Implementation of a Protection, Control, and Automation System Based on IEC 61850

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OUTLINE

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- Implementation
- System Components
- Network Architecture
- Protection & Control System Design
- Substation Automation Architecture
- Factory Acceptance Tests & Commissioning
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The Client

- City owned utility in central Alberta, Canada
- Serves over 40,000 customers.
- Primarily an electrical distribution company
- 10 year average growth rate of 3%
- Owns 3 138-25 KV and 11 25-4 KV substations

Primary Reasons for Upgrade

- The existing substation required a complete protection & control, and SCADA upgrade.
  - The protection system consisted of old electro-mechanical and static protection relays which were outdated
  - There was little or no automation. A single RTU provided monitoring and control via DNP to the control center.
  - The P&C building was in need of major repairs
  - There was no centralized control in the substation i.e. HMI
  - The City wanted a modern platform for future distribution automation

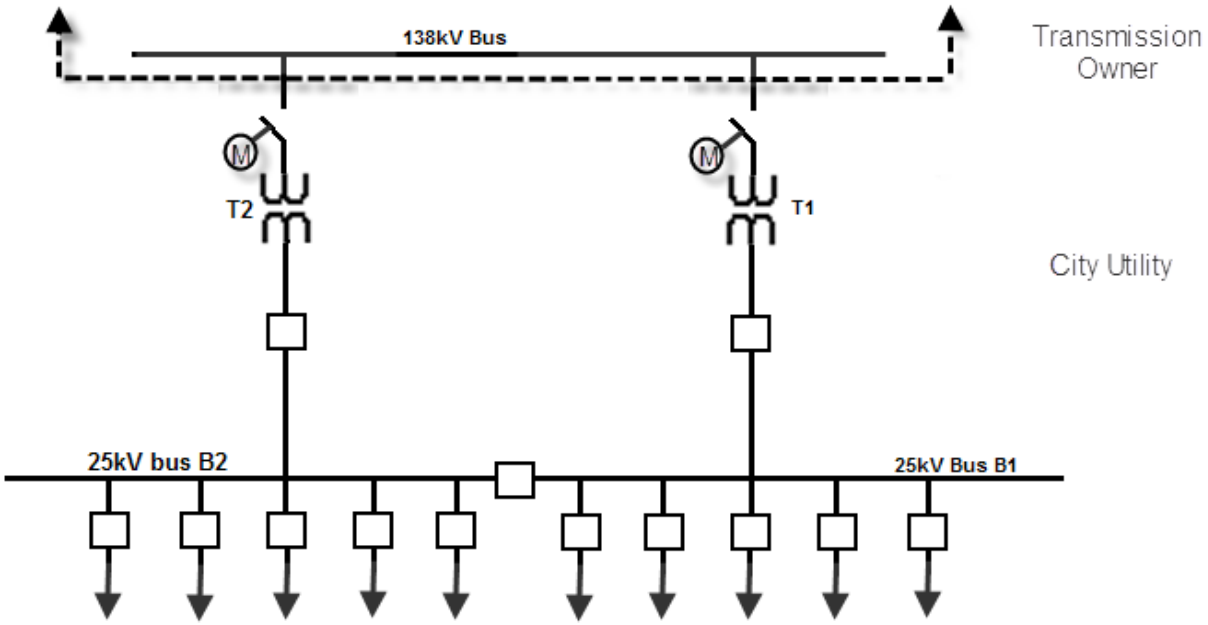
Key Technical Requirements

- All communications must comply with IEC 61850, both vertical (MMS) and horizontal (GOOSE)
  - Required for future distribution automation
- The station bus must run on a redundant network with minimum failover time to ensure dependability and security of the P&C system. Each device must have redundant fiber optic ports
- Substation IED's must be GPS time synchronized using IRIG-B or SNTP.

Key Technical Requirements Con't

- Ethernet switches shall be ruggedized for the substation environment and include priority tagging, support for VLAN's and RSTP. Switch module's should be swappable
- The Substation automation System (SAS) should include control and monitoring, event and alarm list among other's. The Link to the control center should be DNP
- At the client's request: 52CS Breaker Control, 43L/R selector switches were included. External 86 lockout relays were used and the existing tap-changer controller was maintained

Single Line Diagram



- The Substation consists of:
  - Two 36.4/56 MVA 138kv-25kv transformers, supplying 10x 25kv feeders, with a normally open tie breaker
  - The 138kv section is owned by the transmission facility operator. The design specifications for this system maintained traditional hard wired controls, alarms and status with DNP communications to the control center and HMI

Implementation

- It was jointly decided to use a single source for all substation automation products i.e. relays and SCADA system
  - The reasons were:
    - To reduce the 61850 learning curve
    - Limit engineering and operational risks
    - Reduce commissioning time
  - Future projects will explore multi-vendor inter-operability.

Protection Components – Transformers

- A & B Transformer Relay's
  - "A" protection is used for control, such as LTC, circuit breaker and MOD
  - Publishes GOOSE signals to the bus protection to initiate BF and trip re-enforcement
  - Hard wired trips are still maintained

Panel Type	Protection Functions	Control Functions
138kV Transformer	Main Transformer Differential (87T) Restricted Earth Fault (87G) LV Over-current backup (51) LV ground Over-current backup (51N) Auxiliary Trip Lockout Relay	Open/Close of HV MOD and 25kV Main Breaker from IED HMI Open/Close of HV MOD and 25kV Breaker from Selector Switch (52CS) Local/Remote Control Selection (43) Lockout Reset Push Buttons (PB) Lockout Indication

Protection Components – Buses

- Bus Protection Relay
  - Centralized Bus and breaker failure protections. Send trip signals via GOOSE to connected IEDs when operated
  - Hardwired trips still maintained

Panel Type	Protection Functions	Control Functions
25kV Bus	Main 3-phase Bus Differential (87B) Breaker Failure Protection for Each Connected Bay (50BF x 7) Trip Re-enforcement Relay for each bay Auxiliary Bus Trip Lockout Relay Auxiliary BF Trip Lockout Relay	Lockout Reset Push Buttons (PB) Lockout Indications

Protection Components – Feeders

- Feeder Protection Relay
  - Publishes GOOSE signals to bus IED to initiate BF and trip re-enforcement
  - Hard wired trips are still maintained

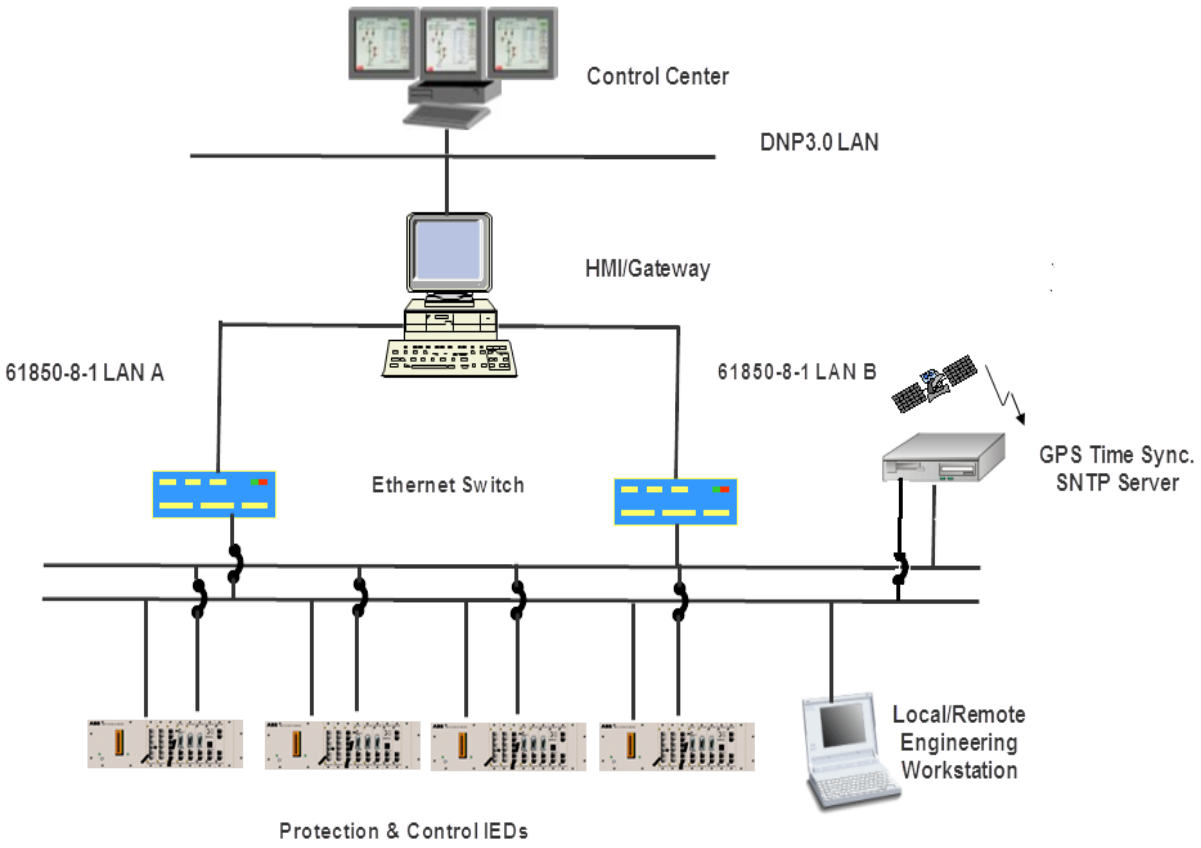
Panel Type	Protection Functions	Control Functions
25kV Feeder	Feeder Over-current Protection (50/51) with alternate, more sensitive, settings in line tagging mode 2-shot auto-reclosing (79) disabled by hot line tagging under-frequency load shedding (81)	Open/Close Feeder Breaker from SLD on IED HMI Open/Close Feeder Breaker from Selector Switch (52CS) On/Off Control of line auto-reclosing via IED HMI On/off Control of line 81 load shedding through IED HMI Local/Remote Control Selection (43) Live Line Tagging Selector Switch

SA System

Automation Architecture

- The IED's, IRIG-B clock and Industrial PC (HMI, Gateway and Data concentrator) are installed on the same panel and connected in a dual Star configuration
- PRP provides complete redundancy, through dual 100FX fiber ports on the relays
- The PC has 4 fiber ports and 2 copper ports which can be paired independently of physical medium i.e. a copper port can be paired with a fiber port
- The GPS clock sends a SNTP signal over both LAN A & LAN B

Simplified SA System Architecture



SCADA System

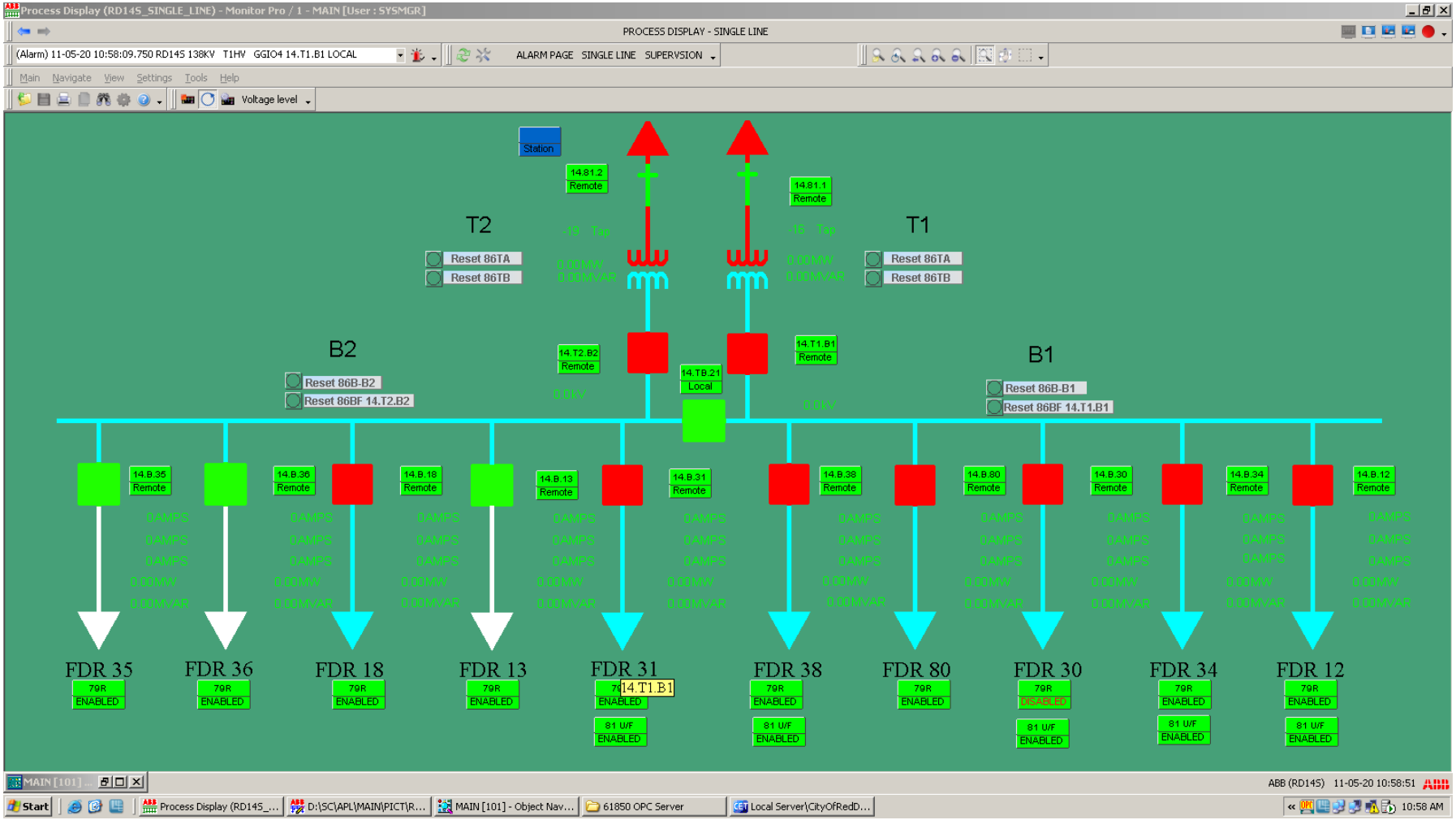
- Data Concentrator/Gateway/HMI
  - A single device is used as a gateway, HMI and data concentrator
  - The device collects data using IEC61850 MMS from the IEDs and forwards the data to the City's control center via DNP
  - Logic functions are preformed in the device as needed.
- DNP Unsolicited reporting was used to the control center to reduce traffic
- A second DNP link was also enabled to the control center in the event Master A failed

SCADA System Con't

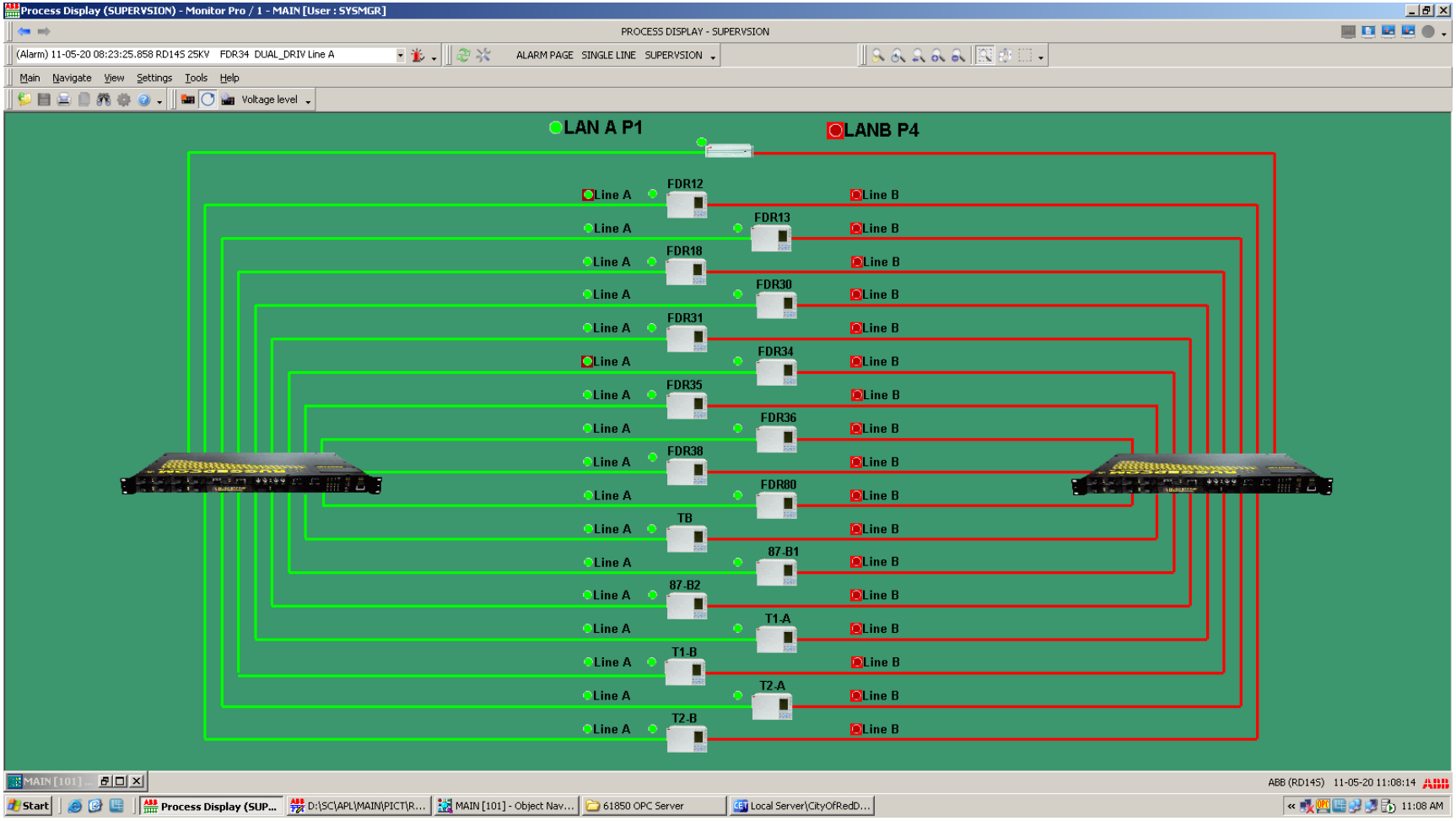
The HMI provides:

- A control page for operators to monitor and control the substation locally: apparatus positions/control, metering info, selector switch status/control, lockout & tagging status/control
- A display which includes bus coloring i.e. the bus changes color depending on whether it is energized or feed from single or dual sources
- There are several displays which show:
  - The status of communications, i.e. whether relays are off-line and if one of the dual ports has failed etc.
  - Any events or alarm which have occurred

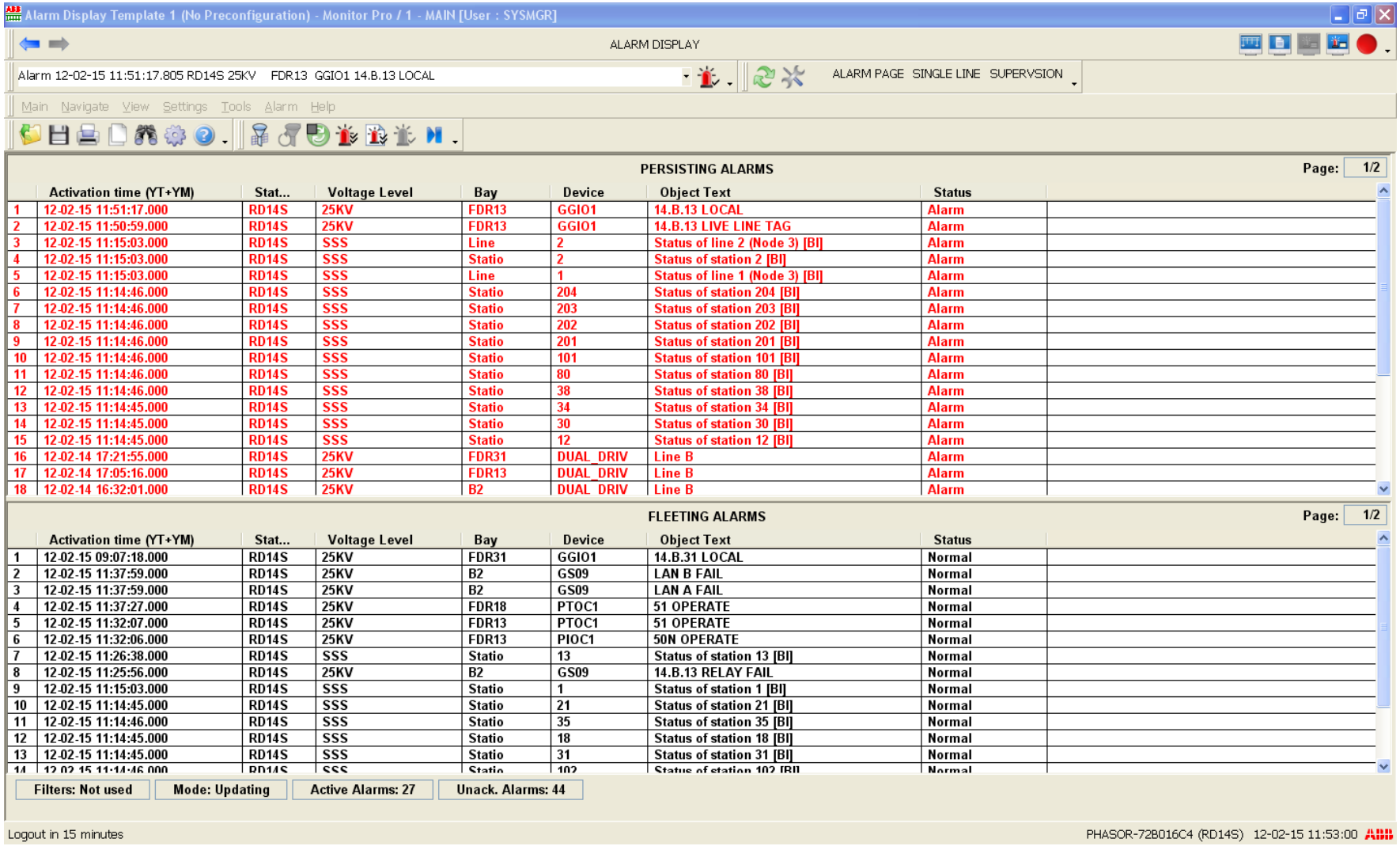
HMI Single Line



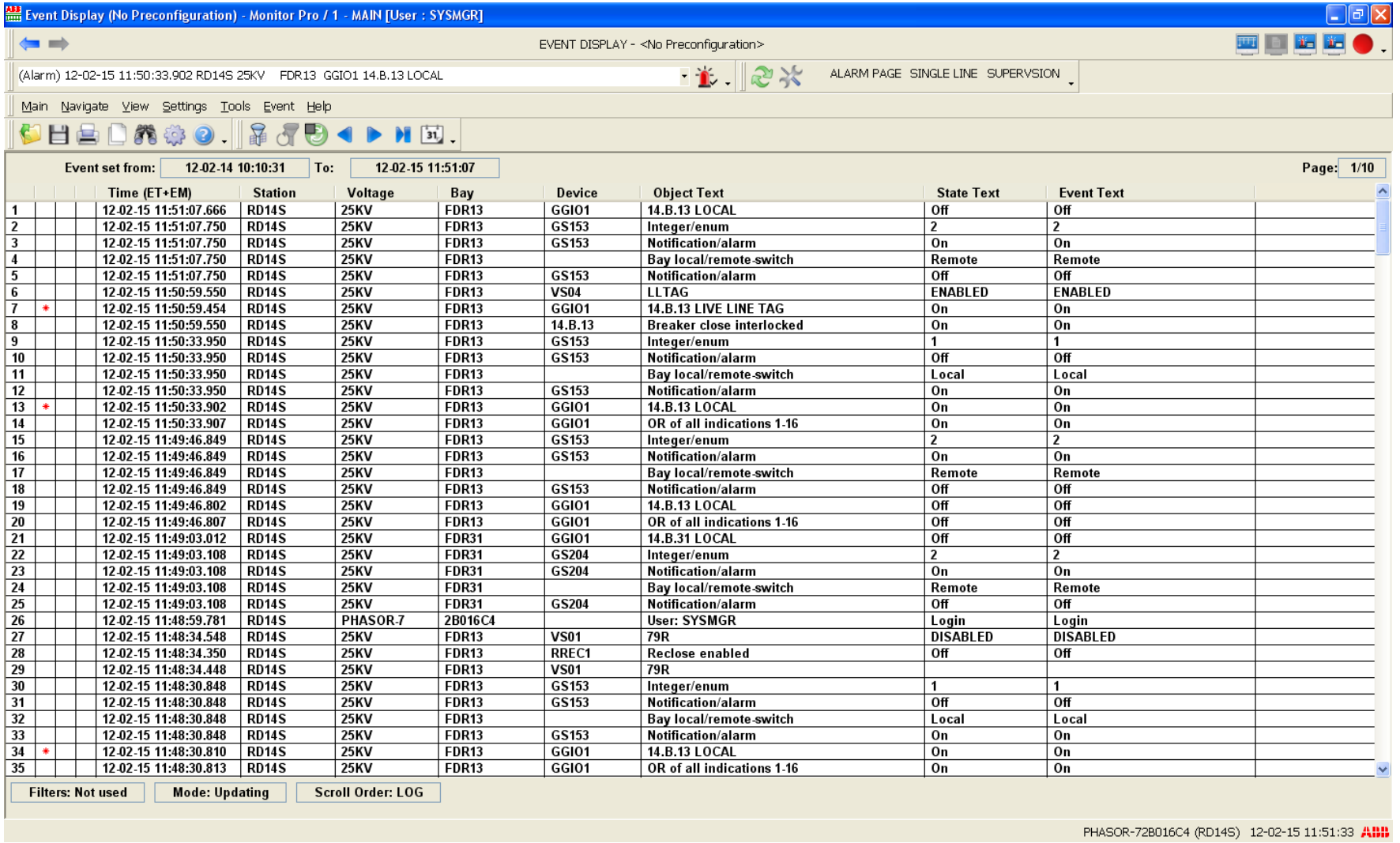
Communication Supervision



Alarm Page

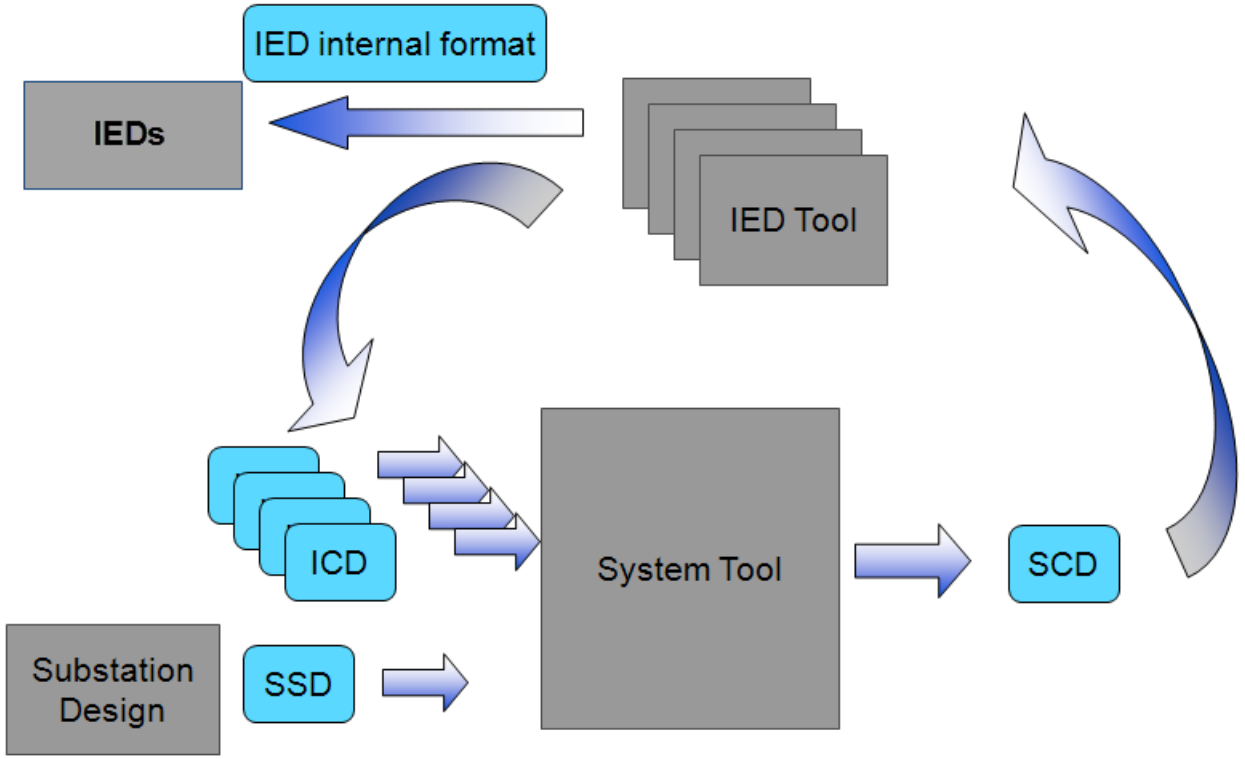

Alarm Display Template 1 (No Preconfiguration) - Monitor Pro / 1 - MAIN [User : SYSMGR]
ALARM DISPLAY
Alarm 12-02-15 11:51:17.805 RD14S 25KV FDR13 GGIO1 14.B.13 LOCAL
ALARM PAGE SINGLE LINE SUPERVSION
Main Navigate View Settings Tools Alarm Help
PERSISTING ALARMS
Page: 1/2
Activation time (YT+YM) | Stat... | Voltage Level | Bay | Device | Object Text | Status
1 | 12-02-15 11:51:17.000 | RD14S | 25KV | FDR13 | GGIO1 | 14.B.13 LOCAL | Alarm
2 | 12-02-15 11:50:59.000 | RD14S | 25KV | FDR13 | GGIO1 | 14.B.13 LIVE LINE TAG | Alarm
3 | 12-02-15 11:15:03.000 | RD14S | SSS | Line | 2 | Status of line 2 (Node 3) [BI] | Alarm
4 | 12-02-15 11:15:03.000 | RD14S | SSS | Statio | 2 | Status of station 2 [BI] | Alarm
5 | 12-02-15 11:15:03.000 | RD14S | SSS | Line | 1 | Status of line 1 (Node 3) [BI] | Alarm
6 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 204 | Status of station 204 [BI] | Alarm
7 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 203 | Status of station 203 [BI] | Alarm
8 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 202 | Status of station 202 [BI] | Alarm
9 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 201 | Status of station 201 [BI] | Alarm
10 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 101 | Status of station 101 [BI] | Alarm
11 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 80 | Status of station 80 [BI] | Alarm
12 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 38 | Status of station 38 [BI] | Alarm
13 | 12-02-15 11:14:45.000 | RD14S | SSS | Statio | 34 | Status of station 34 [BI] | Alarm
14 | 12-02-15 11:14:45.000 | RD14S | SSS | Statio | 30 | Status of station 30 [BI] | Alarm
15 | 12-02-15 11:14:45.000 | RD14S | SSS | Statio | 12 | Status of station 12 [BI] | Alarm
16 | 12-02-14 17:21:55.000 | RD14S | 25KV | FDR31 | DUAL_DRIV | Line B | Alarm
17 | 12-02-14 17:05:16.000 | RD14S | 25KV | FDR13 | DUAL_DRIV | Line B | Alarm
18 | 12-02-14 16:32:01.000 | RD14S | 25KV | B2 | DUAL_DRIV | Line B | Alarm
FLEETING ALARMS
Page: 1/2
Activation time (YT+YM) | Stat... | Voltage Level | Bay | Device | Object Text | Status
1 | 12-02-15 09:07:18.000 | RD14S | 25KV | FDR31 | GGIO1 | 14.B.31 LOCAL | Normal
2 | 12-02-15 11:37:59.000 | RD14S | 25KV | B2 | GS09 | LAN B FAIL | Normal
3 | 12-02-15 11:37:59.000 | RD14S | 25KV | B2 | GS09 | LAN A FAIL | Normal
4 | 12-02-15 11:37:27.000 | RD14S | 25KV | FDR18 | PTOC1 | 51 OPERATE | Normal
5 | 12-02-15 11:32:07.000 | RD14S | 25KV | FDR13 | PTOC1 | 51 OPERATE | Normal
6 | 12-02-15 11:32:06.000 | RD14S | 25KV | FDR13 | PIOC1 | 50N OPERATE | Normal
7 | 12-02-15 11:26:38.000 | RD14S | SSS | Statio | 13 | Status of station 13 [BI] | Normal
8 | 12-02-15 11:25:56.000 | RD14S | 25KV | B2 | GS09 | 14.B.13 RELAY FAIL | Normal
9 | 12-02-15 11:15:03.000 | RD14S | SSS | Statio | 1 | Status of station 1 [BI] | Normal
10 | 12-02-15 11:14:45.000 | RD14S | SSS | Statio | 21 | Status of station 21 [BI] | Normal
11 | 12-02-15 11:14:46.000 | RD14S | SSS | Statio | 35 | Status of station 35 [BI] | Normal
12 | 12-02-15 11:14:45.000 | RD14S | SSS | Statio | 18 | Status of station 18 [BI] | Normal
13 | 12-02-15 11:14:45.000 | RD14S | SSS | Statio | 31 | Status of station 31 [BI] | Normal
Filters: Not used
Mode: Updating
Active Alarms: 27
Unack. Alarms: 44
Logout in 15 minutes
PHASOR-72B016C4 (RD14S) 12-02-15 11:53:00

Event Page



				Time (ET+EM)	Station	Voltage	Bay	Device	Object Text	State Text	Event Text
1				12-02-15 11:51:07.666	RD14S	25KV	FDR13	GGIO1	14.B.13 LOCAL	Off	Off
2				12-02-15 11:51:07.750	RD14S	25KV	FDR13	GS153	Integer/enum	2	2
3				12-02-15 11:51:07.750	RD14S	25KV	FDR13	GS153	Notification/alarm	On	On
4				12-02-15 11:51:07.750	RD14S	25KV	FDR13		Bay local/remote-switch	Remote	Remote
5				12-02-15 11:51:07.750	RD14S	25KV	FDR13	GS153	Notification/alarm	Off	Off
6				12-02-15 11:50:59.550	RD14S	25KV	FDR13	VS04	LLTAG	ENABLED	ENABLED
7	*			12-02-15 11:50:59.454	RD14S	25KV	FDR13	GGIO1	14.B.13 LIVE LINE TAG	On	On
8				12-02-15 11:50:59.550	RD14S	25KV	FDR13	14.B.13	Breaker close interlocked	On	On
9				12-02-15 11:50:33.950	RD14S	25KV	FDR13	GS153	Integer/enum	1	1
10				12-02-15 11:50:33.950	RD14S	25KV	FDR13	GS153	Notification/alarm	Off	Off
11				12-02-15 11:50:33.950	RD14S	25KV	FDR13		Bay local/remote-switch	Local	Local
12				12-02-15 11:50:33.950	RD14S	25KV	FDR13	GS153	Notification/alarm	On	On
13	*			12-02-15 11:50:33.902	RD14S	25KV	FDR13	GGIO1	14.B.13 LOCAL	On	On
14				12-02-15 11:50:33.907	RD14S	25KV	FDR13	GGIO1	OR of all indications 1-16	On	On
15				12-02-15 11:49:46.849	RD14S	25KV	FDR13	GS153	Integer/enum	2	2
16				12-02-15 11:49:46.849	RD14S	25KV	FDR13	GS153	Notification/alarm	On	On
17				12-02-15 11:49:46.849	RD14S	25KV	FDR13		Bay local/remote-switch	Remote	Remote
18				12-02-15 11:49:46.849	RD14S	25KV	FDR13	GS153	Notification/alarm	Off	Off
19				12-02-15 11:49:46.802	RD14S	25KV	FDR13	GGIO1	14.B.13 LOCAL	Off	Off
20				12-02-15 11:49:46.807	RD14S	25KV	FDR13	GGIO1	OR of all indications 1-16	Off	Off
21				12-02-15 11:49:03.012	RD14S	25KV	FDR31	GGIO1	14.B.31 LOCAL	Off	Off
22				12-02-15 11:49:03.108	RD14S	25KV	FDR31	GS204	Integer/enum	2	2
23				12-02-15 11:49:03.108	RD14S	25KV	FDR31	GS204	Notification/alarm	On	On
24				12-02-15 11:49:03.108	RD14S	25KV	FDR31		Bay local/remote-switch	Remote	Remote
25				12-02-15 11:49:03.108	RD14S	25KV	FDR31	GS204	Notification/alarm	Off	Off
26				12-02-15 11:48:59.781	RD14S	PHASOR-7	2B016C4		User: SYSMGR	Login	Login
27				12-02-15 11:48:34.548	RD14S	25KV	FDR13	VS01	79R	DISABLED	DISABLED
28				12-02-15 11:48:34.350	RD14S	25KV	FDR13	RREC1	Reclose enabled	Off	Off
29				12-02-15 11:48:34.448	RD14S	25KV	FDR13	VS01	79R		
30				12-02-15 11:48:30.848	RD14S	25KV	FDR13	GS153	Integer/enum	1	1
31				12-02-15 11:48:30.848	RD14S	25KV	FDR13	GS153	Notification/alarm	Off	Off
32				12-02-15 11:48:30.848	RD14S	25KV	FDR13		Bay local/remote-switch	Local	Local
33				12-02-15 11:48:30.848	RD14S	25KV	FDR13	GS153	Notification/alarm	On	On
34	*			12-02-15 11:48:30.810	RD14S	25KV	FDR13	GGIO1	14.B.13 LOCAL	On	On
35				12-02-15 11:48:30.813	RD14S	25KV	FDR13	GGIO1	OR of all indications 1-16	On	On

IEC 61850 Engineering



IEC 61850 Engineering

The engineering steps followed were:

1. IED engineering (IED configuration tool)
   - Substation structure (station, voltage, bay)
   - Networking design (device subnet, IP, etc.)
   - P & C configuration
2. Communication engineering (System Integration Tool)
   - Substation section “conducting” equipment and object mapping (later SCADA database import)
   - Dataset engineering (GOOSE and report datasets)
   - GOOSE Control Engineering (GCB parameters, publisher/subscriber relationship, subscribers application configuration)
   - Report control Engineering (RCB parameters)

IEC 61850 Engineering

1. HMI engineering
   - 61850 OPC Server engineering (scd import, IED communication)
   - Process database and data development (scd import or manual)
   - Process objects addressing
   - Process display (SLD) design and engineering (animation, control/indication data mapping, coloring etc).
2. Gateway engineering
   - Remote connection definition (name, IP/baud rate, protocols)
   - Points in monitoring direction (DNP addressing, data handling, object variations, scaling, alarm grouping)
   - Points in control direction (DNP addressing, type/purpose of commands)

GOOSE Applications

IED Type	GOOSE Published (To)	GOOSE Received (From)
Feeder Protection	Bus IED	Bus IED
	- Overcurrent Trips - Trip reinforcement request for control open or UF element operation - Breaker status	- 87B or 50BF trip (trip feeder breaker)
Transformer Protection	Bus IED	Bus IED
	- Transformer non-electrical protection operation - Transformer electrical protection operation - Non-protection trip - LV breaker status	- 87B or 50BF other than transformer LV breaker (trip transformer LV breaker) - 50BF of transformer LV breaker (clear HV bus)

Client/Server Applications

IED Type	Indication	Control
Bus Protection	- 86B lockout indication - 86BF Lockout indication - protection alarms	- 86B reset lockout control - 86BF reset lockout control
Feeder Protection	- Breaker position - local/remote control mode - Auto-reclosing on/off indication - UFLS (81U) on/off indication - protection and apparatus alarms	- Breaker open/close commands - On/off auto-reclosing control - On/off UFLS (81U) control
XFMR Protection	- HV MOD positions - HV MOD local/remote status - LV breaker positions - LV breaker local/remote status - 86LO Indication (transformer faults) - OLTC tap positions and manual/auto mode - protection and apparatus alarms	- HV MOD open/close commands - LV Breaker open/close commands - Reset 86LO - OLTC manual Raise/Lower commands

Factory Acceptance & Commissioning

- Factory Acceptance
  - Performed at Engineer's integration shop
  - Panel wiring verified
  - The complete SA system was connected as in the substation and functionally tested
  - Protection functions tested as in conventional system by secondary injection
  - HMI indication and control functionality tested and verified
  - Inter-panel GOOSE communication tested and verified by monitoring test breakers and IED response or using network analyzer to monitor GOOSE traffic
  - Reduce time and labor onsite for commissioning

Factory Acceptance Tests & Commissioning

- Site Commissioning
  - Inter-IED and HMI-IED functionality already verified
  - Cursory random system tests after installed on-site (eg. BF operations, apparatus status, events, alarms)
  - Control cable installation and wiring termination to primary equipment
  - Testing of indications/control functionality to/from client's control center (most time spent on this task)
  - Additional functional implementations/modifications identified later on-site upon client's request
  - GOOSE testing tools from a third party vendor (test set manufacturer) were employed during on site testing
  - SA system commissioning lasts around 3 weeks

Lessons Learned

- Thorough planning of IED functionality prior to beginning system integration to avoid repetitive work
- Develop documentation standards for GOOSE messages to aid proper device isolation during maintenance
- Training/education to operators/maintenance crew to gain confidence and experience on virtual control functionality of modern IEDs and HMIs
- GGIO used in some instances instead of standard IEC 61850 data attributes

Conclusions

- IEC 61850 works as claimed
- Initial learning curves on the standards, Ethernet, multiple configuration tools, and testing methods
- Education and training required for engineers, operators and maintenance team
- Reduction of inter-panel wiring and labor
- FAT further reduces time spent on-site
- Efficient testing tools for GOOSE messages are commercially available from third party vendors
- Scalability and expandability for future similar projects

QUESTIONS?