scope and completeness of selected standards

*) source DTS IEC 62351-10 10: Security architecture guidelines

# Protect – Defense in Depth
# Unauthorized access or attack



# Cyber Security – Defense in Depth
## Substation Security Architecture



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# Conclusions

- The Digital World has changed our industry through innovation and technology
- From the first microprocessor relays introduced in 1984 to the modern digital systems, protection and control solutions will continue to evolve enabling:
  - Higher performance and improved accuracy
  - Improved reliability and personnel safety
  - Functional consolidation in the control house and in the switchyard
  - Greater system visibility improving fleet management
- Challenges
  - New skills are required to design, commission and operate
  - Embracing cyber security and replacing fear with knowledge

# Questions?