Case Study: Designing Centralized Protection and Control Systems for a Distribution Substation at Duke Energy

Stephen B. Ladd, Taylor I. Raffield, and Ethan Haithcox
Duke Energy

Jackson Fultz
Schweitzer Engineering Laboratories, Inc.
(formerly of University of North Carolina at Charlotte)

Arun Shrestha, Arunabha Chatterjee, and Priyanka Nadkar
Schweitzer Engineering Laboratories, Inc.

Agenda

- Case study overview
- Current distribution substation design
- Overview of CPC systems
- Utility's perspective on CPC
- CPC system design
- Comparative evaluations
  - Device count
  - Protection scheme unavailability
  - Protection system operation speed

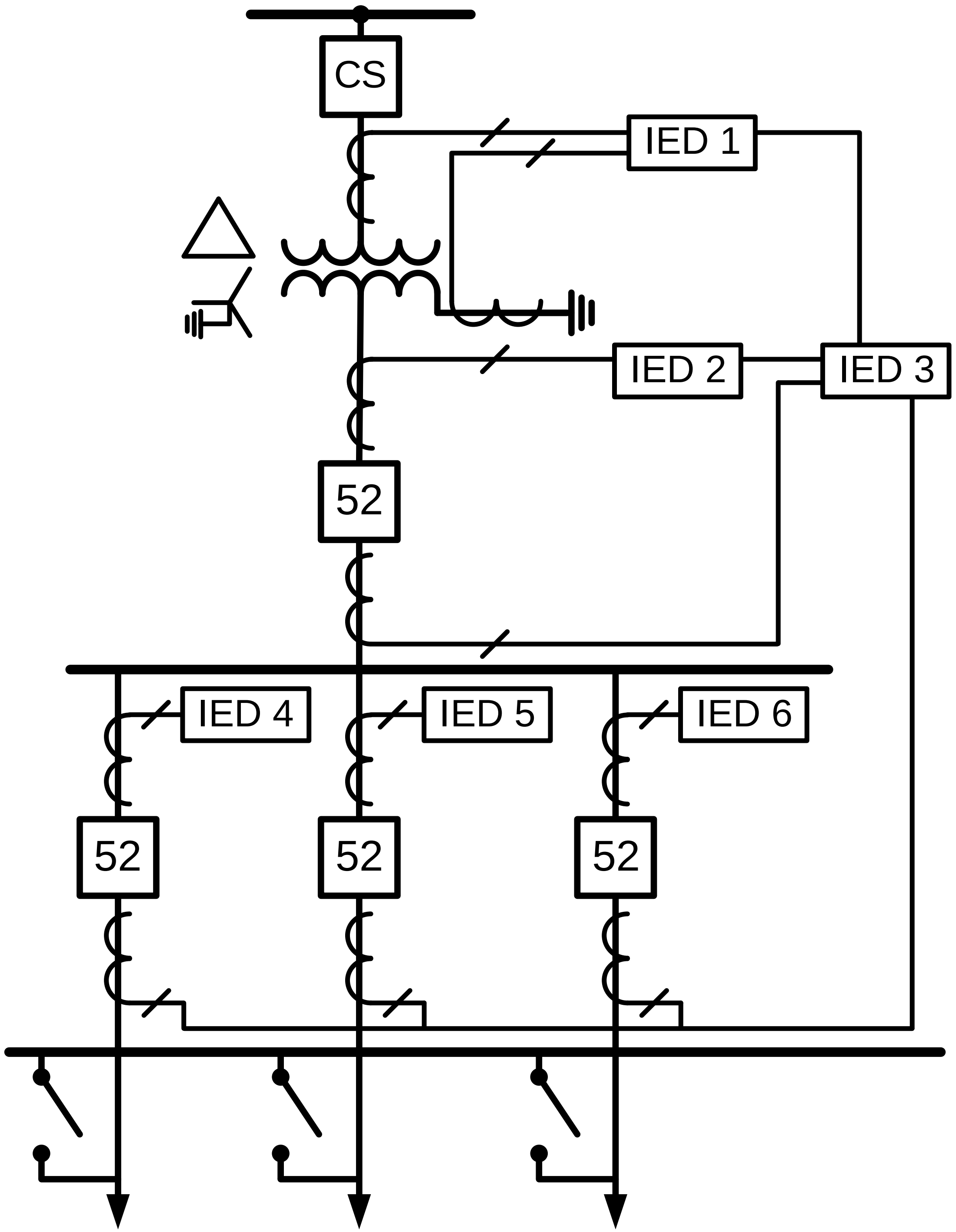
    Breaker failure application
- Lessons learned and future plans
- Conclusion

Case study overview

- Evaluate current distribution substation protection
- Explore CPC designs and provide the utility’s perspective on CPC implementation
- Detail CPC design for existing 100 kV/24 kV distribution substation
- Compare evaluations between traditional and CPC designs
  - Device count
  - Protection scheme unavailability
  - Protection system operation speed

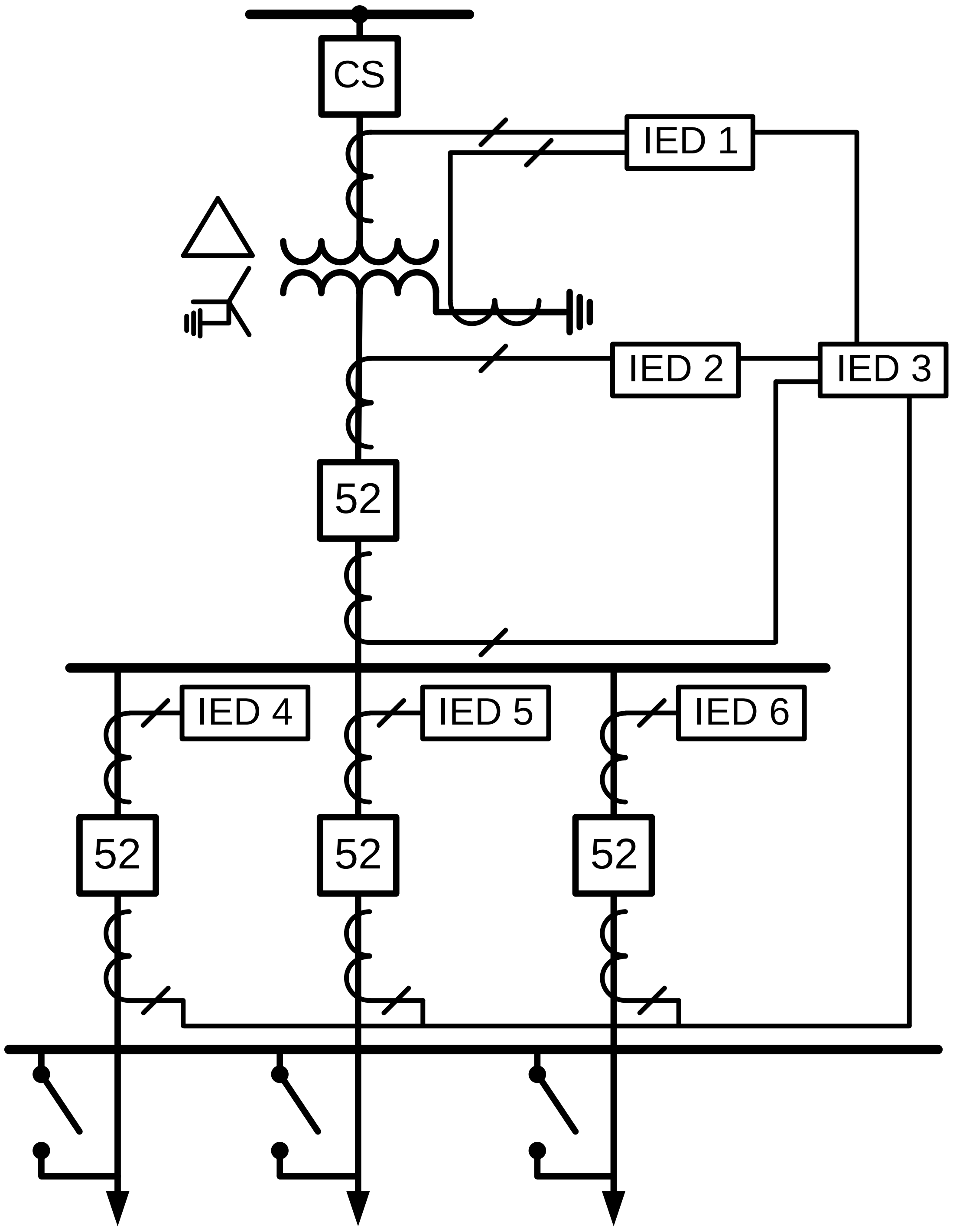
Overview of utility's current distribution substation protection

- Normal operation – fast protection is maintained within substation
- Backup protection, not redundancy
- Two protection panels, transformer bank panel, and circuit exit panel



Overview of utility's current distribution substation protection

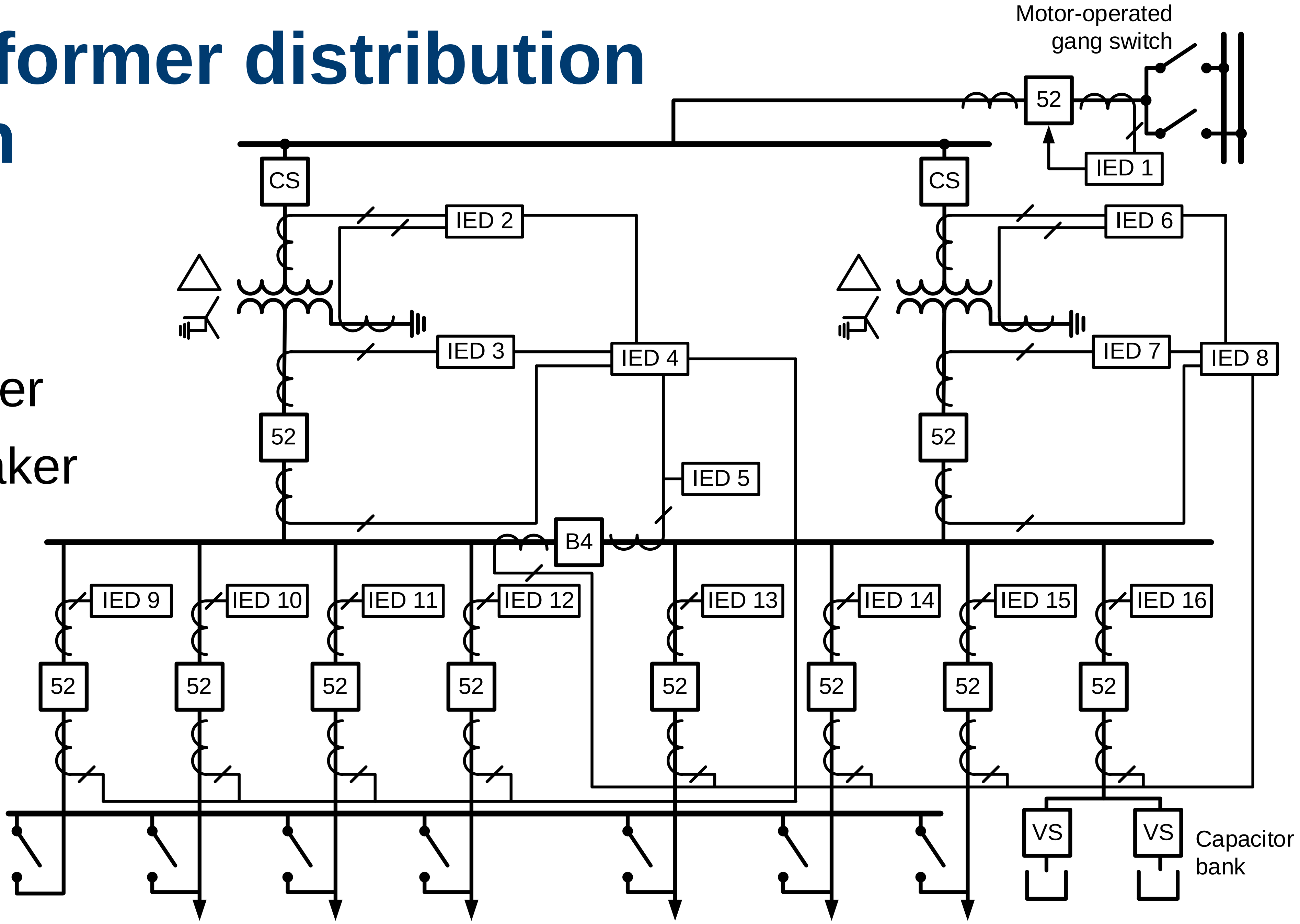
- Current test blocks, control handles, lockouts, and test switches
- Bus and transformer differential in one device



Two-transformer distribution substation

Has additional components

- Bus-tie breaker
- Auxiliary breaker
- Capacitors
- High-side swapover



Overview of CPC systems

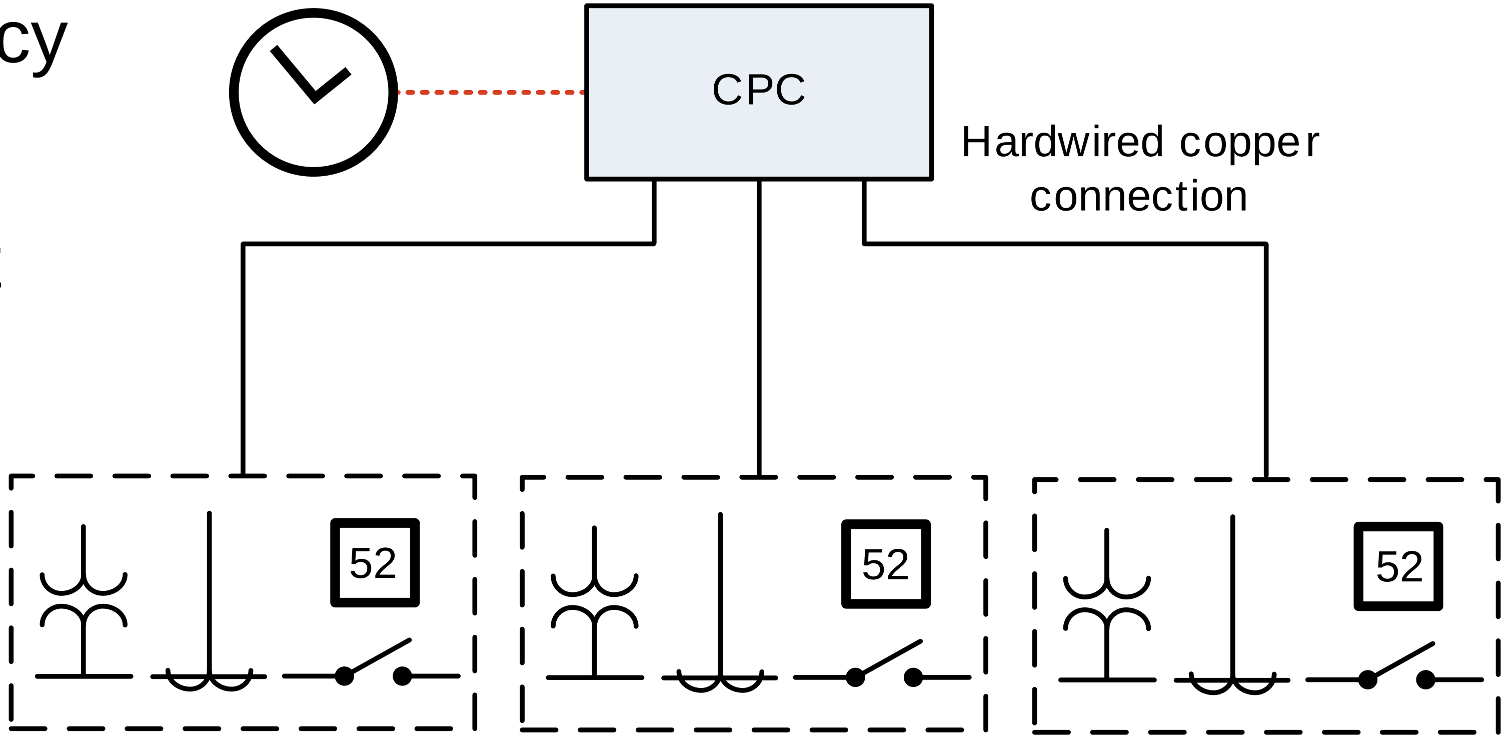
- Are central brain of substation and make all decisions within substation
- Aim to replace all individual relays in substation
- Act as central hub for all P&C purposes

Types of CPC

- Hardwired CPC system
- P2P-based CPC system
- IEC 61850-based CPC system

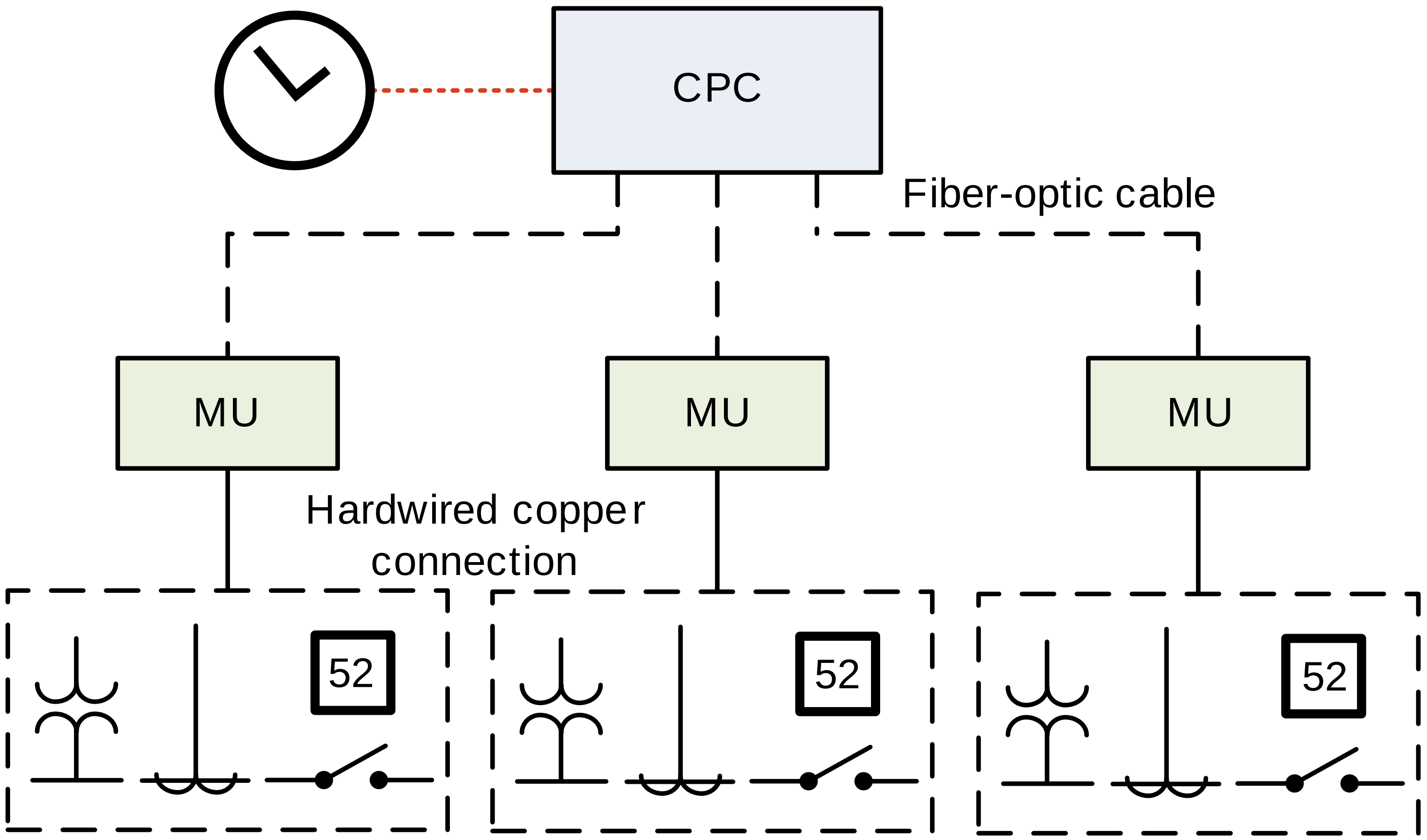
Hardwired CPC

- Has CTs, PTs, and switchgear signals hardwired directly to CPC
- Exhibits no signal latency
- Provides simple design
- Is well-suited for retrofit applications, small substations, and industrial applications
- Requires no network engineering or time synchronization



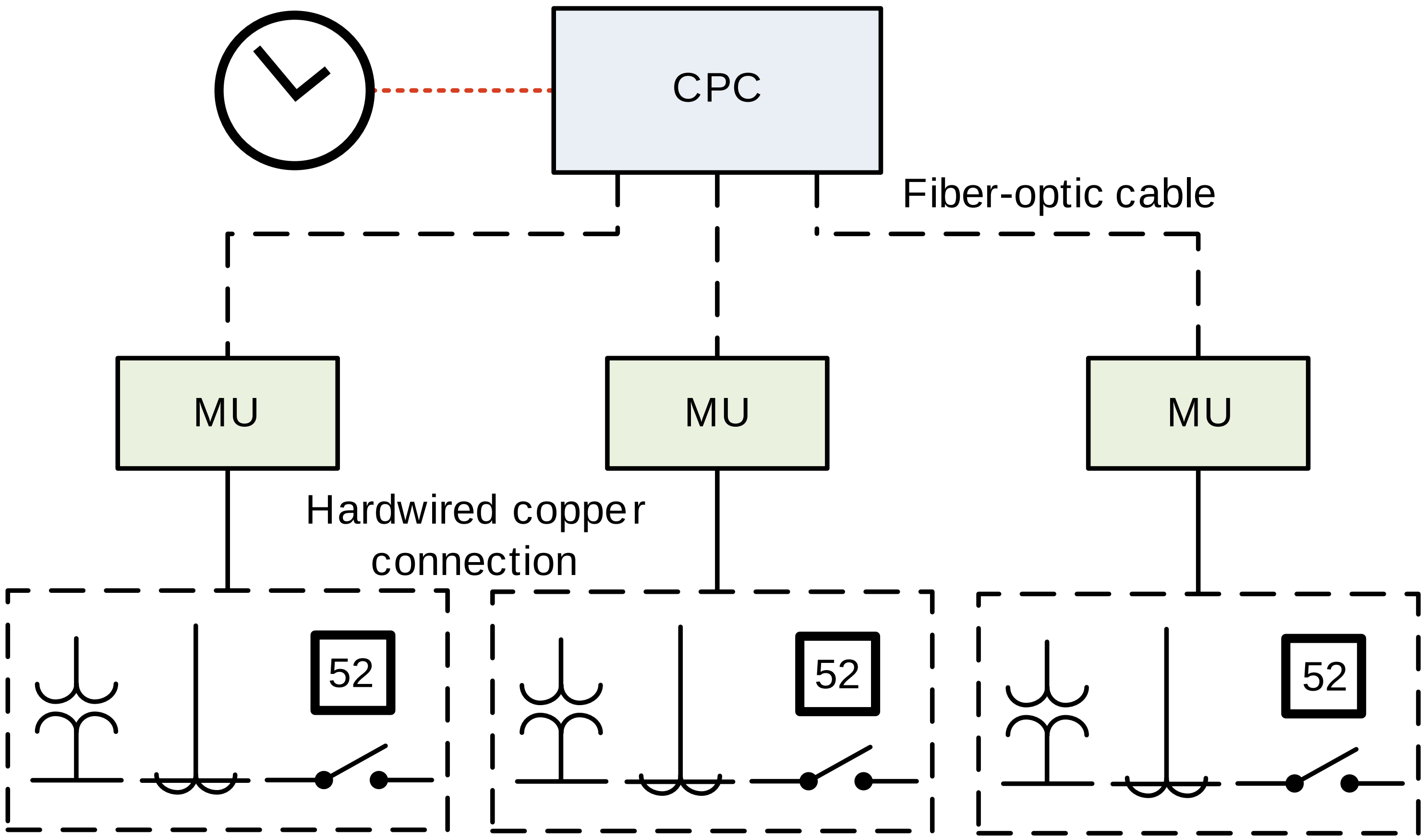
P2P-based CPC

- Data acquisition from CTs, PTs, and switchgear signals is carried out by MUs
- CPC connects directly to MU via fiber-optic cables
- Design eliminates copper cables between switchyard and control house



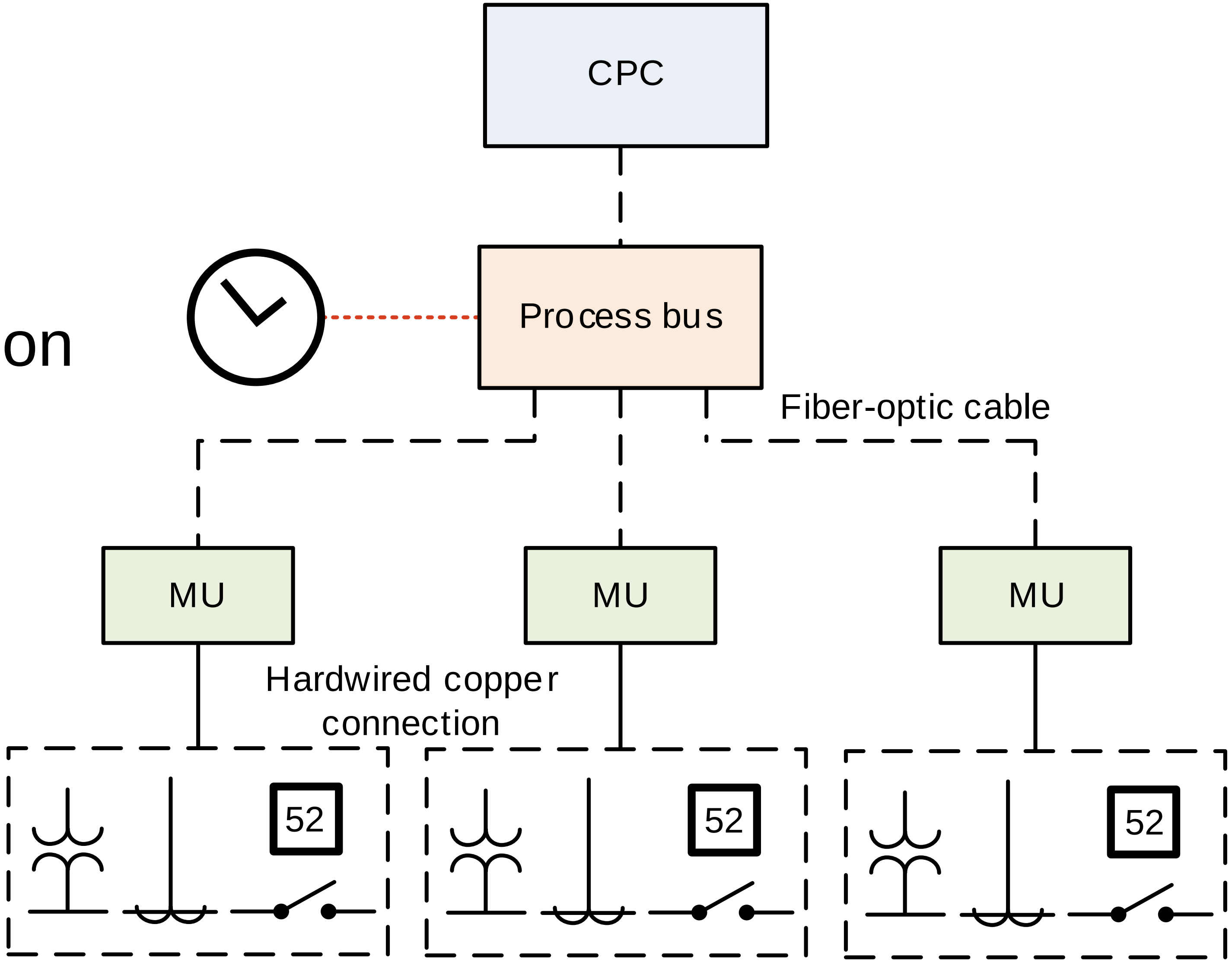
P2P-based CPC

- Time synchronization is not required
- CPC is well-suited for small- and medium-sized substations
- Expansion is limited by number of ports on CPC



IEC 61850-based CPC

- Acquires data from MU
- Connects to MU via networked process bus
- Requires time synchronization
- Requires robust network engineering
- Supports interoperability
- Is not limited by number of physical ports on CPC



Utility's perspective on CPC

Potential Benefits

- Reduced number of devices to keep in inventory
- Reduced number of devices to test and commission
- Reduced panel wiring (interrelay wiring) and panel space
- Reduced complexity in settings and software – reduction in the number of settings templates required
- Reduced commissioning time
- Simplified SCADA communications

Utility’s perspective on CPC

Challenges

- Implementation of multiple settings groups – historical practice on feeder and transformer relays
- Control logic implementation with primary and secondary CPCs
- Operational complexity and operator interface changes
  - Blocking protective elements
  - Obtaining relay targets after an event
  - Opening/closing a breaker with pushbuttons

Utility’s perspective on CPC

Challenges

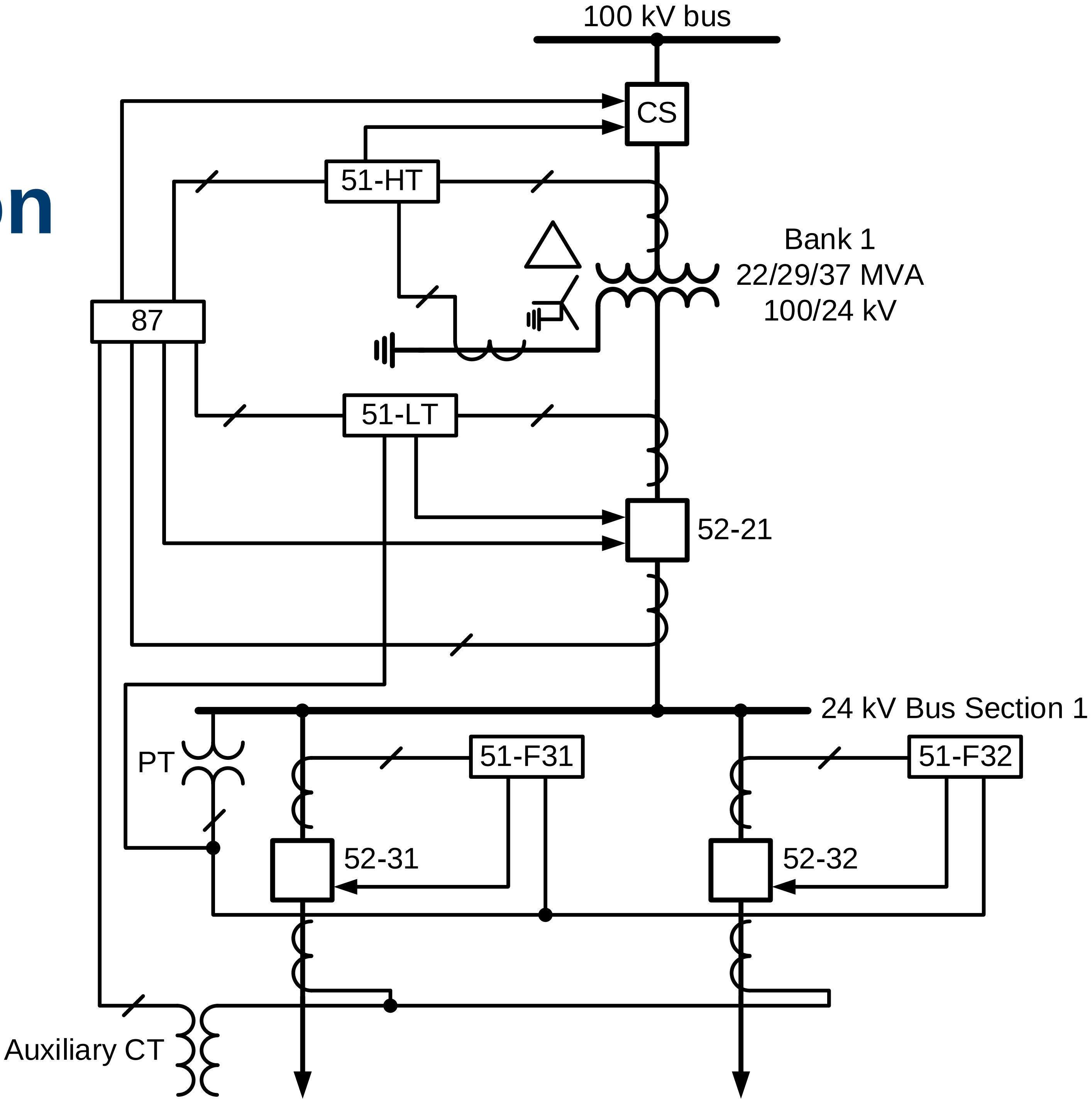
- Change management plan for P2P- or IEC 61850-based CPC systems
  - Extensive lab testing prior to implementation
  - Training of relay technicians and operators

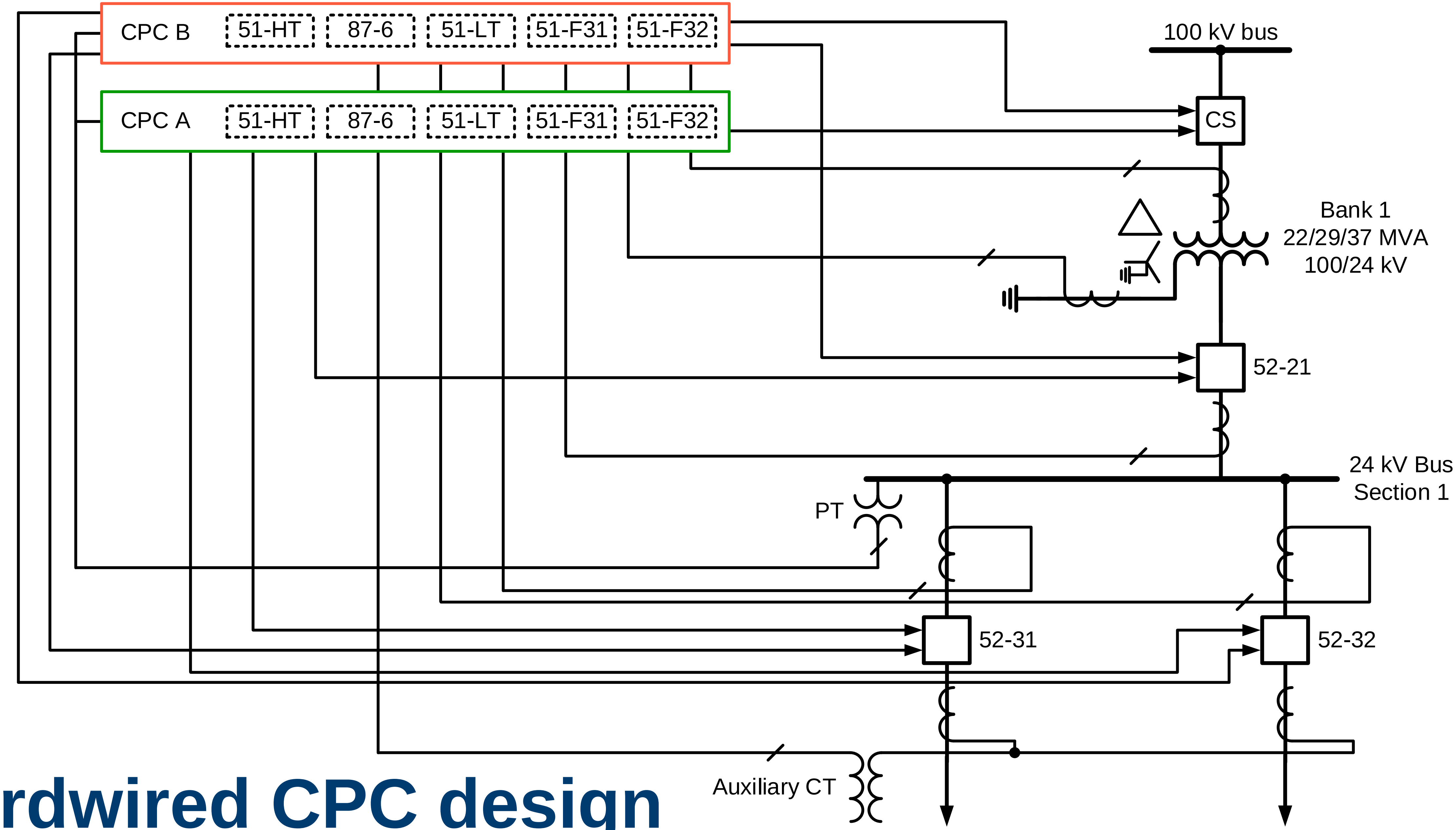
Utility’s perspective on CPC

Design Questions/Considerations

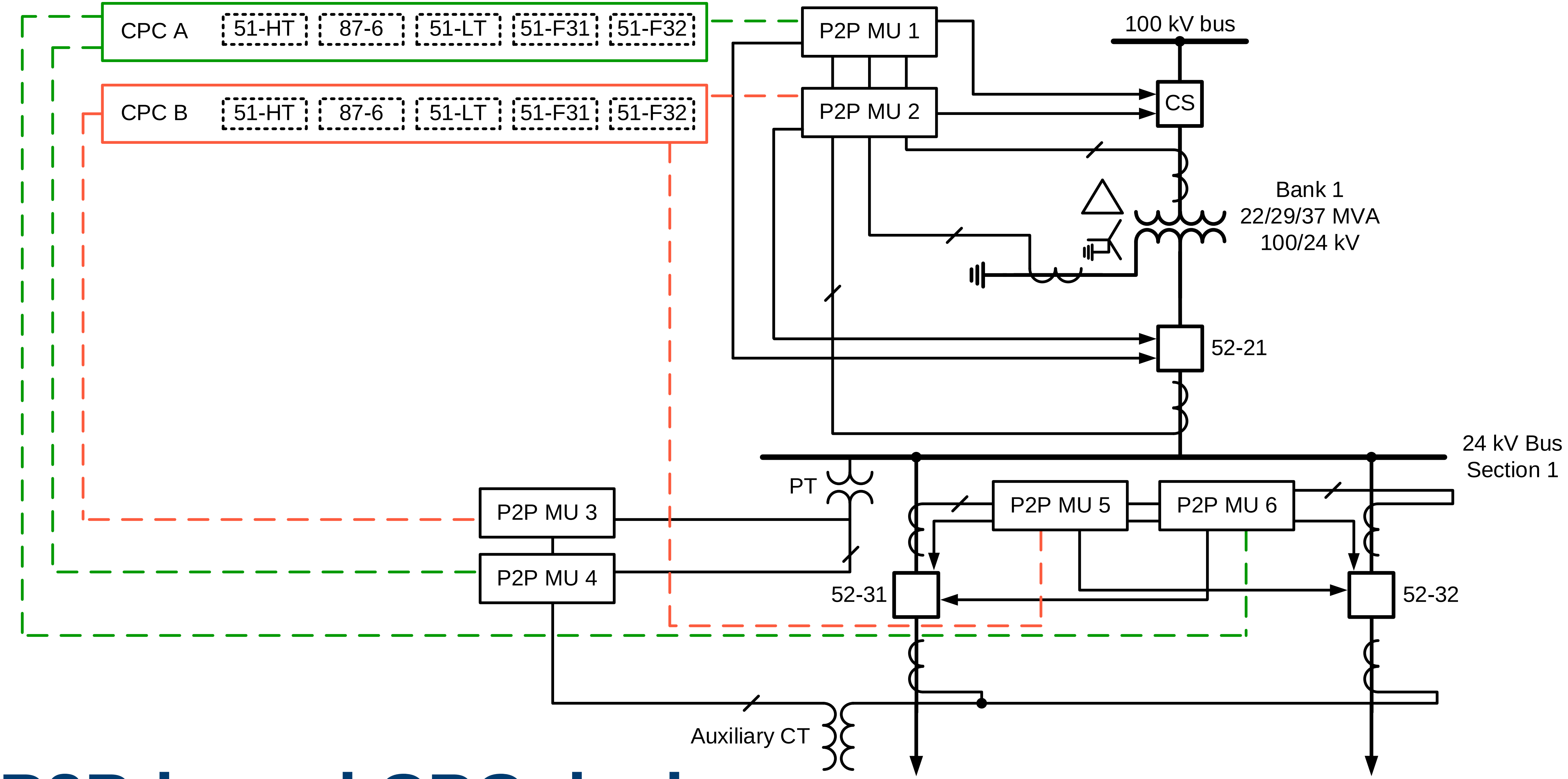
- Backup versus redundancy
- Standardization and repeatability – minimal customization in both design and settings?
- Simplicity – Is the protection scheme easily understood by all?
- How easy is the design to install and test?
- How is the ease of troubleshooting and maintenance impacted?
- How much centralization is too much in one CPC system?
- How is cost versus benefits evaluated?

Existing substation

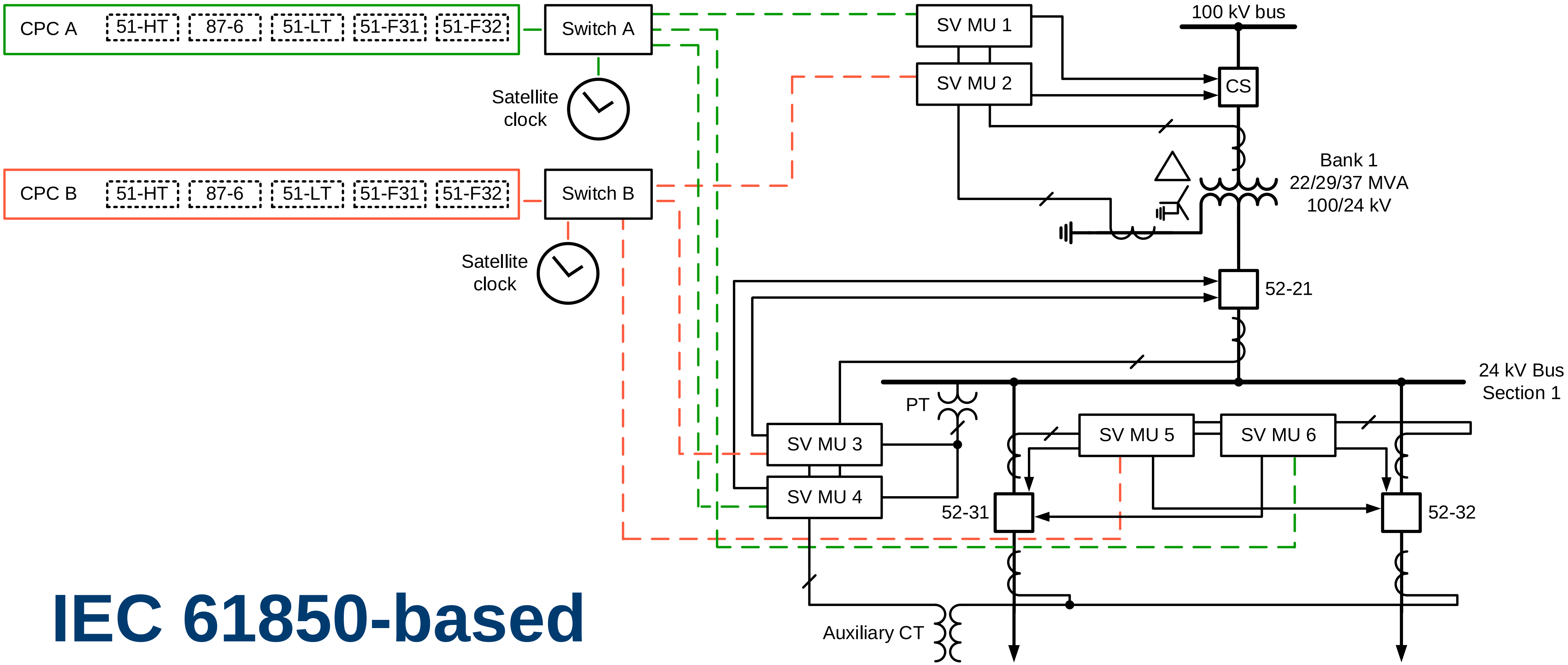




Hardwired CPC design



P2P-based CPC design



IEC 61850-based CPC design

Comparative evaluation

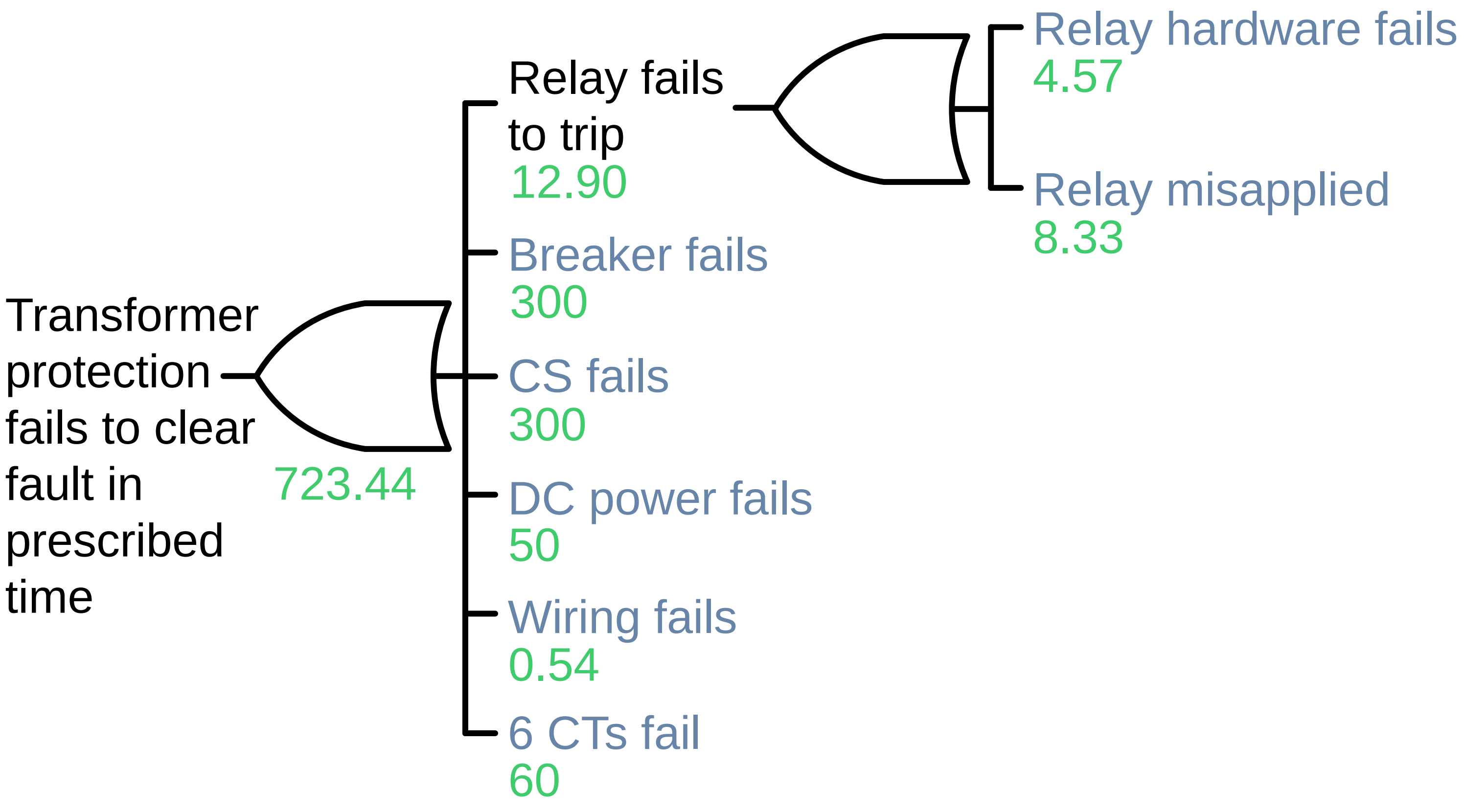
Device count

Device	Existing P&C Design	Hardwired CPC Design	P2P-Based CPC Design	IEC 61850-Based CPC Design
Relay	5	0	0	0
CPC	0	2	2	2
MU (P2P/IEC 61850)	0	0	6	6
Ethernet switch	0	0	0	2
Satellite clock	0	0	0	2
Total Device Count	5	2	8	12

Protection scheme unavailability

Traditional

Numbers shown are unavailabilities • 10^{-6}

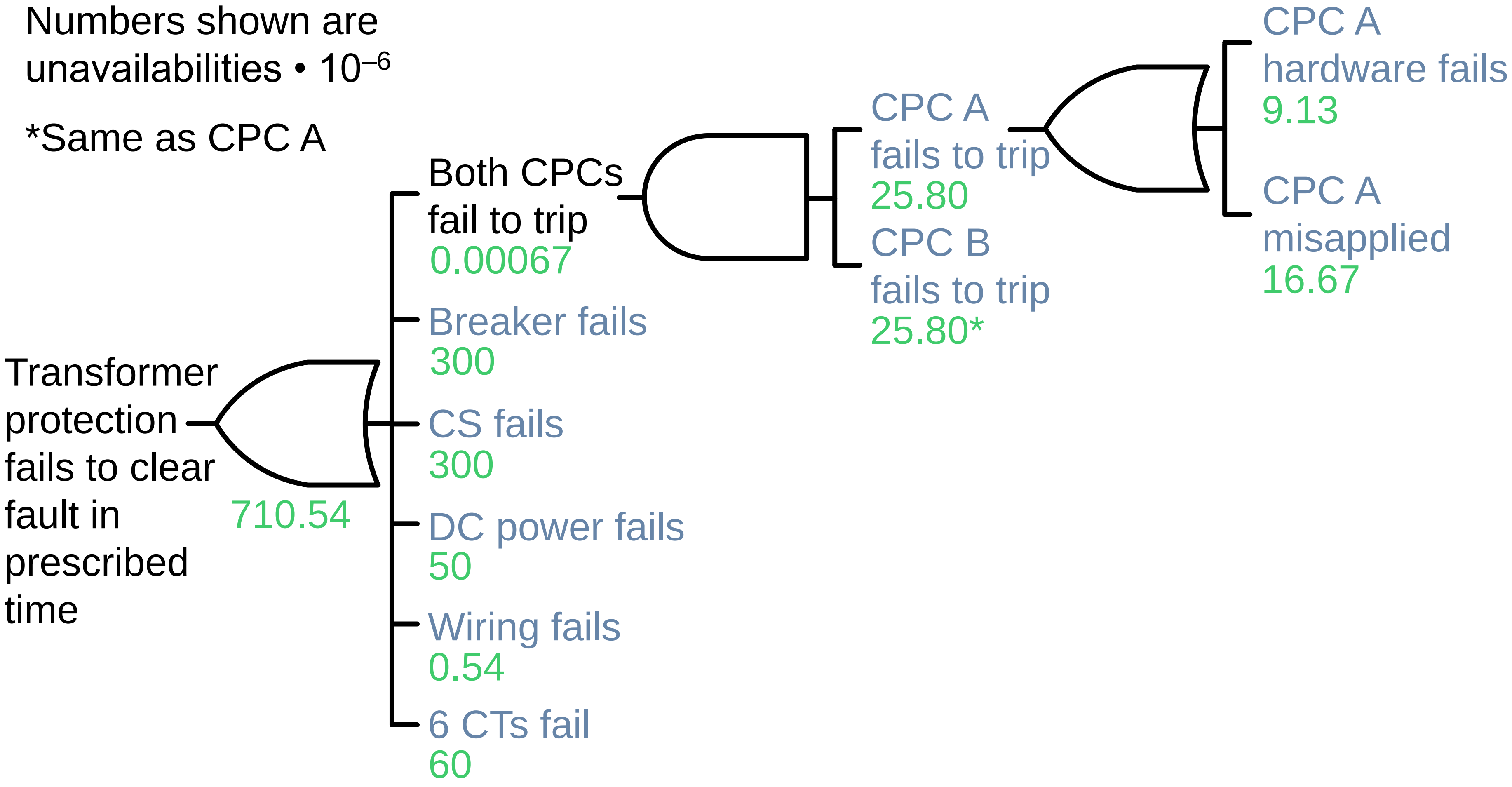


Protection scheme unavailability

Hardwired CPC

Numbers shown are unavailabilities • 10^{-6}

*Same as CPC A

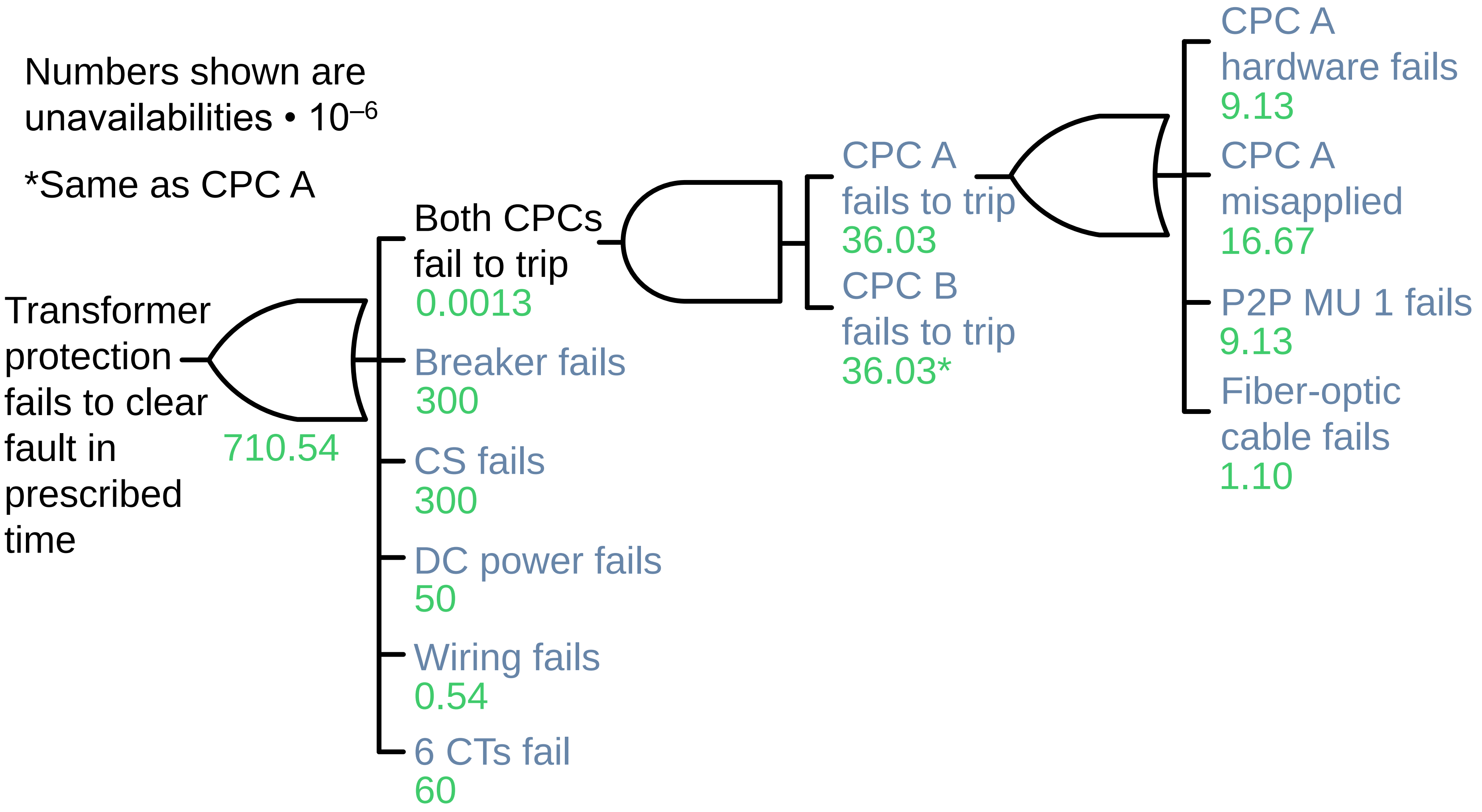


Protection scheme unavailability

P2P-based CPC

Numbers shown are unavailabilities • 10^{-6}

*Same as CPC A

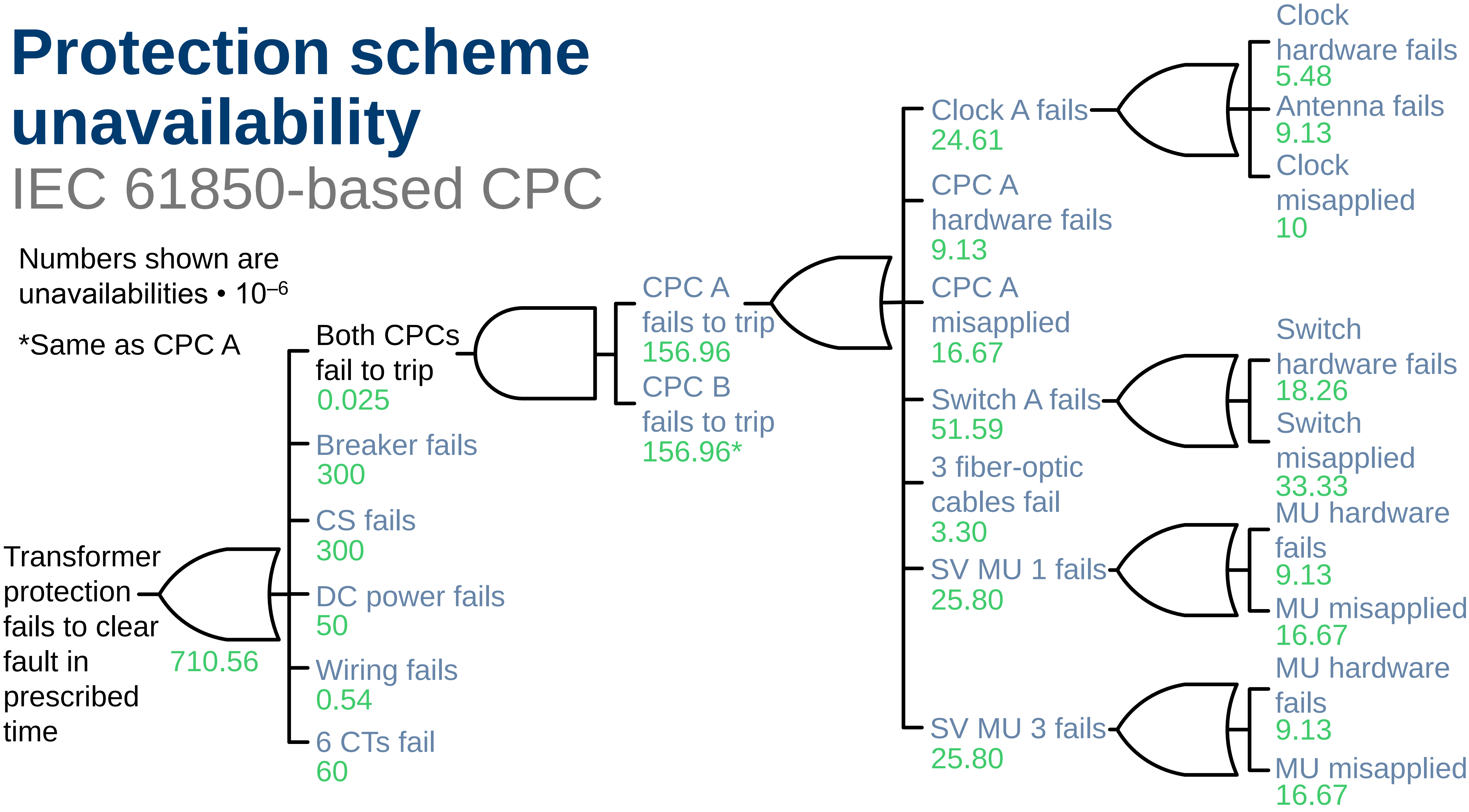


Protection scheme unavailability

IEC 61850-based CPC

Numbers shown are unavailabilities • 10^{-6}

*Same as CPC A



Protection scheme unavailability

Overall unavailability (10^{-6})

Solution	Transformer Protection	Feeder Protection
Traditional substation	723.44	393.44
Hardwired CPC system*	710.54	380.54
P2P-based CPC system*	710.54	380.54
IEC 61850-based CPC system*	710.56	380.56

* With full redundant design

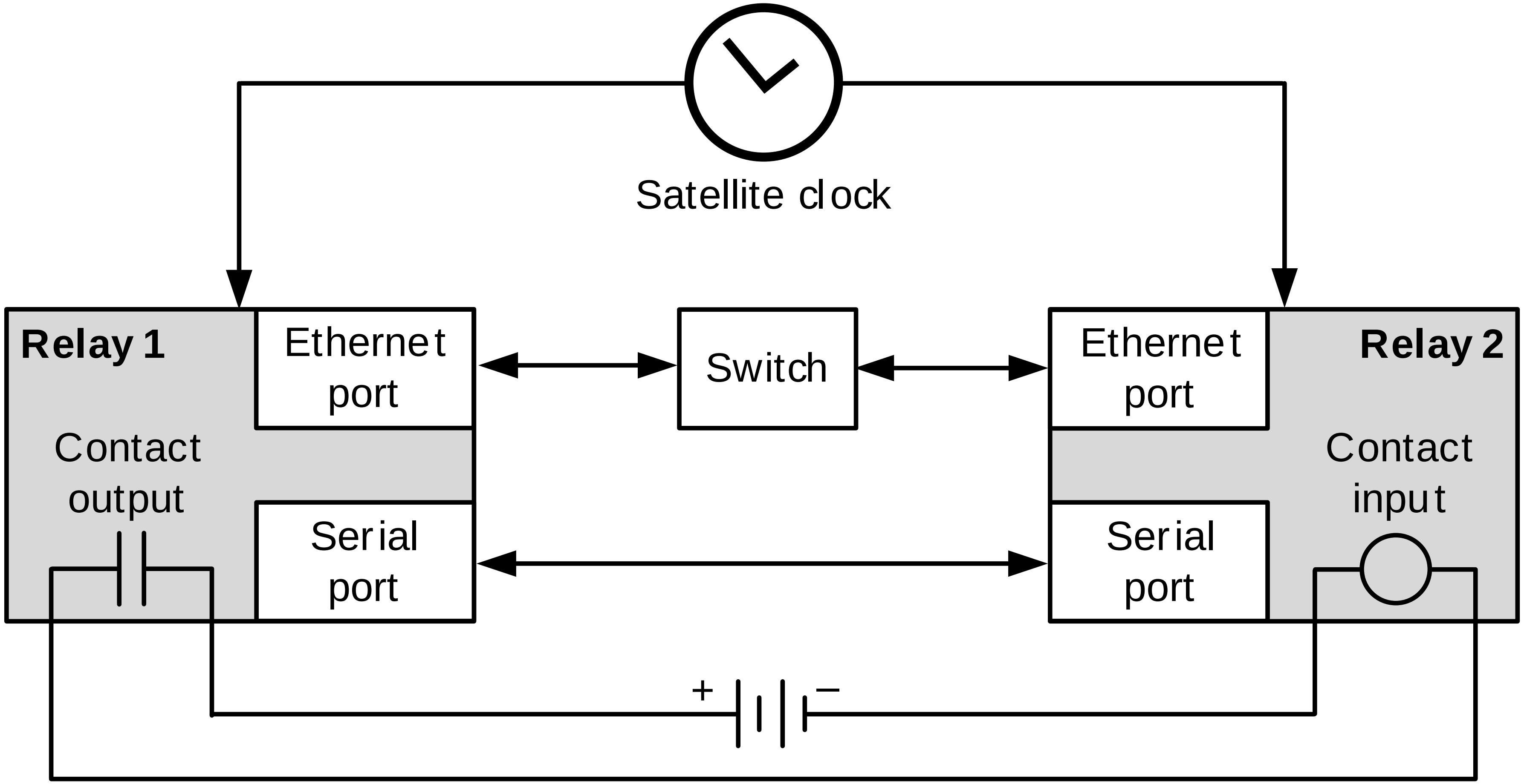
Relay and CPC unavailability

Overall unavailability (10^{-6})

Solution	Without Redundancy	With Redundancy
Traditional relay	12.90	NA
Hardwired CPC	25.80	0.00067
P2P-based CPC	36.03	0.0013
IEC 61850-based CPC	156.96	0.0250

Peer-to-peer communications speed test

Test setup



Peer-to-peer communications speed test

Results

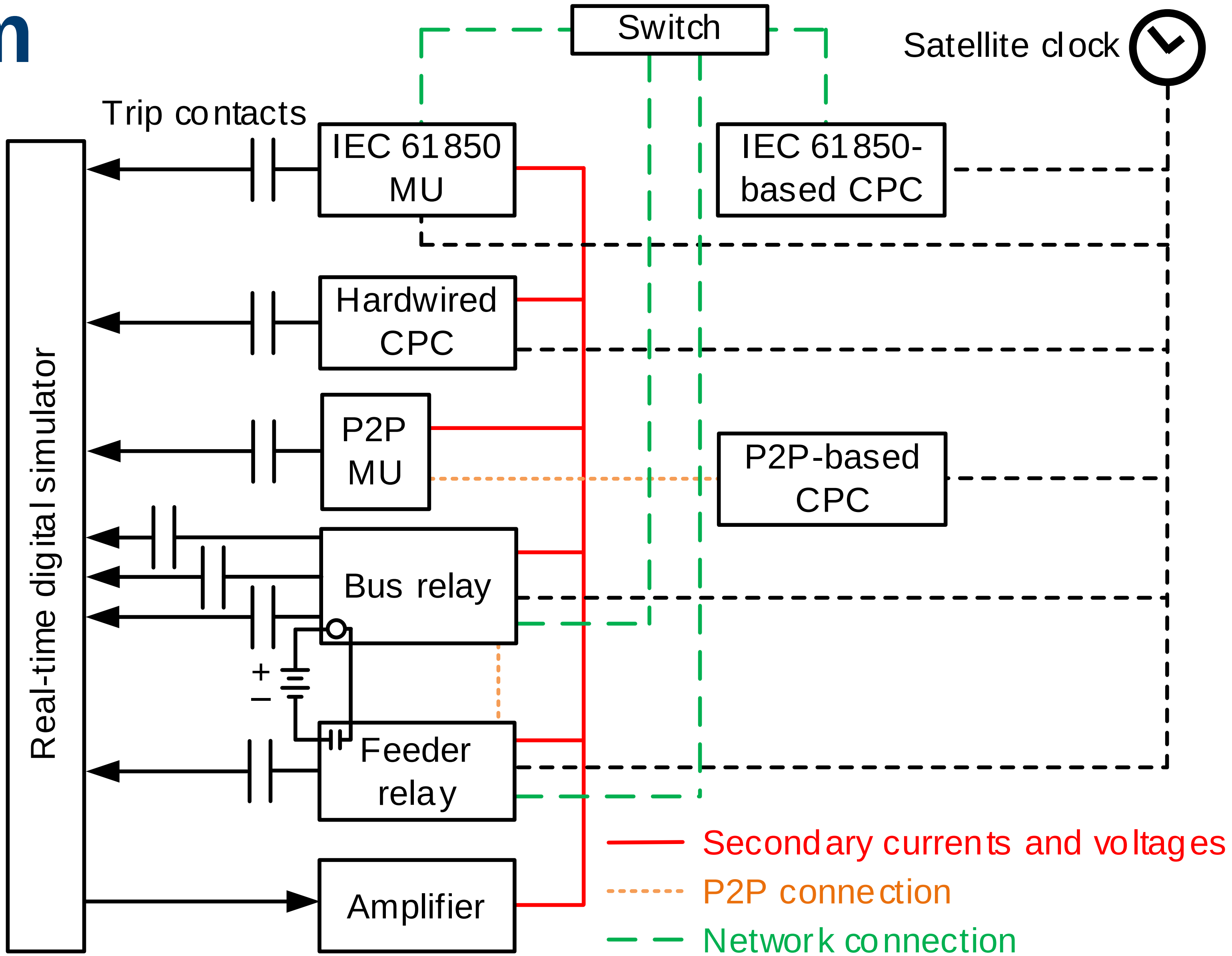
Solution	Maximum Time (ms)
Contact I/O*	18
Mirrored Bits communications†	10
GOOSE	6

* Binary input debounce setting: 0.50 cycle

† Baud rate: 19200

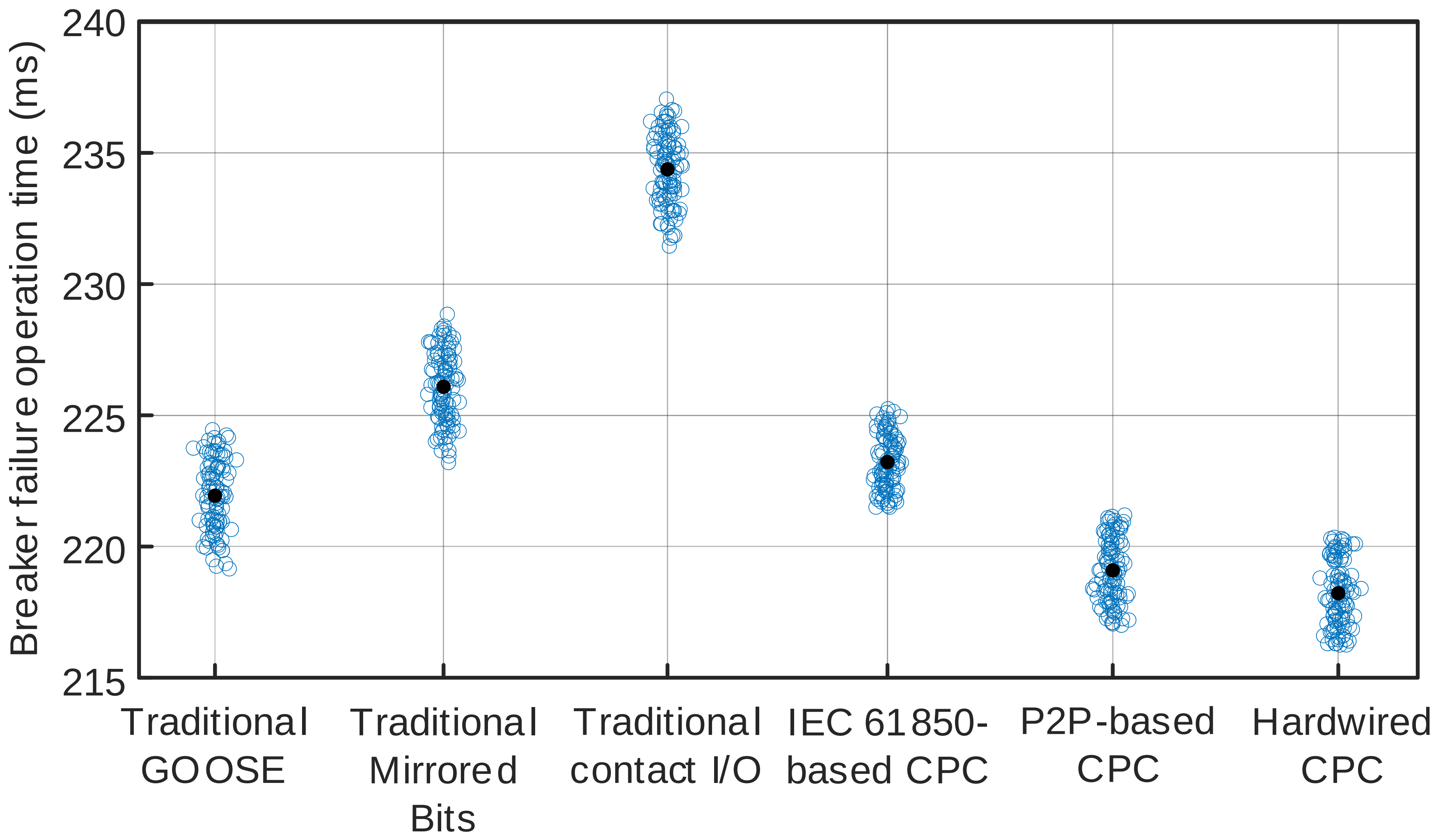
Protection system operation speed

Test setup



Protection system operation speed

Breaker failure scheme operation time



Protection system operation speed

Breaker failure scheme operation time (average)

System	Operation Time (ms)	Difference (ms)
Hardwired CPC	218.252	NA
P2P-based CPC	219.091	0.8725
Traditional GOOSE	221.936	3.7170
IEC 61850-based CPC	223.225	5.0035
Traditional Mirrored Bits communications	226.088	7.8690
Traditional contact I/O	234.375	16.156

Lessons learned

- A CPC system aggregates all protection, control, and monitoring functions, originally distributed in many relays
- CPC failure will result in total loss of protection; all CPC system designs require a redundant CPC
- Depending on the CPC design selected, the number of devices can decrease or increase

Lessons learned

- Protection speed benefits were observed for communications-based protection schemes
- Aggregating all substation functions in a few CPCs brings challenges for operation and maintenance
- Redundant CPC increases the overall reliability of the protection system

Conclusion

- Three CPC system designs are possible
- Device count can increase or decrease based on the design chosen
- With full redundancy, the unavailabilities of all three designs are very close to the existing design
- Significant gain in protection speed was observed for breaker failure and fast bus trip schemes in all three CPC system designs

Future

Phased approach is being considered

- Initial applications will probably use a hardwired CPC approach (limits change management issues)
- Single bank reduces the complexity associated with the configuration required for a multiple bank substation
- This initial step would help build confidence within the engineering and field organizations with the CPC approach

Future

Phased approach is being considered

- Build confidence and help reduce human performance errors associated with changing too many established processes
- Expand plans to include multiple banks and digital substation technologies dependent upon success of initial designs and success of implementation
- Explore opportunities with multiple transformer substations based on results of initial efforts

Questions?