Synchronized Phasor Measurements

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- Communication Protocol
  - » IEEE C37.118
  - » Vendor specific (mostly legacy equipment)
- Separate communication network from SCADA

Four Message Types

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- Data messages:
  - » Measurements made by the phasor measurement unit.
- Configuration:
  - » Machine-readable message describing the data types, calibration factors, and other meta-data that the phasor measurement unit or phasor data concentrator sends.
- Header information:
  - » Human readable descriptive information sent from a phasor measurement unit or phasor data concentrator provided to the user.
- Commands:
  - » Codes sent to the phasor measurement units or phasor data concentrators for control or configuration.

Format of Data Frame

- One frame is one set phasors at a time instance V_{abc}, I_{abc}, P, Q, f, df/dt
  - » Positive sequence components
- IEEE C37.118 standards define the frame organization

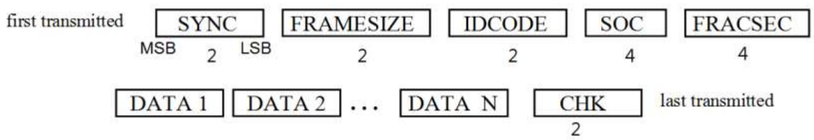

Figure 3—Example of frame transmission order

Data Frame Organization

No.	Field	Size (bytes)
1	SYNC	2
2	FRAMESIZE	2
3	IDCODE	2
4	SOC	4
5	FRASEC	4
6	STAT	2
7	PHASORS	4xPHNMR or 8xPHNMR
8	FREQ	2/4
9	DFREQ	2/4
10	ANALOG	2xANNMR or 4xNNMR
11	DIGITAL	2xDGNMR
	Repeat 6 to 11	
12+	CHK	2

Configuration Frame: Three Options

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- **CFG-1: All of the data a PMU/PDC can report**
- CFG-2: Indicates measurements only
- CFG-3: Extends CF-1 and 2 that define PMU characteristics and quantities sent

Header Frame

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No	Field	Size (bytes)
1	SYNC	2
2	FRAMESIZE	2
3	IDCODE	2
4	SOC	4
5	FRACSEC	4
6	DATA 1	1
K+6	DATA K	1
K+7	CHK	2

Command Frame

No	Field	Size (bytes)
1	SYNC	2
2	FRAMESIZE	2
3	IDCODE	2
4	SOC	4
5	FRACSEC	4
6	CMD	2
7	EXTFRAME	0-65518
8	CHK	2

Command Functions Include

- Turn off transmission
- Turn-on transmission
- Send header
- Send CFG-1 frame
- Send CFG-2 frame,
- Send CFG-3 frame

Input and Output

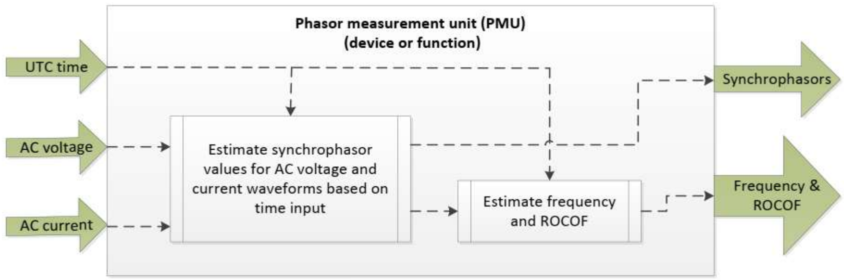
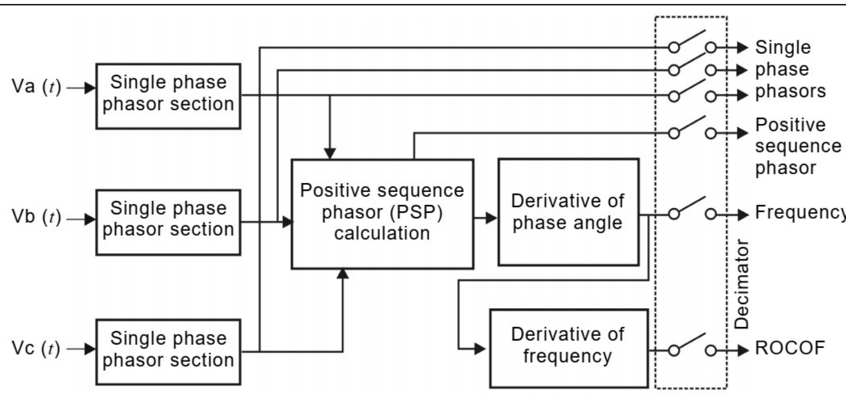


Figure 1 – Input and output quantities

60255-118-1-2018 - IEEE/IEC International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems - Measurements

Processing Model



60255-118-1-2018 - IEEE/IEC International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems - Measurements

Power Systems Signal

$x(t) = X_m \cos[(\theta(t)] + D(t)$

- t is time in seconds, t=0 is coincident with a UTC second rollover
- X_m is the peak magnitude
- θ is angle in radians
- $D(t)$ is a disturbance signal with harmonics, noise, dc offset, interference, etc.

Synchrophasor Output

- Phase angle between angle between measured and nominal frequency

$$\phi(t) = \theta(t) - 2\pi f_0 t$$

- The synchrophasor measurand (polar, rectangular)

$$X(t) = \left(\frac{X_m(t)}{\sqrt{2}}, \phi(t)\right) \qquad X(t) = \left(X_r(t), X_i(t)\right)$$

- Frequency measurand

$$f(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} = f_0 + \frac{1}{2\pi}\frac{d[\phi(t)]}{dt}$$

- Rate of change of frequency (ROCOF) in Hz/s

$$\text{ROCOF}(t) = \frac{df(t)}{dt} = \frac{1}{2\pi}\frac{d^2\theta(t)}{dt^2} = \frac{1}{2\pi}\frac{d^2\phi(t)}{dt^2}$$

Synchrophasor Estimation

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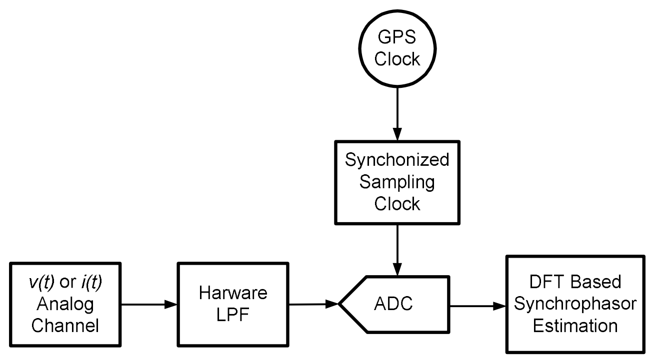
- Fourier Transform Approach



Improved Synchrophasor Estimation

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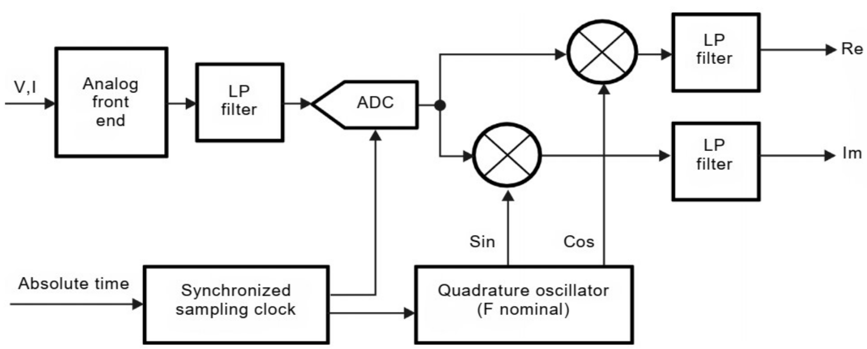
- Quadrature Demodulation Method



60255-118-1-2018 - IEEE/IEC International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems - Measurements

Comparison of Estimation Methods

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- The DFT method does not have adequate filter response for detection inter-area oscillations
- Quadrature demodulation method provides flexibility for tailoring the total filtering frequency to a particular application

Comparison of Estimation Methods

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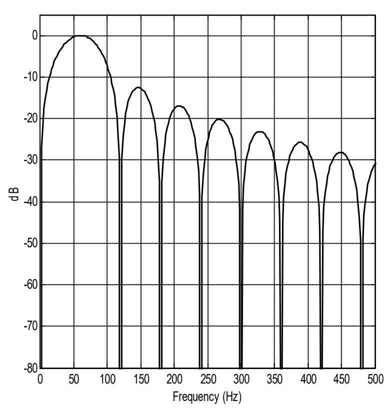
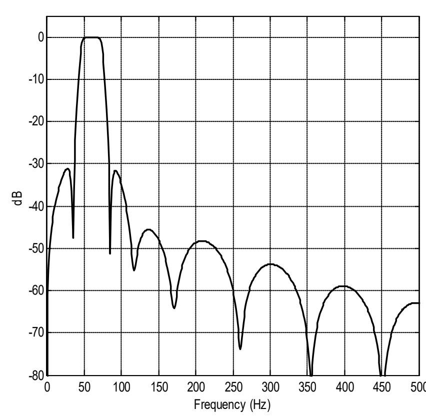
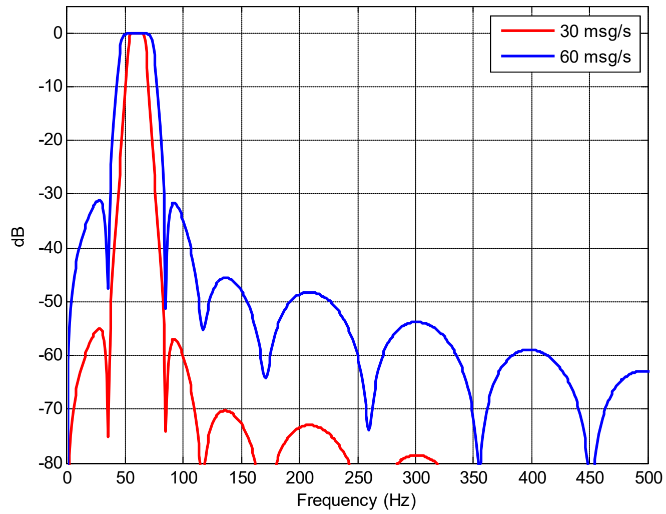




Effect of Frame Rate: 30 and 60 messages/second



Measurement Performance Classes

- P-Class
  - » Applications that required fast response
  - » Protection application
- M-Class
  - » Applications that required high precision, but not fast response
  - » System monitoring

Phasor Data Concentrator (PDC)

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- Function
  - » PDC collects synchrophasor data from PMUs
  - » PDC time-aligns synchrophasor data
  - » PDC stores synchrophasor data
- How it works:
  - » PDC receives synchrophasor data
  - » PDC receives time signal from GPS clock
  - » PDC time-aligns synchrophasor data
  - » PDC saves synchrophasor data in an embedded historian

Data Collection Network

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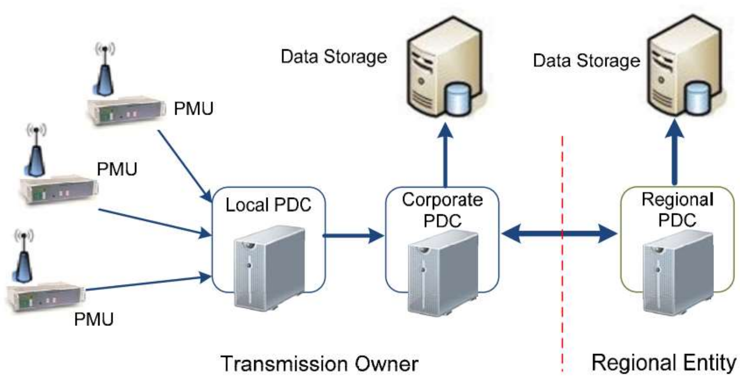
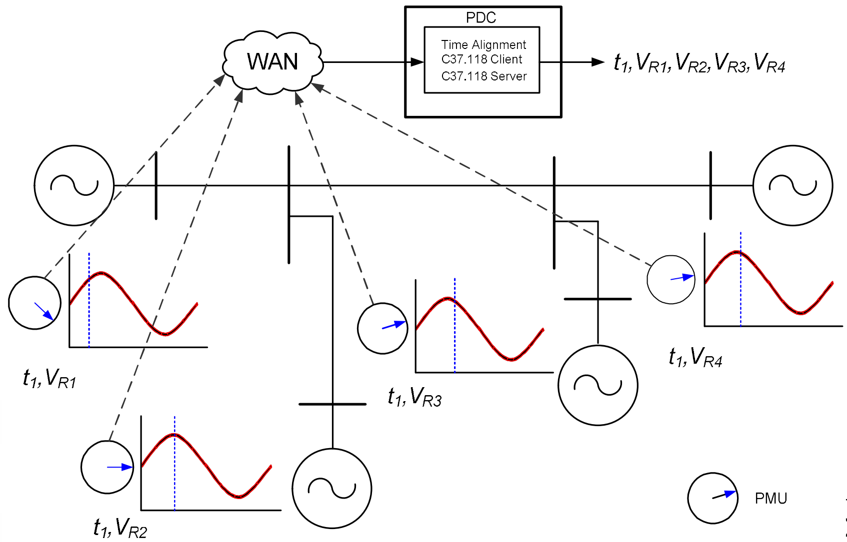


C37.118.2-2011 - IEEE Standard for Synchrophasor Data Transfer for Power Systems

Snapshot of System in Time



Super PDC

- Function
  - » collects synchrophasor data from PDCs
  - » time-aligns synchrophasor data
  - » stores synchrophasor data
- How it works:
  - » receives synchrophasor data
  - » receives time signal from GPS clock
  - » time-aligns synchrophasor data
  - » saves synchrophasor data in a server

Phasor Measurement and Control Unit

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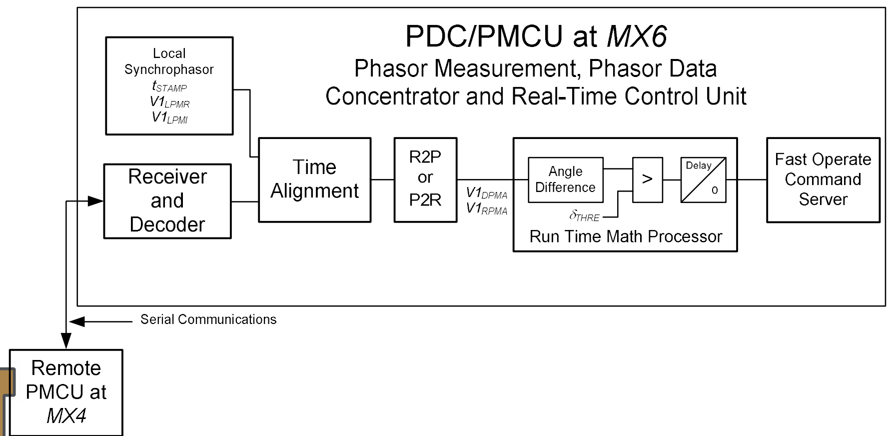

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Data Transmission

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- Inside substation
  - » Serial using RS-232
  - » Local Area Network (LAN) communication
    - – TCP/IP
    - – UDP
    - – Unicast, multicast, or broadcast – one or multiple clients
    - – PMUs to local PDC
    - – Commands to devices
- Outside substation
  - » Wide area network
    - – To regional PDC/SuperPDC
    - – To control center
  - » Measurements and commands—both directions

Applications

- Post event analysis
- Validation of parameters
- Energy management systems
  - » Supplement SCADA
- Moving toward online measurement (wide area measurements) WAMS
- Wide area protection systems (WAPS)
- Wide area control systems (WACS)
- Distribution systems → microPMUs

References

- 60255-118-1-2018 - IEEE/IEC International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems - Measurements
- C37.118.2-2011 - IEEE Standard for Synchrophasor Data Transfer for Power Systems
- 1588-2008, IEEE Standard for Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
- North American Synchrophasor Initiative (NAPSI) http://www.napsi.org

- Application example: A. Johnson, R. Tucker, T. Tran, J. Paserba, D. Sullivan, C. Anderson and D. Whitehead, "Static Var Compensation Controlled via Synchrophasors," Presented at 2007 Western Protective Relay Conference, Spokane Washington