Grid Monitoring Using Phasor Measurement Units

Chuck Wells

Technical Basis of our approach

- Analysis of Blackout data from 14 August, 2003
- Analysis of Blackout data from 23 September, 2003
- Analysis of Blackout data from June 15, 2005
- Zaborszky-Ilic textbook

Oscillations before Blackout

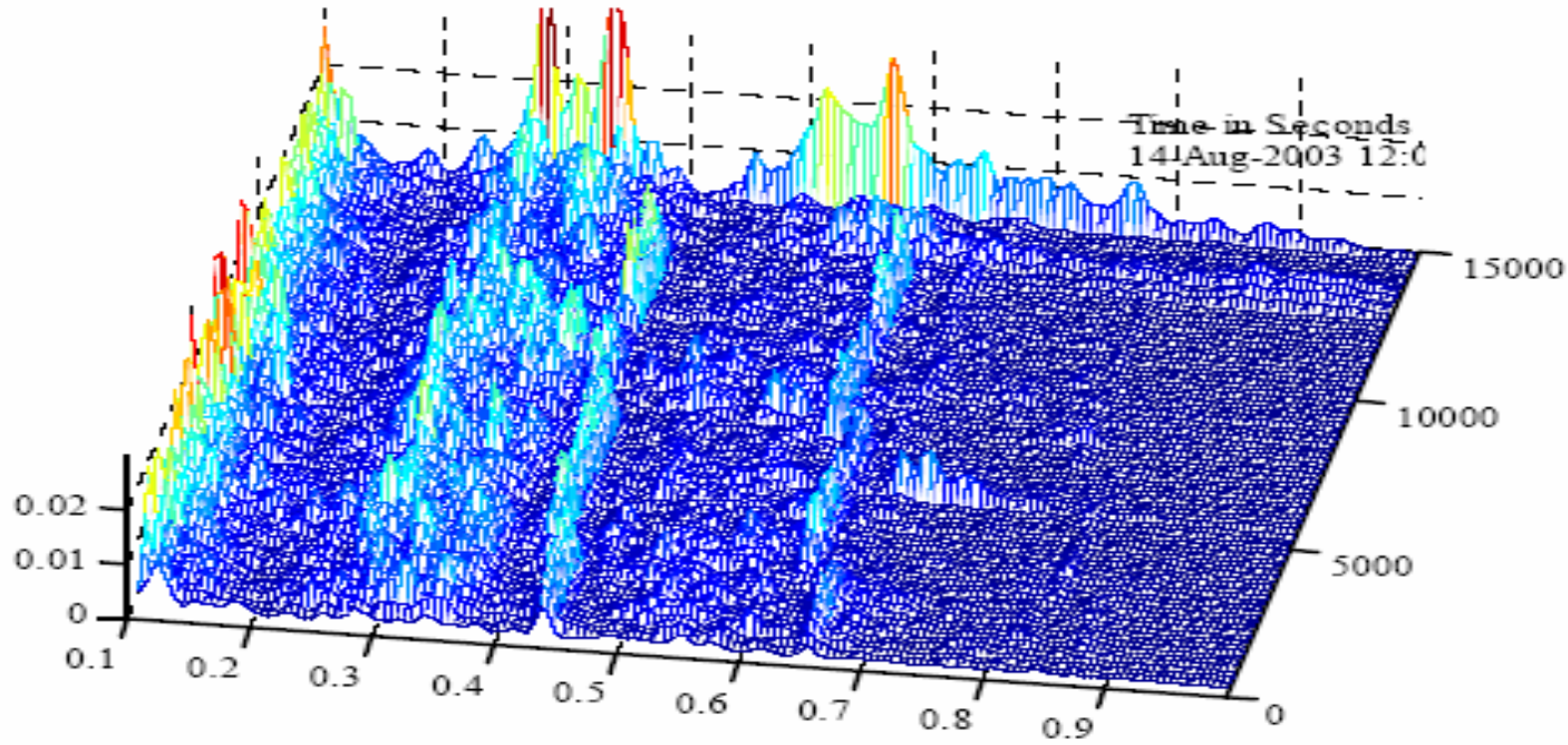


Fig. 12. Spectral history of AEP Kanawha River bus frequency for August 14 Blackout. 12:00-16:10 EDT

Oscillations before Blackout

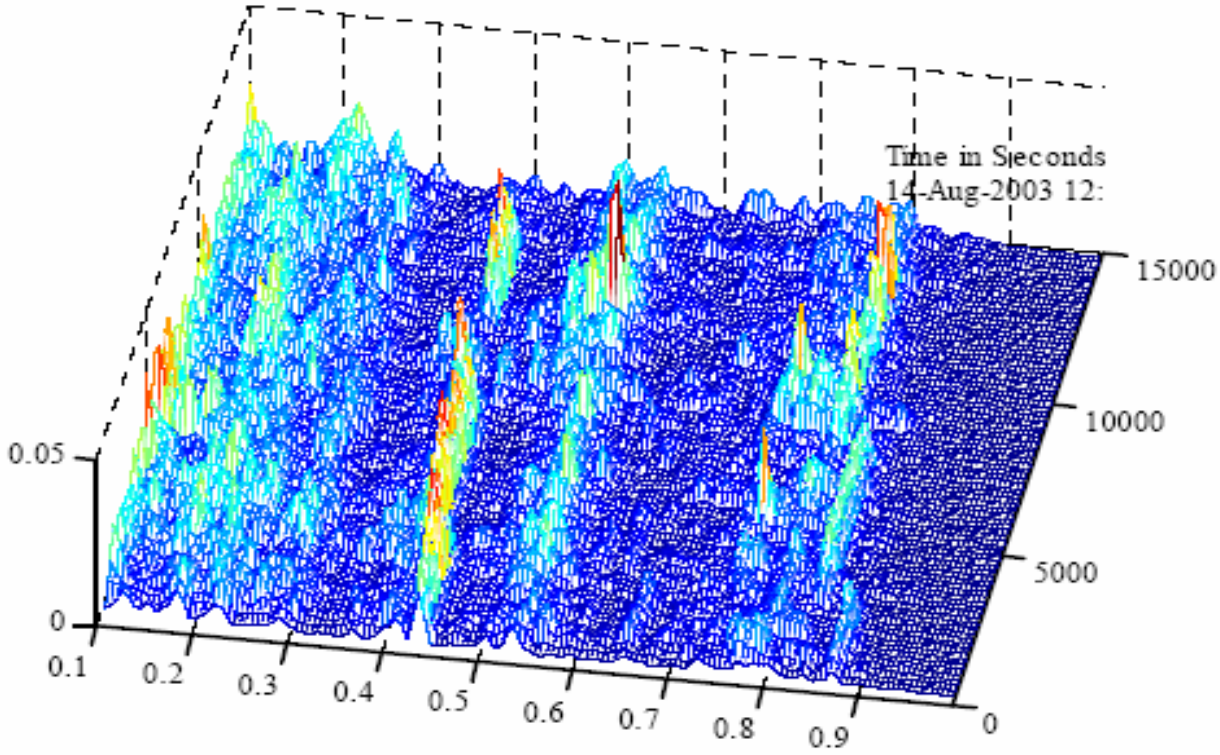
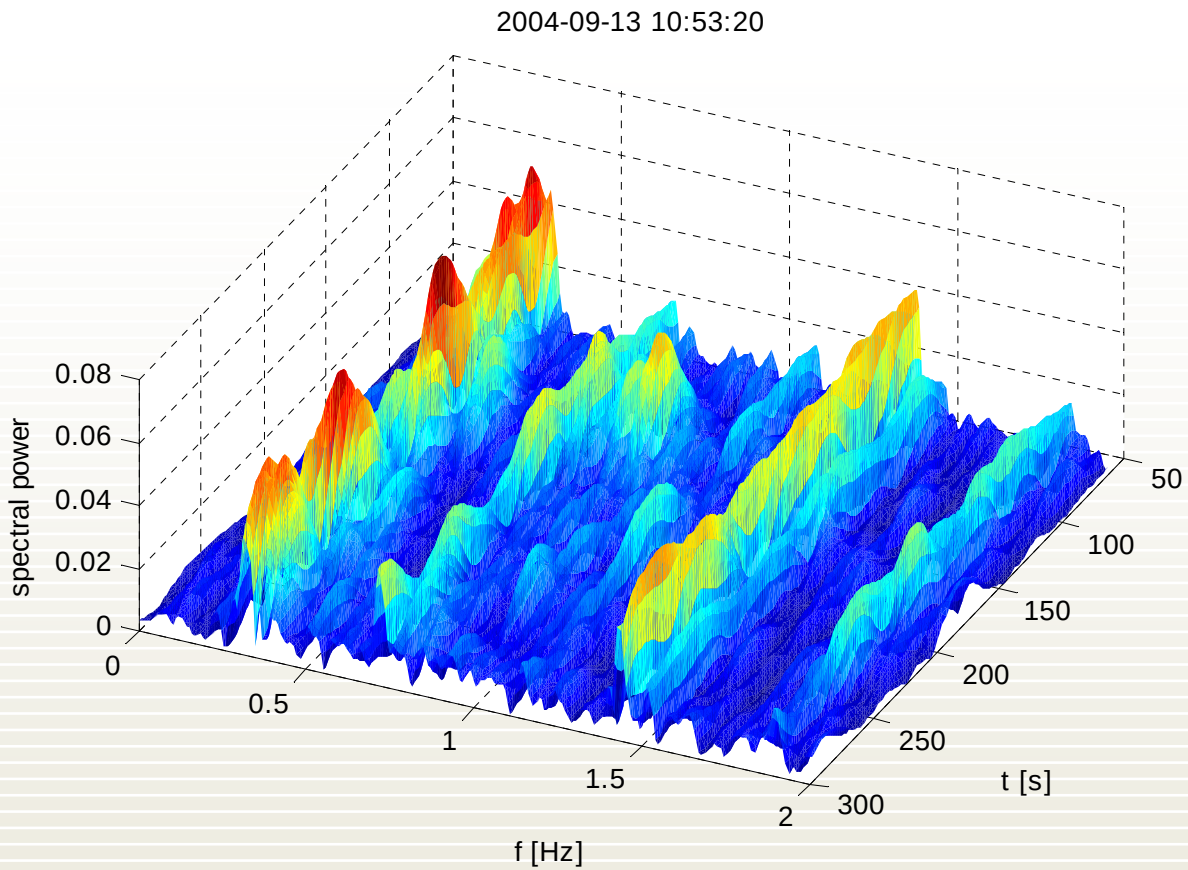
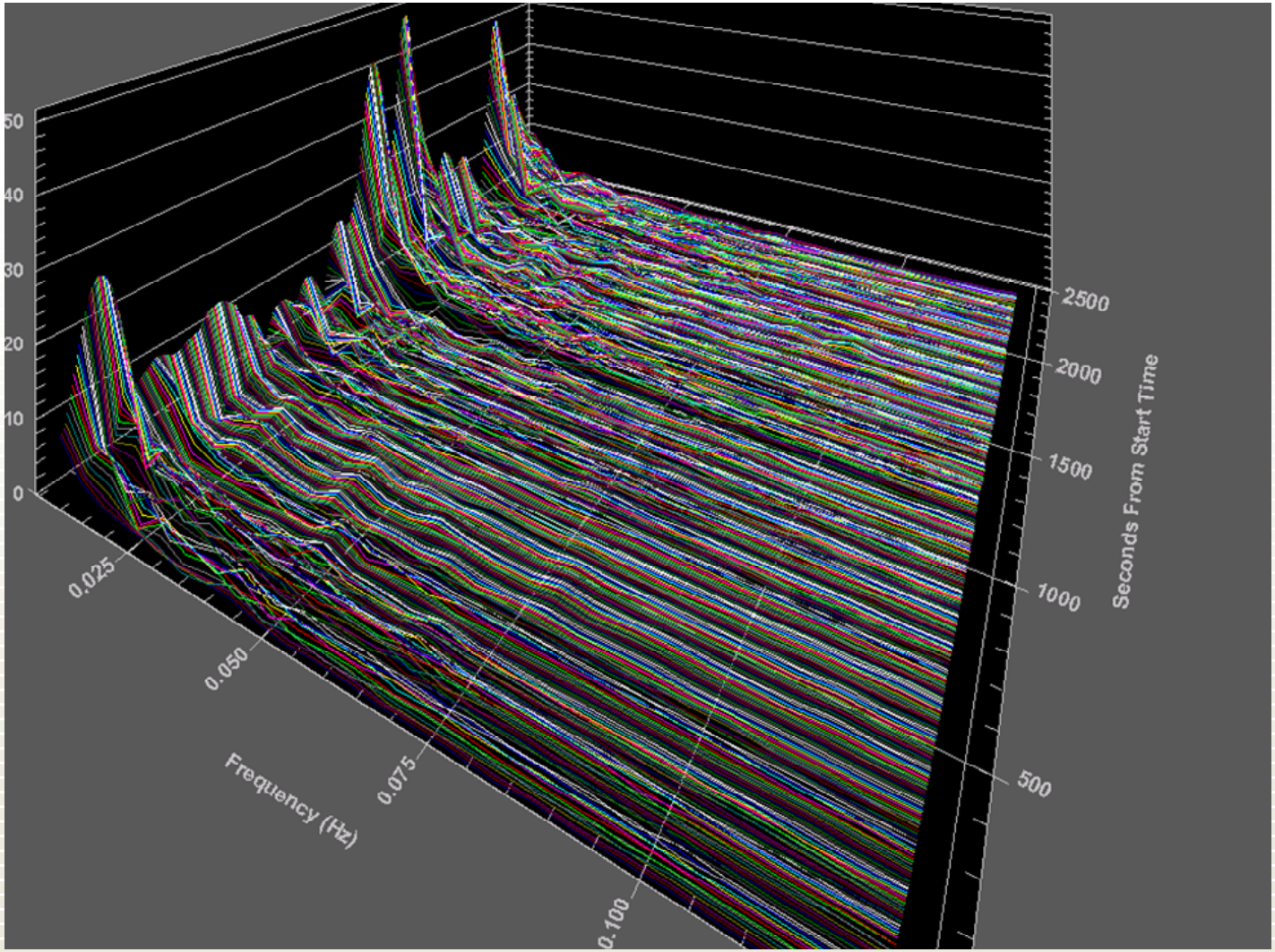


Fig. 13. Spectral history of Ameren Rush Island bus frequency for August 14 Blackout. 12:00-16:10 EDT

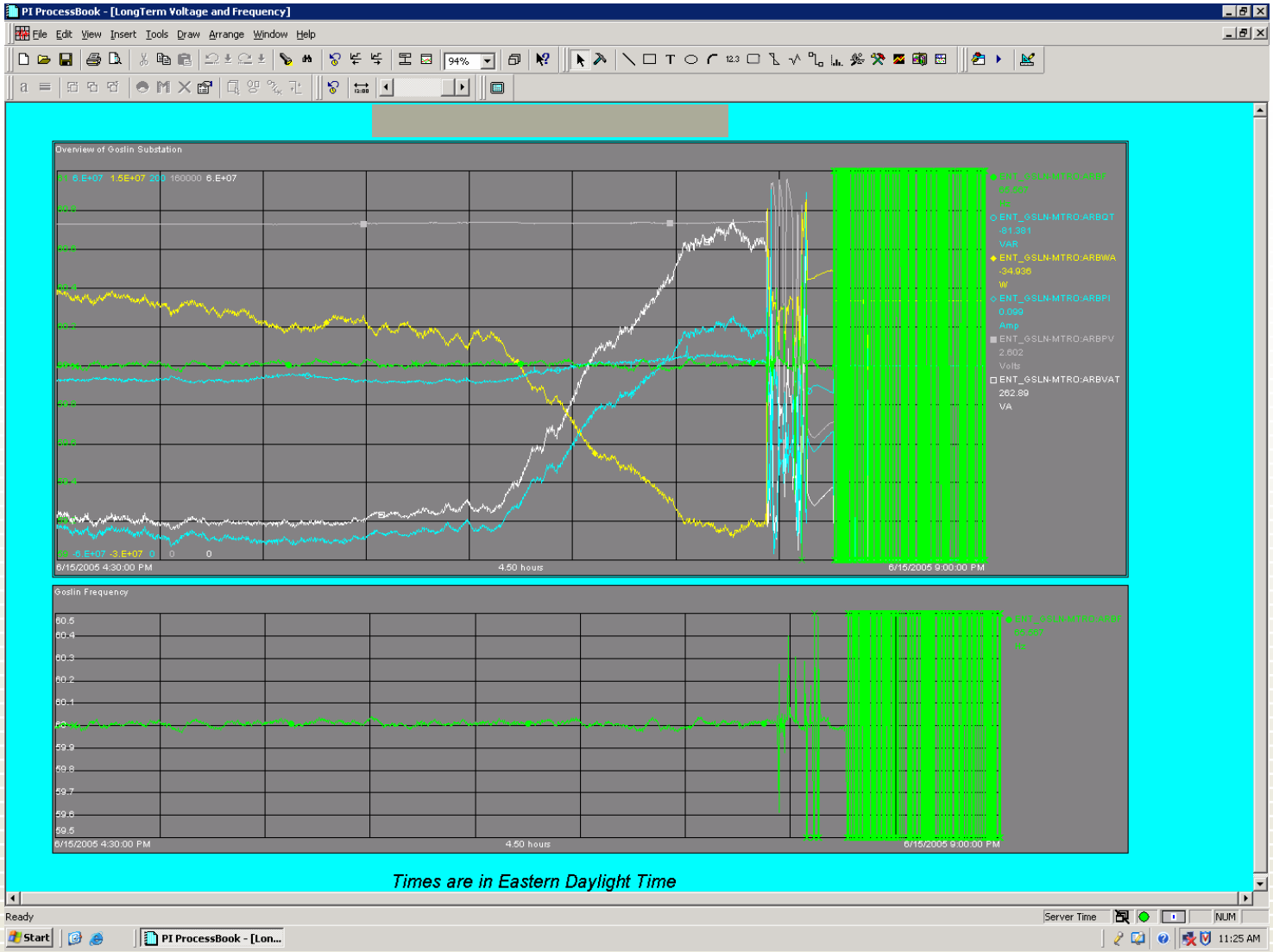
Oscillations in Sweden



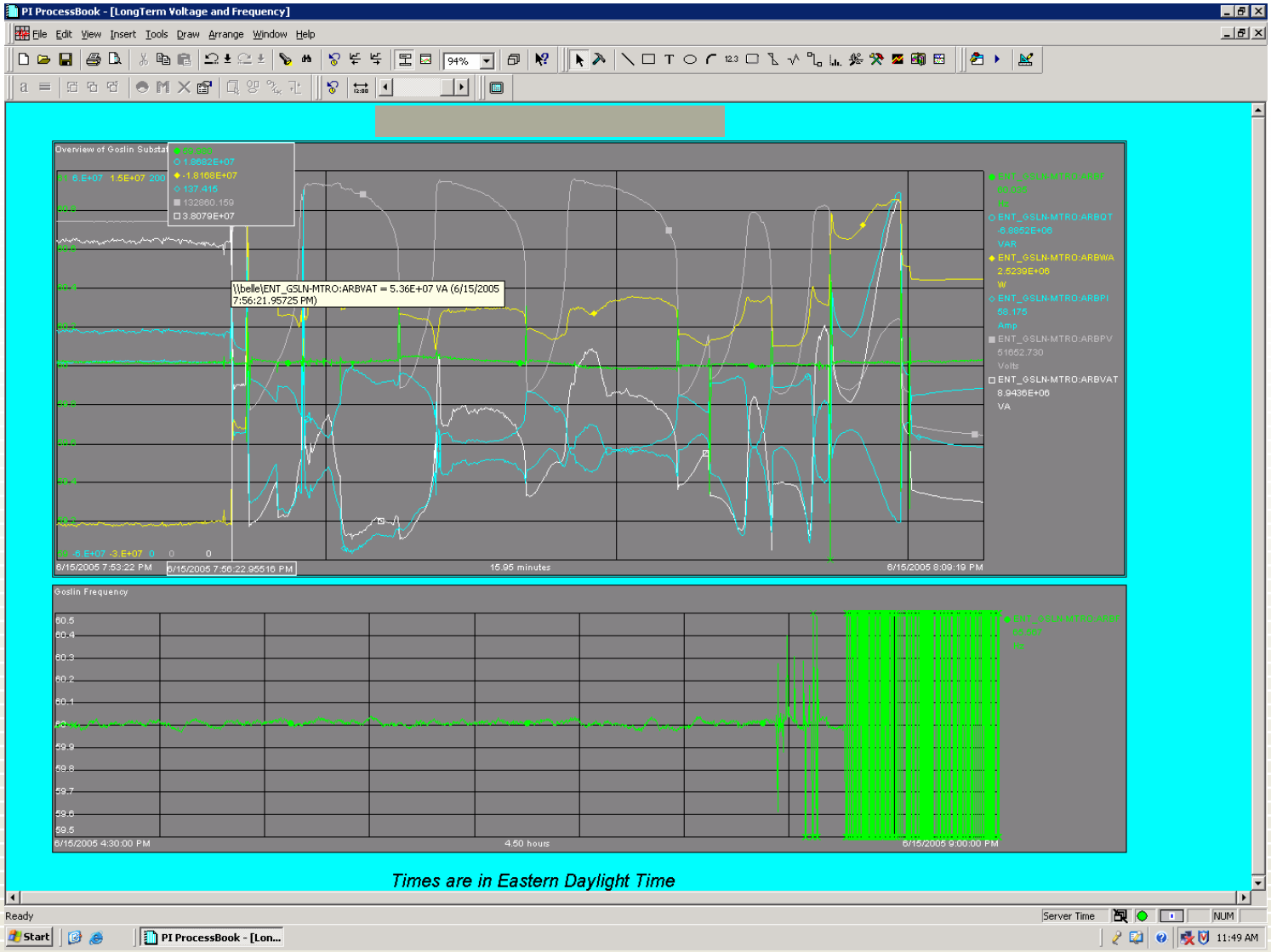
Oscillations before blackout June 15, 2005



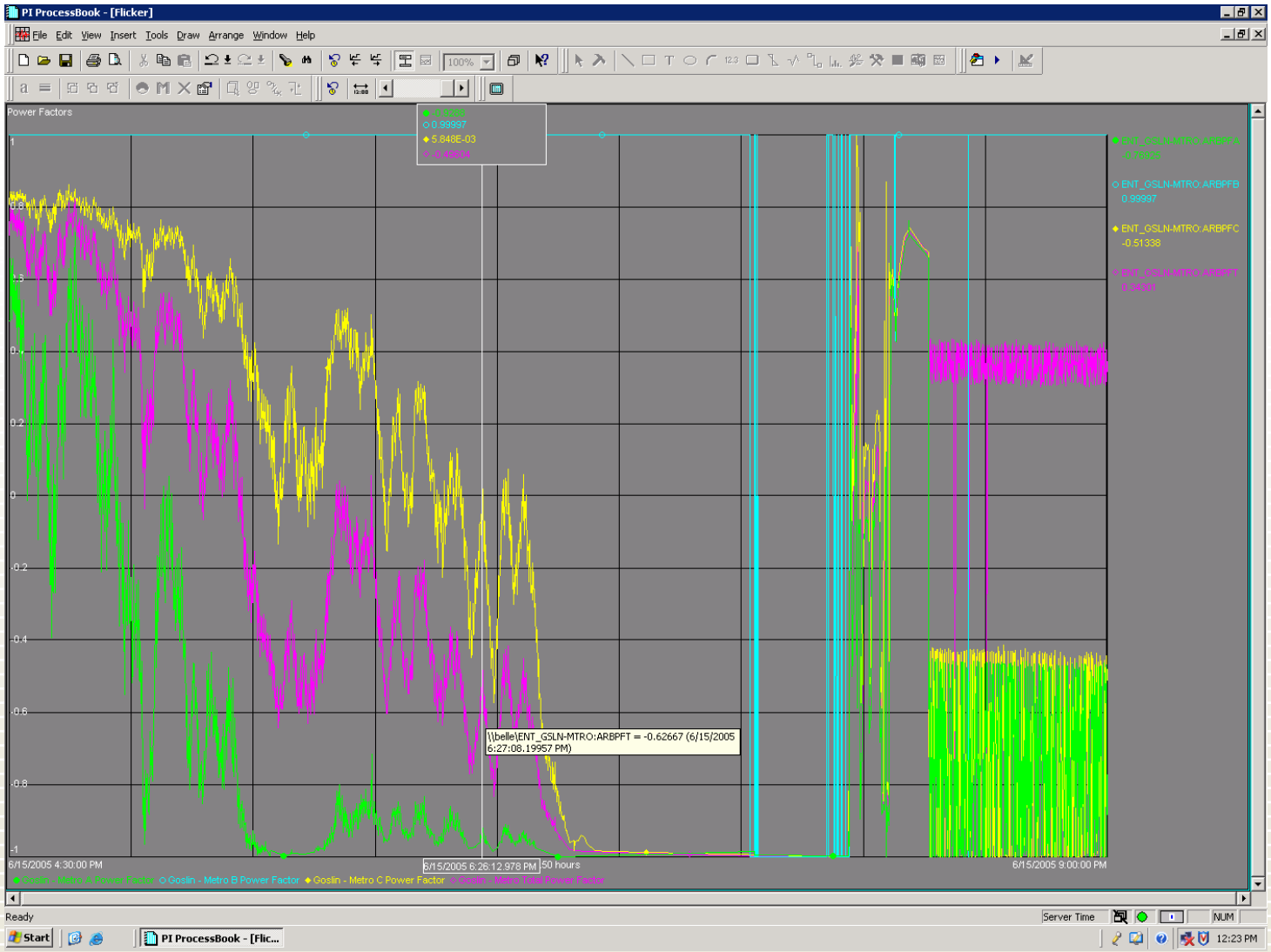
First event, power factor reversal



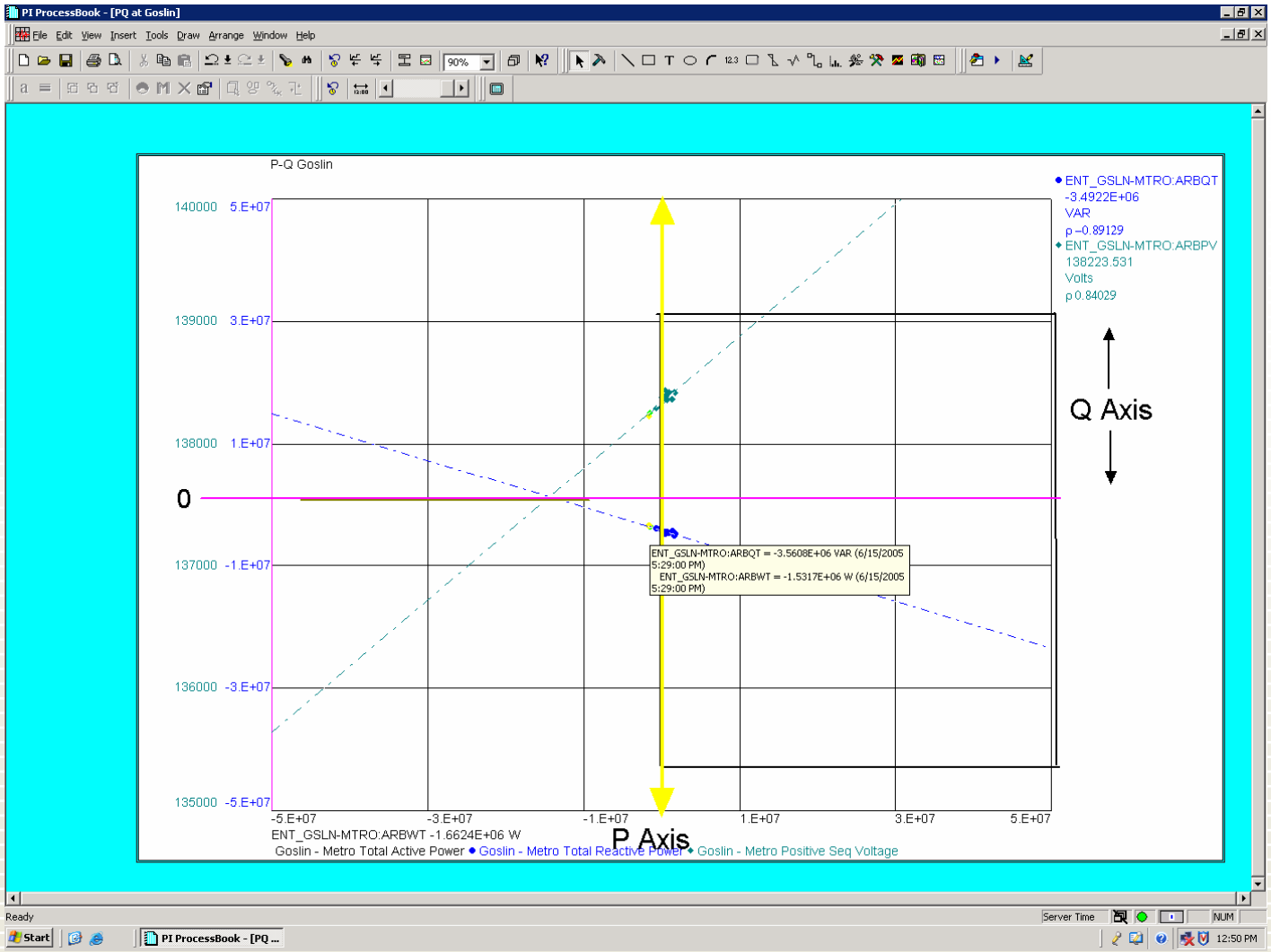
Zoomed in view



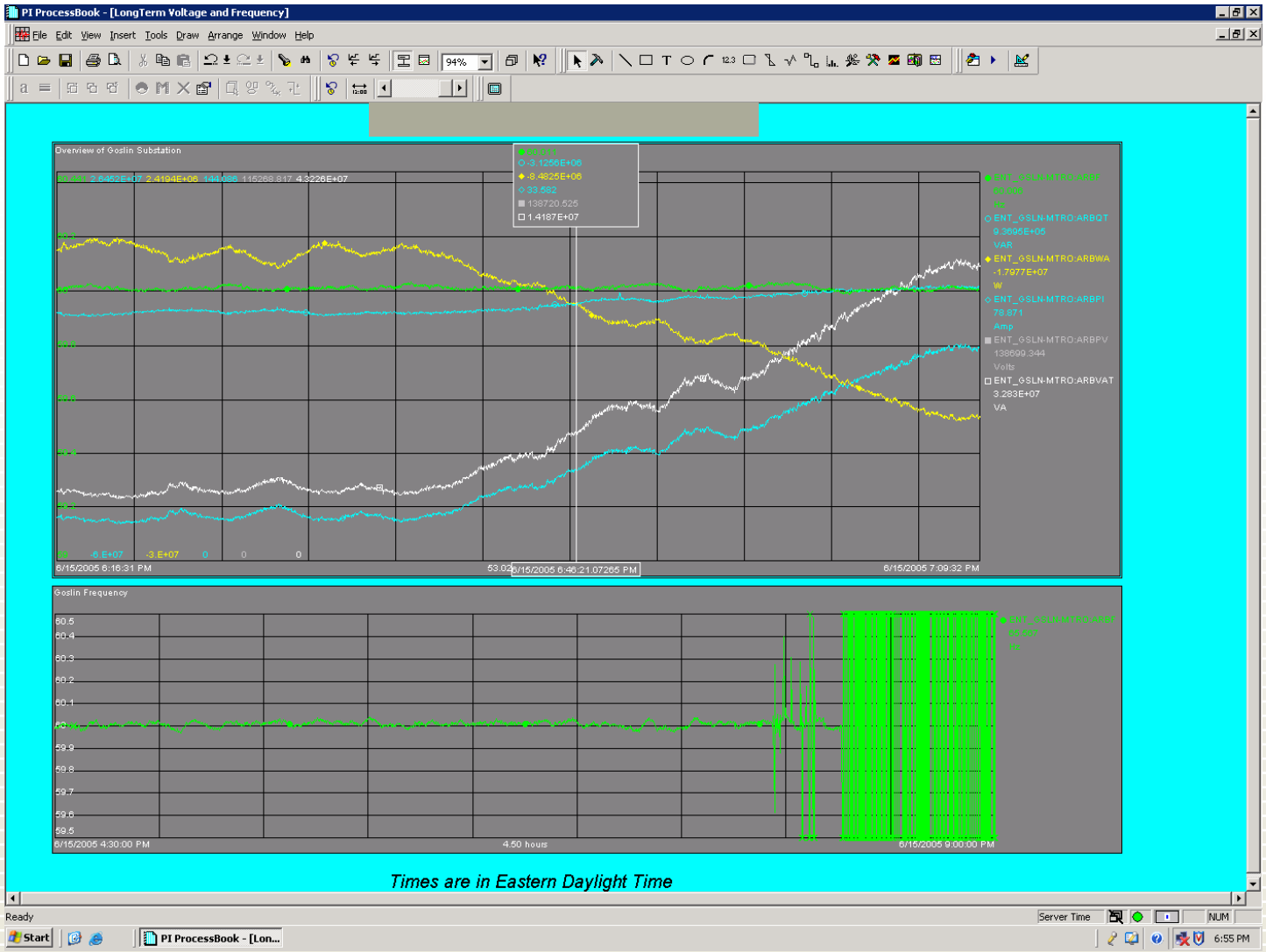
Power factor reversal



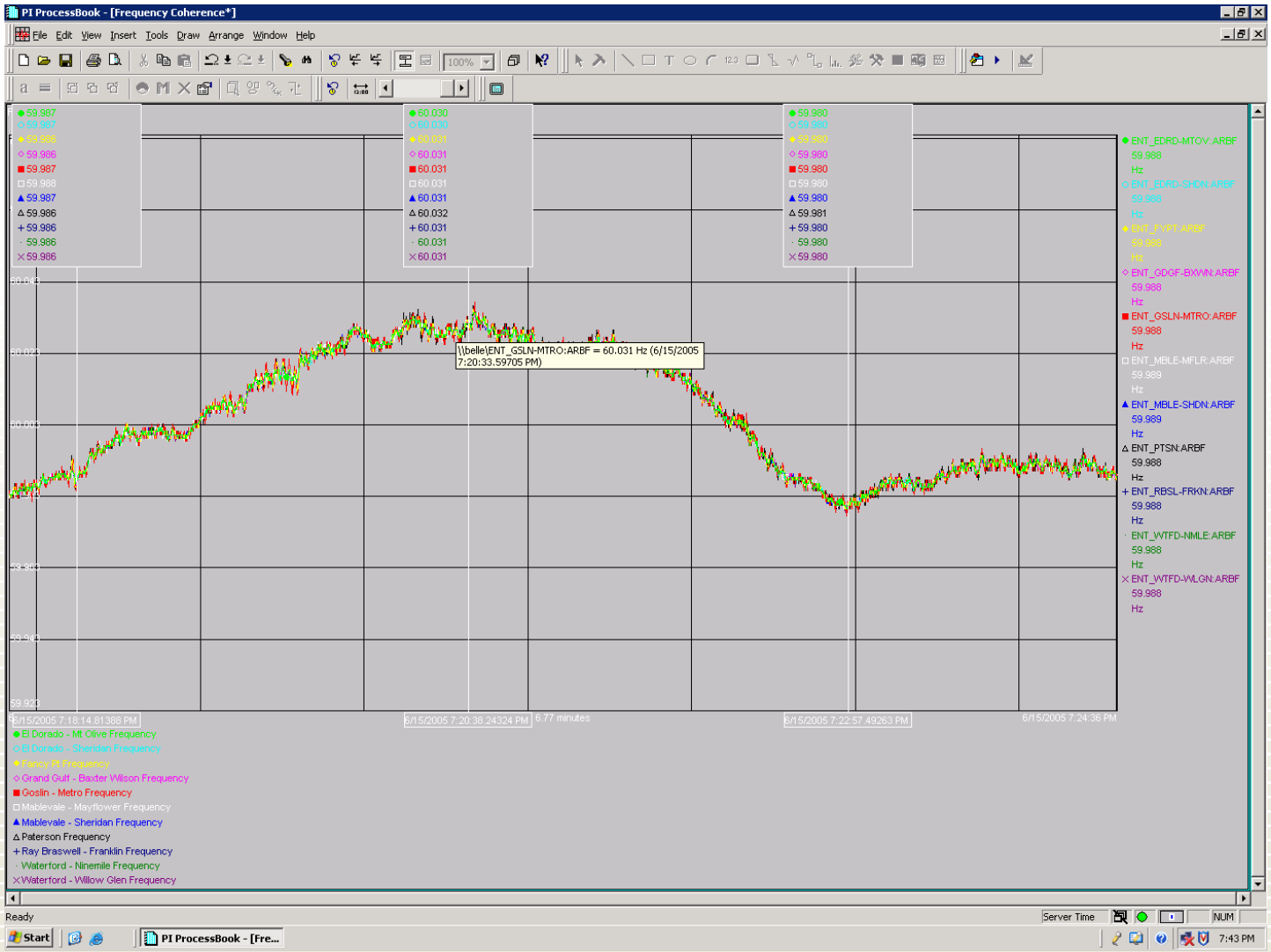
Power flow reversal



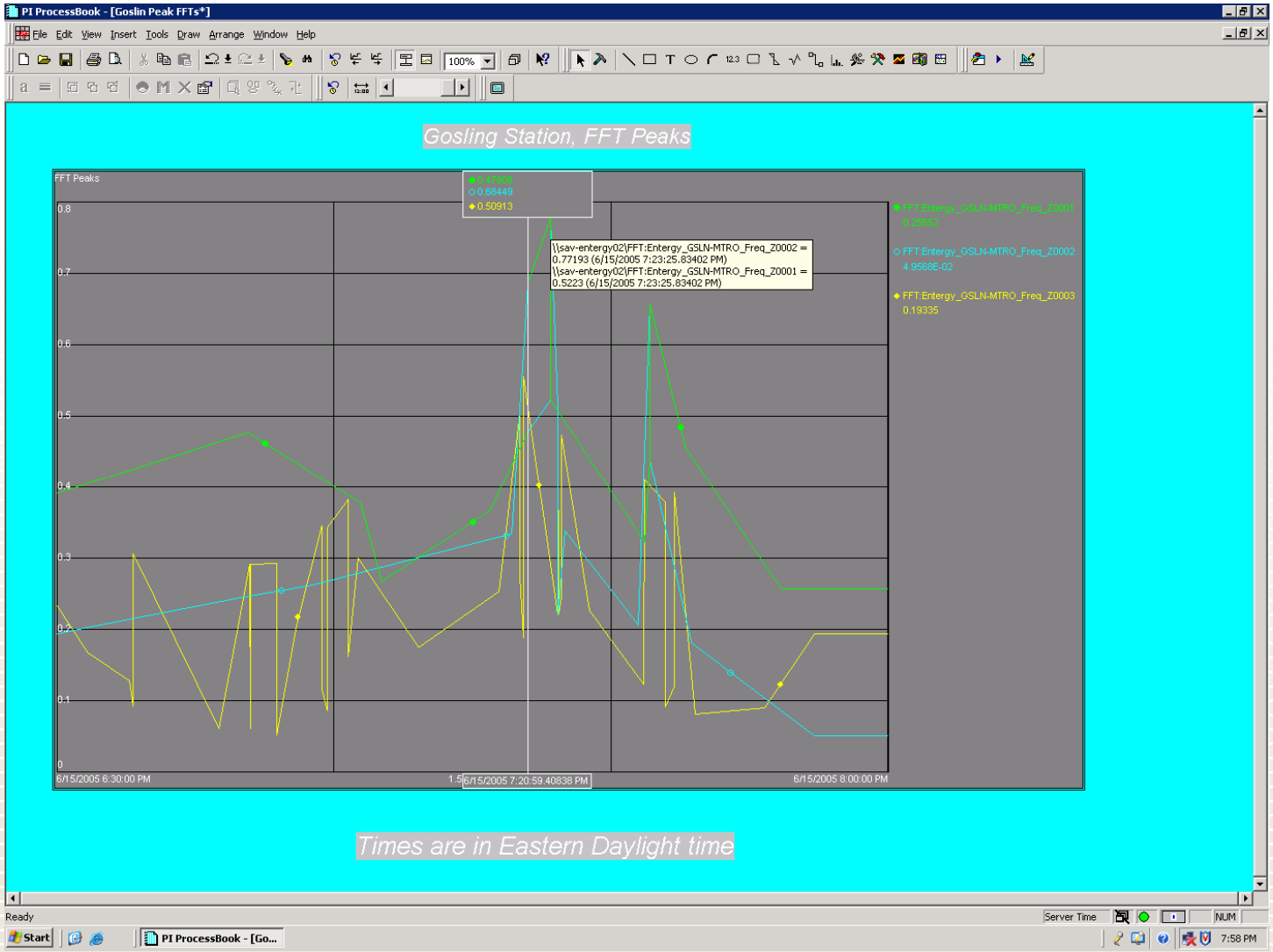
Increase in reactive power flows



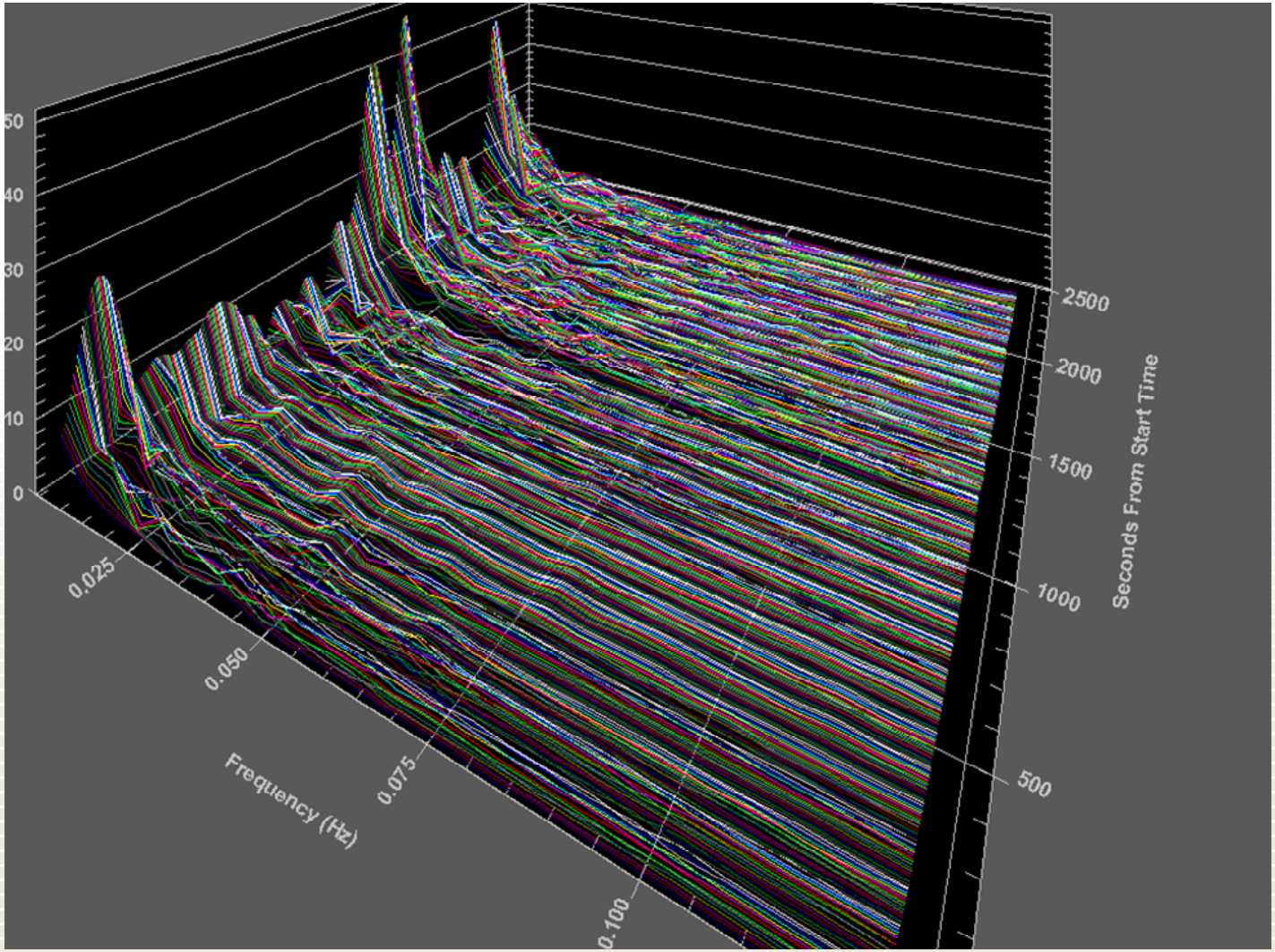
Frequency swell, Gosling high



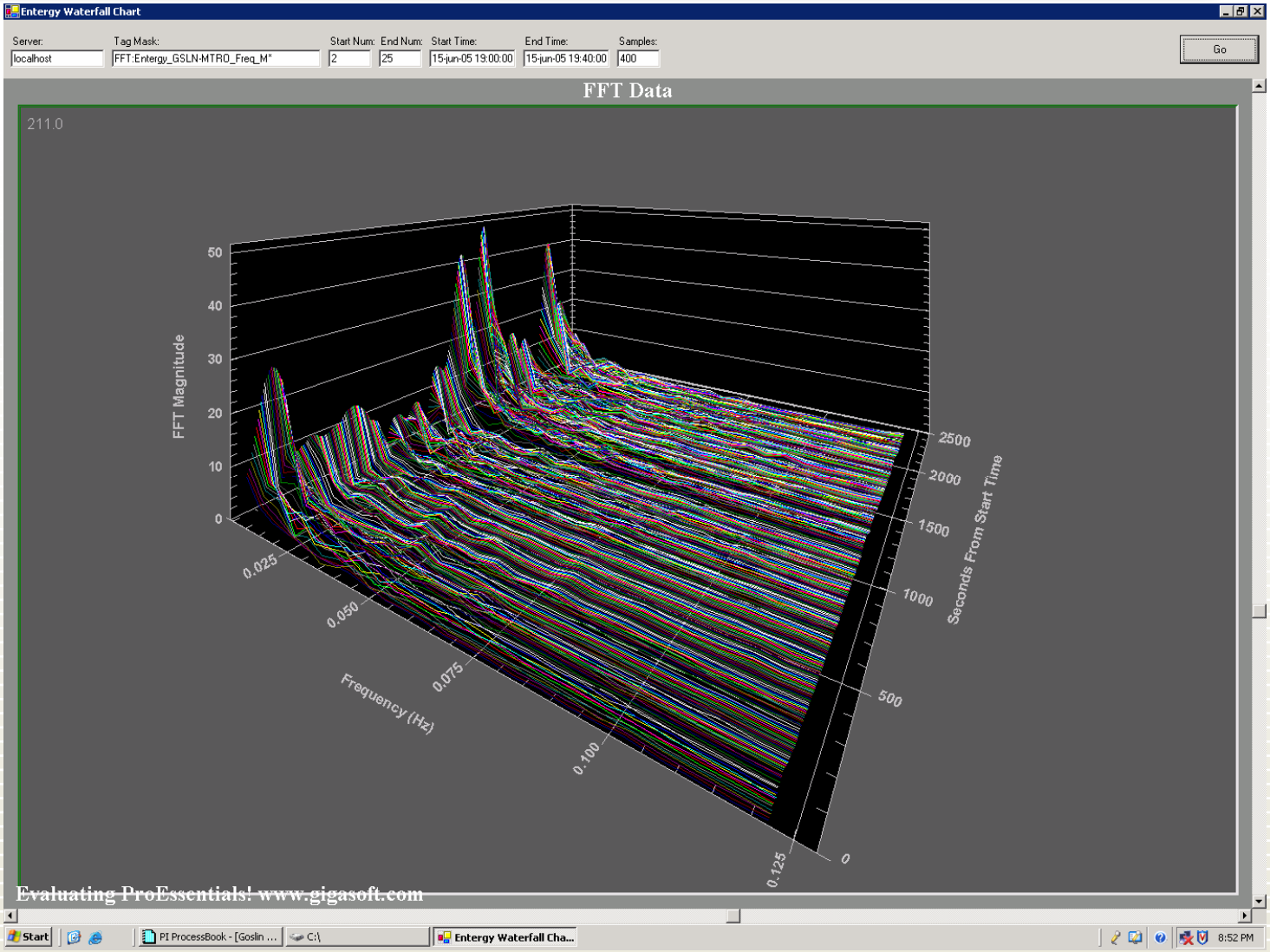
First grid oscillation



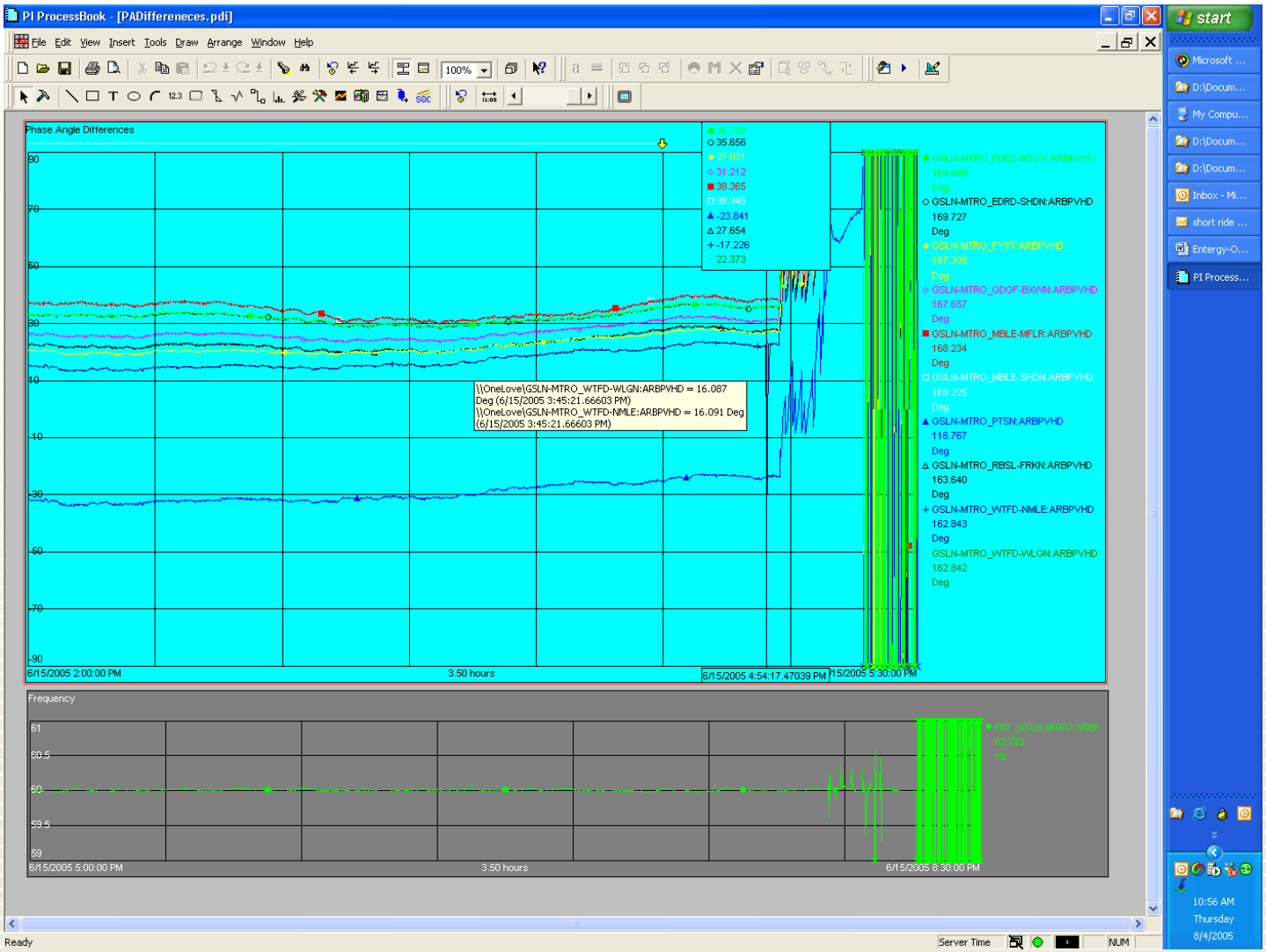
Waterfall chart of first oscillation



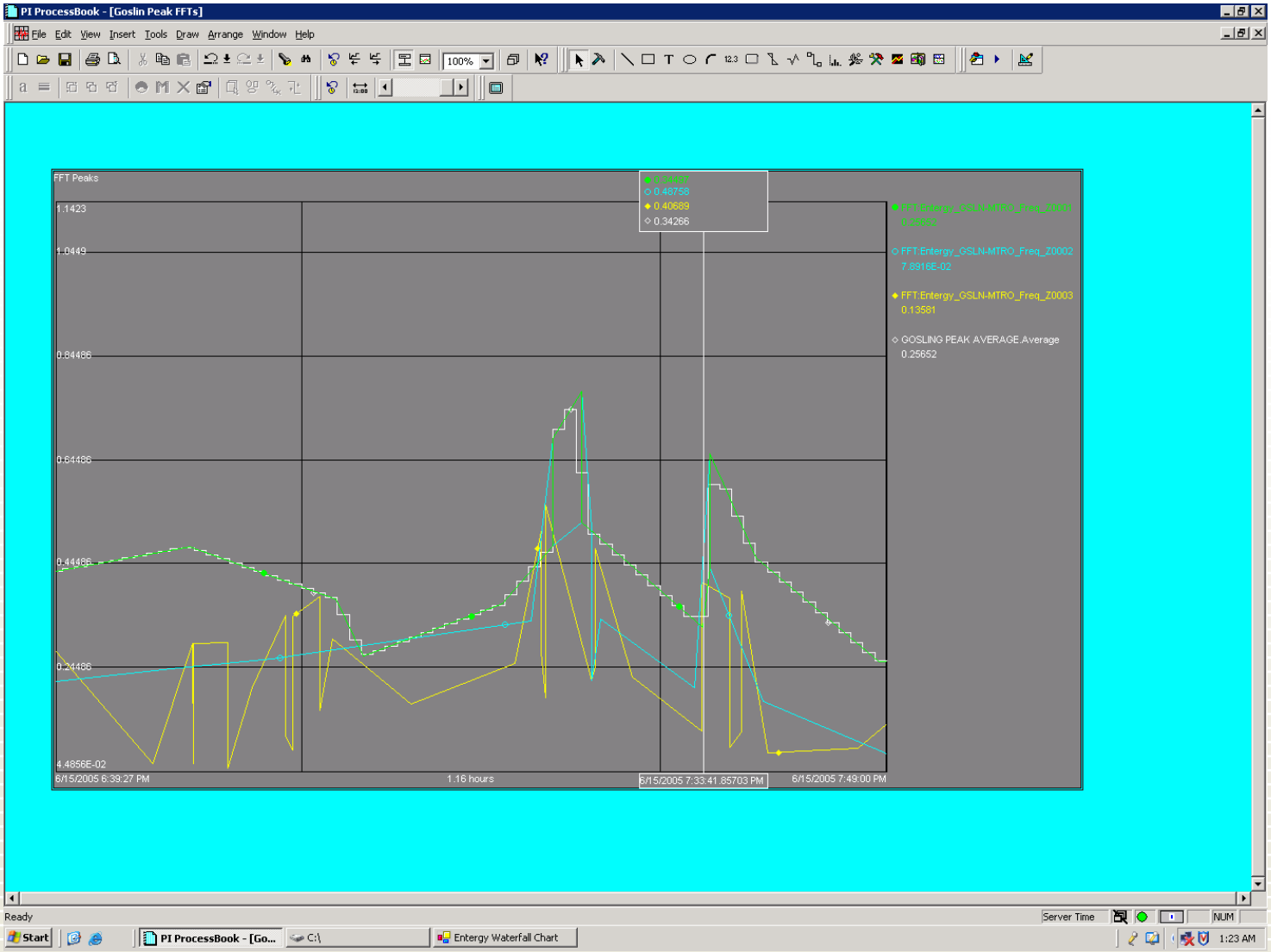
Waterfall rotation



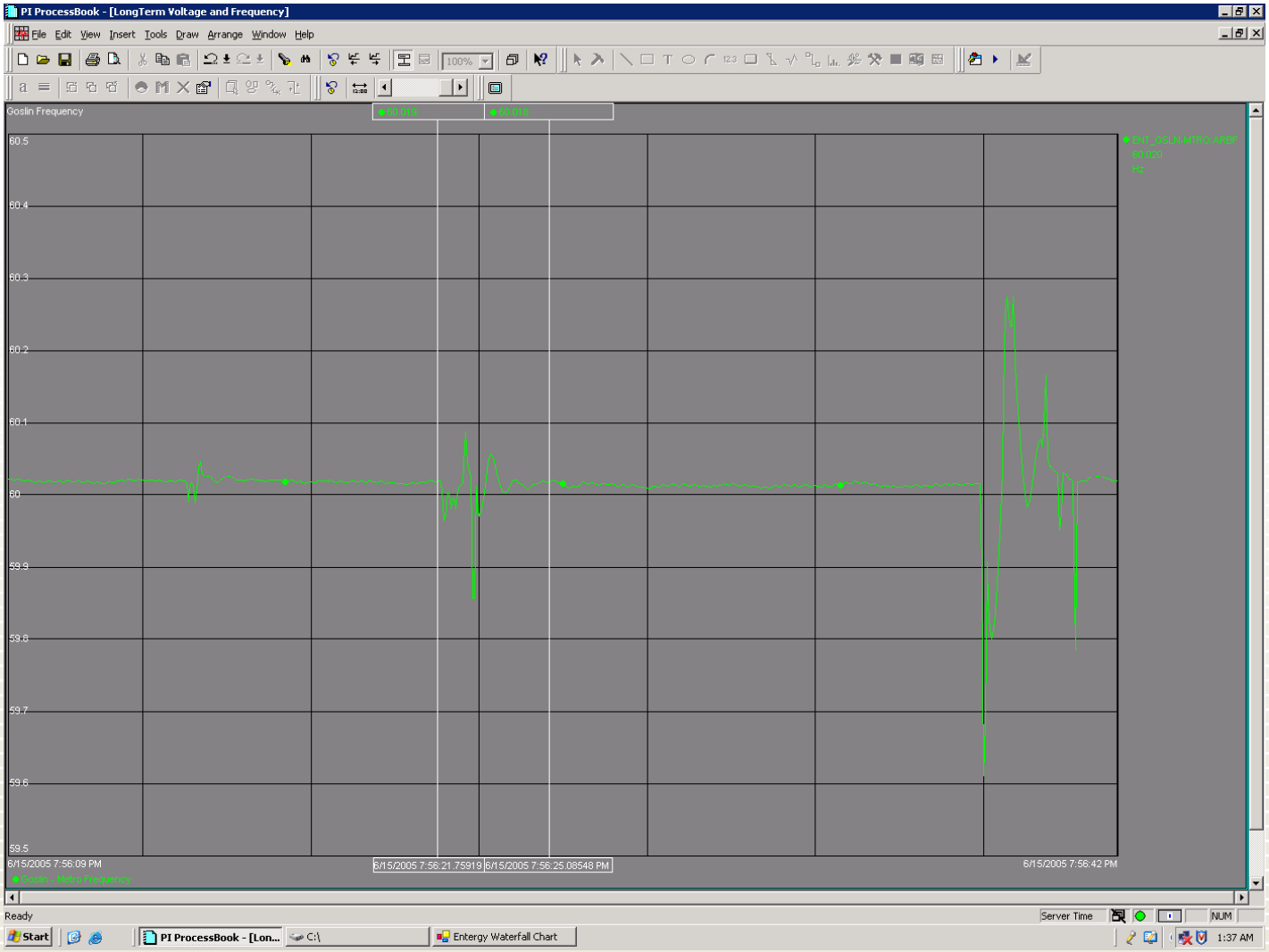
Gosling relative phase angles



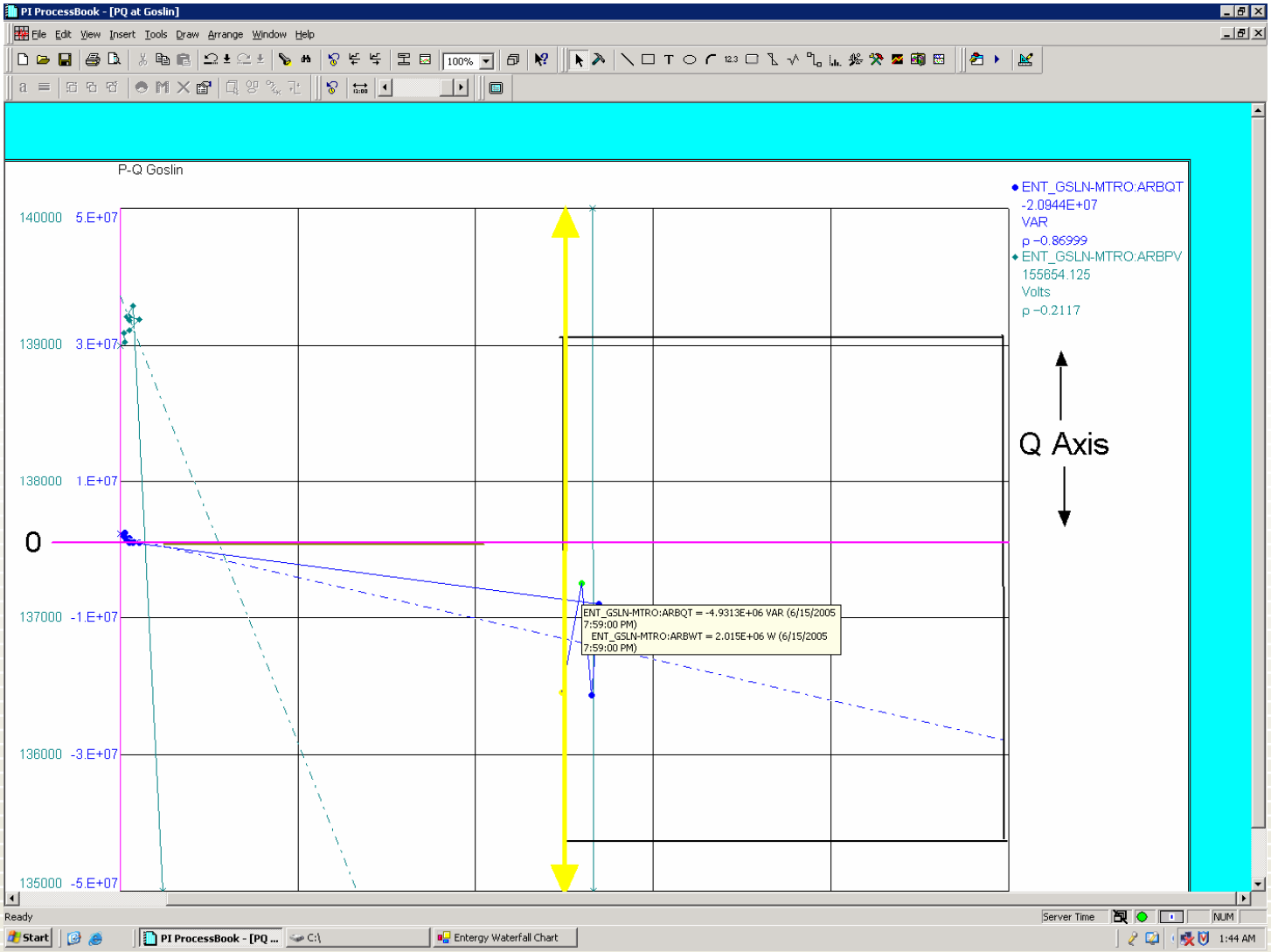
Second oscillation in grid



Decrease in damping

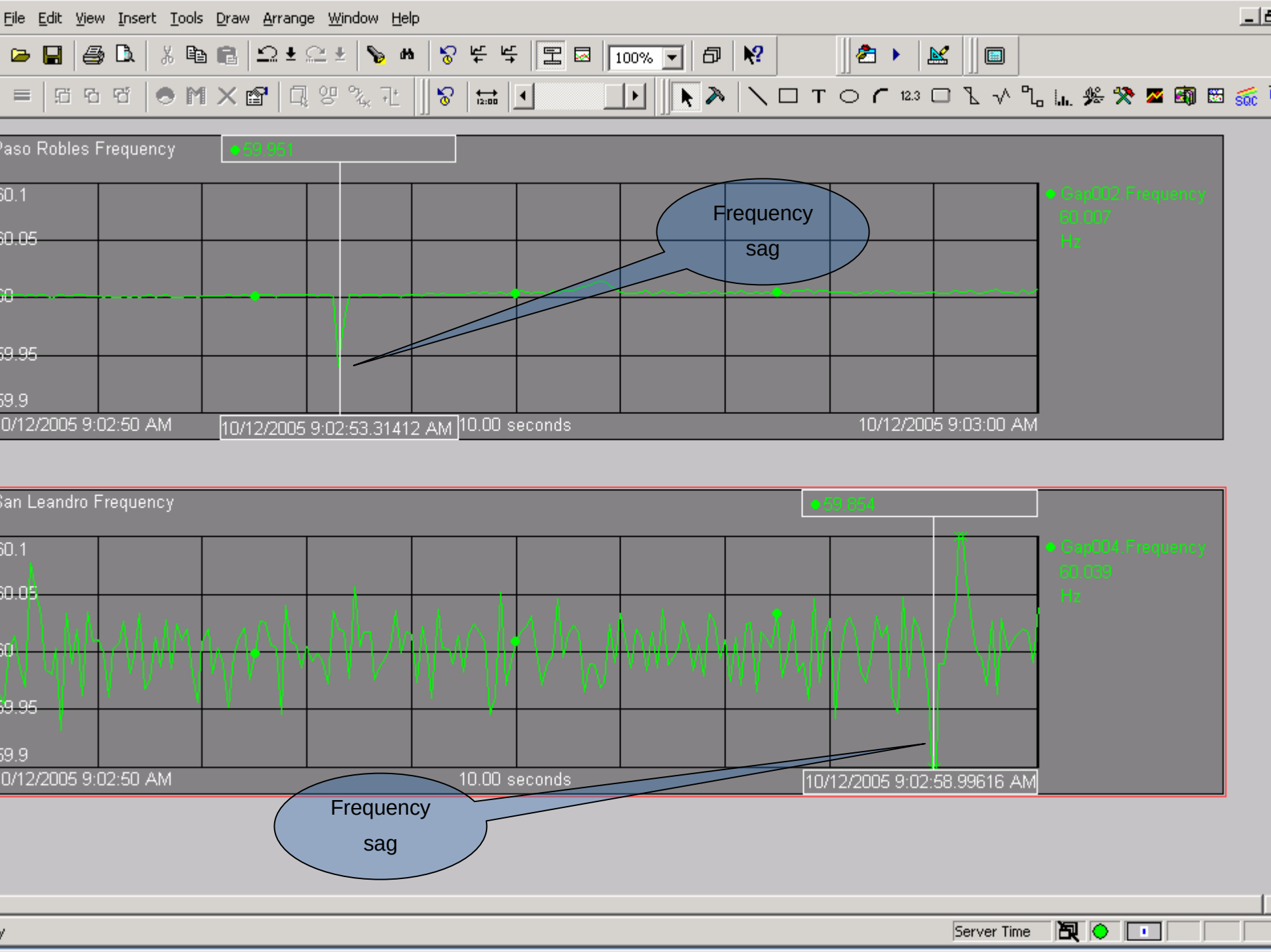


Collapse: 6:56 pm



Los Angeles Blackout

- Wave front propagation speed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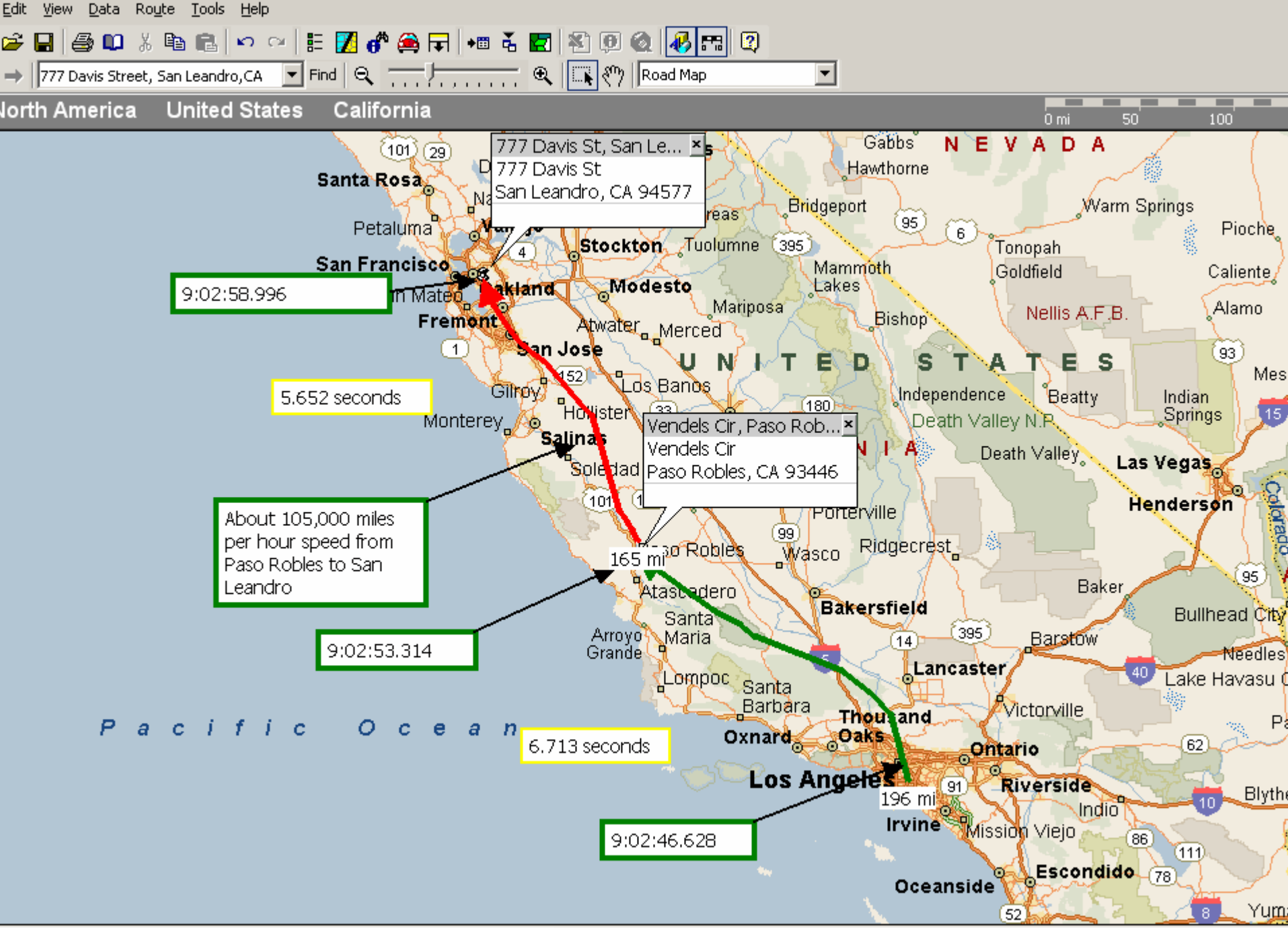
100%
Paso Robles Frequency
59.951
60.1
60.05
60
59.95
59.9
Gap002 Frequency
60.007
Hz
Frequency
sag
10/12/2005 9:02:50 AM
10/12/2005 9:02:53.31412 AM
10.00 seconds
10/12/2005 9:03:00 AM
San Leandro Frequency
59.954
60.1
60.05
60
59.95
59.9
Gap004 Frequency
60.059
Hz
10/12/2005 9:02:50 AM
10.00 seconds
10/12/2005 9:02:58.99616 AM
Frequency
sag
Server Time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777 Davis Street, San Leandro,CA
Find
Road Map
North America
United States
California
0 mi 50 100
777 Davis St, San Le...
777 Davis St
San Leandro, CA 94577
Vendels Cir, Paso Rob...
Vendels Cir
Paso Robles, CA 93446
9:02:58.996
5.652 seconds
About 105,000 miles per hour speed from Paso Robles to San Leandro
9:02:53.314
6.713 seconds
9:02:46.628
165 mi
196 mi
Pacific Ocean
NEVADA
UNITED STATES
Santa Rosa
Petaluma
San Francisco
Oakland
Fremont
Stockton
Modesto
Tuolumne
Mariposa
Merced
Atwater
San Jose
Gilroy
Los Banos
Hollister
Monterey
Salinas
Soledad
Paso Robles
Atascadero
Arroyo Grande
Santa Maria
Lompoc
Santa Barbara
Oxnard
Thousand Oaks
Los Angeles
Irvine
Ontario
Riverside
Indio
Mission Viejo
Oceanside
Escondido
Victorville
Lancaster
Barstow
Bakersfield
Wasco
Ridgecrest
Porterville
Baker
Bullhead City
Needles
Lake Havasu
Las Vegas
Henderson
Death Valley
Death Valley N.P.
Independence
Beatty
Indian Springs
Nellis A.F.B.
Bishop
Mammoth Lakes
Tonopah
Goldfield
Caliente
Alamo
Pioche
Warm Springs
Bridgeport
Hawthorne
Gabbs

777 Davis Street

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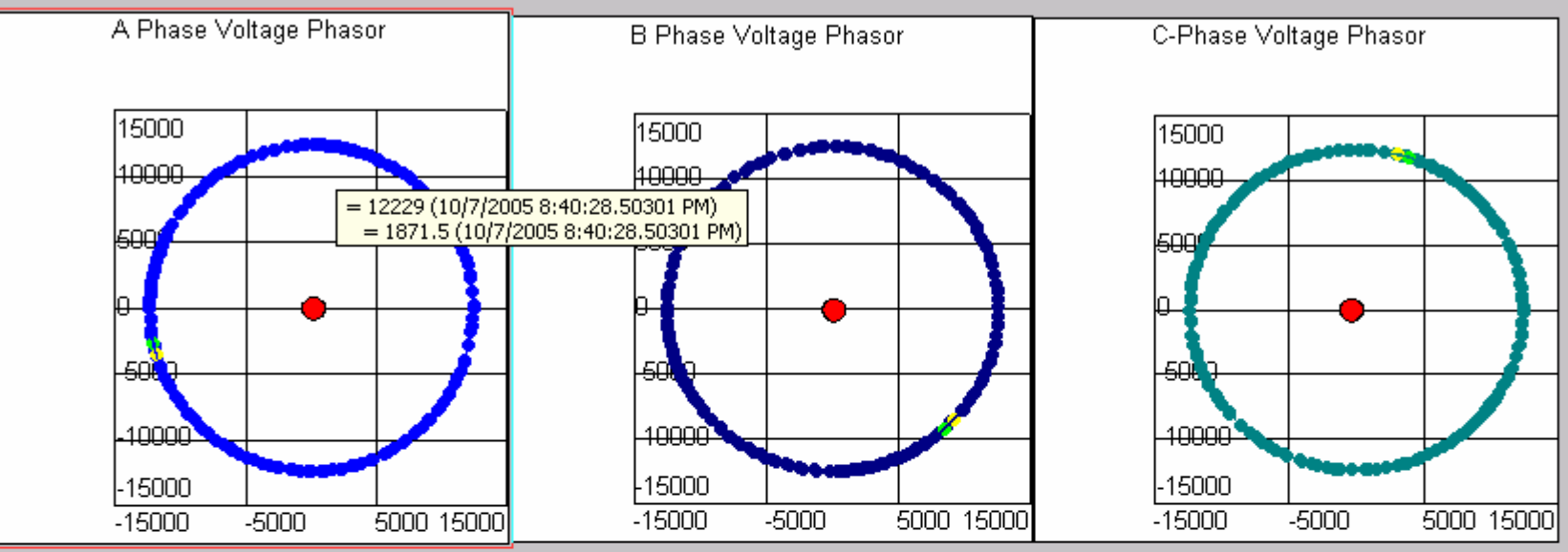
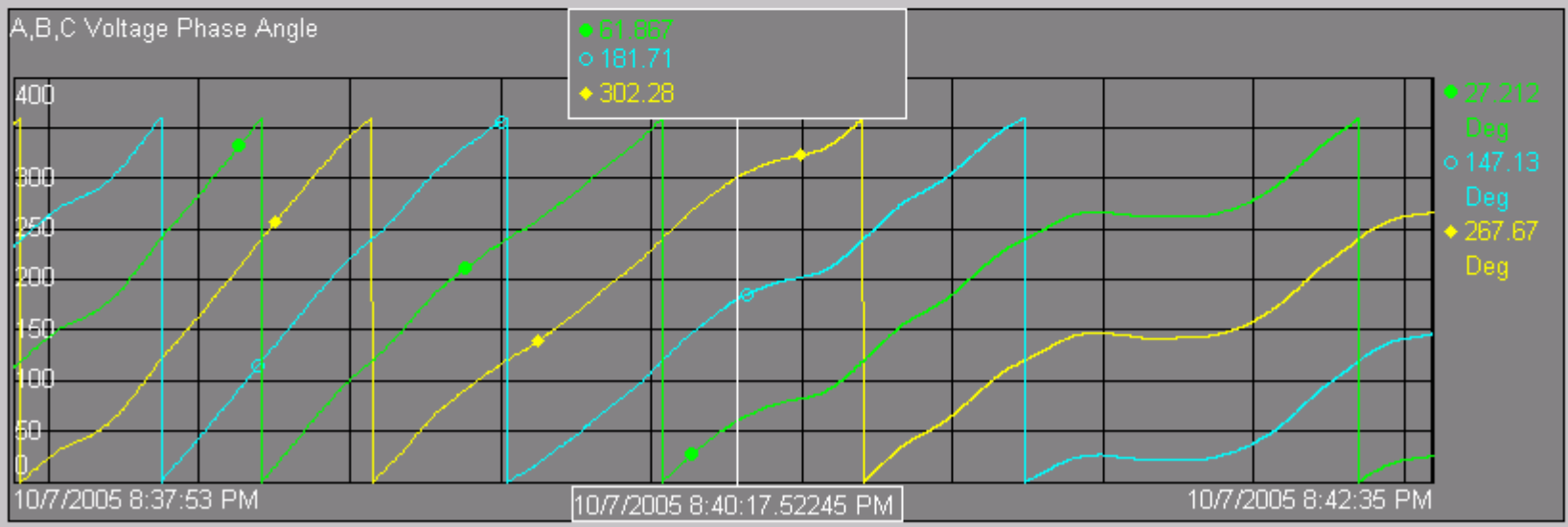


Voltage phasor



Voltage Phase Angl

Server Time

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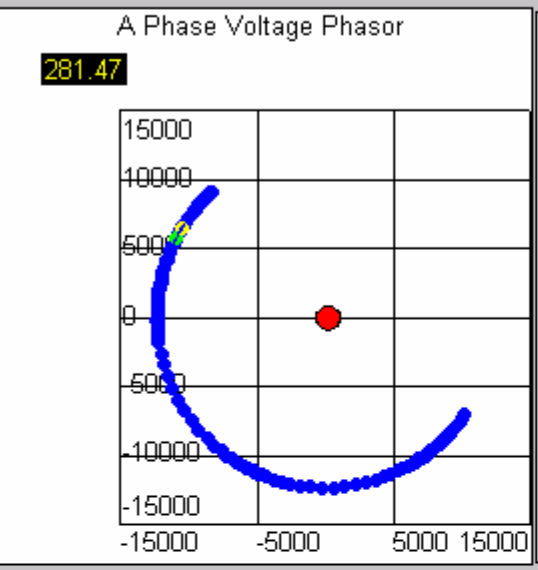
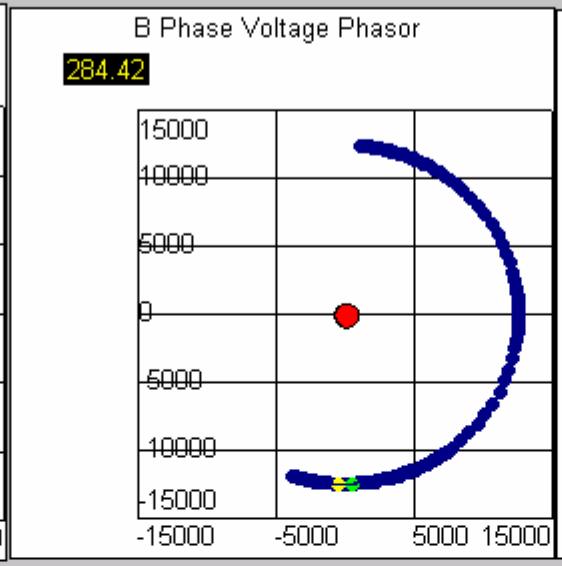
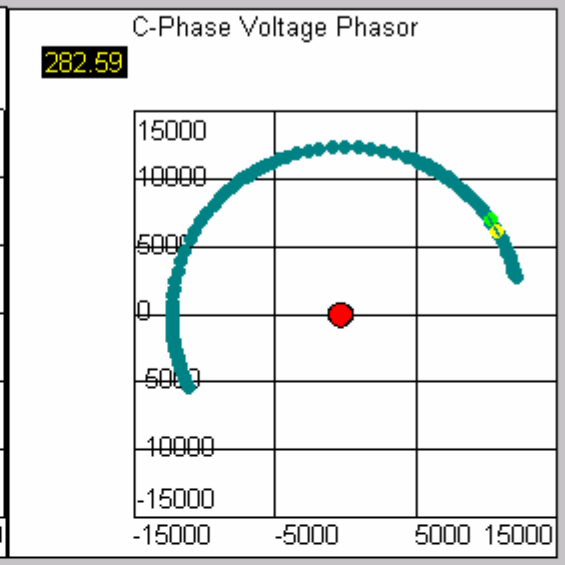
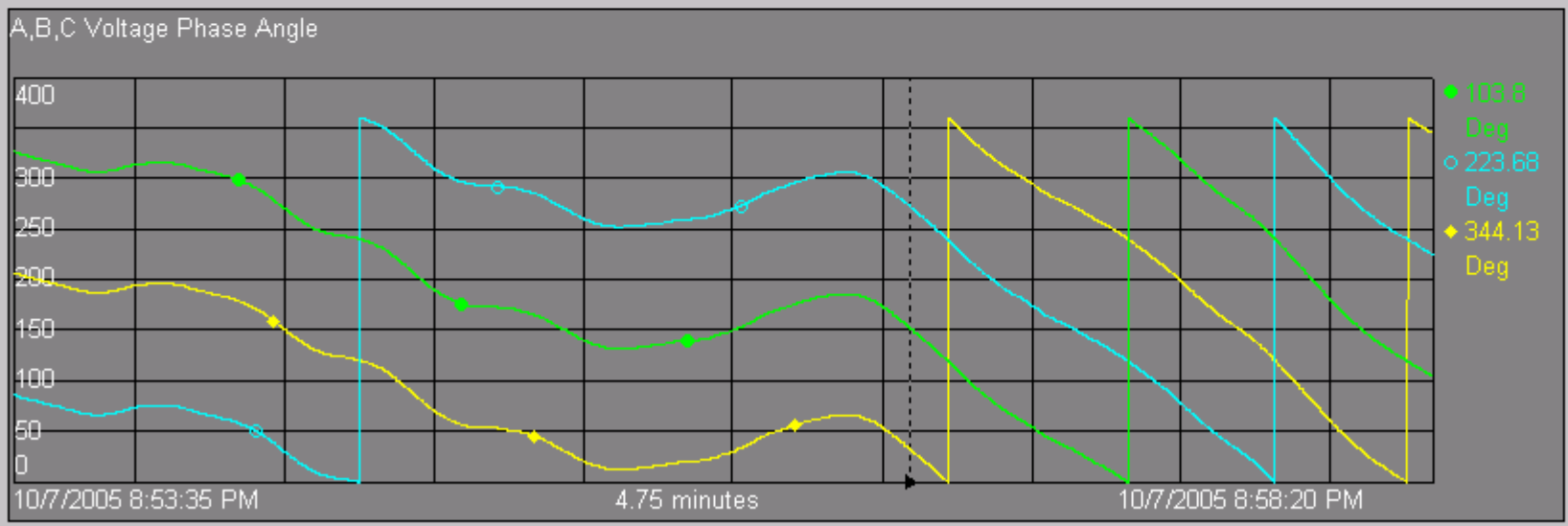






Voltage phasor



Voltage Phase Angl

Server Time

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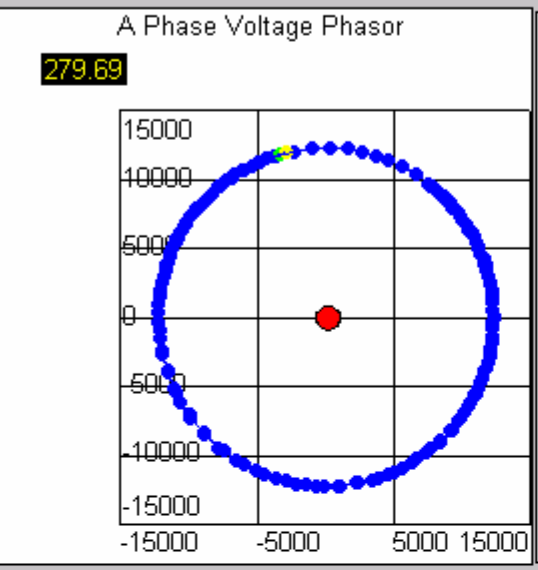

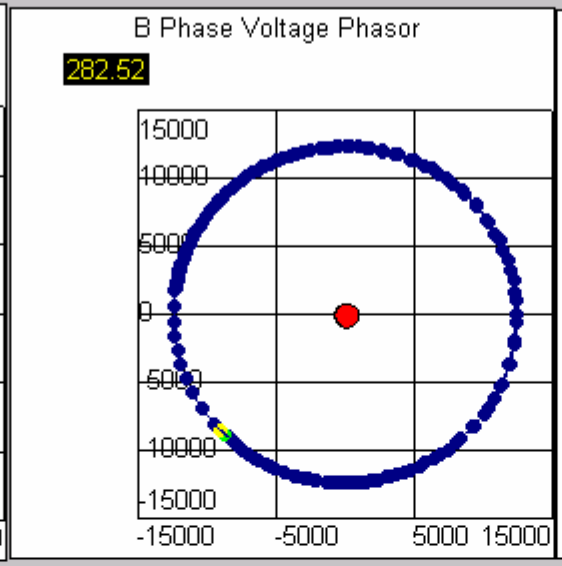

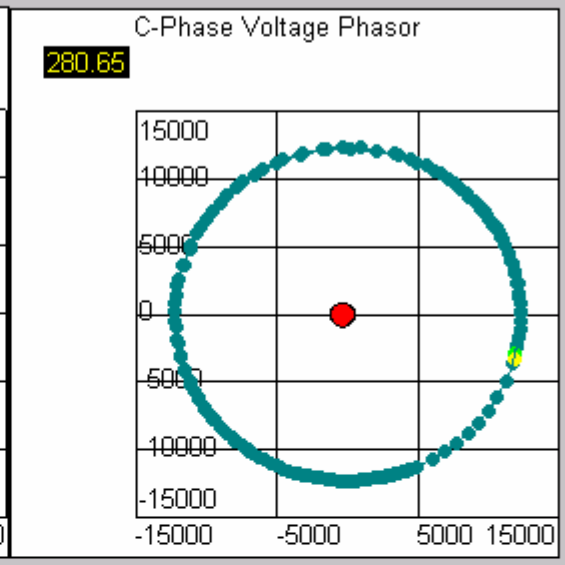

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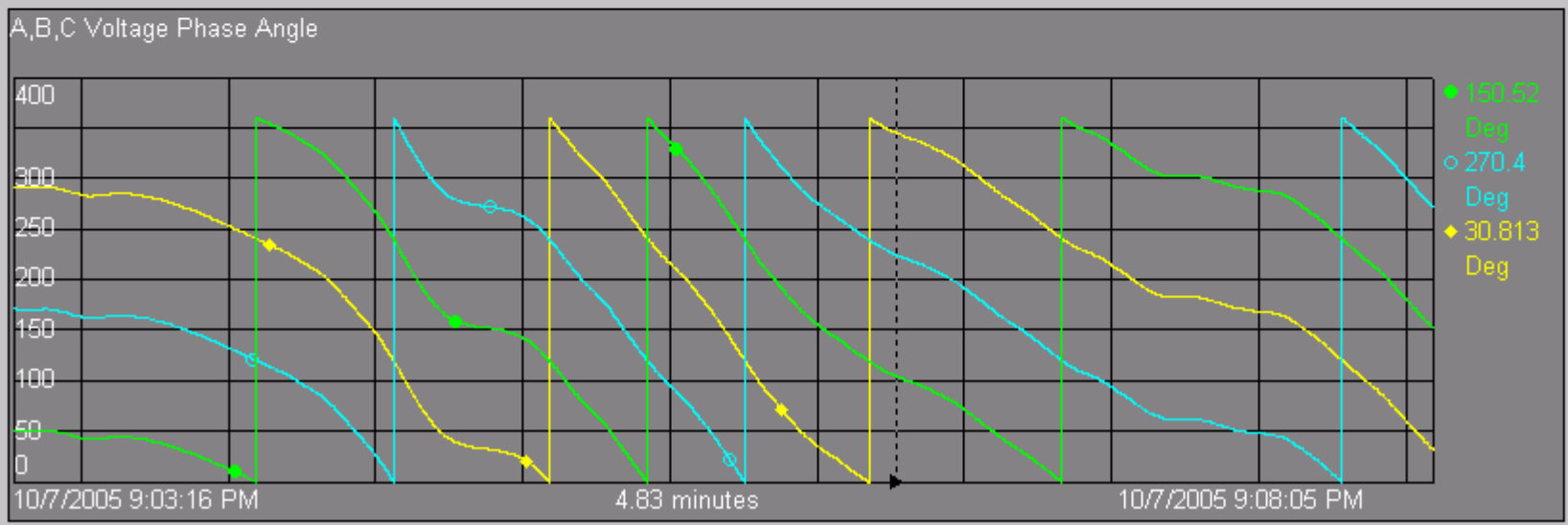

Voltage Phase Angl

Server Time

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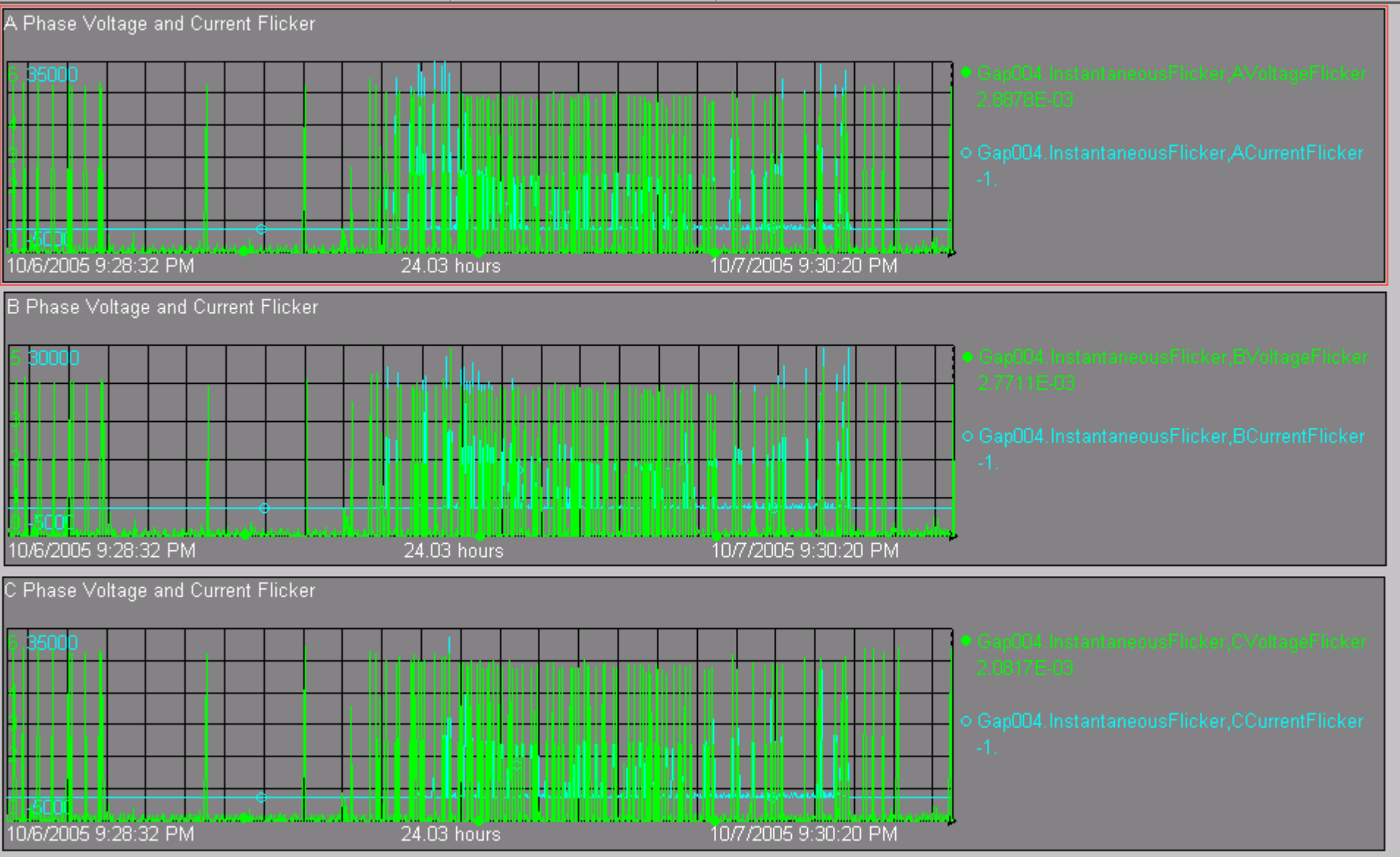

to initial time range settings

Server Time

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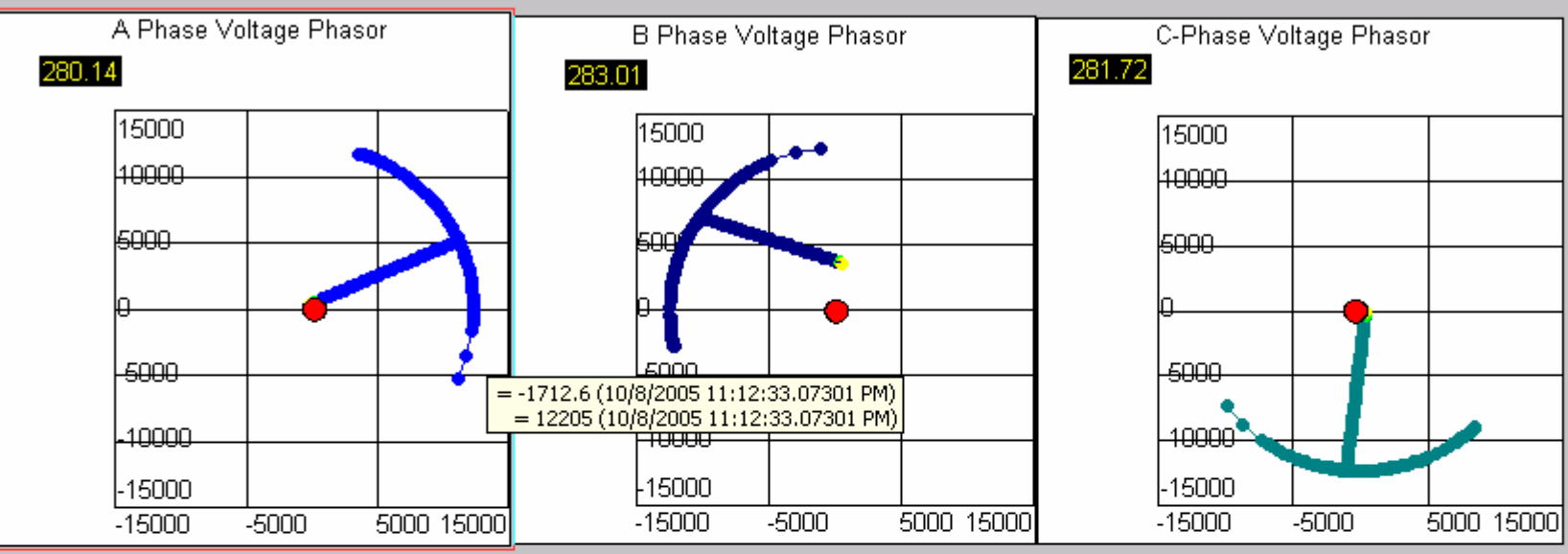
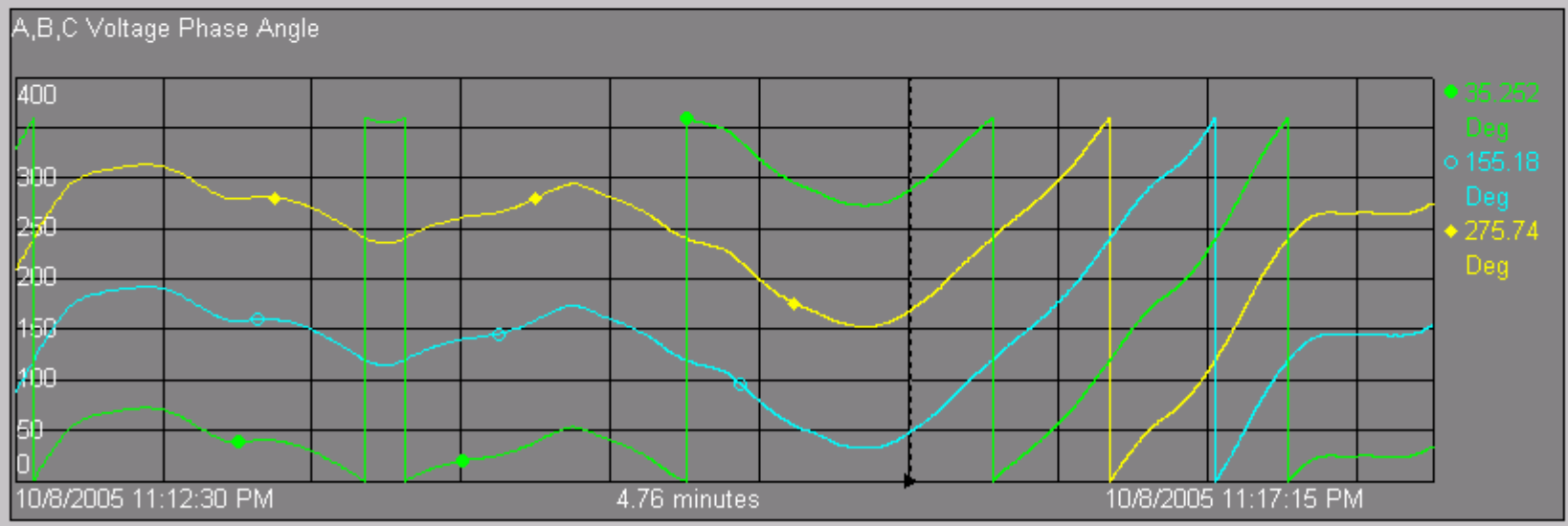


Voltage phasor



Voltage Phase Angl

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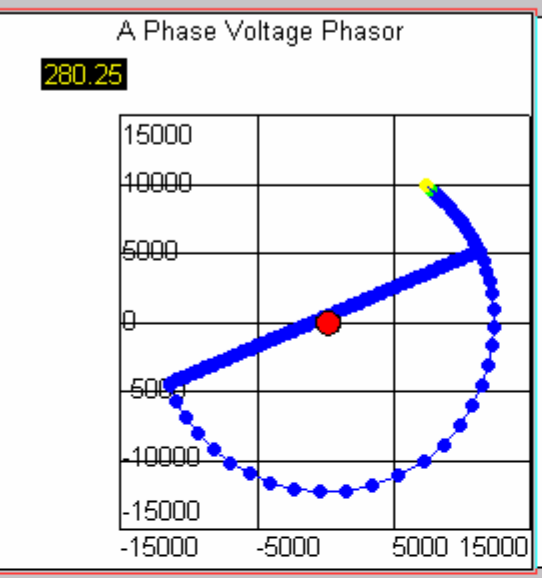

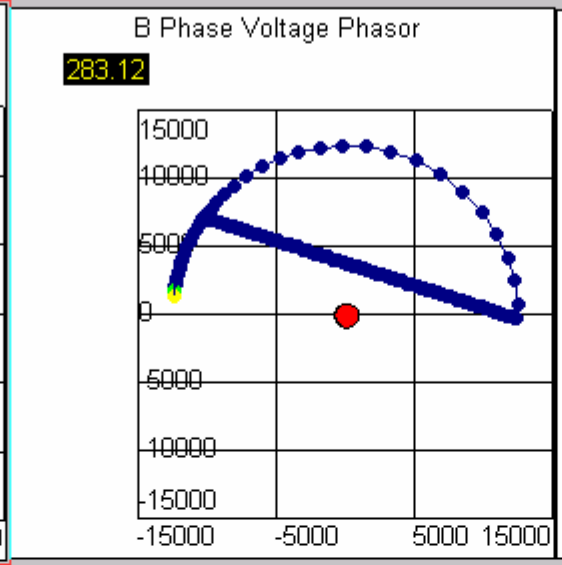

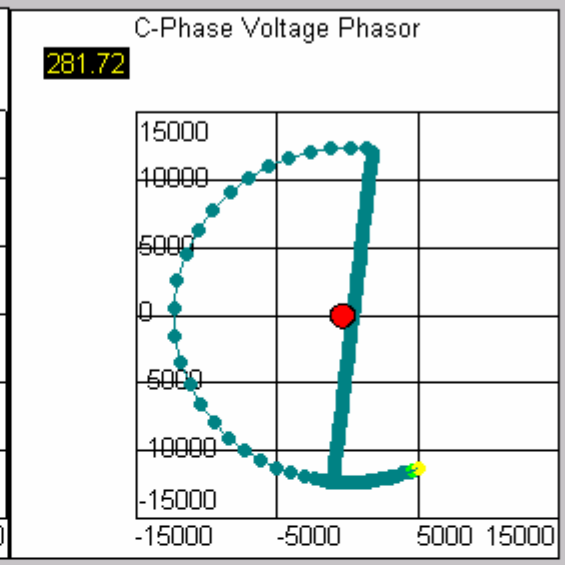

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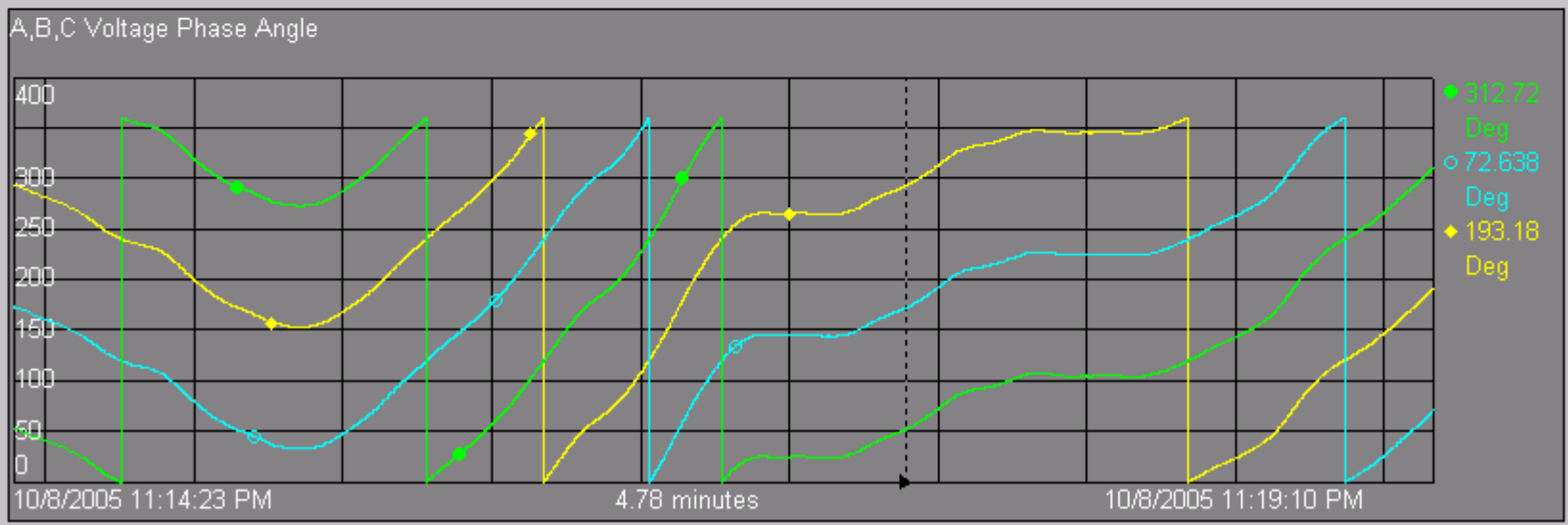

Voltage Phase Angl

Server Time

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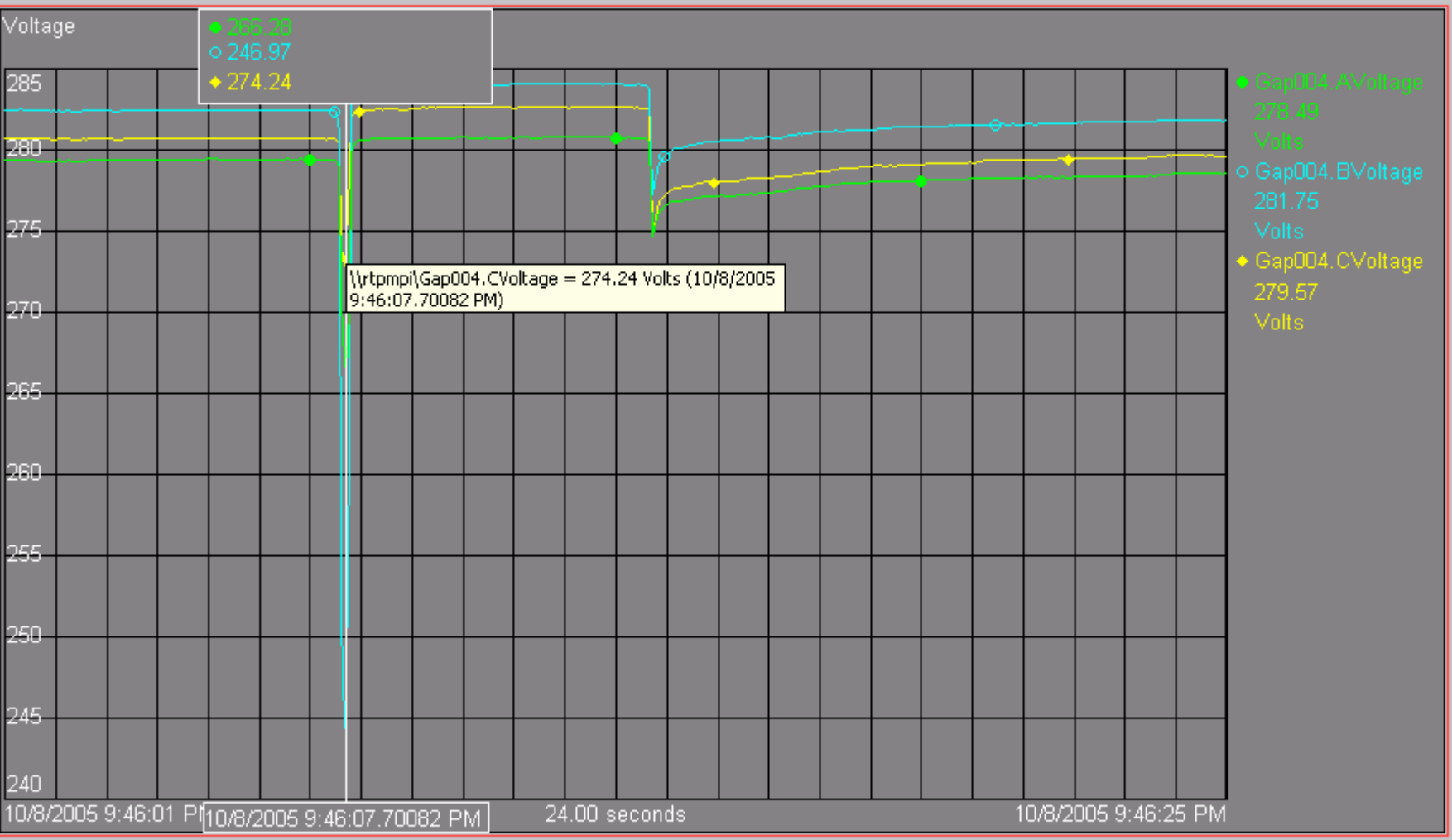

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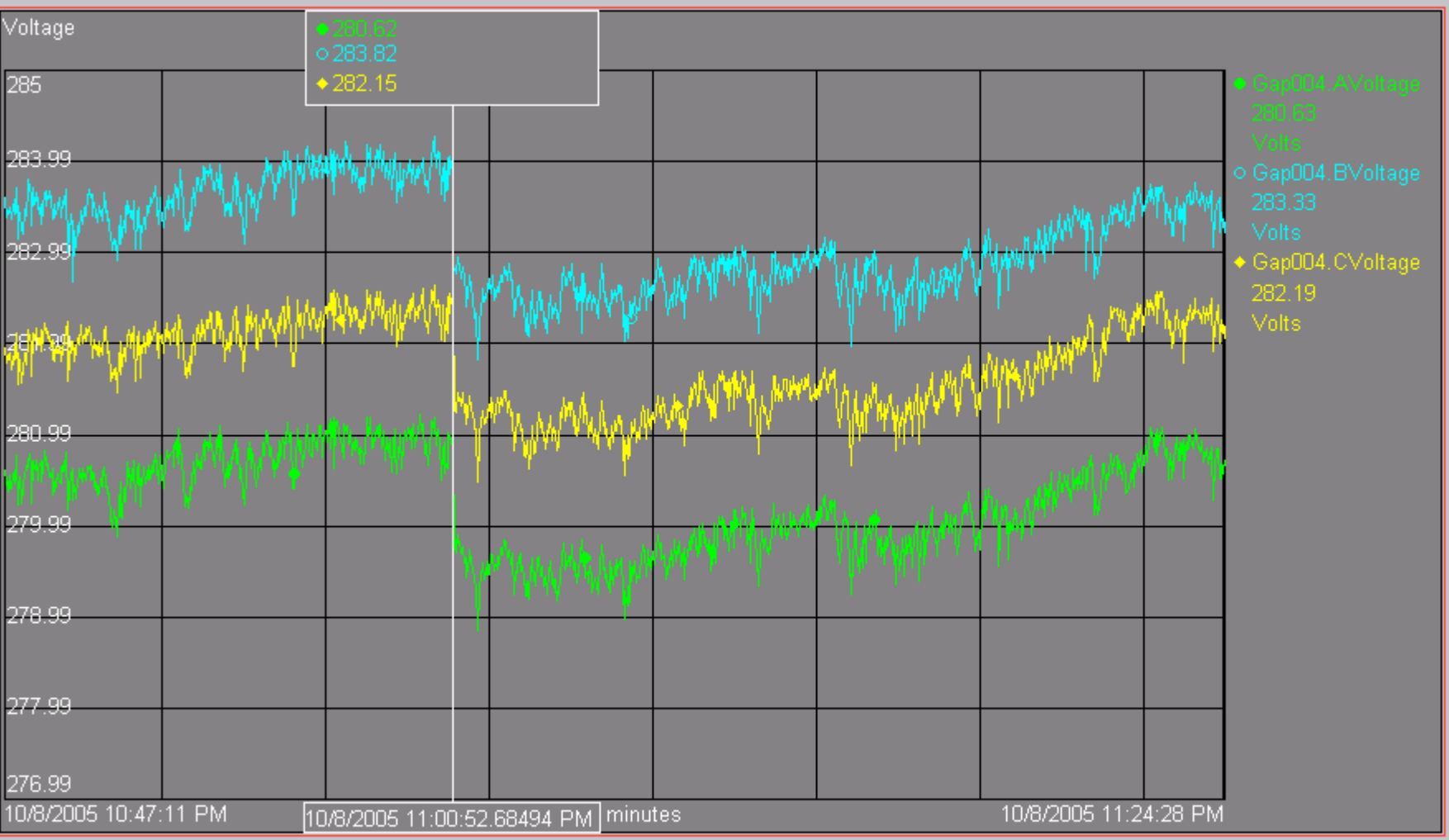

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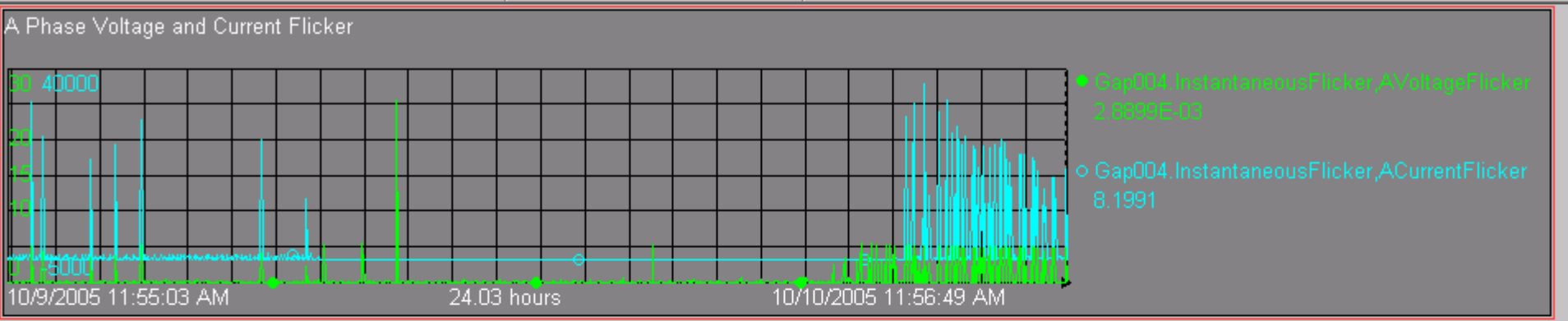

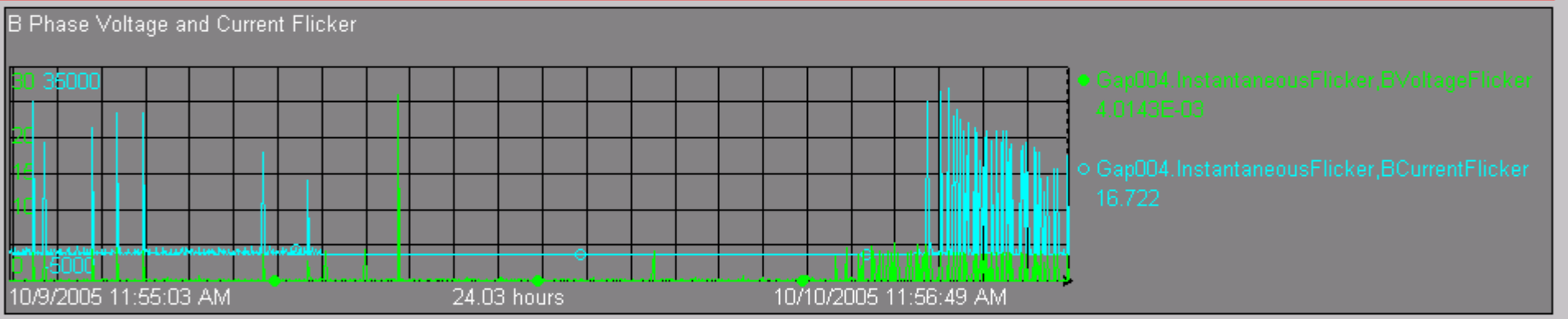

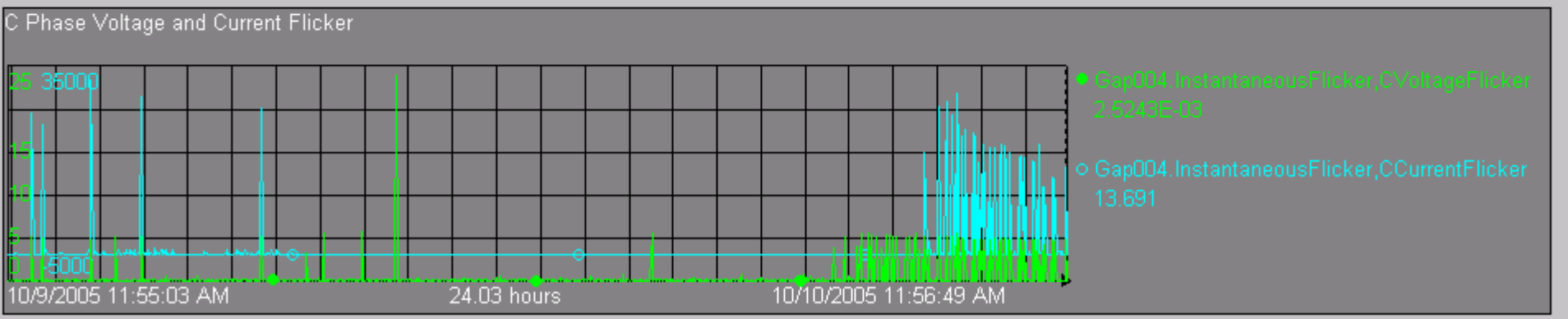

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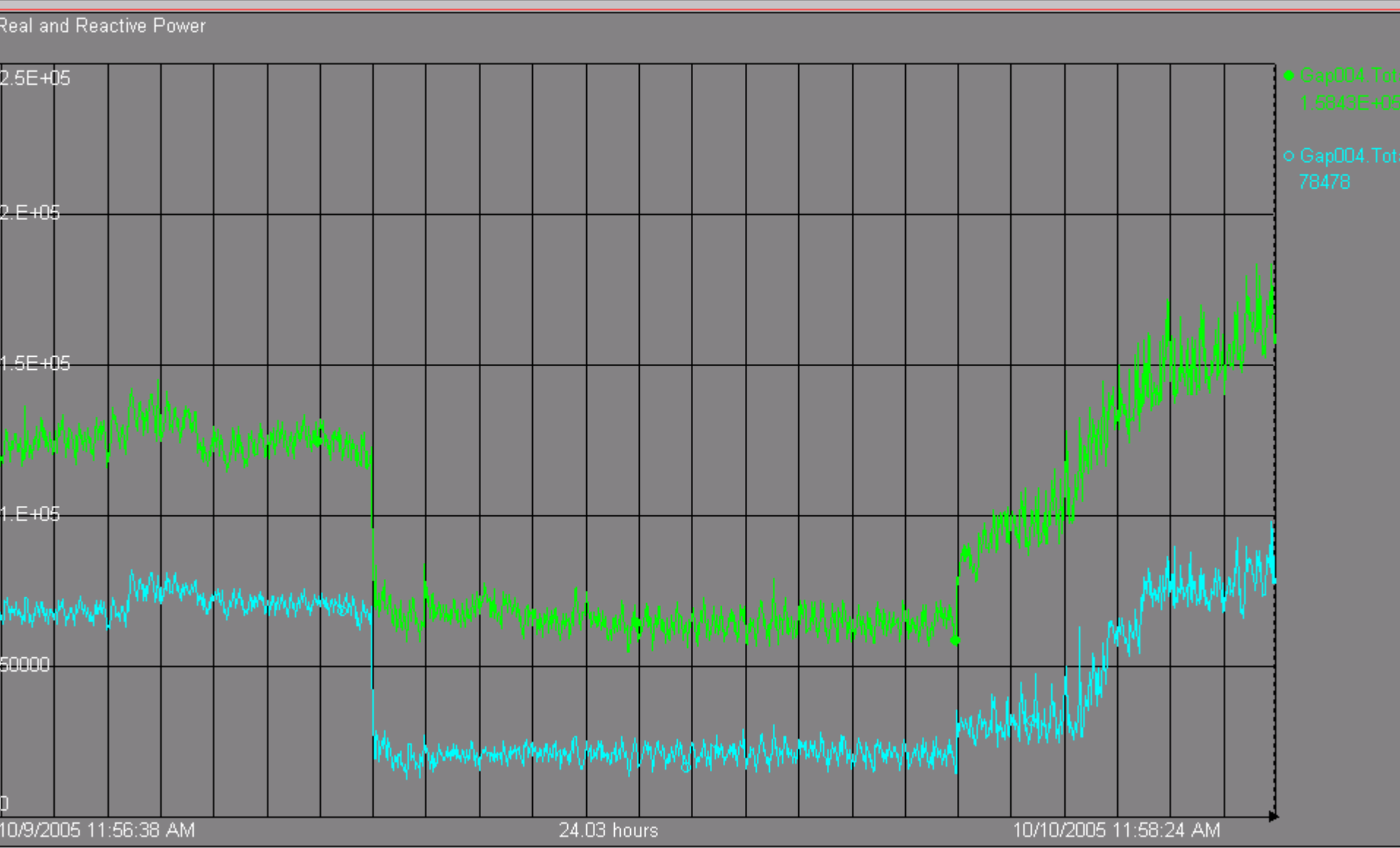

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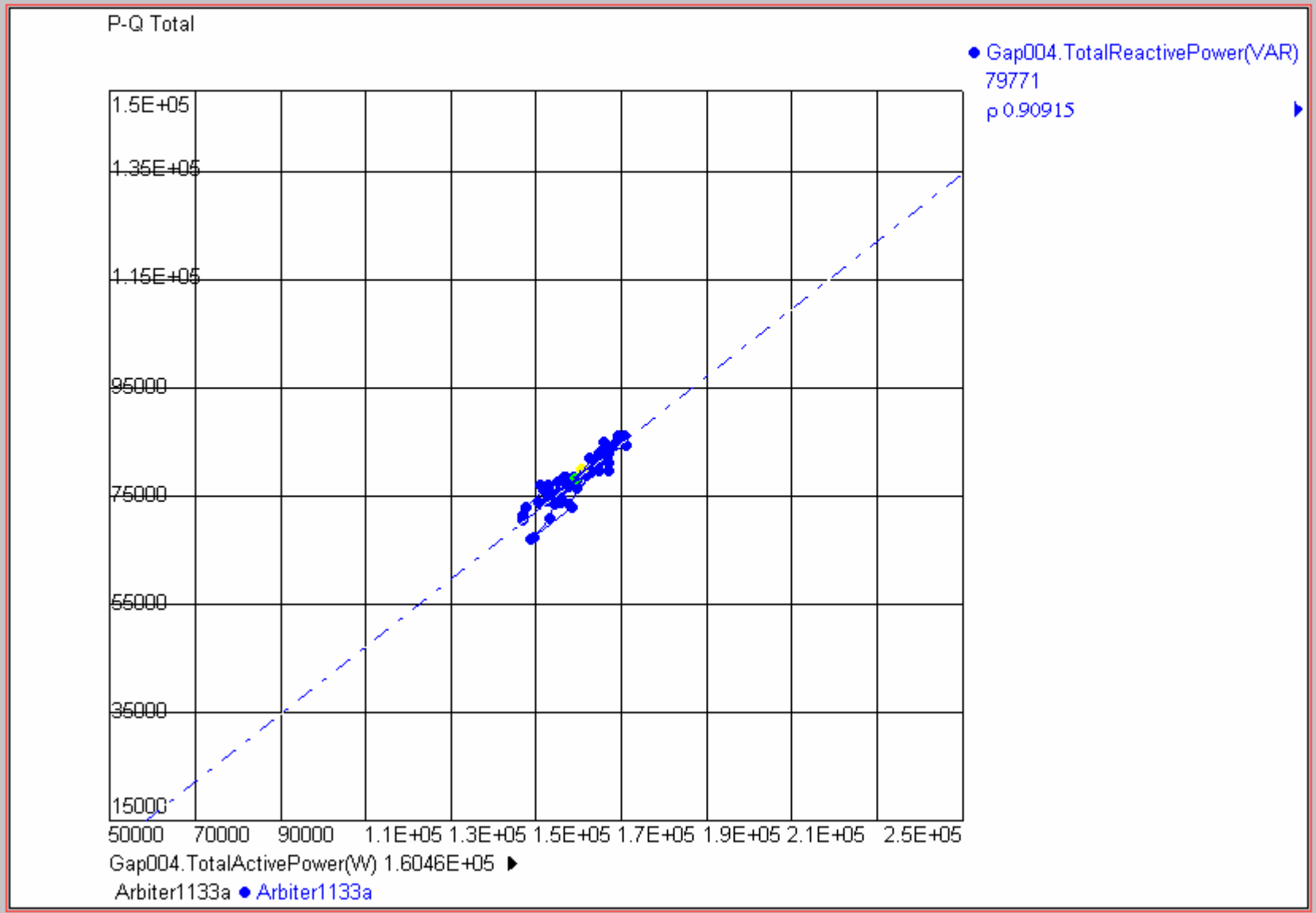
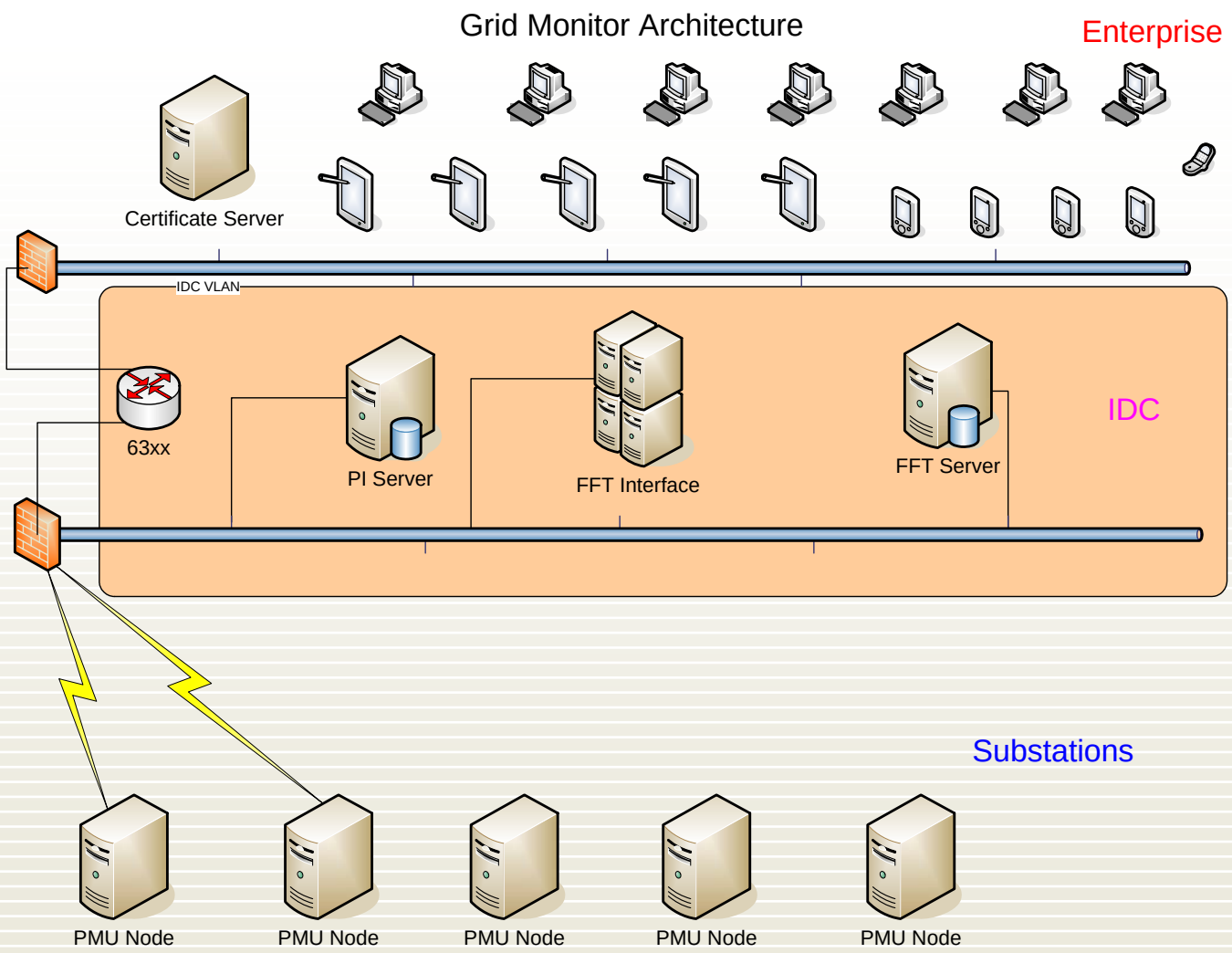


Server Time

Phasor display approaches

- DHS (II)
- DHS (I)

Overall system architecture



PMU technology

- Time synchronized measurements
- 110 measurements from each PMU
  - Power, Volts, Current, Frequency, Phase, ….
- Meets IEEE 1344 Syncrophasor standard
- Meets proposed IEEE C37.118 standard
- Accuracy .01 deg, 1 mHz, 0.025 % V,I
- Manufactured by Aribiter Systems

Grid Monitor technology

- Real time spectral analysis
  - All critical modes identified, tracked, and alarmed
- Real time synchronized differences
  - Angle, phasor, frequency, voltage, power, current
- Phasor “tool box”
- Synchronized pseudoACE calculations
- Frequency coherence calculations
- Real time Dynamic ampacity calculations