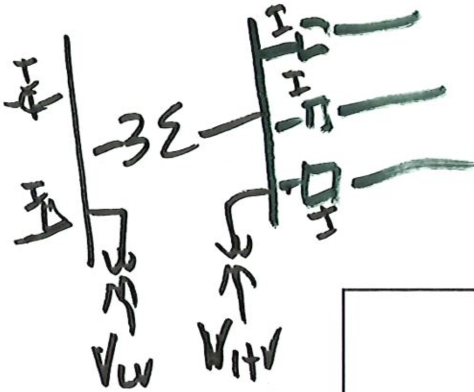
ECE 444 / ECE 544 / CS 444 / CS 544
Supervisory Control and Critical Infrastructure Systems

Session 24



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Input and Output

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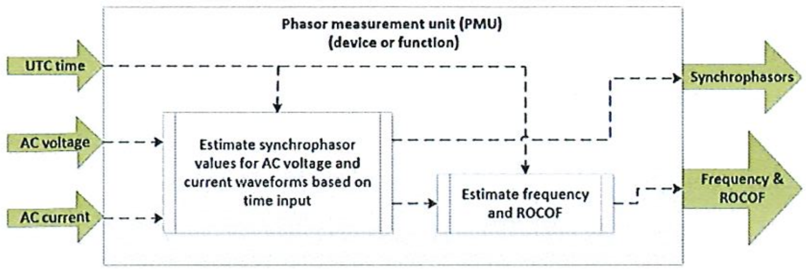

Figure 1 – Input and output quantities

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

Processing Model

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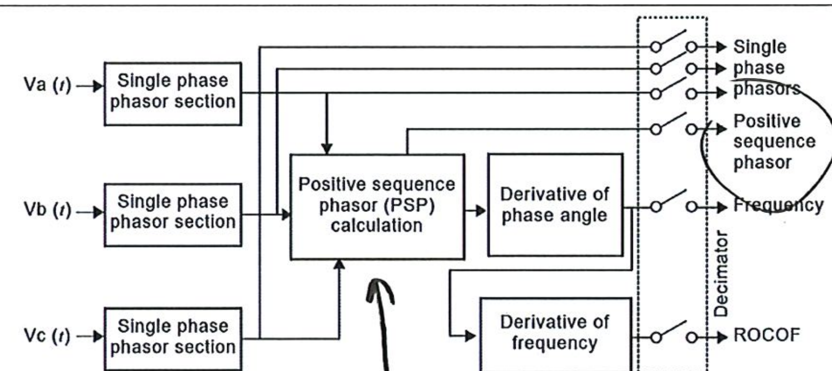

60255-118-1-2018 - IEEE/IEC International Standard - Measuring relays and protection equipment - Part 118-1: Synchrophasor for power systems - Measurements

Just find positive sequence voltage

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)

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

- 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

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

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gain 1.0 60Hz f 0 ≈ fs/2

Synchrophasor Estimation

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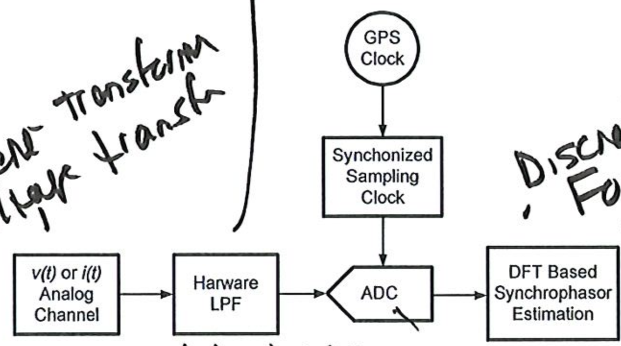
- Fourier Transform Approach

current transform or voltage transf

Discrete Fourier transform



Antialiasin filter

Improved Synchrophasor Estimation

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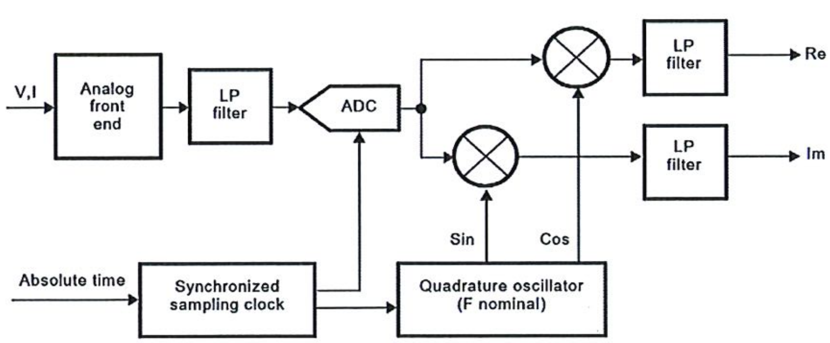
- Quadrature Demodulation Method



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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

Low frequency oscillations - on the order of 0.25Hz & up

Comparison of Estimation Methods

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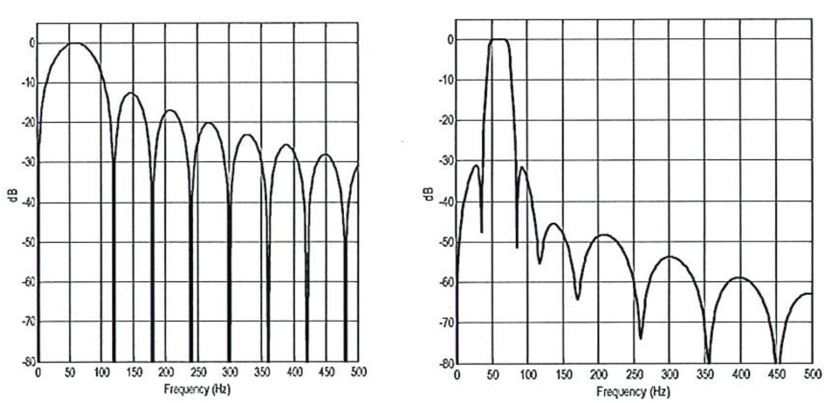

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Dynamic System State Estimation with PMU data

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- Synchrophasor data only
  - » Have time aligned data with angle information
  - » Could possibly do a linear solution (direct state measurement)
    - – Could solve up to frame rate (even 60 samples/sec)
    - – Can catch power system dynamics
    - – Dynamic state estimator
  - » But may not have PMUs at every bus where need state
    - – Still need an observable system
  - » Measurement error
    - – So may end up over measuring.
- Hybrid

·As dynamics speed up with wind & PV penetration (and natural gas making coal uneconomical)

Modal Analysis

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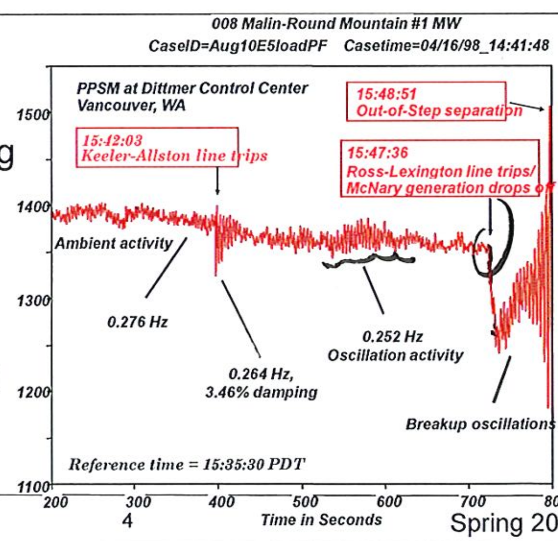
- Identify modal frequency
- Identify damping ratio
- Could take it further to implement remedial action



Effect of Frame Rate: 30 and 60 messages/second

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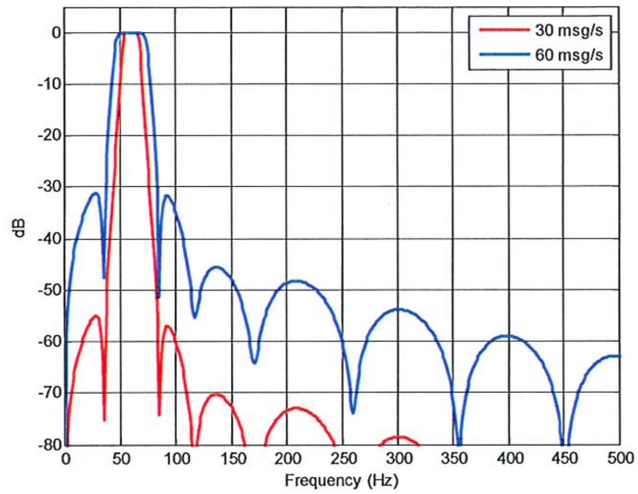

Measurement Performance Classes

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- P-Class
  - » Applications that required fast response
  - » Protection application

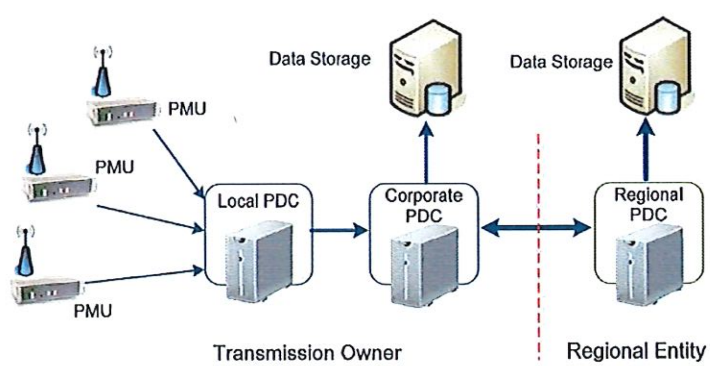
  } less stringent accuracy

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

Phasor Data Concentrator (PDC)

- 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



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

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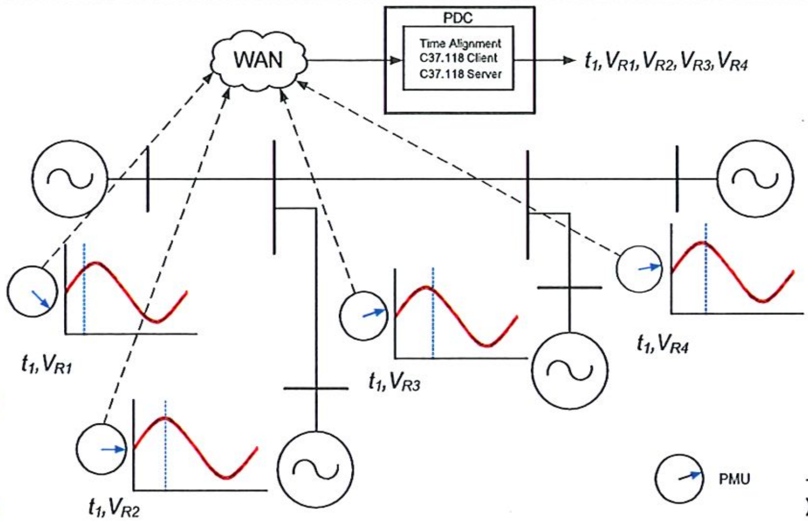
Snapshot of System in Time



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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

larger data sets

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Phasor Measurement and Control Unit

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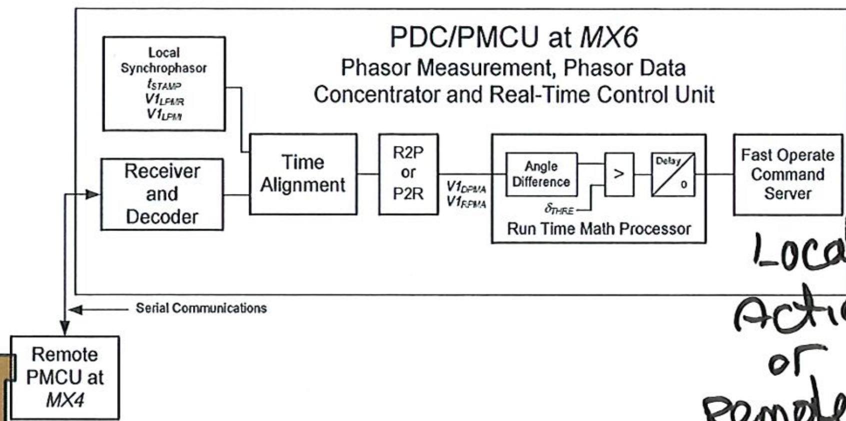

Local Actions or Remote actions

Data Transmission

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- Inside substation
  - » Serial using RS-232
  - » Local Area Network (LAN) communication
    - – TCP/IP
    - – UDP (no acknowlegements)
    - – Unicast, multicast, or broadcast – one or multiple clients
    - – PMUs to local PDC
    - – Commands to devices
- Outside substation
  - » Wide area network (WAN) - dedicated network
    - – To regional PDC/SuperPDC
    - – To control center
  - » Measurements and commands—both directions

seperate network (LAN)

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Applications

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- Post event analysis
- Validation of parameters
- Energy management systems] toward state estimation
  - » Supplement SCADA
- Moving toward online measurement (wide area measurements) WAMS) real time information - observability of entire system or a part
- Wide area protection systems (WAPS)
- Wide area control systems (WACS)
- Distribution systems → microPMUs (more localized) higher degree of angle precision

Transmission system - over large areas

References

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- 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

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Algorithm to Detect Unstable Power Oscillations and Take Remedial Action

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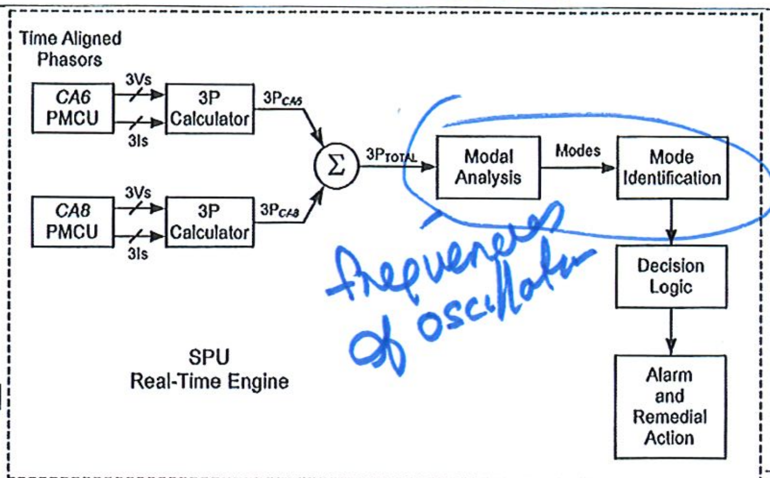

Remedial action scheme (RAS) or special protection scheme (SPS)

Complex Multi-Task System Integrity Protection Scheme

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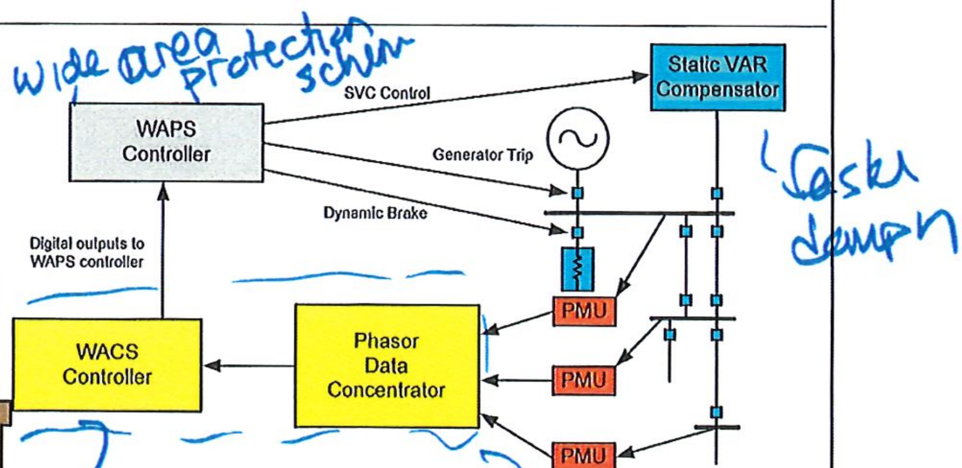

wide area control system

combined into one box

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