E.S. Cornwall Memorial Scholarship

Second Quarterly Report

September 2025 to December 2025

Working for ABB in Vaasa, Finland

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Acknowledgements

I would like to thank the ES Cornwall Memorial Scholarship and the Advisory Committee for the excellent opportunity provided to me by the scholarship. I am incredibly thankful for this opportunity to obtain special experiences internationally and share my learnings and experience with the Australian Power Industry.

I would like to thank Energy Queensland for enabling me to temporarily step away from my role and pursue this opportunity to gain international engineering experience. I would especially like to thank my supervisor Alex Yu and manager Carson Care for their enablement and support. I would also like to thank Rob Coggan for his valuable insights into emerging protection and control technologies, and for the role played in facilitating international opportunities for me.

I would like to thank ABB for providing me with such an exciting opportunity within the company. I would especially like to thank Marco Nunes for being an exceptional driving force in setting up an exciting opportunity to help me achieve my goals. I would also like to thank Timo Eskola and Johan Pensar for welcoming me into the team, introducing me to the company and facilitating my involvement in projects.

Disclaimer

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Glossary

Term/Abbreviation	Definition
9-2LE	Sampled Value communication defined by the IEC 61850-9-2LE implementation guide
PAC	Protection and Control
CPC	Centralised Protection and Control
VPC	Virtualised Protection and Control
GOOSE	Generic Object Orientated Substation Events. GOOSE is an ultra-high speed and reliable communication protocol defined by IEC 61850 used to share signals.
SMV	Sampled Measured Values. SMV is a time-synchronised, real time communication protocol defined by IEC 61850 or IEC 61869 and used to share measured data.
MU	Merging Unit. An IED used to interface between the physical/analogue power system and the digital protection and control system.
PIXIT	Technical document that specifies the protocol implementation extra information for testing.
PTP	Precision Time Protocol. A communication protocol used for high accuracy time synchronisation defined in IEEE 1588 v2.
CBF	Circuit Breaker Fail protection scheme
HIL	Hardware in the Loop
RTDS	Real-Time Digital Simulator
R&D	Research and Development
IT	Information Technology
Hypervisor	A software that runs and manages virtual machines. Can be used to allow one host computer to support multiple virtual machines and virtually manage the computer's resources.
VM	Virtual Machine

Executive Summary

The Australian Power Industry is experiencing an increase in the portfolio of substation projects to be delivered, which is driving an increase in spending and strain on resources in utility companies. One of the key factors to this is the rapid adoption of renewable distributed energy generators connecting to the network to meet renewable energy targets. To ensure the industry can effectively deliver the large portfolio of work required to transform the grid, the efficient delivery of future-proof substation upgrades is more important than ever.

One of the keys to efficiently delivering future-proof substations modifications is a protection and control system that is both scalable and flexible. The traditional protection and control systems typically utilised throughout the industry has a level of rigidity that is typically costly and time-consuming to expand or modify to meet the network's changing requirements.

I believe that the Australian Power Industry would benefit from learning about new and innovative protection and control technologies that can make these systems more flexible and scalable. I consider Centralised and Virtualised Protection and Control to be one of the most promising technological developments in this space with the potential to create significant value to the power industry.

This report provides an overview of the second quarter of my ES Cornwall Memorial Scholarship Experience. In this quarter I continued my first placement with ABB's Distribution Solutions Division based in Vaasa, Finland. This report is focussed on sharing my key learnings on technical topics including IEC61850 configuration and commissioning, IEC61869-9 sampled values, and the architecture and design principles of CPC and VPC systems. I also discuss my learnings regarding the other potential advantages that can be realised by implementing digital substations (CPC/VPC), and my learnings from the projects I have been involved in.

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1. Application of IEC61850 Communication Engineering

In my first quarterly report, I introduced the fundamentals of IEC61850 communication including GOOSE and SMV. In this report, I will expand on these fundamentals by sharing my learnings regarding the practical application of IEC61850 communication. This includes both the design and the commissioning/testing process of both GOOSE and SMV.

1.1. GOOSE Communication Design

In my experience, a valuable first step in designing GOOSE communication is to identify and plan the signals/data that needs to be transmitted via GOOSE and plan the communication. I have found it useful to develop a matrix that describes the functional description of the data to be communicated and creates a clear link to the GOOSE dataset naming.

Figure 1 shows an example of planning the GOOSE communication from the SSC600 CPC/VPC device to a Feeder Bay's Merging Unit. This type of planning would be repeated for each of the other instances where the SSC600 needs to send GOOSE data to other MU's, and also for each instance where a MU needs to send GOOSE data to the SSC600.

GOOSE Dataset Name	GOOSE Sender	GOOSE Receiver	Data Object Functional Description	GOOSE Data Set Entry
SSC600_FDRX_GOOSE_DS	SSC600	FDRX Bay MU	FDRX Bay CB Trip Command	LD0/TRPPTRC1.Tr.General
				LD0/TRPPTRC1.Tr.q
			FDRX Bay CB Open Command	CTRL/CBCSWI1.OpOpn.general
				CTRL/CBCSWI1.OpOpn.q
			FDRX Bay CB Close Command	CTRL/CBCSWI1.OpCls.general
				CTRL/CBCSWI1.OpCls.q
			FDRX Bay Line Isolator Open Command	CTRL/DCCSWI1.OpOpn.general
				CTRL/DCCSWI1.OpOpn.q
			FDRX Bay Line Isolator Close Command	CTRL/DCCSWI1.OpCls.general
				CTRL/DCCSWI1.OpCls.q
			FDRX Bay Main Bus Isolator Open Command	CTRL/DCCSWI2.OpOpn.general
				CTRL/DCCSWI2.OpOpn.q
			FDRX Bay Main Bus Isolator Close Command	CTRL/DCCSWI2.OpCls.general
				CTRL/DCCSWI2.OpCls.q
			FDRX Bay Backup Bus Isolator Open Command	CTRL/DCCSWI3.OpOpn.general
				CTRL/DCCSWI3.OpOpn.q
			FDRX Bay Backup Bus Isolator Close Command	CTRL/DCCSWI3.OpCls.general
				CTRL/DCCSWI3.OpCls.q

Figure 1 - Example of Planning GOOSE Communication from SSC600

When designing GOOSE communication, there are different data types that must be included and in the correct order. For each data point that is sent via GOOSE, it **must** be directly followed by an associated quality datapoint (.q). This is demonstrated in Figure 1, as each datapoint included in the GOOSE dataset first includes the actual datapoint, and then immediately followed by the associated quality datapoint. Time stamp datapoints (.t) can also be included for each datapoint, and must be located directly following the quality data point. However, it is not essential to include time stamp data points in GOOSE datasets.

An important component for planning and configuring GOOSE communication is understanding how to map signals between the function blocks used in the application configuration to the associated GOOSE datapoint. There are two key components to this, understanding the function blocks used, and using the "Parameter List" technical document.

Figures 2 and 3 demonstrate how this can be done using the open and close commands for the Line isolator and Main Bus Isolator as an example.

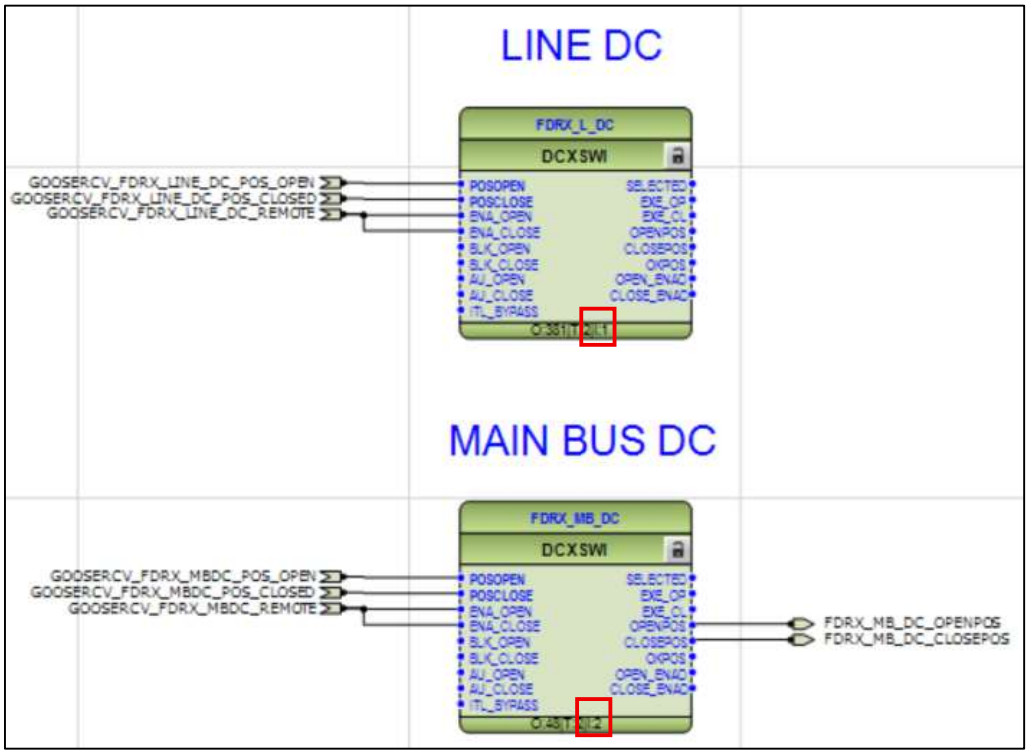


Figure 2 - Example Disconnector Application Configuration in SSC600 using PCM600

When building the application configuration of a SSC600 device using PCM600, multiple instances of the same function block are typically allowed, especially for control blocks like the DCXSWI disconnector control function block. When planning the GOOSE communication associated with function blocks like this, it is important to note the “instance” of the function block. In Figure 2, it is seen that the FDRX bay’s line disconnector is associated with instance 1 of the DCXSWI function block, and the main bus disconnector for the same bay is associated with instance 2 of the DCXSWI function block.

SSC600 Parameter list

DCXSWI1	I<->O DCC(1)	I<->O DCC(1)	OUT	CTRL.DCCSWI1.OpOpn.general	ACT	BOOLEAN	ST	B				DN	EXE_OP	Executes the command for open direction
DCXSWI1	I<->O DCC(1)	I<->O DCC(1)	OUT	CTRL.DCCSWI1.OpCls.general	ACT	BOOLEAN	ST	B				DN	EXE_CL	Executes the command for close direction

Figure 3 - SSC600 Paramater List for DCXSWI Function Block

Figure 3 shows how to use the Parameter List technical document to finish the GOOSE data point definition. The two rows displayed in Figure 3 show the GOOSE data points associated with the disconnector open and close commands. Column 1 and 4 identifies that the points are outputs of the DCXSWI1 function block. And the last two columns on the right identify

exactly which signals/functions the data points are associated with. An important detail is that figure 3 is referring to instance 1 of the function blocks as an example. Therefore, for the main bus disconnector's open command, the data point should be CTRL.DCCSWI**2**.OpOpn.general because this needs to refer to the second instance of the DCXSWI function block.

After planning the GOOSE communication, configuring the GOOSE datasets is quite simple using the ABB configuration tool PCM600, as seen in figure 4.

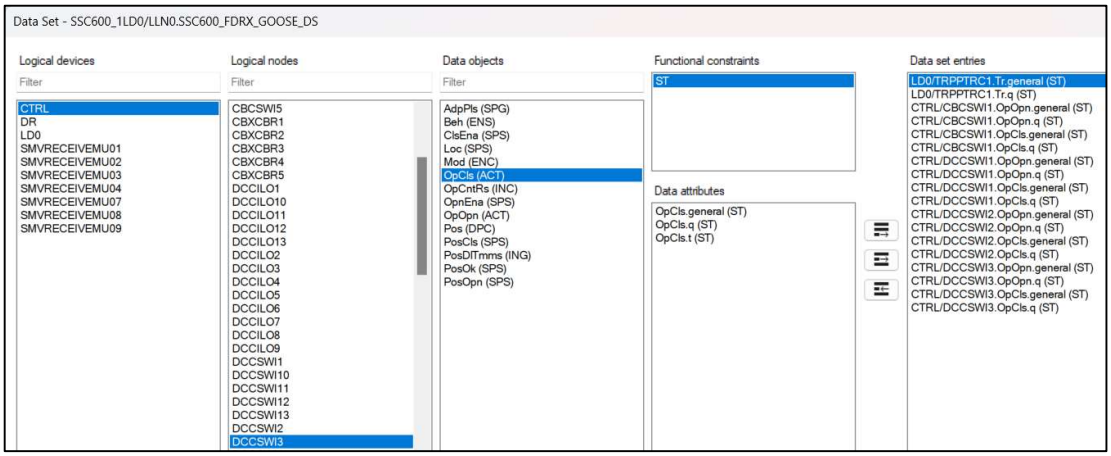


Figure 4 - Example of Configuring GOOSE Datasets in PCM600

After creating the GOOSE datasets. the next step is to configure the GOOSE control blocks, as demonstrated in Figure 5. The important factors for configuring GOOSE control blocks are to identify the subscribers via the checkboxes and ensure that each control block has a unique APP ID and MAC Address. When creating new control blocks in PCM600, it will automatically assign a unique APP ID and MAC Address, however I would still recommend confirming this, as non-unique values will prevent the GOOSE publishing from working.

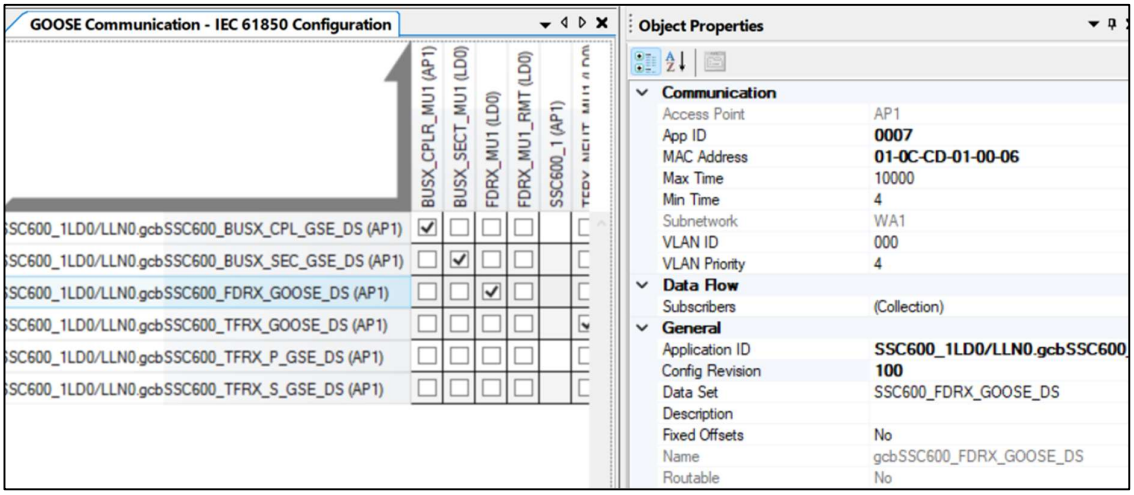


Figure 5 - Example of Configuring a GOOSE Control Block

The final step is mapping how the received signals will be used by the receiving device, which is displayed in Figure 6. My biggest recommendation for doing this signal mapping is to ensure that in the application configuration, each GOOSE receive function block has a unique user-defined name that clearly describes how the received signal will be used. By doing this, I have found this step to be very simple.

IED, Logical Device :		SSC600_1, LD0		SSC600_1, LD0	SSC600_1, CTRL	SSC600_1, CTRL							
				TRPPTRC1		CBCSWI1		DCCSWI1		DCCSWI2		DCCSWI3	
Data Object: Data Attribute:				Tr, general		OpCls, general	OpOpn, general	OpCls, general	OpOpn, general	OpCls, general	OpOpn, general	OpCls, general	OpOpn, general
BBDC_AU_CLS;GOOSERCV_BIN:15													
BBDC_AU_CLS;GOOSERCV_BIN:15	IN											X	
BBDC_AU_OPN;GOOSERCV_BIN:14													
BBDC_AU_OPN;GOOSERCV_BIN:14	IN												X
CB_AU_CLOSE;GOOSERCV_BIN:2													
CB_AU_CLOSE;GOOSERCV_BIN:2	IN					X							
CB_AU_OPEN;GOOSERCV_BIN:1													
CB_AU_OPEN;GOOSERCV_BIN:1	IN						X						
LDC_AU_CLS_1;GOOSERCV_BIN:11													
LDC_AU_CLS_1;GOOSERCV_BIN:11	IN							X					
LDC_AU_OPN;GOOSERCV_BIN:10													
LDC_AU_OPN;GOOSERCV_BIN:10	IN								X				
MASTER_TRIP;GOOSERCV_BIN:0													
MASTER_TRIP;GOOSERCV_BIN:0	IN			X									
MBDC_AU_CLS;GOOSERCV_BIN:13													
MBDC_AU_CLS;GOOSERCV_BIN:13	IN									X			
MBDC_AU_OPN;GOOSERCV_BIN:12													
MBDC_AU_OPN;GOOSERCV_BIN:12	IN										X		

Figure 6 - Example for Configuring Signal Matrix for GOOSE Communication

1.2. GOOSE Commissioning and Testing

An essential component for being able to commission and test GOOSE communication is to understand how it works. The GOOSE publisher publishes data at regular intervals when there is no change in data. However, when data in the GOOSE dataset changes, it instantly publishes a burst of messages. The messages are published to the process bus, meaning all IED's connected to the process bus can see the message (except when using VLANs). However, only IEDs that are configured as subscribers to the message will actively receive and read the data.

It is also essential to understand how the GOOSE sending and receiving functions work within the specific devices, which can be found in the "PIXIT" technical documentation. Figure 7 shows a screenshot of the PIXIT for ABB's GOOSE subscribe/receive functions, with the "Y" used to indicate which properties are checked when determining the validity of GOOSE messages.

PIXIT for GOOSE subscribe model

ID	Ed	Description	Value / Clarification	
Gs1	1,2	What elements of a subscribed GOOSE header are checked to decide the message is valid and the all data values are accepted? If yes, describe the conditions. Note: the VLAN tag may be removed by a ethernet switch and should not be checked	N	source MAC address
			Y	destination MAC address
			Y	Ethertype = 0x88B8
			N	gocbRef
			N	timeAllowedtoLive
			N	datSet
			N	goID
			N	t
			Y	stNum
			Y	sqNum
			Y	test
			Y	confRev
			Y	ndsCom
			Y	numDatSetEntries
			Y	APPID

Figure 7 - SSC600 GOOSE Subscribe model PIXIT

One of the most useful tools for commissioning GOOSE communication is a network traffic analyser software like Wireshark. This tool enables the analysis of the communication traffic on the network and facilitates the identification and diagnosis of problems. Figure 8 and 9 demonstrates screenshots taken from a Wireshark trace of GOOSE traffic on a process bus. As seen in Figure 8, GOOSE messages were being published every 10 seconds until a data point changed state at 58 seconds, at which stage a burst of GOOSE messages were published, before progressively returning to 10 second intervals.

Time	Source	Destination	Protocol
6.383979	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
16.386556	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
26.383219	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
36.384036	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
46.383701	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
56.382773	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.215926	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.217304	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.221095	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.229187	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.245454	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.277186	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.341261	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.469260	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
58.725261	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
59.237186	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
60.261163	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
62.309845	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
66.405823	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
74.603499	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
84.597235	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
94.597805	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
104.597697	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
114.597305	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
124.597178	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
134.597594	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE
144.596893	TyphoonHIL_f:ce:30	IecTc57_01:00:0a	GOOSE

Figure 8 - Wireshark Screenshot of GOOSE Messages Over Time

Figure 9 demonstrates the information included inside a GOOSE message. This is quite useful for confirming the GOOSE messages are configured correctly and for diagnosing issues. In my experience, the most common issues with GOOSE configuration are destination MAC Address and APPID (both of which are hexadecimal), however the full list can be found in the PIXIT document.

The destination MAC address and APPID have been highlighted in red, while the actual dataset information can be found if expanding the section highlighted in blue.

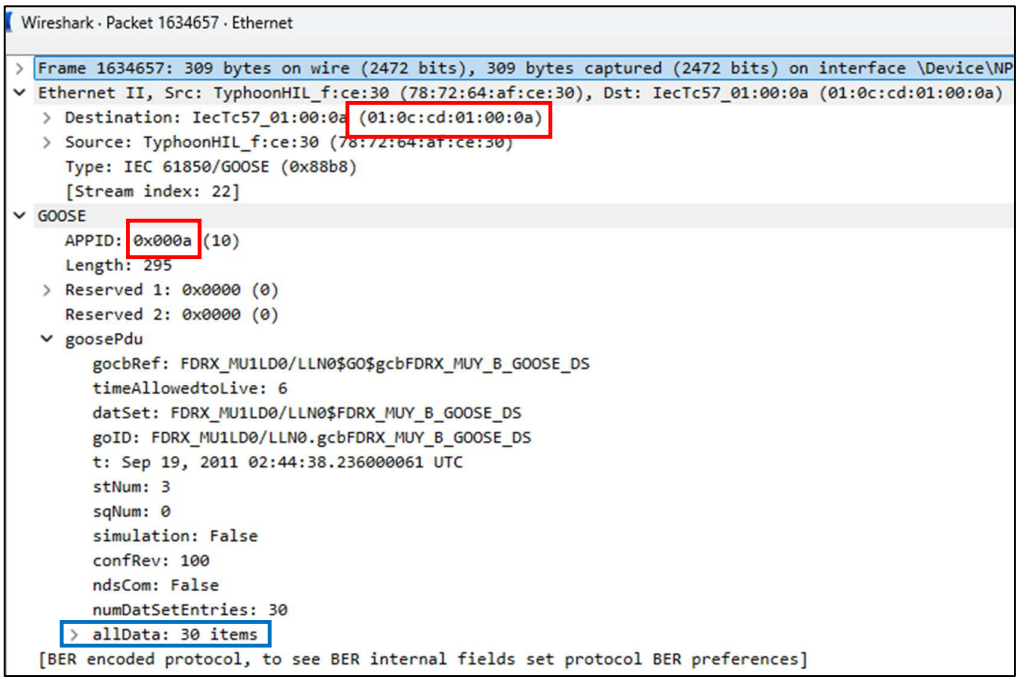


Figure 9 - Wireshark Screenshot of the structure of a GOOSE Message

1.3. Sampled Values Communication Design

1.3.1. IEC61850-9-2LE Sampled Values

As discussed in my first quarterly report, the IEC61850-9-2LE implementation guide was successful at making it easier for the industry to adopt the use of IEC61850 sampled values. This is evident when using ABB's protection and control IED management tool PCM600.

PCM600 makes configuring 61850-9-2LE datasets and control blocks incredibly easy. Simply adding the "SVSENDER" function block to the application configuration of a IEC61850 native IED would automatically create a dataset and control block. The only task required of the user is to edit the control block properties, identify the which devices are subscribers, and map the value to the sampled values receive function block. See below figures 10-13 which illustrating the simple process of configuring IEC61850-9-2LE Sampled values using ABBs PCM600.

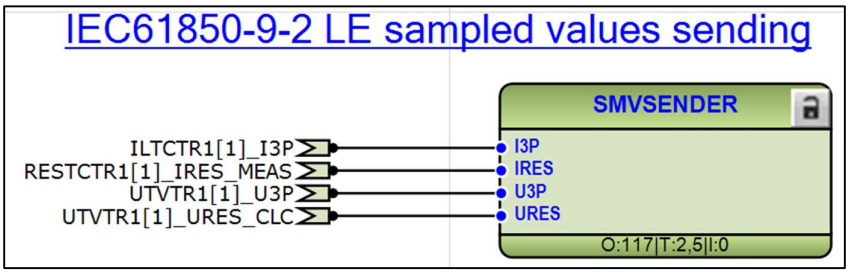


Figure 10 - Application Configuration for 9-2LE Sampled Values

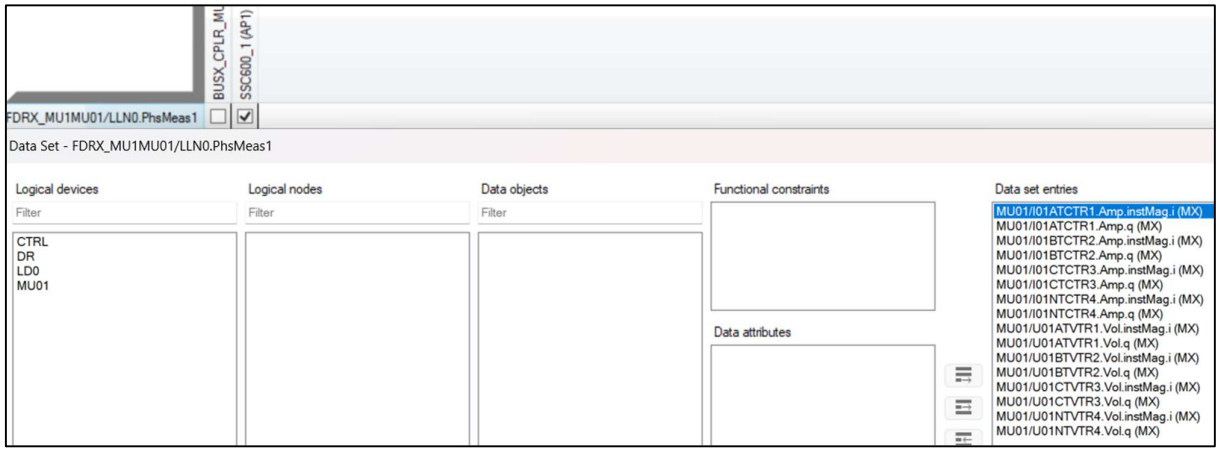


Figure 11 – SV control block mapping and automatically created 9-2LE SV datasets

Communication	
Access Point	LD0
App ID	4001
MAC Address	**01-0C-CD-04-00-08**
Subnetwork	WA1
VLAN ID	000
VLAN Priority	4
Data Flow	
Subscribers	(Collection)
General	
Config Revision	1
Data Set	PhsMeas1
Description	
Multicast	Yes
Name	MSVCB01
Number of ASDUs	1
Sample Rate	80
Sampled Value ID	**FDRX_MU1_SV**

Figure 12 - Sampled Value Control Block Properties

SSC600 - Signal Matrix

		- BUSX_CPLR_MU1	BUSX_CPLR_MU1	- BUSX_SECT_MU1	BUSX_SECT_MU1	- FDRX_MU1	FDRX_MU1	- FDRX_MU1_RMT	FDRX_MU1_RMT	- TFRX_NEUT_MU1	TFRX_NEUT_MU1	- TFRX_PRIM_MU1	TFRX_PRIM_MU1	- TFRX_SEC_MU1	TFRX_SEC_MU1
			BUSX_CPLR_MU1MU01		MU01		FDRX_MU1MU01		FDRX_MU1_RMTMU01		TFRX_NEUT_MU1 MU01		TFRX_PRIM_MU1 MU01		TFRX_SEC_MU1MU01
- BUSX_C_SV;SVRECEIVE_LE:9															
BUSX_C_SV;SVRECEIVE_LE:9	IN		X												
- BUSX_S_SV;SVRECEIVE_LE:8															
BUSX_S_SV;SVRECEIVE_LE:8	IN				X										
- FDRX_LCL_SV;SVRECEIVE_LE:1															
FDRX_LCL_SV;SVRECEIVE_LE:1	IN						X								
- FDRX_RMT_SV;SVRECEIVE_LE:2															
FDRX_RMT_SV;SVRECEIVE_LE:2	IN								X						
- TFRX_NEUT_SV;SVRECEIVE_LE:4															
TFRX_NEUT_SV;SVRECEIVE_LE:4	IN										X				
- TFRX_PRIM_SV;SVRECEIVE_LE:3															
TFRX_PRIM_SV;SVRECEIVE_LE:3	IN												X		
- TFRX_SEC_SV;SVRECEIVE_LE:7															
TFRX_SEC_SV;SVRECEIVE_LE:7	IN														X

Figure 13 - Example of Sampled Value Signal Mapping for SSC600

1.3.2. IEC61869-9 Sampled Values

The ease of implementing “9-2LE” sampled values has led to it currently being the most used form of sampled values. However, I believe that IEC61869-9 defined sampled values is more advantageous and will eventually become the primary protocol for sampled value communication.

Currently, IEC61869-9 is not as commonly implemented due to a few factors, including a lack of merging unit products on the market being capable of sending IEC61869-9 SMV, less experience within the industry in using it, and a lack of tools that are compatible to easily configure it. However, it is possible to configure and use IEC61869-9 with ABB’s SSC600/SW product, and I have been able to successfully do so.

When referring to IEC61869-9 communications profiles, there are many different variations that can be used, providing users with excellent flexibility. Detailed information can be found in the IEC61869-9 standard, especially in section 6.903.2.

I will use the “F4800S26I3U” variant as an example to explain the fundamental concepts of the standard. The “F4800” refers to the sampling rate, which represents frequency of the measurement of the current and voltage measurements. The sampling rate is expressed in samples per seconds, meaning this variant includes 4800 current and voltage measurements every second. Next, the “S2” identifies that there will be 2 ASDU’s, or current\voltage samples per message. Finally, the “6I3U” identifies that the dataset will consist of 6 current and 3 voltage measurements.

To explain the sample rate and ASDU’s/messages further, I will compare the F4800S26I3U with another variant. First, using the F4800S2 variant as an example, there would be 4800 samples of the current/voltage measurements per second. And because there are 2x ASDU’s (samples per message), there will be only 2400 messages per second. In comparison, F4000S14I4U (IEC61850-9-2LE at 50Hz) has a sample rate of 4000 samples\measurements per second, and because there is only 1 ASDU, there would also be 4000 messages per second.

While IEC61850-9-2LE sampled values are easy to configure in PCM600, unfortunately it is not as easy to IEC61869-9 in the current version of the software. However, I have been able to successfully configure IEC61869-9 sampled values in ABB devices by creating a customer .cid file and importing it into PCM600. There might be software available which could be useful in configuring IEC61869-9 .cid files, however I do not have experience with them yet. When downloading the IEC61869-9 standard, a template .cid file is included. This can be used as a starting point for creating a desired variant.

Figures 14 to 17 are screenshots taken from my successful attempt to create an F4800S26I3U dataset. I did this by modifying the example .cid file provided with the IEC61869-9 standard using the notepad application. Figure 14 shows some of the main modifications I made to create the 6I3U dataset, and then turn this into a full F4800S26I3U control block. Figure 15 then shows how the visual representation of the 6I3U dataset after imported to PCM600. Unfortunately, the IEC 61850 Configuration tool in PCM600 does not currently allow users create 61869-9 datasets, but it does allow for them to be visualised after they have been successfully imported.

```
<DataSet name="DS_Example6I3U">
        <FCDA ldInst="MU01" prefix="I01A" lnClass="TCTR" lnInst="11" doName="AmpSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="I01A" lnClass="TCTR" lnInst="11" doName="AmpSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="I01B" lnClass="TCTR" lnInst="12" doName="AmpSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="I01B" lnClass="TCTR" lnInst="12" doName="AmpSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="I01C" lnClass="TCTR" lnInst="13" doName="AmpSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="I01C" lnClass="TCTR" lnInst="13" doName="AmpSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="I02A" lnClass="TCTR" lnInst="21" doName="AmpSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="I02A" lnClass="TCTR" lnInst="21" doName="AmpSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="I02B" lnClass="TCTR" lnInst="22" doName="AmpSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="I02B" lnClass="TCTR" lnInst="22" doName="AmpSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="I02C" lnClass="TCTR" lnInst="23" doName="AmpSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="I02C" lnClass="TCTR" lnInst="23" doName="AmpSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="U01A" lnClass="TVTR" lnInst="11" doName="VolSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="U01A" lnClass="TVTR" lnInst="11" doName="VolSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="U01B" lnClass="TVTR" lnInst="12" doName="VolSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="U01B" lnClass="TVTR" lnInst="12" doName="VolSv" daName="q" fc="MX" />
        <FCDA ldInst="MU01" prefix="U01C" lnClass="TVTR" lnInst="13" doName="VolSv" daName="instMag.i" fc="MX" />
        <FCDA ldInst="MU01" prefix="U01C" lnClass="TVTR" lnInst="13" doName="VolSv" daName="q" fc="MX" />
</DataSet>
<SampledValueControl name="Example91869DS" smvID="Example91869DS" multicast="true" datSet="DS_Example6I3U" smpRate="4800" nofASDU="2" smpMod="SmpPerSec" confRev="1">
        <SmvOpts />
```

Figure 14 - Key components of a F4800S26I3U sampled value. cid configuration

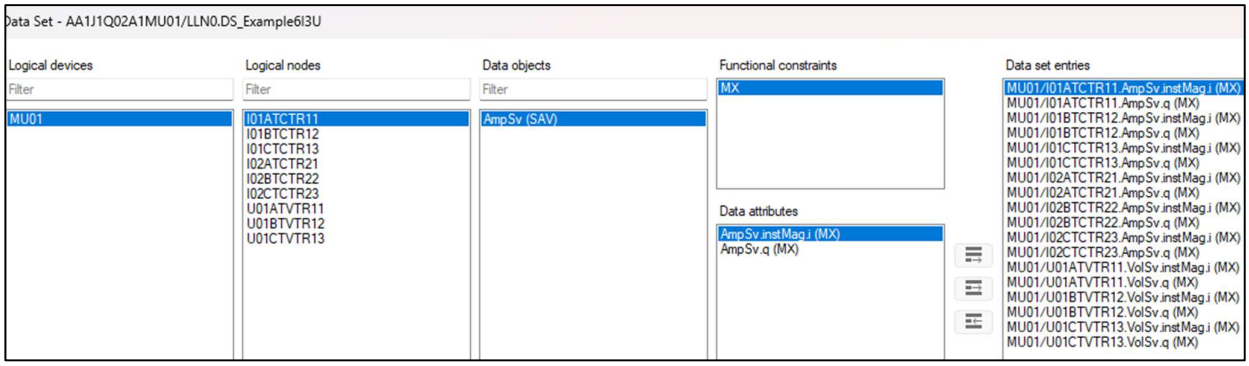


Figure 15 - PCM600 visualisation of 6I3U dataset

Figure 16 shows how the control block properties can be set in the .cid file, however it is worth noting that some of these properties can still be edited after imported into PCM600, as seen in Figure 17.

```
<SMV ldInst="MU01" cbName="Example91869DS">
        <Address>
                <P type="MAC-Address" xsi:type="tP_MAC-Address">01-0C-CD-04-00-01</P>
                <P type="APPID" xsi:type="tP_APPID">4000</P>
                <P type="VLAN-ID" xsi:type="tP_VLAN-ID">000</P>
                <P type="VLAN-PRIORITY" xsi:type="tP_VLAN-PRIORITY">4</P>
        </Address>
</SMV>
```

Figure 16 - Setting the SMV Control Block Properties in a. cid File

Communication	
Access Point	LD0
App ID	**4000**
MAC Address	**01-0C-CD-04-00-01**
Subnetwork	WA1
VLAN ID	000
VLAN Priority	4
Data Flow	
Subscribers	(Collection)
General	
Config Revision	1
Data Set	DS_Example6I3U
Description	
Multicast	Yes
Name	Example91869DS
Number of ASDUs	2
Sample Rate	4800
Sampled Value ID	**Example91869DS**

Figure 17 – PCM600 visualisation of F4800S2 control block Properties

Otherwise, the only difference when configuring IEC61869-9 from IEC61850-9-2LE in PCM600 is that the outputs of the 61869 SV receive function block needs to be manually connected to current or voltage pre-processing function blocks before they can be used. This is not required for IEC61850-9-2LE because it is a fixed dataset, so this preprocessing can be done automatically in the function block.

1.3.3 Time Synchronization

Time synchronization is one of the most important components of sampled value communication, regardless of whether using IEC61850-9-2LE or IEC61869-9. Time synchronization is essential for the use of sample values to ensure the protection functions can ensure a high-level of accuracy. ABB's SSC600 uses the IEEE 1588 v2 Precision Time Protocol (PTP) for it's time synchronisation of sampled values. More specifically, it uses the IEEE C37.238-2011 Power Profile (preferred) or IEC 61850-9-3 Power Utility Profile.

PTP time synchronisation uses a master-slave system, where all local clocks are synchronised to a single grandmaster clock on the network. The recommended network configuration is to install a dedicated high-quality grand master clock and configure the devices to be its slave and synchronise to it. In the ABB relays, this is done by configuring the PTP priority parameter to a higher setting than the desired grandmaster clock. The SSC600 Engineering manual has an excellent amount of technical information about time synchronisation and PTP.

1.4. Sampled Values Commissioning and Testing

Based on my experience, the most common causes of issues with sampled values communication is time synchronisation, or non-unique MAC Address and AppID. All control blocks sending messages on a process bus (including GOOSE and sampled values) must have a unique MAC Address and AppID, so diagnosing and fixing this issue is typically simple. Meanwhile, time synchronisation can be checked by reviewing the self-monitoring information on the IED's on the network. An example of this can be seen in figure 18, which shows a successfully time-synchronised REX640 IED. The important factors are that the Synch status is "up", the Synch accuracy, and the PTP gm identity matches that of the network's grandmaster clock.

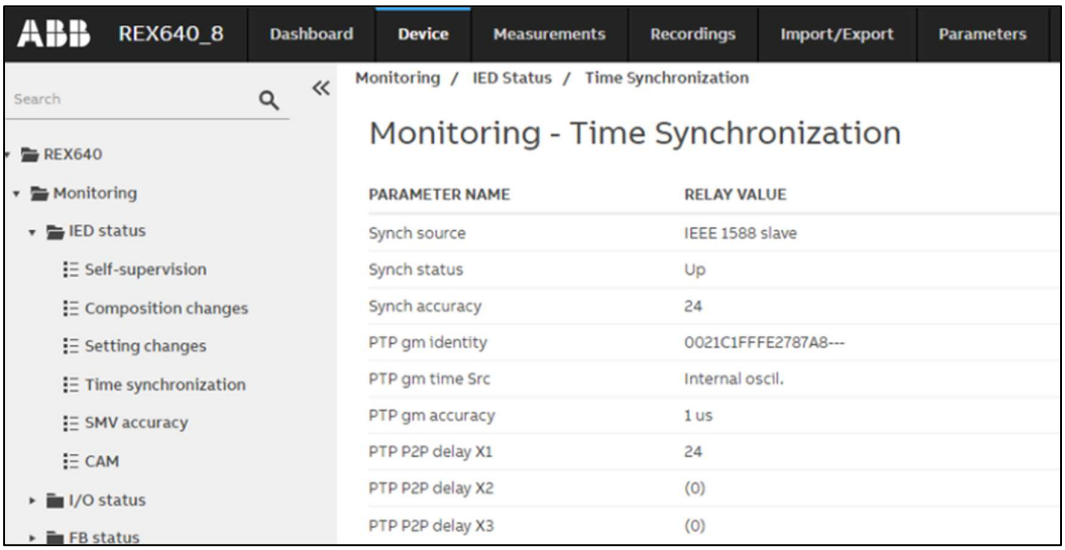
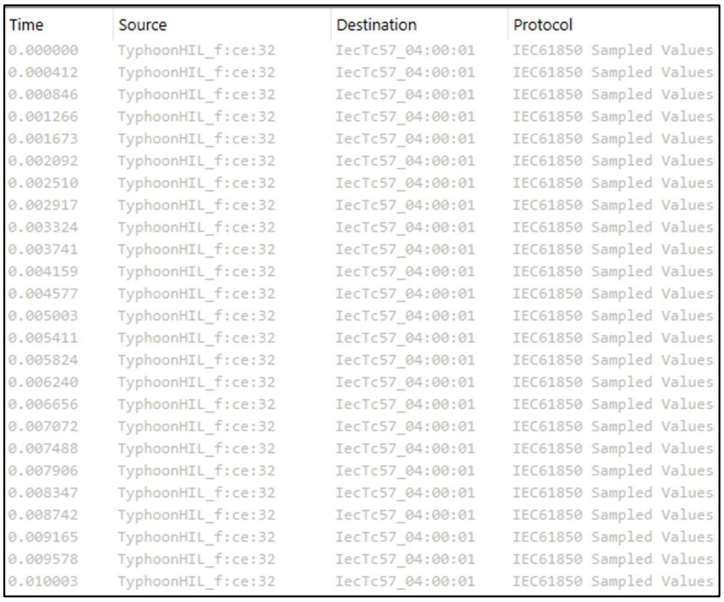


Figure 18 - Example of Time Synchronisation Monitoring

As with GOOSE communication, arguably the most important tool for commissioning and testing sampled values is a network traffic analyser software like Wireshark. See figures 19 and 20 for screenshots taken from Wireshark during the testing of F4800S26I3U IEC61869-9 sampled values. Figure 19 shows each of the individual sampled value messages being published to the process bus, which should be at a rate of 2400 messages per second. This figure included a filter to only include messages regarding these particular sampled values, however, typically the PTP time synchronisation messages can also be seen using Wireshark.



Time	Source	Destination	Protocol
0.000000	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.000412	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.000846	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.001266	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.001673	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.002092	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.002510	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.002917	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.003324	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.003741	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.004159	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.004577	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.005003	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.005411	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.005824	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.006240	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.006656	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.007072	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.007488	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.007906	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.008347	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.008742	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.009165	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.009578	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values
0.010003	TyphoonHIL_f:ce:32	IecTc57_04:00:01	IEC61850 Sampled Values

Figure 19 - Wireshark Screenshot of IEC61869-9 SV over time

Figure 20 shows the internal data of a single sampled value message. This view contains a significant amount of important information useful for diagnosing the sampled value communication. The MAC Address and APPID are in the same position as the GOOSE communication and as highlighted above in Figure 9. Highlighted in red is the key information for diagnosing time synchronisation inside the communication message, as you can see if the sample is time synched, and to which grandmaster clock. Figure 20 visualises how 2x ASDU's work, as it can be clearly seen that the one message has two different ASDU's/samples in it instead of one. Each individual sample is identified using the smpCnt, which counts from 0 to the maximum sample rate to indicate which sample the data is associated with, which would be 4800 in this situation.

The sampled values receive function in the SSC600 has warning and alarming outputs to assist with diagnosing errors or disruptions with the sampled value communication. The warning is triggered if two consecutive samples are not received, in which case the previous values are used during this minor interruption. Further, the alarm is triggered if three consecutive samples are lost. When using IEC61850-9-2LE and IEC61869-9 variants with 1 ASDU, this means that 2 whole messages need to be lost before the alarm is triggered. However, when using IEC61869-9 and two ASDU's, it is important to note that the loss of one message means that two samples will be lost, and therefore the alarm is triggered.

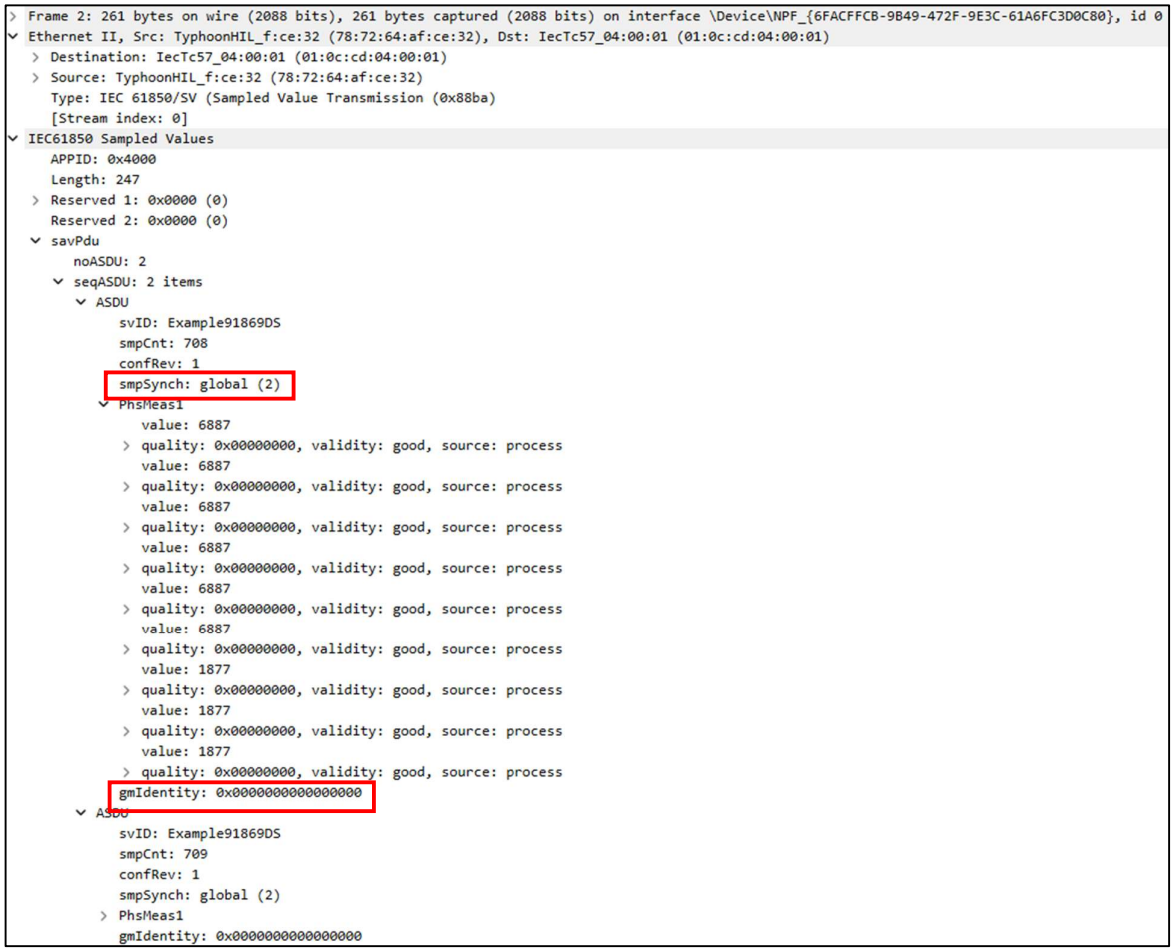


Figure 20 - Wireshark screenshot of a F4800S26I3U data packet

I would like to share a valuable learning experience I had in diagnosing sampled value communication. When performing testing of the F4800S26I3U variant that I created using a Typhoon HIL as the publisher, I encountered an issue where the SV receive alarm was intermittently occurring. Initially, I just simply recorded the traffic using Wireshark and analysed it, however, the issue was not obvious. In fact, it was like looking for a needle in a haystack because there were 2400 messages posted per second and no correlation between the timestamp in the Wireshark recording and the PTP time which the devices are using. To assist with this problem solving, I mapped the SV receive alarm output to a GOOSE dataset, so that a burst of GOOSE messages would be sent when the SV receive alarm is triggered. Knowing that there is a very small-time delay associated with GOOSE messages, I started looking at the sampled value messages from just before the burst of GOOSE messages was sent. This was very effective, and enabled me to identify the issue quite easily, which was that occasionally the sampled value message containing samples 0 and 1 was not being sent by the Typhoon HIL. After discussing this finding with the Typhoon HIL team, they identified that this was a known issue with the current version of the software and was solved in the next version release of the software shortly after.

2. Advantages of IEC61869-9 Sampled Values

As I mentioned above, I believe that IEC61869-9 sampled values have significant benefits over IEC61850-9-2LE. The first benefit I would like to discuss is the ability to choose to use multiple ASDU's. Using multiple ASDU's is useful as it reduces the bandwidth used on the process bus communication network. A large portion of each sampled value message is the "header", or the other required information that isn't the actual current and voltage measurements. This is somewhat demonstrated in Figure 20. However, as discussed, a consideration to be made is that combining multiple samples into one message means that the loss of a message has a bigger impact on protection operation, as multiple samples would be missing if a single message is lost.

Another benefit of IEC61869-9 sampled values is the ability to select sample rates, including more frequent sample rates. For example, if using 9-2LE in a 50Hz network, the sample rate is locked at 4000 samples per second, meanwhile IEC61869-9 is much more flexible, and can be configured for greater sample rates like 4800 or 14400. These greater sampling rates would be quite useful for specific applications like quality metering where greater accuracy is required.

And the final, but likely most valuable benefit of IEC61869-9 is the ability to flexibly configure the datasets of current and voltage measurements. Multiple examples of situations in where this would be very useful immediately come to mind from my experience.

Using a single-phase bus VT as an example, instead of needing a 9-2LE dataset that includes 4 currents and 4 voltages, bandwidth could be saved by simplifying the dataset to the 1 voltage measurement required.

Considering a typical 2-winding power transformer as another example, if using 9-2LE, three merging units publishing three seperate sets of 9-2LE sampled values would be required. This is because you would typically need to send the data from the primary side CT, secondary side CT, and the neutral CT. However, using IEC61869-9, it is possible to communicate all these measurements in a single dataset. Therefore, this would reduce the required amount of merging units from three to one (assuming the product also meets IO and functionality requirements).

Another example could be to use multiple CT cores to ensure ideal protection zone overlap. When using 9-2LE, the data from only one CT core can be included per dataset, so protection schemes that would ideally overlap (e.g. Feeder protection and bus protection), would typically have to share the same CT core. Meanwhile IEC61869-9 would allow for multiple CT cores to be included in the same dataset, enabling for the protection schemes to be ideally overlapped. Similarly, this would also apply for scenarios where different CT cores would be ideal for different functions due to their specifications (e.g. protection core and a metering core).

Some of these advantages will be discussed further in section 3.

3. CPC/VPC Design Architecture

Based on my experiences, I have developed high-level example architectures for the design of CPC and VPC systems. These are demonstrated using a simplified “zone substation” configuration and a single protection system.

3.1 Example Simple solution (CPC, 9-2LE)

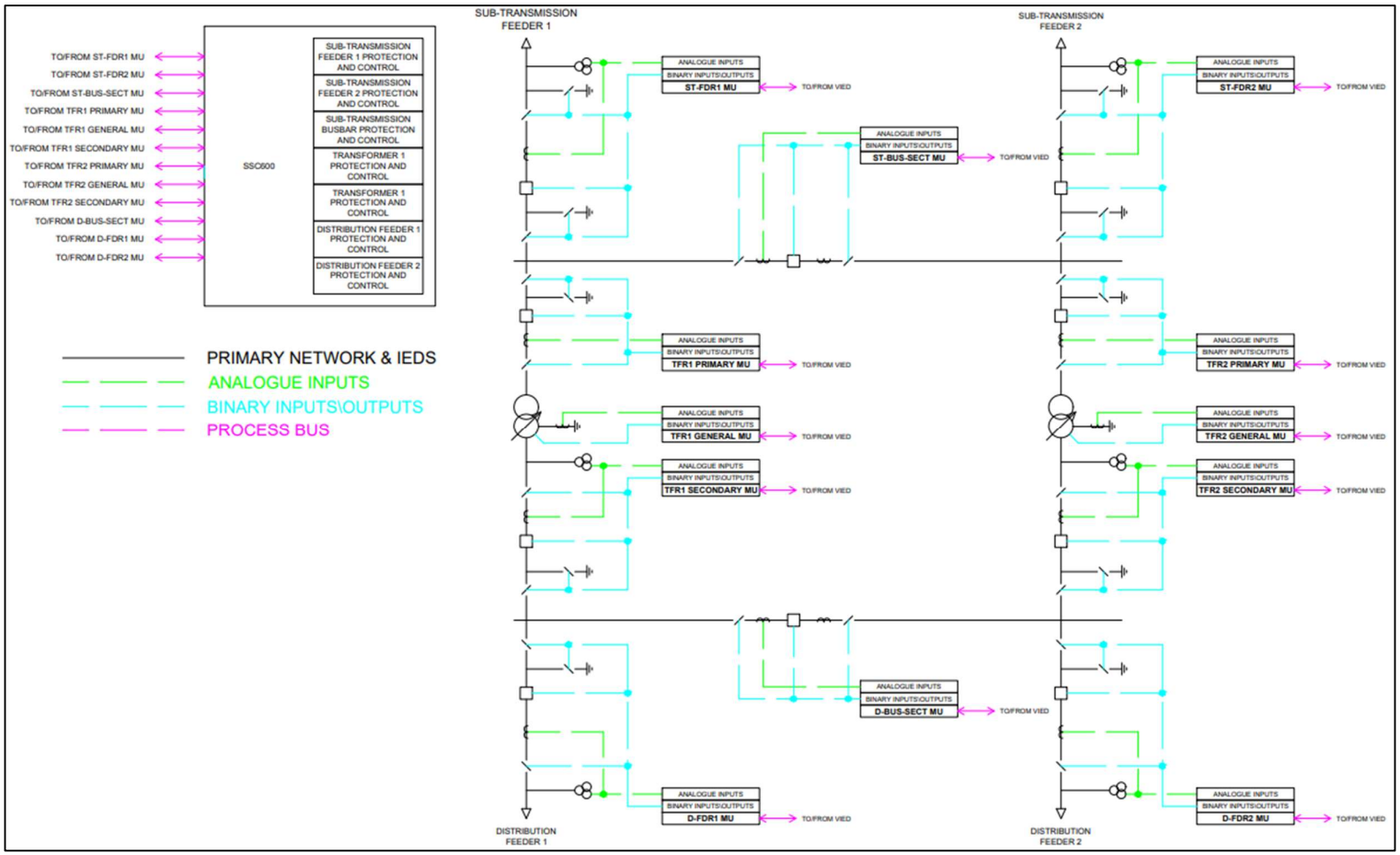


Figure 21 - Example of a Simple solution based around Centralised PAC and 9-2LE SV

3.2 Example Advanced solution (VPC, 9-9, modular MU's)

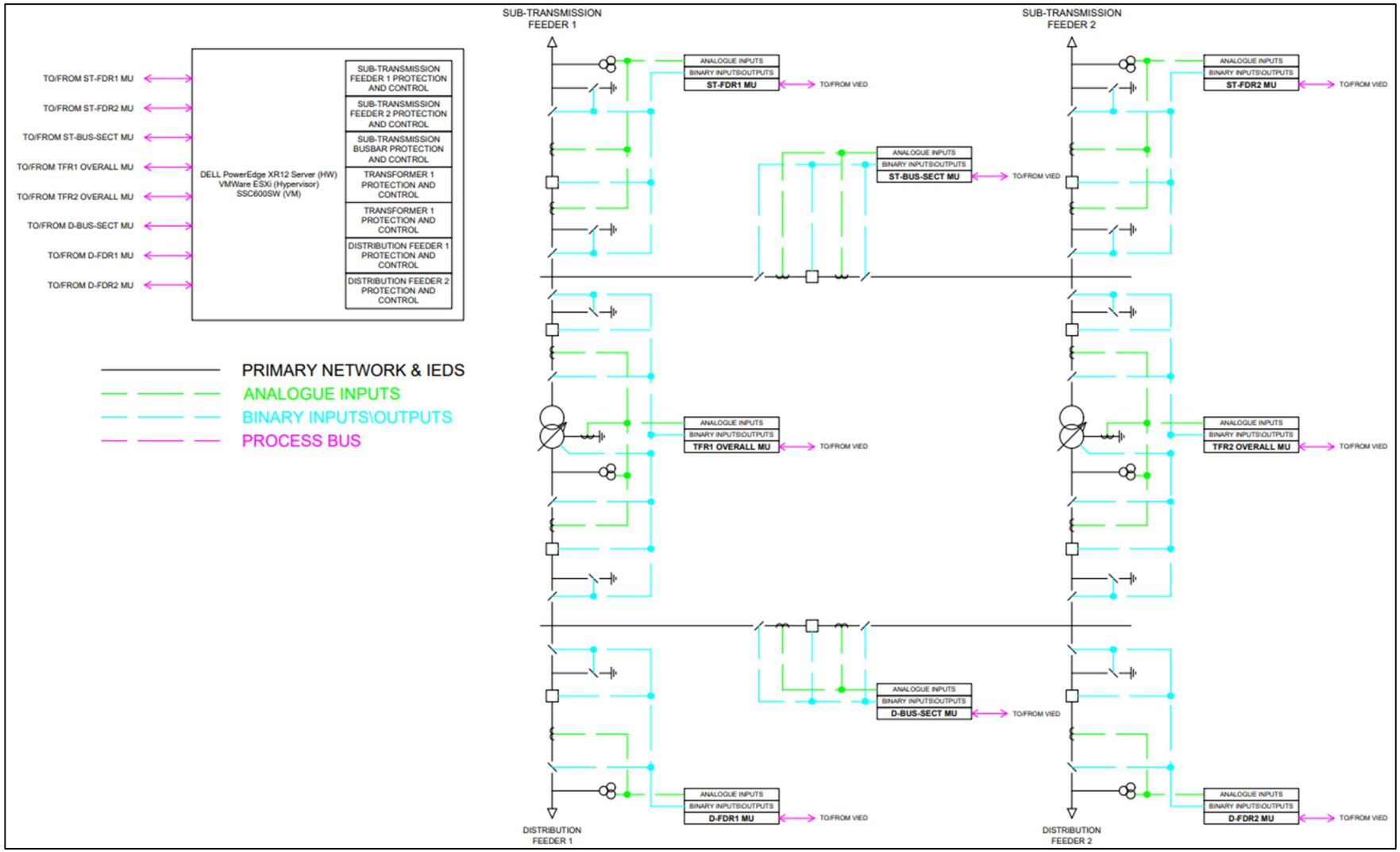


Figure 22 - Example of a more complex solution using Virtualised PAC and IEC61869-9 SV

3.3 Discussion

Substation Configuration and Scalability

For simplicity, both example solutions have been shown on a simplified zone-substation configuration. The simplified substation configuration includes two sub-transmission feeders, a sub-transmission busbar including a bus sectionaliser bay, two power transformer including primary and secondary side bays, a distribution busbar with a bus sectionaliser bay, and two distribution feeders. One of the key benefits to centralised and virtualised PAC systems is their scalability, and these example designs can be used to demonstrate that scalability. While a simple substation configuration has been shown, the same principles would apply to larger or more complex substation applications. For example, if another distribution feeder is to be added to the substation configuration, the only modifications required to be made on the PAC system would be to install a new merging unit wired to the new primary plant, a communication connection from the new MU to the SSC600, and an updated configuration uploaded to the SSC600. No additional hardware modifications would be required to integrate with other schemes like bus protection, CBF, underfrequency, SCADA etc., because all these integrations are made inside the software space.

Physical Design Factors

There are some additional benefits of CPC and VPC systems that were unable to be displayed in Figures 21 and 22. The first of which is related to the location of the merging units and the hardware wiring required in the substation. Because merging units aren't necessarily required to perform protection and control functions, they can sometimes be much more compact and robust than typical multi-function protection IED's. This, along with interfacing between different substation schemes being done via communication and software enables the ability to install merging units at the primary plant/switchgear instead of in a remote building/room. This provides multiple benefits, including a reduction in traditional copper wiring hardware, and reducing the amount of hardware to be installed in control buildings. By installing the merging unit close to the bay's primary plant, much of the copper wiring required is significantly reduced to the short distance between the equipment and the nearby MU. Therefore, the wiring back into the control room would be significantly reduced and simplified, with most of the information being inside the communication cabling. This would be much more cost-effective than running the long lengths of multiple copper control cables which is typically required in traditional systems. This not only saves on material costs of the cable, but also labour costs, and civil construction of conduits or ducts.

Additionally, the amount of hardware like protection and control panels inside the control building is significantly reduced. This is because there would no longer be a need to have the many panels required to house the numerous individual protection relays and control equipment required by traditional PAC systems. This is a significant advantage, especially as utilities try to reduce the footprint of their substations while introducing more functionalities.

Protection Systems and Redundancy

The example solutions only show a single protection system for simplicity. However, Australian utilities would typically require a second duplicated system to meet N-1 redundancy requirements. Something I found interesting is that some international utilities and companies in other industries address redundancy requirements by implementing backup protection schemes inside the merging units. While this is a cost-effective solution, I do not believe this would meet the requirements of the Australian industry. This is because if the merging unit hardware fails for example, both the centralised/virtualised PAC system, and the backup functionality inside the merging unit would be impacted, and all protection and control functionality for that part of the network would be lost.

Therefore, I believe the ideal solution for the Australian industry would be to have completely duplicated merging units and centralised/virtualised PAC unit hardware. I believe this is necessary to ensure that the failure of 1 device would not result in the complete loss of protection and control of a part of the network.

Further, products associated with VPC, like the SEAPATH hypervisor, are investigating the implementation of functionalities like clustering which would further improve redundancy of these systems

Process Bus & Station Bus Communication systems

A significant factor in Centralized/virtualized PAC systems is the design of the communication system. The most strongly recommended communication system protocol/topology for process bus communication is the Parallel Redundancy Protocol (PRP). While not the most cost-effective option, PRP is strongly recommended for power system protection applications due to its extremely high availability and reliability. A positive factor for the PRP Process Bus design is that theoretically the same PRP network design topology that would be applicable for a single system would also be applicable for completely duplicated/redundant applications.

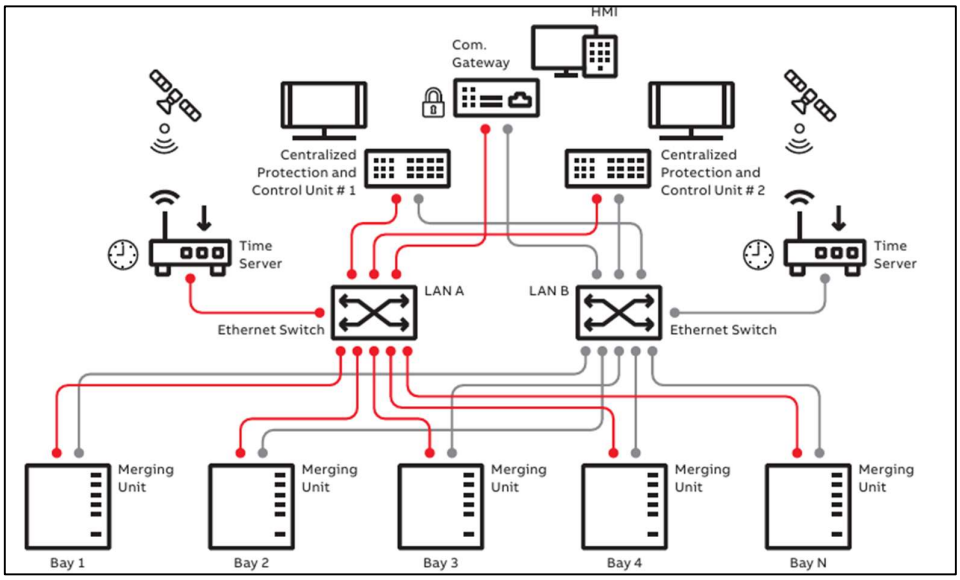


Figure 23 - Example PRP Process Bus design. Including redundant CPC IED, but not redundant MU's

Another key component to the communication system design of the process bus is the inclusion of a dedicated IEEE 1588 PTP Grandmaster clock. A second dedicated grandmaster clock other existing devices on the network like merging units could be configured as back-up master clocks to take over as grandmaster clock in the event of the failure of the main dedicated grandmaster.

An additional factor in the communication system design is the station bus, which is responsible for communicating control data with the SCADA system. ABB's SSC600 enables station bus communication to be either combined or separate to the process bus. Assuming a combined approach, the only additional communication architecture required would be a connection to a gateway to the SCADA control center. The SSC600 also enables station bus communication using various protocols including MMS, DNP3 and IEC 60870-5-104.

Discussion of Example Simple Solution

The example of a simple solution shown in figure 21 depicts a solution that uses Centralised Protection and Control and uses the IEC61850-9-2LE for sampled value communication. I have proposed this solution as I believe overall it would be the easiest transition from current traditional PAC systems, and is generally ready for implementation today given the current market of products available. Using ABB products as an example, I think the REX615W is an ideal product for the merging unit, and the SSC600 (Hardware) as the centralised protection unit. I think the REX615W is a good option for use as a merging unit due to the flexibility of adding or removing I/O and other cards as required to suit the specific practical application, while still using the same fundamental device. Further, while the REX615 is an effective

protection relay, it is also possible to purchase the device at a lower price by not including the protection functionality from the licence since, which is possible as it will be operating only as a merging unit.

I believe that using the SSC600 hardware version would be easier for utilities and technical staff to adopt because of the closer similarity to traditional protection and control hardware than virtualised solutions. Similarly, I believe that using the 9-2LE sampled value communication would be easier for the industry to adopt earlier.

While I perceive this kind of solution to be easiest to adopt, there are some limitations and areas for improvement with the design. The first of which is the inability to overlap protection schemes ideally due to the 9-2LE. Using the CT on a transmission feeder bay as an example, ideally the bus protection and feeder protection schemes would overlap by using separate protection cores. However, due to only one set of CT current measurements being able to be transmitted per merging unit using 9-2LE sampled values, these protection schemes use the same CT core and therefore do not overlap like they ideally should.

Another area where the design could be improved can be seen in the transformer bay, where three merging units are required per transformer and per system. This is an increase from traditional systems, where typically 1 protection relay is required per system and per transformer. This limitation is driven by the use of the 9-2LE standard, where because only one set of CT measurements can be communicated per MU, three merging units are required to handle the primary side CT, secondary side CT, and neutral CT.

Further, another area for improvement is the current selection of merging units. Personally, I think that the ideal merging unit product would be a more modular device where there is a consistent main power/processing unit, and the flexible selection of additional cards that couple be added as required, such as additional IO. While the REX615 and similar relays do allow some customisation through the selection of cards in the relay, I believe an ideal device would be a dedicated merging unit product that has improved flexibility and scalability.

Discussion of Example Advanced Solution

The example advanced solution shown in Figure 22 is similar to the simple solution, however with the key differences of using virtualised PAC and IEC61869-9 sampled values. These small changes create key advantages over the simple solution, however, also require some additional considerations for implementation.

First, the use of a virtualised PAC system creates significant advantages over centralised PAC systems. These advantages include improved scalability, flexibility, and efficiency of hardware. Scalability and efficiency of hardware are provided by the ability to use multiple hypervisors on the one hardware, enabling for multiple VM’s to be ran on the same piece of hardware, including multiple instances of the SSC600SW Virtualised PAC software or other important

software. Also, flexibility is provided by giving companies more control over the hardware being used in their networks. However, a challenge with using virtualised PAC is that it will probably look and feel quite different from traditional PAC hardware which may make adoption harder for operations staff.

The use of IEC61869-9 has significant advantages over IEC61850-9-2LE. This was discussed earlier in this report in section 2 and can be visually seen when comparing Figures 21 and 22. However, the use of IEC61869-9 does introduce some challenges for implementation. The key challenge is that there are significantly fewer merging units in the market which are capable of transmitting IEC61869-9 sampled values. And another limitation is that there is significantly less experience and tools to assist with the configuration of this communication.

4. What are some other advantages to Digital/Virtual substations?

As I have mentioned, I strongly believe that virtualised and centralised PAC systems have significant advantages over traditional PAC systems in many aspects. However, so far, I have been focussing on the technical benefits regarding the protection and control system itself. Throughout my time at ABB, I have also encountered various other advantages associated with this type of technology that I would like to share. These additional advantages beyond just protection and control make this type of technology even more valuable for utilities and a more feasible solution for implementation.

4.1 ABB's Fleet Management and AI Fault Prediction Products

One of the most exciting examples of this is ABB's Fleet Management and AI fault prediction products. These products have only been released very recently from ABB and are designed to interface directly with the SSC600/SW product. The products receive data from the SSC600 like disturbance recordings, fault records and anomaly detections to record and analyse operational data about network assets. This data is both available for human analysis by technical experts through the fleet management product and can also be used by the AI Fault prediction product to analyse and predict faults.

The AI fault predictions is, able to predict faults than are caused by gradual degradation of equipment by monitoring abnormalities and minor disturbances recorded on the network. This product has been successfully trialled by international utilities with successful results. A particular pilot project that was performed with a utility company yielded results of being able to predict 67% of all faults, including successfully predicting 90% of predictable faults, and returning no false positives.

The ability to leverage this new protection and control technology to enable other value-adding features like fleet (asset) management and fault prediction is a huge bonus which can make centralised/virtualised PAC even more of a valuable solution for utilities.

4.2 Remotely Located Protection and Control Concept

Another advantage to using this kind of technology is the ability to continue developing to even more creative system architectures. In particular, an exciting concept that has become more feasible because of the developments in this technology is remotely located protection and control. By transitioning protection and control data from analogue signals over copper cabling to communication systems, it is now more feasible to send protection and control data over much larger distances in real time. This is already evident through the ability to perform line differential protection via IEC61850 communication, but there is possibly an opportunity to take this concept even further. Theoretically, there may be an opportunity to investigate taking this to the next level by having the protection and control functionality located in a location that is remote to the substation. This could have huge benefits like avoiding the need for technicians to travel as much, both saving labour costs and improving safety by avoiding travel risks. This kind of solution is definitely not simple, and would definitely require significant investment, especially for the likely requirement for dedicated communication infrastructure. However, I think creative solutions like this are becoming more feasible when using digital substation solutions like centralised/virtualised protection and control.

5. Projects

Throughout this quarter I continued to be involved in various customer projects where centralised and virtualised protection and control was being trialled and implemented. While I cannot provide certain specific details of these projects, I will summarise the projects, my involvement, and my key learnings for some of these projects.

5.1 Project 1: VPC Proof of Concept

This project is a continuation of “Project 1” discussed in section 4.1 of my first quarterly report. For context, this is a proof-of-concept project with a transmission utility with the aim of demonstrating the effectiveness of a SSC600SW Virtualised PAC system at meeting their typical protection and control requirements. In quarterly report 1/phase 1 of the project, this was demonstrated using a protection panel including a Typhoon HIL simulator, two physical merging units (SMU615 & REX640), and two instances of SSC600SW installed on separate platforms consisting of supported hardware and hypervisor.

In phase 1, the SSC600SW and Typhoon HIL were successfully configured to suit a specific and unique substation topology. However, my understanding is that this unique and complex topology is no longer used for the construction of new substations. Instead, the utility utilises what I consider to be a more typical transmission substation topology for all of their new substation builds. The aim of phase 2 of the project was to now simulate this different and more common substation topology. Further, the scope of the protection and control functionality in phase 1 was limited for simplicity during the early stages, whereas phase 2 was aimed to deliver as close to the utility's technical specifications for protection and control requirements as possible. This saw the protection and control functionality requirements increase significantly to cover a typical complete substation application.

My role on this project was to provide as much support as possible, especially regarding forming a detailed scope document that aligns with the utility's technical specifications and assisting with the configuration of the PAC system. This proved to be an excellent opportunity for me to continue learning about the application of VPC, while practically applying my learnings by designing and configuring a virtualised protection and control system.

In addition to gaining practical experience in applying centralised and virtualised PAC systems, there were some key learnings about centralised/virtualised protection and control I would like to share. Firstly, this project was an excellent demonstration of the flexibility of CPC/VPC systems. The same hardware setup that was used in phase 1 was able to be directly used with almost no modifications for the phase 2 project, even though there was a completely different substation topology and type of functionality required. The only hardware requirement that needed to be considered was increasing/modifying the IO capacity of the merging units to suit the proposed substation's requirements. This is something that I have been discussing in my reports, and this situation was an excellent demonstration of this benefit.

Additionally, the benefits for using templated designs was also realised in this project. As I will discuss later, I developed a template design for CPC/VPC systems, and I found implementing this and modifying to meet the particular situation's requirements to be very efficient. This was thanks to the flexibility of software-based protection and control, which makes it incredibly easy to modify functionality as required. Being able to efficiently modify the software configuration to change functionality without any hardware modifications is a huge benefit for this type of technology that was demonstrated in this project.

And finally, the scalability of CPC/VPC was another key advantage demonstrated by this project. Even though there were only two instances of each bay, it became evident how easy it is to scale the use of this technology when implementing in larger and more complex substations. For example, after creating the design for the first feeder, it is easy to copy it for another second feeder, with minimal additional work required. Therefore, it is obvious that for larger and more complex substations, this technology would make it easy and efficient to scale the substation protection and control design up accordingly.

5.2 Project 2: RTE VIP'R Project

This project is a continuation of "Project 2" discussed in section 4.2 of my first quarterly report. For context, this is a pilot project with French Transmission utility RTE which aims to investigate the technical feasibility and capabilities of implementing virtualised protection and control to meet their requirements. A highlight of this project is the significant focus on the R&D development of the interfacing between the hypervisor and protection VM (SSC600SW). In particular, this project is focussing on the development of the SSC600SW's ability to effectively operate on the SEAPATH hypervisor, which is currently not tested/supported.

My involvement in this project was to provide technical support where possible on the OT (protection and control) topics, and to facilitate and learn from discussions and work being done on the IT components. This was an excellent opportunity, enabling me to develop my knowledge and gain experience with both important aspects of this technology.

This project showed me the importance of the convergence between IT and OT in digitalisation projects like this. RTE sees this as an incredibly important component of the VIP'R project, and has placed a significant emphasis on ensuring that this union of IT and OT exists within this project and their company. I found this highly noticeable through their team consisting of people with strong skillsets in both areas, processes that enable collaboration, and a culture that encourages partnership between the IT and OT worlds.

Personally, one of the most valuable benefits from my involvement in the project was attending an in-person workshop with all the key stakeholders. This workshop included technical experts from RTE, the ABB team, and other third parties, and facilitated very valuable collaboration and outcomes. I found it extremely promising to see such positive mutual collaboration between leaders in the utility industry and the company developing the technology.

RTE not only has a high level of power system expertise but also has an excellent level of IT expertise. I personally do not believe it is common for utilities to have this level of IT expertise or resources having this much involvement in R&D projects like this. Therefore, I see this project as being very valuable for the rest of the industry, as it is promising to know that IT experts with the perspective of the utility are also so heavily involved in the research and development of the technology.

Due to my lack of IT expertise and experience, I sometimes found it challenging to keep up with all of the technical IT topics being discussed. However, the key learning from these discussions is that these kinds of development activities are occurring to ensure that the products going to the market are as effective as possible for all users. A concern that I had at one stage of the project was that utilities and companies that do not have this level of IT resources and expertise might struggle with this technology. However, I learned that this is definitely not the case, as while the research and development requires such level of expertise, the released products will be provided with prescriptive documentation and support that will enable all utilities to adopt the technology.

5.3 Project 3: Template Configurations and Typhoon HIL Simulations

A non-customer-related project that I also worked on was to develop template designs and configurations for CPC/VPC systems. The aim of this was to develop templates that could be used by customers and internal staff to make it easier to design and configure CPC/VPC systems. The methodology I followed was to develop a configuration for a typical substation topology with the most thorough application of protection and control functionality possible. The idea behind this was that this would be easiest to use, as the user would just have to remove any functionality not required and make only minor modifications to suit the particular application. The template configuration included the full configuration of a feeder bay, busbar including a sectionaliser and a bus coupler, and a two-winding transformer with associated switchgear.

After completing a draft of the template configuration, I needed to conduct testing to validate the work done. This aligned well with another task assigned to me, which was to learn how to use the Typhoon HIL simulator and develop documentation to help others use it. This documentation included a user guide, as well as example/template configurations of models to use the Typhoon HIL for power system protection and control testing.

After learning how to use the Typhoon HIL, I was able to successfully develop a suite of simulation models that enabled me to test and validate all of the protection and control functionality included in my template configuration. This included testing control functionality like interlocks, auto-reclose, transformer tap changer, voltage synchronisation and voltage regulation control etc. As well as protection functions like line distance, transformer differential, busbar differential, negative phase sequence, circuit breaker fail etc.

This project provided me an excellent opportunity to improve my detailed protection engineering experience, as well as power system and protection simulation/modelling skills. This project proved how valuable simulation technology can be for testing and validating protection, control, and communication designs, especially when working with new technology like CPC/VPC. I think it would be very valuable for utilities implementing centralised/virtualised PAC to have simulation devices like Typhoon HIL or RTDS. They enable the testing and validation of protection schemes and configurations in-house before implementation. And they would also be very valuable for facilitating training and development, which would be essential for any utility transitioning from traditional protection and control to new technology like CPC/VPC.

6. Placement 1 Summary

As I finish my 6-month placement with ABB Finland, I would like to reflect on and summarise my overall experience of this placement. Overall, I have thoroughly enjoyed the opportunity to live in Finland and work for ABB for 6 months and I am very grateful for the amazing opportunity.

Finland (and the other Nordic countries) are beautiful, full of lovely people, and have an excellent standard of living. From midnight sun in summer to orange leaves in autumn and snow in winter, I really enjoyed watching this beautiful country change over my 6 months there. The Finnish language is incredibly challenging to learn, however communication at work and in public was very easy as the vast majority of Finns all speak English fluently. Outside of work, I was able to have many unique experiences with some highlights being Finnish midsummer festivities, Finnish sauna culture, hiking through forests, watching an international basketball tournament, seeing the northern lights, living in a snowy town, and visiting nearby countries like Sweden and Norway.

The working experience that I was provided at ABB was excellent and something I am incredibly grateful for. ABB enabled me to achieve all of my goals and more thanks to the opportunities I was provided and the support I received from colleagues. I was not only able to learn about new PAC technology like CPC and VPC, but I was also able to realise significant personal development in technical and professional skills.

During my first weeks I participated in a 2-week-long training program to learn about ABB's digital products like the Relion series and the SSC600. This was an ideal start to my placement as it enabled me to immediately learn the technical fundamentals that underpin digital PAC systems like CPC and VPC. Training programs like this is something that ABB also provides to customers to assist them in understanding how to use ABB's products as well as possible.

Throughout the rest of my placement, I was involved in numerous customer projects where centralised or virtualised protection and control was being investigated, tested and piloted. This was an excellent opportunity to collaborate with many different international utilities to understand their vision of the technology, the advantages and challenges they are experiencing, and how they are implementing it. Overall, it feels like while overall adoption of this technology has not been incredibly fast, there are many utilities who have plans to move to this technology in the future and are actively working towards that goal. Personally, I think that the current pace of adoption is probably due to CPC/VPC being quite different from traditional PAC systems. Therefore, utilities are conducting a significant amount of research, testing, development and training to ensure the transition can be made as effectively as possible. This aligns with my vision for how CPC/VPC could be adopted in the Australian industry, especially due to the recognised importance of effective change management in Australia.

Another highlight from my experience was the opportunity to use the customer testing lab, including access to the Typhoon HIL simulator and products like the SSC600, merging units, and protection relays. Being able to practically use, simulate and test this new technology was

amazing and certainly helped me to learn as much as possible about CPC and VPC systems. It also enabled me to develop technical skills like power system protection, protection testing, and power system modelling and simulation.

And finally, a significant highlight from my time at ABB has been the ability to network and collaborate with so many excellent people. Internally at ABB, there have been so many lovely and talented people that I have enjoyed creating relationships with. And from a CPC/VPC perspective, it has been valuable to be able to create relationships with technical support staff, members of the R&D team, the product managers, the product line management, and others who are involved and important to this technology.

7. Future Works

In the third quarter of my ES Cornwall Memorial Scholarship, I will begin my second placement with RTE International in Lyon, France. I look forward to the opportunity to continue working with Centralised/Virtualised Protection and Control and Digital Substation solutions from a different perspective in the industry.