IEC 61850 Testing and Commissioning Advantages Using GOOSE Messaging

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***Abstract*— when a utility looks at implementing new changes with technology or their engineering and design standards, it is human nature to be resistant to these changes. This also holds true when a utility makes the transition from a conventional substation protection and control (P&C) system to a fully digital IEC 61850 based scheme. Existing testing procedures for conventional P&C schemes involves testing every element associated with that scheme. This often requires lengthy testing procedures and modifications to the relay setting. The modifications include assigning multiple protection elements, time overcurrent pickups, logic pickups, timers, and mapping elements to additional output contacts. When the transition from these conventional systems to IEC 61850 occurs, the question is raised "How am I going to test a protection or control scheme with no test switches to isolate the equipment?"**

This paper explores how IEC61850 can provide a more efficient testing and commissioning solution to the utility. It creates a more user-friendly interface with the equipment and an opportunity to provide a solution to existing problems. One of those opportunities that can be provided by IEC61850 utilizes GOOSE messages. The messages can be published from the devices for not only normal operation, but also contain data sets for testing purposes. By adding data sets for testing purposes, such as time overcurrent pick up (PTOC.Str) to the GOOSE message we eliminate the need for relay technicians to modify the relay settings. IEC61850 has built in testing capabilities directly and indirectly into the standard, this paper will examine how these implementation differences can be exploited.

I. INTRODUCTION

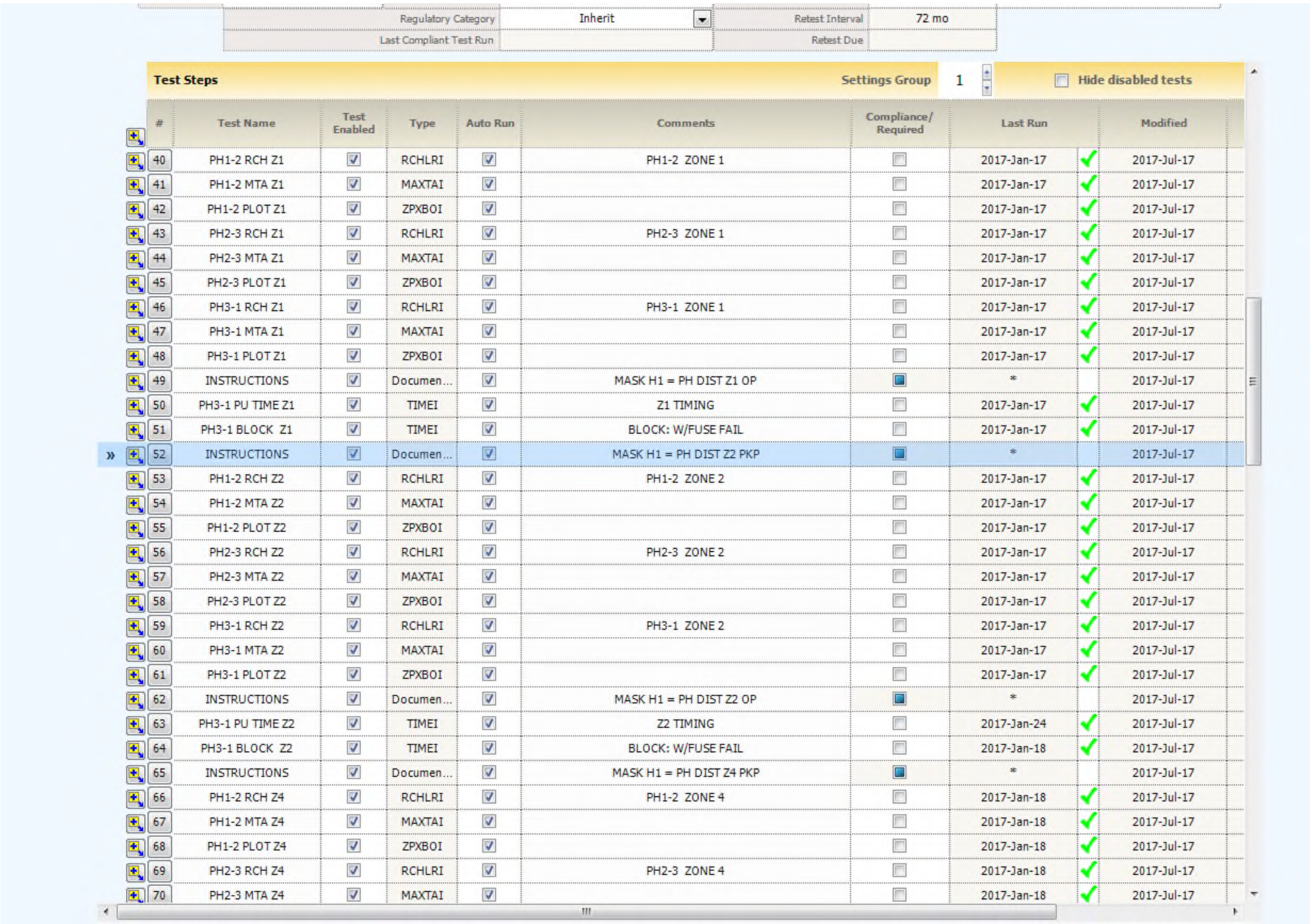
The use of IEC 61850 and other associated standards, especially the concept of GOOSE and Sampled values has paved the path to digital substations. A substation protection and control system based on the concepts of IEC 61850 can be built faster, more efficiently, and lower commissioning time by replacing physical wiring with network communications. Utilizing IEC61850, GOOSE Messages for testing can dramatically reduce the testing time per relay. Today the devices we call relays are Intelligent Electronic Devices (IED) capable of so many functions, all the elements utilized in these IEDs must be completely tested. This testing is not just to prove the performance of the relay, but to make sure the settings are correct as well. It is hard for people to acknowledge that they make mistakes, but we do. Protection engineers sleep better at night knowing that the relay settings issued are completely tested by the technicians.

Although this paper focuses on testing a complete IEC61850 digital substation using GOOSE messages, the concepts can still be applied to conventional relay design using traditional wiring.

II. TRADITIONAL RELAY TESTING METHODS

There are multiple methods to test a relay and it is based on utility past practices. A report from IEEE Power System Relaying Committee entitled Relay Performance Testing [1] discusses methods of modern day testing. These methods include dynamic-state, steady-state, and transient testing. The discussion of this paper can be utilized for any of these testing practices. However, the examples will focus on traditional steady-state method testing in which individual elements are tested one at a time to emphasis the efficiency that GOOSE messages can provide.

Existing testing practices require the testing of each individual element being utilized in the protection scheme. For an example, consider a high side transformer protection relay utilizing time overcurrent protection and instantaneous overcurrent protection. These elements are all assigned to a tripping matrix in the relay to output a "Trip" to the isolating devices such as a circuit switcher and or circuit breaker. This simple overcurrent protection example requires a test plan of approximately six steps. The time overcurrent pick-up element, time overcurrent trip/operate (After time delay), and instantaneous pick-up for both phase and ground elements. Testing each of these elements often requires the technician to modify relay settings to output each individual element. Analog signals are then injected into the relay and the output hardwired contact is monitored using test equipment. The results are recorded and documented in the test plan. This process requires additional time to set up for each step. Figure 1 below shows another example of test plan steps for testing Zone 2 setting for a line distance relay.



Regulatory Category	Inherit	Retest Interval	72 mo
Last Compliant Test Run		Retest Due	

Test Steps — Settings Group 1 — ☐ Hide disabled tests

#	Test Name	Test Enabled	Type	Auto Run	Comments	Compliance/ Required	Last Run		Modified
40	PH1-2 RCH Z1	☑	RCHLRI	☑	PH1-2 ZONE 1	☐	2017-Jan-17	✓	2017-Jul-17
41	PH1-2 MTA Z1	☑	MAXTAI	☑		☐	2017-Jan-17	✓	2017-Jul-17
42	PH1-2 PLOT Z1	☑	ZPXBOI	☑		☐	2017-Jan-17	✓	2017-Jul-17
43	PH2-3 RCH Z1	☑	RCHLRI	☑	PH2-3 ZONE 1	☐	2017-Jan-17	✓	2017-Jul-17
44	PH2-3 MTA Z1	☑	MAXTAI	☑		☐	2017-Jan-17	✓	2017-Jul-17
45	PH2-3 PLOT Z1	☑	ZPXBOI	☑		☐	2017-Jan-17	✓	2017-Jul-17
46	PH3-1 RCH Z1	☑	RCHLRI	☑	PH3-1 ZONE 1	☐	2017-Jan-17	✓	2017-Jul-17
47	PH3-1 MTA Z1	☑	MAXTAI	☑		☐	2017-Jan-17	✓	2017-Jul-17
48	PH3-1 PLOT Z1	☑	ZPXBOI	☑		☐	2017-Jan-17	✓	2017-Jul-17
49	INSTRUCTIONS	☑	Documen...	☑	MASK H1 = PH DIST Z1 OP	■	*		2017-Jul-17
50	PH3-1 PU TIME Z1	☑	TIMEI	☑	Z1 TIMING	☐	2017-Jan-17	✓	2017-Jul-17
51	PH3-1 BLOCK Z1	☑	TIMEI	☑	BLOCK: W/FUSE FAIL	☐	2017-Jan-17	✓	2017-Jul-17
52	INSTRUCTIONS	☑	Documen...	☑	MASK H1 = PH DIST Z2 PKP	■	*		2017-Jul-17
53	PH1-2 RCH Z2	☑	RCHLRI	☑	PH1-2 ZONE 2	☐	2017-Jan-17	✓	2017-Jul-17
54	PH1-2 MTA Z2	☑	MAXTAI	☑		☐	2017-Jan-17	✓	2017-Jul-17
55	PH1-2 PLOT Z2	☑	ZPXBOI	☑		☐	2017-Jan-17	✓	2017-Jul-17
56	PH2-3 RCH Z2	☑	RCHLRI	☑	PH2-3 ZONE 2	☐	2017-Jan-17	✓	2017-Jul-17
57	PH2-3 MTA Z2	☑	MAXTAI	☑		☐	2017-Jan-17	✓	2017-Jul-17
58	PH2-3 PLOT Z2	☑	ZPXBOI	☑		☐	2017-Jan-17	✓	2017-Jul-17
59	PH3-1 RCH Z2	☑	RCHLRI	☑	PH3-1 ZONE 2	☐	2017-Jan-17	✓	2017-Jul-17
60	PH3-1 MTA Z2	☑	MAXTAI	☑		☐	2017-Jan-17	✓	2017-Jul-17
61	PH3-1 PLOT Z2	☑	ZPXBOI	☑		☐	2017-Jan-17	✓	2017-Jul-17
62	INSTRUCTIONS	☑	Documen...	☑	MASK H1 = PH DIST Z2 OP	■	*		2017-Jul-17
63	PH3-1 PU TIME Z2	☑	TIMEI	☑	Z2 TIMING	☐	2017-Jan-24	✓	2017-Jul-17
64	PH3-1 BLOCK Z2	☑	TIMEI	☑	BLOCK: W/FUSE FAIL	☐	2017-Jan-18	✓	2017-Jul-17
65	INSTRUCTIONS	☑	Documen...	☑	MASK H1 = PH DIST Z4 PKP	■	*		2017-Jul-17
66	PH1-2 RCH Z4	☑	RCHLRI	☑	PH1-2 ZONE 4	☐	2017-Jan-18	✓	2017-Jul-17
67	PH1-2 MTA Z4	☑	MAXTAI	☑		☐	2017-Jan-18	✓	2017-Jul-17
68	PH1-2 PLOT Z4	☑	ZPXBOI	☑		☐	2017-Jan-18	✓	2017-Jul-17
69	PH2-3 RCH Z4	☑	RCHLRI	☑	PH2-3 ZONE 4	☐	2017-Jan-18	✓	2017-Jul-17
70	PH2-3 MTA Z4	☑	MAXTAI	☑		☐	2017-Jan-18	✓	2017-Jul-17

Fig. 1. Example of Zone 2 Line Impedance Test Plan

III. IEC 61850 TESTING FUNCTIONALITY

The IEC 61850 standard defines the test mode capabilities of an IED. The standard provides the use of “Test Mode” and “Simulation Mode” [2] for testing and troubleshooting purposes. Each Logical Node is accompanied by a quality data attribute. The thirteen bits of the quality attribute provide quality information associated with that data. Each bit represents a quality issue, if any of the bits are high it denotes a problem with the message. Not all the quality issues are necessarily bad, in fact the twelfth bit denotes if the data is in test mode (See Fig. 2).

Test mode allows the users to test Protective functions or devices without interrupting the entire protection scheme. Essentially test mode replaces test switches to isolate and test an IED for a digital substation. The entire physical Device or just a Logical Node can be put in test mode using a Manufacturing Message Specification (MMS) message from a Client Server application or from the device itself.

Test mode has five modes:

Bit(s)	IEC 61850-7-3		Bit-String	
	Attribute name	Attribute value	Value	Default
0-1	Validity	Good	0 0	0 0
		Invalid	0 1	
		Reserved	1 0	
		Questionable	1 1	
2	Overflow		TRUE	FALSE
3	OutofRange		TRUE	FALSE
4	BadReference		TRUE	FALSE
5	Oscillatory		TRUE	FALSE
6	Failure		TRUE	FALSE
7	OldData		TRUE	FALSE
8	Inconsistent		TRUE	FALSE
9	Inaccurate		TRUE	FALSE
10	Source	Process	0	0
		Substituted	1	
11	Test		TRUE	FALSE
12	OperatorBlocked		TRUE	FALSE

Fig. 2. Quality Attribute Table [3]

- ON – The application represented by the Logical Node is in service

- ON-BLOCKED – The application represented by the Logical Node is in service. However, the IED output data will be blocked.

- TEST – The Application by the Logical Node is in test mode. The logical node will still receive updates. However, only other IEDs in test mode will accept the message. If the test bit is set to true, then any devices not in test mode will not interact with the message if it was configured to normally subscribe to the message.

- TEST/BLOCKED - The Application by the Logical Node is in test mode. The logical node will still receive updates. However, only other IEDs in test mode will accept the message. Output data from the Logical Node will not be issued.

- OFF- The Application by the Logical Node is out of service.

Simulation Mode is another testing capability in the standard that allows the simulation of data from test equipment such as Sample Values or Logical Node inputs. When a device is in simulation mode, it is now allowed to subscribe to messages with simulation bit = TRUE which would be published by test equipment. Simulation mode applies to GOOSE Messages as well as Sample Values (See Figure 3). Simulation mode essentially replaces injecting analog values and discrete input signals into a device in conventional testing practices. A note to the tester, simulation mode and test mode are independent functions. If the user is testing an IED in service and puts the device in simulation mode but not in test mode, any other devices that normally subscribe to the data will respond (Mis-operation).

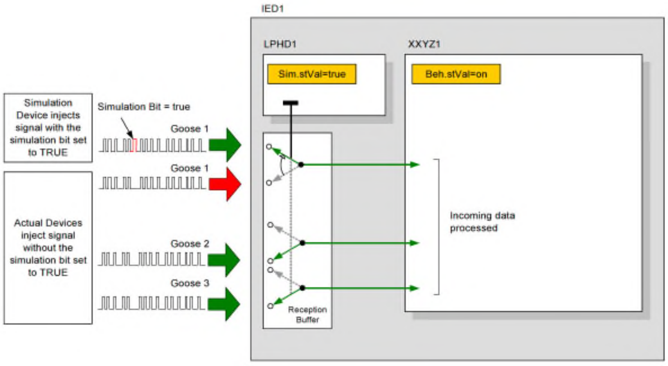


Fig. 3. Simulation Mode IEC 61850-7-1 [4]

IV. IEC 61850 DATA MODEL APPROACH TO TESTING

To utilize GOOSE messages or data sets for testing purposes you must first decide what elements you will require for testing. Similar to the traditional methods, plan out all the elements required for a relay such as time overcurrent pick up and trip/operate. Once you populate your list of elements required you can correlate the elements with the available logical nodes and data objects. IEC61850-7-4 [5] discusses data modeling semantics, a breakdown of logical nodes, data objects, and data attributes available for use in a digital substation. A data set for testing purposes can be populated with what you require for testing and assigned to a GOOSE message to be published onto the network. This GOOSE message is published onto the network for testing and troubleshooting purposes.

Logical Node/DO	Description
LPHD1.Sim	Physical device simulation mode status
LLN0.Mod	Physical device test mode status
EF4_1PTOC1.Op	Ground Time Overcurrent element operate
EF4_1PTOC1.Str	Ground Time Overcurrent element pick up
EFPIOC.Op	Ground Instantaneous Overcurrent element operate
PDIS1.Op	Zone 1 distance element operate
PDIS2.Op	Zone 2 distance element operate
PDIS2.Str	Zone 2 distance element pick up
PDIS3.Op	Zone 3 distance element operate
PDIS3.Str	Zone 3 distance element pick up
LCCH1.ChLiv	Port 1 communication status
LCCH2.ChLiv	Port 2 communication status

Fig. 4. Example data set for testing

Figure 4 is an example data set created for testing an IED with line impedance and directional ground overcurrent protection. Along with the logical nodes for testing these protection elements, there are also logical nodes for communication testing. LCCH1.ChLIV is the logical node and data object for physical port communication.

We now look at an example of a test plan for the testing of line impedance functionality using IEC 61850. Figure 5 is an example test plan for an IED. The hierarchy tree in the left box below are the test modules that were performed. the box on the right are the test result documentation which shows each test result, and if it passed or failed based on testing criteria.

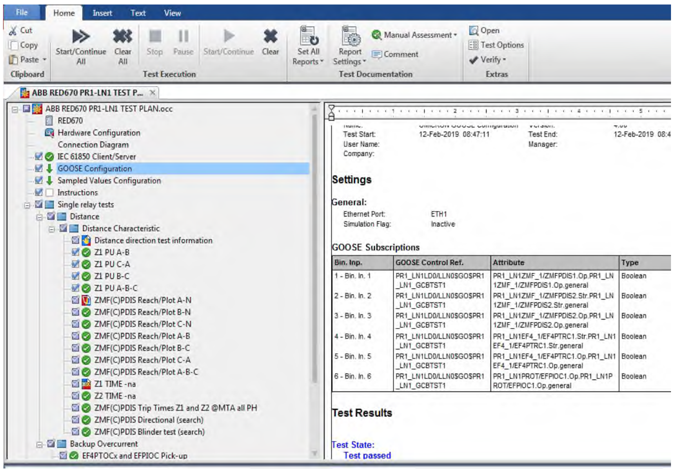


Fig. 5. Test Plan example of Line Impedance relay

The first module in the test plan “IEC61850 Client/Server” is a module which when run will automatically put the entire physical device into test mode and simulation mode using test equipment to send MMS messaging to change the status of the physical device (See Figure 6). Test Mode is changed via MMS by changing the status of LLN0.Mod & LPHD.Sim = TRUE. In this test module we also take advantage of the module by performing a meter check of the device as well. As can be seen in Figure 6 the meter check results were within the required boundaries and therefore passed. This was accomplished by setting up the test to poll the metering quantities from the relay via MMS.

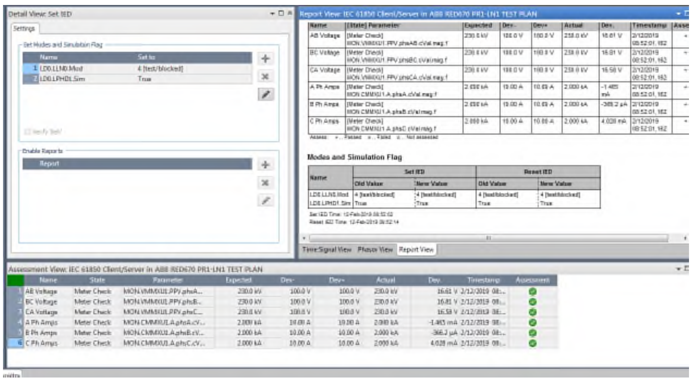


Fig. 6. IEC61850 Client/Server Module

From Figure 5, the next test modules in the test plan are the GOOSE Configuration and Sample values configuration. The GOOSE Configuration module is where you assign the data objects that you would use throughout your test plan to variables in your test set software for both subscribing to and to simulate. As you go through setting up the test plan you can utilize the variables on the top left box in Figure 7 for monitoring.

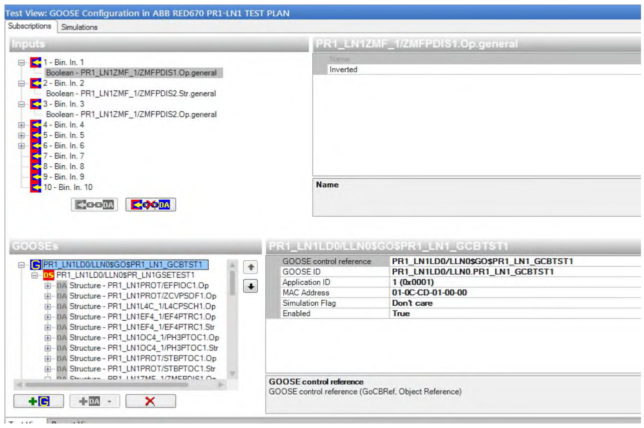


Fig. 7. Example test plan

An example test step for testing Zone 1 performance of the IED was set up using an impedance-current constant ramping module using simulated sample values from Figure 8.

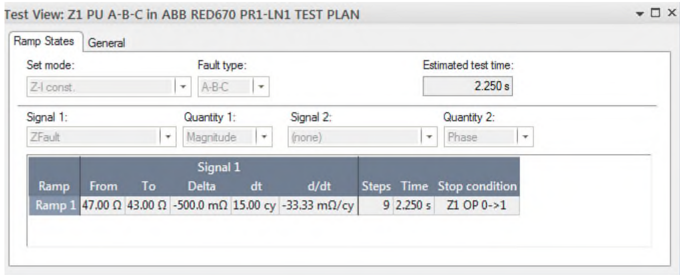


Fig. 8. Zone 1 ramp test parameters

The trigger condition used in Figure 9 Z1 OP is the test software variable Binary 1 which from Figure 7 in the GOOSE Configuration PDIS1.Op was assigned to. The test stops once PDIS1.Op changes from false to true and the results were recorded in Figure 10.

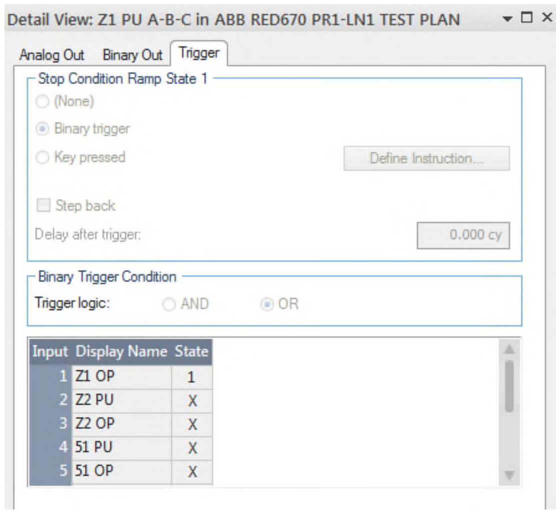


Fig. 9. Zone 1 trigger conditions

Fig. 10. Zone 1 Test Results

V. Conclusion

Current testing practices require the need for hundreds of testing steps which require time to reconfigure the devices and testing connections as well as create room for errors or mistakes. An Utility's existing test plans can be modified to streamline the testing process per device or scheme. Once the data within the digital messages are configured and assigned to the test set software, the only requirement is to click a button and the test can be complete at a significantly reduced rate. Most testing can be done off site which can reduce commissioning and outage times. With IEC 61850 and test set capabilities to allow uploading and linking of parameter settings as well as GOOSE and Sample Values into a test plan, the test process becomes mostly automated. Relay settings and configurations no longer need to be modified for every step in the test plan when all the logical nodes required for your test are published in a GOOSE message onto the network.

Power system Protective relay devices have changed over the course of the power grid history. The technology changed from electromechanical, to solid state, to microprocessor, and now a complete digital substation solution. While the technology has changed rapidly, the testing practices have not caught up. With more renewable generation connecting to the power system there is a need for tools to adapt to the dynamic power system we have today. IEC 61850 is one of the tools that can help keep up with the technology.

Acknowledgment

I would like to thank the National Grid IEC61850 team for being a great team to work with and the National Grid Protection and Telecommunication Department. A special note of thanks to Aleksandr and Vasiliy Terebey for working diligently with me in the IEC 61850 testing lab.

References

[1] IEEE Power System Relaying Committee entitled Relay Performance Testing

[2] IEC 61850-7-1, Ed. 2.0, 2013-03

[3] IEC 61850-7-3, Ed. 2.0 2013-03

[4] IEC 61850-7-1, Fig. 40, Ed. 2.0, 2013-03

[5] IEC 61850-7-4, Ed. 2.0, 2013-03

Biography

Antonio Riccardo Jr. received his B.S. degree in Electrical Engineering Technology from the State University of New York in 2004. He received is M.S. degree in Electrical Engineering from Syracuse University in 2007 & MBA from Le Moyne College in 2018. Upon graduating from Syracuse University, he has served nearly 12 years at National Grid, where he worked in various departments, including Meter Engineering, Substation Engineering, Control & Integration, IEC 61850 Digital Substations, and Protection Engineering. He is the Chairman of the IEEE Power System Relaying Committee P13 Working Group and Vice Chairman of H47 Working Group. Antonio is a registered professional engineer in the State of New York and a member of IEEE.