SINCROFASORES EN SSEE

CONCEPTOS Y APLICACIONES

Rep. Dominicana, Nov. 2016

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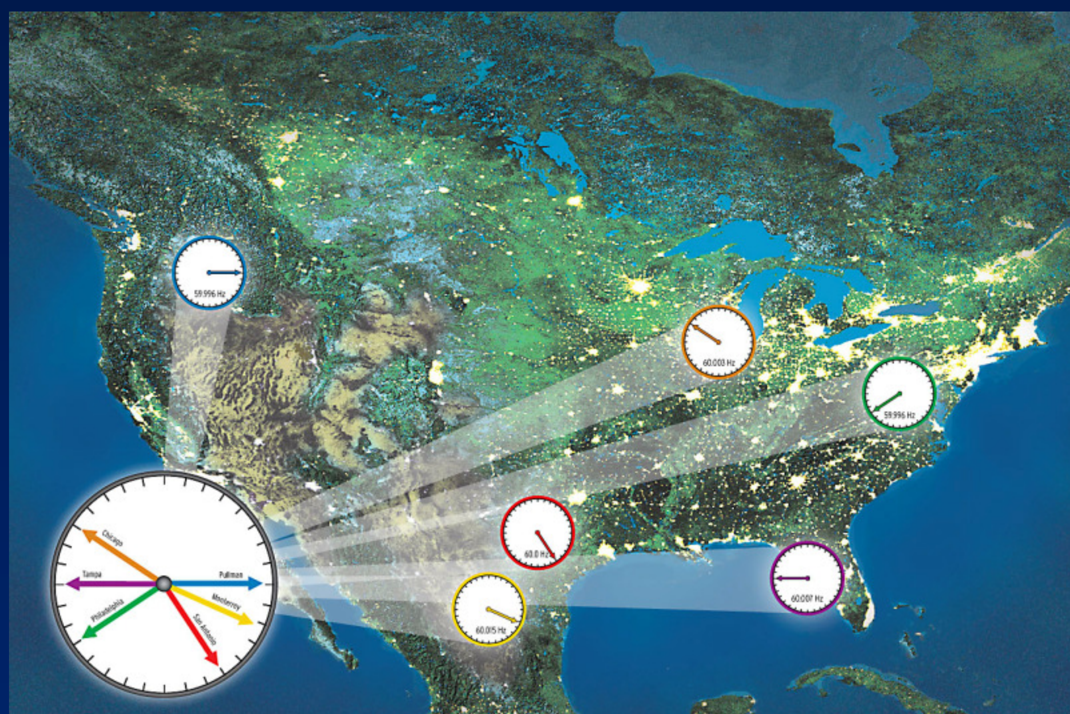
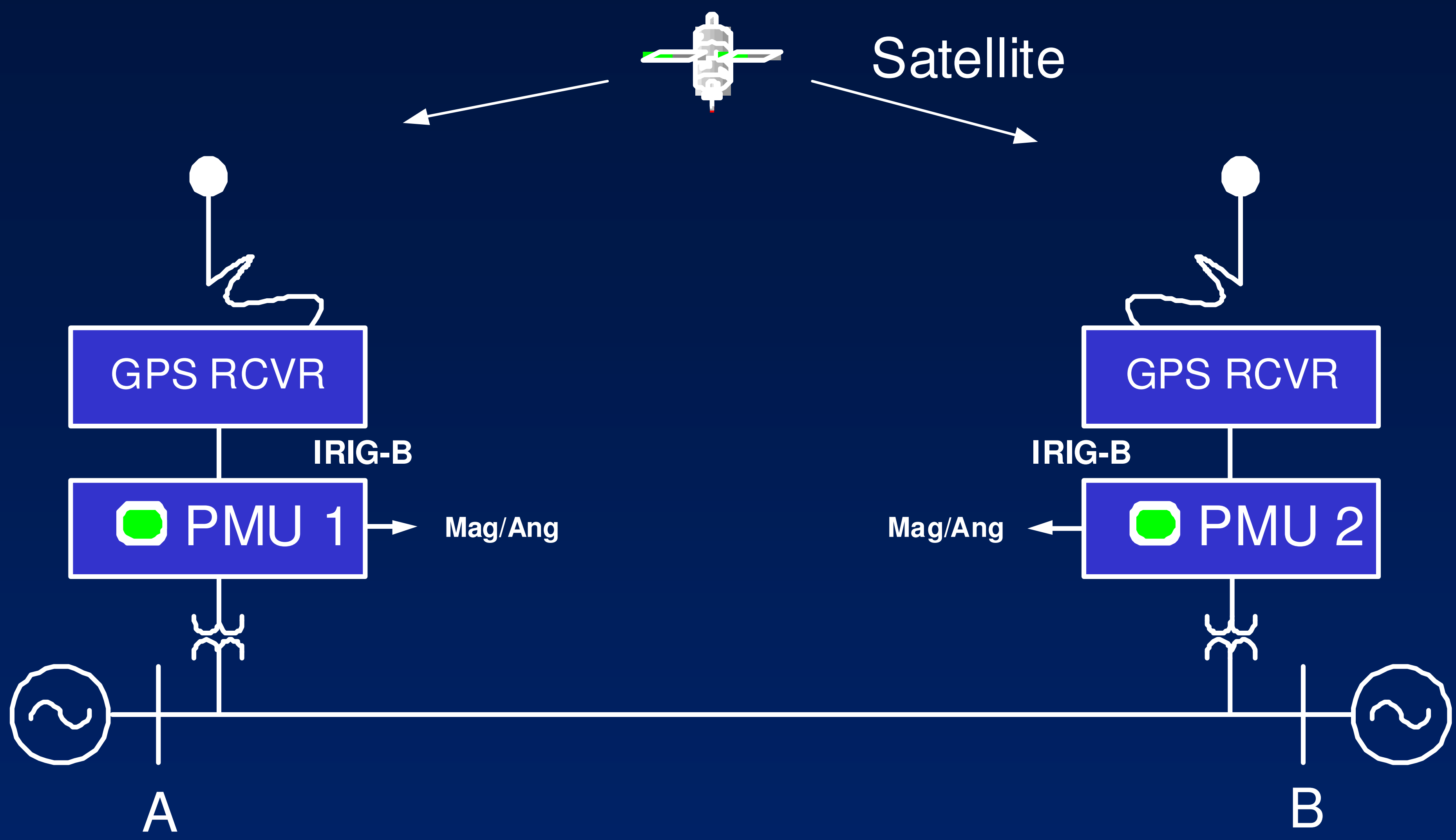
“Sincrofasor”

Un Sincrofasor es la medicion de un fasor con respecto a una referencia de tiempo absoluta. Con esta medicion podemos determinar la relacion absoluta de angulo de fase entre magnitudes de fase en diferentes locaciones en el sistema de potencia



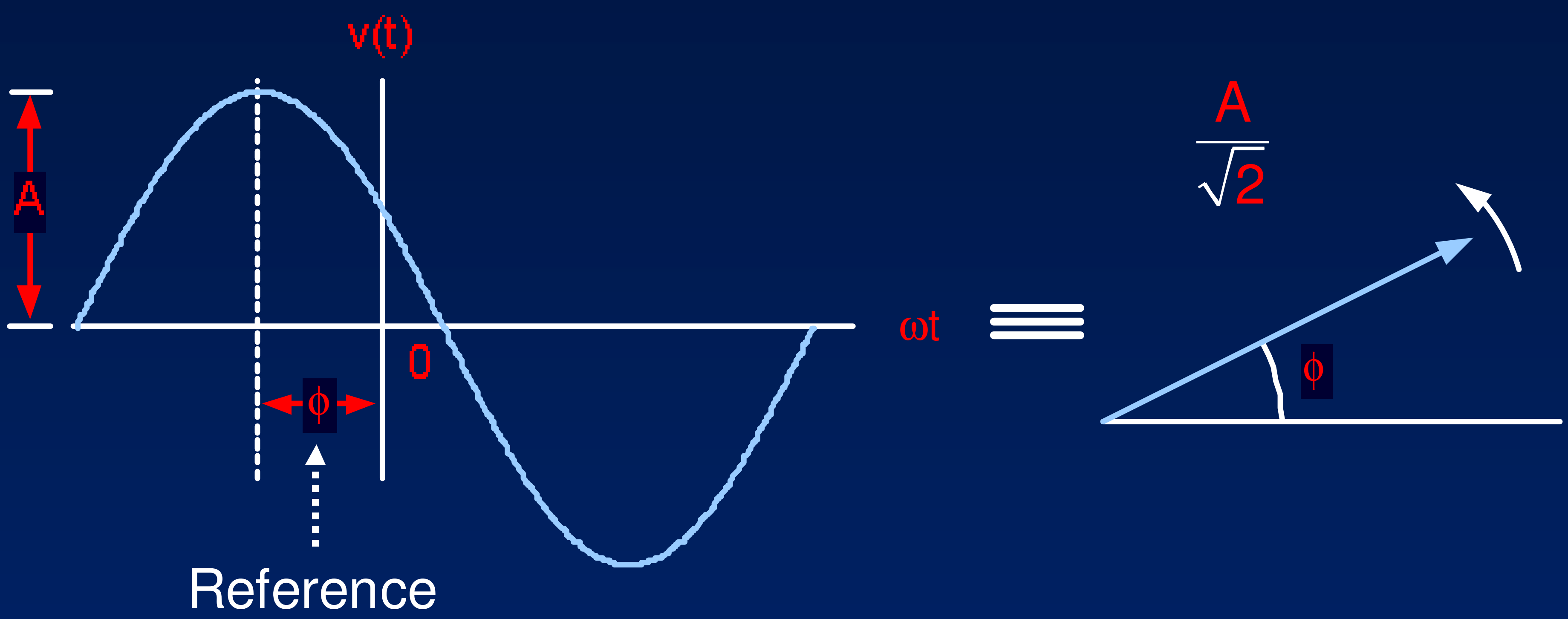
La Sincronizacion Absoluta de Tiempo ha cambiado susbtancialmente al mundo



Time Waveform

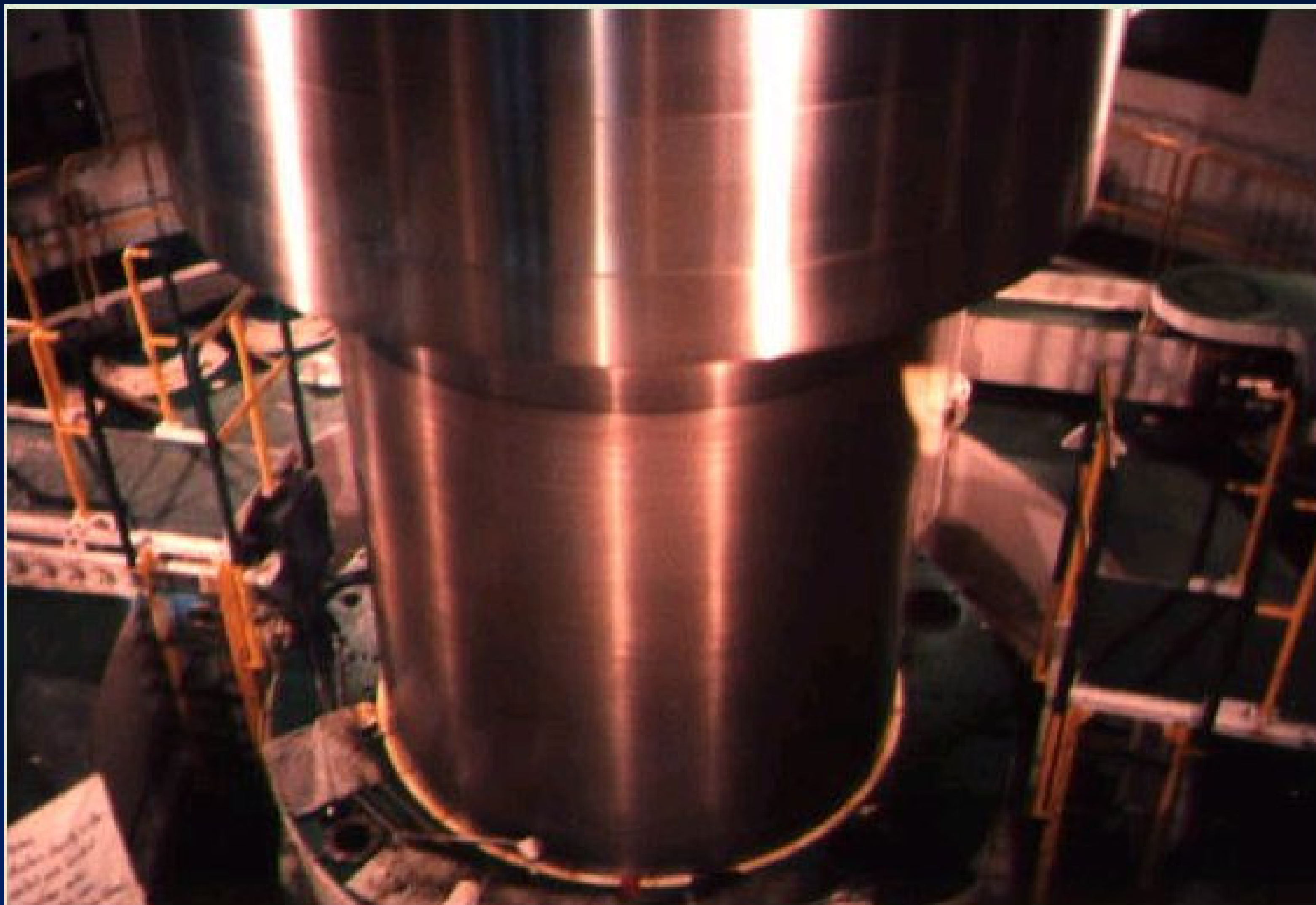
Forma de Onda en el Tiempo

y Representacion Fasorial



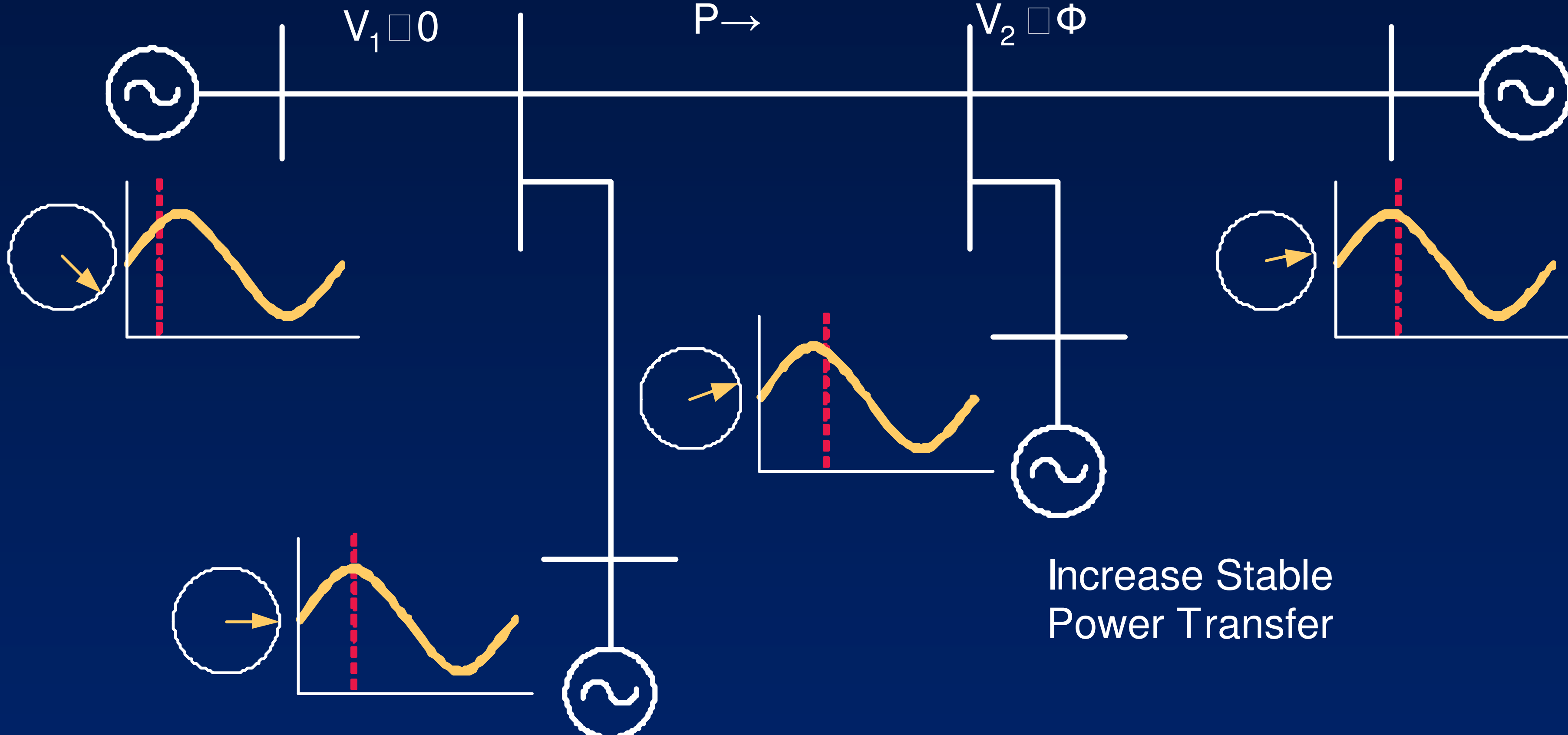
Una Marca de Tiempo en un Eje de Generador

A Timing Mark on a Generator Shaft



Los Sincrofasores proveen una “Instantanea” del Sistema de Potencia

$P = |V_1|\,|V_2| \sin\Phi / X$ $\Phi = \sin^{-1}(PX / |V_1|\,|V_2|)$



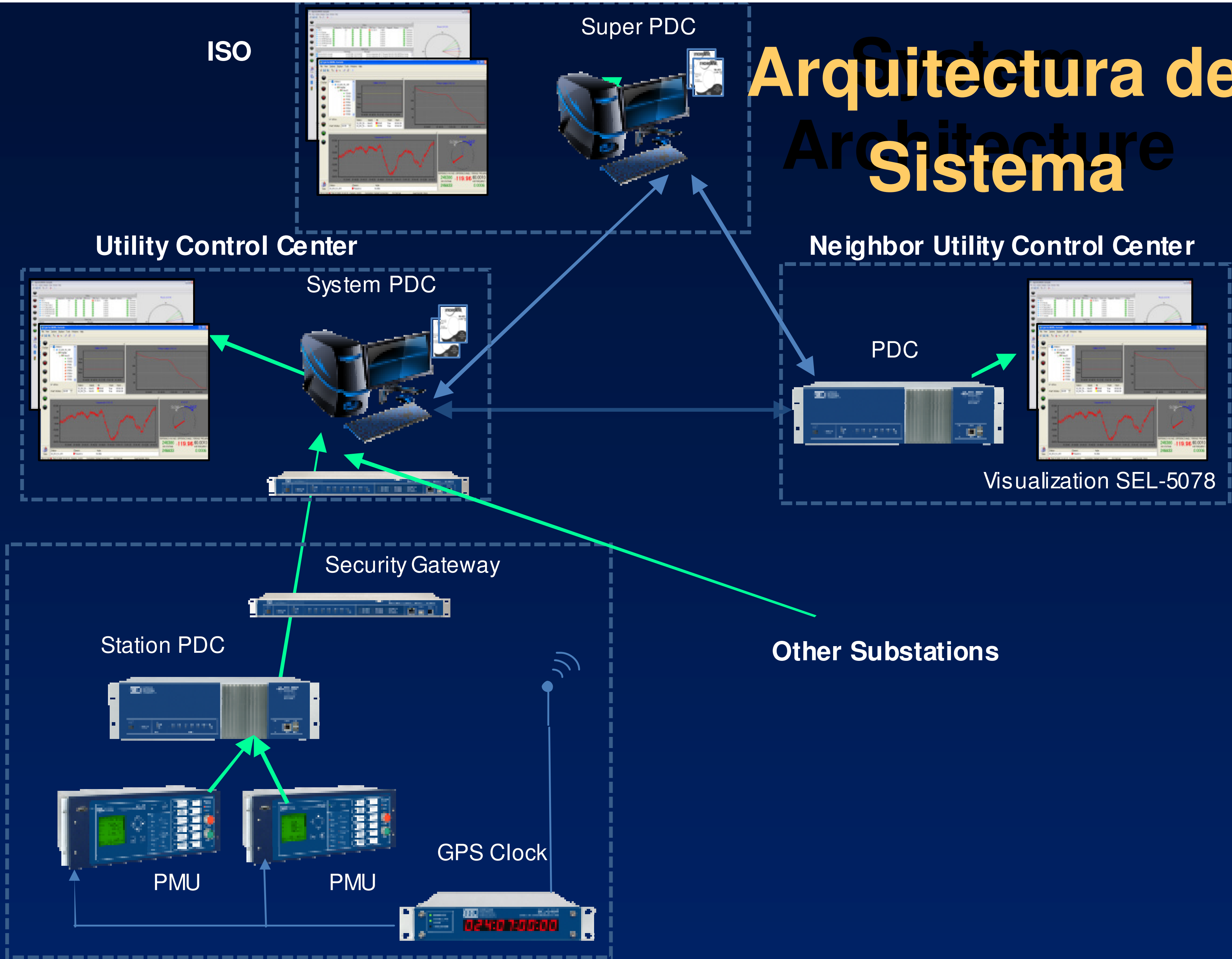
Increase Stable Power Transfer

Componentes del Sistema de Sincrofasores

Componentes del Sistema

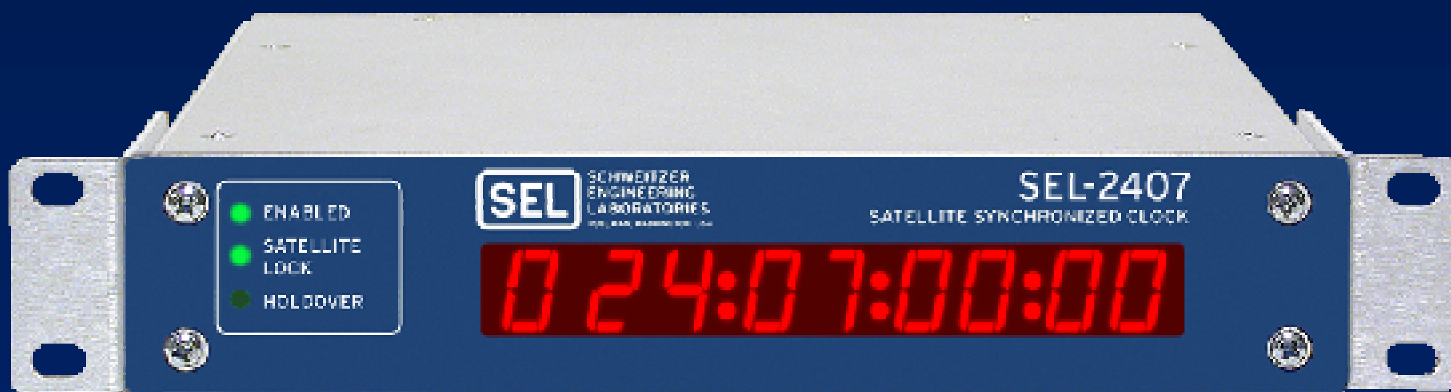
- Clocks (relojes)
- PMUs (Phasor Measurement Unit)
- PDCs (Phasor Data Concentrators)
- Visualization (Visualizacion)
- Medios de Comunicacion seguros

Arquitectura del Sistema



Requerimientos de Presicion de Tiempo

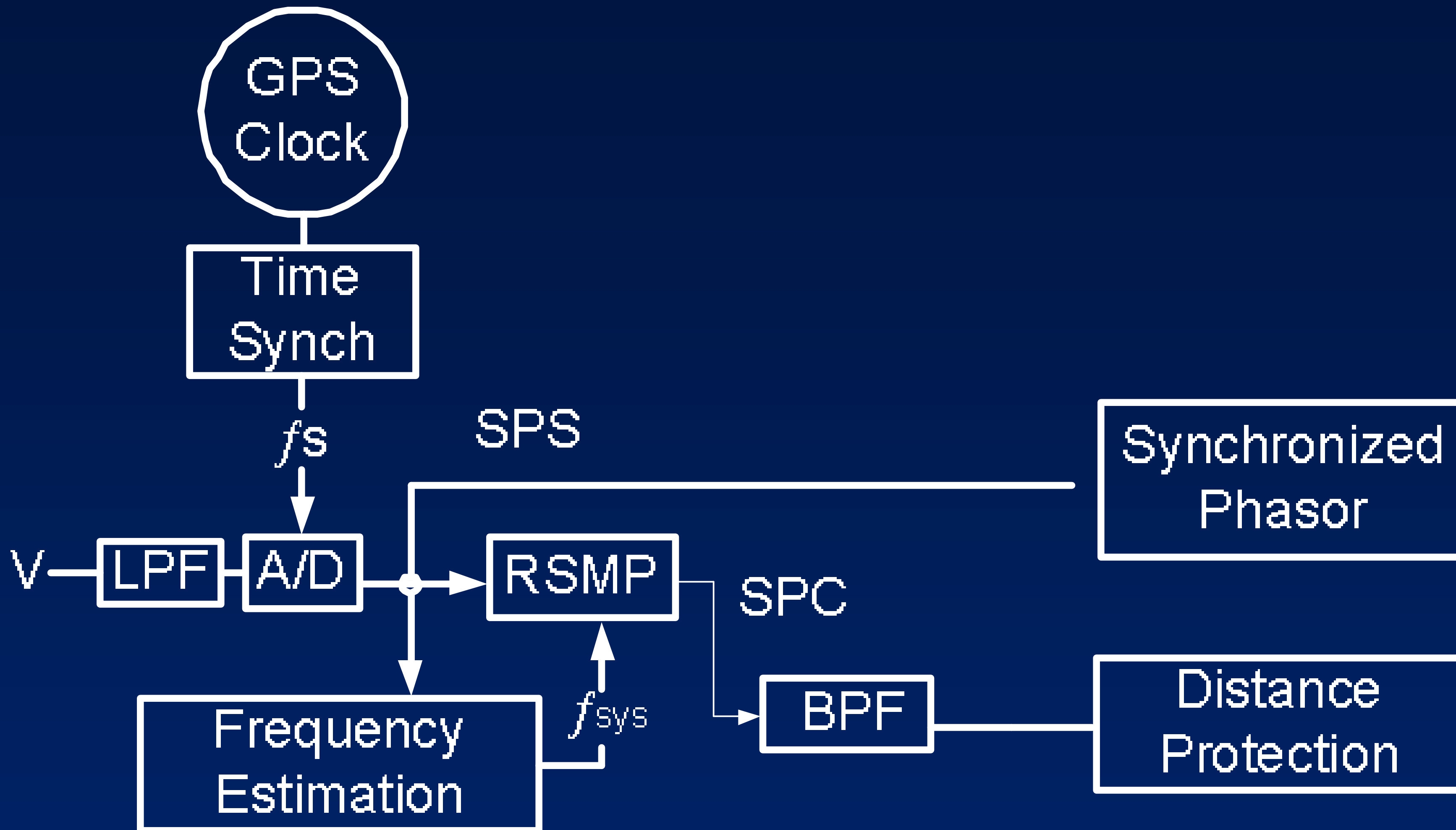
- Los Sincrofasores requieren ±500 ns
- Los Relojes Modernos proveen ±100 ns
- Los relojes sincronizados GPS tipicamente utilizados:



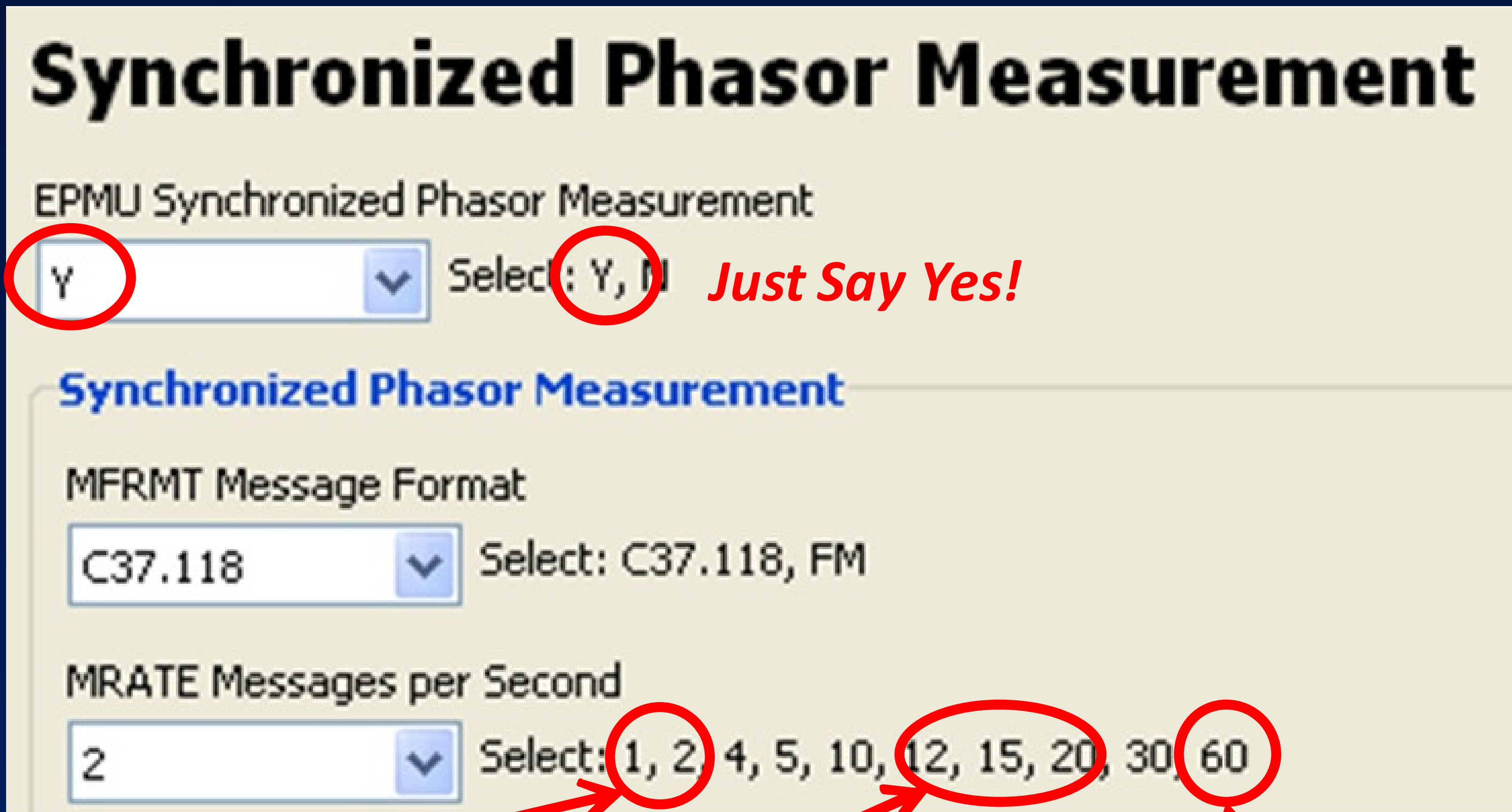
Phasor Measurement Units (PMUs)

Unidades de Medicion de Fasores (PMUs)

Medicion Sincronizada de Fasores y Proteccion de Distancia



Permitiendo la Capacidad de las PMU en el Rele



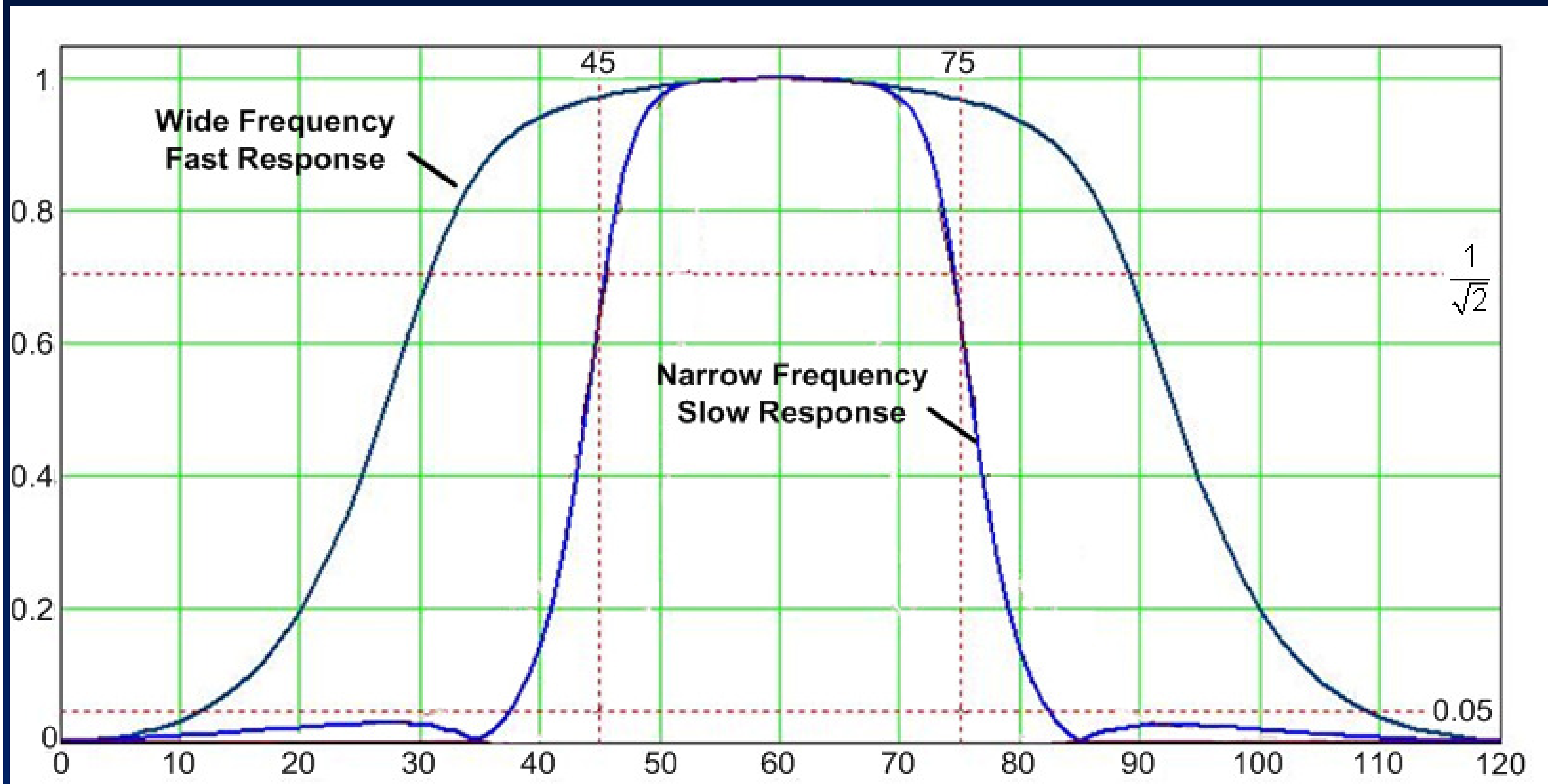
SCADA

Registro de Perturbaciones

Control de Alta Velocidad

C37.118 Signal Processing Filter

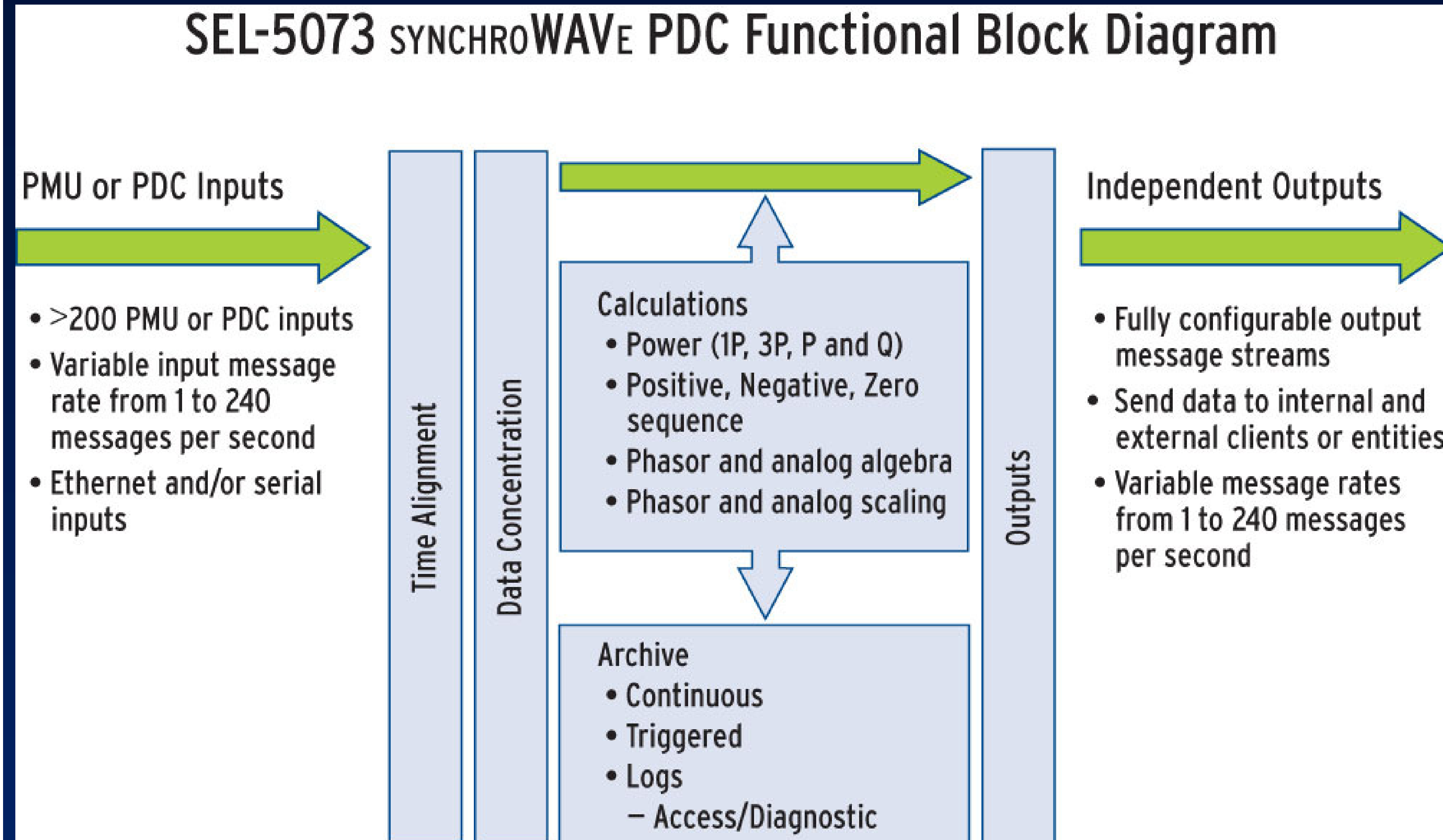
Seleccion de la Respuesta en Frecuencia



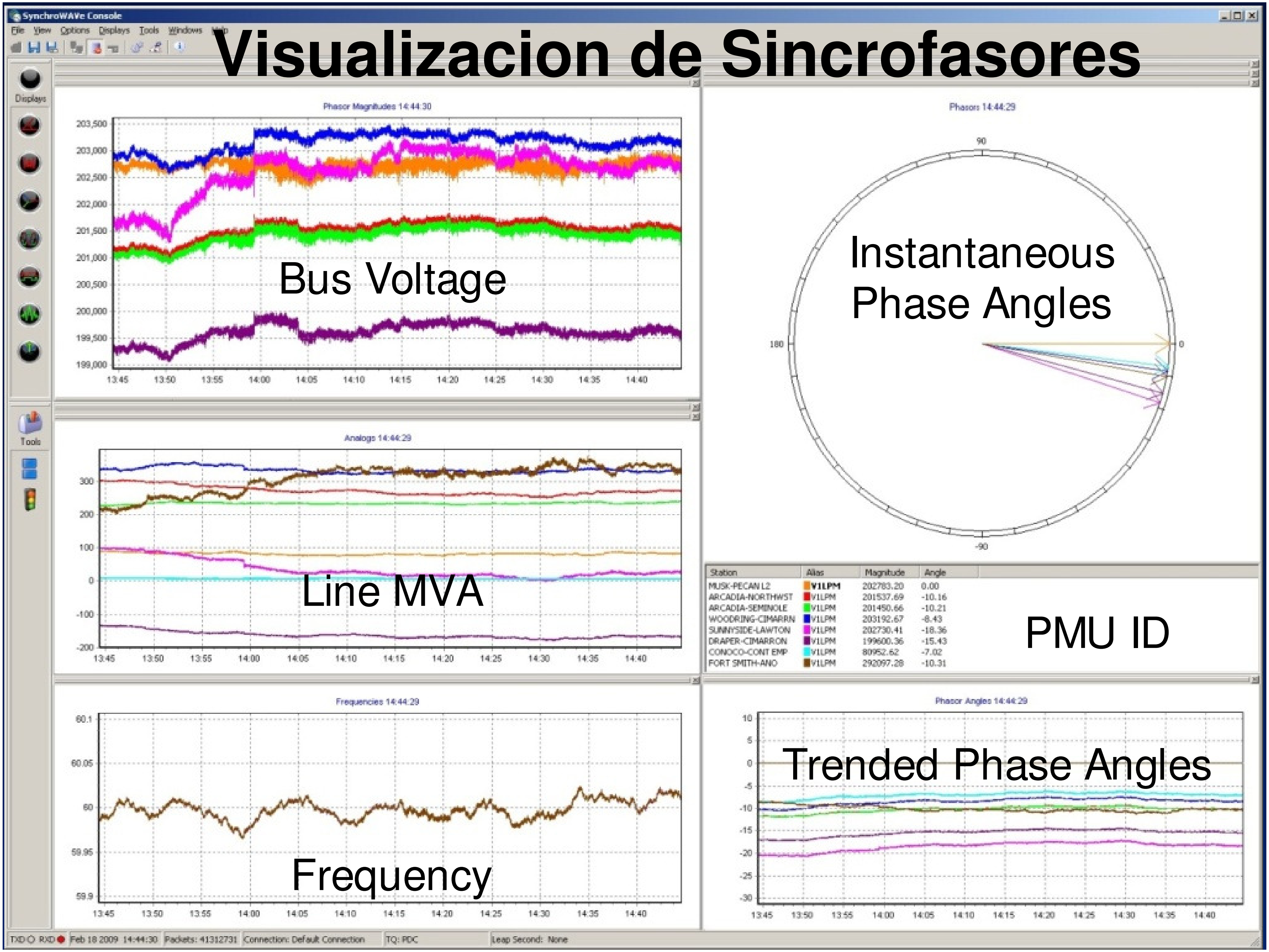
Concetracion de Datos y Archivo

- Alineamiento Temporal y Creacion de Superpaquetes
- Conversion de Potocolo
- Analisis de Datos (Data Parsing)
- Cambio de Velocidad de los Datos
- Archivamiento Local del Maximo de Datos

Arquitectura de los PDC

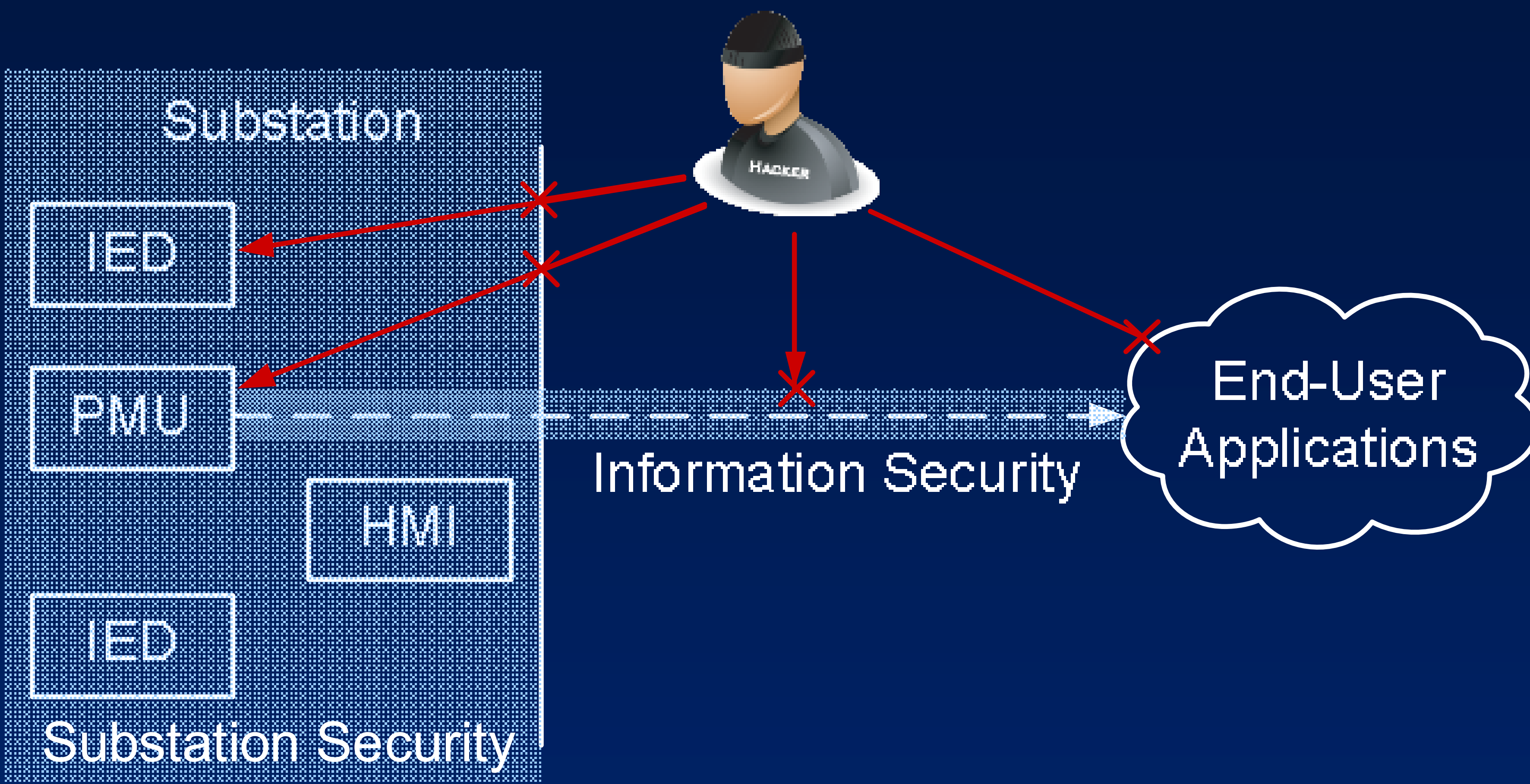


Visualizacion de Sincrofasores



Seguridad de la Informacion

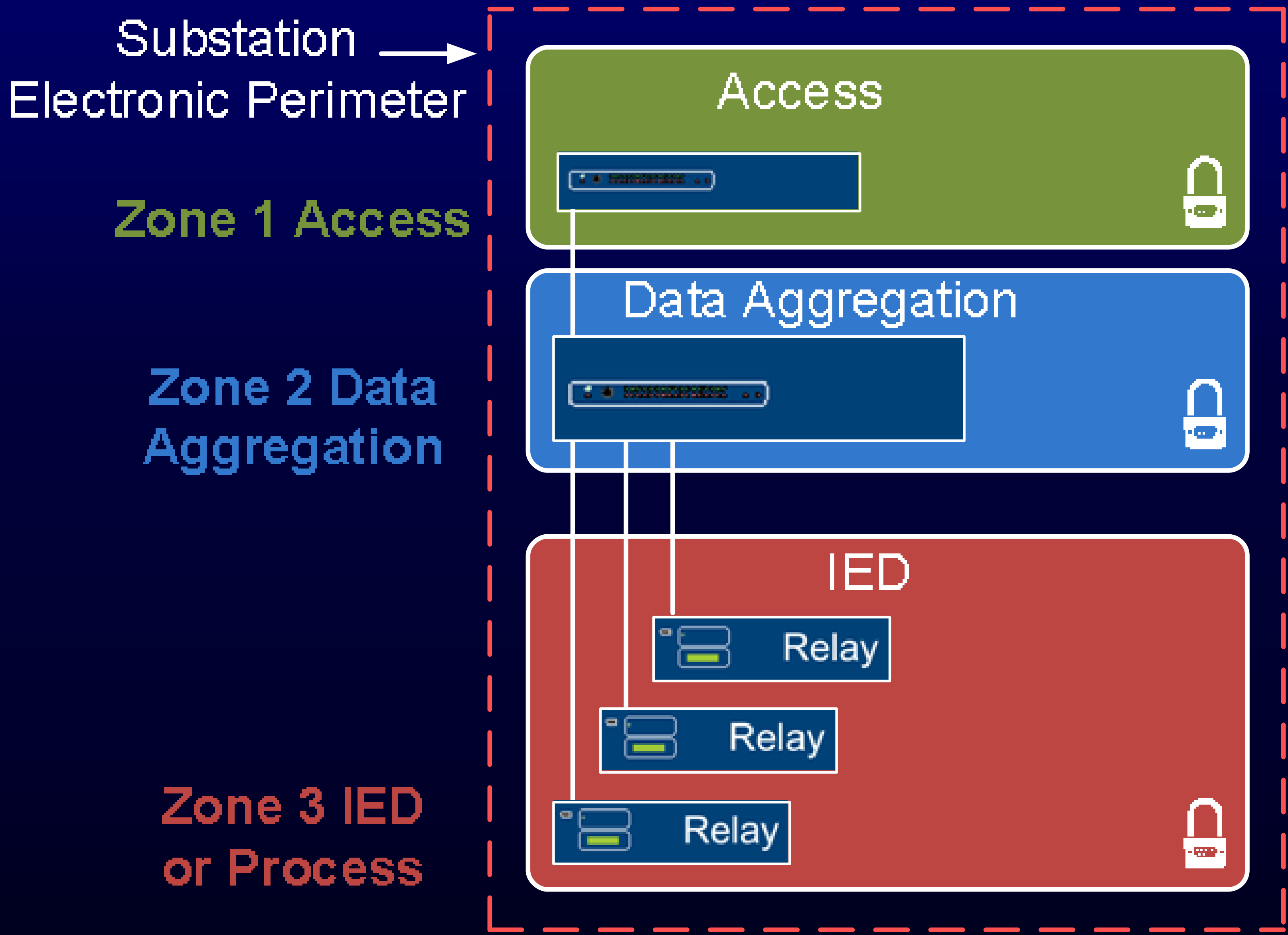
Seguridad de Extremo a Extremo



Seguridad de la Informacion

- Establecer un perimetro de seguridad electronica
- Utilizar sistema multi-capa que incluya un firewall
- Comunicaciones encriptadas in/out de la subestacion
- Deshabilitar ports no utilizados en todos los dispositivos
  - Send C37.118 data using UDP Secure (UDP_S)

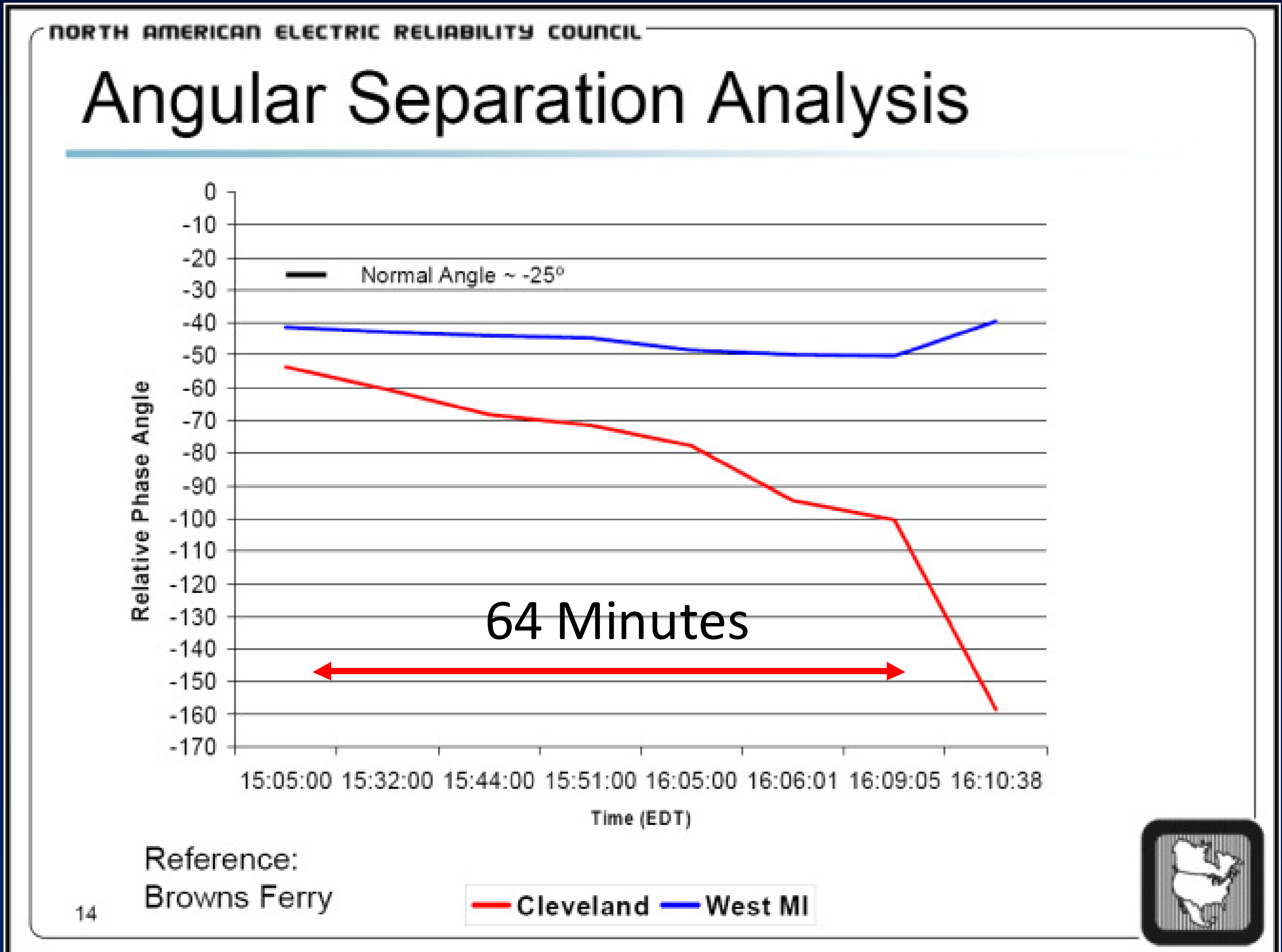
Arquitectura Segura Multi-capa



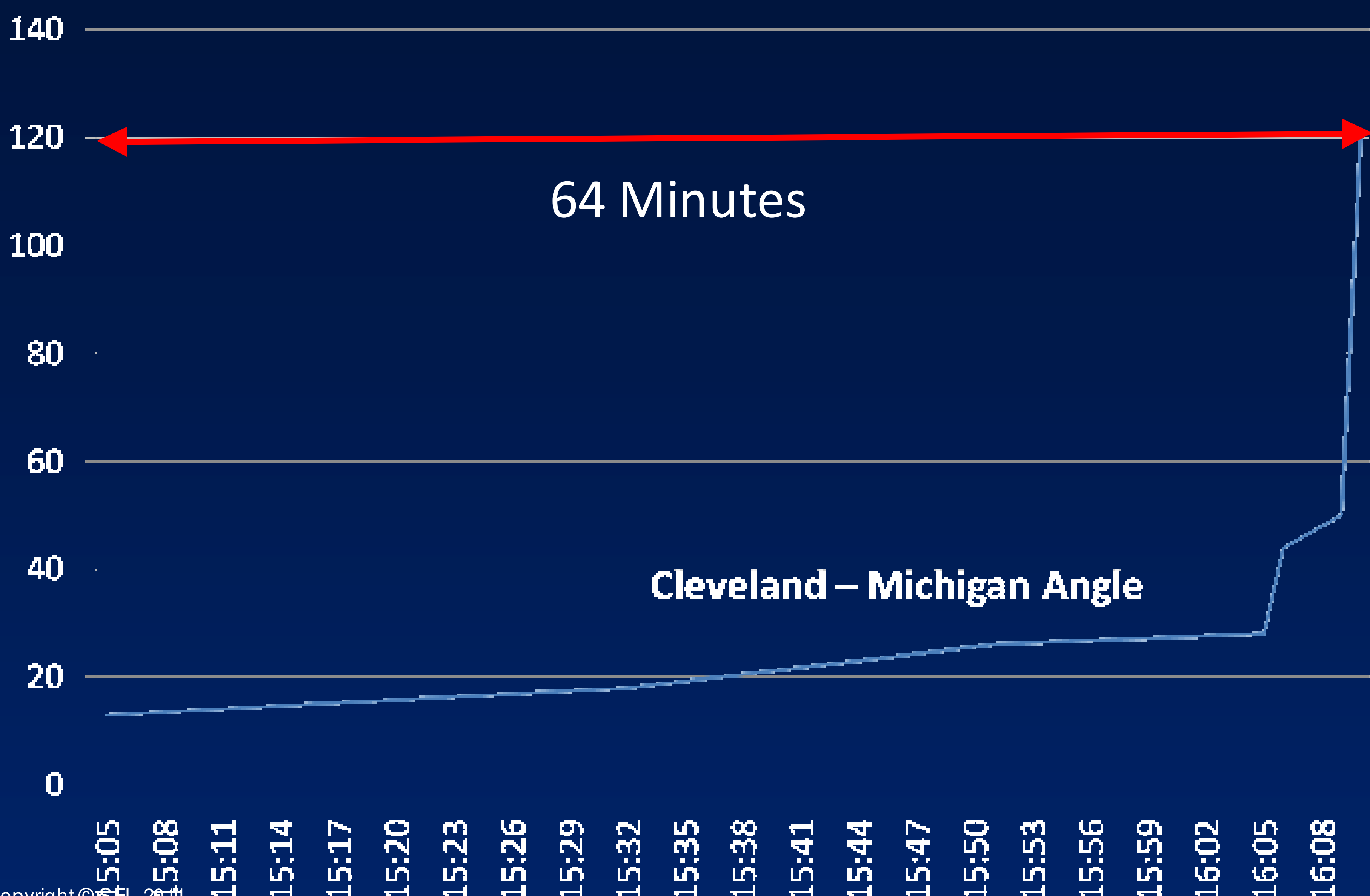
SCADA Speed Sufficient for Many Special Protection Schemes

System operators need data before things start to happen

A veces la Necesidad de Velocidad no es Obvia



Puede Desmoronarse en Tres Minutos



Los Sincrofasores son una Herramienta Flexible

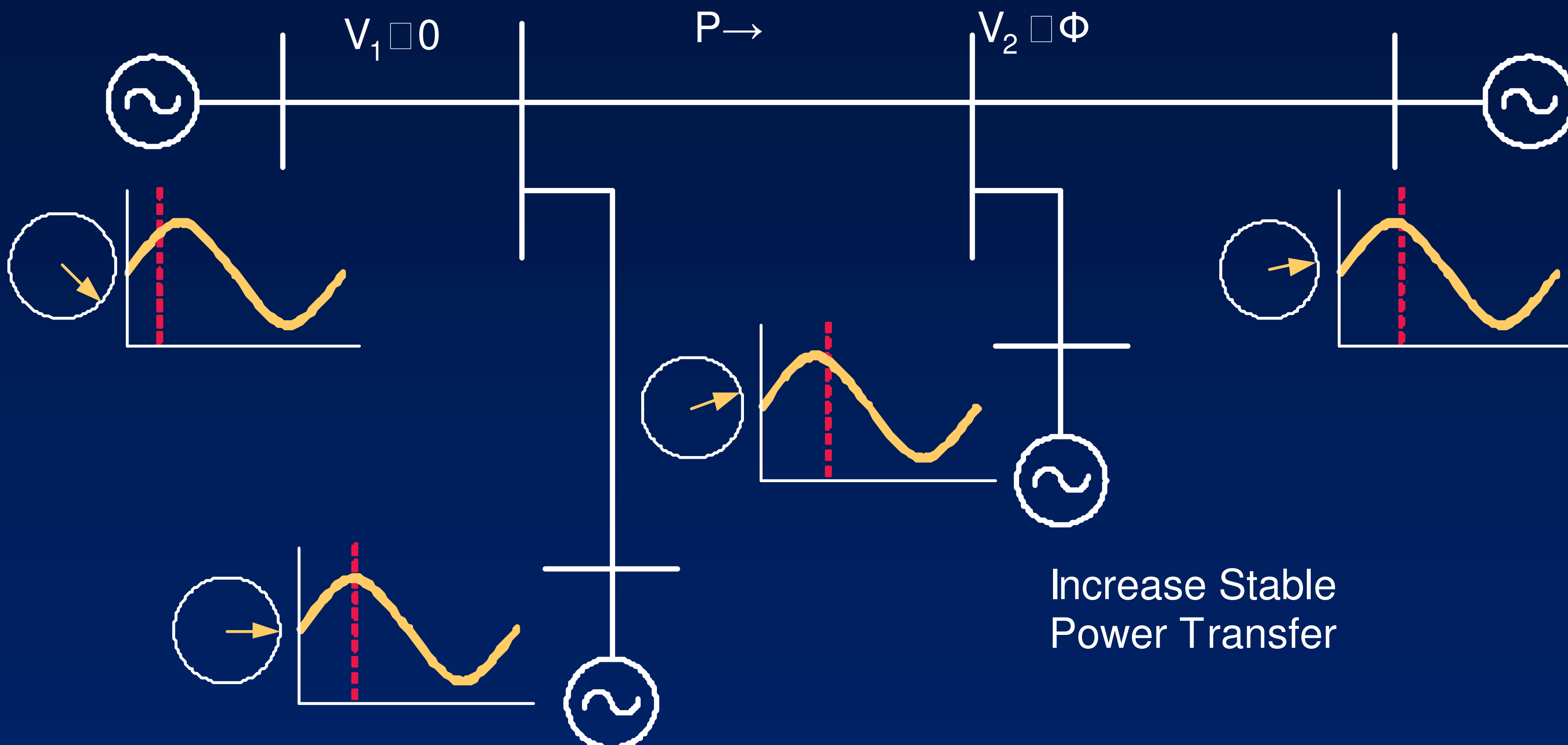
- Medicion de Estado
- Registro de Perturbaciones
- Analisis Modal
- Medicion de la Respuesta Dinamica y....

Proteccion Control de alta velocidad

Aplicaciones de los Sincrofasores

Los Sincrofasores proveen una "Instantanea" del Sistema de Potencia

$$P = |V_1|\,|V_2| \sin\Phi \,/\, X \qquad\qquad \Phi = \sin^{-1}(PX \,/\, |V_1|\,|V_2|)$$



Streaming Data Better than SCADA

- Imagine Driving in 5 Second Blinks

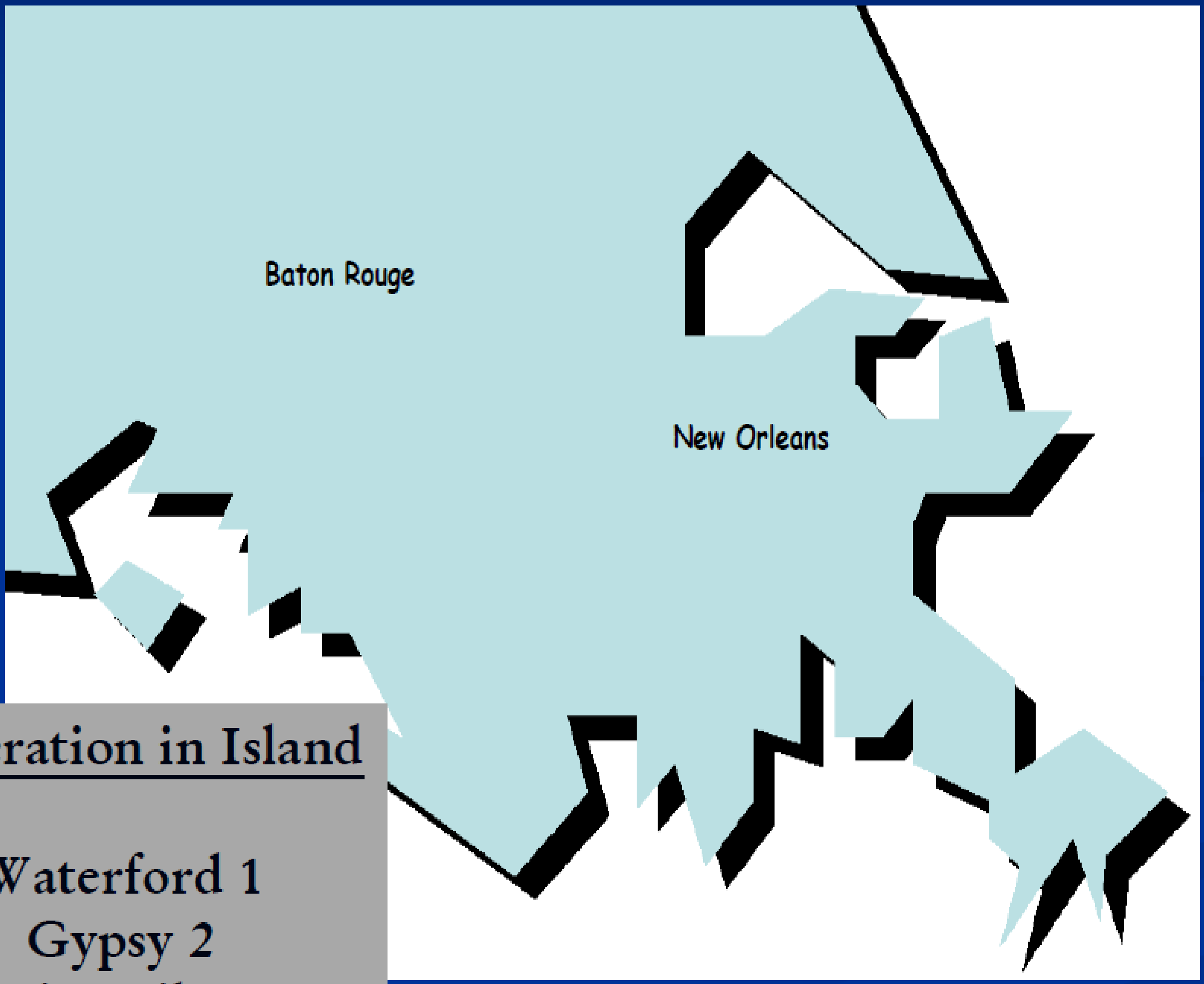
Los Datos de los Sincrofasores son criticos

Hurricane Gustav: By the Numbers

- 241 transmission lines and 354 substations outaged
- 4,349 Distribution transformers damaged or destroyed
- 2500 circuit miles affected
- 964,000 customer outages, second only to the 1.1 million customer outages in 2005 during Hurricane Katrina.

Courtesy of Entergy Corp.

Island Formation



2 - 500 kV Lines
9 - 230 kV Lines
3 - 115 kV Lines

~ 100 miles across
~ 200-250K Customers
~ 300 MW Load

Island formed:

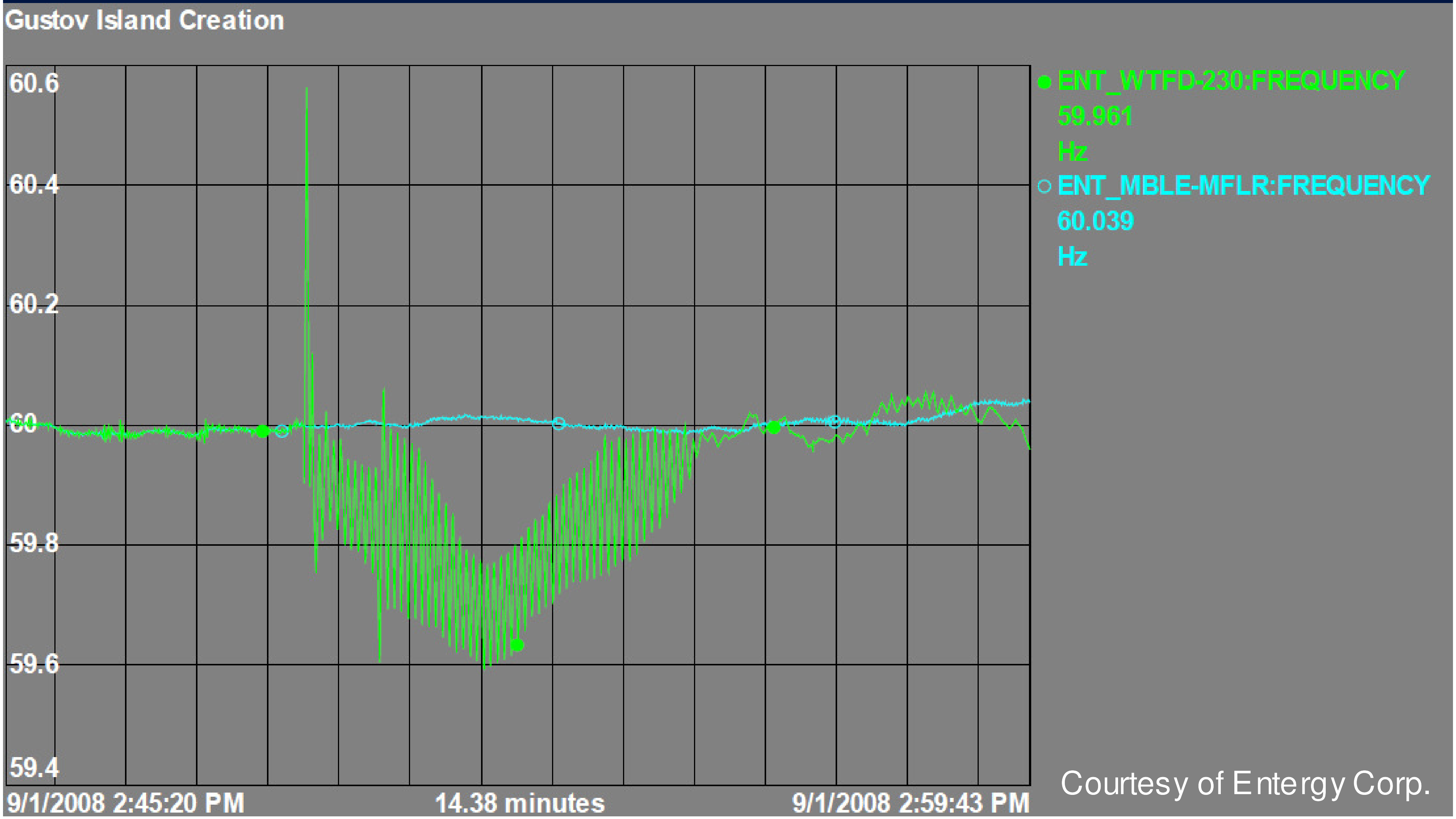
September 1, 2008
2:49 PM

Generation in Island

Waterford 1
Gypsy 2
Ninemile 5

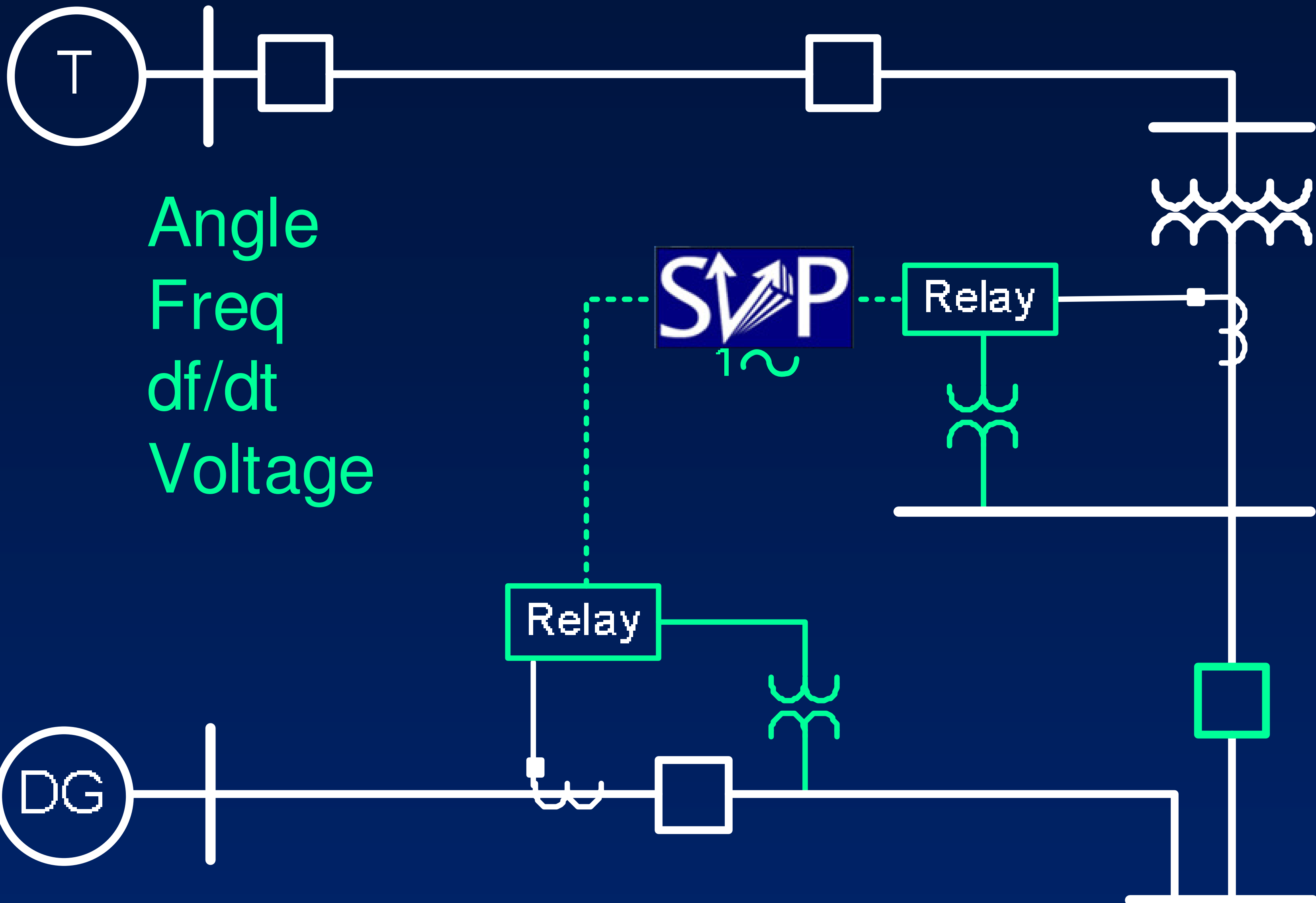
Courtesy of Entergy Corp.

Los Sincrofasores detectan Islas



Courtesy of Entergy Corp.

Florida Power & Light: Proteccion Anti-Isla de la Generacion Distribuida



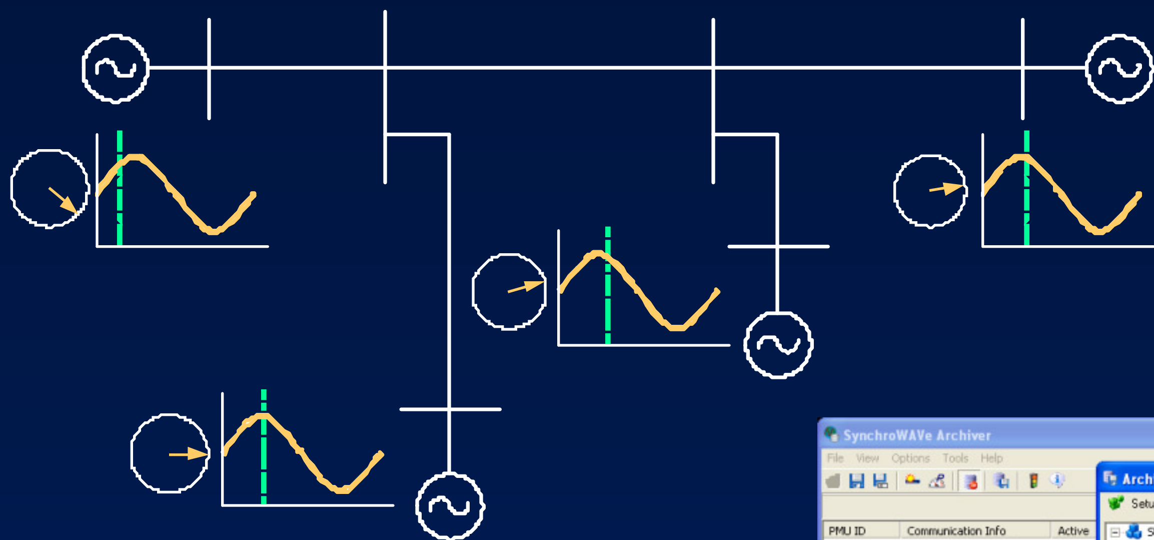
SEGIS Anti-Islanding Demo

- Advanced Energy led
- ODOT solar project: 100 kW installation
- Stage 3 demo planned for August '11

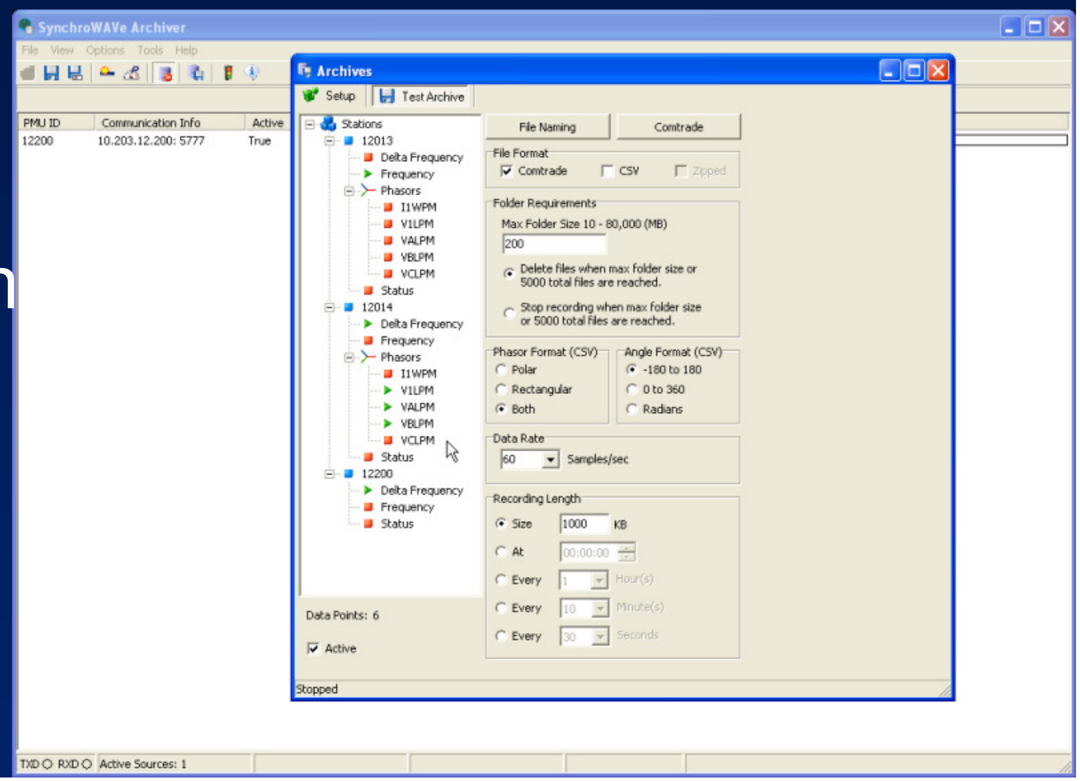
SEGIS Field Testing Results

- Island event
  - Longest trip 1.1 seconds
- Utility functions
  - Curtailment
  - Ramp rate
  - Power factor

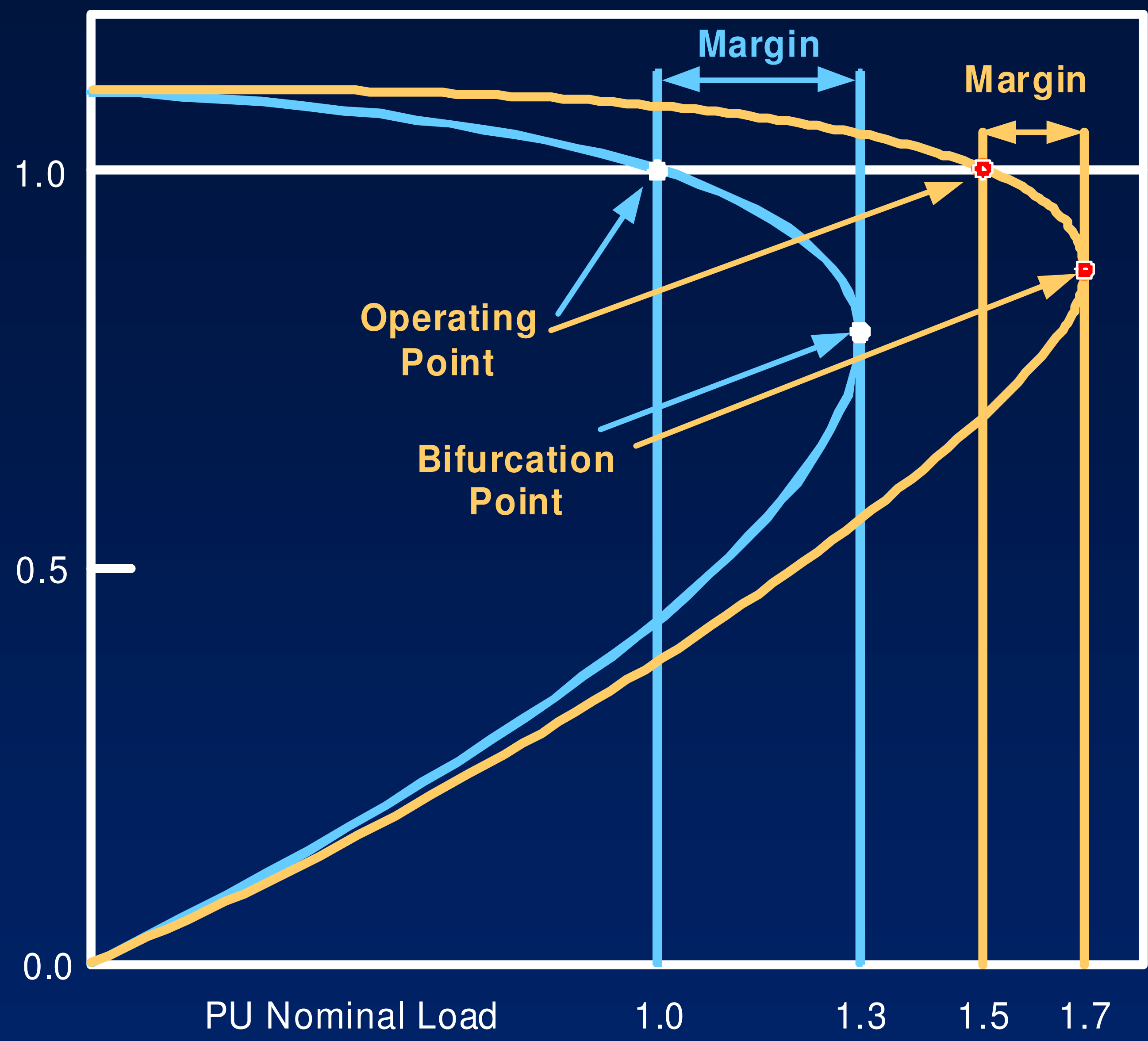
Sistema de Archivo



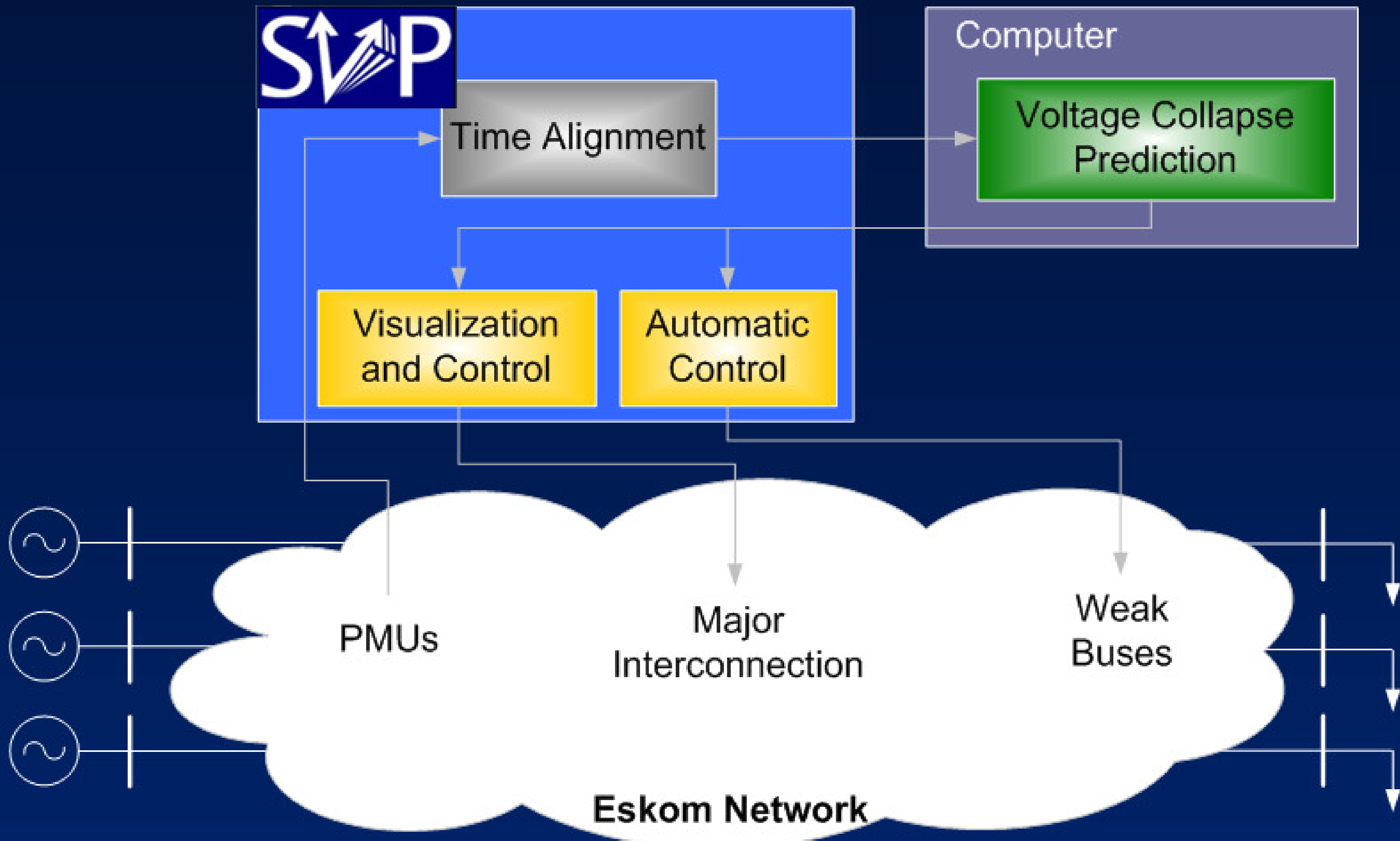
- Registro de Perturbacion
- Captura y Analisis de Eventos



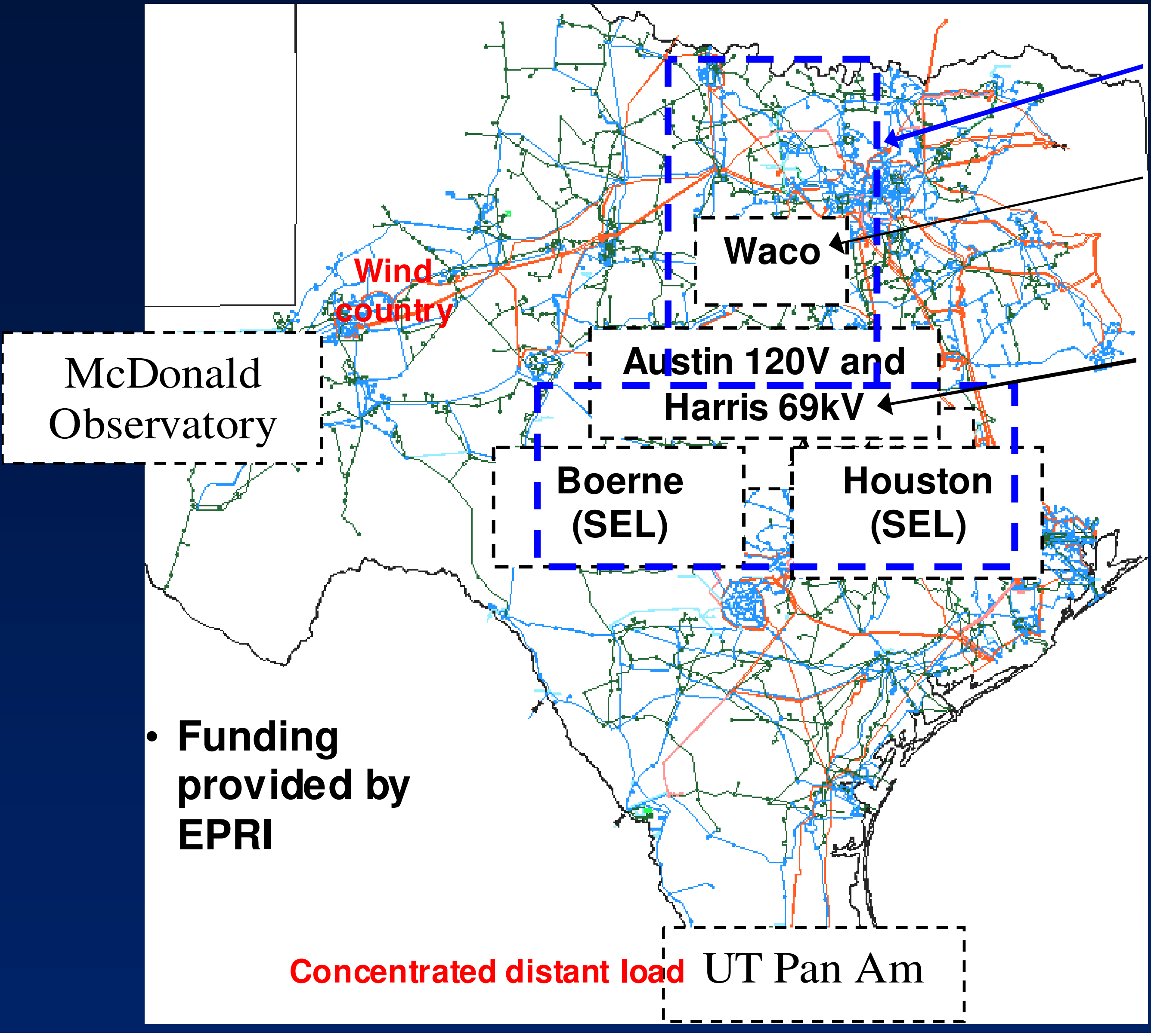
Las Companias estan operando mas cerca de sus limites



Eskom's Voltage Stability Assessment System



Red de Sincrofasores de Texas



Blue outlines: Central ERCOT

Brazos Electric PMU

Austin Energy PMU

- **Funding provided by EPRI**

Estimacion de las Impedancias de Thevenin a lo largo de la Red con Sincrofasores

Vangle = δ

Bus 7 WIND

Pexport →

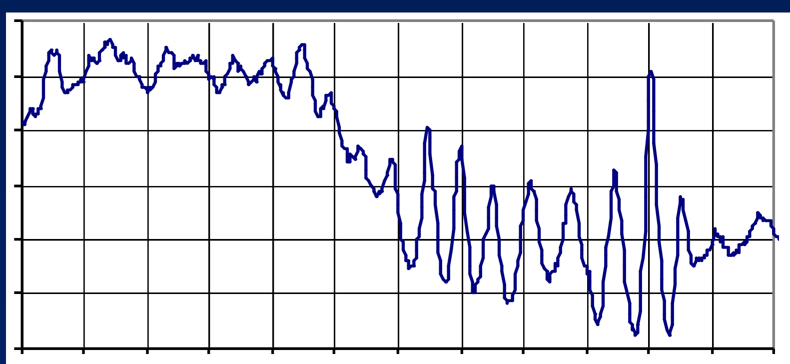
500 km

Thevenin Impedance
jXTH

Central ERCOT
Vangle = 0

Local conventional
Pload,conv – Pgen,conv

Use the Excel Solver with angle measurements to minimize least-squared error and obtain Xth



$$P \approx \frac{V_1 V_2}{X_{TH}} \bullet \sin(\delta)$$

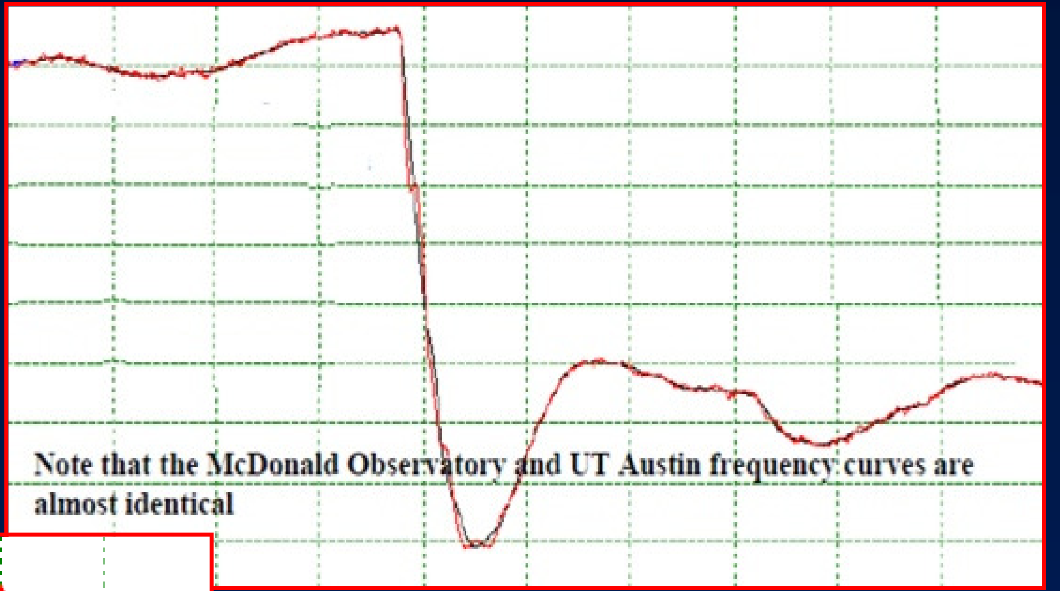
Only Synchrophasors

Solo los Sincrofasores

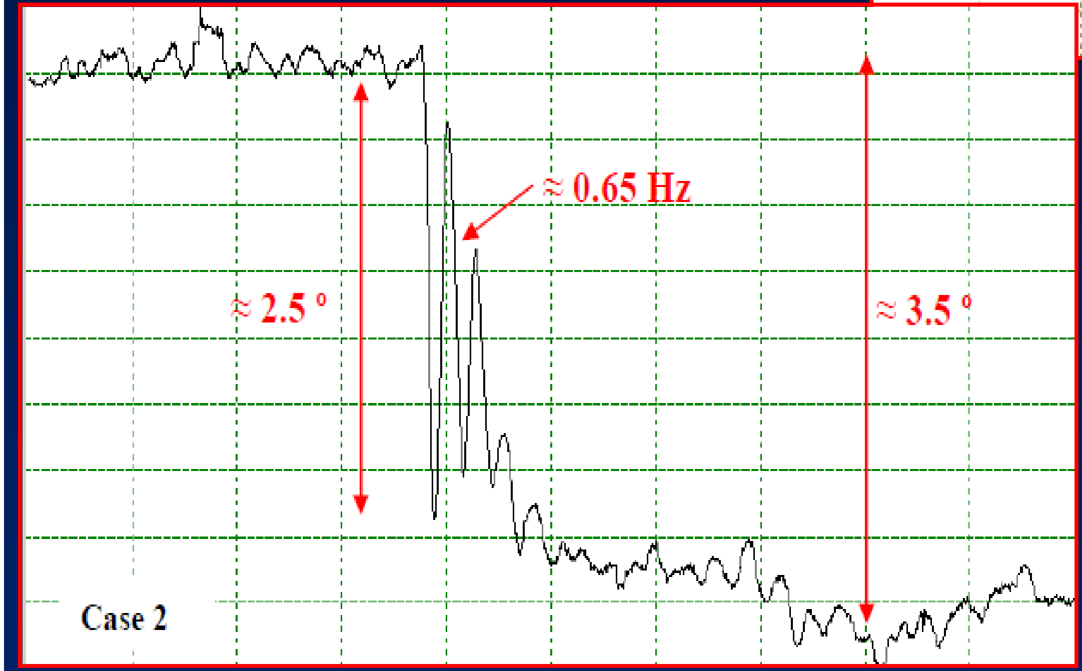
Difference

Proveen

Diferencias de Angulos



Frequency



Angle Difference

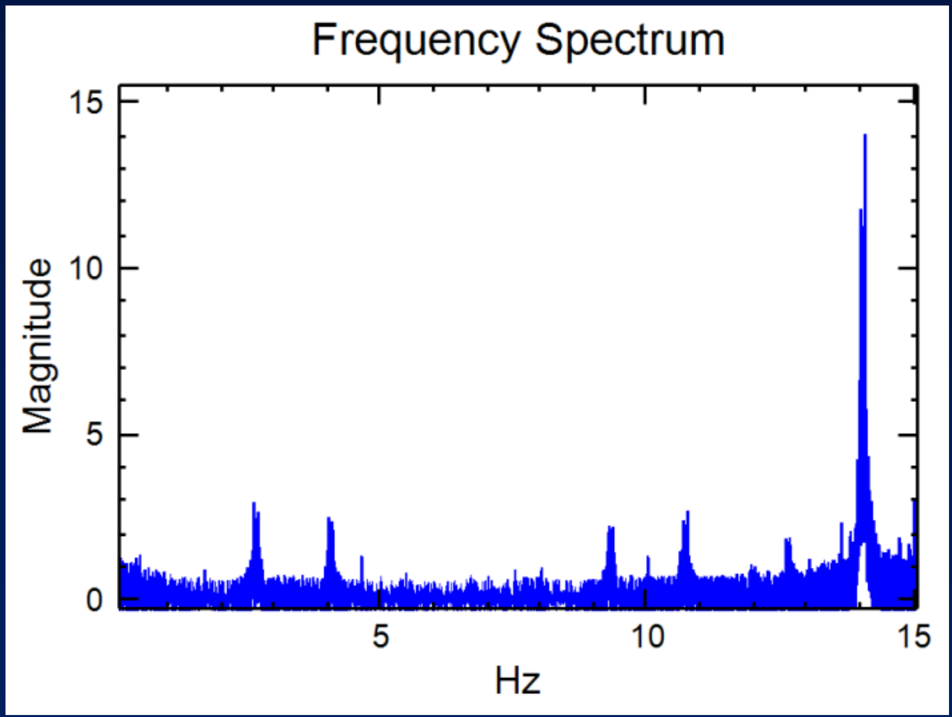
Charts provided by University of Texas

Integration of Renewable Energy

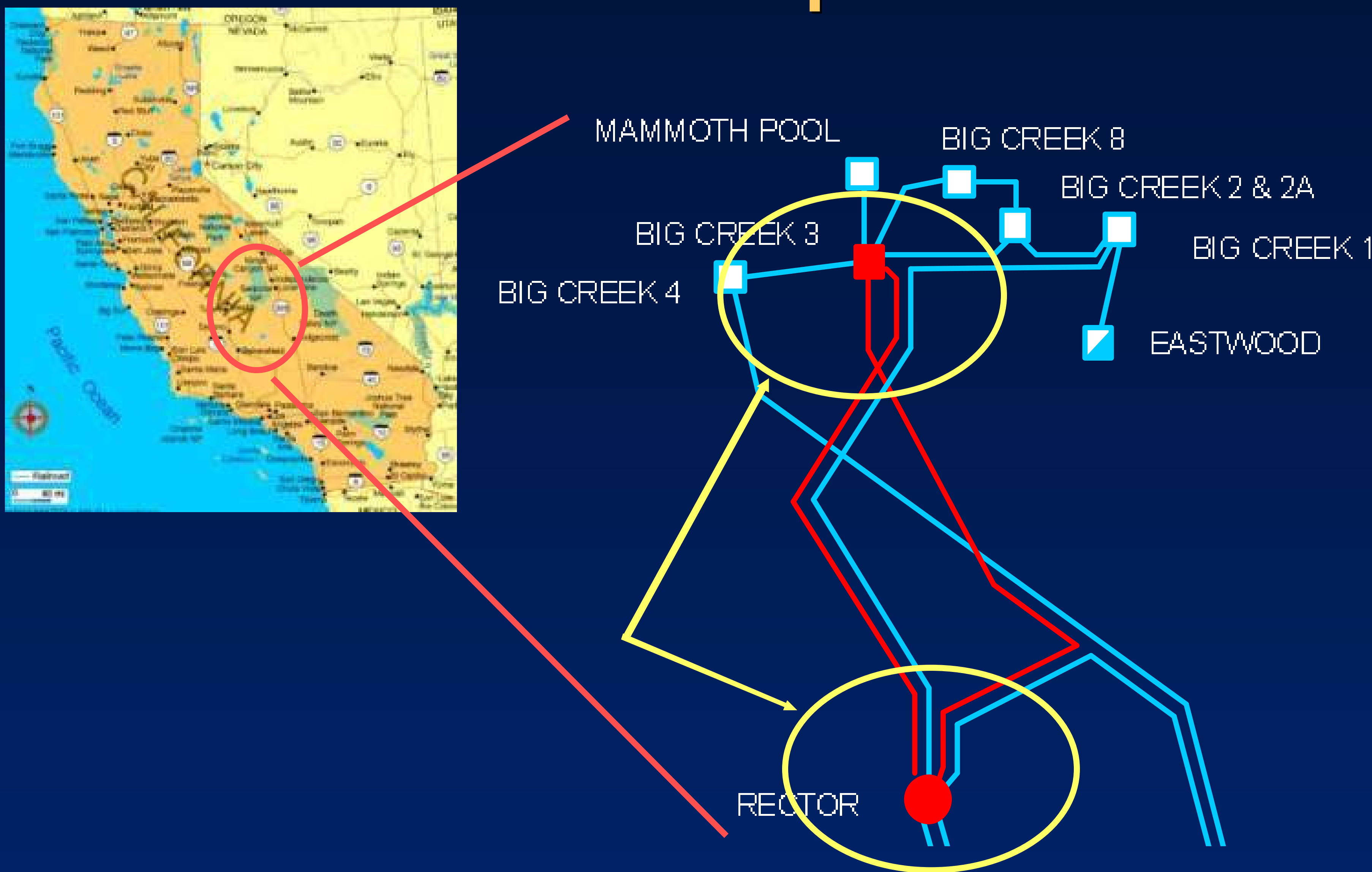
- With over 28GW of wind power in the SPP interconnection queue, this is a big deal!
- OG&E requiring a PMU at the point of interconnection for every wind farm
- Important to monitor power quality and dynamic response

Oscillations Due to Wind Farm

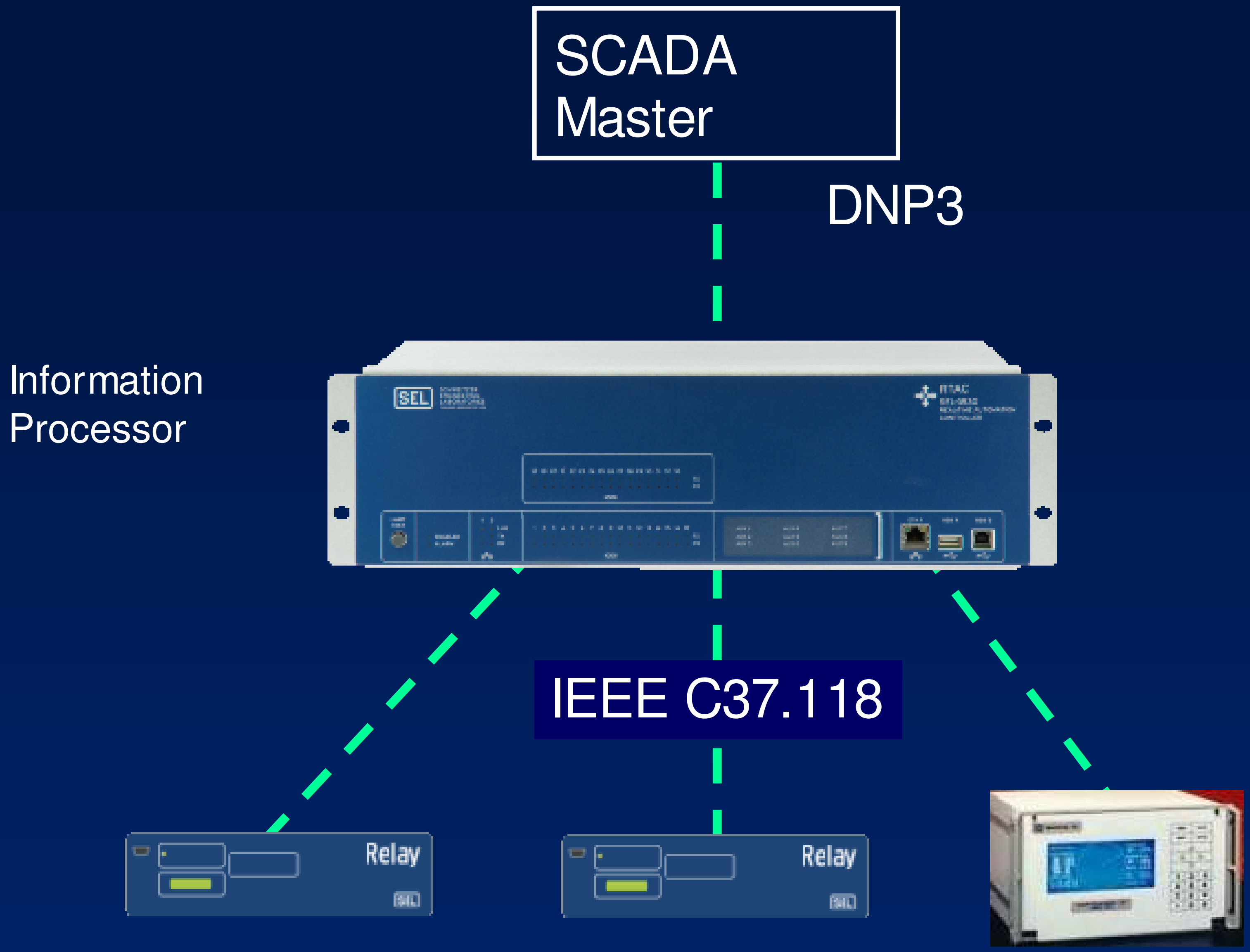
- Wind farm PMU shows many undesirable components, the worst at 14Hz



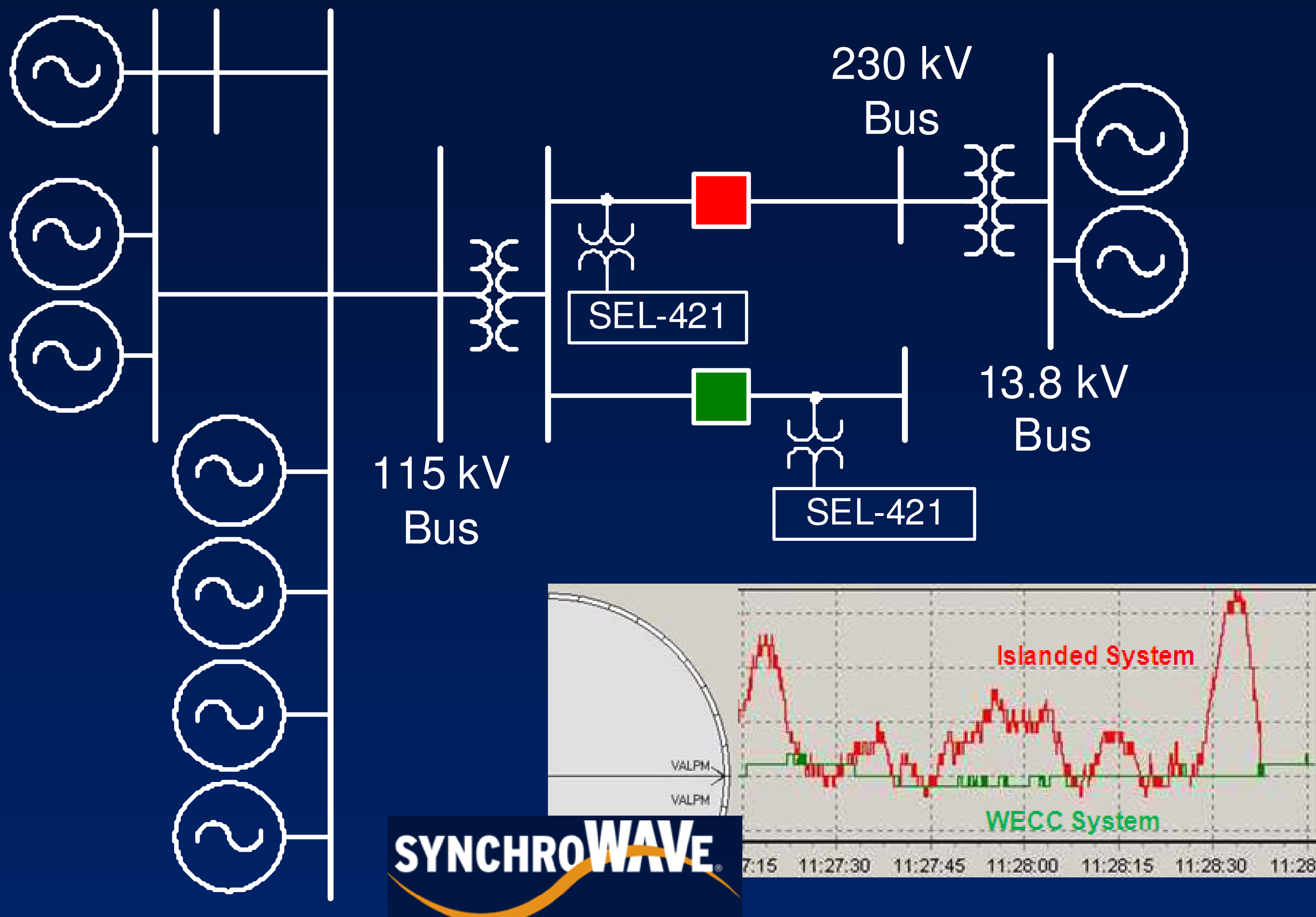
Big Creek Controls Rector Static VAR Compensator



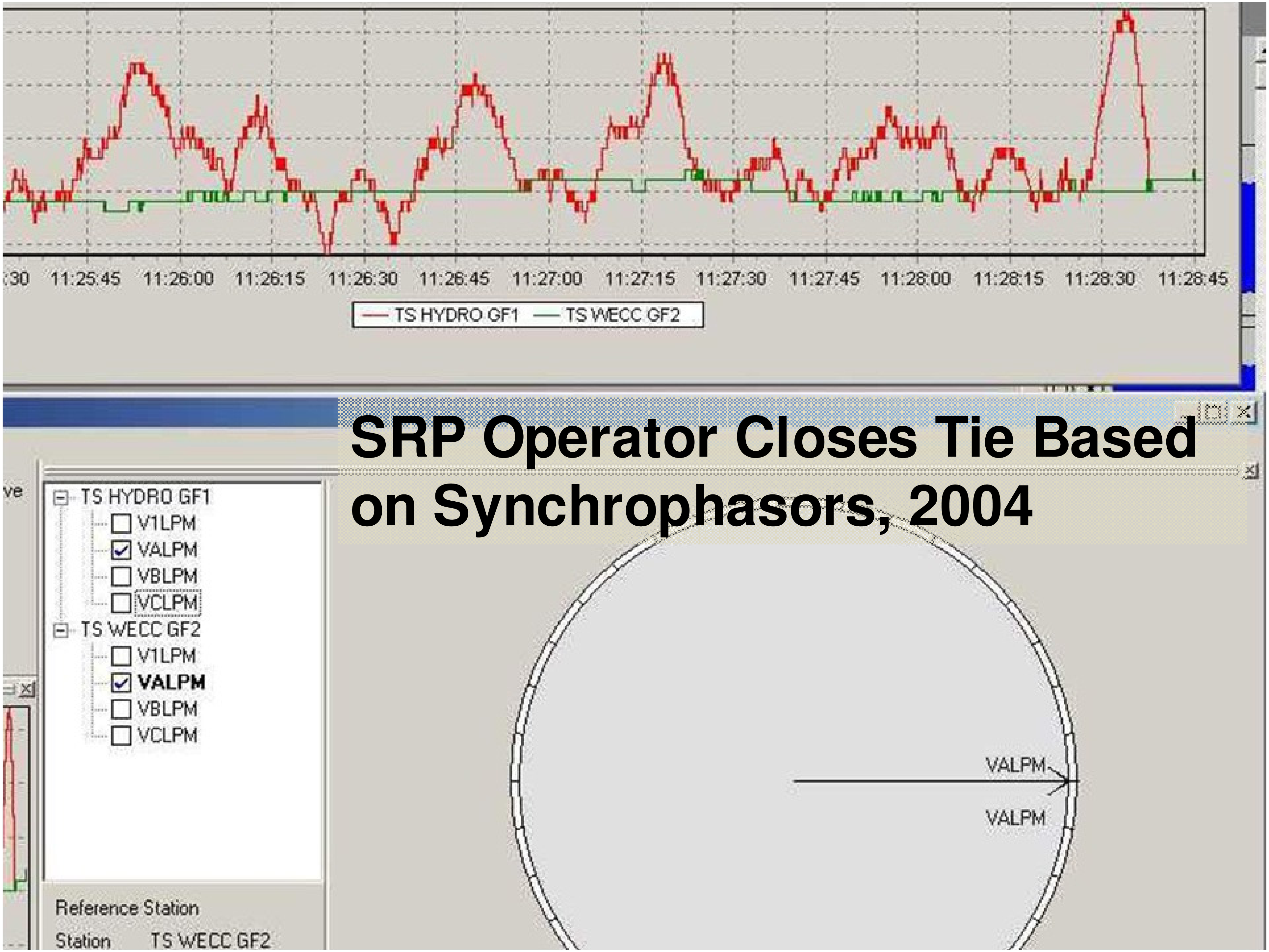
C37.118 to SCADA based FACTS Control



SRP – SynchroWAVe Synchroscope



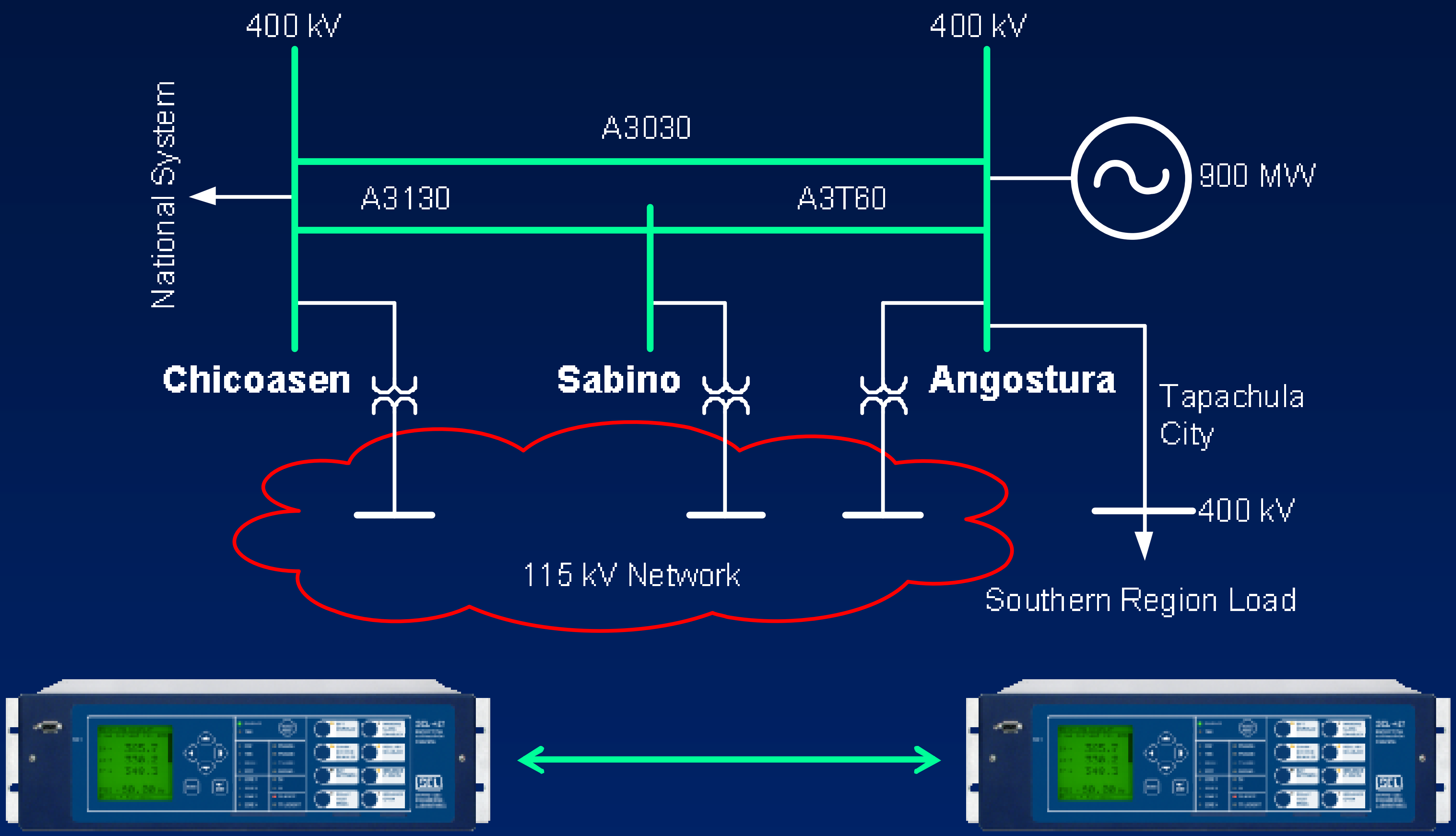
SRP Operator Closes Tie Based on Synchrophasors, 2004



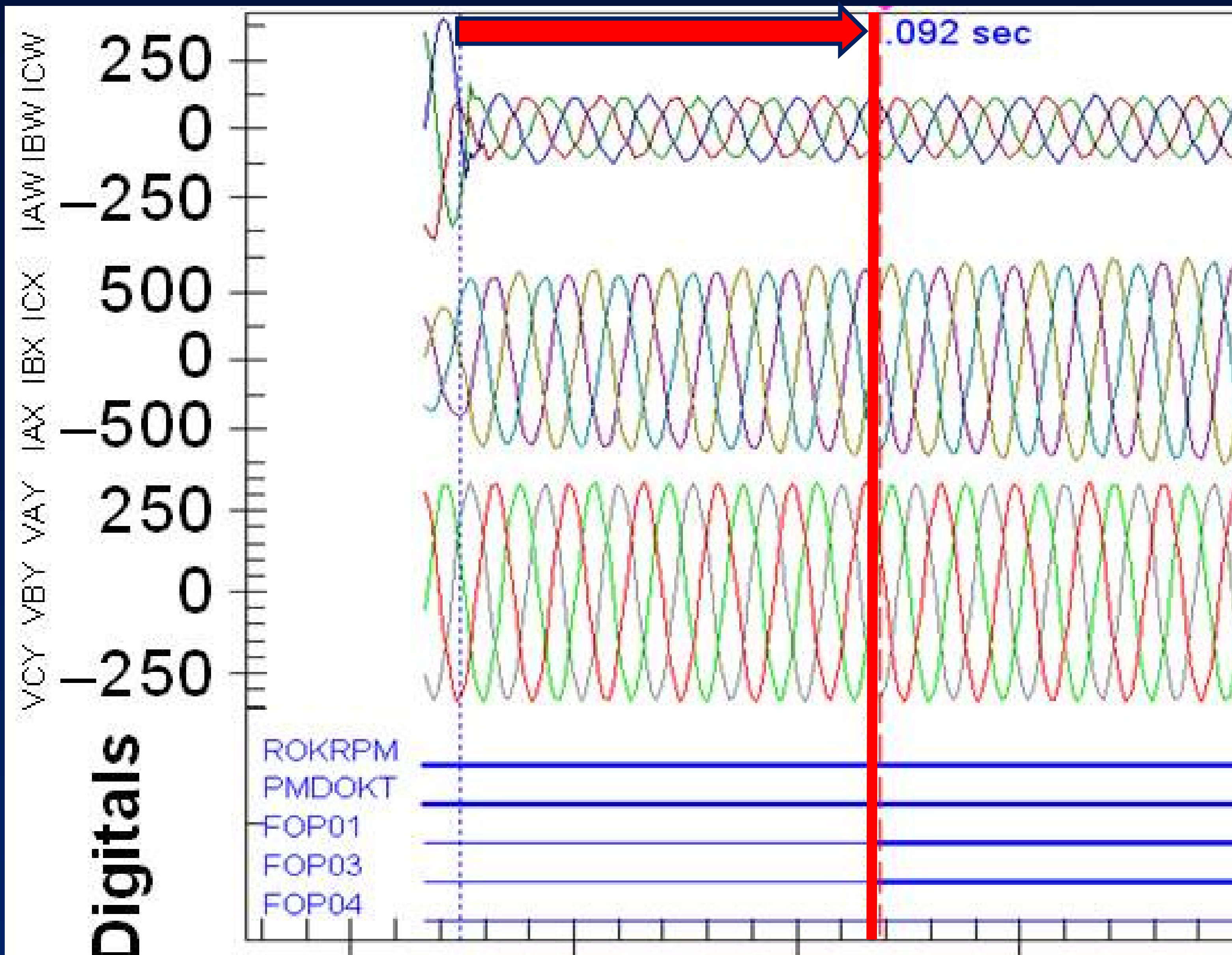
Relay-to-Relay Synchrophasors for Generator Shedding

Generator Shedding Based on Angle

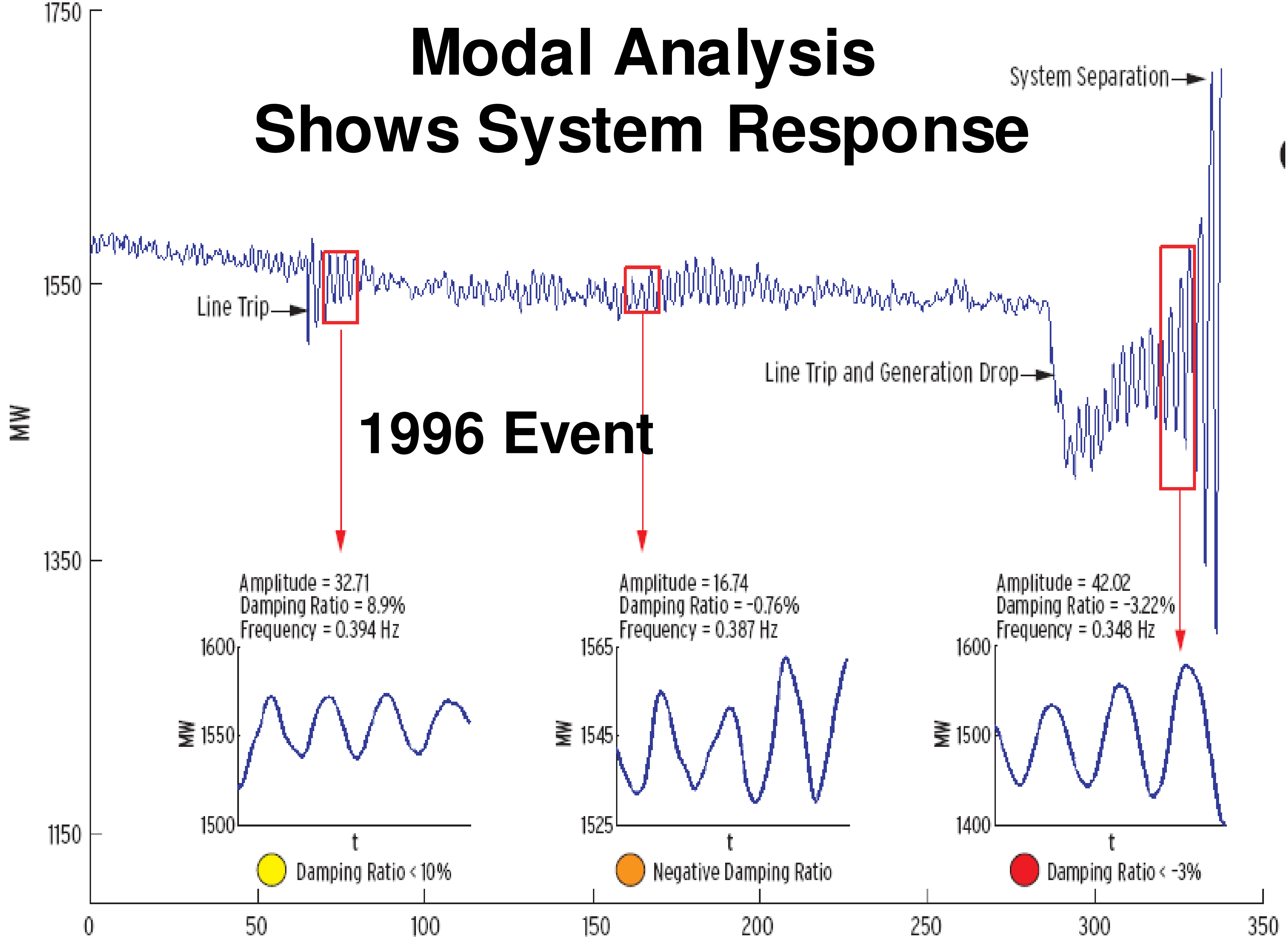
Chicoasen – Angostura



Wide-Area Protection at Relay Speeds



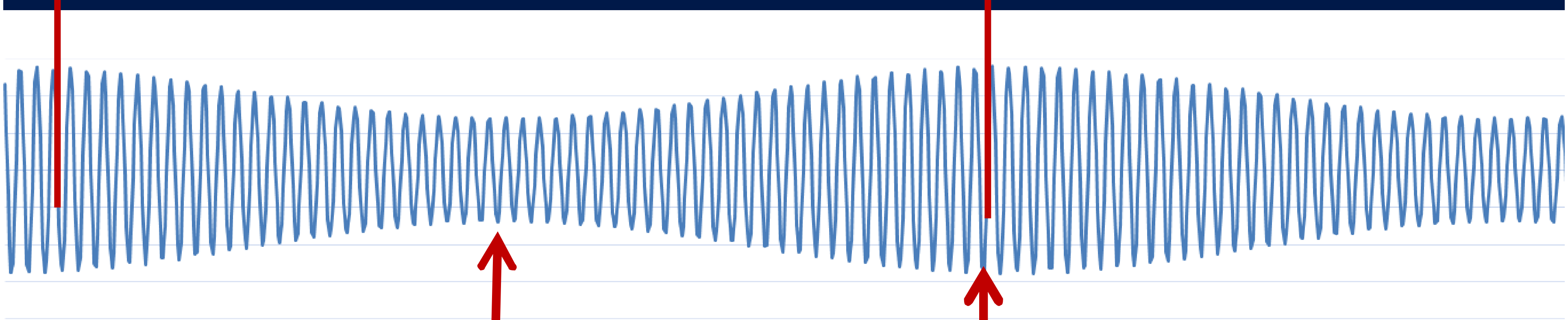
Modal Analysis Shows System Response



Slow Oscillations Facilitate Control

$P = |V_1|\ |V_2| \sin\Phi \ / \ X$

0.4 Hz → 2.5 sec.



Raise Voltage

Reduce Voltage

A New Tool for Old Problems
Synchrophasors

Sinrcofasores

- Son rentables
- Provee informacion de eventos sincronizada en el tiempo en forma precisa
- Pueden aplicarse para satisfacer cualquier Norma
- Estan siendo utilizados en nuevos metodos de Proteccion y Control

URLs for More Application Information

SEL website:

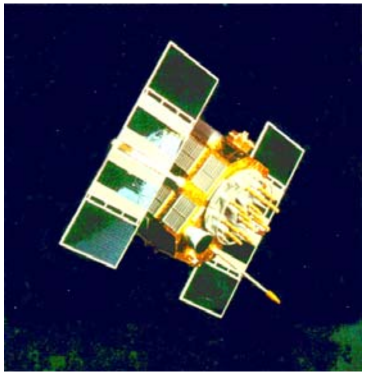
- Eskom Voltage Stabilty
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=6378
- Solar Generator Control – PV Powered
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=8494
- Generator Black-start – SRP
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=3194
- Anti-islanding at FPL
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=6375
- UT Texas with Dr. Mack Grady
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=7264
- SCE Static VAR Control
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=3487
- Using Modal Analysis to Mitigate Power System Oscillations
  https://www.selinc.com/WorkArea/DownloadAsset.aspx?id=5322

Another useful website - North American SynchroPhasor Initiative (NASPI) website:
http://www.naspi.org/

- OGE presentation , Entergy presentation and many others

Contenido

- Conceptos generales y definiciones
- Necesidades de la Industria
- Beneficios esperados
- Proyectos de la Industria y Experiencia
- Arquitectura del Sistema
- Desafios
- Estandarizacion, Tests, and Certificacion

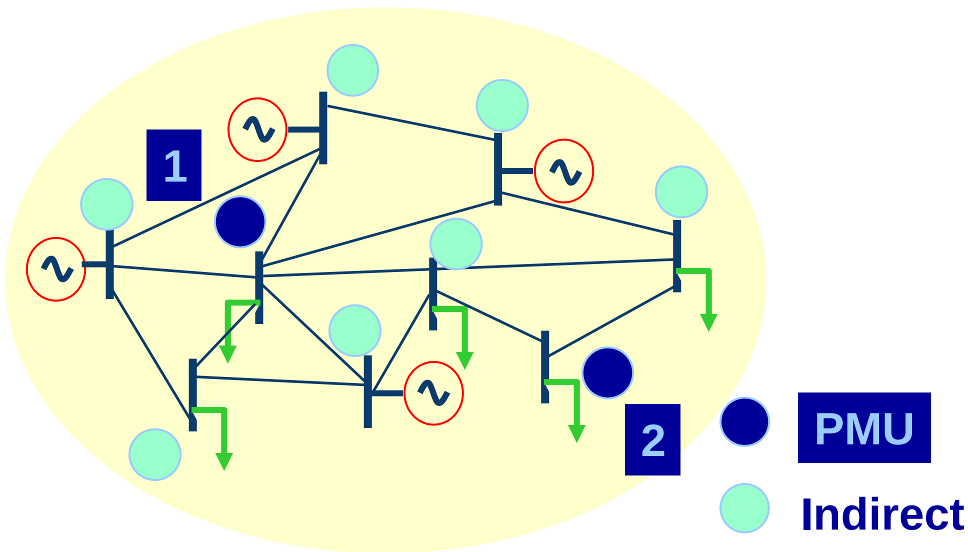


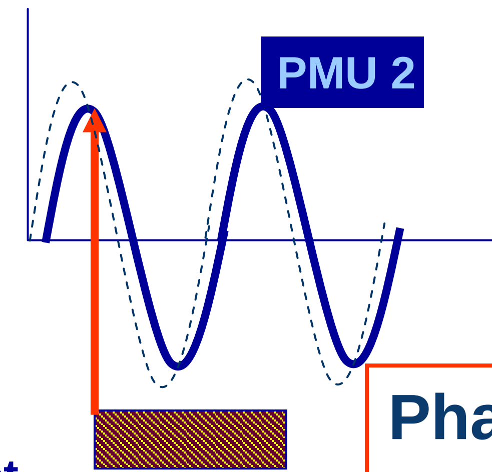
Conceptos generales y definiciones

Overview: Synchronized Measurements

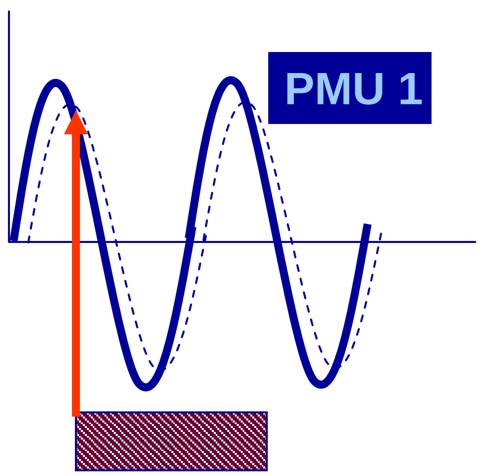
- A PMU at a substation measures voltage and current phasors
  - Very precise synchronization, with μs accuracy is becoming standard
  - Compute MW/MVAR and frequency
- Measurements are reported at a rate of 20-60 times a second
  - Well-suited to track grid dynamics in real time (SCADA/EMS refresh rate is seconds to minutes)
- Each utility has its own Phasor Data Concentrator (PDC) to aggregate and align data from various PMUs based on the time tag
- Measurements from each utility's PDC is sent to the Central Facility (e.g. TVA's SuperPDC) where the data are synchronized across utilities

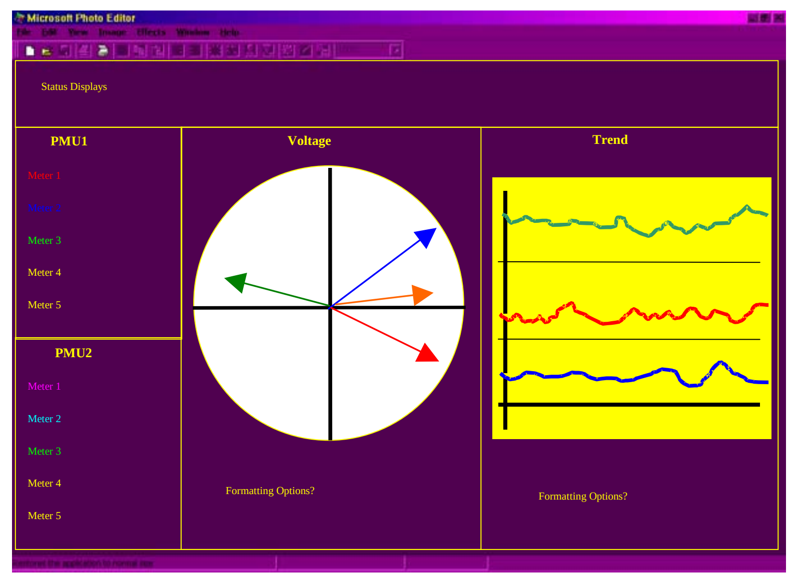
Señales de Sincronizacion a cientos de Millas de distancia



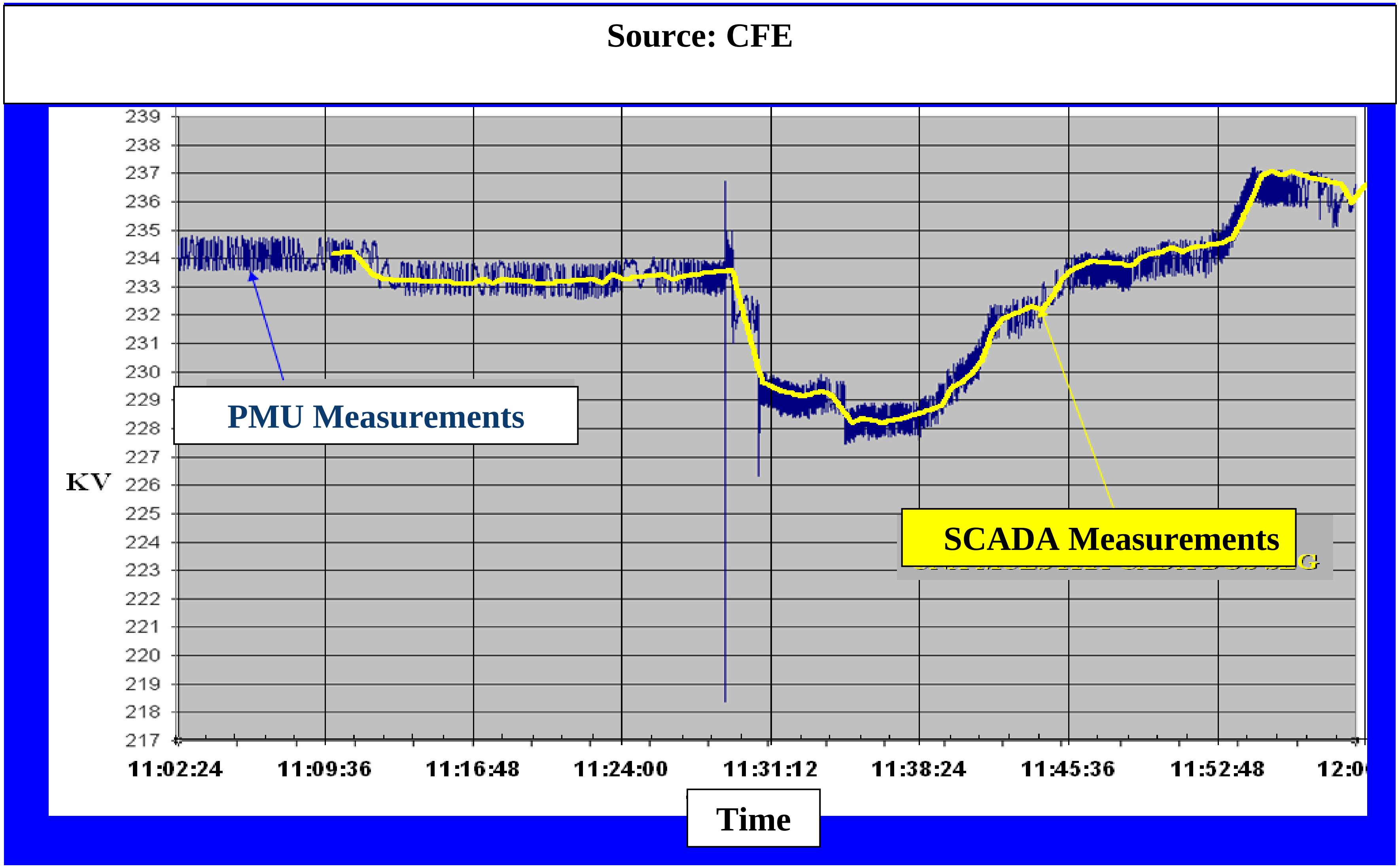


Phasors on the same diagram





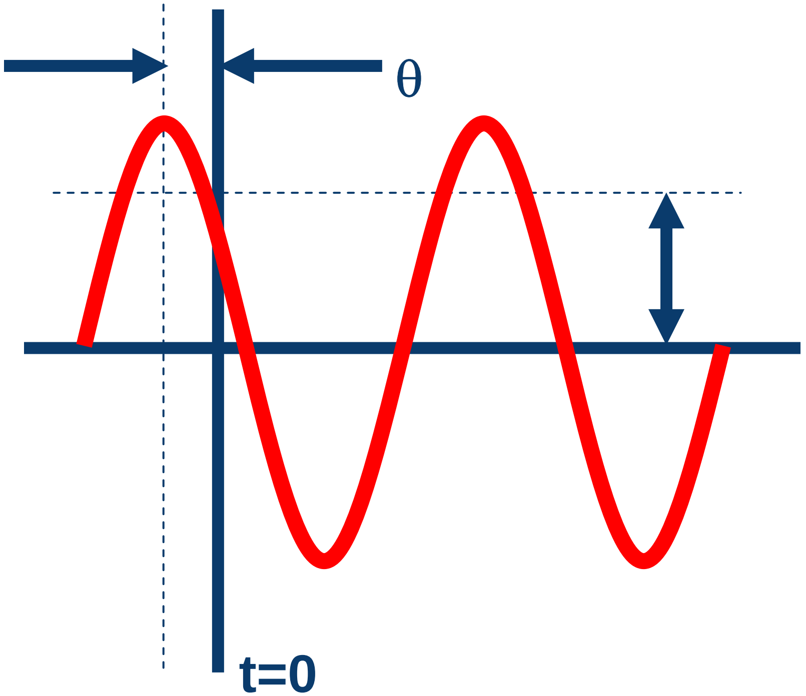
Comparacion entre SCADA y PMUs

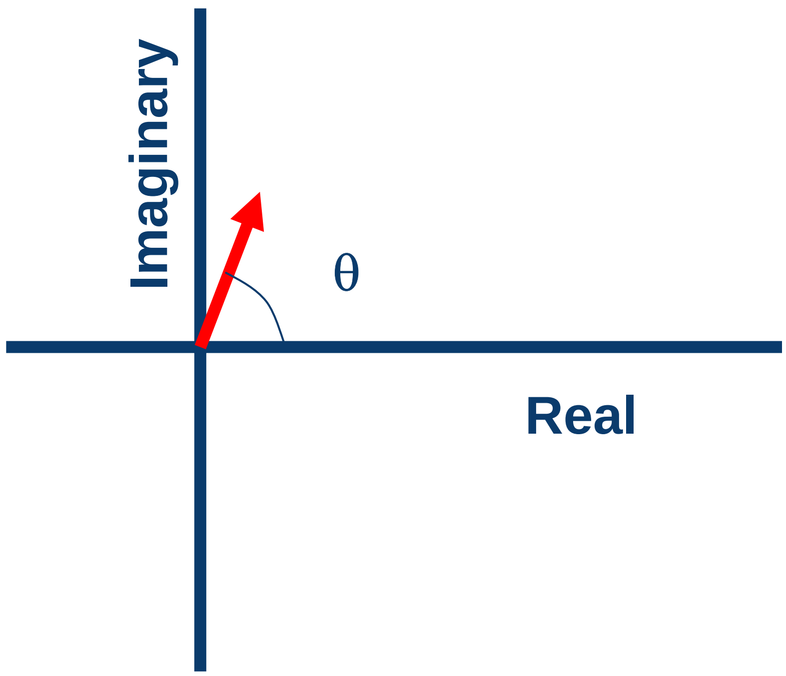


Definicion de Sincrofasor

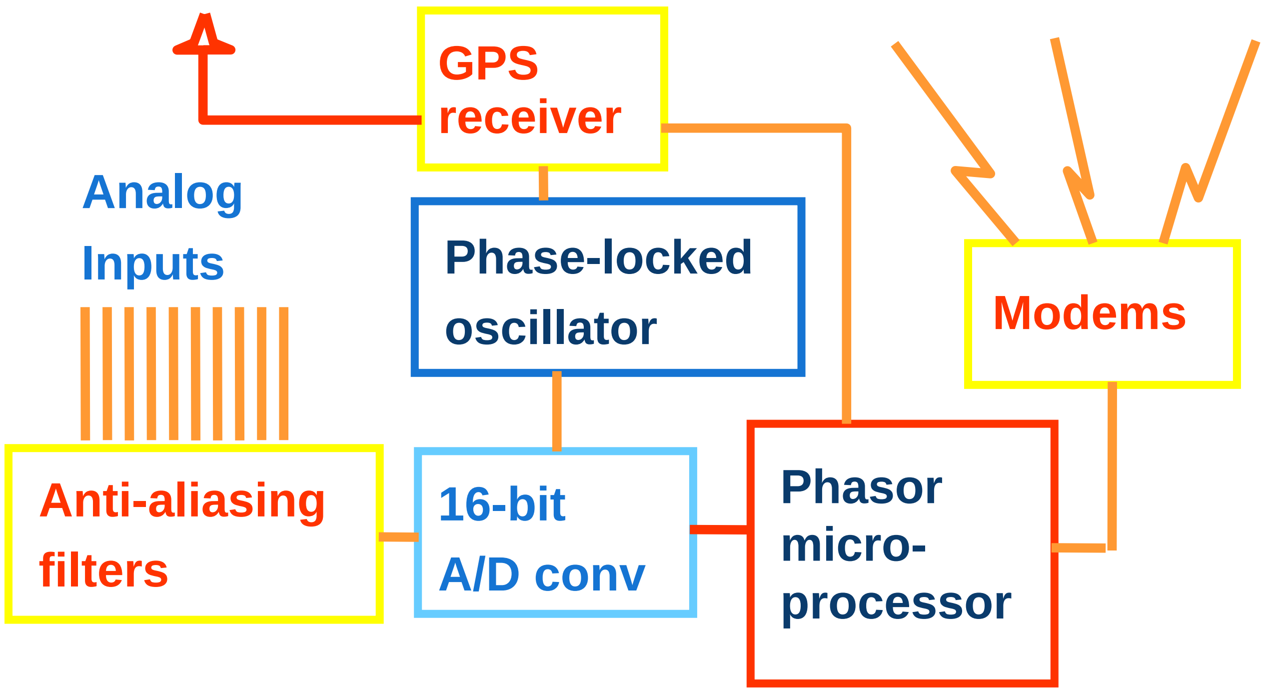
- *Synchrophasor* – Precision Time-tagged Positive Sequence Phasor measured at different locations

- *Phasor Measurement Unit* (PMU) – A transducer that converts three-phase analog signal of voltage or current into Synchrophasors



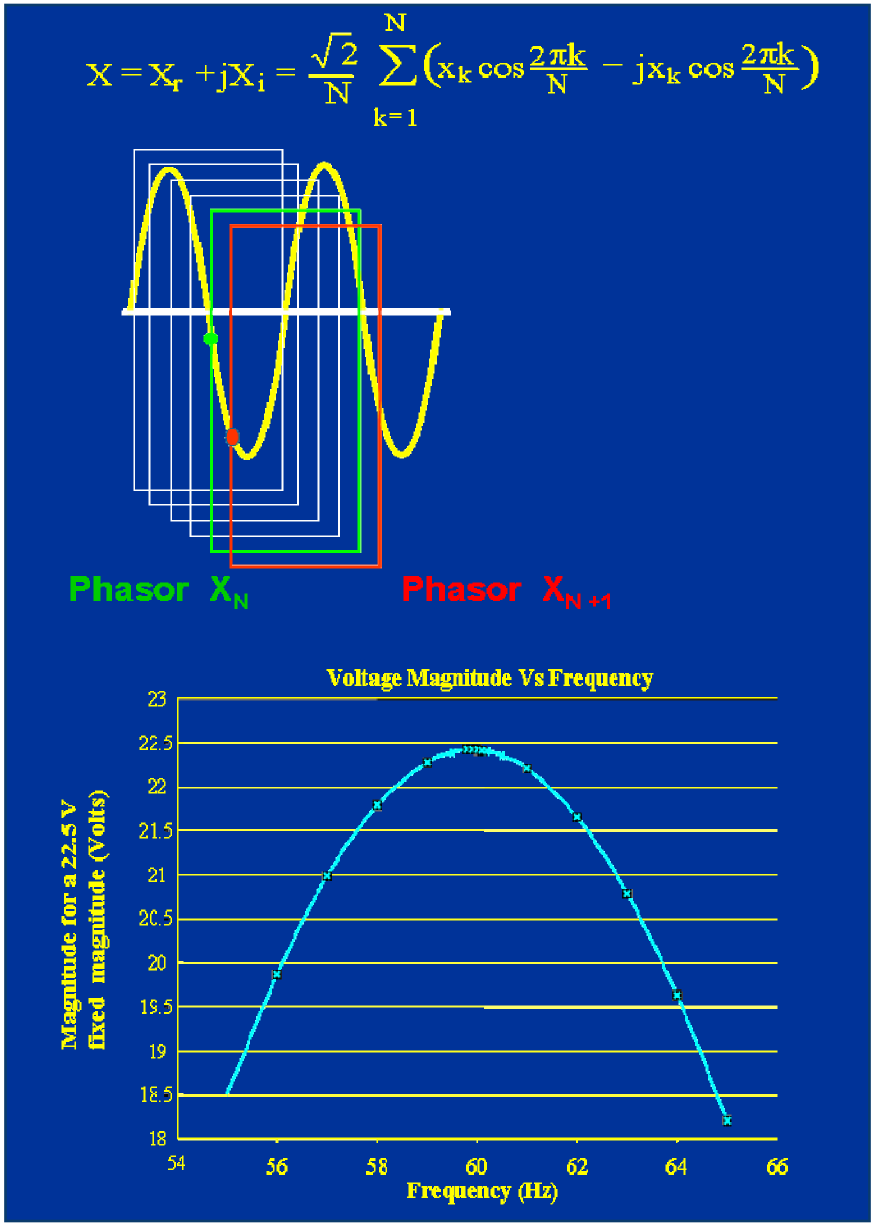


Overview: Synchronized Measurements



$$\text{Phasor } X = \frac{\sqrt{2}}{N} \sum x_k(\cos k\theta - j \sin k\theta)$$

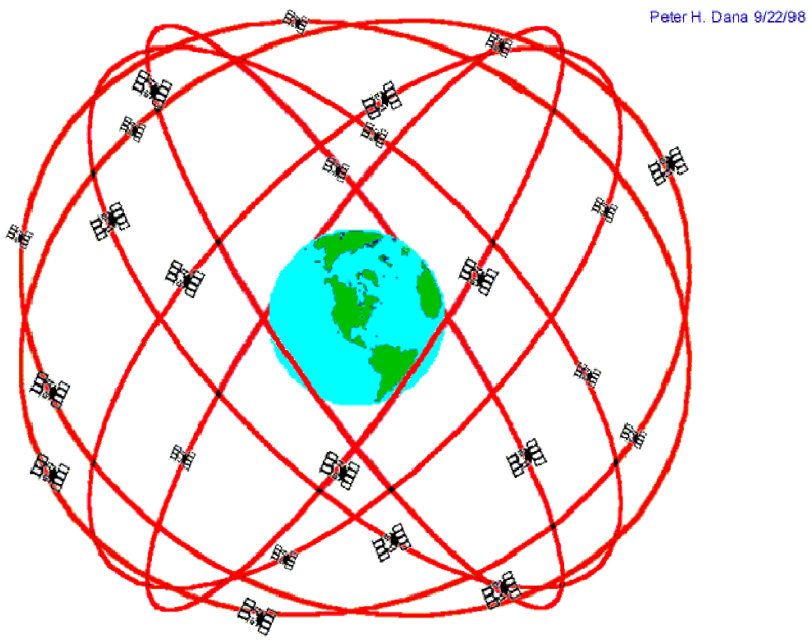
Algoritmo Original



- Recursive algorithm calculate the fundamental frequency component as the phasor
- Assumed the fundamental frequency is fixed at 60 Hz
- Angles are affected at off-nominal frequencies
- This problem has been corrected in modern PMUs using frequency tracking algorithms

Sincronizacion de Mediciones

- 24 Satellites
- 12 Hour Orbit Time
- Visibility: 5 to 8 Units from Any Point at Any Time
- Signal: Position, Velocity, Time
- Precise Positioning Service (PPS):
  - 22 meter Horizontal accuracy
  - 27.7 meter vertical accuracy
  - 100 nanosecond time accuracy
- Performance is 95% Reliable

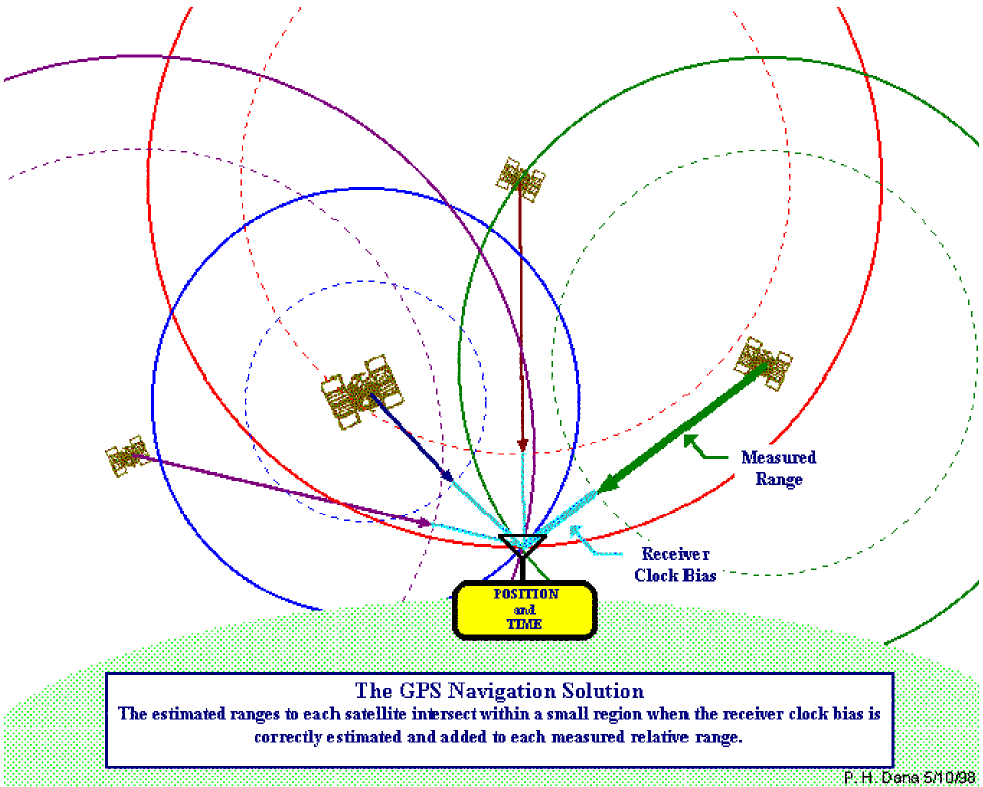


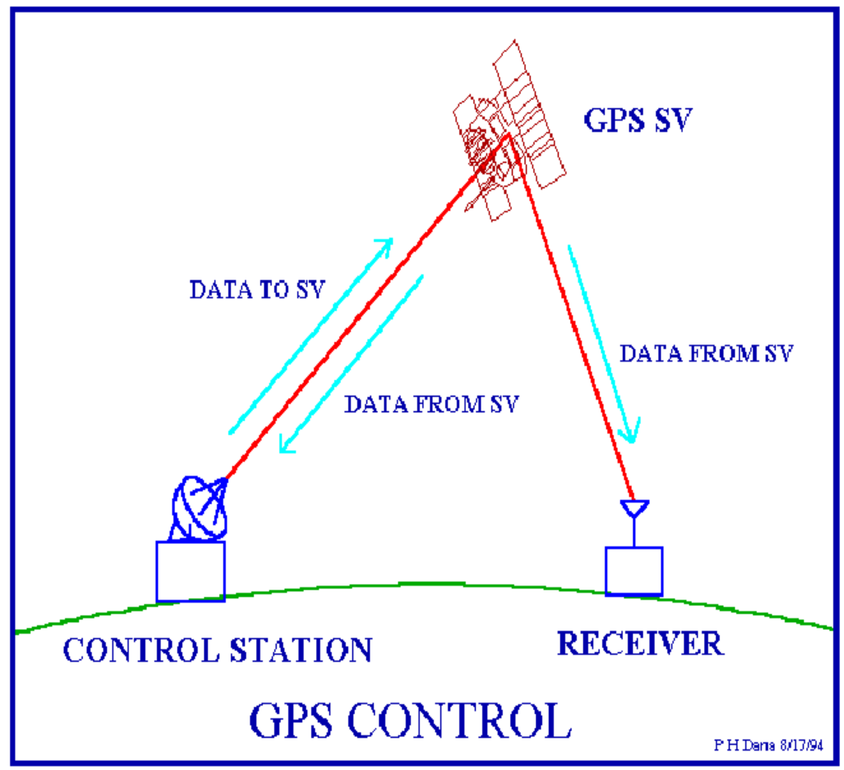
GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Fuentes de Sincronizacion

- **Pulses**
- **Radio**
- **GOES**
- ***GPS***

GPS





Necesidades de la Industria

Beneficios Reconocidos

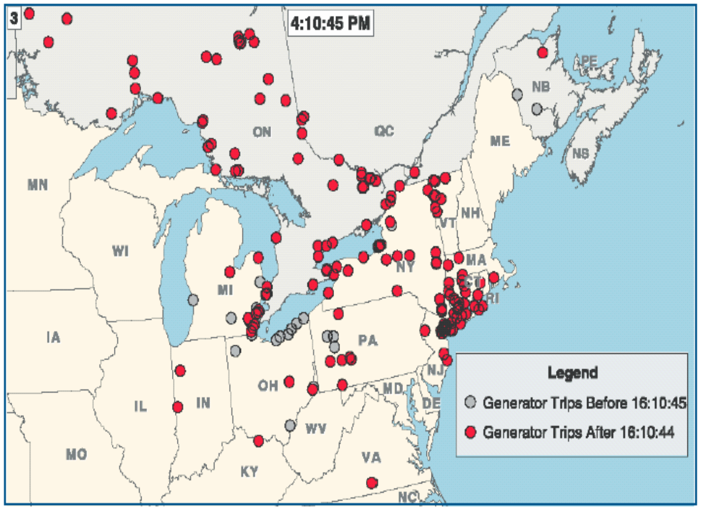
The primary benefits of a real-time transmission monitoring system could be to:

- provide early warning of deteriorating system conditions, so operators can take corrective actions;
- limit the cascading effect of disturbances (by providing wide-area system visibility); and
- improve transmission reliability planning and allow for immediate post-disturbance analysis and visualization through the use of archived monitoring system data.

The secondary benefits of a real-time transmission monitoring system could be to:

- provide more diagnostic tools than are currently available;
- allow for the more effective use of automatic controls for self-correction such as automatic switching or controlling the flow of power; and
- improve computer models of the power system.

Wide Area Monitoring, Protection, and Control (WAMPAC): Industry Needs

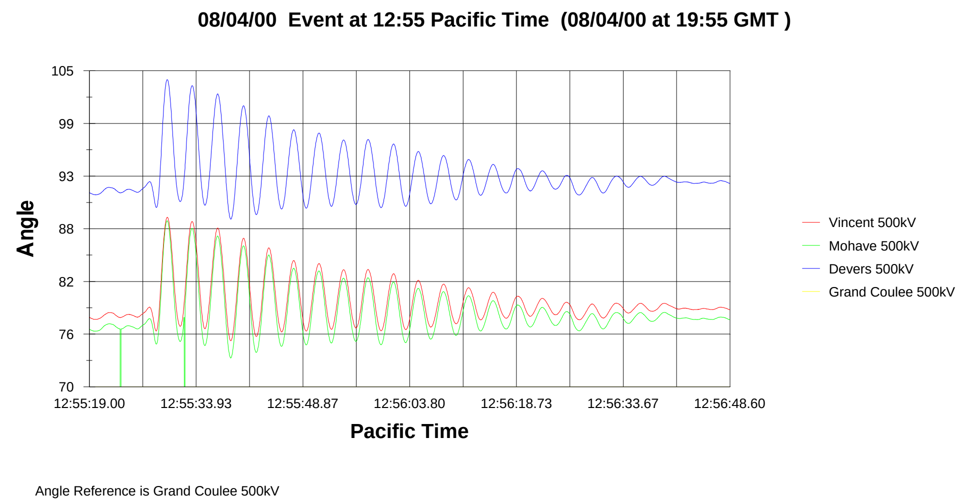


- System Vulnerability
  - Response to emergencies

    (blackouts being the extreme case)
    - Emergency operations
      Prevent disturbance propagation:
      Planned islanding with well coordinated under-frequency load shedding scheme; Avoid tripping generators & lines too early; etc.
    - Faster system restoration (e.g. reclosing the tie line)
    - Compliance monitoring and reduction in post-mortem troubleshooting time and effort
  - Asset management/Aging infrastructure
    - Capacity deferments
    - Increase transmission capacity and power reserve management
    - Condition assessment

Wide Area Monitoring, Protection, and Control (WAMPAC): Industry Needs

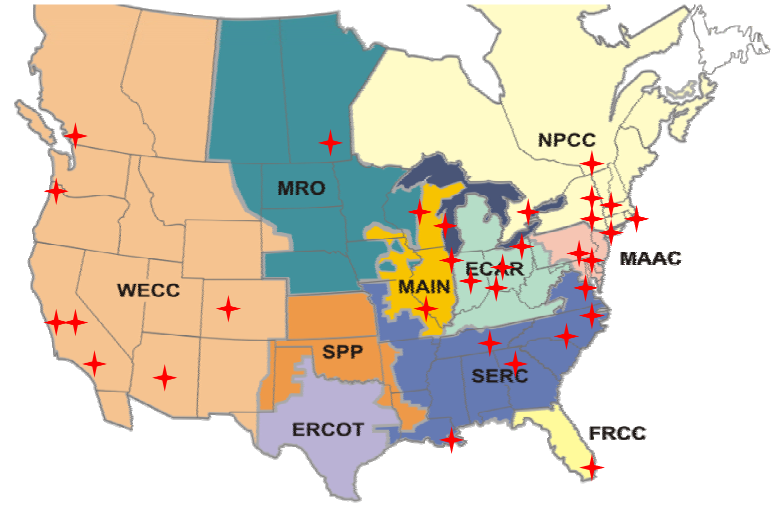
WECC System Oscillations under stressed conditions – August 4, 2000



- System Operations and Planning
  - State est. improvements
  - Model validation
  - Benchmarking, etc.
- Market Operations
  - Congestion management
    - Nominal Transfer Capability (NTC) based on thermal, voltage, or stability limitations
    - Unused transfer capability and lost opportunity dispatch costs
- DG monitoring, protection, and control

WAMPAC Enablers

- **Application Modules**
  - Angular & voltage stability monitoring and control
  - Dynamic line models:
    Overload monitoring and control and Fault location
  - Power oscillation monitoring & damping (e.g. PSS)
  - Critical equipment status and condition monitoring
  - Frequency and df/dt monitoring and protection
  - Monitoring machine excitation & governor systems
  - Adaptive relay settings and protection
  - Etc.

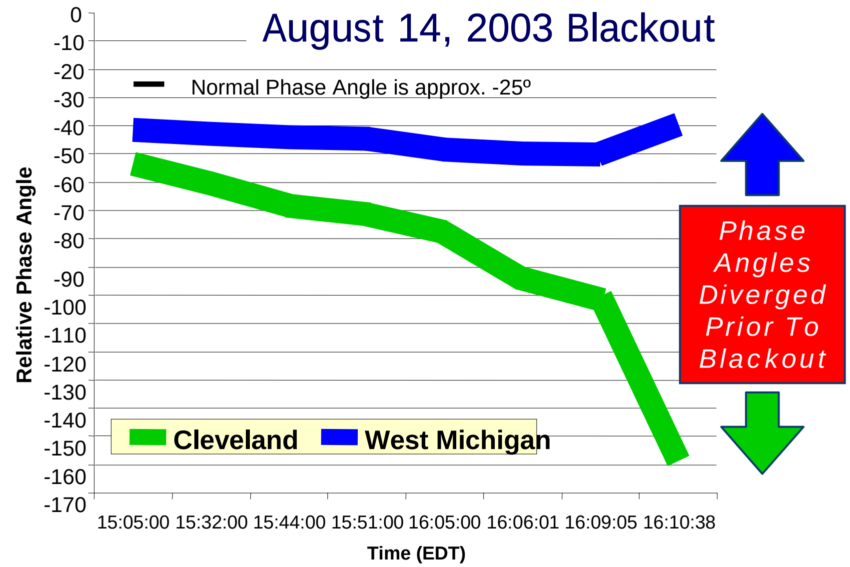


- **Technology**
  - Integrated system-wide communication infrastructure allowing flexible and secure data collection and transfer where and when needed
  - Synchronized measurements
  - Use of standard technology, such as IEC61850, for easier integration, configuration, engineering, and maintenance
  - Advanced sensors (line thermal monitors, equipment condition assessment, etc.)
  - Advanced visualization tools and algorithms

Beneficios Esperados y Limitaciones

Monitoreo y Control de Angulos de Fase

- Needs:
  – Provide operators with real-time angle and angle change between buses
  – Avoid incorrect out-of-step operation
  – Improved planned power system separation
- Benefits:
  – Improved real-time awareness, incl. neighboring systems
  – Improved out-of-step tripping and blocking
  – Separate the system on most-balanced way
  – Assist operator during manual reclosing of tie lines



Source: TVA

- Technology:
  – Advanced algorithms using wide-area information
  – Visualization tools
  – Smart algorithms for instability and coherency detection, separation boundary
  – PMU system

Estimacion de Estado Ampliada (SE)

- Need: Use phasors directly to enhance SE
- Benefits: Better network observability; robust performance due to more measurements; more precise derived calculations

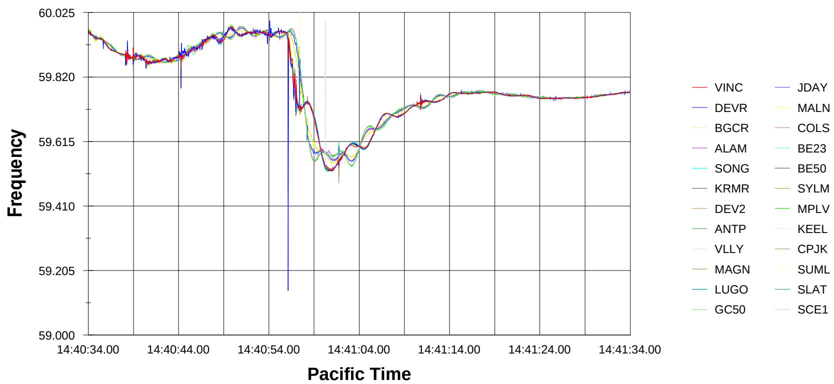
Analisis Post-Falla

- <u>Need:</u> To reconstruct sequence of events after a disturbance has occurred
- <u>Benefits</u>: Savings in troubleshooting time (several orders of magnitude) and resources
- <u>Technology</u>:
  – PMU with low comm. requirements
  – Data storage in substations
  – "Smart Analyzer" to sift through vast amount of data for key info from an assortment of data loggers (DFR, SER, Relays, PMUs,…)
- <u>Gap</u>: No commercial products exist as Smart Analyzer

Loss of Palo Verde Units 1, 2 & 3 on June 14th, 2004

Frequency plots from different PMUs

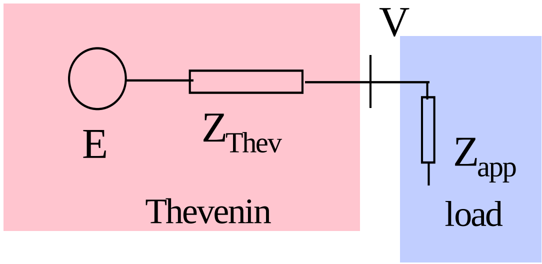
06/14/04 Event at 07:40 Pacific Time (06/14/04 at 14:40 GMT)

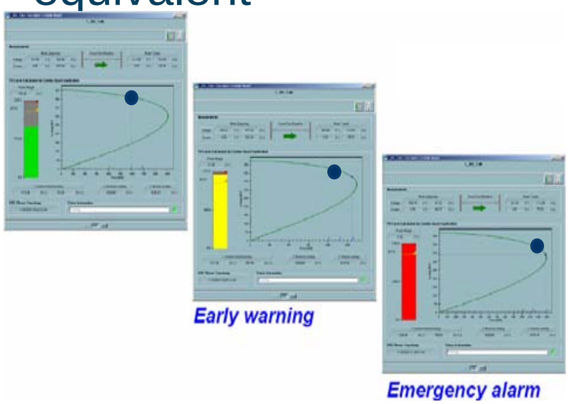


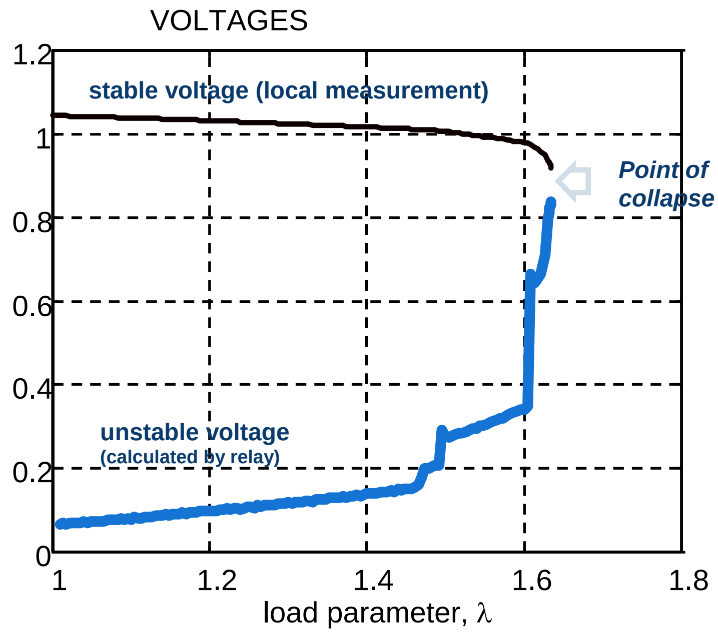
Source: SCE

Prediccion de Inestabilidad de Tension

- Maximal power transfer ⇔
  $|Z_{app}| = |Z_{Thev}|$ is point of collapse
- Measuring the proximity to instability - improvement to UV LS
- Corridor version: Two PMUs on the both side of the line
  – More accurate Thevenin equivalent







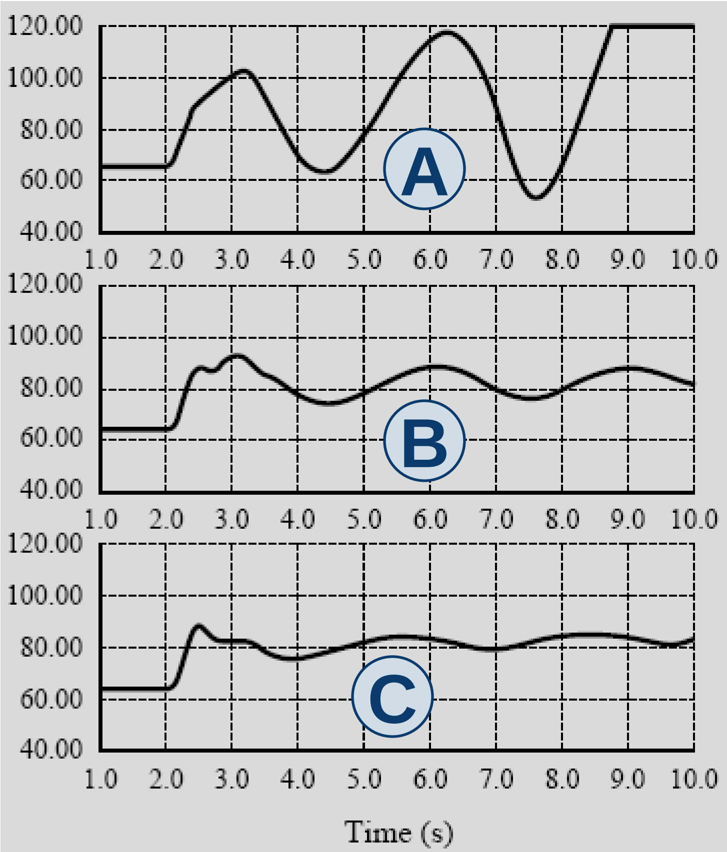
* K. Vu and D. Novosel, "Voltage Instability Predictor (VIP) - Method and System for Performing Adaptive Control to Improve Voltage Stability in Power Systems," US Patent No. 6,219,591, April 2001.

Manejo de Congestion en Tiempo-Real

- Need: Improve calculation of real-time path flows and increase transfer limits for optimal market dispatch
- Benefits: Avoid large congestion costs
  - Avoids unused transfer capability and lost opportunity dispatch costs through more accurate real-time ratings
  - Experience from real-time ratings will help hour-ahead, and day-ahead limits
  - Leads to better utilization of generation resources and less load curtailment
- Technology:
  - Adequate visibility of corridors with incorporation of improved basic modules to EMS/SE: Angular stability, Voltage stability, Thermal constraints
  - PMU applications
- Gap:
  - Industry and staff adoption of new rules and procedures and PMU-based calculations

Wide-Area Power System Stabilizer (PSS)

- Need: Generator control to suppress low-freq. oscillations in interconnected grids
- Benefits: Better system damping by feeding multi-input PSS with wide-area signals
- Technology:
  - Selection of signals; design and tuning of algorithm
  - Fall-back scheme: use local signals when remote ones are disrupted
- Gap:
  - Dedicated communications link
  - Quantified benefits of WA-PSS

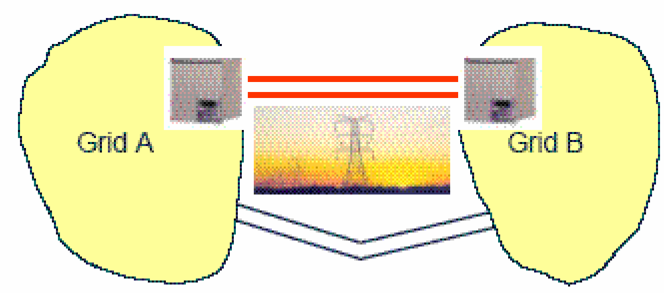


A: Conventional PSS.
B: Multi-input PSS; local signals.
C: Multi-input PSS; wide-area signals.

Source: Hitachi.

Modelos Dinamicos de Lineas

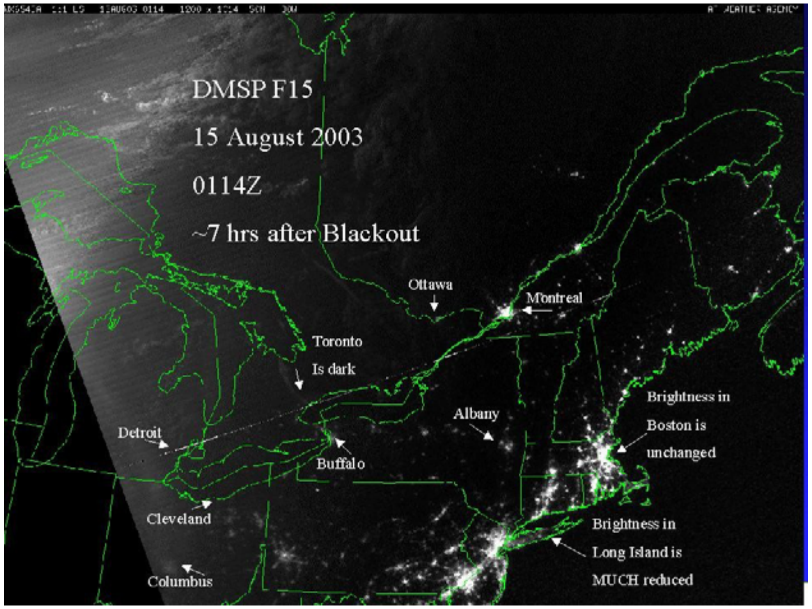
- Need:
  1. Dynamic rating by real-time assessment of transmission lines thermal limits
  2. More accurate line parameter detection for accurate fault-location
- Benefits:
  1. Operator can determine the proper loading
  2. Faster restoration for permanent faults and better detection of week spots for temporary faults
- Technology:
  - Temperature measurements
  - PMUs in substations



- Gap:
  - Industry acceptance

Restauracion de Sistemas de Potencia

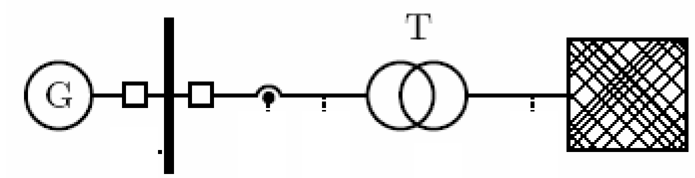
- Need: Use of phase-angle monitoring to assist operator during restoration



- Benefits: Time savings
  - Operator knows if it is feasible to reclose the tie line
  - Valuable tool for operator who works under stress to reenergize grid.
- Technology:
  - PMU system
- Gap:
  - Operator training required
  - Simulators need to provide trainee with feedback signals that simulate direct measurements

Monitoreo/Proteccion/Control de DG

- Need: Better monitoring /protection/ control methods
- Benefits: Determination of unintentional islanding

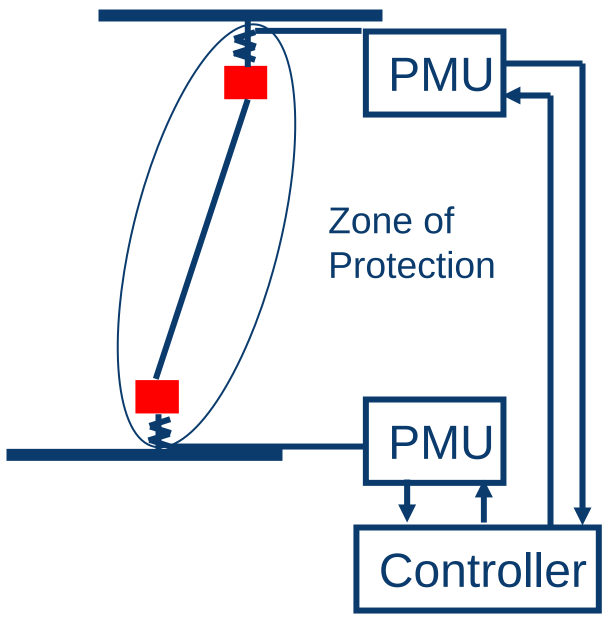


- Technology:
  – A pair of PMUs has been shown to detect islanding cases where local-based methods could not
- Gap:
  – Field experience still lacking
  – Cost requirements

Proteccion Adaptiva

- Need: To use synchronized phasors to allow relays to adapt to prevailing system conditions

- Benefits:
  - Line relays: to better handle complex configurations (e.g., multi-terminal lines, series-compensated lines)
  - Adaptive Security & Dependability to avoid cascading (2 out of 3)
  - Improved backup protection



- Technology:
  - PMU signals
  - Advanced algorithms

- Gap:
  - More field experience needed
  - Acceptance by engineers

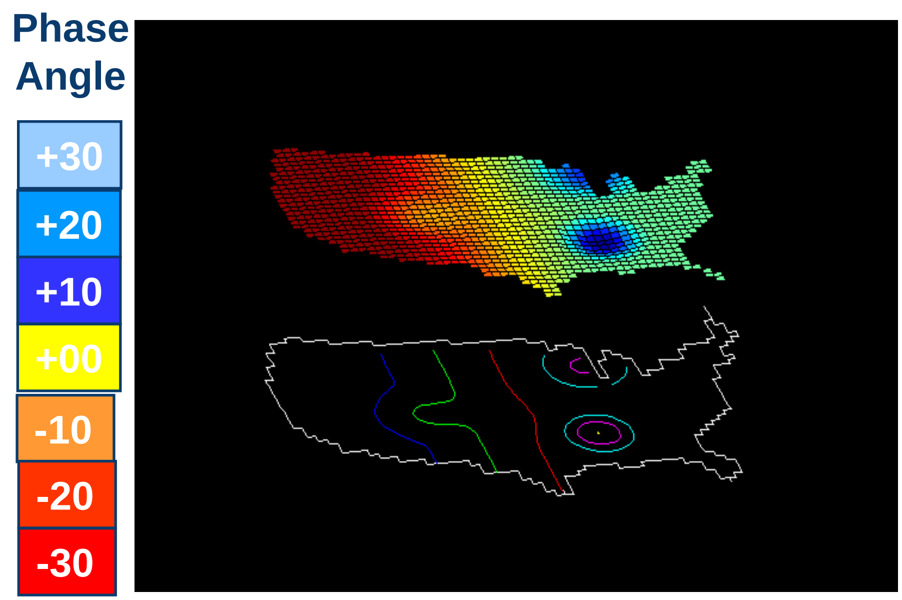
Dynamic Relay Settings

- Needs:
  - Reduce complexity of implementation, maintenance, testing, and verification of relay settings with multi-function IEDs
  - Avoid that equipment protection operates incorrectly under stressed system conditions not set and designed for
- Benefits: Ease of applying and changing settings with IEDs
  - Automated review and update of relay settings as system conditions change (e.g. load growth, new equipment installations)
  - Dynamic setting adjustments under stressed system conditions (e.g. line overload, voltage and angular instability)
- Technology:
  - Enterprise level process and tools
  - WAMS high-resolution “system data” data, detect stressed conditions and system changes
  - First level alarm => Second level automated adjustments
- Gap: Industry acceptance

Proyectos Industriales y Experiencia

Estado de Avance

- Synchronized Measurement (SM) and Synchronized Phasor Measurement (SPM) devices are available from many vendors
  - ABB, AMETEK, Arbiters, GE, Macrodyne, Mehta Tech, SEL, …
- Systems are already installed and operating
- Large scale deployment
  - WECC, EIPP, ONS-Brazil, etc.
- New IEEE C37.118 standard has been approved



Source: A. Phadke, VT

- Many ongoing SM/SPM application researches/studies

Eastern Interconnection Phasor Project (EIPP)

Under DOE leadership, EIPP participation has been unprecedented:

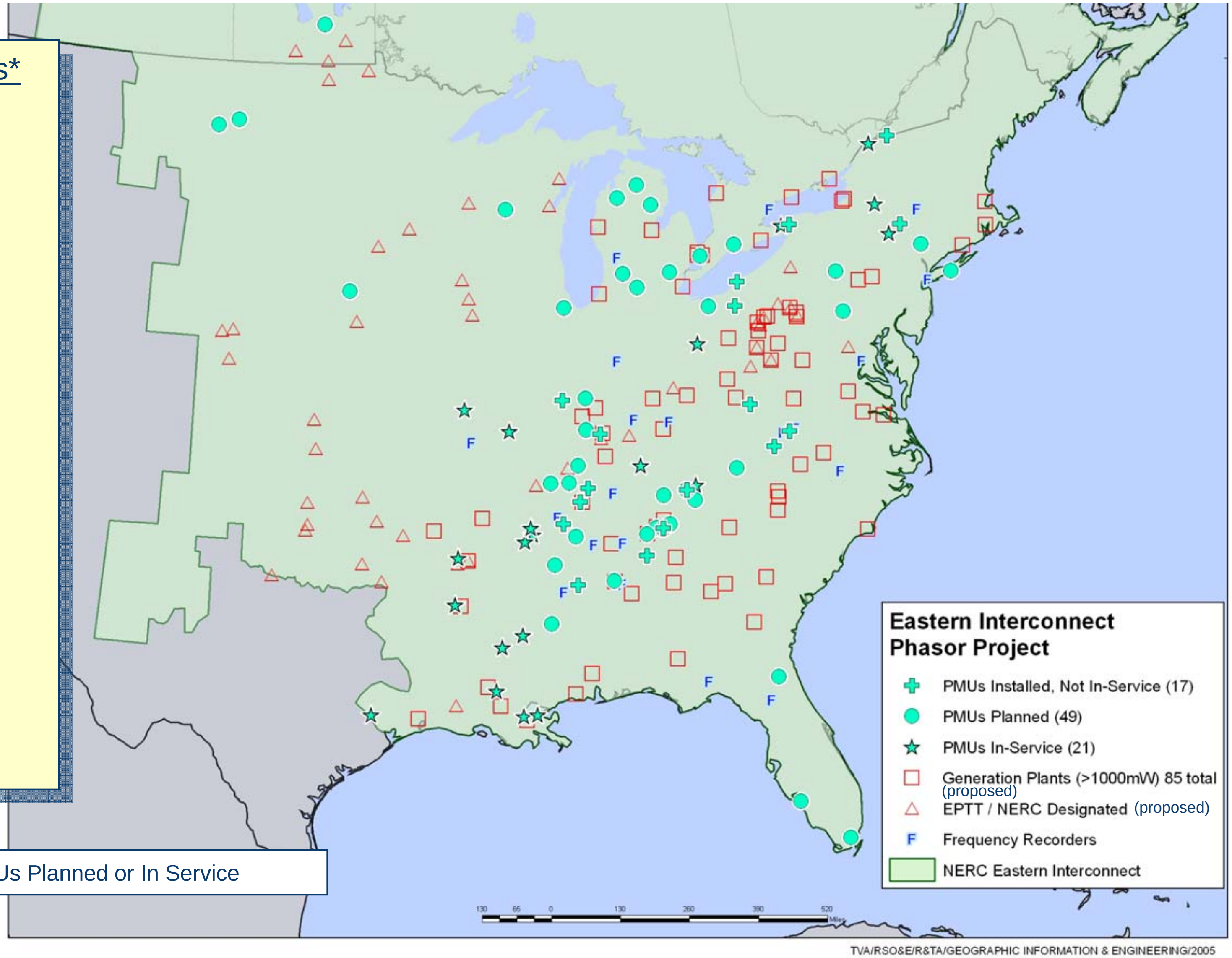
• Number of utilities:	➢ 32
• Number of research organizations:	➢ 14
• Number of vendors:	➢ 27
• DOE investment in EIPP:	➢ $3 million (since 2002)
• Industry investment in EIPP:	➢ $15 million (5 to 1 leverage)
• Future DOE investment needed:	➢ $5 million (yearly)
• Number of years needed:	➢ 5 years

Source: EIPP

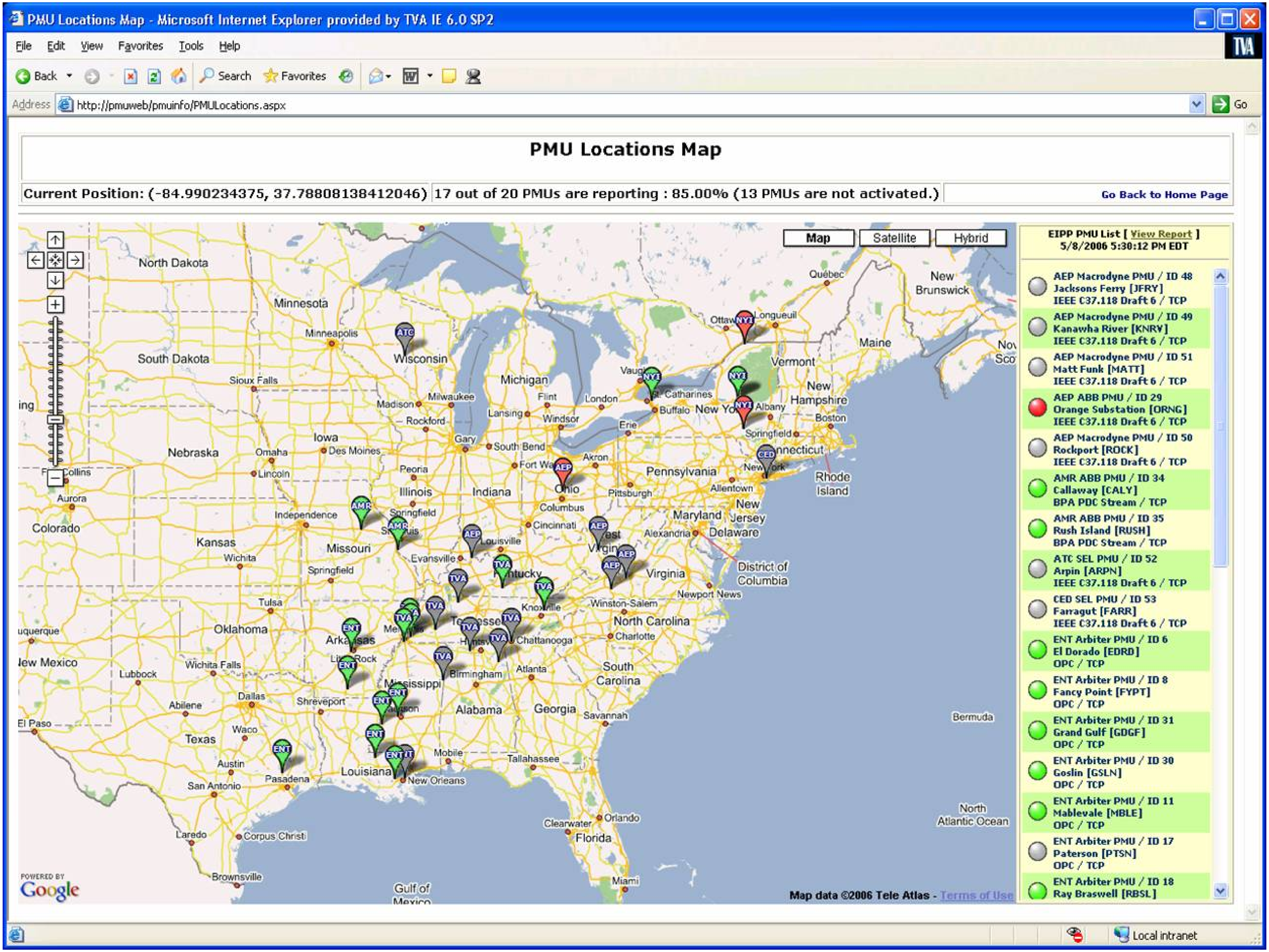
Eastern Interconnection Phasor Project (EIPP)

EIPP PMU Companies*

- Ameren
- AEP
- American Trans. Co.
- ConEdison
- Entergy
- Excelon/ComEd
- Excelon/PECO
- First Energy
- Hydro 1
- LIPA
- Manitoba Hydro
- METC
- Midwest ISO
- NY ISO / NYPA
- PPL Corp.
- Southern Company
- TVA



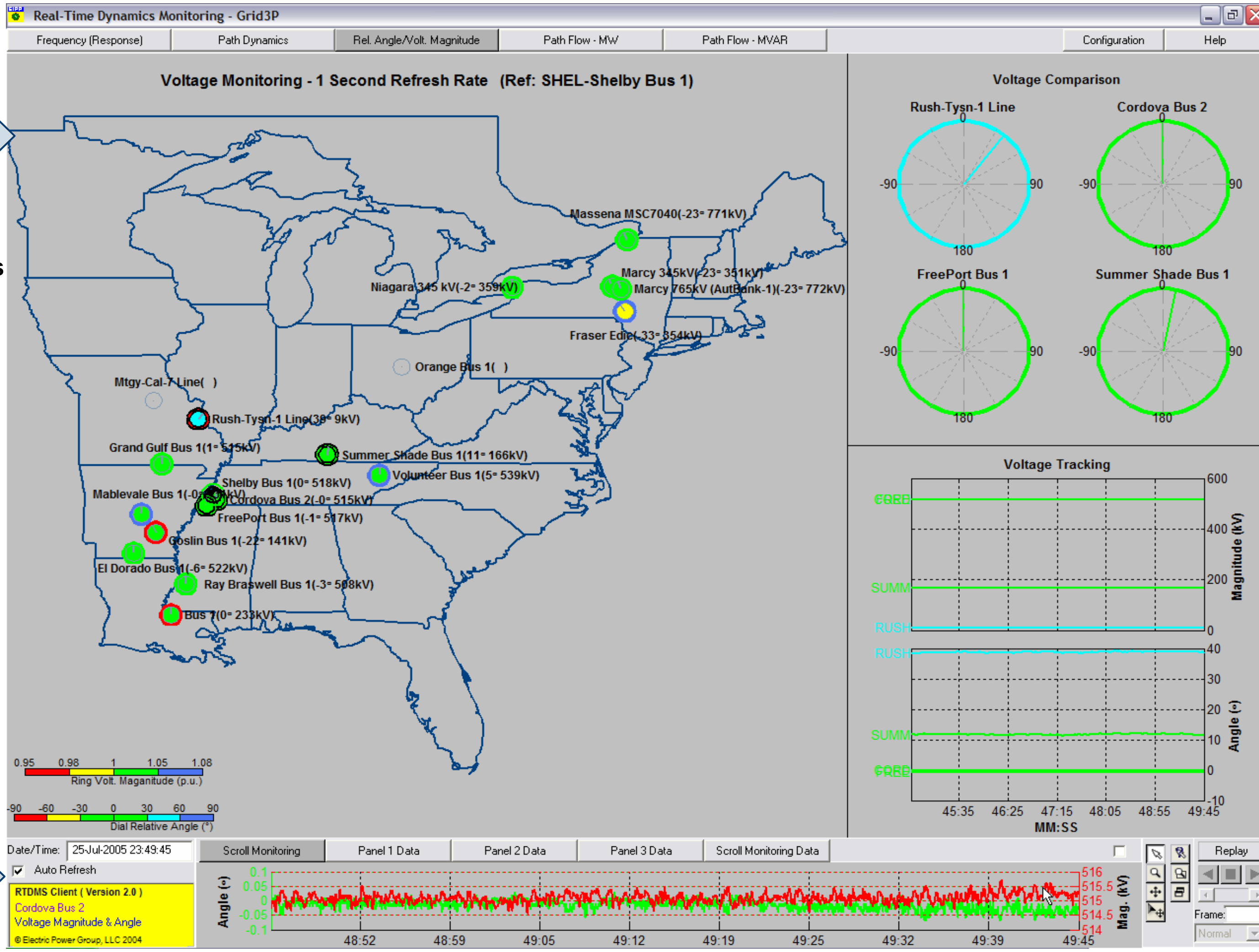
* Companies with PMUs Planned or In Service


PMU Locations Map - Microsoft Internet Explorer provided by TVA IE 6.0 SP2
File Edit View Favorites Tools Help
Back Search Favorites
Address http://pmuweb/pmuinfo/PMULocations.aspx
Go
PMU Locations Map
Current Position: (-84.990234375, 37.78808138412046)
17 out of 20 PMUs are reporting : 85.00% (13 PMUs are not activated.)
Go Back to Home Page
Map Satellite Hybrid
Map data ©2006 Tele Atlas - Terms of Use
POWERED BY Google
EIPP PMU List [View Report]
5/8/2006 5:30:12 PM EDT
AEP Macrodyne PMU / ID 48
Jacksons Ferry [JFRY]
IEEE C37.118 Draft 6 / TCP
AEP Macrodyne PMU / ID 49
Kanawha River [KNRY]
IEEE C37.118 Draft 6 / TCP
AEP Macrodyne PMU / ID 51
Matt Funk [MATT]
IEEE C37.118 Draft 6 / TCP
AEP ABB PMU / ID 29
Orange Substation [ORNG]
IEEE C37.118 Draft 6 / TCP
AEP Macrodyne PMU / ID 50
Rockport [ROCK]
IEEE C37.118 Draft 6 / TCP
AMR ABB PMU / ID 34
Callaway [CALY]
BPA PDC Stream / TCP
AMR ABB PMU / ID 35
Rush Island [RUSH]
BPA PDC Stream / TCP
ATC SEL PMU / ID 52
Arpin [ARPN]
IEEE C37.118 Draft 6 / TCP
CED SEL PMU / ID 53
Farragut [FARR]
IEEE C37.118 Draft 6 / TCP
ENT Arbiter PMU / ID 6
El Dorado [EDRD]
OPC / TCP
ENT Arbiter PMU / ID 8
Fancy Point [FYPT]
OPC / TCP
ENT Arbiter PMU / ID 31
Grand Gulf [GDGF]
OPC / TCP
ENT Arbiter PMU / ID 30
Goslin [GSLN]
OPC / TCP
ENT Arbiter PMU / ID 11
Mablevale [MBLE]
OPC / TCP
ENT Arbiter PMU / ID 17
Paterson [PTSN]
OPC / TCP
ENT Arbiter PMU / ID 18
Ray Braswell [RBSL]
Local intranet

RTDMS VISUALIZATION – SAMPLE DISPLAY

Monitor :

- voltage angles and magnitudes
- color coded
- quickly identify low or high voltage regions



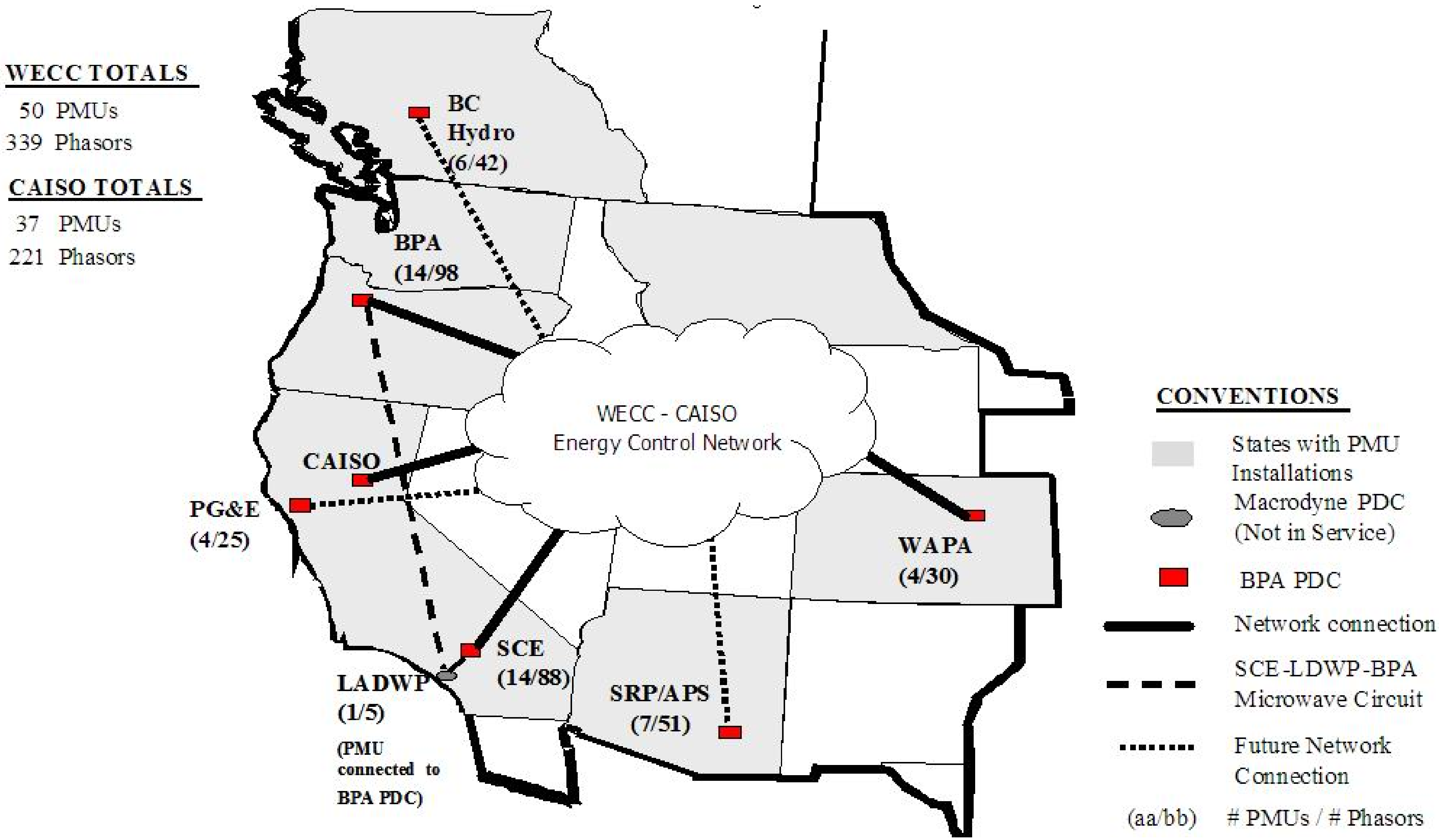
compare angles selected

historical tracking and comparison over specified time duration

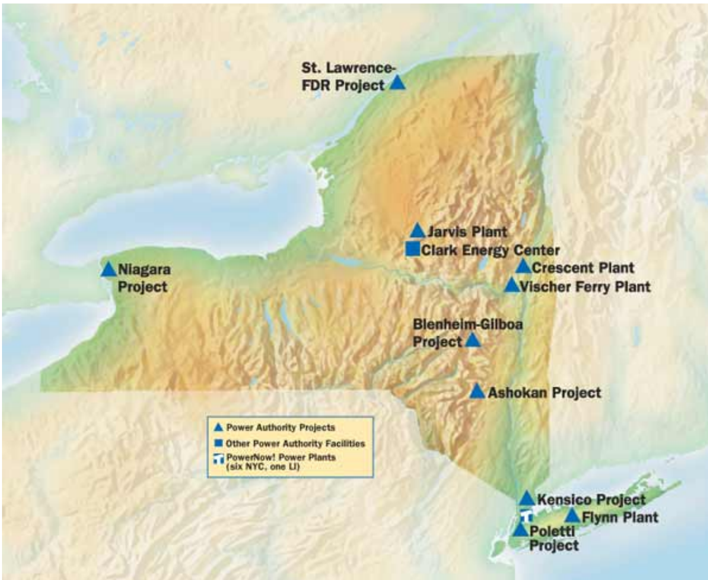
voltage angle and magnitude tracking at selected location

Source: EPG

Conceptual Proposal for Build-out of a WECC Synchronized Phasor Network



Phasor-Assisted State Estimation, NYPA/EPRI



New York Power Authority

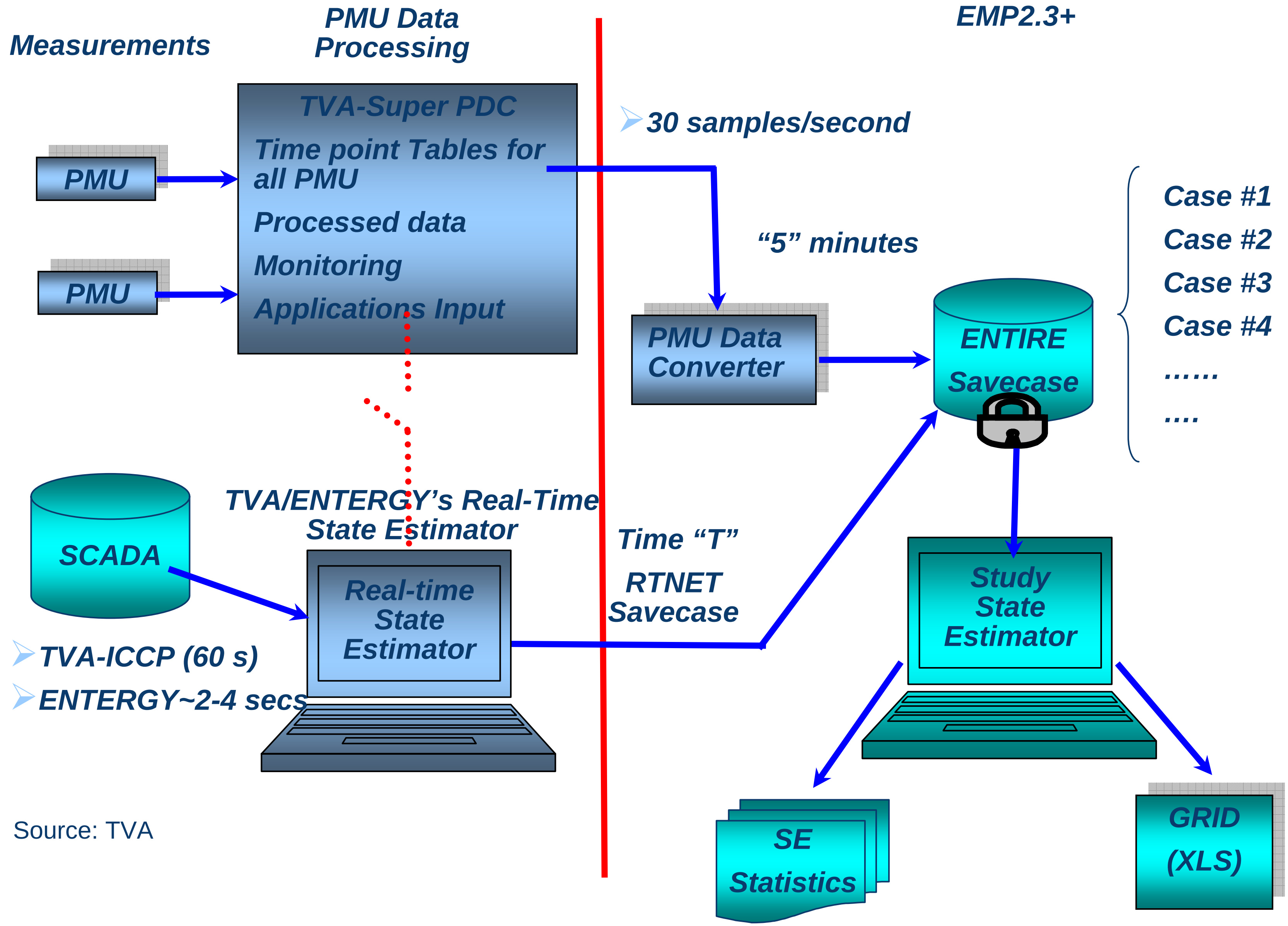
Source: Bruce Fardenesh, NYPA

- Goal: with PMU data, State Estimation can be solved non-iteratively delivering much improved performance.
- Experience:
  - First PMU installed in 1992; now 6+ units in NY State
  - On-line data streamed from PMUs to the EMS computer via dedicated communication channels
  - Modified the traditional State Estimation algorithm
  - Tested to confirm improvements to the traditional SE
  - Adopted phasors as integral part of the EMS

Entergy/TVA PMU-SE Project Objectives

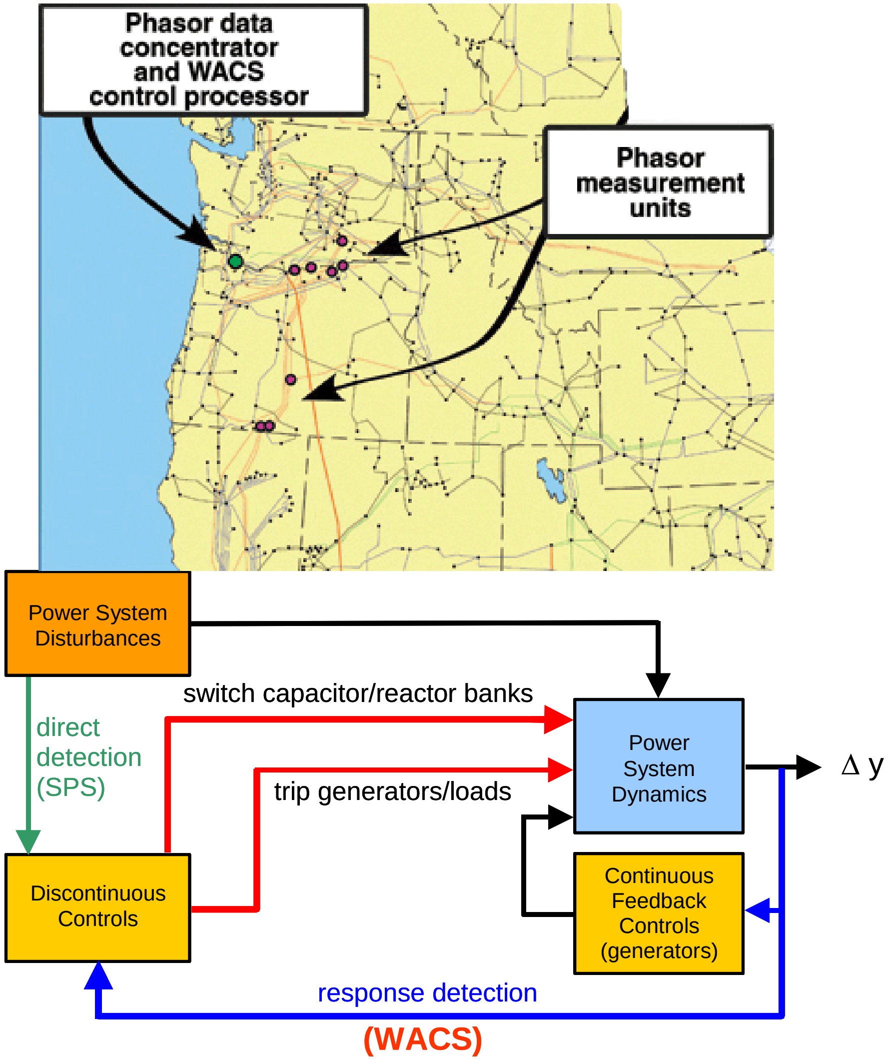
- **Phase 1: Benefits using PMU measurements in the State Estimator**
  Partners: Entergy, TVA, AREVA
  – Off-line case studies with captured real-time data from TVA and ENTERGY control centers
  – Use captured real-time PMU data synchronized with SCADA
  – Demonstrate results
- **Phase 2: Online EMS SE Demonstration**
  Partners: AREVA, TVA, Entergy, PG&E, and Manitoba Hydro with expressed interest from Idaho Power, WECC, First Energy, and BPA
  – Automate transfer of PMU/PDC data to EMS
  – Selection of PMU data relevant to current SCADA data for SE
  – Test online TVA State Estimator using PMU measurements from TVA's Super Phasor Data Concentrator
  – Assess and quantify benefits using online performance metrics
  – Implement & demonstrate at TVA control center, on a parallel (non-operational), online SE which uses PMU data

State Estimation-PMU Data exchange-Phase 1



Source: TVA

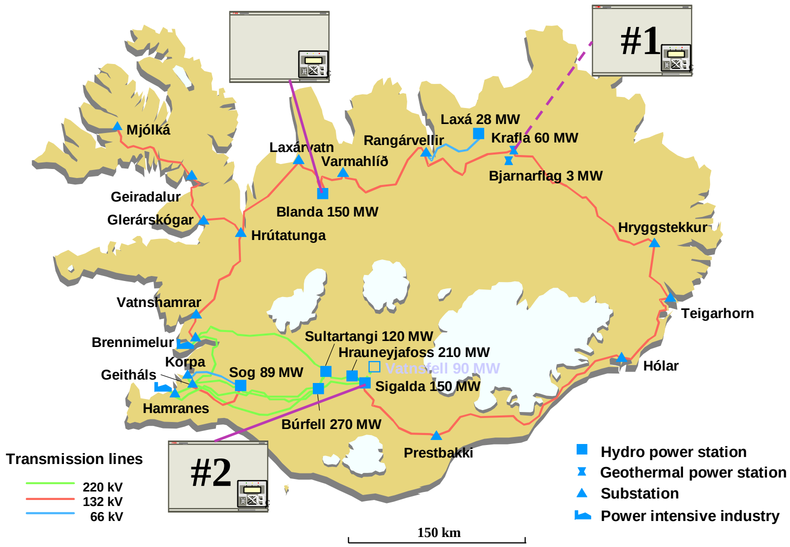
Wide-Area Stability and Voltage Control System (WACS)



- On-line demonstration project
- Inputs from 8 PMUs (2005)
- Fiber optic communications (SONET)
  - Data rate: 30 packets per second
- Existing Remedial Action Scheme (RAS) transfer trip from control center to power plants and substations
- Computer at control center:
  - LabVIEW real-time HW and SW
  - Algorithms based on: voltage magnitudes and generator VARs
  - Actions: Generator tripping and capacitor/reactor switching

"Model studies predict that when WACS is fully accepted, an additional 300 MW could be routed down the Pacific Intertie, resulting in a conservative estimate of $7.2 million per year benefit." **Source: BPA.**

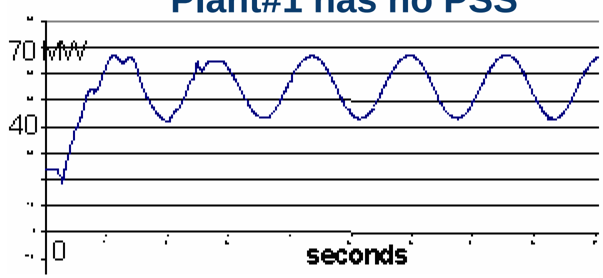
Wide-area PSS

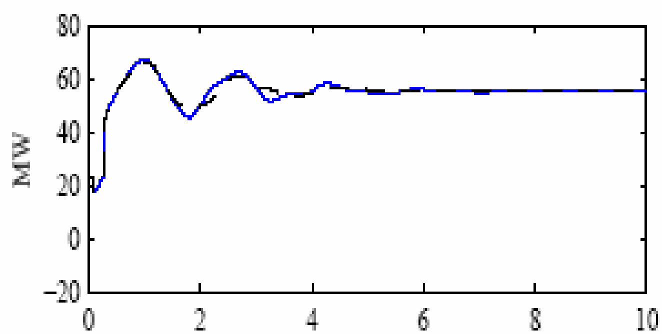


Source: Landvirkjun (Iceland’s National Power)

- Iceland has a strong 220kV grid connected to a weak 132kV ring.
- Power oscillation occurs when ring is opened (due to line fault).
- Two PSS designs have been studied for Plant #1:
  - Conventional PSS -- use (local) shaft speed as input.
  - Wide-area PSS -- use remote signal (PMU#2’s freq.) and local signal (PMU#1’s freq.) to produce Δf as input

Real-life recording; Plant#1 has no PSS





Simulated local and wide-area PSS at Plant#1


File Edit Operate Tools Window Help
SUBESTACION
REFERENCIA MMT
POZA RICA
HUINALA
GOMEZ PALACIO
VALLADOLID
SAMALAYUCA
ESCARCEGA
RIO ESCONDIDO
SALAMANCA
TEXCOCO
TEMASCAL
KV KV HZ GRADOS GPS
402.78 0.00 59.90 0.00
408.56 236.12 59.90 72.03
0.00 0.00 60.00 NaN
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237.60 59.90 55.29
0.00 60.00 NaN
COMISION FEDERAL DE ELECTRICIDAD
SISTEMA DE MEDICION FASORIAL DEL
SISTEMA ELECTRICO INTERCONECTADO
ELECTRICIDAD PARA EL PROGRESO DE MEXICO
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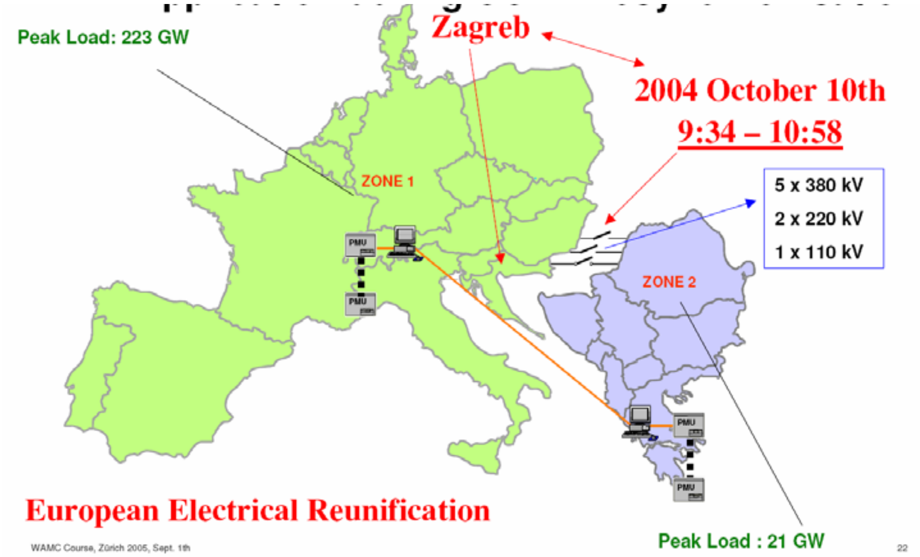
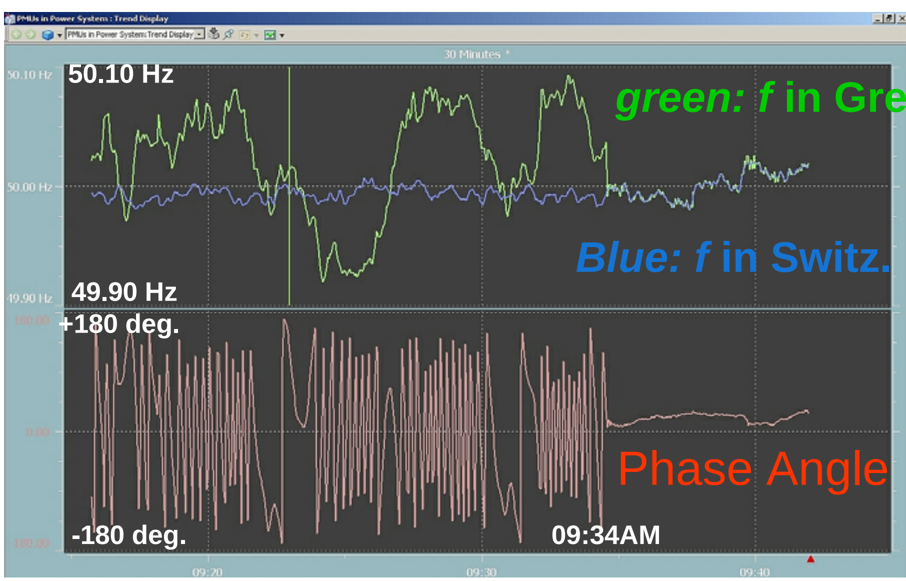
ANGULO DE FASE
GRADOS
VOLTAJES DE 230 KV
FRECUENCIA
HZ
VOLTAJES EN BUSES DE 400 KV

WAMS as a tool during UCTE Reconnection



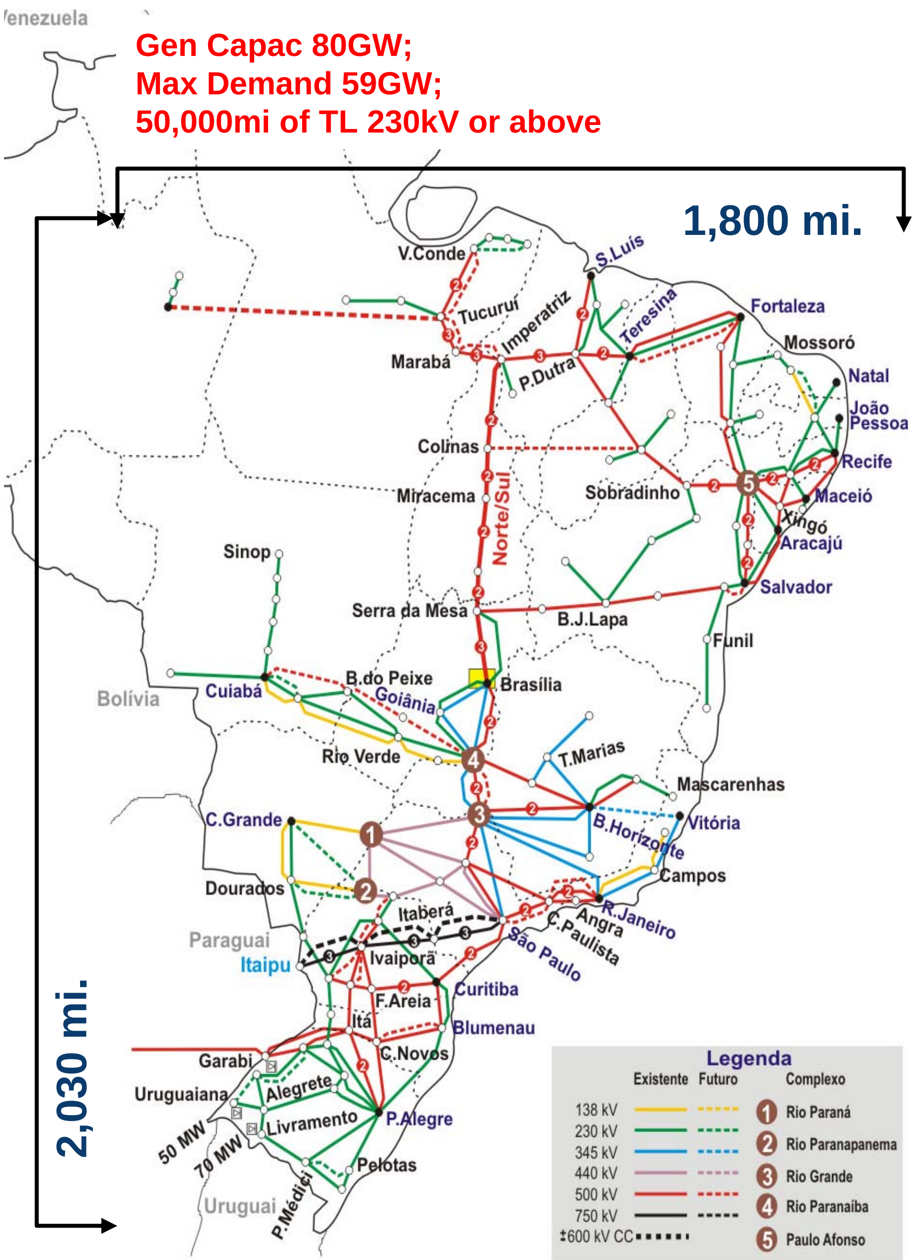


- Wide Area Monitoring system provided more confidence and security during the reconnection of UCTE:
  - Zone 1: Green
  - Zone 2: Blue

- Critical grid oscillations/separations could be detected fast

Sources: ETRANS, UCTE

Synchronized Phasor Measurement System, Brazil



- 1999: ISO study of a PMU-based recording system for:
  - Post-disturbance analysis (inter-area oscillations)
  - Dynamic model evaluation
- 2003: Experiment project by university:
  - 3 PMUs and 1 PDC; All locally made.
  - Monitoring 3-ph distribution voltage at three universities in Southern Brazil.
  - Applications: Frequency monitoring, disturbance detection, phase-angle monitoring.
- 2006: Brazilian ISO, “ONS”, prepares for wide-area deployment:
  - “Specification of the Phasor Measurement System” as a blueprint for how the system will be built.
  - Local utilities will buy and install PMUs and PDC according to the blueprint’s specs.
  - Master PDC at the ISO control center.
  - Anticipated uses include: forensic analysis of grid disturbances; validation of model parameters; evaluation of protection-system performance.

WAMS in China

Sources: CEPRI, China

- 15% annual growth in consumption; Generation and tie lines are being added:
  - Interconnecting of six regional networks have rendered challenges to operations
  - Low-freq. oscillations; Volt/VAR problems
- Power shortage costs economy 2 BUSD/year
- Systems and Apps under development
- 10 WAMS; PMUs--80 installed, 60 planned

- Basic function:
  - BF1: integrated Phasor data platform
  - BF2: Wide Area Dynamic monitoring and analysis
  - BF3: on-line synchronizing recording and redisplay
- Advanced function:
  - AF1: Generator State P/Q
  - AF2: on-line Low Freq. Osc. Anal.
  - AF3: hybrid state estimation
  - AF4: emergency cont. decision
  - AF5: Angle Stab. Predict. & alert
  - AF6: on-line disturb. Identi.
  - AF7: Voltage dyn. monitoring
  - AF8: model/parameter identi.
  - AF9: simulation validation
  - AF10: AVC (Aux. Vol. Con.)

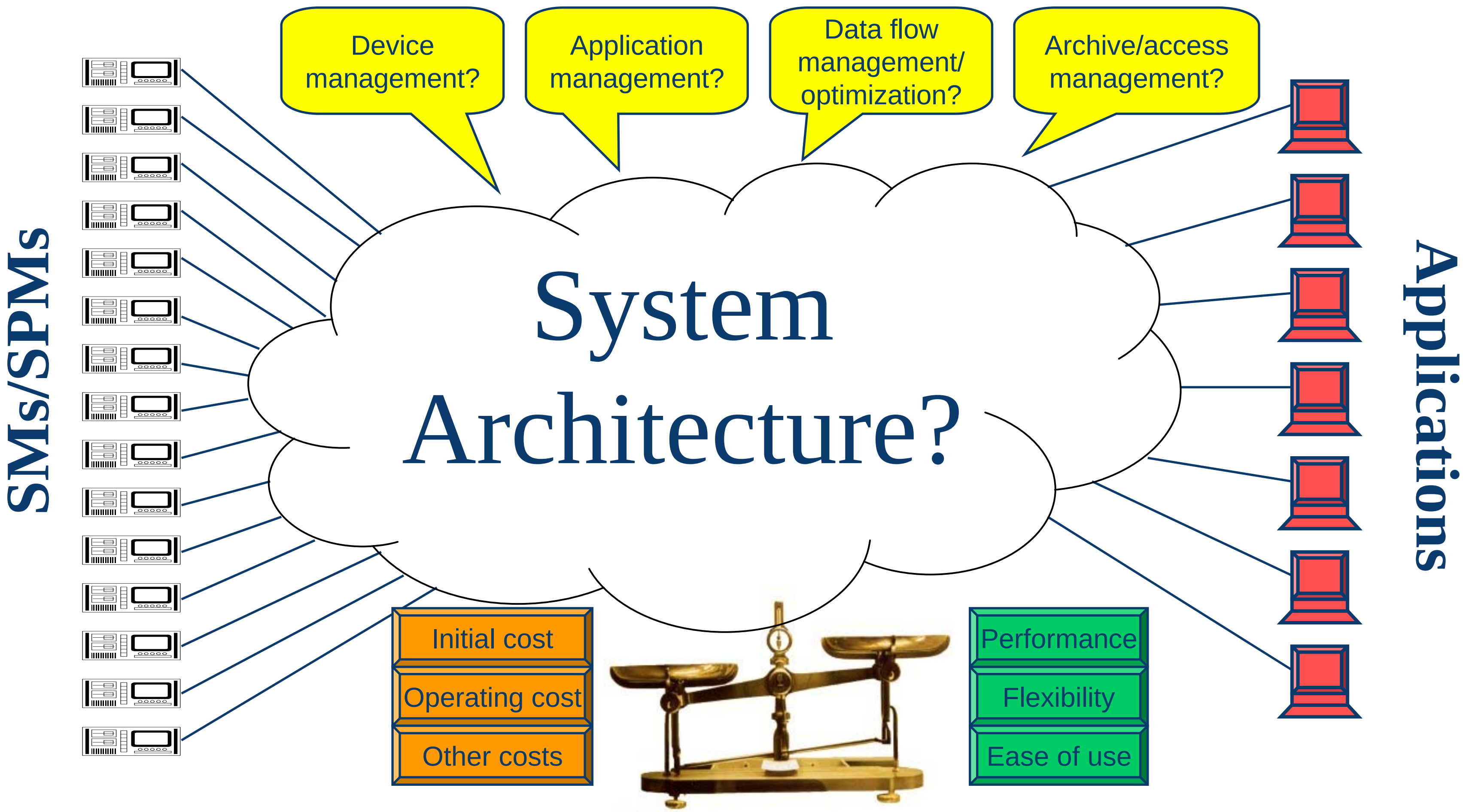
Arquitectura del Sistema

Architecture Today

- Most installations consist of one-PDC architecture with a limited number of PMUs
- Sistemas mas Sofisticados
  - Multiple PDCs with a master data concentrator
    - The master data concentrator
      - Aggregate real-time PMU data and rebroadcast to other PDCs
      - Provide online/archived data for non-real-time applications
      - Custom developed
  - Evolved from interconnecting single-PDC based systems of the participating utilities

Arquitectura del Sistema

- How to connect SMs/SPMs with Applications?



Need for New Architecture

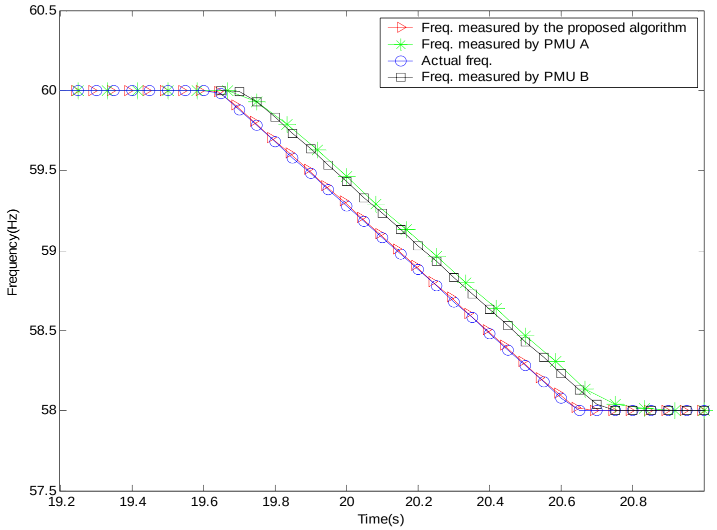
- Standardized system architecture design
  - Meet the diverse requirements of different applications
  - Enable data sharing → minimize overall cost
  - Use off-the-shelf products (e.g. process automation)
  - Be supported by available communication infrastructure
    - Bandwidth, protocol, latency
  - Can be easily integrated and configured
    - Highly scalable and flexible
    - Reliable and secure
    - Easy to install, operate, and maintain
    - Easy to interface with other systems

Desafios

- Disparity among algorithms used by PMU vendors (e.g. phase angle calculations)

- Challenges for data analysis
  - Disparate sampling rates
  - Disparate filtering techniques
  - Data compression practices

- Unaccountability of instrumentation errors



- C37.118 is for Steady State Operation

- Visualization of vast amount of data

- Secure and non-corrupted data through data links

- Scalability: Design architecture to accommodate application additions

- High accuracy and data bandwidth requirements

Conclusions and Next Steps

- Advances in sensing, communication, computing, visualization, and algorithmic techniques for Wide Area Monitoring, Protection, and Control Systems provide cost effective solutions to reduce costs, improve system performance, and minimize risks
- Need for WAMPAC application and deployment roadmap based on "business case" analysis to support utilities, regulators, and vendors
- Leverage benefits through integration of applications
- Early adopters lead the industry – Need for wider deployment
- Needs for education, training, and process and culture change
  - Ownership within a utility and how to share benefits among groups
- System-wide implementation and common architecture
- Uniform requirements and protocols for data collection, communications, and security achieved through guidelines/standards
- Sharing experience and best practices (e.g. EIPP)