The role of data exchange standards in developing automated fault disturbance monitoring

Mladen Kezunovic and Papiya Dutta

***Abstract*-- As the power systems become more complex due to integration of renewables and increased transmission demands, monitoring fault disturbances becomes more important task. Manual analysis of faults and related impacts on the system due to protective relay miss-operation or unintended operation is not sufficient to restore the grid in a timely manner. Hence, an automated approach is required. This paper describes a system developed for that purpose and deployed at several utilities in the USA at different levels of complexity. The barriers to implementation and development are addressed. The role of interoperability standards in overcoming the barriers is explained. While the use of IEC standards 61850 and 61970 is emphasized the focus is also on many other IEC and IEEE standards that need to be applied. The paper ends in a discussion of how such a solution may be built using standards for data exchange.**

***Index Terms*-- Automation, data exchange, faults, monitoring, outage management, standards.**

I. Nomenclature

The following list contains the meaning of abbreviations used in this paper.

CIM	Common Information Model
DFR	Digital Fault Recorder
DPR	Digital Protective Relay
FERC	Federal Energy Regulatory Commission
GWAC	GridWise® Architecture Council
IED	Intelligent Electronic Device
ISO	Independent System Operator
NERC	North American Electric Reliability Corporation
NIST	National Institute of Standards and Technology
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
PUC	Public Utility Commission
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition System
SCL	Substation Configuration Language
SER	Sequence of Event Recorder
SGIP	Smart Grid Interoperability Panel

Mladen Kezunovic and Papiya Dutta are with the Department of Electrical and Computer Engineering, Texas A&M University, College Station, TX 77843-3128, USA (emails: kezunov@ece.tamu.edu, papiya82@neo.tamu.edu) .

II. Introduction

MONITORING fault disturbances should be performed automatically to facilitate quick fault detection, classification, location and restoration immediately after the fault occurs as well as efficient handling of data through integration and interoperability. The fault disturbance monitoring should be able to detect fault event by automatically choosing and interpreting information from huge amount of measurements and alarms generated due to the occurrence of several switching events, classify the type of fault and the faulted region and accurately locate the faulted equipment very quickly to help maintenance crew to find and repair the faulted equipment as soon as possible.

Several IEDs (DPRs, DFRs, SERs etc.) are currently installed in substations, which can record considerable amount of data after occurrence of an event like fault. The recorded data, often designated as non-operational, if integrated with operational data captured by RTUs and PMUs can help detailed system wide analysis of fault events. This analysis should be performed in a very short time frame which requires a considerable amount of information exchange in a large power system. To restore service after occurrence of a fault quickly, it is desirable that these exchanges are performed automatically and seamlessly between number of IEDs and centralized database using several data exchange standards in use and proposed which will in turn help achieving interoperability.

Several IEEE and IEC standards for data exchange are in use or proposed for this purpose. The NIST Framework and Roadmap for Smart Grid Interoperability Standards [1] developed a conceptual architectural reference model that includes protocols and standards for information management. The framework is mostly developed for the legacy solutions not allowing full understanding of how the data exchange is going to be implemented for new or enhanced applications. Developing standardized data exchange means for enhanced applications like new solutions for automatic fault disturbance monitoring, and preparing use cases for such applications is required to gain the required understanding.

This paper addresses the drawbacks of existing practices of fault disturbance monitoring. Need for data exchange standards aimed at interpreting and exchanging data captured in several IEDs, PMUs and RTUs (from different vendors, having different sampling rates and different naming and nomenclature designations for power system components) and correlating proprietary defined power system models is discussed. Although an all-encompassing standard is almost impossible to create, still we can unify all related standards (by unifying complementary data models and harmonizing overlapping standard semantics) to expedite automation of fault disturbance monitoring from data and information integration and exchange perspective.

III. Background

Power system components exposed to different weather, as well as human and animal contacts are subject to several types of faults which are caused by random and unpredictable events. Therefore a power system operator should always remain alert by monitoring disturbances caused by faults. Fault disturbance monitoring consists of the following stages:

1) Detection of event: An event is a disturbed power system condition which can be triggered by several reasons and can be of different types (fault is one of them).
2) Measurement and Alarm (M&A) processing: A major disturbance can trigger numerous alarms most of them may be redundant or false. Alarm processors analyze alarm messages and extract information explaining events. It also uses measurements of analog waveforms to draw final conclusions
3) Fault detection: From the information extracted from the alarm processor, faulted region is detected by cause-effect analysis of alarms and measurements.
4) Fault location: An exact location of fault is required to help the maintenance crew find and repair the faulted equipment as soon as possible. It is calculated using samples from the transient waveforms

A fault location monitoring scheme requires adequate information (measurements data as well as power system modeling information) to perform all these four steps successfully.

Traditionally in a substation, remote terminal units acquire analog measurements such as bus voltages, flows (amps, MW, MVAR), frequency, transformer tap position etc) and status (breaker status) signals and send them to the energy management systems (EMS) in every two to ten seconds. These are called supervisory control and data acquisition system (SCADA) scans and those measurements are gathered in a SCADA database in a centralized location.

With the rapid advancement of technology, large scale deployment of intelligent electronic devices (IEDs) became a reality. When triggered by an event, these computer-based devices can record a huge amount of data (both analog and status) with much higher sampling rate than SCADA scans. Substation database stores these data recorded by IEDs and makes it available for further processing.

The third type of data acquisition devices, phasor measurement units (PMUs) continuously calculate time-synchronized phasors with high sampling rates. Phasor data concentrators (PDC) gather PMU measurements from all the substations to a centralized location.

Besides the measurements and the information extracted from them, a system wide fault disturbance monitoring requires power system model information. EMS applications generally are performed in a less detailed bus-branch model (proprietarily defined) of the entire power system while the detailed substation node-breaker model is also required to analyze data captured and stored in substations.

Fig. 1 shows the data & information flow in an advanced fault disturbance monitoring implementation. It is evident that all four applications need to communicate with all the databases and models and also between them which sometimes results in duplicate information extraction and exchange. As the substations are generally modeled in a detailed node-breaker model while power system static model is less detailed bus-branch model, the names and numeric designations of same power system components described in those two models may become different due to different nomenclature used by various utility groups that maintain given models and data acquisition devices. Nomenclatures used in IED database follows that of substation model while nomenclature used in SCADA database and PDC follows that of static system model. Therefore all these applications require significant number of mappings between all types of data and models to create a unified correlation between the nomenclatures. Sometimes the mapping has to be done manually or semi-automatically resulting in longer operating time.

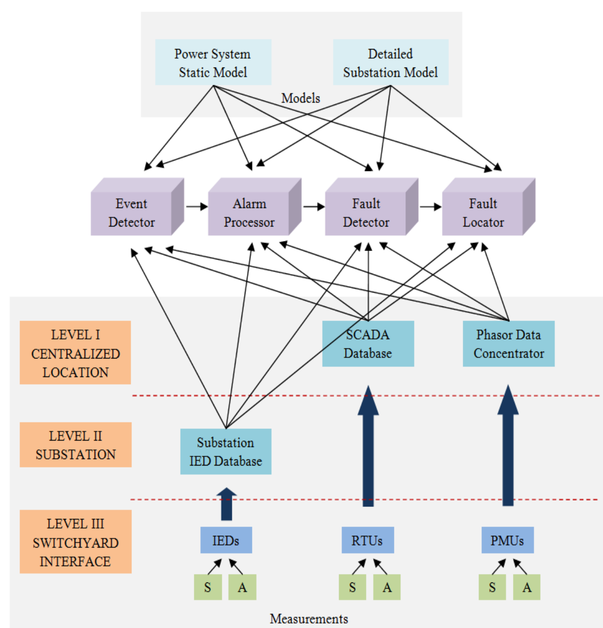

Fig. 1. Data and information flow for fault disturbance monitoring

Therefore to speed up system restoration under fault disturbances, automated fault disturbance monitoring requires handling and exchanging data and information automatically as well as performing all four of these steps automatically. In this paper we will focus mainly on automated handling and exchanging of data and information without any user intervention.

Data exchange standards play a major role in automatic exchange of data and information through different applications and within a database. Several IEEE and IEC data exchange standards are present and already deployed in utility and many others are proposed. Appropriate understanding of these standards is required to implement automatic data and information exchange seamlessly within all of the stages mentioned earlier.

IV. Data exchange standards

Both IEEE and IEC prepared list of standards (in use and proposed) related to smart grid [2-3]. Smart Grid Interoperability Panel also has defined a catalog of standards to achieve interoperability in the proposed smart grid [4]. Several standards [5-15] related to fault disturbance monitoring application are listed in table I. Standards proposed by IEEE and IEC TC57 related to smart grid applications are listed in [14-15].

The Grid Wise Architecture Council (GWAC) proposed a context-setting interoperability framework (GWAC Stack) [16] to address interoperability requirements (to enable automated information sharing within and between different power system applications) in eight levels of interoperability categories. The interoperability levels from the bottom to the top are:

1) **Basic Connectivity:** Mechanism to Establish Physical and Logical Connections of Systems
2) **Network Interoperability:** Exchange Messages between Systems across a Variety of Networks
3) **Syntactic Interoperability:** Understanding of Data Structure in Messages Exchanged between Systems
4) **Semantic Understanding:** Understanding of the Concepts Contained in the Message Data Structures
5) **Business Context:** Relevant Business Knowledge that Applies Semantics with Process Workflow
6) **Business Procedures:** Alignment between Operational Business Processes and Procedures
7) **Business Objectives:** Strategic and Tactical Objectives Shared between Businesses
8) **Economic/Regulatory Policy:** Political and Economic Objectives as Embodied in Policy and Regulation

TABLE I
Standards related to fault disturbance monitoring application

Standard No.	Standard Title	Purpose related to fault disturbance monitoring	Status
IEEE C37.2-2008	IEEE Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations	Device numbering scheme	Approved
IEEE C37.111-1999	IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems	Exchange of transient data captured in IEDs to applications	Approved
IEEE C37.118-2005	IEEE Standard for Synchrophasors for Power Systems	Measurement requirements and data format for PMU measurements and communication between PMU and PDC	Approved
IEEE PC37.118.1	Standard for Synchrophasor Measurements for Power Systems	Measurement requirements and data format for PMU measurements	Proposed
IEEE PC37.118.2	Standard for Synchrophasor Data Transfer for Power Systems	Communication of phasor measurements	Proposed
IEEE C37.232-2007	IEEE Recommended Practice for Naming Time Sequence Data Files	Naming convention of time sequence data files	Approved
IEEE C37.239-2010	IEEE Standard Common Format for Event Data Exchange (COMFEDE) for Power Systems	Common data format for event data exchange	Approved
IEC 61850-6	Communication networks and systems for power utility automation - Part 6: Configuration description language for communication in electrical substations related to IEDs	Specify data format for IEDs. Describes substation equipments and configuration in details	Approved
IEC 61850-90-5	Communication networks and systems for power utility automation Part 90-5: Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118	Integration of PMU (data expressed as in IEEE C37.118) into IEC 61850 environment	Proposed
IEC 61970	Energy management system application program interface (EMS-API)	Application program interfaces to integrate EMS applications by exchanging information. The semantics for this API is called CIM	Approved
IEC 61968	Application integration at electric utilities - System interfaces for distribution management	Same as IEC 61970 but applied to distribution management	Approved
IEC 61588 Ed.2 (2009-02) (IEEE 1588-2008)	Precision Clock Synchronization Protocol for Networked Measurement and Control Systems	Synchronization requirements of PMU measurements	Approved
IEEE PC37.238	IEEE Draft Standard Profile for Use of IEEE Std. 1588 Precision Time Protocol in Power System Applications	Profile for application of IEEE 1588 to power applications	Proposed

These layers can again be sub-grouped in three major categories:

1) Technical: Deals with syntax/format and communication of exchanged data
2) Informational: Deals with semantics of exchanged data
3) Organizational: Deals with pragmatic aspects of interoperability between organizations or their units

According to GWAC interoperability is "the capability of systems or units to provide and receive services and information between each other, and to use the services and information exchanged to operate effectively together in predictable ways without significant user intervention". In other words, interoperability in power system context means correlating data and models expressed in different formats but having similar descriptions seamlessly, extracting useful information from them automatically, and using such information in all power system application consistently. The outcome allows an application with the same functional description to replace the former one, and this should happen without unnecessary complicacy encountered today. Therefore, interoperability requirements enforce automation.

The lower 2 layers of GWAC stack deal with defining connections and exchanging messages through networks thereby providing capability of system or units to provide and receive information between each other. Layers 3-4 enable seamless data exchange by understanding syntax and meaning of the data so exchanged. Upper layers 5-8 focus on utilizing information within an application and between several applications. Fig. 2 shows how data and information related to fault disturbance monitoring flows between all these layers.

In the scope of this paper, we are interested in layers 3-4 (Syntactic interoperability and Semantic understanding) considering unified data and information flow across different databases and applications. Fig. 3 shows the layers 3-4 of GWAC stack with related data exchange standards (related to fault disturbance monitoring).

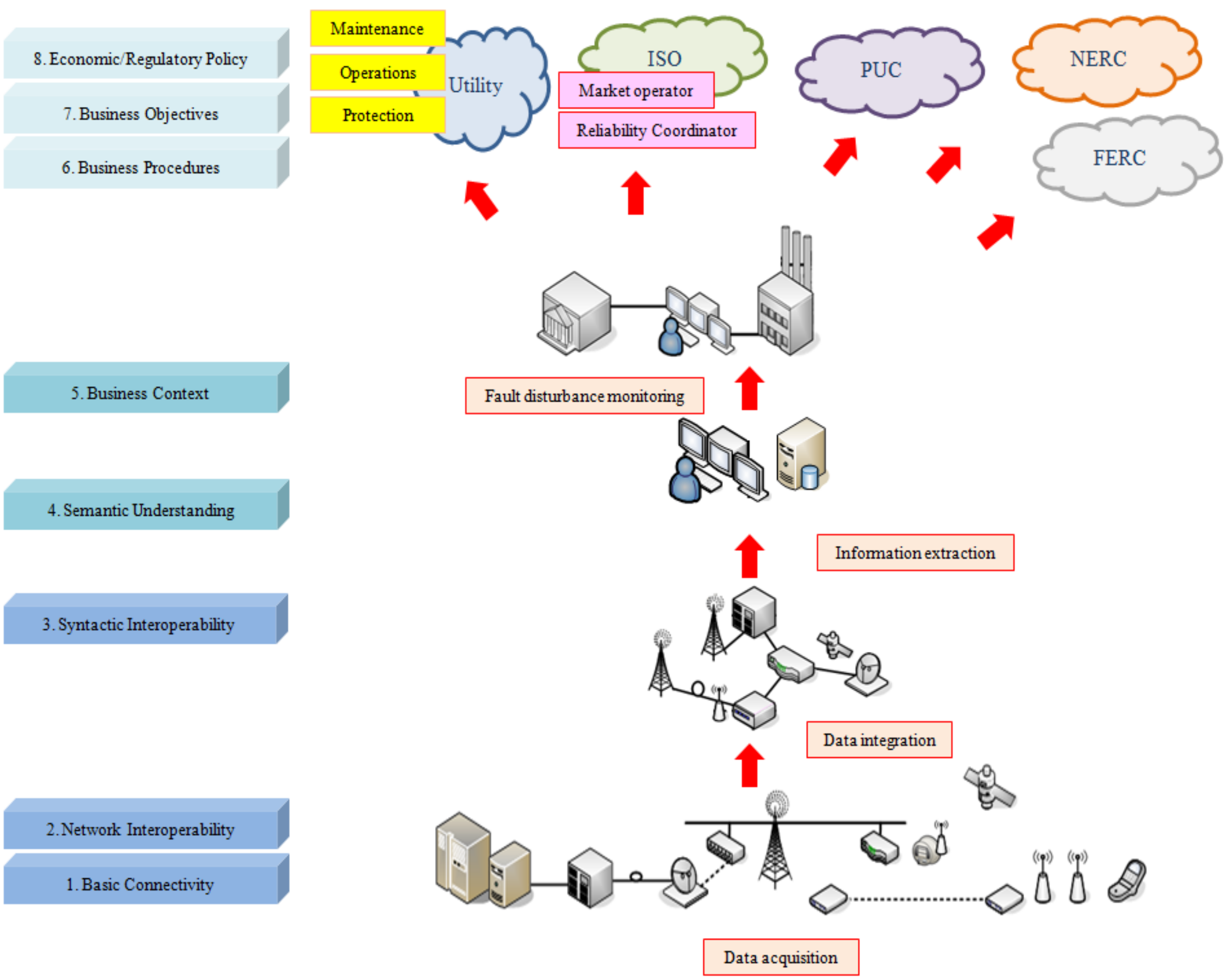

Fig. 2. GWAC Stack with data and information flow related to fault disturbance monitoring (part of the picture adopted from [17])

Syntactic interoperability needs understanding of the syntax for data exchange. Common data format for IEDs are described in IEEE C37.111 and that of PMUs are described in IEEE C37.118 (also in proposed IEEE PC37.118.1). IEEE C37.239 describes common data format for event data exchange. SCL (IEC 61850-6) provides description for substation equipments and their configuration as well as data format for IEDs. IEEE PC37.118.2, which is still in development, covers the communication issues of synchrophasor measurements. IEC TC57 is also working on extending IEC 61850 to a proposed standard IEC 61850-90-5 which will define PMU as a logical node in 61850 environment and cover the communication issues of synchrophasor measurements. If and when approved, IEC 61850-90-5 and IEEE PC37.118.2 will be complementary standards.

Semantic understanding requires interpreting exchanged data. CIM (combined IEC 61968 & 61970) contains semantics for data modeling and information sharing across control center applications. SCL has the semantics of data modeling and sharing inside a substation. IEEE C37.2 and IEEE C37.232 help understanding naming convention of devices and time sequence data files respectively. IEC 61588 (IEEE 1588) helps understanding the synchronization requirements for time-tagged measurements. IEEE PC37.238 describes a common profile for Precision Time Protocol (PTP) for power system applications (extension of IEEE 1588).

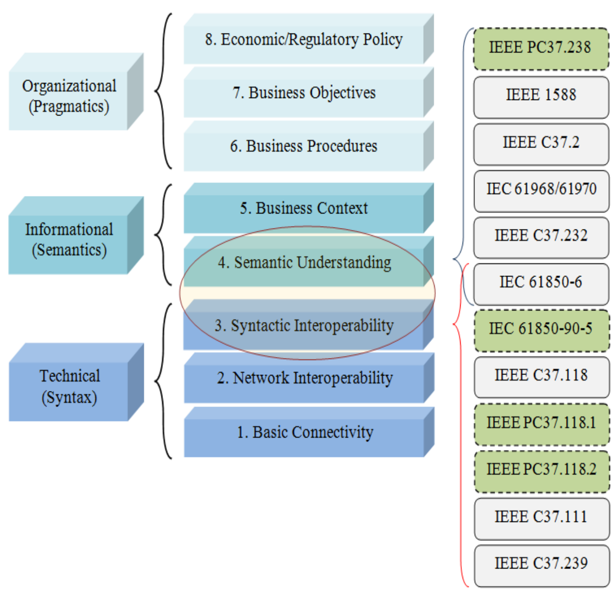

Fig. 3. GWAC Stack with associated standards for data exchange

All these standards though somewhat overlapping can be used for understanding the syntax and interpretation of exchanged data. Several harmonization efforts are in practice, for example EPRI worked on defining an unified semantic model to harmonize CIM and IEC- 61850 [18], harmonization of IEEE C37.118 with IEC 61850 and Precision Time Synchronization is being performed by priority action plan - 13 (PAP 13) by SGIP [19].

V. Proposed Automatic Fault Disturbance Monitoring

An automatic fault disturbance monitoring scheme is proposed using unified generalized representation of data and power system model. As shown in Fig. 4, there are several options how to represent PMU data. CIM will be used to describe power system static model and SCADA measurements captured by RTUs. In the first option, PMU measurements expressed in IEEE C37.118 (will be extended to IEEE PC37.118.1) will need to be correlated to CIM. In the second option, PMU measurements expressed in IEEE C37.118 can be represented in SCL with proposed standards IEC 61850-90-5 or IEEE PC37.118.2. The measurements captured by IEDs expressed in COMTRADE may also be represented in SCL with the help of detailed substation model. Therefore, all measurements and models are expressed in either CIM or SCL. Mapping is required only to correlate between the model and measurements represented in CIM and that of SCL to obtain a uniform representation. All the proposed approaches can use this unified representation of model and measurements.

Therefore in the proposed application amount of data and information exchange between different databases and applications is clearly reduced from the existing approach.

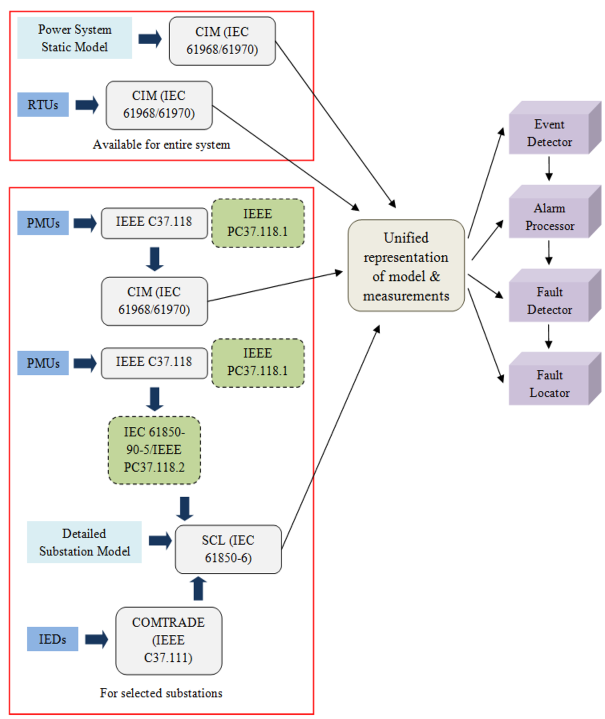

Fig. 4. Data flow for fault disturbance monitoring using unified model representation of data and power system.

VI. Conclusions

Fault disturbance monitoring should be done automatically to reduce restoration time as well as efficiently to handle myriad of data recorded (unmanageable by manual effort) by advanced substation devices such as RTUs, DPRs, DFRs PMUs and other IEDs. To assure such solutions work as expected, the following will need to be resolved:

1) To properly use the data, appropriate information

extraction should be performed which requires consistent and comprehensive understanding of data (syntax and semantics). The GWAC stack is proposed as the framework for achieving such an understanding.

2) Several standards are in use or proposed, which can provide full understanding of syntax and semantics for our application. These standards may have overlapping specifications when end-to-end solutions are considered. Selecting and harmonizing the standards is needed in our application and several possible approaches are pointed out.

3) A unified generalized data and power system model definition to correlate overlapping and complementary standards and extract appropriate information for fault disturbance monitoring is needed. The paper outlines how this may be done to significantly simplify the implementation.

VII. References

[1] NIST, NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, NIST Special Publication 1108, January 2010. [Online]. Available: http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf

[2] IEEE, Smart Grid Standards. [Online]. Available: http://smartgrid.ieee.org/standards

[3] IEC, Core IEC Stabdards. [Online]. Available: http://www.iec.ch/smartgrid/standards/

[4] SGIP, SGIP Catelog of Standards. [Online]. Available: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPCatalogOfStandards

[5] *IEEE Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations*, IEEE Standard C37.2-2008, Oct 2008.

[6] *IEEE Standard Common Format for Transient Data Exchange*, IEEE Standard C37.111-1999, March 1999.

[7] *IEEE Standard for Synchrophasors for Power Systems*, IEEE Standard C37.118-2005, March 2006.

[8] *IEEE Recommended Practice for Naming Time Sequence Data Files*, IEEE Standard C37.232-2007, August 2007.

[9] *IEEE Standard Common Format for Event Data Exchange (COMFEDE) for Power Systems*, IEEE Standard C37.239-2010, Nov 2010.

[10] *Communication networks and systems for power utility automation - Part 6: Configuration description language for communication in electrical substations related to IEDs*, IEC Standard 61850-6,

[11] *Energy management system application program interface (EMS-API)*, IEC Standard 61970,

[12] *Application integration at electric utilities - System interfaces for distribution management*, IEC Standard 61968,

[13] *Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*, IEC Standard 61588 Ed.2 (2009-02) (IEEE Standard 1588™-2008)

[14] IEEE, IEEE Proposed Standards Related to Smart Grid. [Online]. Available: http://smartgrid.ieee.org/standards/ieee-proposed-standards-related-to-smart-grid

[15] IEC, TC 57 Working Documents since 2010-05-25. [Online]. Available: http://www.iec.ch/dyn/www/f?p=103:30:0::::FSP_ORG_ID,FSP_LANG_ID:1273,25

[16] The GridWise Architecture Council, GridWise® Interoperability Context-Setting Framework, March 2008. [Online]. Available: http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf

[17] Grant Gilchrist, “An Overview of Smart Grid Standards” (PPT). [Online]. Available: http://cio.nist.gov/esd/emaildir/lists/t_and_d_interop/pdf00001.pdf

[18] EPRI, Harmonizing the International Electrotechnical Commission Common Information Model (CIM) and 61850 Standards via a Unified Model: Key to Achieve Smart Grid Interoperability Objectives. EPRI, Palo Alto, CA: 2010. 1020098.

[19] PAP13: Harmonization of IEEE C37.118 with IEC 61850 and Precision Time Synchronization. [Online]. Available: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/PAP1361850C27118HarmSynch

VIII. Biographies

Mladen Kezunovic (S’77-M’80–SM’85–F’99) received the Dipl. Ing., M.S. and Ph.D. degrees in electrical engineering in 1974, 1977 and 1980, respectively. Currently, he is the Eugene E. Webb Professor and Site Director of Power Engineering Research Center (PSerc), an NSF I/UCRC.at Texas A&M University He worked for Westinghouse Electric Corp., Pittsburgh, PA, 1979-1980 and the Energoinvest Company, in Europe 1980-1986, and spent a sabbatical at EdF in Clamart 1999-2000. He was also a Visiting Professor at Washington State University, Pullman, 1986-1987 and The University of Hong Kong, fall of 2007. His main research interests are digital simulators and simulation methods for relay testing as well as application of intelligent methods to power system monitoring, control, and protection. Dr. Kezunovic is a Fellow of the IEEE, member of CIGRE and Registered Professional Engineer in Texas.

Papiya Dutta (S’08) received her Bachelor’s of Engineering in Electrical Engineering degree from Jadavpur University, India in 2003. She received MS (by research) degree from IIT Kharagpur, India from 2007. She is currently a graduate student in Texas A & M University, USA. Her research interests include fault location, substation automation, smart grid, plug-in hybrid vehicles, and evolutionary algorithms for optimization.