IEC 61850 Portable Digital Substation Training Laboratory

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Introduction and Background

- **Scope**
  - Design, build, configure, and test a new training laboratory for teaching power systems students digital substation smart grid protocols.
  - Deliver a brand new $70k training laboratory donated by Schweitzer Engineering Laboratories (SEL) to the Department of Electrical & Computer Engineering.
  - Use the digital substation portable laboratory in future electrical engineering power systems courses.
- **IEC 61850**
  - An international standard defining communication protocols for intelligent electronic devices at electrical substations.
  - Communication network protocols include Sampled Values (SV) and GOOSE operating on Layer 2 network.
  - Traditional copper wires carrying currents and voltages are replaced by Ethernet/fiber-optic cables
- **Teaching & Collaboration**
  - Provide opportunities to teach the Substation Configuration Description, Commissioning and Testing, Operation, Security, and Maintenance of the digital substation.
  - Collaboration between electrical engineers and computer engineers is an important need in future industry.
  - Valuable pilot demonstration for the industry sponsor, FirstEnergy, to aid in developing the technology for use on the future electric utility grid.

System Design

- **Power System Model**
  - Substation model includes a power transformer, transmission line, and bus bar connected to the grid through three circuit breakers.
- **Hardware**
  - Includes SEL Merging Units (MU), SDN Switches, Digital Protective Relays, and a GPS Clock.
- **Software**
  - Includes AcSELerator QuickSet (SEL-5030), Architect (SEL-5032), Flow Controller (SEL-5056), WireShark, and StationScout.
- **Configurations**
  - Includes device settings (.rdb), Configured IED Descriptions (.cid), IED Capability Description (.icd), Substation Configuration Description (.scd), and network flow database (.db).

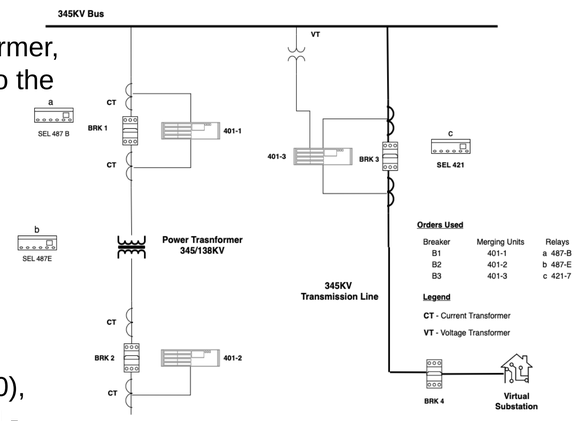


Fig 1: Power System Model

Network Architecture

- **Process Bus Network**
  - Includes SDN Switch, Publishers and Subscribers, Merging Units and Protective Relays. Protocols include SV and GOOSE; also, PTP is used for time synchronization.
- **Station Bus Network**
  - Includes SDN Switch, Merging Units and Protective Relays. Protocols include FTP, ARP, Telnet, and HTTPS, supporting remote access, command-line interfaces, and HMI.

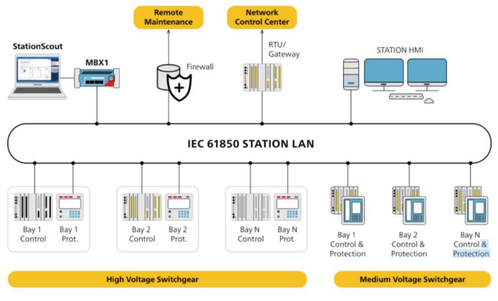


Fig 2: Station Bus Configuration

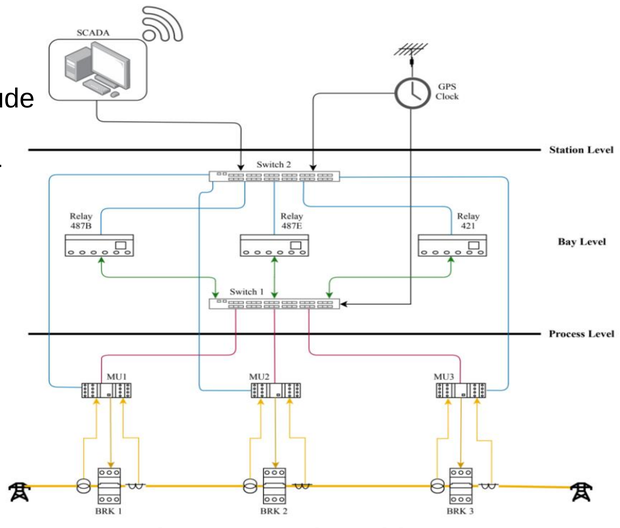
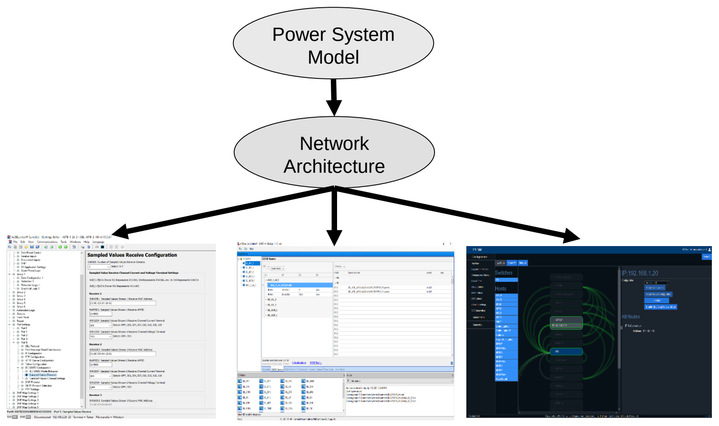


Fig 3: Network Architecture

Design Execution

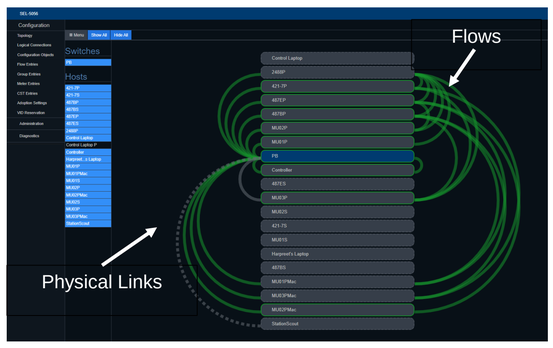


QuickSet [.rdb] **Architect [.cid]** **Flow Controller [.db]**

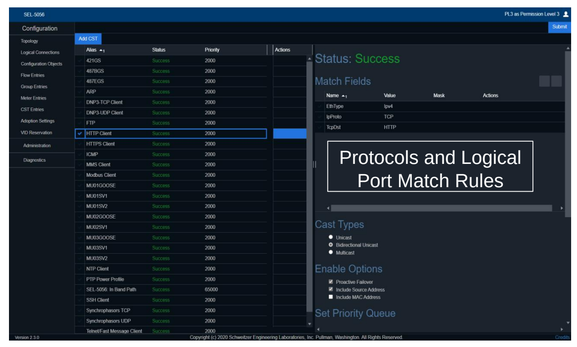
Senior Design Team

Network Flow

Topology



Connection Standard Template (CST)



Experimental Results

- **Merging Units**
  - Successfully published and subscribed GOOSE messages; successfully published SV.
- **SDN Switches**
  - Process Bus successfully directed network flows of Sampled Values and GOOSE messages to the proper devices.
  - Station Bus successfully allowed Telnet, FTP, PTP, ARP, and HTTP to configure all the hardware.
- **Protective Relays**
  - Successfully published and subscribed GOOSE messages; successfully subscribed SV.
  - Successfully processed the digital information and issued trip signals to protect the power system under fault.

Conclusion and Future Recommendations

Conclusion

- The portable laboratory is ready for future EEC protective relay and control courses (January 2022).
- Electrical power system engineers and computer engineers collaborated to design a multi-disciplined project. Power system engineers learned networking skills required for modern digital society.
- FirstEnergy advisors gained valuable experience using the software tools in IEC 61850 to create a functioning digital substation.
- The students integrated different hardware/software interfaces to seamlessly create a working substation laboratory not previously documented before.

Recommendations

- Future work includes expanding the laboratory to verify interoperability between different vendors' equipment.
- Class lab design projects will reconfigure the substation model for their own attempt at designing a digital substation architecture.
- Investigate network redundancy methods supported by hardware.