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Synchronized Rotor Angle Measurement of Synchronous Machines

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Introduction

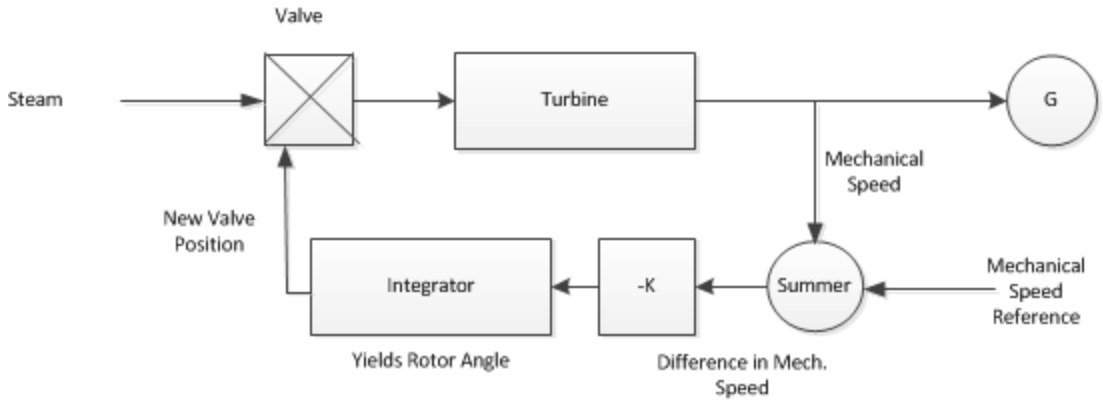
- Torque Angle
  - Delta
  - Key Parameter
    - Stability indicator
    - Provide feedback for control of SM
- Estimated by model
- Previous Attempts
  - Provided Marginal Improvements
  - Lacked Precise Timing
  - Work done 1950s and 1960s [1-2]

Machine Theory

- Various SM models exist
  - Simple Source behind reactance
  - Seven State Variable Model (Used here)
- Blondel Two Reaction Method [3]
  - Removes time / rotor position dependencies
- At point of synchronization [3]
  - Net Flux is aligned with magnetic axis of phase A
    - Rotor Flux and Phase A Stator Flux
      - aligned and in phase

Components Using Delta

- Isosynchronous Speed Governors
  - Angle
- Exciter Systems
  - Frequency (V/Hz)
- Power System Stabilizers (PSSs)[4]
  - Frequency



Possible Local and Wide Area Applications

Local

- Speed Governor Control
- Excitation Control
- Inter-machine oscillations

Wide Area

- Center of Angles
- Angle Coherency
- Improvements to PSSs
  - Coordinated Control

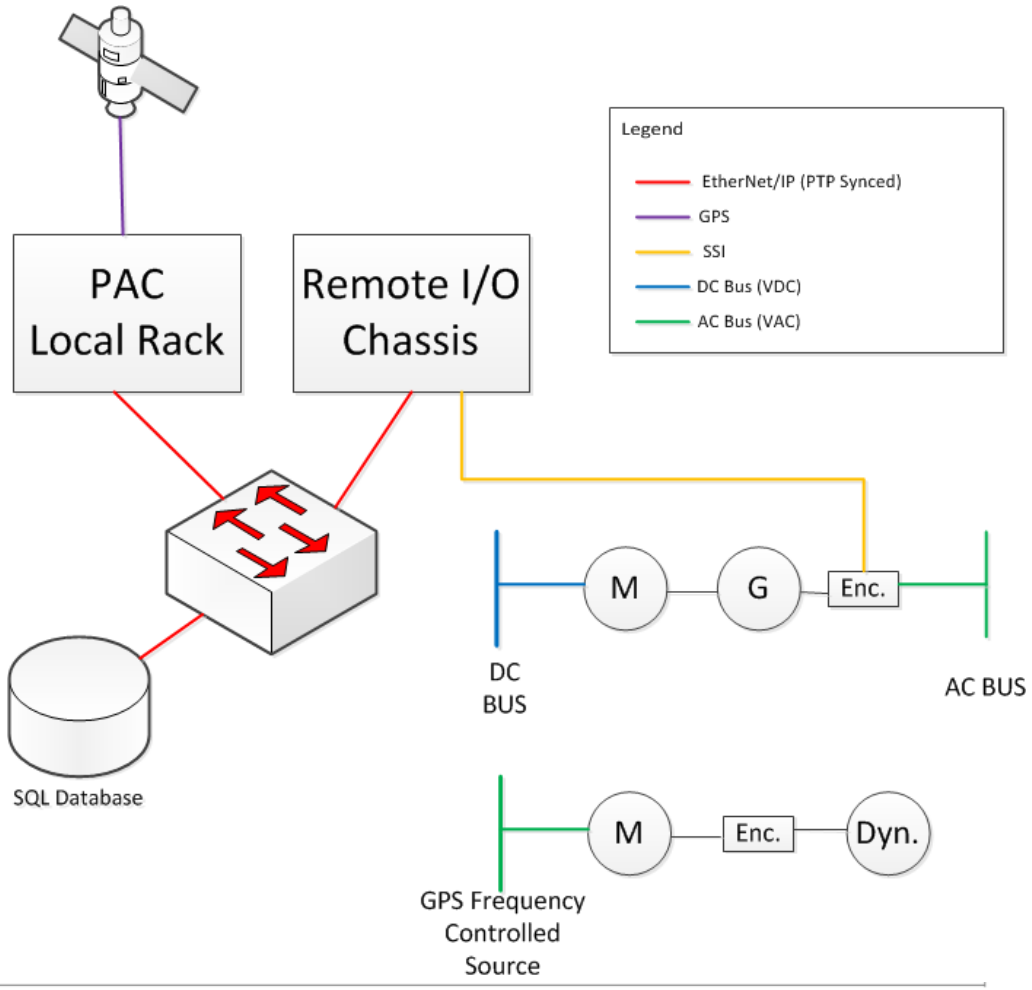
Time Synchronization

- System must be referenced
  - Ultimate Source of Time (GPS)
- IEEE 1588 and IEC 61588
  - Precision Time Protocol
- Construct a Time Synchronized Network
  - Used Managed Switches
  - Time Synchronization accurate to +/- 100 ns [5]
    - Master Clock GPS Receiver

Test Setup

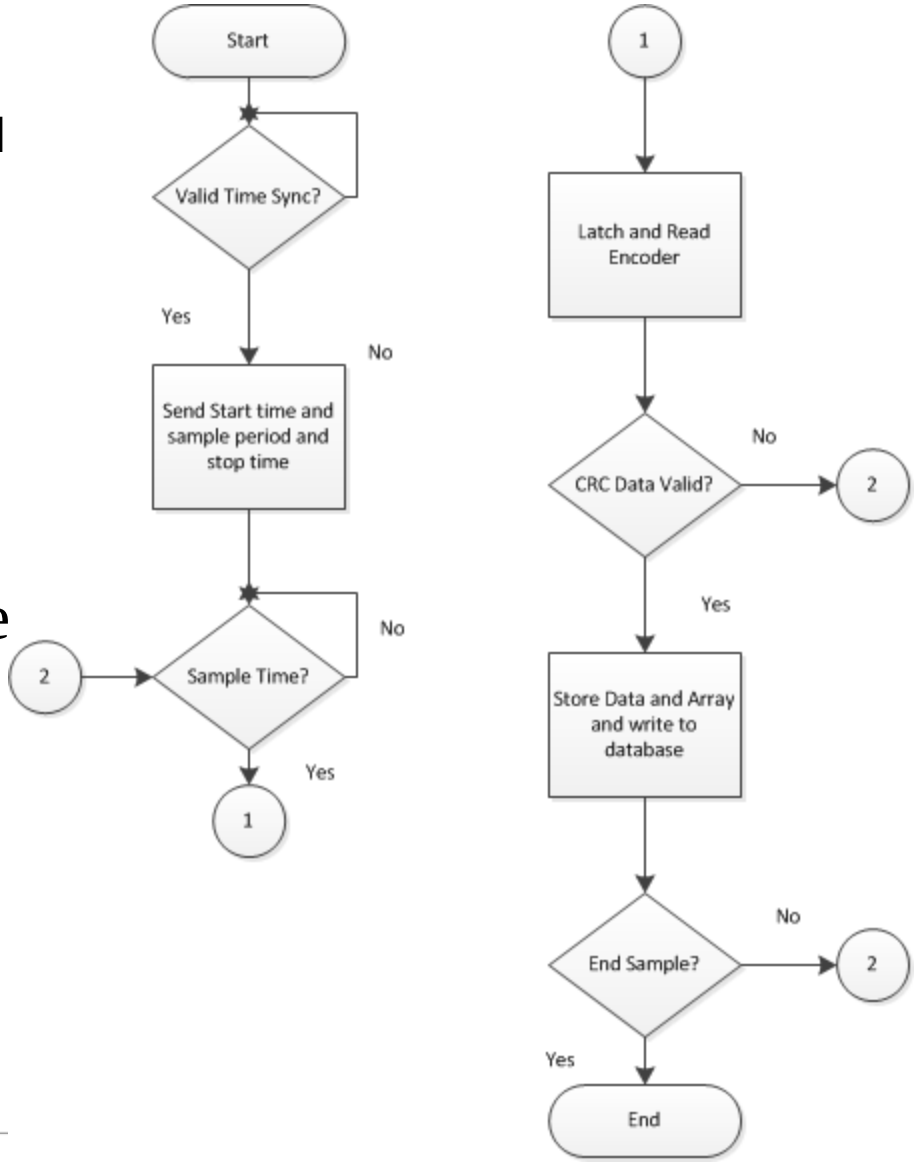
Two Setups

- Synchronous Generator
  - Perm. magnet DC machine coupled to generator
  - SSI encoder
    - Axial Mount
- Synchronous Motor
  - GPS Frequency Controlled Source drove motor
  - Loaded with dynamometer
  - SSI encoder
    - Hollow shaft mount



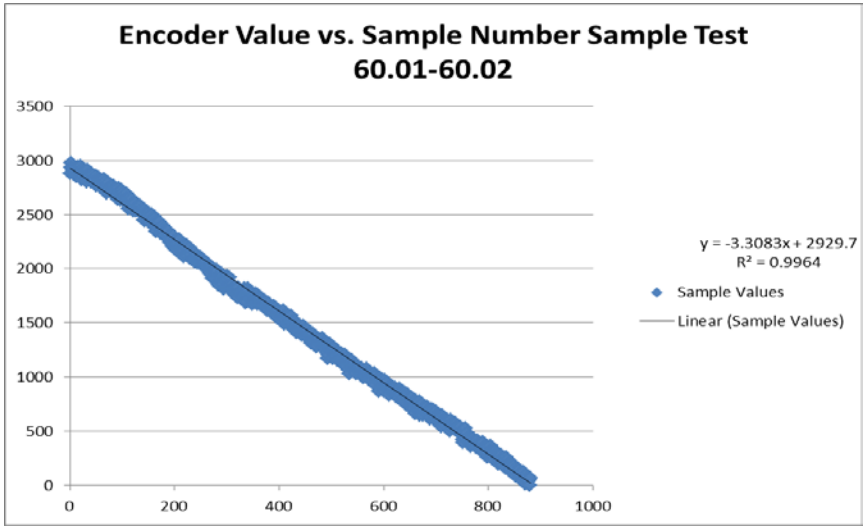
Data Gathering Algorithm

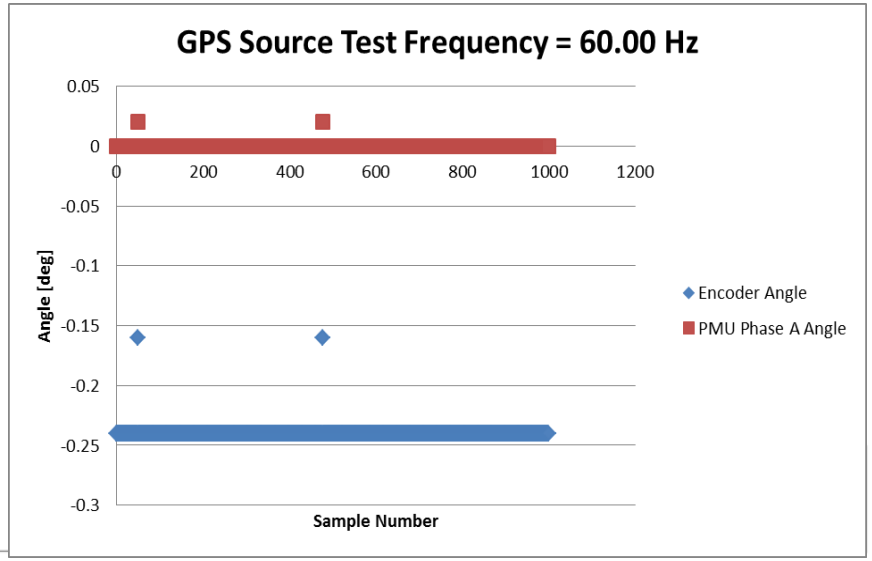
- Synchronized Actuation [6]
  - Send data and event prior to execution time
  - Task executes at desired time
- Functions If…
  - All devices are tied to same reference of time
  - All clocks tuned
    - Frequency and value
    - GPS master clock



Sampling Accuracy Test

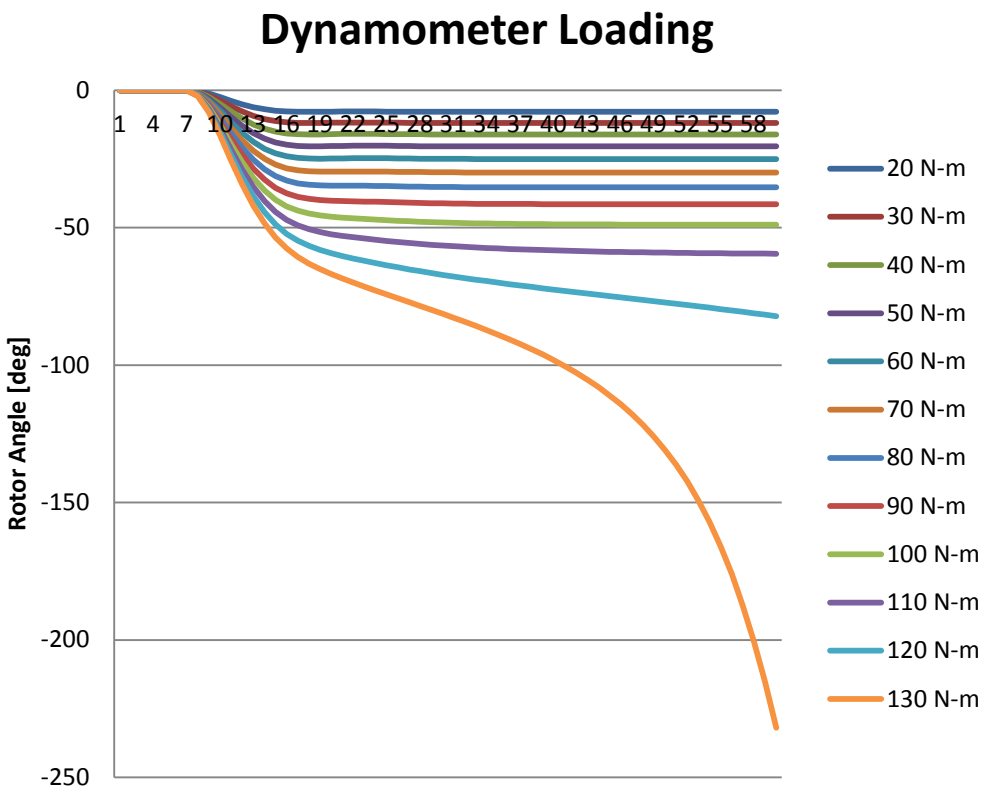
- Used to test accuracy of device
- Three Tests
  - No common time source
  - GPS with varying frequency
  - GPS with constant frequency





Machinery Test Results

- Synchronous machine
  - Run as motor
  - Dynamometer provided different levels of loading
  - Results run against 7 variable state model of synchronous
    - Machine parameters provided by manufacturer



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Conclusions and FAQs

- System accurately measured rotor angle
  - Synchronized Actuation Algorithm
    - Time Synced to IEEE 1588
- Multiple loading tests performed
  - Measured results matched up with machine model theory
- Future Work
  - Provide a C37.118 word to PDC containing torque angle

References

- [1] V. A. Kinitsky, "Measurement of Rotor Displacement Angle on Synchronous Machines," *Power Apparatus and Systems, Part III. Transactions of the American Institute of Electrical Engineers*, vol. 77, pp. 349-352, 1958
- [2] D. G. Lewis and W. E. Austin, "Measurement of rotor load angle of synchronous machines," *Electronics Letters*, vol. 5, pp. 113-114, 1969.
- [3] A. E. Fitzgerald, C. Kingsley, and S. D. Umans, *Electric machinery*: McGraw-Hill, 2002
- [4] P. Kundar, *Power system stability and control*: McGraw-Hill Education (India) Pvt Ltd, 1994.
- [5] "IEC/IEEE Precision Clock Synchronization Protocol for Networked Measurement and Control Systems (Adoption of IEEE Std 1588-2008)," *IEC 61588 First edition 2004-09; IEEE 1588*, pp. 0_1-156, 2004.
- [6] R. A. Inc., "Precision Time Protocol Over EtherNet/IP," in *Motion Over EtherNet/IP Learning Series*, R. A. Inc., Ed., ed. Milwaukee, WI: Rockwell Automation Inc., 2011.