Digital Substation Application Concepts for IBR Renewable Energy Plants

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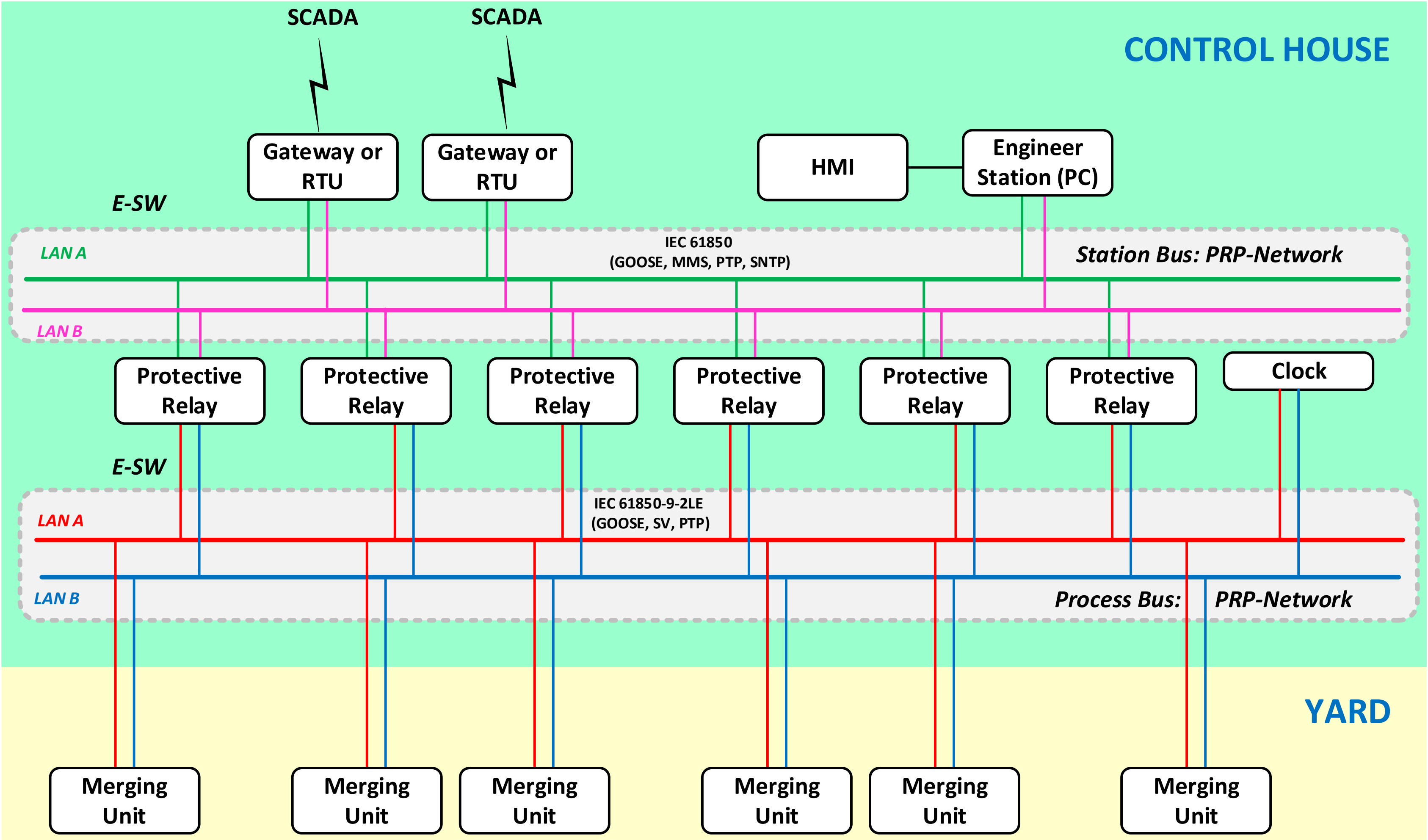
Abstract

- With the fast-tracked planned installations of Utility-Scale Inverter-Based Resource (IBR) Power Plants to the bulk power system, utilities, consultants, EPCs and developers are all seeking methods to standardize P&C designs and hasten execution.
- Many of these power plant designs incorporate a high voltage (HV) section or sections, pooling bus (PLB) section or sections, and collector bus (CLB) sections.
- This paper will explore a typical power plant incorporating all these sections and suggest architectures for standardized yard-to-merging unit connectivity.
- As many of these power plants follow standardized approaches for the power infrastructure, the P&C design also can provide a high degree of standardization.

Quick Review of Digital Substation (DS)

- A DS involves the use the merging units (MUs) to connect to yard elements (CT, VT, 52, 89, status, control), digitizing the data, then communicating to/from relays in the control house over fiberoptic networks.
- The network where the digital data is transmitted between the yard and the control house is called the "process bus."
- Both non-redundant and redundant topologies will be explored
  - Redundant MUs, instrument transformers, the process bus networks, and the protection are employed for high reliability (99.9989%).
- Redundant protection systems are typically employed in transmission, and to a degree in distribution. Analog data (sampled values; SV) as well as binary status and commands are included in the data. High-speed messaging (GOOSE) is used for commands and time critical status.
- Inter-relay or inter-zone information used for interlocking, breaker failure, protection modification and other uses are performed over "station bus" network. Figure 1 shows a simplistic view of a redundant network arrangement described above that employs parallel redundancy protocol (PRP) architecture.

Simple Block Diagram of a Digital Substation using Networked Process Bus and Station Bus



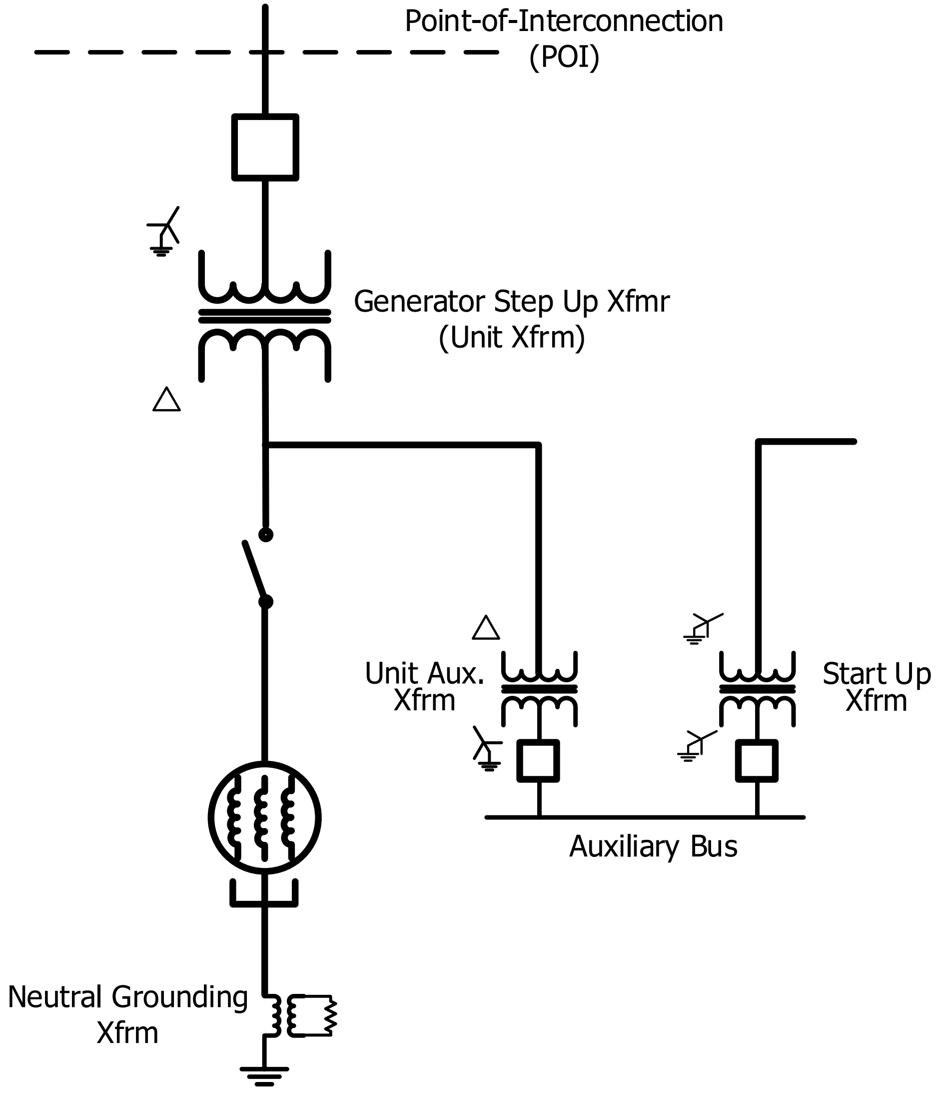
Utility-Scale IBR Renewable Plants vs. Conventional Plants

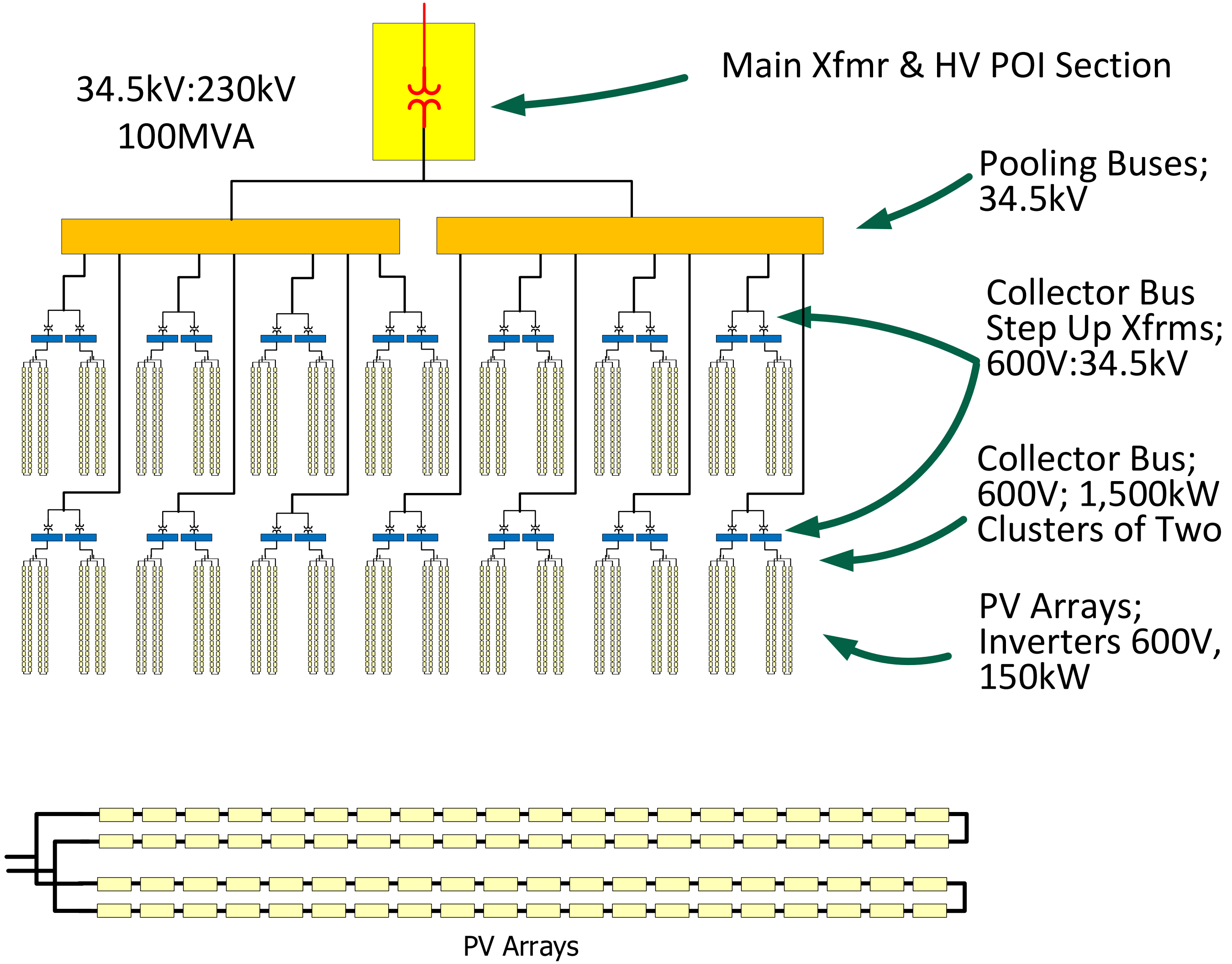
- Both Utility-Scale IBR Renewable (REN) Plants and Conventional Plants typically have a large power transformer (PwrXfmr) as the means of stepping up energy sources to transmission voltage

- Conventional Plants have one or possibly more large generating assets at MV level brought to the PwrXfmr

- REN Plants typically have a large amount of MV and possibly LV sources that are aggregated through various buses and intermediate transformers that lead to the PwrXfmr

Utility-Scale IBR Renewable Plants vs. Conventional Plants

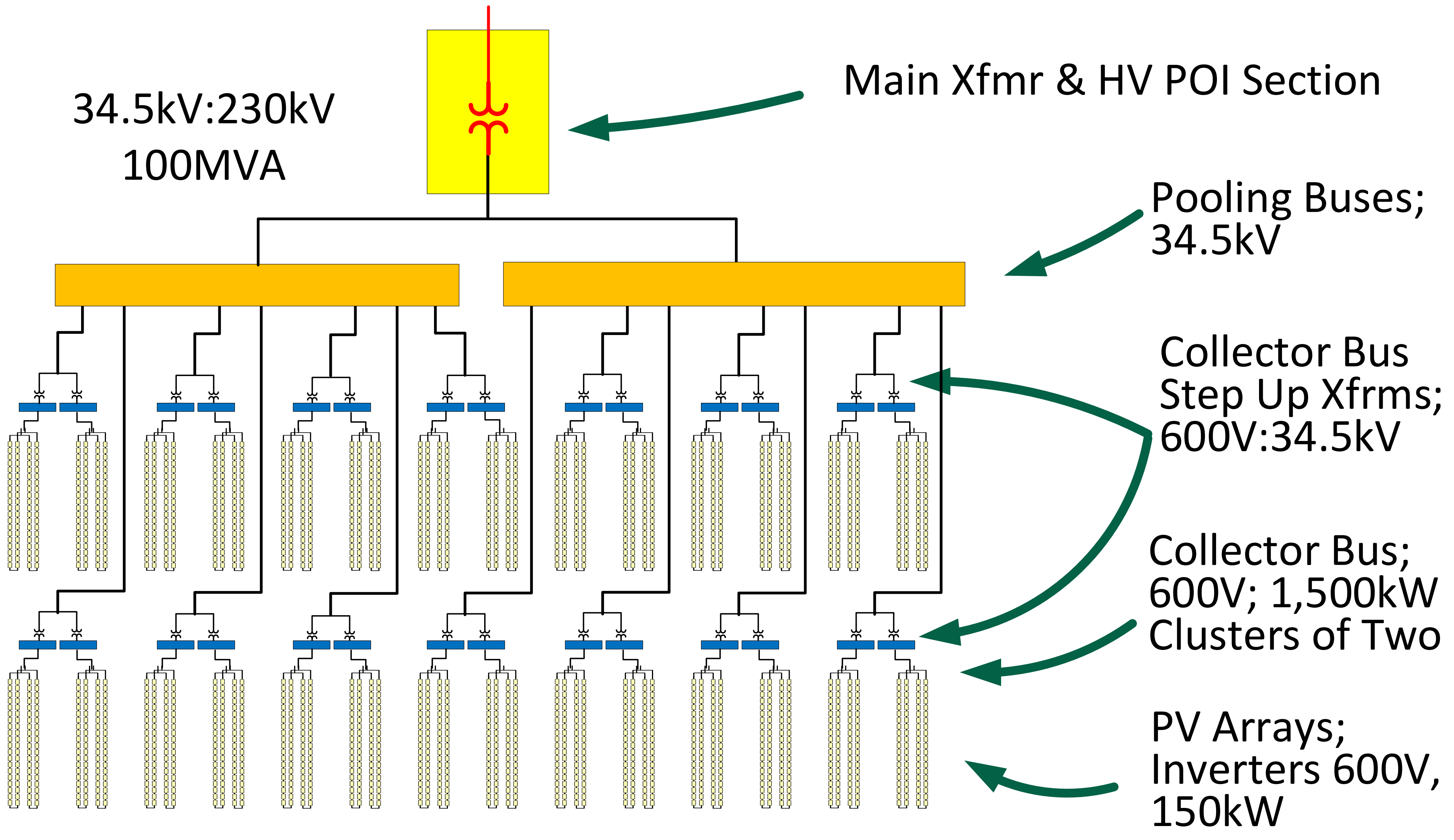




Utility-Scale IBR Renewable Plants vs. Conventional Plants

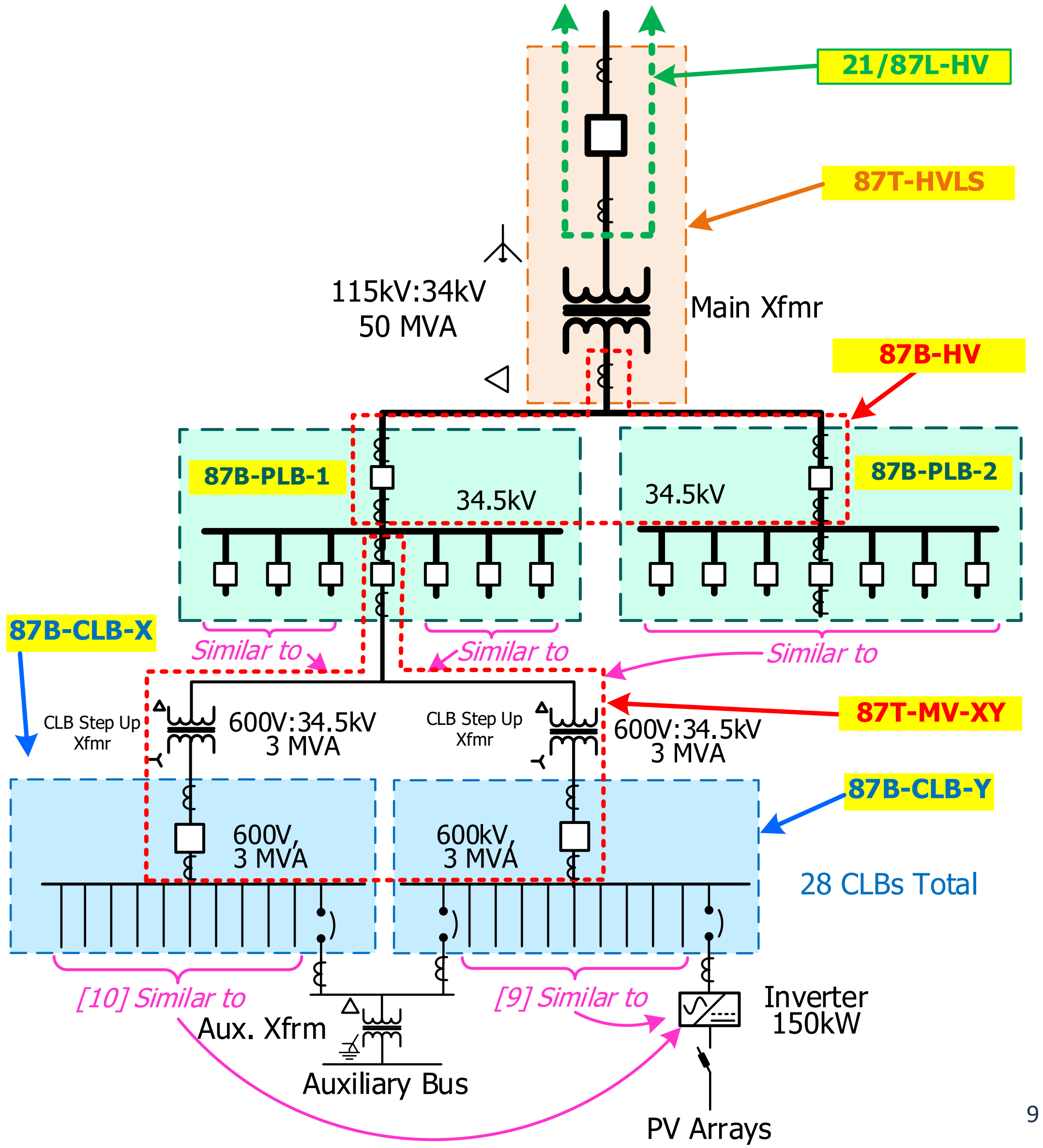
- Conventional Plants typically employ high impedance grounding at the generator neutral. The PwrXfmr acts as the ground source to the Utility and ungrounded source to the generators.
- REN Plant IBR terminals may not be grounded. If that the case, suitable grounding is created with grounding banks at the various buses or at the IBR transformers.
- Protection in a Conventional Plant focuses on the large generator assets, PwrXfmr, support Xfmrs and auxiliary systems
- Protection in a REN Plant focuses on the numerous energy sources, cables and buses, plus many transformers used to step up the inverter AC output voltage up to higher intermediate and finally the transmission voltage level. In addition, there are auxiliary Xfmrs and auxiliary buses and loads.

Utility-Scale IBR Renewable Plant Topology Example



Utility-Scale IBR Renewable Plant Topology Example

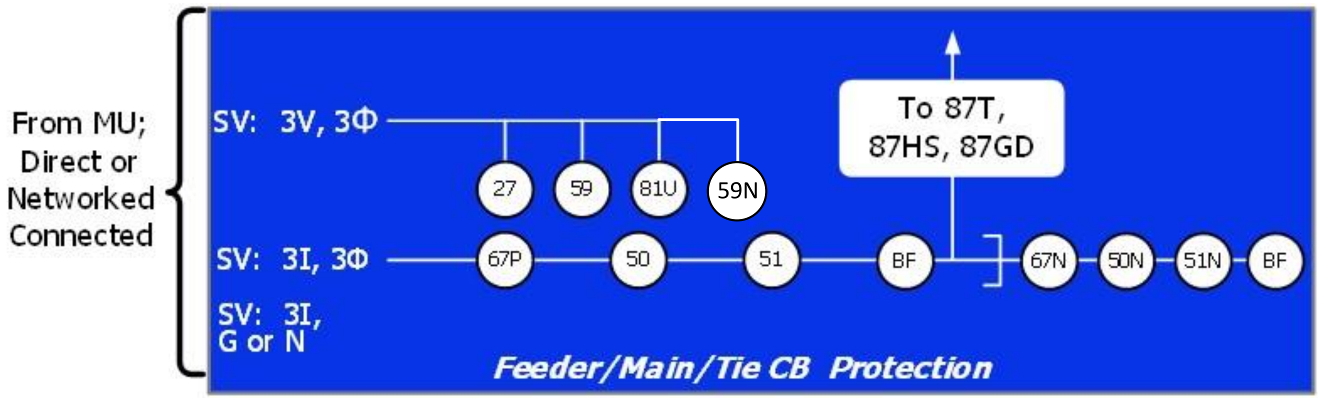
- Two [2] PLBs are used, each with seven [7] sources. AIS, Outdoor CBs.
- The PBLs are identical
- Seven [7] identical sources each PLB input
- The 28 CLBs are identical. LV Switchboards in weather-proof enclosures
- CLB connections are [10] 150kW, 600V inverters, a feeder to supply auxiliary power, and one output to CLB Step Up Xfmr.
- Two CLBs are grouped per PLB input
- Teo PLBs input into the Main Xfmr
- We will make use of the standard infrastructure topology to develop a standard approach to the protection schemes using Digital Substation techniques.



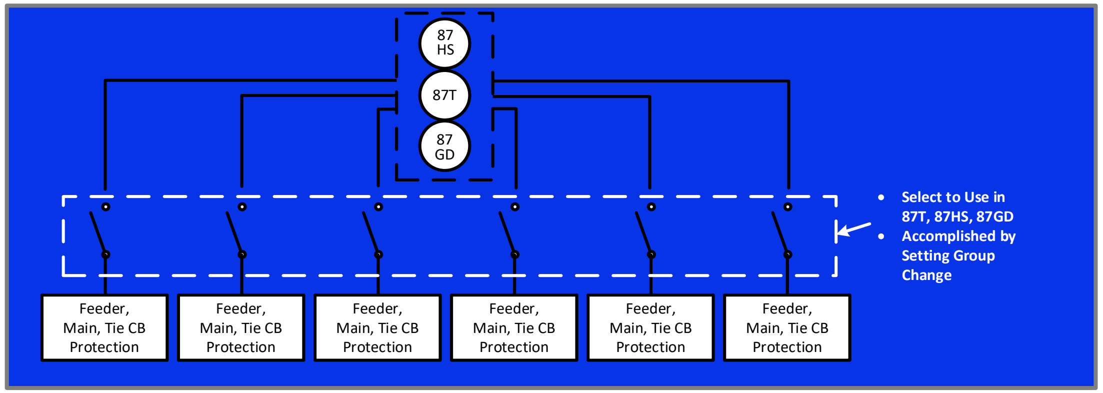
Partially Centralized Systems, #1

We will assume use of three protection systems for application in partially centralized protection schemes:

1. A transformer protection system that can cover <=6 nodes, employing a definable and selectable transformer differential zone, with all nodes employing overcurrent, voltage and frequency elements.



Feeder, Main, Tie CB Protection for a Transformer Protection System

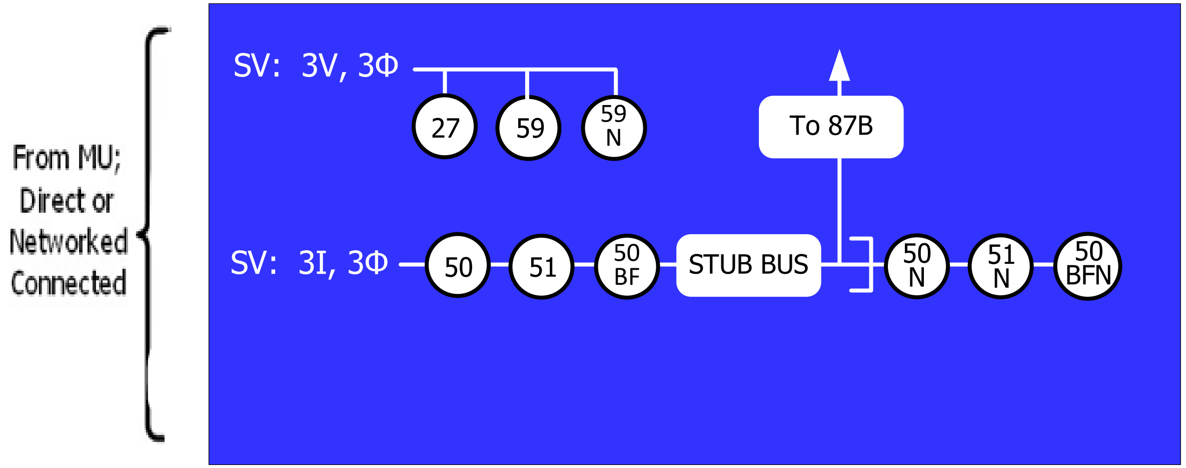


Selectivity for 87T/87HS/87GD Sourcing for Transformer Protection System

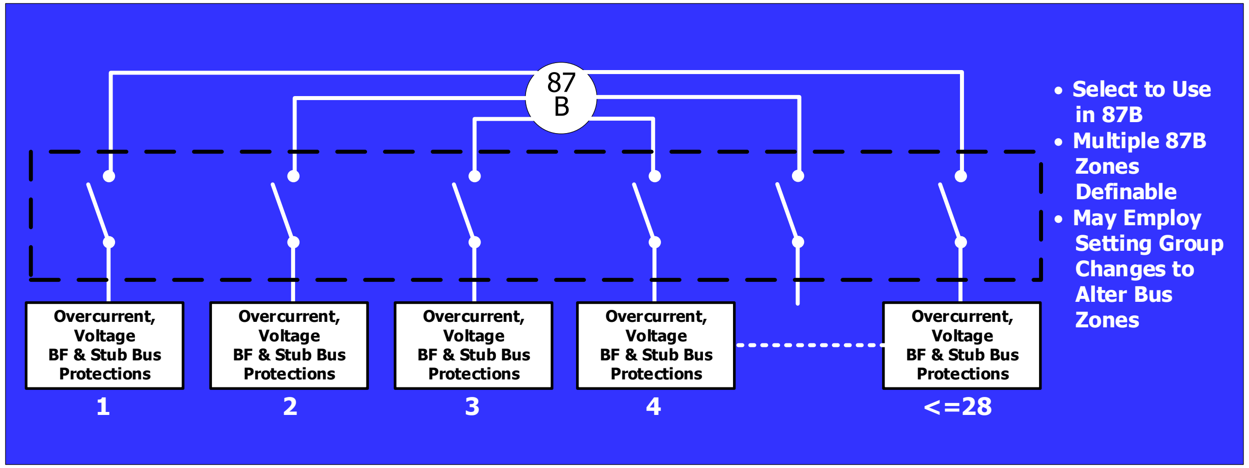
Partially Centralized Systems, #2

We will assume use of three protection systems for application in partially centralized protection schemes:

2. A bus protection system that can provide up 28 nodes of bus differential protection, with each node providing non-directional overcurrent, voltage, stub bus and breaker failure protections



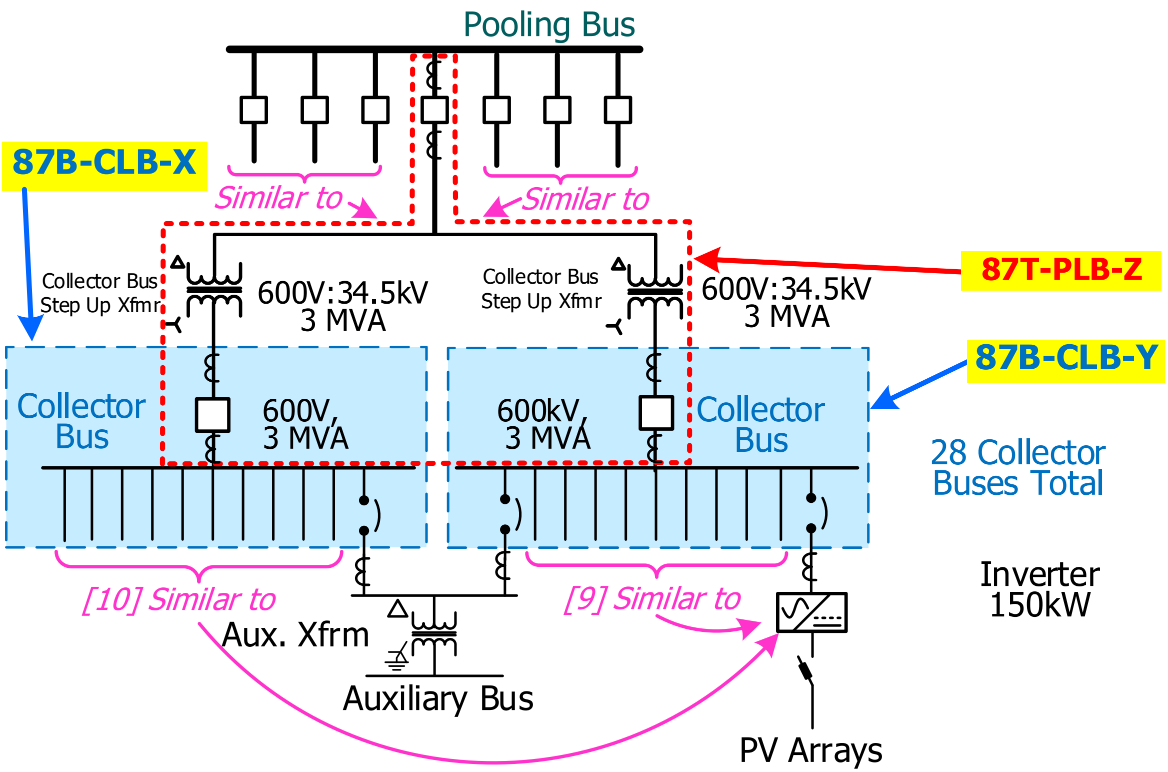
Combination Bus and Overcurrent, Voltage, Stub Bus and BF Protection System



Selectivity for 87B Sourcing for Combination Bus and Overcurrent, Voltage, Stub Bus and BF Protection System

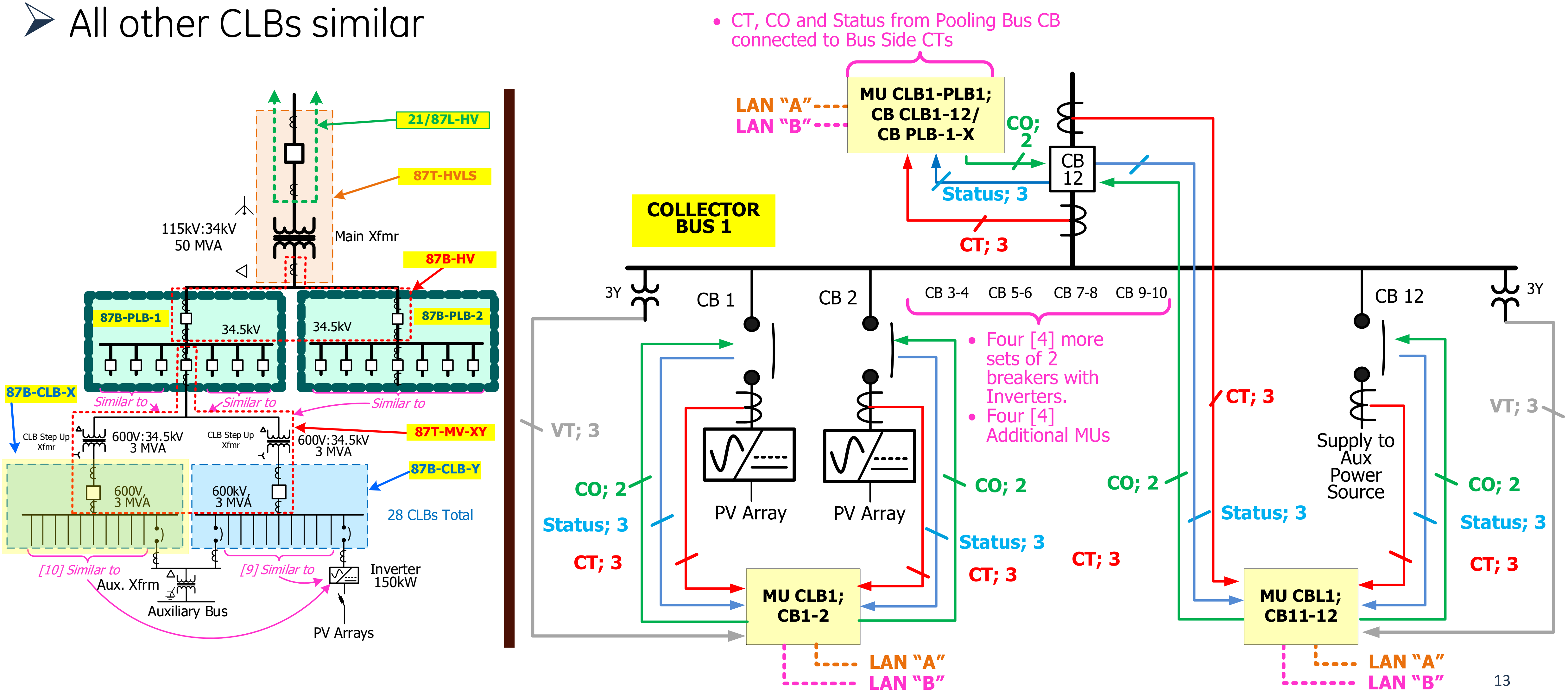
CLB Protection

- Each protection system, System #2, will cover two [2] CLBs and cabling to the CLB Step Up Xfmr low side winding
- Seven [7] groups of two [2] CLBs per PLB input, 7 2-CLBs connected to each PLB.
- Each CLB has 10 Inverters, One [1] Auxiliary Source and one [1] Main as nodes (12 nodes).
- Total nodes used by CLB-X and CLB-Y = 12+12+1 = 25 (<=28)
- Overcurrent, voltage and BF protection provided for all nodes by Centralized Protection (CP) #2
- Voltage protection from Bus VT by Centralized Protection #2
- Each CLB is a 12 node 87B zone, 87CLB-X and 87CB-Y
- Non-redundant protection for the set of two CLBs will require one [1] Protection System #1
- Non-redundant protection for the set of two Collector Buses application will require 14 MUs.



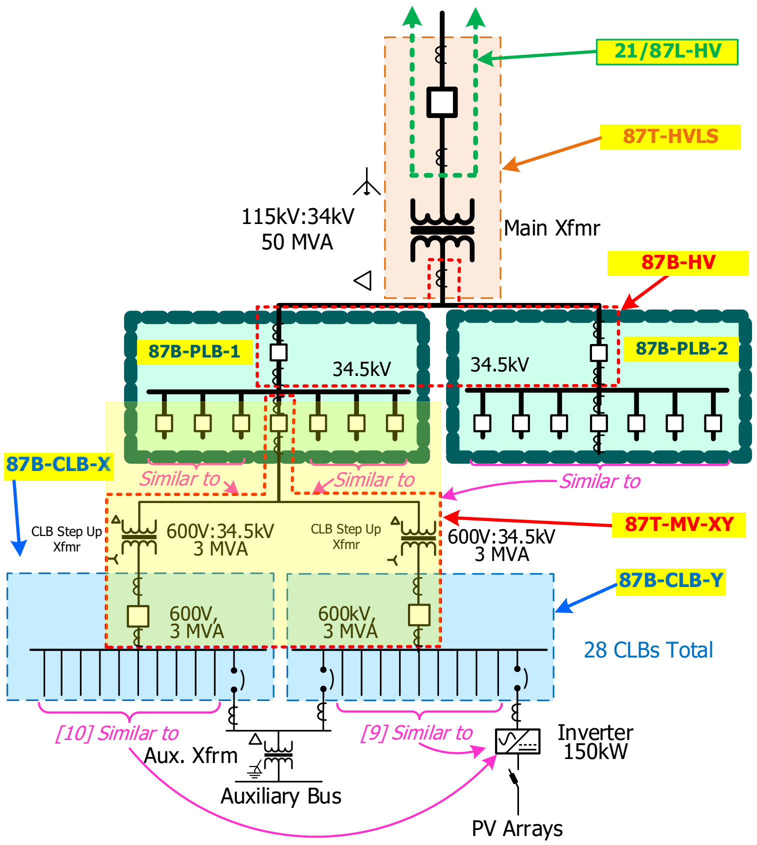
CLB Protection

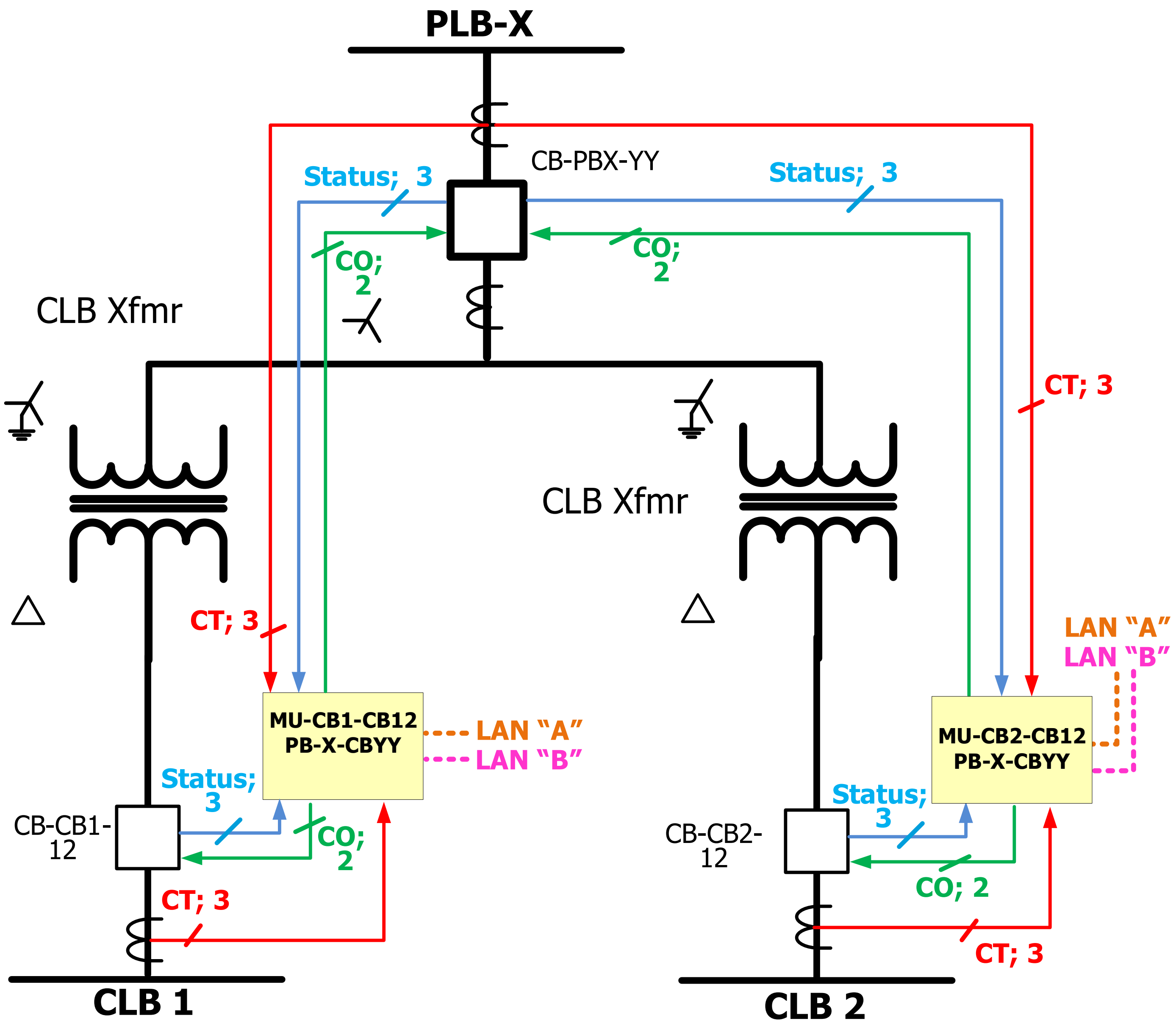
- Yard to MU Connectivity for CLB 1
- All other CLBs similar



CLB to PLB Protection

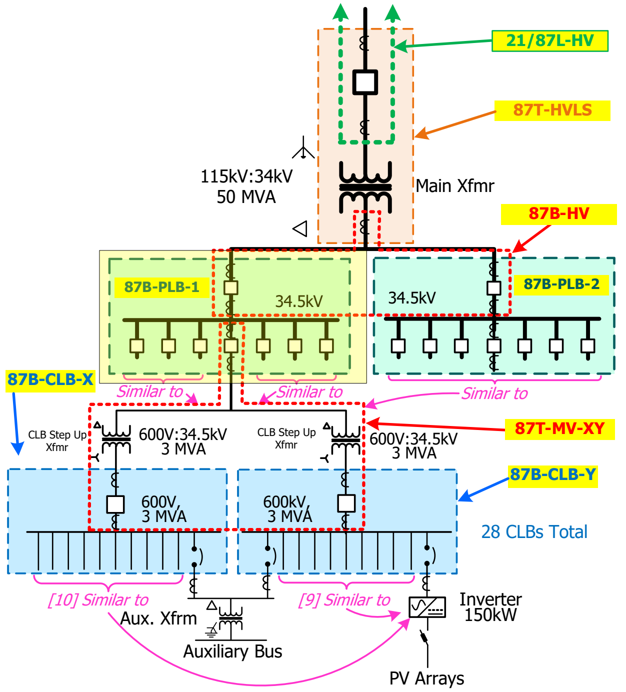
- Yard to MU Connectivity CLB-1 and CLB-2 to CLB Xfmr 1 & 2 to a PLB input
- Both CLB Xfmr-1 and CLB Xfrm-2 included in 87T zone
- All interconnecting cables in the 87T zone

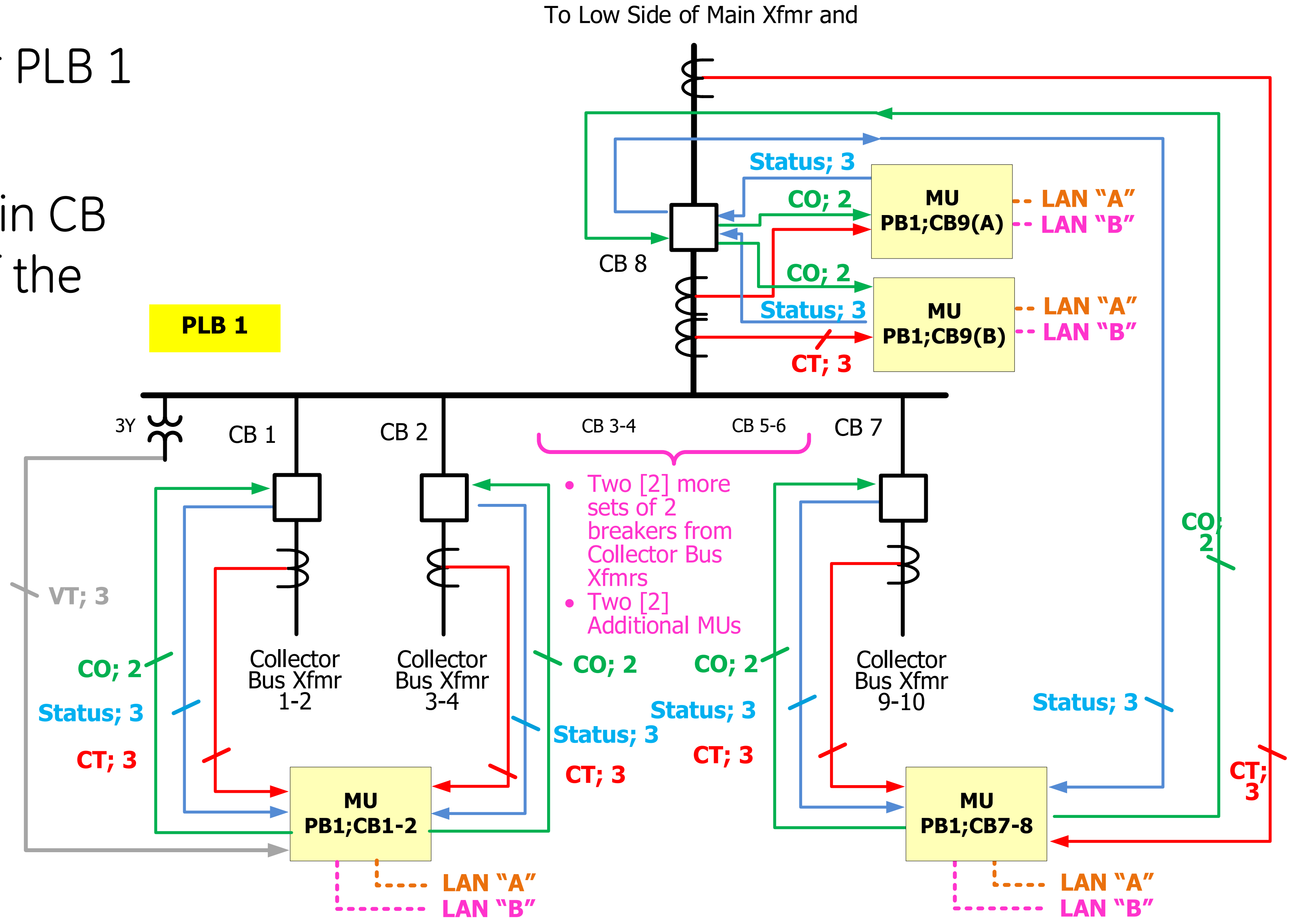




PLB Protection

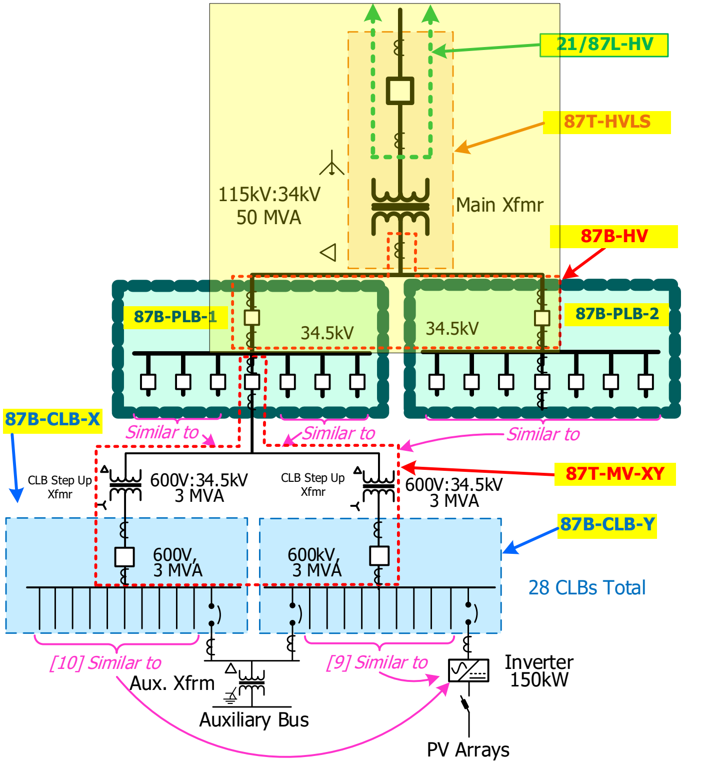
- Yard to MU Connectivity for PLB 1
- PLB 2 similar
- Redundant MUs on PLB Main CB bus side as they are part of the Main Xfmr 87T (HV, NERC)

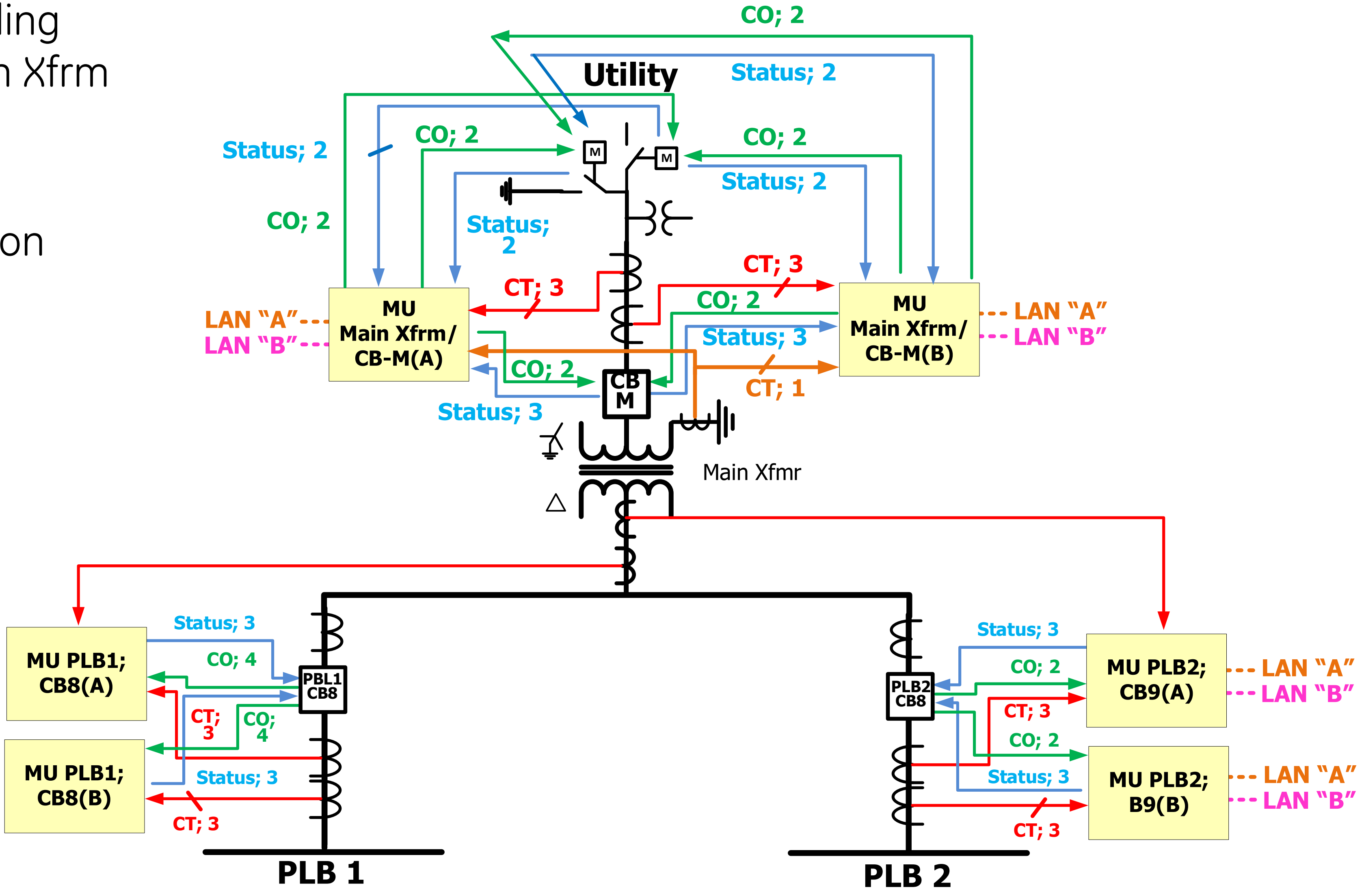




Main Xfmr and HV Interconnection Protection

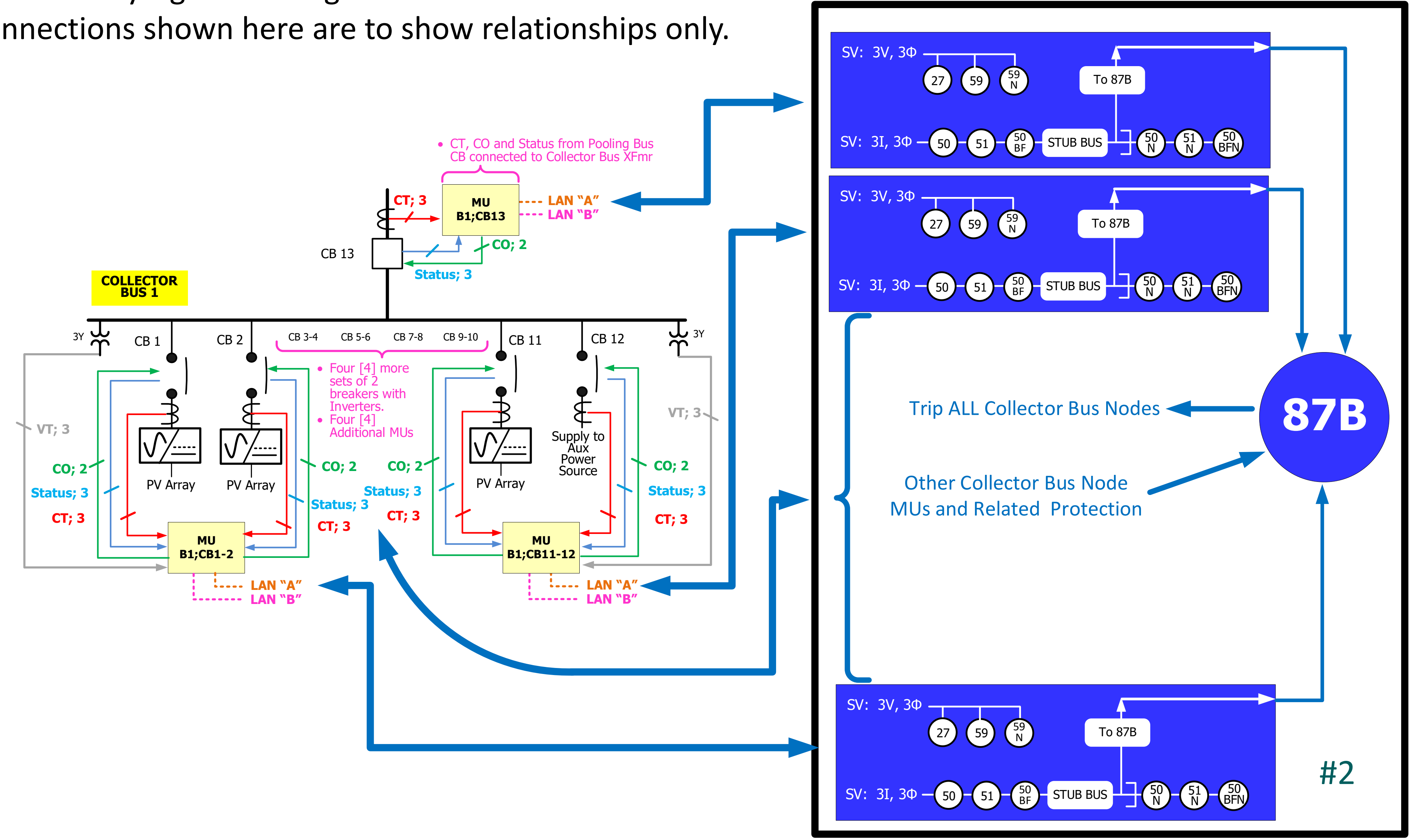
- Yard to MU Connectivity for Pooling Bus Main CBs, Main CB and Main Xfrm
- Redundant MUs on all Nodes Impacting Main Transformer Protection 87T and Line Protection (HV, NERC)





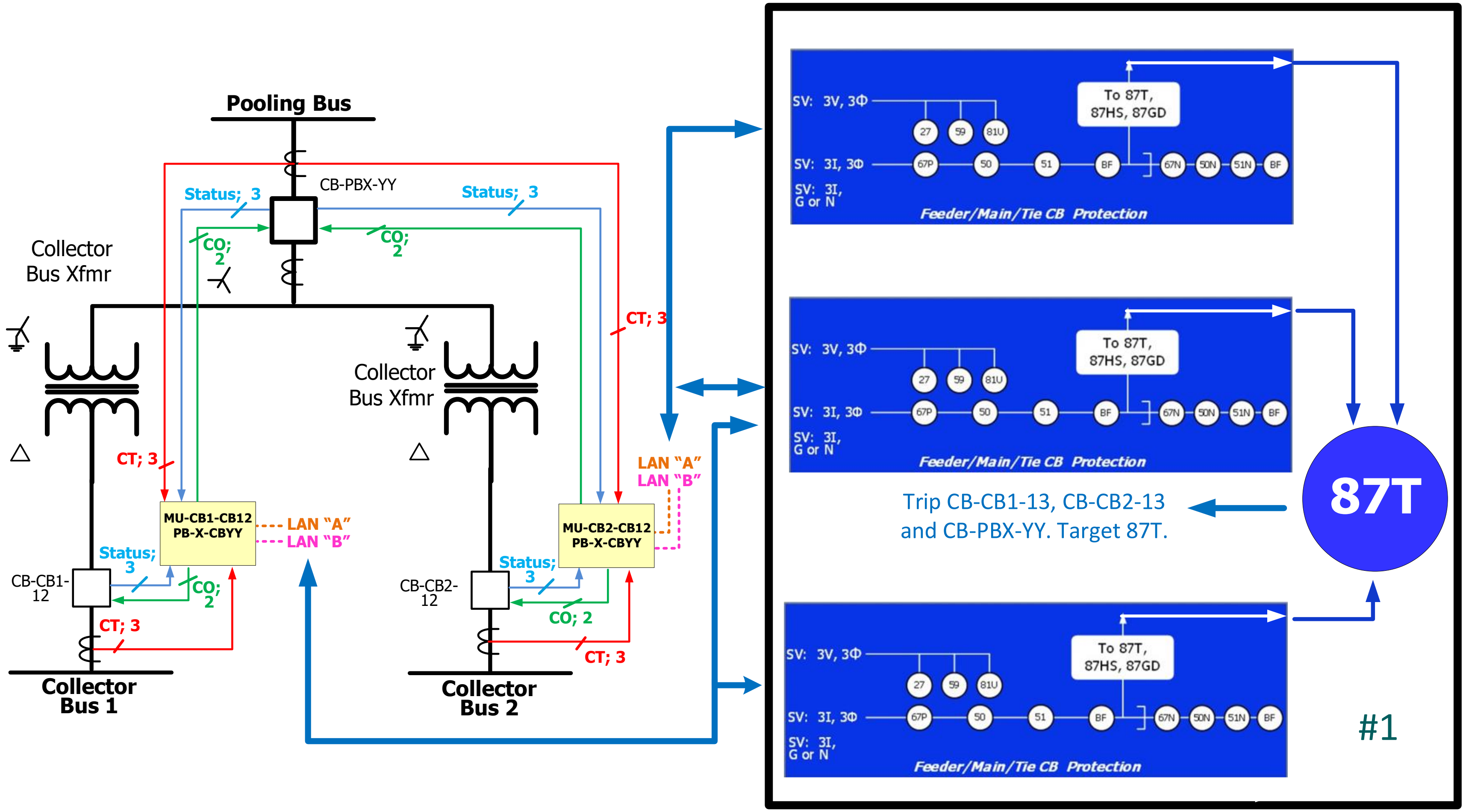
Protective Relay – MU Relationships: CLB

Note: All MU-Relay signals through networked connection.
Connections shown here are to show relationships only.

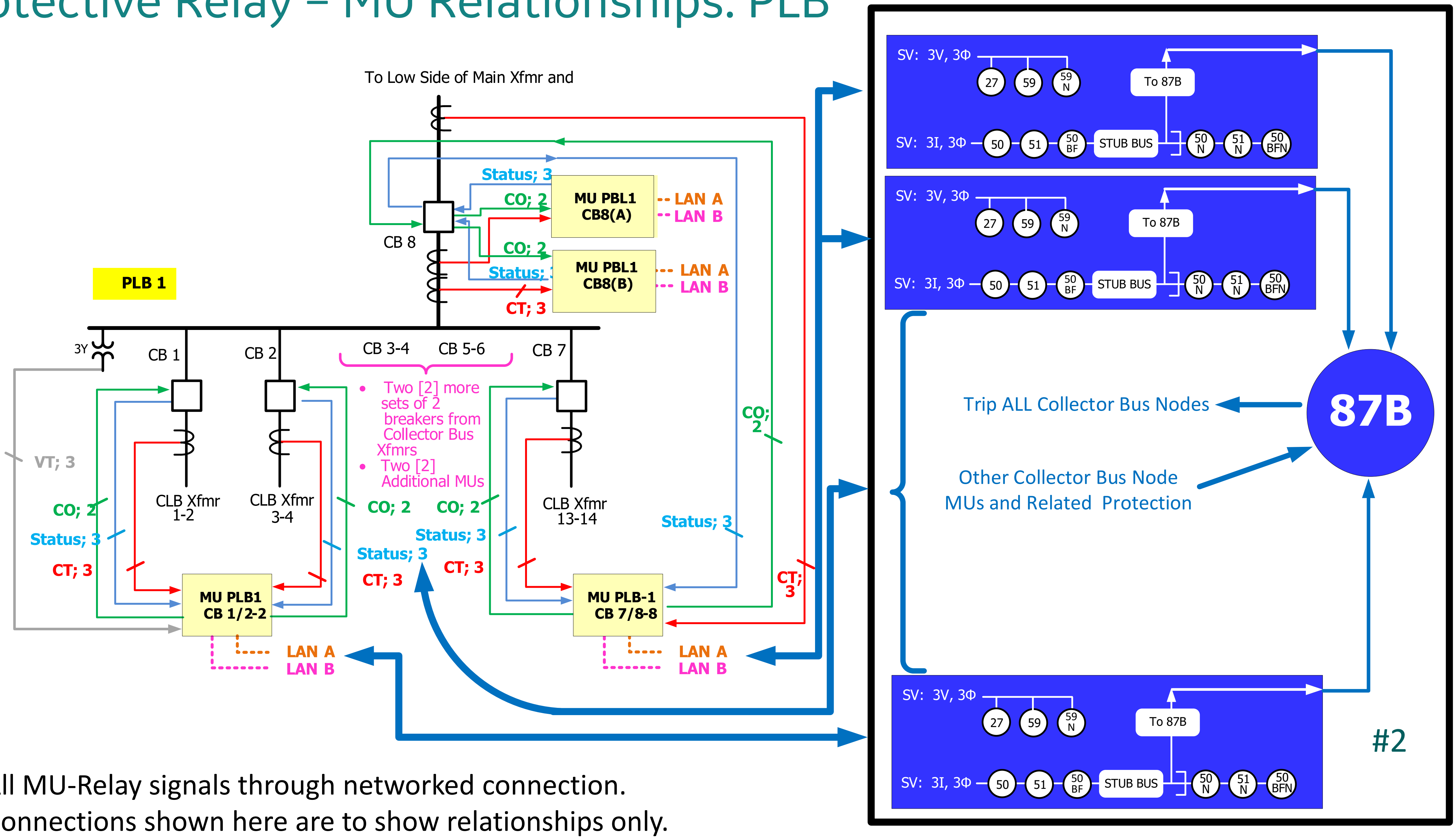


Protective Relay – MU Relationships: CLB to PLB, CLB 87T

Note: All MU-Relay signals through networked connection.
Connections shown here are to show relationships only.



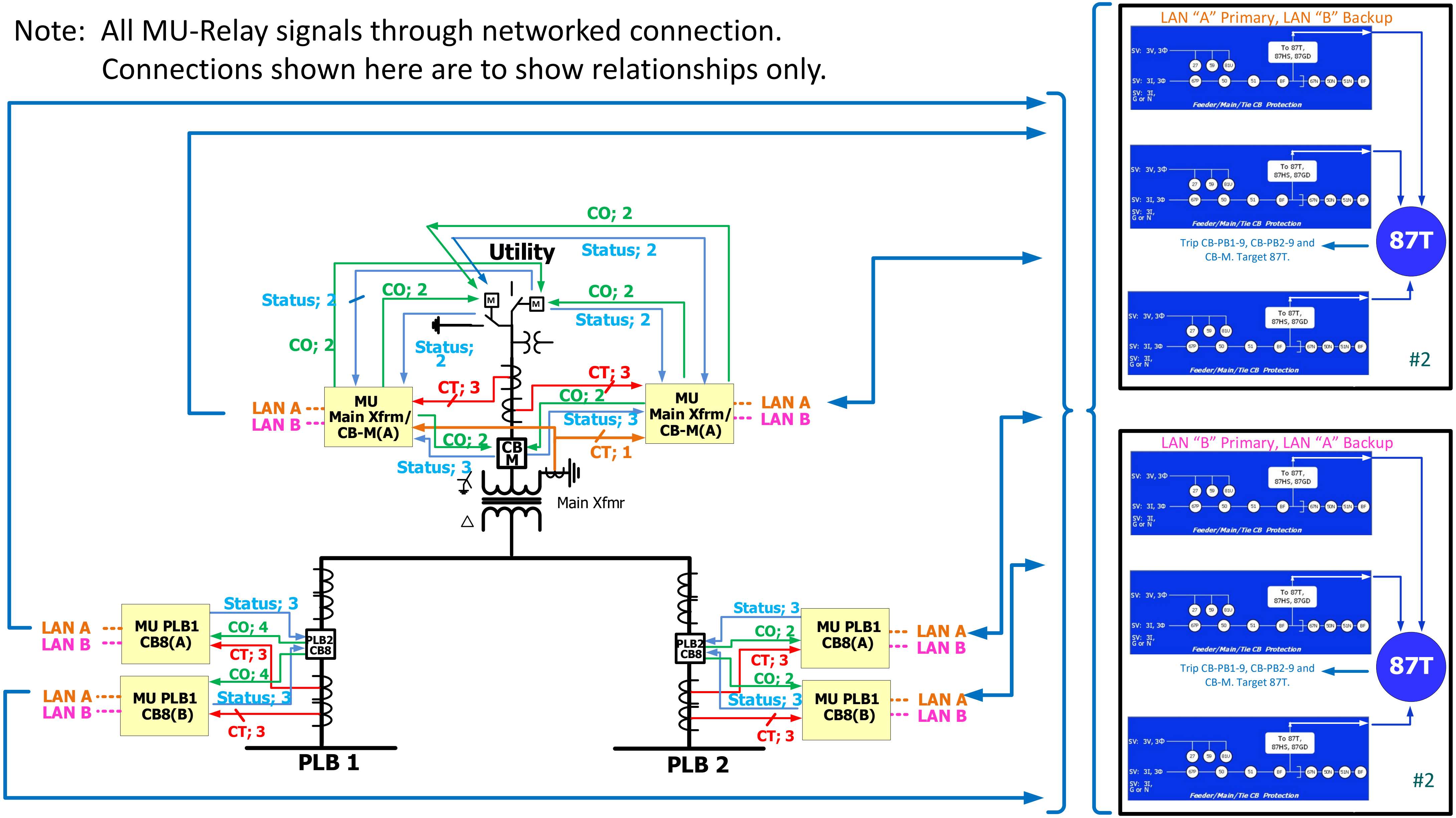
Protective Relay – MU Relationships: PLB



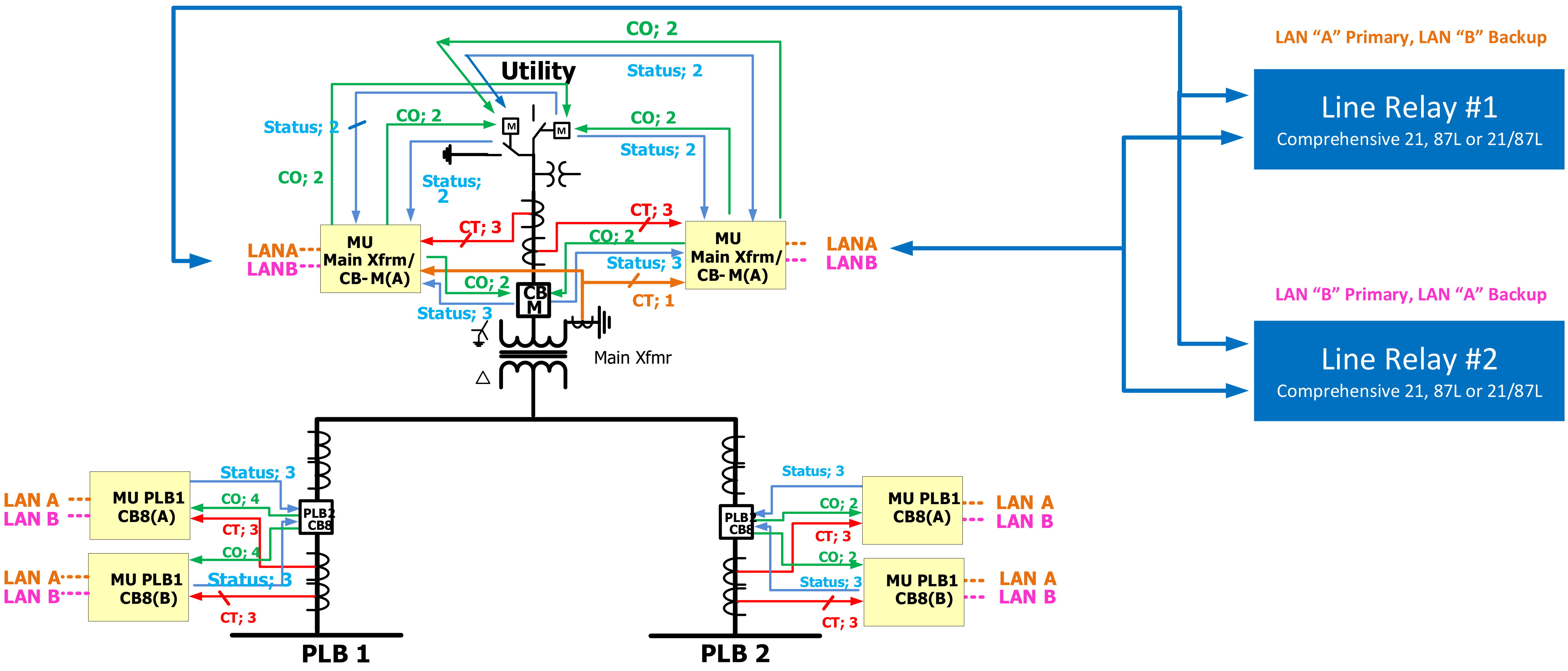
Note: All MU-Relay signals through networked connection.
Connections shown here are to show relationships only.

Protective Relay – MU Relationships: Main Xfmr 87T

Note: All MU-Relay signals through networked connection.
Connections shown here are to show relationships only.

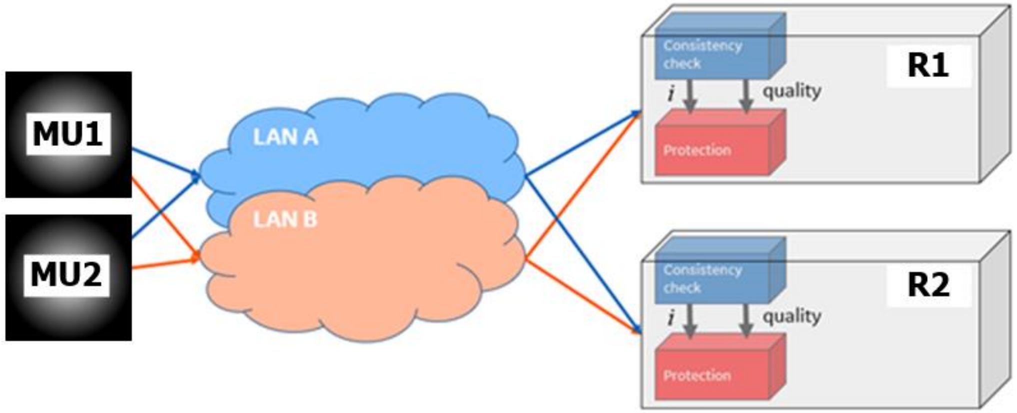


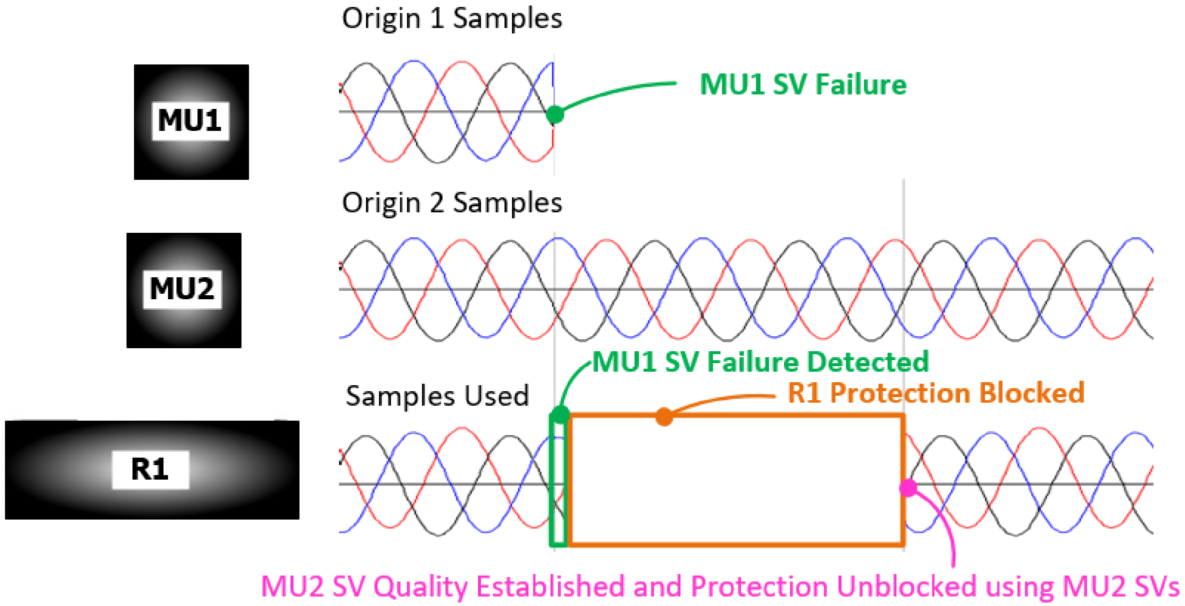
Protective Relay – MU Relationships: Utility POI



Note: All MU-Relay signals through networked connection.
Connections shown here are to show relationships only.

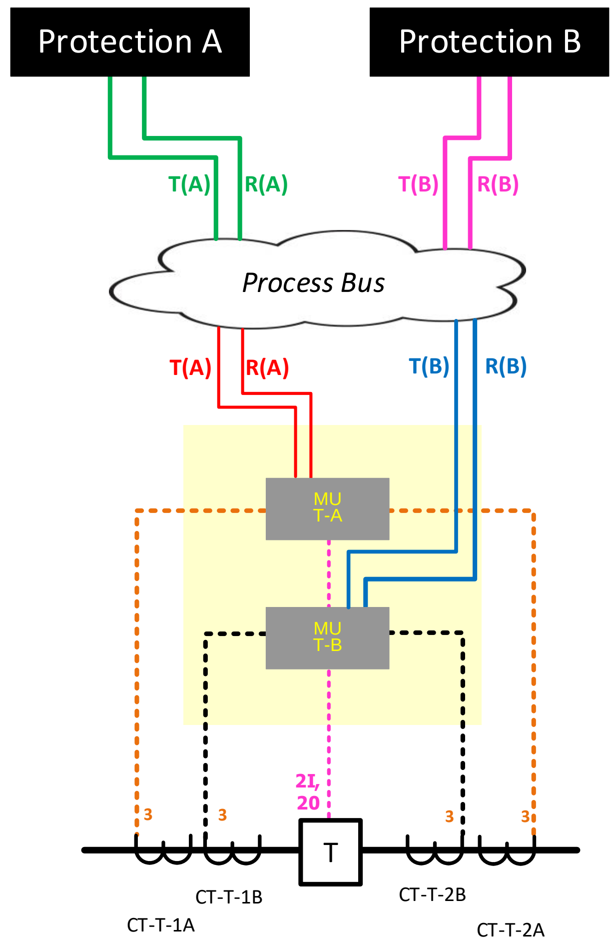
Reliability Better Than Hardwired Designs



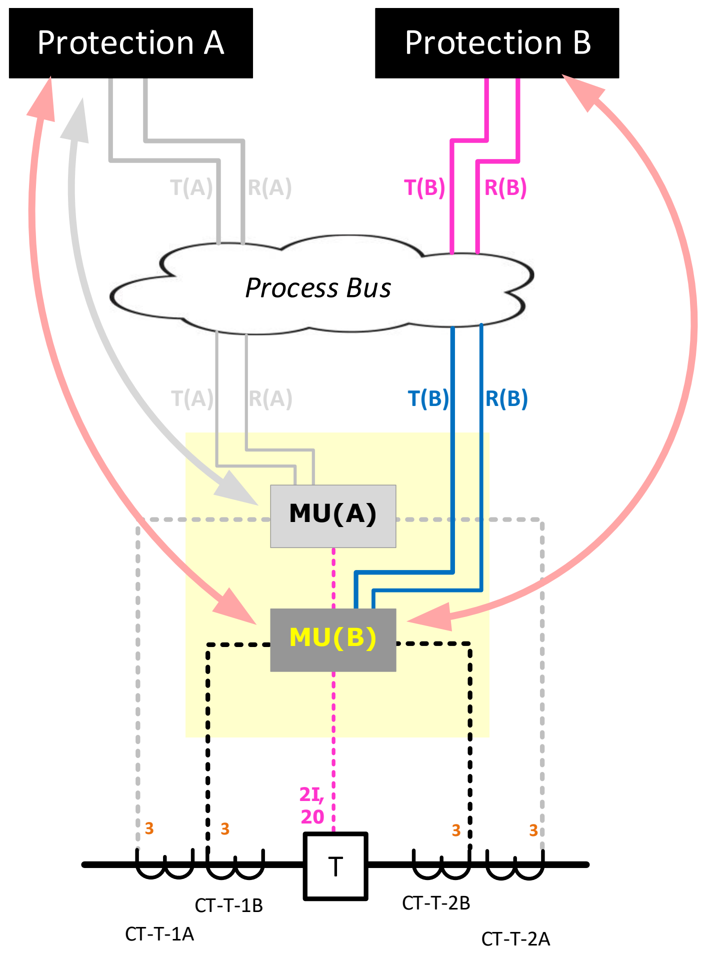


- Redundant designs incorporate redundant Process and Station Bus Networks, MUs and Protection
- In the event of failure of a MU or Network, Relays can switch to an alternate sampled value (SV) stream, increasing system availability
- During switchover, protection blocked in relay switching SV stream for 2 seconds while new SV stream is evaluated for quality

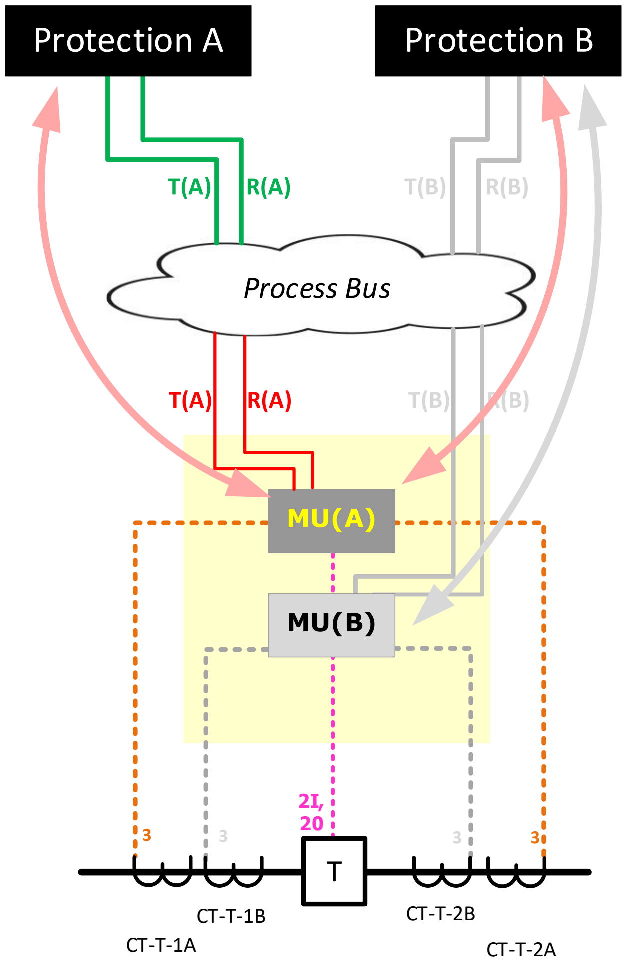
Sampled Value Switching for Failures



Normal: Both MUs Functional



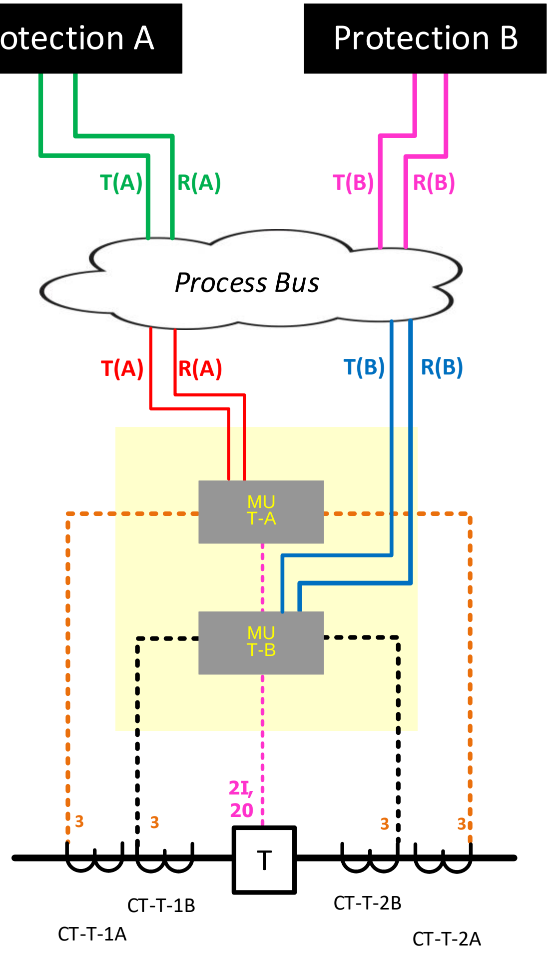
N-1: MU(A) Fails, MU(B) Functional



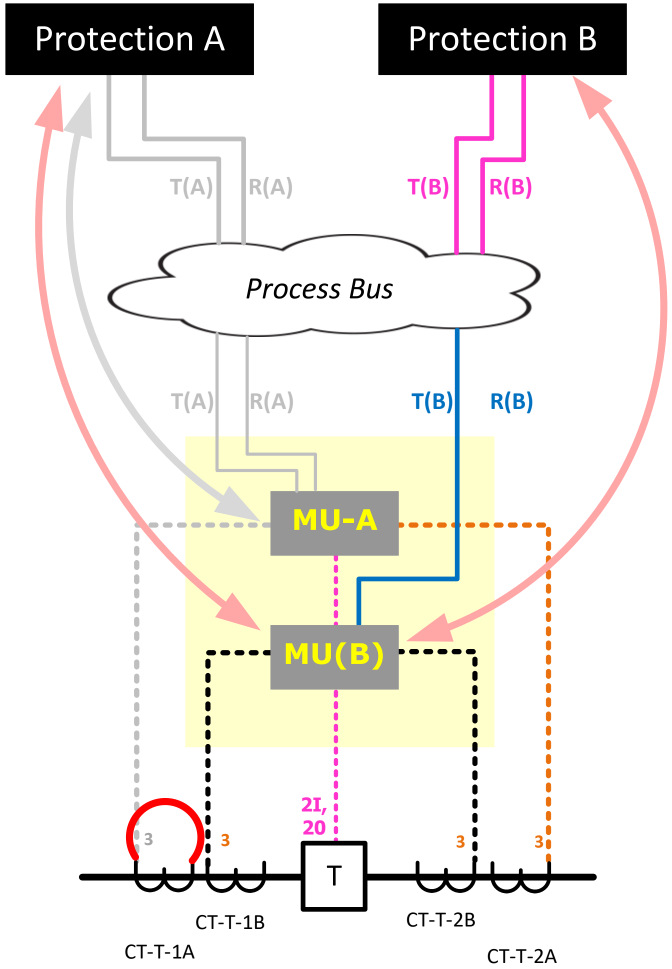
N-1: MU(B) Fails, MU(A) Functional

Note: Both protection systems send/receive commands and status from both MUs

MU Switchover for instrument Transformer Failure



Normal: All CTs Functional



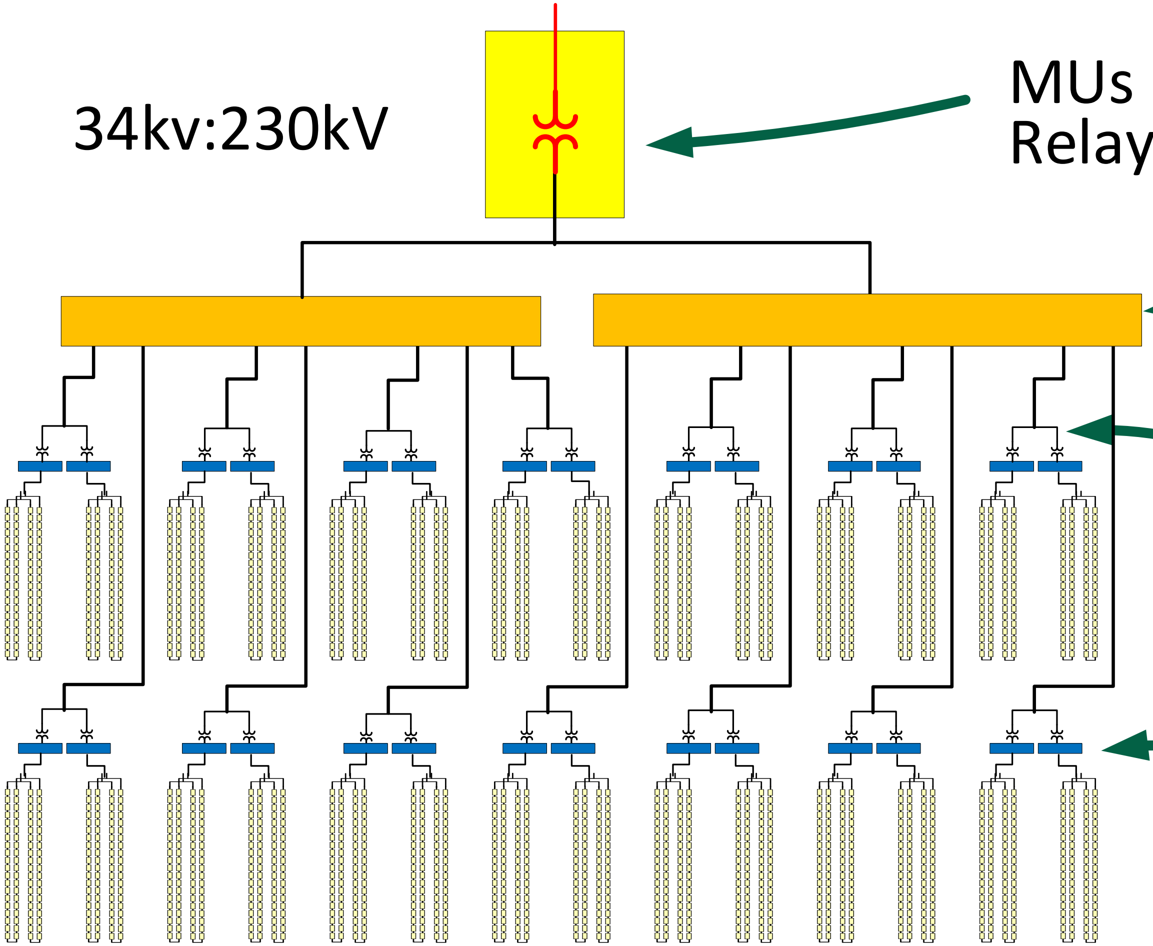
N-1: CT for MU(A) Shorts,
MU(B) CTs Functional

Note: Both protection systems send/receive commands and status from both MUs

MU & Relay Placement: Enclosures or Use of Existing Compartments

- In retrofit application, MUs typically are housed in kiosks or enclosures, strategically sited close to the process they are connecting to
- Designing, fabricating and installing enclosures incurs cost
- In Greenfield work, for outdoor breakers, breaker panels may be used for enclosing the MUs provided there is adequate space. This space my be requested during the breaker quoting phase of the project
- In Greenfield work, for metal-clad switchgear, the LV compartments where relays would typically be mounted can be used for enclosing the MUs
- In cases where breaker cabinets or switchgear LV compartments were not available, one could employ dedicated enclosures as needed.

Enclosure of MUs



MUs in kiosk adjacent to HV breaker cabinet; Relays in Control House

PLB Breakers: MUs in breaker cabinets; Relays in Control House

CLB Step Up Transformers; in CLB switchgear LV compartments

CLB Breakers; MUs and Relays in CLB switchgear LV compartments

Summary and Conclusions

- In some Utility-Scale IBR Renewable Plants, there may be high quantity use of granulized and repeated power infrastructure.
- These designs lend themselves to the use of centralization for a high degree of standardization in the P&C design
- Savings on the quantity of protective devices, quantity of panels and space inside the control house can be obtained
- In Greenfield applications, MUs can often be housed in breaker cabinets and LV switchgear compartments, with attendant enclosure and civil savings

Summary and Conclusions

- A large amount of standardization can occur from the standardized design and fabrication of MU enclosures (if applied)
- Wiring runs from MUs to the yard elements are short and standardized.
- If the MU information for all accessed points is brought into the control house, the Operators have full view of every element off the plant, from the high voltage POI to the individual inverter AC inputs, without having to travel to various areas of the plant.

Author Bio:

Wayne Hartmann is Advanced Applications Advisor (NAM) for GE Grid Solutions. In this role, he explores the application of new technologies in protection and control with Electric Utilities, Industrials and the Consultants the support them.

- Wayne also provides market research, input for new product development and is active working with the Sales and Application Teams.
- Before joining GE Grid Solutions, he was in Standards Development at Duke Energy, and in Application, Sales and Marketing Management capacities at Beckwith Electric, PowerSecure, General Electric, Siemens Power T&D and Alstom T&D.
- Wayne is a Senior Member of IEEE and serves as a Main Committee Member of the Power System Relaying and Control Committee (PSRC) for over 30 years.
  - Chair Emeritus of the IEEE PSRC Rotating Machinery Subcommittee ('07-'10).
  - Contributed to numerous IEEE Standards, Guides, Reports, Tutorials and Transactions, delivered Tutorials at IEEE Conferences, and authored and presented numerous technical papers at key industry conferences.
- Contributed to McGraw-Hill's "Standard Handbook of Power Plant Engineering."

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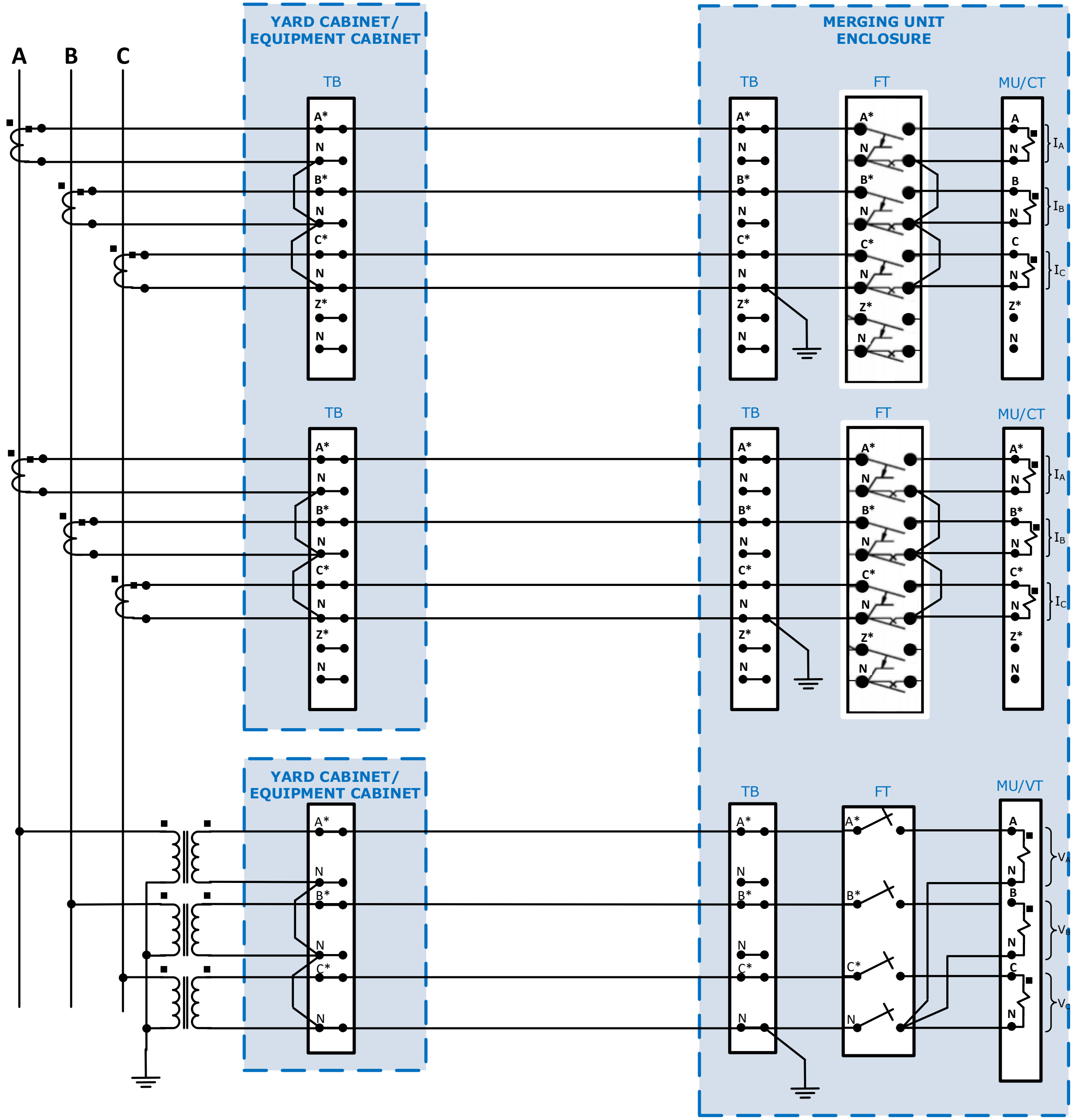
Questions ?

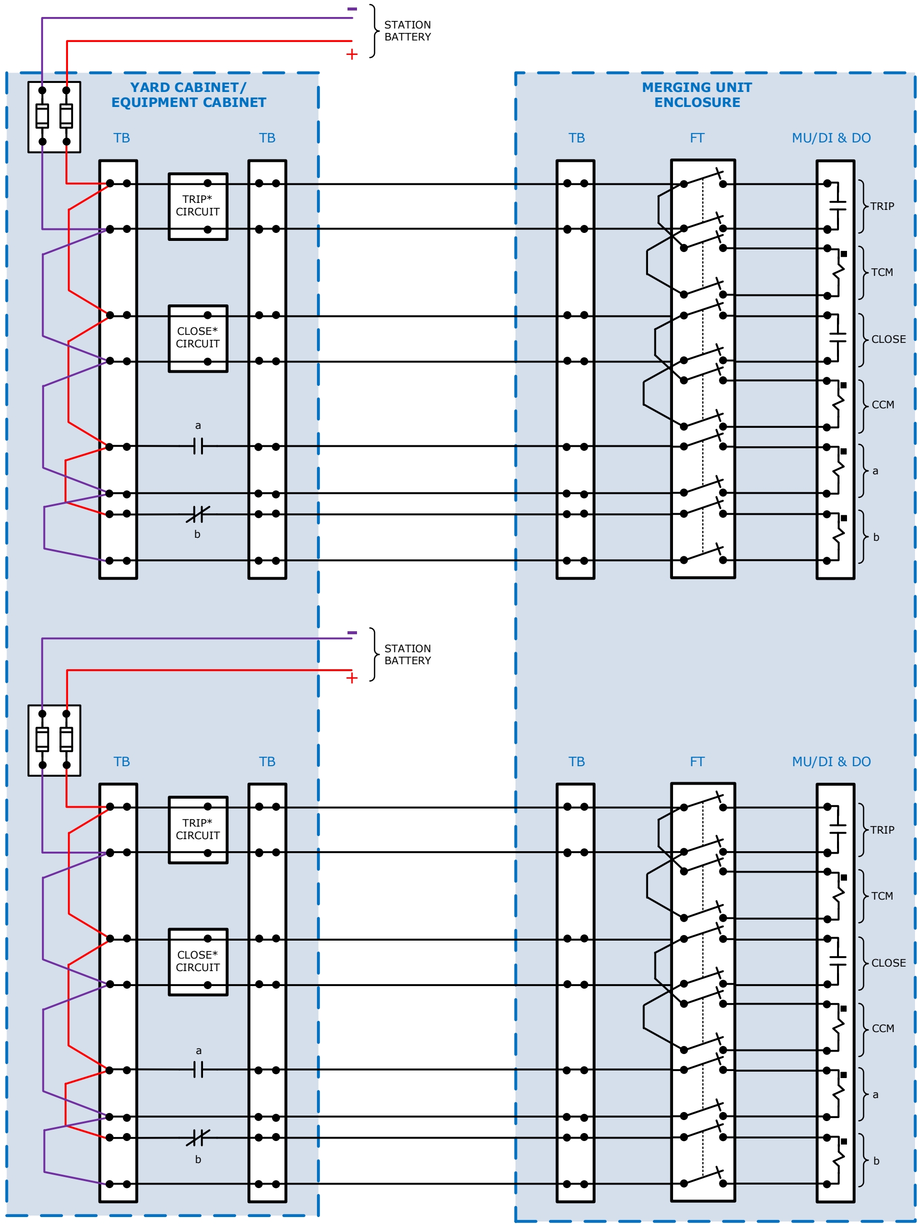
Annex: 3-Line Standardized MU-Yard Connectivity

- Two CT Sets
- Single VT Set
- Redundant MUs
- FT-Switches included in MU Enclosure



Annex: DC Elementary Standardized MU-Yard Connectivity

- Dual Battery
- Dual Trip/Close Circuits
- Redundant MUs
- TCM and CCM at MUs using Hi-Z inputs and relay logic
- FT-Switches included in MU Enclosure



Annex: Lockout Function with Dual Trip Coil, Single Close Coil