

Test Bed for a Cyber-Physical System Based on Integration of Advanced Power Laboratory and eXtensible Messaging and Presence Protocol

Matin Meskin
PhD Candidate
matinmes@buffalo.edu

Ilya Grinberg
Professor
grinbeiy@buffalostate.edu

Mohammed Safiuddin
Professor
safium@buffalo.edu

Joint SUNY Buffalo State/University at Buffalo Smart Grid Laboratory

Abstract

Today, Supervisory Control and Data Acquisition (SCADA) system is used widely in substations and industrial plants to monitor and to control them. Collected data from these nodes helps researchers to find and to develop effective method and algorithm of power networks monitoring and control. Right now many of transmission lines and power plants work close to their limitation and losses of the network are high due to aging and out-of-date equipment in the network. Installation of new infrastructures is time consuming and requires a lot of investment. Adding more renewables to the electrical grids in the future makes the power networks operation and monitoring more complicated. In these conditions, changing of traditional electricity grid into a state-of-the-art Smart Grid becomes more valuable. To do that, many studies should be done and tested before applying to the power networks. In this case, test-beds become more important as a tool that helps to test the idea about smart grids.

In here, a test-bed for real-time monitoring of power networks is presented. Three features, SCADA, CPS and XMPP came together to create this test-bed, which can be used not only for research proposes but also for education. XMPP was a protocol utilized only for secure session initiation before and it is the first time that this tool is applied to the power networks.

The test-bed provides the research community a facility to analyze their designs and protocols in lab environment.

Introduction

Integration of Advanced Power Laboratory with Supervisory Control and Data Acquisition (SCADA) as a test bed for a Cyber-Physical System (CPS) is illustrated here. Such integration has large-scale application in a smart grid realm as well as in power engineering education and professional development for energy professionals. As a result, a complete smart grid training system including generation, high voltage transmission, and medium and low voltage distribution has been developed. Integration of advanced power laboratory has been performed with Lucas-Nülle (LN) smart grid training systems and Schweitzer Engineering Laboratories (SEL) protective relays at the joint Buffalo State College and University at Buffalo Smart Grid Laboratory. One of the key features of the test bed is utilization of eXtensible Messaging and Presence Protocol (XMPP). The use of XMPP allows multiple users, devices, and applications to share critical information in power applications. The laboratory system includes a model of long-distance transmission line combined with fault protection system by SEL. During the lab conditions, SEL relays operate as intended to clear the fault. Information of the system state is collected from Smart Grid laboratory sensors (smart meters and relays) and transferred via MODBUS TCP protocol to Supervisory Control and Data Acquisition (SCADA) system to display parameters of the system's state.

The XMPP system interface establishes secure session with registered users, devices, and applications. The link provides metadata to enable sensor data to be viewed by others. These notifications can be directed to operators that can control other equipment in response to the event. Actions by an operator can also be sent to remote devices extending the SCADA capability over any wired or wireless networks, including the Internet.

XMPP has been used to provide secure session initiation for many years but had not been used in CPS power applications. The capabilities can be used with mobile devices to provide alerts to maintenance and operations personnel. The event can also be shared with emergency response personnel who are trusted to receive this information.

The integrated CPS test bed provides real-time data, including power flow and information flow, to power system operators and other authorized personnel, which aids them in making more effective and intelligent decisions. The test bed provides educational and research experience to undergraduate and graduate students, and significantly raises their interest in energy field and broader areas of cyber-physical systems, and provides a unique "hands-on" experience with important aspects of the modern grid.

Cyber-Physical System (CPS)

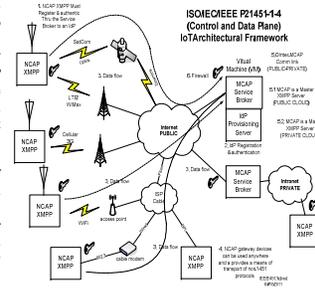
The emergence of Cyber-Physical Systems (CPS) has opened up new horizons for automated, dependable, secure, and safe energy applications, which has created unprecedented avenues for communication, monitoring and control at the utility level.

Cyber-Physical Systems can be described as smart systems that encompass computational and physical components, which are seamlessly integrated and closely interact, to sense and monitor the changing state of the real world. These systems involve a high degree of complexity at numerous spatial and temporal scales and involve highly networked communications with robustly coordinated software and hardware components.

eXtensible Messaging and Presence Protocol (XMPP)

XMPP offers a common transport protocol that can be sent to mobile devices to provide alerts and messages to users among its other capabilities. It demonstrates that such information can be provided to utility maintenance and operations personnel as well as to regulators, consumers, and others who are trusted to receive the information. The XMPP framework utilizes Internet of Things (IoT) XEPs (XMPP Extensions) to provide link to Object Linking and Embedding for Process Control Unified Architecture (OPC UA) servers. The use of XMPP provides multicast capabilities and provides secure communications without the need for a Virtual Private Network (VPN). The data exchange security is achieved by using Transport Layer Security (TLS). XMPP provides real-time updates that are more cost effective and can share information directly with the data source. The owner of the end device must authorize the sensor information to be shared, for example, with a Big Data system to perform Data Analysis. Confidentiality of the end users' data is protected by mutual trust. Maintaining trust and security is paramount.

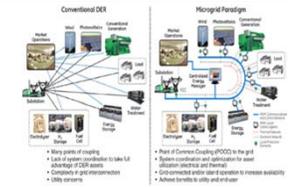
An intermediary known as a XMPP Service Broker is used to authorize access for users, applications, and devices to exchange information. XMPP also provides built-in security, which includes encryption of the data. XMPP is currently widely used in social networks, conferencing services, and Software Defined Networks. XMPP has demonstrated its scalability and now with the IoT XEPs, XMPP can address interoperability, which is an important concern for CPS.



Microgrid Paradigm

Typical power systems currently provide centralized power control and monitoring that communicates to substations (at the utility level). The data collected are sent to a third party or to a utility.

Microgrids offer a decentralized distributed control approach. They can provide isolation and protect communities, while minimizing loss of power and maintaining reliable operation. Renewable energy sources, though desirable, also pose a concern. They must be integrated with the grid, must notify their generation availability, and must provide alerts whenever there is a problem. Currently, outage management systems at the utility companies rely mostly on phone calls from consumers to identify affected areas.



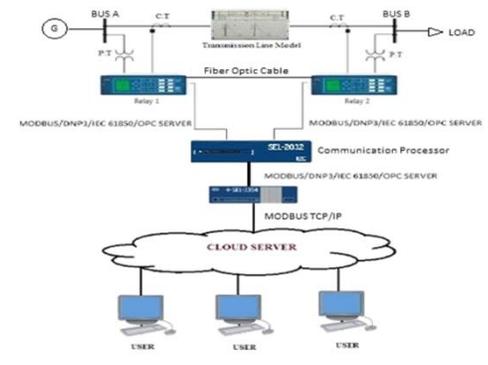
Test-Bed Establishment and Operation

The model of the Microgrid at Smart Grid Lab consists of a scaled-down set of equipment that includes generation, transmission, distribution, protection, monitoring, and control. SCADA system supplied by Schweitzer Engineering Laboratories (SEL) has been installed to facilitate connection of IEDs (such as relays, meters, sensors, etc.) for access to the cloud servers. The SCADA system consists of the communication processor (SEL-2032) and a computer (SEL-3353 or SEL-3354) with SCADA software. The SCADA system sends commands to equipment and receives data on the status of the system. Data, such as voltages, currents, and powers among others, can be acquired via SCADA system. In addition, circuit breakers and other interrupting devices can also be monitored and controlled. Line differential protection is set to protect transmission line and a fiber optic cable connects two relays.

Cloud server is a virtual server space rather than a physical server. Therefore, the space is allocated to users once required and after completing the job the space is released. This causes the cost to be lower in comparison to a physical server. Allocating more space upon the user request makes it an appropriate tool for many tasks such as data sharing over the Internet. Ease of setting up, flexibility and reliability are among many benefits of the cloud server. In addition, cloud server is more secure for data exchange due to inaccessibility of data by other clients on the server. Moreover, the workload does not affect the performance speed.

Communication Processor collects the test circuit data from the relays. RELAB OPC Console software supplied by Relab Software Co. is used to display this data in the text form. Available SEL protocols are used for communication between all of the SEL devices including communication processor and RELAB OPC Console software. MODBUS TCP/IP protocol is used to send data over the Internet and therefore, a conversion is needed to convert SEL protocols to MODBUS TCP/IP protocol. This is accomplished by RELAB Protocol Service Bridge software, serving as an interface between SCADA system and the Internet.

Software has been developed by Clayster, allowing a user to connect to Smart Grid Lab and get access to data. This software can be installed on any computer or on a smart mobile device.



Exp Name	Exp Name	Value	Timestamp	Quality	Access	Type	Description
SECURITY	RELAB_OP_C	True	1/21/2015 12:08:20	Good	Relay	Relay	
SECURITY	RELAB_OP_C	True	1/21/2015 12:08:20	Good	Relay	Relay	
SECURITY	RELAB_OP_C	True	1/21/2015 12:08:20	Good	Relay	Relay	
SECURITY	RELAB_OP_C	True	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL1	6.20828	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	CURRENT_A_REL1	6.20828	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL2	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL3	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL4	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL5	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL6	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL7	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL8	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL9	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL10	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL11	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL12	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL13	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL14	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL15	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL16	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL17	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL18	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL19	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL20	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL21	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL22	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL23	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL24	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL25	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL26	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL27	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL28	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL29	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL30	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL31	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL32	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL33	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL34	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL35	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL36	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL37	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL38	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL39	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL40	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL41	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL42	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL43	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL44	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL45	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL46	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL47	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL48	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL49	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL50	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL51	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL52	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL53	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL54	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL55	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL56	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL57	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL58	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL59	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL60	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL61	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL62	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL63	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL64	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL65	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL66	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL67	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL68	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL69	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL70	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL71	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL72	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL73	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL74	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL75	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL76	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL77	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL78	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL79	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL80	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL81	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL82	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL83	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL84	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL85	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL86	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL87	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL88	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL89	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL90	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL91	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL92	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL93	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL94	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL95	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL96	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL97	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL98	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL99	120.800	1/21/2015 12:08:20	Good	Relay	Relay	
ANALOG_DATA	VOLTAGE_A_REL100	120.800	1/21/2015 12:08:20	Good	Relay	Relay	

Conclusion

This project provides apparent benefits of coordinating integrated computation, communication, and control into electrical power systems, resulting in real time optimized demand/response system and outage management; improved system safety and reliability; enhanced communication capacity between providers and consumers; accelerated response times in emergency scenarios; expanded situational awareness; improved consumer relations and trust; minimized adverse impacts on people and systems due to real time information sharing with first responders.

- Other impacts include but are not limited to:
- Educating future workforce by exposing undergraduate and graduate students to the state-of-the-art technologies and systems methodology of cyber-physical systems
 -