Wide Area Monitoring, Control, and Protection
Acronyms

- Wide Area Monitoring Systems (WAMS)
- Wide Area Monitoring Control Systems (WAMCS)
- Wide Area Monitoring Protection and Control Systems (WAMPACS)
Contents

• Recap of the SCADA and Communication Networks
• WAMCS architecture
• WAMCS components
• Standards relevant to WAMCS
• Quality of Service challenges
• Other frontier architectures
Recap
SCADA and Communication Networks

• IEC61850
Recap
SCADA and Communication Networks

- IEC 60870-5-x
WAMS
Wide Area Monitoring, Control and Protection Systems

• Architecture
WAMS
Wide Area Monitoring, Control and Protection Systems

• Large Scale WAMS Concept

Centralized

Decentralized
WAMS
Wide Area Monitoring, Control and Protection Systems

• Large Scale WAMS Concept
  - Centralized LS-WAMS
    • Advantages:
      – easy for data access, coordinated alarming and remedial actions, and administration for data exchange
    • Disadvantages:
      – Single node failure
  - Decentralized LS-WAMS
    • Advantages:
      – Reliability, regional coordinating functions
    • Disadvantages:
      – Limited extend of stability analysis, higher communication cost, coordinating the event in wide area is complexed, and higher implementation costs
WAMS
Wide Area Monitoring, Control and Protection Systems

• Components
  - PMU (Phasor Measurement Unit)
  - PDC (Phasor Data Concentrator)
  - Synchronization Clock
  - Communication Infrastructure
  - Communication principle
WAMS
Wide Area Monitoring, Control and Protection Systems

- PMU – Phasor Measurement Unit
  - CT and VT
  - Sampling
  - A/D convert
  - Signal Process
  - Data Server
PDC – Phasor Data Concentrator

- Real-time data exchange
  - Data acquisition from PMUs
  - Data exchange with other PDCs, SCADA/EMS systems, control and protection application, system visualization

- Real-time data processing-detection functions
  - Angle difference detection
  - Low frequency oscillation detection
  - Oscillation source location
  - Islanding detection
  - Voltage stability detection

- Data Storage

- Data visualization
WAMS
Wide Area Monitoring, Control and Protection Systems

- **Synchronization clock**
  - IRIG-B (InterRange Instrumentation Group Time Code Format B)
  - GPS (Global Positioning System)
    - PPS (Pulse per second)
  - IEEE1588 PTP (Precision Time Protocol)
    - Accuracy less than 1 microsecond via Ethernet network

- **Format**
  - Coordinated Universal Time (UTC): the time of day at the Earth’s prime meridian (0 degree longitude).
  - As the number of seconds since at 1970-01-01 00:00:00.000
Communication Infrastructure and Principle

- Infrastructure
  - IP based communication network (Wide Area Network)

- Communication principle
  - Client-Server
    - PMU: server
    - PDC: server or client
    - Other devices receives phasor data: client

- Modes of operation
  - Spontaneous: server send data directly to the client
  - Commanded: client request, server send

- TCP, UDP, and multicast communication
IEEE standard C37.118 (2011)
IEEE Standard for Synchrophasor Measurements for Power Systems
- C37.118.1

1.1 Scope
This standard is for synchronized phasor measurement systems in power systems. It defines a synchronized phasor (synchrophasor), frequency, and rate of change of frequency (ROCOF) measurements. It describes time tag and synchronization requirements for measurement of all three of these quantities. It specifies methods for evaluating these measurements and requirements for compliance with the standard under both static and dynamic conditions. It defines a phasor measurement unit (PMU), which can be a stand-alone physical unit or a functional unit within another physical unit. This standard does not specify hardware, software, or a method for computing phasors, frequency, or ROCOF.

- C37.118.2

1.1 Scope
This standard defines a method for exchange of synchronized phasor measurement data between power system equipment. It specifies messaging including types, use, contents, and data formats for real-time communication between phasor measurement units (PMU), phasor data concentrators (PDC), and other applications.
Definition of synchrophasor, frequency, and ROCOF

Measurement evaluation
- Algorithm relevant errors
- Response time and process delay time
- Reporting latency
- Measurement error and operational error

Reporting rates

<table>
<thead>
<tr>
<th>System Frequency</th>
<th>50 Hz</th>
<th>60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reporting Rates (frames per second)</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

Measurement compliance
- Performance classes (P class and M class)
- Steady-state compliance
- Dynamic compliance – Measurement bandwidth

Phasor representation of sinusoidal signals is commonly used in ac power system analysis. The sinusoidal waveform defined in Equation (1):

\[ x(t) = X_m \cos(\omega t + \phi) \]

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

\[ X = \left(\frac{X_m}{\sqrt{2}}\right) e^{j\phi} = \left(\frac{X_m}{\sqrt{2}}\right) (\cos \phi + j \sin \phi) = X_r + jX_i \]
Standard
IEEE Std C37.118.2 (2011)

- Synchrophasor message format
  - Data frame
  - Configuration frame
  - Header frame
  - Command frame
Standard
IEEE Std C37.118.2 (2011)

- Data Frame

  - Synchronization word
  - Total number of bytes in the frame
  - Data Stream ID number
  - Time Stamp
  - Fraction of second and Time Quality
  - Check word

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAT</td>
<td>Bit-mapped flags.</td>
</tr>
<tr>
<td>PHASORS</td>
<td>Phasor estimates. May be single phase or 3-phase positive, negative, or zero sequence. Four or 8 bytes each depending on the fixed 16-bit or floating-point format used, as indicated by the FORMAT field in the configuration frame. The number of values is determined by the PHNMR field in configuration 1, 2, and 3 frames.</td>
</tr>
<tr>
<td>FREQ</td>
<td>Frequency (fixed or floating point).</td>
</tr>
<tr>
<td>DFRQ</td>
<td>ROCOF (fixed or floating point).</td>
</tr>
<tr>
<td>ANALOG</td>
<td>Analog data. 2 or 4 bytes per value depending on fixed or floating-point format used, as indicated by the FORMAT field in configuration 1, 2, and 3 frames. The number of values is determined by the ANNMR field in configuration 1, 2, and 3 frames.</td>
</tr>
<tr>
<td>DIGITAL</td>
<td>Digital data, usually representing 16 digital status points (channels). The number of values is determined by the DGNMR field in configuration 1, 2, and 3 frames.</td>
</tr>
</tbody>
</table>
- **CFG-1**: denotes the PMU/PDC capability, indicating all the data that the PMU/PDC is capable of reporting.
- **CFG-2**: indicates measurements currently being reported (transmitted) in the data frame.
- **CFG-3**: indicates measurements currently being reported in the data frame.

### Table 8—Configuration frame 1 and 2 organization

<table>
<thead>
<tr>
<th>No</th>
<th>Field</th>
<th>Size (bytes)</th>
<th>Short description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SYNC</td>
<td>2</td>
<td>Sync byte followed by frame type and version number.</td>
</tr>
<tr>
<td>2</td>
<td>FRMLEN</td>
<td>2</td>
<td>Number of bytes in frame, defined as 6.2.</td>
</tr>
<tr>
<td>3</td>
<td>IDCODE</td>
<td>2</td>
<td>Source ID number, 16-bit integer, defined in 6.2.</td>
</tr>
<tr>
<td>4</td>
<td>SOC</td>
<td>4</td>
<td>SOC time stamp, defined in 6.2.</td>
</tr>
<tr>
<td>5</td>
<td>FRACSEC</td>
<td>4</td>
<td>Fraction of second and Message Time Quality, defined in 6.2.</td>
</tr>
<tr>
<td>6</td>
<td>TIME_BASE</td>
<td>4</td>
<td>Resolution of FRACSEC time stamp.</td>
</tr>
<tr>
<td>7</td>
<td>NUM_PMU</td>
<td>2</td>
<td>The number of PMUs included in the data frame.</td>
</tr>
<tr>
<td>8</td>
<td>STNM</td>
<td>16</td>
<td>Station Name—16 bytes in ASCII format.</td>
</tr>
<tr>
<td>9</td>
<td>IDCODE</td>
<td>2</td>
<td>Data source ID number identifies source of each data block.</td>
</tr>
<tr>
<td>10</td>
<td>FORMAT</td>
<td>2</td>
<td>Data format within the data frame.</td>
</tr>
<tr>
<td>11</td>
<td>PHNSNR</td>
<td>2</td>
<td>Number of phasors—2-byte integer (0 to 32767).</td>
</tr>
<tr>
<td>12</td>
<td>ANNSR</td>
<td>2</td>
<td>Number of analog values—2-byte integer.</td>
</tr>
<tr>
<td>13</td>
<td>DNSR</td>
<td>2</td>
<td>Number of digital status words—2-byte integer.</td>
</tr>
<tr>
<td>14</td>
<td>CHNAM</td>
<td>16 (PHNSNR + ANNSR + DNSR)</td>
<td>Phasor and channel names—16 bytes for each phasor, analog, and each digital channel (10 channels in each digital word) in ASCII format in the same order as they are transmitted. For digital channels, the channel name order will be from the least significant to the most significant. The second name is for bit 0 of the first 16-bit status word, the second is for bit 1, etc., up to bit 15. If there is more than 1 digital status, the next name will apply to bit 0 of the second word and so on.</td>
</tr>
<tr>
<td>15</td>
<td>PHNMR</td>
<td>4 - PHNSNR</td>
<td>Conversion factor for phasor channels.</td>
</tr>
<tr>
<td>16</td>
<td>ANNSR</td>
<td>4 - ANNSR</td>
<td>Conversion factor for analog channels.</td>
</tr>
<tr>
<td>17</td>
<td>DNSR</td>
<td>4 - DNSR</td>
<td>Mask words for digital status words.</td>
</tr>
<tr>
<td>18</td>
<td>FNMOS</td>
<td>2</td>
<td>Nominal line frequency code and flags.</td>
</tr>
<tr>
<td>19</td>
<td>CFGCNT</td>
<td>2</td>
<td>Configuration change count.</td>
</tr>
<tr>
<td>20</td>
<td>Report</td>
<td>8 - 19</td>
<td>Fields 8–19, repeated for as many PMUs as in field NUM_PMU.</td>
</tr>
<tr>
<td>21</td>
<td>DATA_RATE</td>
<td>2</td>
<td>Rate of data transmissions.</td>
</tr>
<tr>
<td>22</td>
<td>CHK</td>
<td>2</td>
<td>CRC-CCITT.</td>
</tr>
</tbody>
</table>
• **Header frame**
  - Human-readable information about the PMU
    - The data sources
    - Scaling
    - Algorithms
    - Filtering
    - Other information

<table>
<thead>
<tr>
<th>No</th>
<th>Field</th>
<th>Size (bytes)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SYNC</td>
<td>2</td>
<td>Sync byte followed by frame type and version number (AA1 hex).</td>
</tr>
<tr>
<td>2</td>
<td>FRAMESIZE</td>
<td>2</td>
<td>Number of bytes in frame, defined in 6.2.</td>
</tr>
<tr>
<td>3</td>
<td>IDCODE</td>
<td>2</td>
<td>PMU/PDC data stream ID number, 16-bit integer, defined in 6.2.</td>
</tr>
<tr>
<td>4</td>
<td>SOC</td>
<td>4</td>
<td>SOC time stamp, defined in 6.2.</td>
</tr>
<tr>
<td>5</td>
<td>FRACSEC</td>
<td>4</td>
<td>Fraction of Second and Time Quality, defined in 6.2.</td>
</tr>
<tr>
<td>6</td>
<td>DATA 1</td>
<td>1</td>
<td>ASCII character, 1st byte.</td>
</tr>
<tr>
<td>K+6</td>
<td>DATA k</td>
<td>1</td>
<td>ASCII character, Kth byte, K&gt;0 is an integer.</td>
</tr>
<tr>
<td>K+7</td>
<td>CHK</td>
<td>2</td>
<td>CRC-CCITT.</td>
</tr>
</tbody>
</table>
• Command frame
  - A data sending device (PMU or PDC) shall be able to receive commands and take appropriate actions.

### Table 14 — Command frame organization

<table>
<thead>
<tr>
<th>No</th>
<th>Field</th>
<th>Size (bytes)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SYNC</td>
<td>2</td>
<td>Sync byte followed by frame type and version number (AA41 hex).</td>
</tr>
<tr>
<td>2</td>
<td>FRAMESIZE</td>
<td>2</td>
<td>Number of bytes in frame, defined in 6.2.</td>
</tr>
<tr>
<td>3</td>
<td>IDCODE</td>
<td>2</td>
<td>PMU/PDC ID data stream number, 16-bit integer, defined in 6.2.</td>
</tr>
<tr>
<td>4</td>
<td>SOC</td>
<td>4</td>
<td>SOC time stamp, defined in 6.2.</td>
</tr>
<tr>
<td>5</td>
<td>FRACSEC</td>
<td>4</td>
<td>Fraction of Second and Time Quality, defined in 6.2.</td>
</tr>
<tr>
<td>6</td>
<td>CMD</td>
<td>2</td>
<td>Command being sent to the PMU/PDC (0).</td>
</tr>
<tr>
<td>7</td>
<td>EXTFRAME</td>
<td>0–65518</td>
<td>Extended frame data, 16-bit words, 0 to 65518 bytes as indicated by frame size, data user defined.</td>
</tr>
<tr>
<td>8</td>
<td>CHK</td>
<td>2</td>
<td>CRC-CCITT.</td>
</tr>
</tbody>
</table>

### Table 15 — Commands sent to the PMU/PDC

<table>
<thead>
<tr>
<th>Command word bits</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000 0000 0000 0001</td>
<td>Turn off transmission of data frames.</td>
</tr>
<tr>
<td>0000 0000 0000 0010</td>
<td>Turn on transmission of data frames.</td>
</tr>
<tr>
<td>0000 0000 0000 0011</td>
<td>Send HDR frame.</td>
</tr>
<tr>
<td>0000 0000 0000 0100</td>
<td>Send CFG-1 frame.</td>
</tr>
<tr>
<td>0000 0000 0000 0101</td>
<td>Send CFG-2 frame.</td>
</tr>
<tr>
<td>0000 0000 0000 0110</td>
<td>Send CFG-3 frame (optional command).</td>
</tr>
<tr>
<td>0000 0000 0000 1000</td>
<td>Extended frame.</td>
</tr>
<tr>
<td>0000 0000 xxxx xxxx</td>
<td>All undesignated codes reserved.</td>
</tr>
<tr>
<td>0000 yyyy xxxx xxxx</td>
<td>All codes where yyyy ≠ 0 available for user designation.</td>
</tr>
<tr>
<td>yyyy xxxx yyyy xxxx</td>
<td>All codes where yyyy ≠ 0 reserved.</td>
</tr>
</tbody>
</table>
QoS challenges

- **Quality of Service**
  - **End-to-end delay**
    - Refers to the time taken for a packet to be transmitted across a network from source to destination.
  - **Packet loss**
    - When one or more packets of data travelling across a computer network fail to reach their destination.
  - **Packet jitter**
    - The variation in latency as measured in the variability over time of the packet latency across a network
  - **Data rate**
QoS challenges

• Example: Latency Effects on WAMC applications
QoS challenges

• Mechanism
  - WAMC application design
    • QoS fault tolerant
  - Communication network management
    • Priority control
    • Data link path duplication
    • Data scheduling
WAMCS
Wide Area Monitoring, Control and Protection Systems

- Other frontier architectures - NASPInet
• Other frontier architectures - GridStat