Monitoring of IEC 61850-Based Fully Digital Substations: Challenges and Solutions

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Abstract

IEC 61850-based digital substations with sampled values (IEC 61850 9-2) support are becoming more attractive and useful worldwide due to their unique features such as flexibility, reduced wiring cost, and technological benefits. These digital substations include various equipment such as merging units, sampled values-based relays, network switches, and time synchronization clocks. Monitoring is a major requirement in utility digital substations to observe the correct operation of equipment/sensors and capture power system events at various sampling resolutions. Utility applications demand monitoring applications such as wide area monitoring using synchrophasors, power quality calculations, fault location estimates, power swing detection and harmonic monitoring. This paper investigates the technical and application requirements, as well as solutions to the challenges related to developing a monitoring system suitable for IEC 61850-based fully digital substations.

Introduction

Major utilities around the world are at various stages of adopting and implementing the IEC 61850 standard. However, most of the focus has been on IEC 61850 Generic Object-Oriented Substation Events (GOOSE) messages and reporting using Manufacturing Message Specification (MMS). As utilities move towards completely digital substations (encompassing digitized currents and voltages, and switchgear statuses and control signals) for protection and control schemes, it is expected that the measurement infrastructure for fault and disturbance recording will change and be based on digitized IEC 61850 sampled values (SVs).

Digital substations require that analog signals from current and voltage instrument transformers (CTs and VTs) be digitized by merging units (MUs), and transmitted over the process bus using Ethernet communication. The process bus is an Ethernet network that links the primary equipment in a substation with various secondary equipment including protection, control, and monitoring equipment. In greenfield digital substations, large-size CTs and VTs can be replaced by non-conventional instrument transformers (NCITs) which directly convert the electrical signals into optical signals.

The IEC 61850 standard was initially released as a standard for 'communication networks and systems in substations' by the International Electrotechnical Commission TC 57 WG 10 in 2003 [1]. Part 9-2 of the IEC 61850 standard [2] defines the service mapping required for the transmission of SVs. However, specific implementation requirements were not defined in the IEC 61850-9-2 standard. The IEC 61850-9-2LE implementation guideline [3] was drafted by the UCA International Users Group to fill this gap by providing a guide that defines the logical devices, dataset and attributes, sampling rates, time synchronization requirements, and message format to be used by MUs in publishing SVs.

MUs typically sample analog measurements from current transformers (CTs) or voltage transformers (VTs), convert these analog quantities to digital signals, and then publish them over Ethernet communication network as Layer 2 IEC 61850-9-2 multicast messages. Sampled values are transmitted using a publisher/subscriber multicast mechanism using two sampling rates. These are 80 and 256 samples per cycle (s/c), respectively. The former is specified for protection applications, while the latter is to be used for measurements-related applications.

Some of the benefits of an IEC 61850-9-2 system include: a decrease in project cost due to the reduction in copper cabling, better system-wide data availability/sharing, and reduced risk of CT saturation. Substation safety is also improved by eliminating concerns associated with open CTs (since electrical signals from the CTs and PTs are digitized).

Technical and Application Challenges

Monitoring devices used in IEC 61850 based digital substations requires multiple features:

- Subscription of IEC 61850 SV and GOOSE data
- Perform mathematical calculations for PQ, harmonics, etc.
- Publish calculated data using IEC 61850
- Perform synchro-phasor calculations and publish the data for wide area monitoring
- Store the fault data and calculated data
- Support network redundancy
- Accurate time synchronization

Implementation of a device/IED capable of handling these features leads to several technical and application challenges, which we will now address.

Subscribing IEC 61850 9-2 sampled value data from multiple merging units

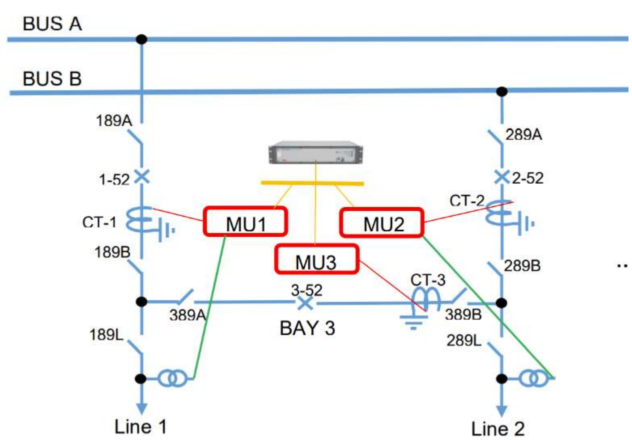

Figure 1: Subcribing data from muliple murging units

IEC 61850 based substations include multiple merging units publishing data. Subscription of data from multiple merging units into a single monitoring device requires a higher processing power and communication bandwidth. It is important to consider/select/develop a suitable platform capable of handling these challenges.

Subscribe multiple IEC 61850 GOOSE messages

Substations include hundreds of status measurements that are monitored using GOOSE messages. The subscription of multiple IEC 61850 GOOSE messages into a single monitoring device (IED) requires a high processing/computation power. Developing an IED capable of monitoring status changes in multiple GOOSE messages simultaneously would be challenging.

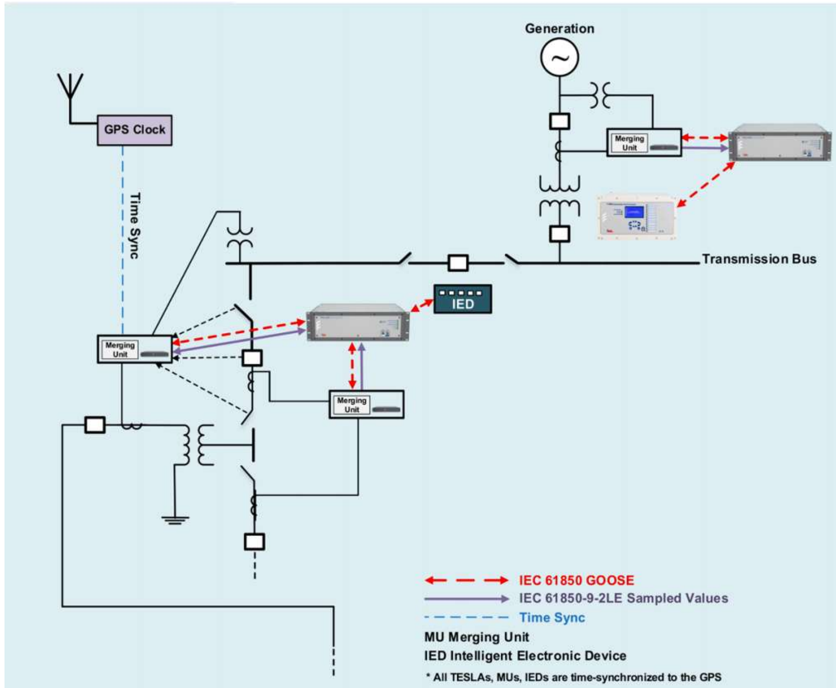

Figure 2: Subscription of GOOSE data

Publishing of IEC 61850 measurements suitable for wide area monitoring

IEC 61850 based wide area monitoring has become useful for digital substation applications. Publishing of IEC 61850 data/measurements requires utilization of IED resources such as processing power and communication bandwidth. In addition, a reasonable latency must be maintained between the publisher and subscriber. When developing a monitoring device/IED, all these factors must be considered.

Monitoring large substations with multiple measurement inputs

The measurement requirement for larger substations can be as high as 200 (or more) current or voltage analog measurements and 500 (or more) status measurements. The sampling rate of current and voltage measurements can be up to 256 s/c sample rate. Developing a device/IED able to provide visibility for the complete substation could be challenging.

Synchrophasor calculations and streaming synchrophasor data

Standard IEC/IEEE synchrophasor calculations [5] require implementation of P and M class filtering for multiple channels, involving significant computational power. In addition, reporting synchrophasor data as per the IEC/IEEE synchrophasor standard requires publishing calculated/measured data at higher reporting rates. In order to support synchrophasor calculations and streaming synchrophasor data, hardware must be selected carefully.

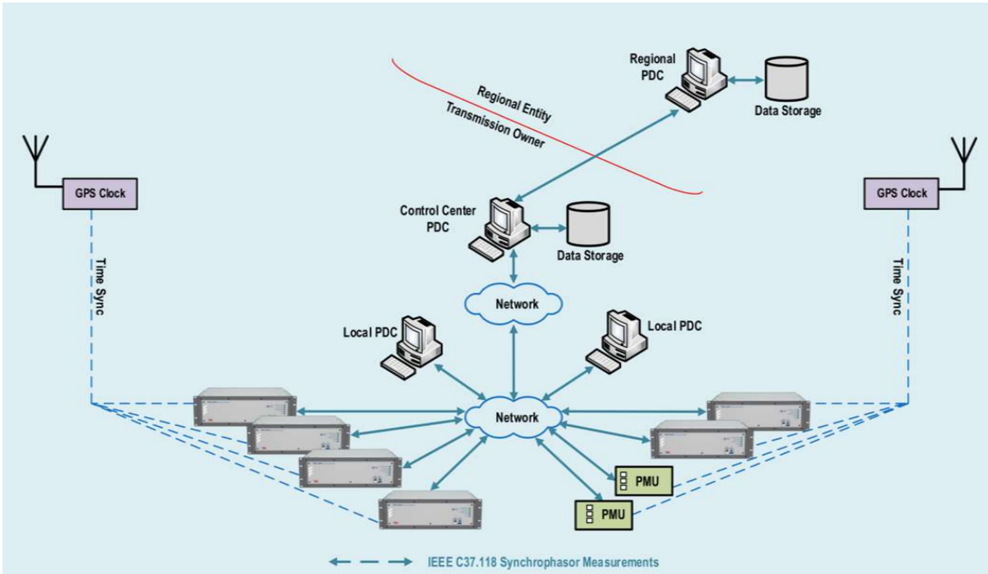

Figure 3: PMU applications

Performing calculations

Multifunctional IEDs used for digital substation monitoring require several functions. A list of typical features are summarized below:

- Summation channels
- Sequence calculations
- Power quality calculations
- Active power, reactive power and power factor calculations
- Flicker, harmonics and THD calculations
- Fault location estimates in transmission lines
- Power swing, voltage sag and voltage swells

All these calculations listed above require mathematical calculations such as digital filtering, discrete Fourier transform, vector transform, additions, subtractions, etc. An IED capable of handling all these functionalities requires a high degree of computational capacity. In addition, some of these calculations require buffering of historical data that demands extensive usage of memory.

In summary, technological challenges demand the following requirements for a monitoring device or IED:

- Adequate processing power to handle extensive calculations, filtering of data, etc.
- Adequate memory to buffer historical data
- Higher communication bandwidth to handle SV data
- Multiple communication paths to publish and subscribe data from multiple IEDs
- Capability of meeting network redundancy requirements
- Capability of storing data or samples

Proposed Solution – Prototype and Results

The proposed solution includes a modular implementation of a monitoring system suitable to overcome these technical challenges.

Monitoring IED/Module

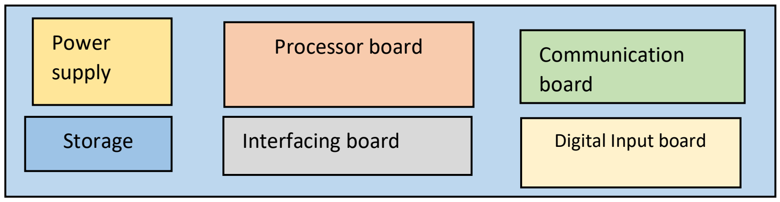

Figure 4: Hardware architecture of the monitoring IED prototype

Figure 4 shows the hardware elements of the proposed solution:

- *Processor Board:* consists of a DSP, a power PC processor, serial ports, Ethernet ports, an IRIG-B processor
- *Communication Board:* consists of four independent Ethernet communication ports, modem, IRIG-B input, etc. More details can be found in [4].
- *Power Supply:* conditions and converts the input power for use by the internal electronics
- *Storage:* data storage capacity is 16GB
- *Interface Board:* the front panel board provides visual indication of the status of the IED
- *Digital Input Board:* input board provides interface for hardwired digital inputs

Monitoring IED has following features:

- Subscribe 36 sampled value inputs from 8 sampled value data streams (80 s/c and 256 s/c)
- Subscribe 256 GOOSE inputs
- Perform synchrophasor calculations for 36 inputs
- Stream synchrophasor data into multiple PDCs
- Perform PQ calculations

Co-operative mode of operation

Co-operative operation mode can be used to monitor large IEC 61850 sampled value based digital substations. This mode of operation provides flexibility for users to collect and analyze events (faults) captured during wide area events. This co-operative mode of operation provides following features:

- Subscribe, record and monitor 216 IEC 61850 sampled value inputs from 48 data streams at a rate of 256 s/c
- Subscribe, record and monitor 1024 GOOSE inputs/messages

Example Settings

Sampled value input channels can be configured as either voltages or currents. Figure 5 shows and an example application.

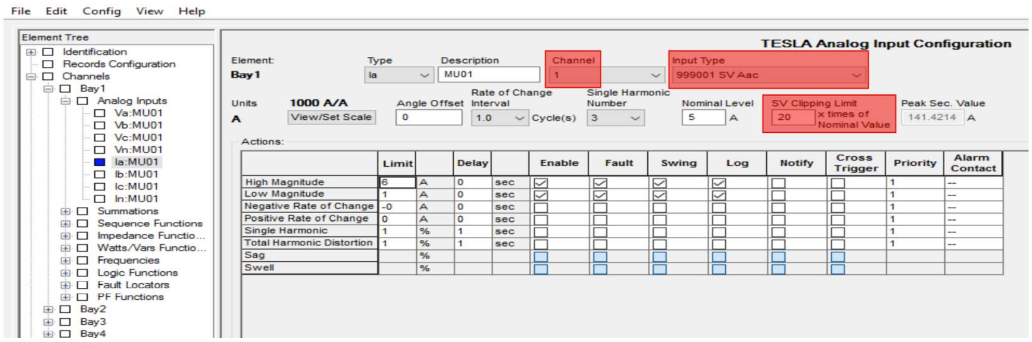

Figure 5: Sampled value input channel configuration

Configuration of Summation Channels

IEC 61850 sampled value inputs can be configured for summation calculations, as shown in Figure 6.

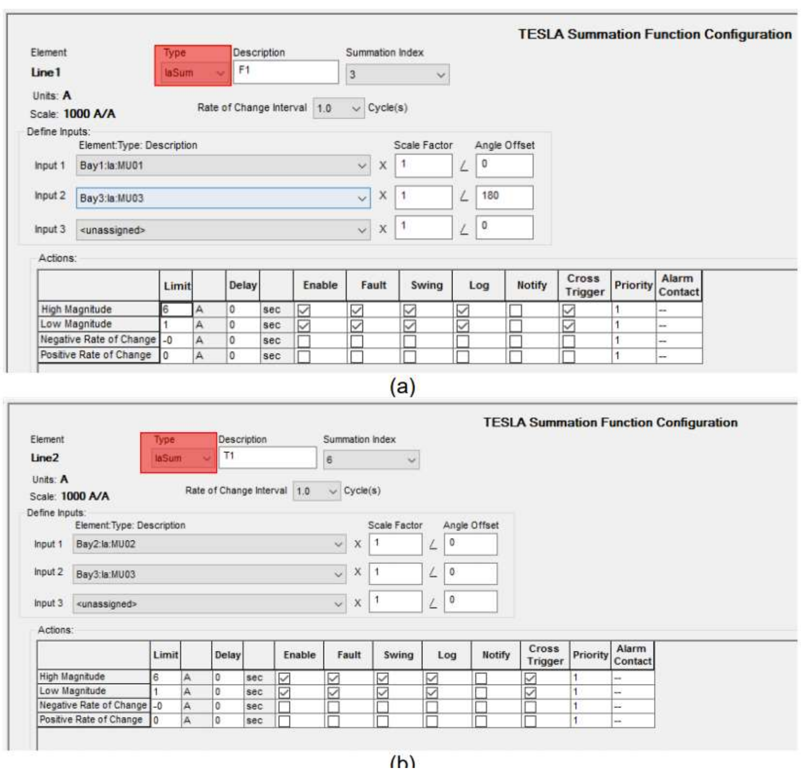

Figure 6: Summation channel configuration

Power Quality Calculations

Figure 7 shows an example of power quality calculations using IEC 61850 9-2 LE sampled value data captured during the prototype testing.

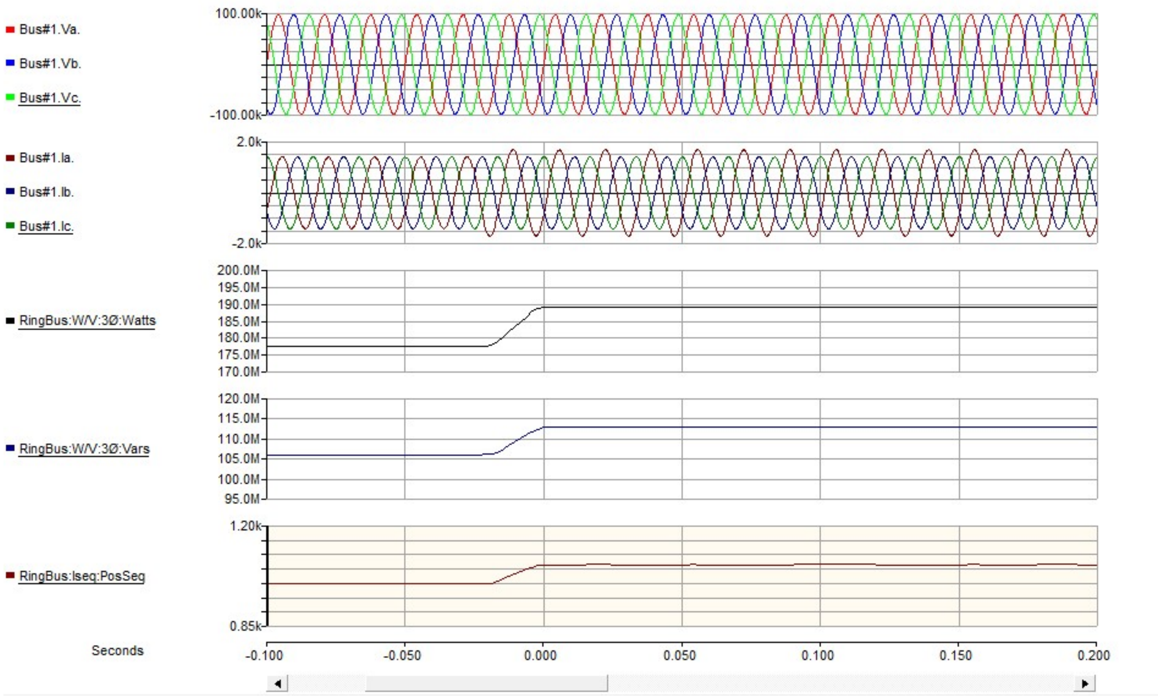

Figure 7: Power Quality calculations

Figure 8 shows the harmonics calculations performed using IEC 61850 9-2 LE data.

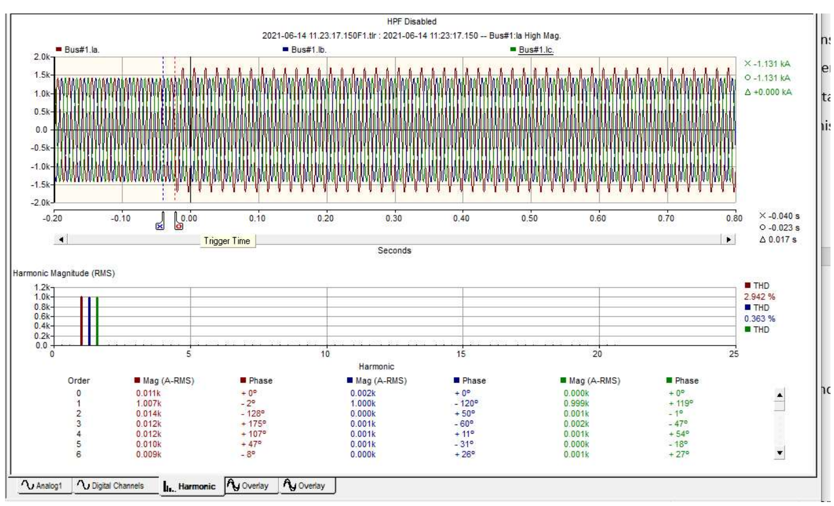

Figure 8: Harmonics calculations

GOOSE Input Configuration

Proposed IED can subscribe to single point status (Boolean), double point status, Health, Int32, or Int32u data types, as shown in Figure 9. Figure 10 shows an example of GOOSE data measurements captured by the device.

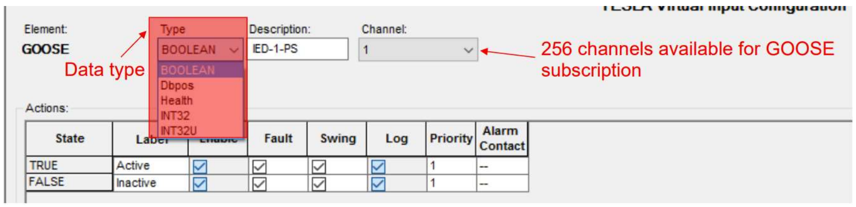

Figure 9: GOOSE subscription setting

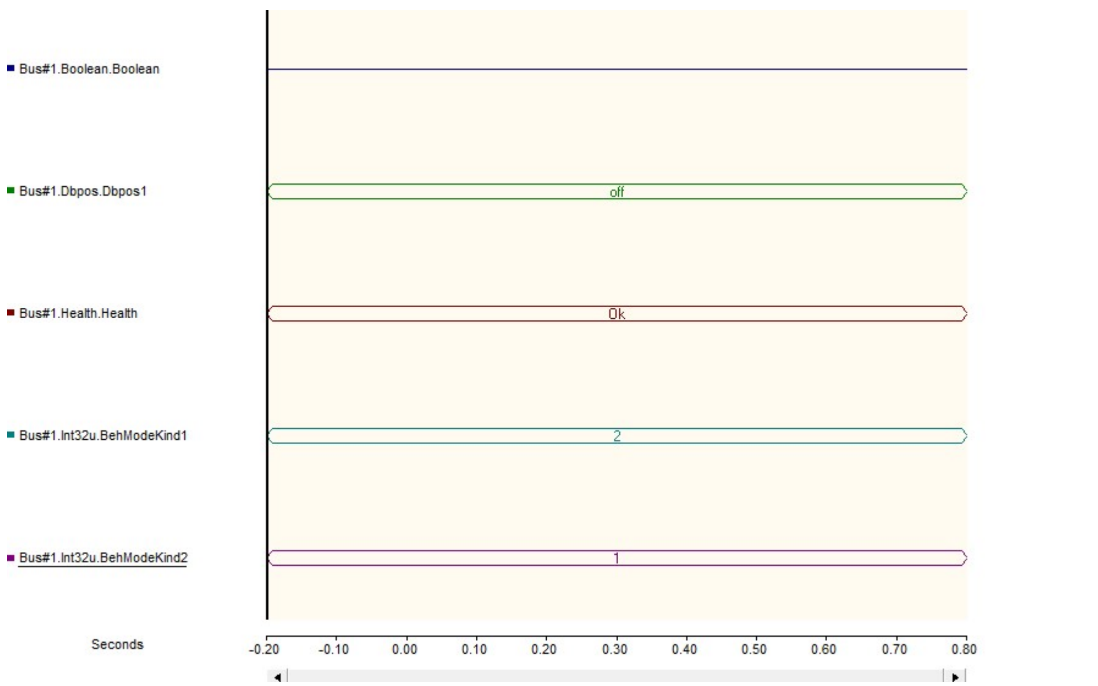

Figure 10: GOOSE data monitoring

IEC 61850 Server Model

Measurements from the IEC 61850 server can be obtained using an IEC 61850 client such as IEDScout software. Figure 11 shows the Phase A current (Figure 11a) and positive sequence voltage (Figure 11b) from the measurement LD of the IEC 61850 server of the IED.

Figure 11: Measurements from IEC 61850 server, including (a) Phase A current, (b) Positive sequence voltage

Data Sharing – Network Ports

Four communication/network ports available in the proposed IED can be configured to share the network traffic/loading, as shown in Table-1.

Table-1: Communication port sharing

Network Port	SV Subscription	GOOSE Publish	GOOSE Subscription	MMS	PTP	PRP/HSR/RSTP
401		✓	✓	✓		
402	✓		✓	✓		
410/412			✓	✓	✓	✓
411			✓	✓		

This configuration enables load sharing on the communication networks for non-IEC 61850 applications such as PMU.

Synchrophasor Application

Operation of the synchrophasor function was tested using a Real Time Digital Simulator (RTDS) using IEC 61850 sampled value data. Testing has been carried out per the synchrophasor test specifications [6]. Figure 12 shows the PMU configuration settings.

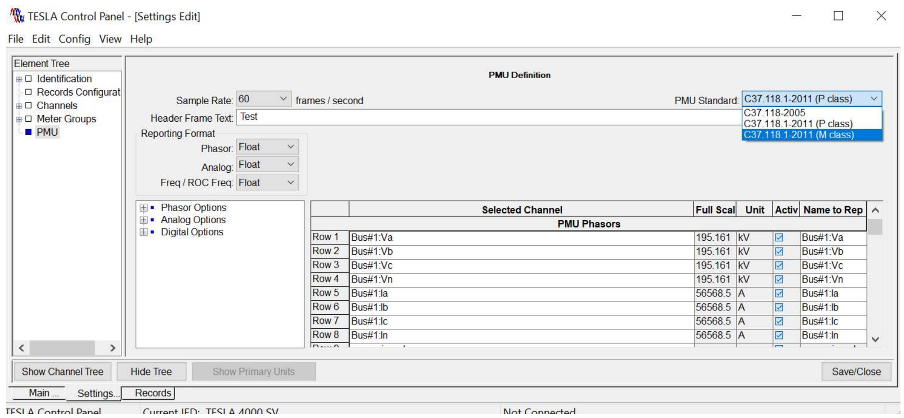

Figure 12: PMU configuration

Figure 13 shows the test results obtained from RTDS setup for PMU testing.

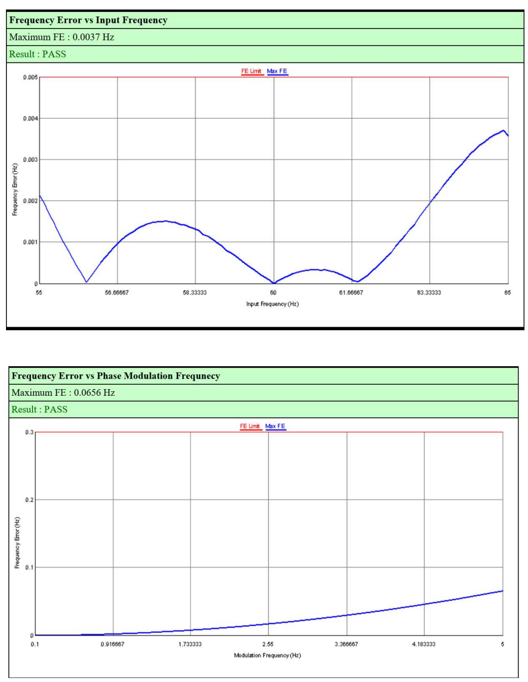

Figure 13: PMU Test Results using RTDS

Conclusion

As more digital substations are implemented around the world, protection and disturbance recording functions will be completely digitized and based on communication networks. This shift will result in reduced copper cabling, decreased project costs, reduced maintenance costs, smaller form factor, better system-wide data availability, increased electrical isolation for improved substation safety, and easier expansion in the future. In this paper, technical and application related challenges related digital substation monitoring have been discussed. A solution was proposed including the results obtained from the testing using merging units and RTDS.

References

1. IEC 61850-1:2013, Communication Networks and Systems for Power Utility Automation - Part 1: Introduction and Overview.

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4. ERLPhase Power Technologies TESLA 4000-SV Power System Recorder Manual.

5. IEEE/IEC 60255-118-1-2018 - IEEE/IEC International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems – Measurements.

6. IEEE Synchrophasor Measurement Test Suite Specification-Version 3.