MODERN TECHNOLOGIES FOR POWER SYSTEMS MONITORING

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REZUMAT. Operatorii sistemelor electroenergetice pot obține măsurări fazoriale din sistem prin instalarea de dispozitive de masurări fazoriale în nodurile sistemului. Una din problemele ce guverneaza instalarea acestor tehnologii este aceea a modalității de obținere în timp real a informațiilor furnizate de aceste dispozitive şi modul de stocare a acestor date pentru analize post avarie sau alte aplicații cum ar fi estimarea parametrilor liniilor electrice, incarcarea dinamică a acestora pentru a reduce costul congestiilor din sistem şi cresterea duratei de viața a echipamentului.

Cuvinte cheie: sistem electroenergetic, masurări fazoriale sincronizate, DMF, GPS.

ABSTRACT. Power system operators can obtain synchrophasor measurements from their systems by installing phasor measurement units (PMUs). One concern when installing this new technology is how to get real-time information to a central location and how to store data for further analysis that can reveal useful information for power system restoration and other applications such as transmission line parameter estimation, dynamic thermal rating to reduce congestion costs and increasing asset utilization.

Keywords: power systems, synchrophasor, PMU, GPS.

1. INTRODUCTION

As the electric power grid continues to expand and as transmission lines are pushed to their operating limits, the dynamic operation of the power system is becoming more a concern and more difficult to accurately model.

Synchronized phasors (synchrophasors) provide a real-time measurement of electrical quantities from across the power system. Applications include wide-area control, system model validation, determining stability margins, maximizing stable system loading, islanding detection, system-wide disturbance recording, and visualization of dynamic system response [2].

The concept of synchrophasor was introduced in the 1980s and standardized for the first time with the standard IEEE 1344. That measurement concept was further developed in the IEEE C37.118 standard that was completed in 2005. In 2011 the IEEE C37.118 standard has sufferd a new revision to fully define the measurement in all conditions including dynamic changes in the power system. This new revised standard has been split into two standards, one with measurement requirements and the other with the data transfer requirements. This split facilitates harmonization of IEEE C37.118-2005 with the IEC 61850 standard [1].

The paper will present a review of the IEEE C37.118-2011.2 communications standard defined for sending synchrophasor information and will propose an implementation of this standard in a computer application to achieve, display and storage data received from PMUs.

2. SYNCHROPHASOR DEFINITION

A phasor is a quantity with magnitude and phase (with respect to a reference) that is used to represent a sinusoidal signal. The sinusoidal signal waveform definened as shown in equation (1):

$$x(t) = X_m \cos(\omega t + \varphi) \tag{1}$$

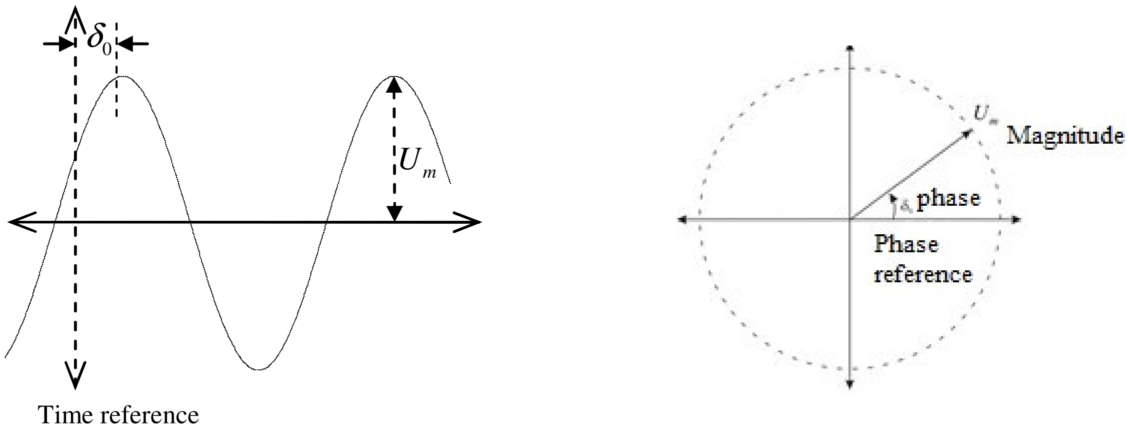
is commonly represented as the phasor shown in equation (2):

$$X = X_m \cdot e^{j\varphi} = X_m(\cos\ \varphi + \text{j}\ \sin\ \varphi) = \text{X}_r + jX_i \tag{2}$$

where X_m is the magnitude in the rms value, $X_m / \sqrt{2}$, of the waveform; $\omega = 2\pi f$ is the angular frequency; r and i subscripts signifying real and imaginary part of a complex value in rectangular components; φ is the instantaneous phase angle of the phasor. It is important to mention that the phasor is defined for the angular frequency ω and evaluations with other phasors must be done with the same time scale and frequency.

In Fig. 1 it is shown the phasor representation of a sinusoidal signal waveform in which quatity δ_0 represent the distance between the time reference and peek of the signal and, if it is used as phasor representation, the same quatity δ_0 represents angle between phase reference and the asociated phasor.

Phasor technology is deemed to be the most promising technology of tomorrow for power system monitoring and control due to its ability to collect information as voltage and current phasors from widely dispersed locations, in synchronism with GPS, and to use them for a wide range of power system applications. This synchronized sampling process applied with different waveforms is based on a common reference for the phasor calculation at all different locations (Fig. 2) [4].



a) Sinusoidal waveform of a signal

b) Polar representation of the same signal

Fig. 1. Phasor representation of sinusoidal signals.

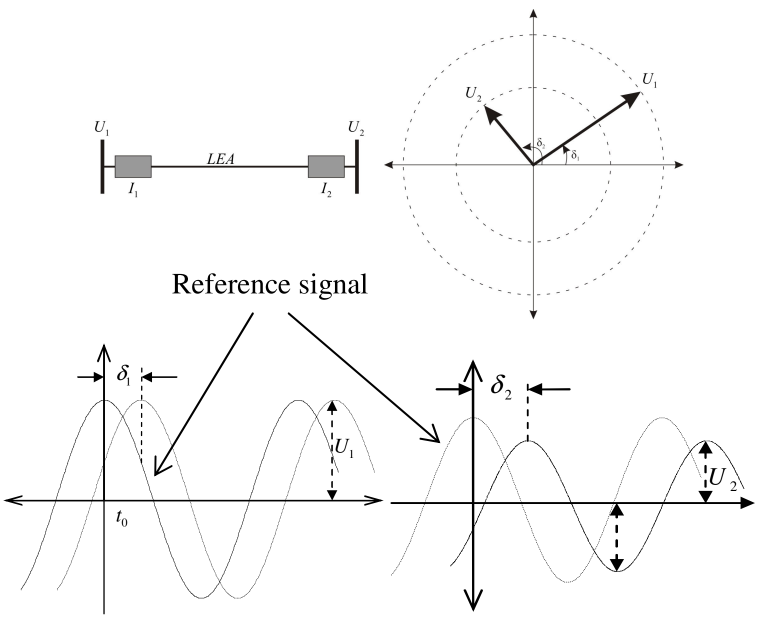


Fig. 2. Common reference for the phasor calculations at different locations.

3. PHASOR MEASUREMENT UNIT

A Phasor Measurement Unit is a device which measures the electrical waves on an electricity grid, using a common time source for synchronization. Time synchronization allows synchronized real-time measurements of multiple remote measurement points on the grid. A PMU can be a dedicated device, or the PMU function can be incorporated into a protective relay or other device.

A PMU can measure 50/60 Hz AC waveforms (voltages and currents) typically at a rate of 48 samples per cycle (2880 samples per second). The analog AC waveforms are digitized by an Analog to Digital converter for each phase. A phase-lock oscillator along with a Global Positioning System (GPS) reference source provides the needed high-speed synchronized sampling with 1 microsecond accuracy. The resultant time tagged phasors can be transmitted to a local or remote receiver at rates up to 60 samples per second[3].

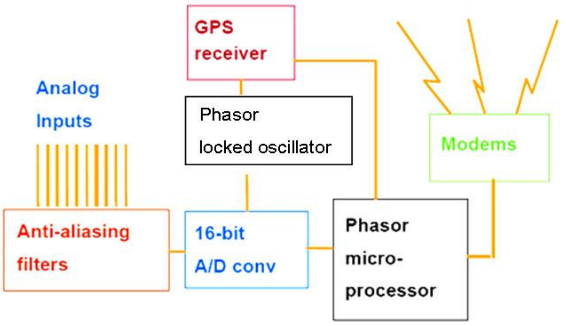


Fig. 3. Phasor Measurement Unit Block Diagram [3].

Numerous manufacturers of digital fault recorders (DFR) and PMUs are present today on the market, such as SEL, Qualitrol or Arbiter. Fig. 4 shown the IDM T1 digital fault recorder manufactured by Qualitrol that was used for tests in this paper.

The IDM digital fault recorder is a distributed multi functional data acquisition system designed to address the data recording requirements of a modern distribution or transmission substation [4].

Fig. 4. Example of PMU produced by Qualitrol.

The IDM records three phase voltages and currents from the substation measurement transformers. Data are synchronized to a time reference signal - the one pulse per second (1 PPS) - using an internal GPS clock. Using these voltage and current waveforms as direct inputs the IDM fault recorder calculates values for positive phase sequence magnitude and phase angle. These values are sent back to a central point (an individual processor or a Phasor Data Concentrator – PDC) where the difference between phasors from different locations (nodes) on the transmission network can be monitored and further used in different frameworks. The accuracy of the IDM is as high as 0.1degrees. A local storage unit (LSU) can be used to collect phasor data from different IDM fault recorders installed at the same location (e.g. a substation); this LSU can convert calculated phase values into the C37.118 protocol.

Fig. 5 shows an example of two PMUs placement at the both ends of a transmission line and how the measuments data are transmitted to a control center using IEEE C37.118 standard and a communication network.

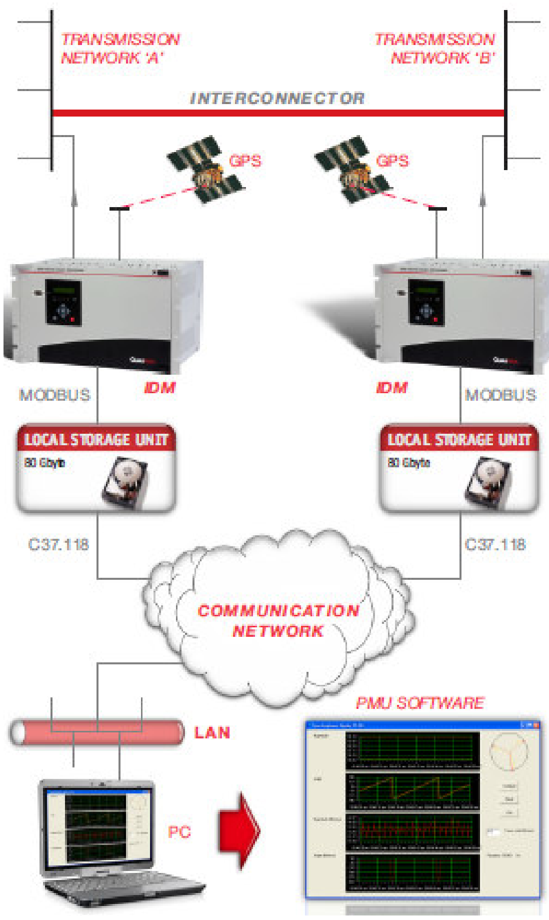


Fig. 5. Example of PMUs placement [4].

4. IEEE C37.118 MESSAGE FORMATS

There are four types of IEEE C37.118 message frames [5]:

- Data
- Configuration
- Command
- Header

Command frames are sent to PMUs to request or input configuration and header frames or to start / stop the data transmission flow. Data frames refer to the actual data being sent using different formatting codes (integer, floating-point, Boolean).

Configuration frames are used to encode information describing how to interpret the raw data bytes. Header frames are considered obsolete, but can be used to transmit any general information about the PMU as text strings.

All the IEEE C37.118 type of frames have some common fields in the beginning and a cyclic redundancy checksum at the end. The common fields of frames are detailed in Table 1 and the frame transmission order is always the same as it is shown in the diagram from Fig. 6.

Each frame message includes a time stamp (or timing information) that is accurate to better than 1 microsecond. This is located in the SOC and FRACSEC fields and because all the PMUs are connected to GPS it provides time-aligned data from across the entire system. The FRACSEC field contains also 4 bits that encode the status of the GPS clock. These bits describes three cases: (i) the GPS clock is locked and operating as expected, (ii) the clock is unlocked and operating with reported time accuracy or (iii) there is an error and the clock time is not reliable. Thus the FRACSEC field provides a proof that each data message is accurately time-stamped.

Table 1

Common fields in IEEE C37.118 frames

Field	Size	Comments
SYNC	2	Provides synchronization and frame type indication; Bits 4–6 designate the frame type
FRAMESIZE	2	Communicates the total number of bytes in the frame, including the CHK bits
IDCODE	2	Identifies the individual PMU that is sending (or receiving) the message
SOC	4	second of century provide the time stamp based on the count starting at midnight Jan. 1, 1970
FRACSEC	4	Includes a 24-bit actual fraction of a second integer and an 8-bit time-quality flag

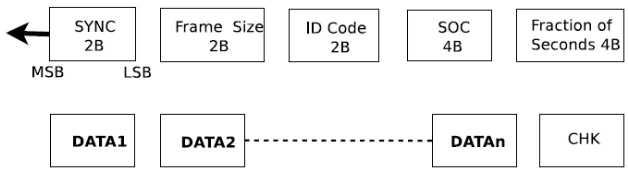


Fig. 6. Transmission order of IEEE C37.118 frame.

A significant amount of useful information is sent as part of the 2-byte, or 16-bit, status word within a data frame. The bits that may be most useful are listed in Table 2 [1].

Table 2

Detailed STAT bits in data frame

Bit	Comments	Status
0 - 3	Identifies the initial cause of a trigger	Triggers include manual, magnitude high, frequency high/low, phase angle difference, df/dt high, digital, or user-defined triggers
4 - 5	Communicates if the PMU is synchronized and locked to the clock and, if not, how long it has been unlocked	Status includes: locked, unlocked for 10, 100,1000 seconds
10	Indicates that the PMU configuration has been changed	Sets a flag for 1 minute when the configuration has been changed
11	PMU trigger detected	Single bit indicates if any of the PMU triggers have occurred
13	PMU synchronization	Indicates PMU is synchronized with clock
14	PMU error	Indicates there is a PMU error
15	Data valid bit	Indicates if the PMU is in test mode or not

The status bits 13, 14, and 15 can be used to verify if data sent to the PMU are valid and are synchronized. On the other hand, Bit 10 can be used to show that a change in PMU configuration has occurred. This status data bits are important descriptors for the PMU configuration state. Bits 4 and 5 provide information about the clock synchronization. They provide the possibility to detect clock failures and even to quantify the length of the outage. Examples of such outages that can limitreception of the GPS signal are a faulty clock or a blocked antenna to the clock. Bits 0 through 3 can be used to capture various predefined or user-defined unique trigger conditions in the PMU. Complete IEEE C37.118 configuration and data frames contents and comments are decribed in Table 3 and Table 4 respectively [1].

Table 3

IEEE C37.118 configuration frame format

No.	Field	Size	Comments
1	SYNC	2	Sync byte followed by frame type and version number
2	FRAMESIZE	2	Number of bytes in frame
3	IDCODE	2	PMU ID number, 16-bit integer
4	SOC	4	SOC time stamp
5	FRACSEC	4	Fraction of Second and Time Quality
6	TIME_BASE	4	Resolution of fraction of second time stamp
7	NUM_PMU	2	The number of PMUs included in data frame
8	STN	16	Station name, 16 bytes in ASCII format
9	IDCODE	2	PMU ID number, identifies source of each data blocks
10	FORMAT	2	Data format
11	PHNMR	2	Number of phasors
12	ANNMR	2	Number of analog values
13	DGNMR	2	Number of digital status words
14	CHNAM	16 x (PHNMR + ANNMR+ 16 x DGNMR)	Phasor and channel names
15	PHUNIT	4 x PHNMR	Conversion factor for phasor channels
16	ANUNIT	4 x ANNMR	Conversion factor for analog channels
17	DIGUNIT	4 x DGNMR	Mask words for digital status channels
18	FNOM	2	Nominal line frequency and flags
19	CFGCNT	2	Configuration change count
	Repeat 8-19		Fields 8-19 are repeated for as many PMUs as in field 7 (NUM_PMU) are indicated
20	DATA_RATE	2	Rate of data transmissions
21	CHK	2	CRC-CCITT

Table 4

IEEE C37.118 data frame format

No.	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number
2	FRAMESIZE	2	Number of bytes in frame
3	IDCODE	2	PMU ID number, 16-bit integer
4	SOC	4	SOC time stamp
5	FRACSEC	4	Fraction of Second and Time Quality
6	STAT	2	Bitmapped flags
7	PHASORS	4 x PHNMR or 8 x PHNMR	Phasor estimates
8	FREQ	2 / 4	Frequency (fixed or floating point)
9	DFREQ	2 / 4	Rate of change of frequency (fixed or floating point)
10	ANALOG	2 x PHNMR or 4 x PHNMR	Analog data, 2 or 4 bytes per value depending on fixed or floating point format used, as indicated by the configuration frame
11	DIGITAL	2 x DGNMR	Digital data, usually representing 16 digital channels
	Repeat 6-11		Fields 6-11 are repeated for as many PMUs as in NUM_PMU field in configuration frame
12	CHK	2	CRC-CCITT

5. SYNCHROPHASOR APPLICATION

Based on IEEE C37.118 specifications an implementation of this standard was developed as a Windows based computer application using Delphi programming platform.

The application proposed in this paper can connect to a PMU over the internet and retrieve from it three phase voltage and current measurements. Once these data are available, the program has options to display these values in a graphic form or to save them in a local or remote MSSQL database. Fig. 7 shows the main screen of the application which was separated into 5 areas and described as follows:

Area 1 contain the main menu and speed buttons toolbar from which data transmission from a PMU can be turned ON/OFF. Additionally, there is a button that opens an editable form to establish the connection to a database to saving data.

Area 2 describes the information necessary to the TCP/IP ethernet protocol that is used for communications and contains the IP and port associated to the current PMU connection.

In area 3, once the connection to the PMU was established, two dropdown comboboxes are filled with data that contains information about the name of substation where the PMU is installed and the actual phasor configuration that was send by the PMU. By selecting a phasor from the list the program display coherent data such as actual date and time, frequency, phasor magnitude and phase. Additionally, the application has capability to compute three phase active and reactive powers that flow through the monitorited equipment.

Area 4 displays in a graphic form all the phasors that are sent by the PMU.

Area 5 is designed to show different messages about the actual state of the PMU and connection as well as information about current frames count, network traffic and state of the connection to the MSSQL database.

Not all applications require using IEEE C37.118 real-time messages. Archiving synchrophasor data is valuable for post-event or offline analysis. This allows the user to look at time-coherent data from across the system and correlate measured data and events [5].

In this purpose, the application has posibility to storage data in a MSSQL database. The structure of the database is automatically modified by inserting new tables when the user chose to save data from the PMU. The fields in these tables are described in Table 5 and they are created based on actual configuration frame received from PMU.

It's worth to mention that if PMU is configured to send phasor data in complex form, the SynchroPhasor application converts these values to polar components to provide a minimum compatibility with those applications that will use these measurements.

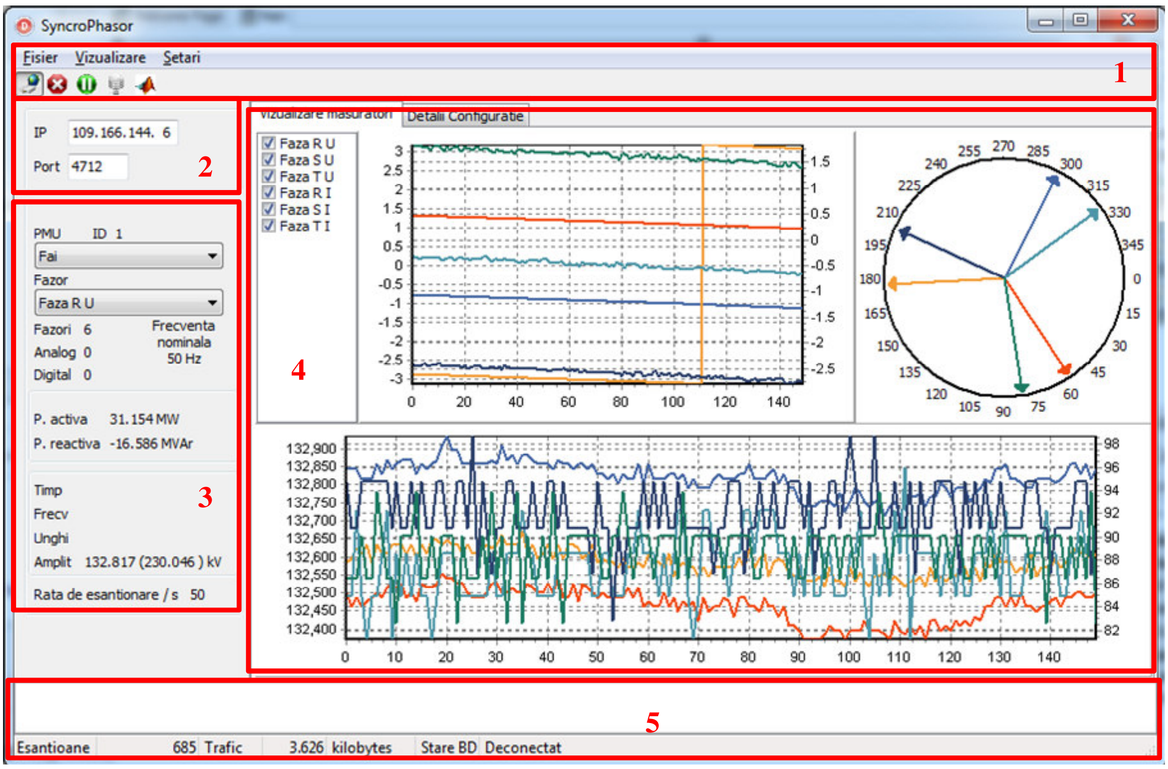


Fig. 7. Main screen of the SynchroPhasor application.

Table 5

Table format in the MSSQL database

Field name	Field type	Description
ID	INT	Actual record id
TIME	DATETIME	Time of the sampled record
FREQ	FLOAT	Actual frequency
Phasor_magnitude	FLOAT	Order of these fields are the same as they are received in configuration frame from the PMU
Phasor_angle	FLOAT	
...		
Phasor_magnitude	FLOAT	
Phasor_angle	FLOAT	

6. CONCLUSION

The paper present a review of the IEEE C37.118-2011 communications standard defined for sending synchrophasor measurements over a communication network to control centers.

The application proposed in this paper can connect to a PMU over the internet and to retrieve from it three phase voltage and current measurements. Once these data are available, the program has options to display these values in a graphic form or to save them in a local or remote MSSQL database, data which can be used by other real-time applications such as transmission line parameter estimation, dynamic thermal rating etc. Tests were performed on a real PMU installed at one end of a transmission line from the Romanian power system.

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