An Overview of the IEEE Standard C37.118.2—Synchrophasor Data Transfer for Power Systems

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***Abstract*—Synchrophasor Standards have evolved since the introduction of the first one, IEEE Standard 1344, in 1995. IEEE Standard C37.118-2005 introduced measurement accuracy under steady state conditions as well as interference rejection. In 2009, the IEEE started a joint project with IEC to harmonize real time communications in IEEE Standard C37.118-2005 with the IEC 61850 communication standard. These efforts led to the need to split the C37.118 into 2 different standards: IEEE Standard C37.118.1-2011 that now includes performance of synchrophasors under dynamic systems conditions; and IEEE Standard C37.118.2-2011 Synchrophasor Data Transfer for Power Systems, the object of this paper.**

***Index Terms*—Data concentrator, DC, PDC, phasor data concentrator, phasor measurement unit, PMU, synchronized phasor, synchrophasor.**

I. SYNCHROPHASOR STANDARDS

A. Previous Synchrophasors Standards

1) IEEE Standard 1344-1995 [1]:

THE first IEEE Standard for Synchrophasors for Power Systems was completed in 1995. It specified synchronization to UTC time, time accuracy, and waveform sampling requirements. It also set the phase angle reference to the second rollover, coincident with a cosine synchronized to UTC. IEEE 1344 did not support transmission hierarchy; messaging was strictly from a phasor measurement unit (PMU) to another device, such as a recording application.

An annex established extensions to the IRIG-B standard to cover year, time quality, daylight saving time, local time offset, and leap second information. It also recommended bi-phase encoding which is more compatible with modern communications than the amplitude modulation that was available them.

When IEEE 1344 came up for renewal in 2000, the working group decided to revisit all aspects of the standard. This included creating a method for evaluating the synchrophasor measurement and defining a communication protocol to operate over networks.

2) IEEE C37.118-2005 [2]: IEEE Standard C37.118-2005 replaced IEEE 1344. The most significant changes were the introduction of a method of evaluating measurement performance, and a messaging system that was usable for synchrophasor systems.

C37.118-2005 introduced the total vector error (TVE) criterion for the evaluation of synchrophasor measurements. This step shifted focus from the measurement method to measurement results, allowing the use of any algorithm or method that produces good results. C37.118-2005 specified accuracy requirements for steady state conditions.

In C37.118-2005 the messaging was essentially redone. The use of data, config, header, and command messages was retained. A consistent header was added, the data section was made extensible to include multiple PMU data, and an analog data type was added to the original phasor, frequency, and digital data types. The PMU ID was reduced to 16 bits and included on all messages to allow multiple message stream communication. This system is widely specified and used throughout the world.

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B. Revision of Standard 37.118-2005

It was recognized that in addition to specifying steady state error in the Standard 37.118—2005, specifications for dynamic performance of synchrophasor measurements were needed. In addition, there were a few minor errors that needed correction, and a need to better define the frequency measurement. Hence, a working group was established to revise C37.118-2005.

Many synchrophasor measurement systems were installed or in the process of deployment worldwide. The majority of these systems adhered to the C37.118-2005 Standard, although several older installations followed the IEEE 1344 or other proprietary protocols. With this large installed base, the WG undertook revision of the Standard with a guideline of maintaining backward compatibility to minimize disruption of existing systems.

In order to gain a wider international acceptance, a coordination effort was undertaken with the International Electrotechnical Commission (IEC), a European based standardization body. Dual logo is a process between IEEE and IEC to adapt standards made by one body into a standard by the other.

The IEEE pursued a dual logo adoption by the IEC for the synchrophasor standard, C37.118-2005. However, since it combines measurement and communication functions in one standard, it was not acceptable since IEC separates these functions into different standards.

In consideration of this harmonization work and the fact there could be some benefit to adapting the measurement clauses to IEC, the IEEE Working Group decided to split the content of C37.118-2005 into time separate standards, one that defines synchrophasor measurement and performance and another that addresses the synchrophasor data transfer. IEC Technical committee 57 (TC57) was already working with the communication portion under WG10. IEC Technical Committee 95 (TC95) deals with measuring relays and thus would deal with synchrophasor measurements. The split thus enabled a smooth transition to harmonization with the IEC.

C37.118.1-2011 [3] is the new IEEE standard for synchrophasor measurements. It is based on the portion of C37.118-2005 that covered synchrophasor measurements. It includes definitions that have been expanded to cover synchrophasors in dynamic conditions as well as frequency and rate of change of frequency (ROCOF). The steady state performance requirements have been improved and requirements have been added for dynamic conditions. Both frequency and ROCOF performance requirements were added.

C37.118.2-2011 [4] is the new IEEE standard for synchrophasor data transfer. It is based on the portion of C37.118-2005 that covered data communication. While some improvements over the 2005 version were possible, most of the possible extensions and enhancements were not included in order to maintain backward compatibility. It was further assumed that the proposed new features and enhancements would be achieved in the future by migration to the IEC 61850 standard suite which already includes many of these desired features. Consequently it is essentially unchanged from the 2005 standard, but includes a new configuration message that will handle large data sets as well as improved naming, scaling, and PMU parameter reporting. The standard actually defines a messaging system rather than a communication system. This allows using any communication system to carry the messages. An annex in the Standard describes the current implementation that is commonly used.

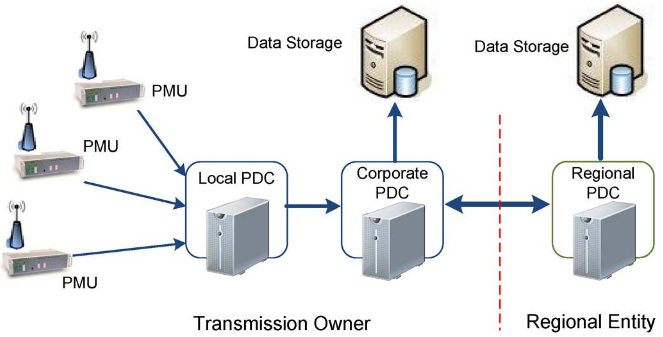

Fig. 1. Typical phasor measurement system.

II. SYNCHROPHASOR MEASUREMENT SYSTEM OVERVIEW AND DEVELOPMENT

Synchrophasor measurement definitions and performance requirements are specified in IEEE C37.118.1. It defines steady-state and dynamic performance requirements for synchrophasors, frequency and ROCOF measurements. It also defines the requirements for synchronization and data rates, which are important for the transfer of these measurements.

A simple synchrophasor network consists of several phasor measurement units (PMUs) and a phasor data concentrator (PDC) as shown in Fig. 1. Typically, many PMUs located at various key substations gather data and send it in real time to a PDC at a location where the data is aggregated and analyzed. If multiple *intelligent electronic devices* (IEDs) in a substation provide synchrophasor measurements, a PDC may be locally deployed at the substation. The data collected by PDCs may be used to support many applications, ranging from visualization of information and alarms for situational awareness, to ones that provide sophisticated analytical, control, or protection functionality. Applications such as dynamics monitoring use full-resolution real-time data along with grid models to support both operation and planning functions. Some of the applications display measured voltages, currents and frequency, as well as derived quantities like real and reactive power flows. Several applications also perform analytics, like oscillation detection and modal damping and display this information for real-time operations. Many PDCs belonging to different utilities can be connected to a common central PDC to aggregate data across the utilities, in order to provide an interconnection-wide snapshot of the power grid measurements.

1) North American Synchrophasor System Development: Synchrophasor technology was developed conceptually over 20 years ago. However, its commercialization and subsequent deployment had been quite slow over the years due to the limited capabilities of existing communication links between substations and control centers, and a scarcity of applications utilizing synchrophasor data. Early adopters were primarily in the western United States interconnection. The eastern interconnection did not have much involvement until the release of the August 14, 2003 blackout report that indicated that the synchrophasor technology would have been extremely useful for subsequent analysis, and potentially could have made operators aware of situations over wide areas of the interconnection and averted the blackout. After the blackout, significant interest developed in the east and this interest expanded and ultimately led to the establishment of the North American Synchrophasor Initiative (NASPI). NASPI is a collaborative effort between the U.S. Department of Energy, the North American Electric Reliability Corporation, and North American electric utilities, vendors, consultants, federal and private researchers and academics. Its purpose is to improve power system reliability and visibility through wide area measurement and control. This is being pursued in North America through deployment of synchrophasor data systems.

There were approximately 150 networked PMUs deployed across the United States by late 2009 providing wide area visibility It is anticipated that within several years the number of installed and connected PMUs will exceed 1000 units.

2) Synchrophasor Deployment Outside North America: PMUs were introduced to China in the late 1990s. Deployment of Synchrophasor Systems started in 2002. As of 2012, there were about 2000 PMUs commissioned and reporting to central data collection. China has developed their own synchrophasor standards which are similar to the IEEE standards. PMU measurement requirements are similar but phase angle and magnitude are evaluated separately. In communications, their standards cover every aspect of the communication system as well as application requirements.

India initiated a project in 2010 for synchrophasor measurements that span the entire grid. All measurements will be reported in real-time to local control centers and forwarded to regional and national monitoring centers. In 2012 there are about 50 PMUs installed and reporting. The expectation is to achieve coverage of all 220 kV and above stations with a total of about 900 PMUs.

There are a number of phasor measurement systems installed in Europe, including systems in Norway, Sweden, Denmark, Finland, Germany, Switzerland, Slovenia, Spain, and Russia. These systems are primarily established and reporting to a control center in each country. Some data exchanges between countries have been established. In 2012 these systems include a total of more than 100 PMUs.

A number of phasor measurement systems are planned in South America, including Brazil, Chile, and Columbia. In 2012 these systems are small or in a pilot stage with less than 50 networked PMUs in operation.

III. SYNCHROPHASOR MESSAGE FORMAT

A. Message Framework

The C37.118.2 Standard describes four message types related to the configuration and transfer of real-time data from a PMU or PDC. These are *data*, *configuration*, *header*, and *command* messages. *Data*, *configuration*, and *header* are sent from data source which can be a PMU or a PDC. Commands are sent from the data receiver to the PMU/PDC to control the data flow or request information. The first three convey PMU measurements, the configuration of the data (e.g. channel numbers, types, scaling) in machine-readable format, and, configuration or descriptive information in human-readable format, respectively. *Command* messages are machine-readable and sent to the PMU/PDC for control or to request configuration. The Standard defines the specific configuration and content of each message including frame synchronization and checksum. Examples and detailed descriptions are provided in the Standard and its Appendices.

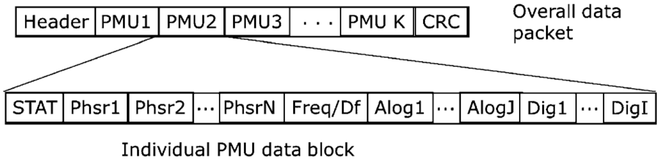

Fig. 2. PMU data packet organization.

B. Data Frame

The *data* frame contains the real-time data measured or calculated by the PMU/PDC. The message includes an identification header, message length, the source ID of the message, a time stamp, detailed status information regarding the data and its source and quality; and, the "data." The "data" includes phasors (in rectangular or polar format), frequency, rate of change of frequency, and analog and digital quantities. All data except digital (Boolean) quantities may be in fixed or floating point format. The status word in the message indicates data validity, time source quality, specific data conditions (trigger types for example) and is meant to be interpreted by a receiving device or application that uses the data. The data frame may contain the data from a single PMU or several PMUs. The data from each PMU is organized as a block of data headed with the status of that block of data as shown in Fig. 2. This allows data from many PMUs to be correlated to a particular time stamp and transmitted as an overall synchronized data frame.

C. Configuration Frame

1) Config1: The configuration frame "CFG-1" denotes the PMU/PDC capability, indicating all the data that the PMU/PDC is capable of reporting. It is identical in the 2005 and 2011 Standards. CFG-1 is identified by bits 6-4 (value "010") of the frame synchronization (SYNC) word. CFG-1 is fixed length frame with 19 fields (excluding data rate and CRC). Fields 8 thorough 19 define the capability of each PMU and are repeated to include all PMUs in the data frame. Table 8 in 2011 version of the standard and table 9 in 2005 version of the standard define the organization of CFG-1 frame.

2) Config2: The configuration frame "CFG-2" indicates the measurements currently being reported (transmitted) in the data frame. It is identical in 2005 and 2011 versions of the standard. CFG-2 is identified by bits 6-4 (value "011") of the frame synchronization (SYNC) word. CFG-2 is a fixed length frame with 19 fields (excluding data rate and CRC). Fields 8 thorough 19 define the included measurements from each PMU and are repeated to include all PMUs in the data frame. Table 8 in 2011 version of the standard and table 9 in 2005 version of the standard define the organization of CFG-2 frame.

3) Config3: The configuration frame "CFG-3" is added in the 2011 revision of the standard and its use is optional (a device without this implemented is still considered compliant with the standard). CFG-3 has similar purpose as in CFG-2, as it indicates the measurements currently being reported in the data frame. CFG-3 differs from CFG-2 by being extensible, having variable length name fields (which are fixed at 16 bytes in CFG-2) and includes added PMU and signal information. CFG-3 is identified by bits 6-4 (value "101") of the frame synchronization (SYNC) word.

CFG-3 is a variable length frame with 27 fields (excluding data rate and CRC). Fields 9 thorough 27 define the included measurements from each PMU. This data block is repeated to include all PMUs in the data frame. The variable length allows more efficient transfer of data. Table 10 in the standard defines the organization of CFG-3 frame.

D. Header Frame

Header Frame is sent from PMU/PDC to the host (PDC) system. It contains information about sender (PMU/PDC) in plain ASCII format. There is no change in the format of header frame as compare to C37.118-2005 standard.

E. Command Frame

The command frame is sent by the host to the PMU/PDC to start or stop transmission, or to request configuration data in the form of configuration or header frames [1]. Command frames are always sent from the data collecting device to the data sending device. The IDCODE in the command frame identifies the particular data stream the command applies to rather than the data sending device itself. This is because a device may send several data streams, including more than one stream to the same destination device.

A new command "Send CFG-3 frame" has been added for requesting the configuration frame 3(CFG-3) from the data sending device. However, this command is optional like the CFG-3 frame.

Unused bits in these commands are reserved and may be used for further command information in future revisions of the standard. An extended frame command type is provided for user-defined functions such as PMU configuration or remote controls.

A part of the reserved command space has been set aside for user designation. The command length is two bytes, i.e., 16 bits, designated 0 to 15. All commands where bits 8 to 11 are nonzero have been reserved for user designation. Users may use these bits for assigning their own customized commands. All other bytes are reserved for future use.

F. Informative Annexes

There are six annexes included in the standard. They are: Bibliography, Cyclic redundancy codes, System communications considerations, Message examples, synchrophasor message mapping into communications, and synchrophasor communication methods for Internet Protocol (IP). The first couple of annexes are fairly straight forward in content. The remaining four get into more details associated with their specific topics. Each of them provides sufficient detail on how to apply each topic.

Annex C addresses issues related to bandwidth, delay and their causes. Since many of the applications of synchrophasor data are expected to be run in near real time, having a thorough understanding of all the delays is important. Annex D gives example messages covering the specifics related to the four message types: *data*, *configuration*, *header*, and *command*. Much of the industry focus has been on data; however understanding the other message types is important to field technicians and future applications. Annex E describes how to map the message into both serial and network communications using IP. Recent installations have predominantly used IP communications, but being aware of the serial option may be useful in situations where IP is unavailable. The final Annex F describes synchrophasor communications using IP with standard Transmission Control Protocol (TCP), User Datagram Protocol (UDP), and TCP/UDP options. IP over Ethernet is the most widely used communication choice. Even though not formally standardized, these implementations have proved to be highly interoperable.

IV. APPLICATION OF DATA TRANSFER

A. Messaging System

C37.118.2-2011 describes a system of messaging and the message contents. The messages can be carried over any communication system using any protocol that will support bandwidth, latency, and reliability requirements of the synchrophasor system it serves.

B. Mapping Into Communication Systems

Normative Annex E requires that C37.118.2 messages are carried in their entirety when they are mapped into a communication protocol. This assures that the applications that send and receive the data can use the same commands for input and output regardless of the underlying communication protocol. Connection establishment and management, retransmission, security, and all other communication issues are left to the communication system protocol. This allows adaptation of synchrophasor data transfer to available means without disruption of applications that use the data. Annex E describes the use of RS-232 serial and Internet Protocol (IP) for message transfer. Annex F provides a detailed description of the most common use of the IP for data transfer. Other communication protocols can be used for carrying C37.118.2 messages

V. FUTURE NEEDS

Evolving synchrophasor networks have a potential to be used for any control related requirement of the power system. The existing hardware will likely be replaced as the application requirements for synchrophasor performance out strip the legacy hardware's ability. However as long as the data from the existing equipment can still be used, the standard will provide an integration path. Communication networks in general will continue to evolve and may be radically different in the future becoming fast broadband platforms where synchrophasors could become a required consumer service similar to internet access today. Since synchrophasors are streaming data and sampling rates will increase, new data storage technology will be required.

As other synchrophasor data transfer protocols, like IEC 61850-90-5 [5] are implemented, implementation agreements among various protocols to be able to coexist in the same system will be required. For example, IEC TC57 WG10 is developing an implementation agreement to define in detail the contents of the 61850-90-5 messages; it is very similar to the C37.118 data messages.

Since the C37.118-2005 was originally published, several needs were identified that have been addressed in C37.118.2-2011. Some of the desired features can be implemented by utilizing the user definable features allowed by the standard. However, several other desirable features for synchrophasor data systems that would be highly useful could not be addressed within the constraints of backward compatibility and development time. These features are required for more complete functionality and can be incorporated in future revisions of C37.118.2. These features include:

A. *Configuration Change Command*

The standard does not include a method for a data destination (e.g.—a control center PDC) to send a configuration change command to a data source (e.g.—a substation PDC). If this feature is implemented, it will allow control center PDCs to configure the whole synchrophasor data network by a set of configuration change commands to constituent PDCs (at substations). These, in turn, can decode/divide and send corresponding configuration change commands to their constituent PMUs. In implementing such features, security as well as providing all the required configurations and other registry information to data consumers in the entire system will need to be addressed.

B. *Missing Data Request*

If a data frame from a PMU/PDC arrives too late at a PDC for an outgoing stream, the data is essentially lost. A mechanism to forward such data would be desirable.

C. *Data Aggregation Without Time Alignment*

The data transfer protocol of C37.118.2 specifies aggregation of data with the same time stamp in a data frame, and does not support data with different time stamps within same frames, which may be desirable in systems with widely varying latencies from different data sources.

VI. CONCLUSION

Early PMU installations were hampered by the limitations of reliability and bandwidth of existing communication infrastructure. Evolving standards have provided a base for common PMU performance and data exchange. Serial links have been replaced with high-bandwidth network connections. Currently, large numbers of PMUs provide real time data to a variety of nodes to support system operation and analysis. This paper has outlined some of the historical perspective of this evolution; described a standard for PMU data exchange that should serve the Power Industry for many years; and, has outlined some extensions that may be addressed in the future.

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