The Use of PMU Technology for System Wide Area Monitoring and Control

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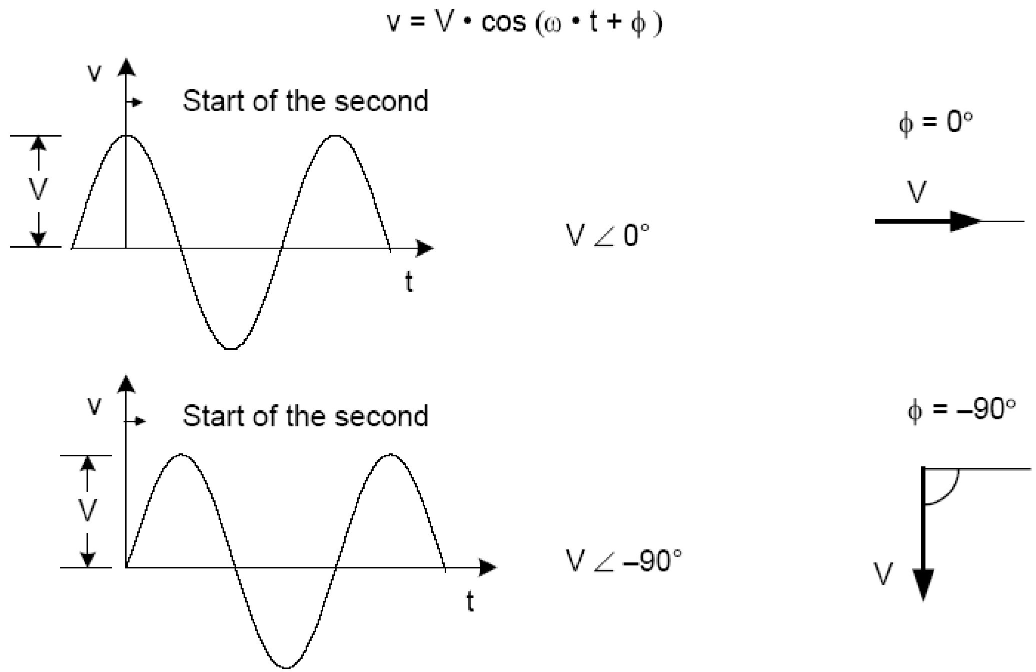
Synchrophasor Simplified

- A synchrophasor is a phasor value obtained from voltage or current waveforms and precisely referenced to a common time base.
- Simultaneous measurement sets derived from synchronized phasors provide a vastly improved method for tracking power system dynamic phenomena for improved power system monitoring, protection, operation, and control



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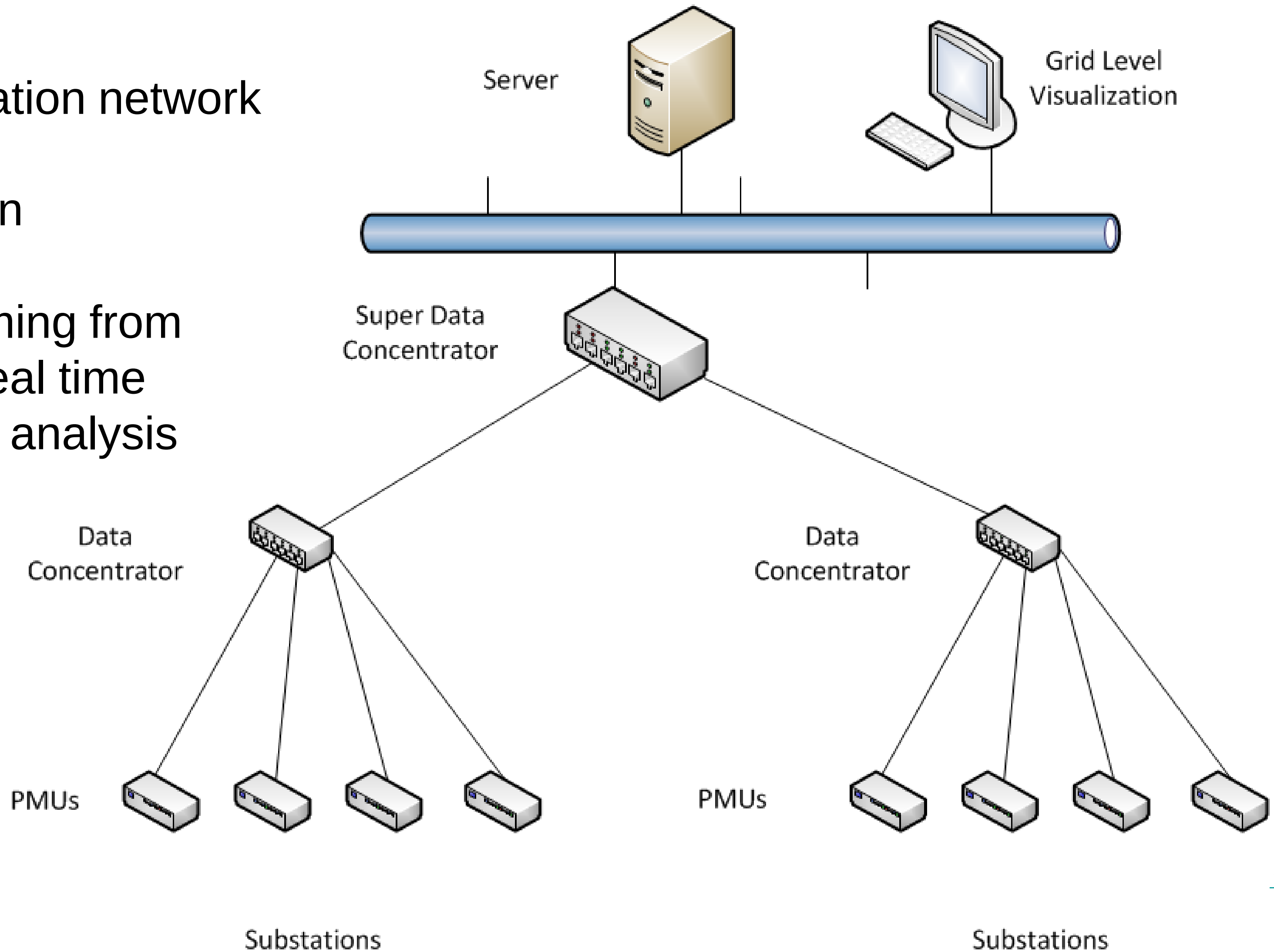
Example of Wide Area Measurement System

PMUs
Communication network
PDC
Visualisation

Data streaming from PMUs for real time display and analysis



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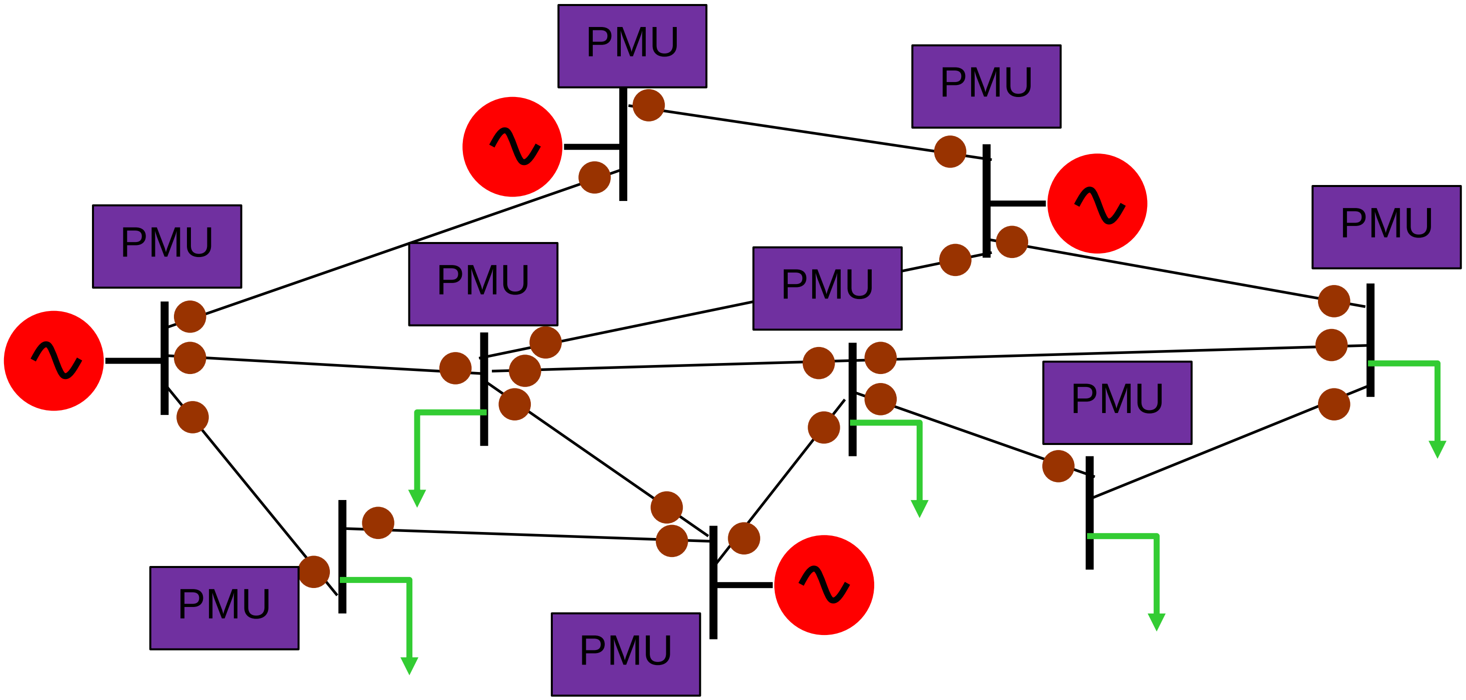
Wide Area Measurement System



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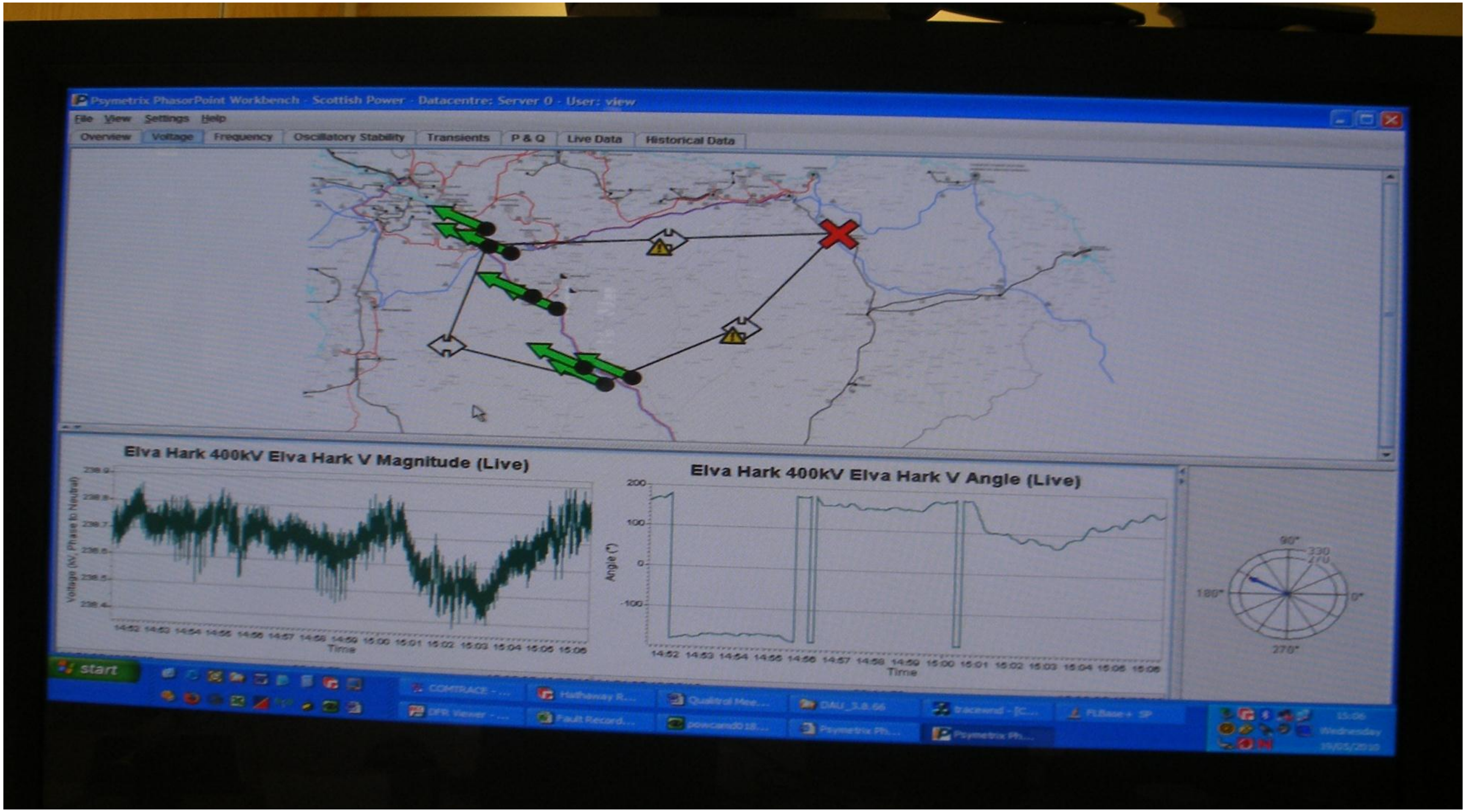
Example of Visualisation Software



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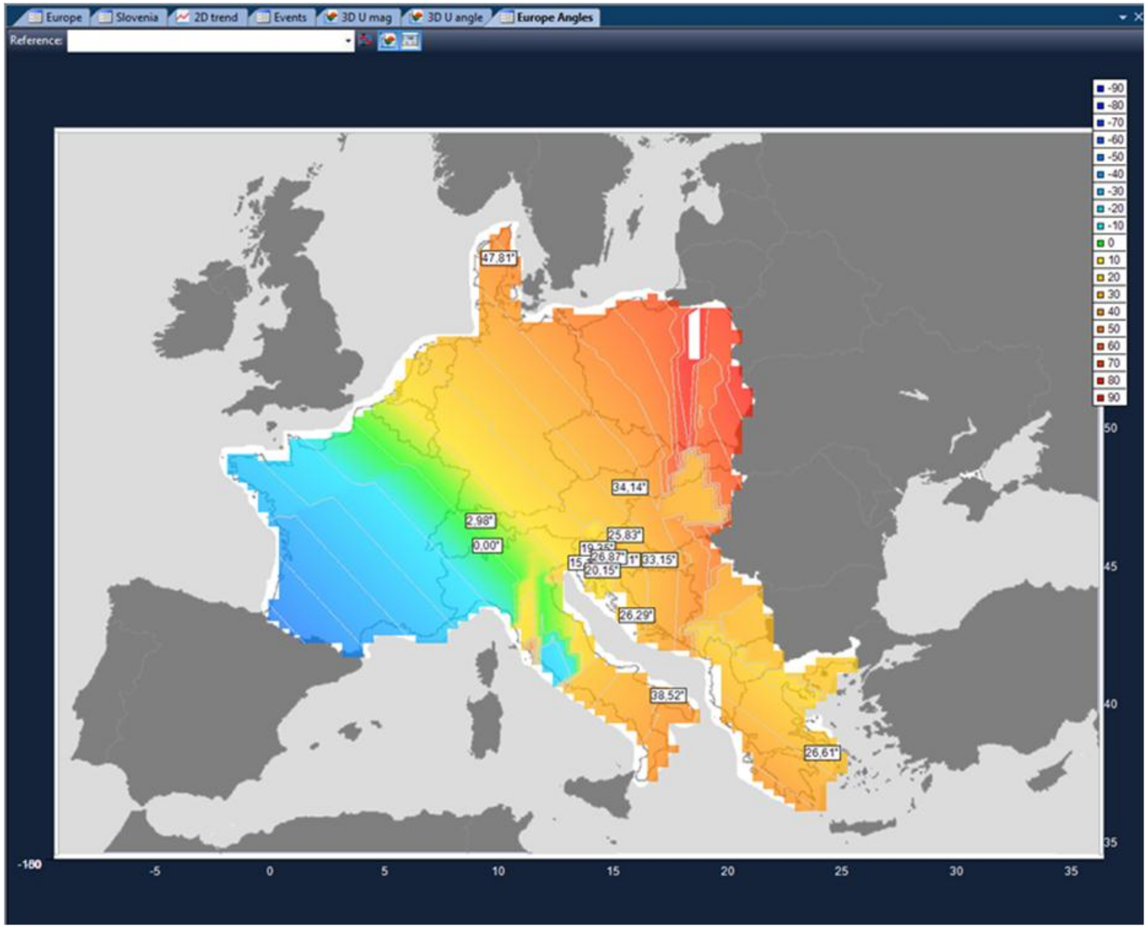
Background map – green arrows show vectors –red arrow a bad measurement node

Example of Visualisation Software



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Background map – phase angle variations colour coded – one sector selected as reference

Types of PMU (Phasor Measurement Units)

- Multi-function Fault Recorders, for example BEN, IDM (?), IDM+
- Stand alone PMUs, for example QPMU
- Relays

Cost effective to use the installed base of fault recorders as PMU devices. They normally are already monitoring the required voltage and current groups

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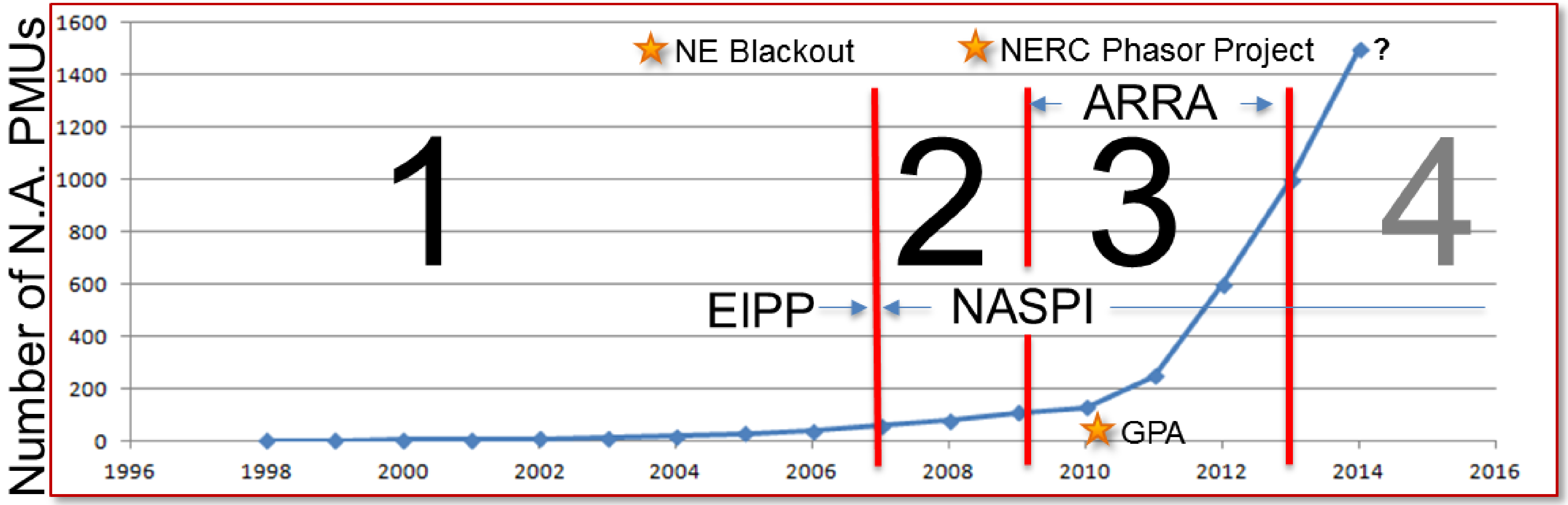
Implementation of PMUs in the US



PMU Numbers Representative

1 R&D phase funded by government grants and led by the Utilities BPA and TVA and Universities. Eastern Interconnector Phasor project (EIPP) to trial new ideas.

2 Consensus building phase – NERC sponsoring NASPI to develop phasor technology

3 Stimulus phase - installation of 950 PMUs by the end of fiscal year 2013, through 12 different projects, with 341 being located in the Western Interconnection. Grid operators not receiving SGIG funding also began making significant investments in synchrophasors to address emerging power system operations issues resulting from a rapid increase in dispersed generation penetration.

4 Production phase – NERC to increase its regulatory scope - end of 2013 NASPI will be transitioned to the Consortium for Electric Reliability Technology Solutions (CERTS) organization, sponsored by DOE.

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Benefits of Phasors

- Real time display of system operating conditions – phase angle and voltage magnitude differences – is the system getting ‘stressed’
- Real time data for state estimators
- Real time stability monitoring – low frequency oscillations from inter area power flows or poorly tuned power system stabilisers on generators
- Detection of islanding and data for faster re-synchronisation
- Real time measurement of power calculated from voltage and current phasors
- Potential for control applications
- Validation of system models – off line
- Validating line impedance
- Post mortem analysis – off line

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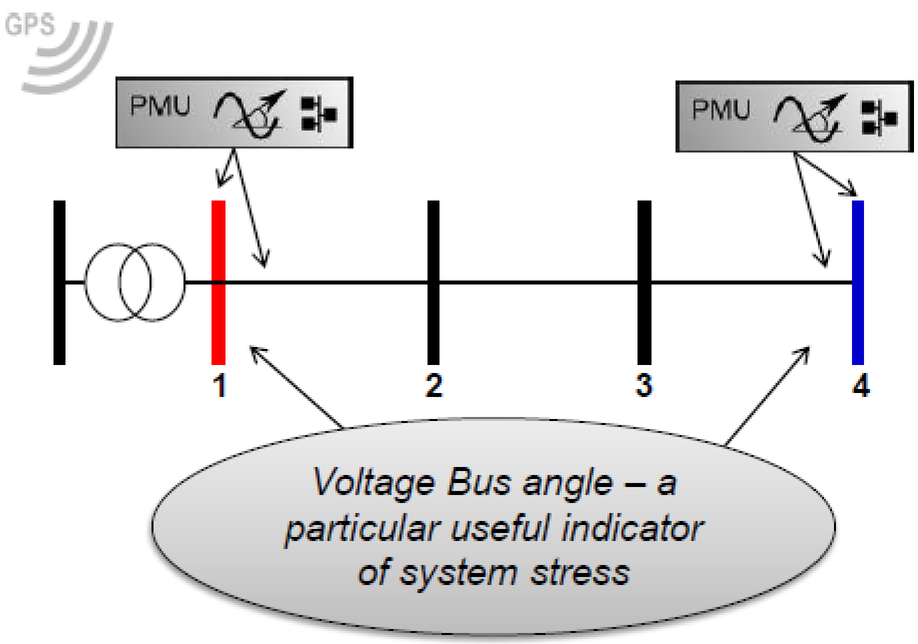
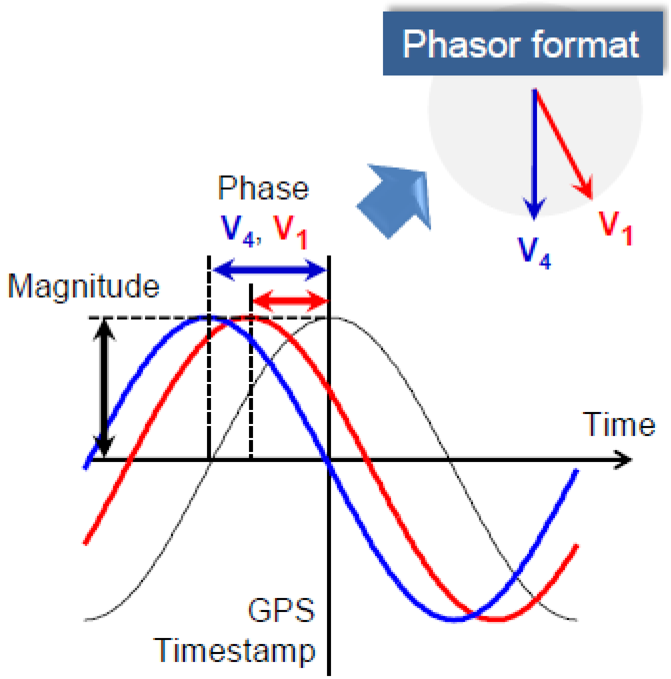
Real time monitoring of phase angle difference can warn when conditions are approaching for voltage collapse or system overload





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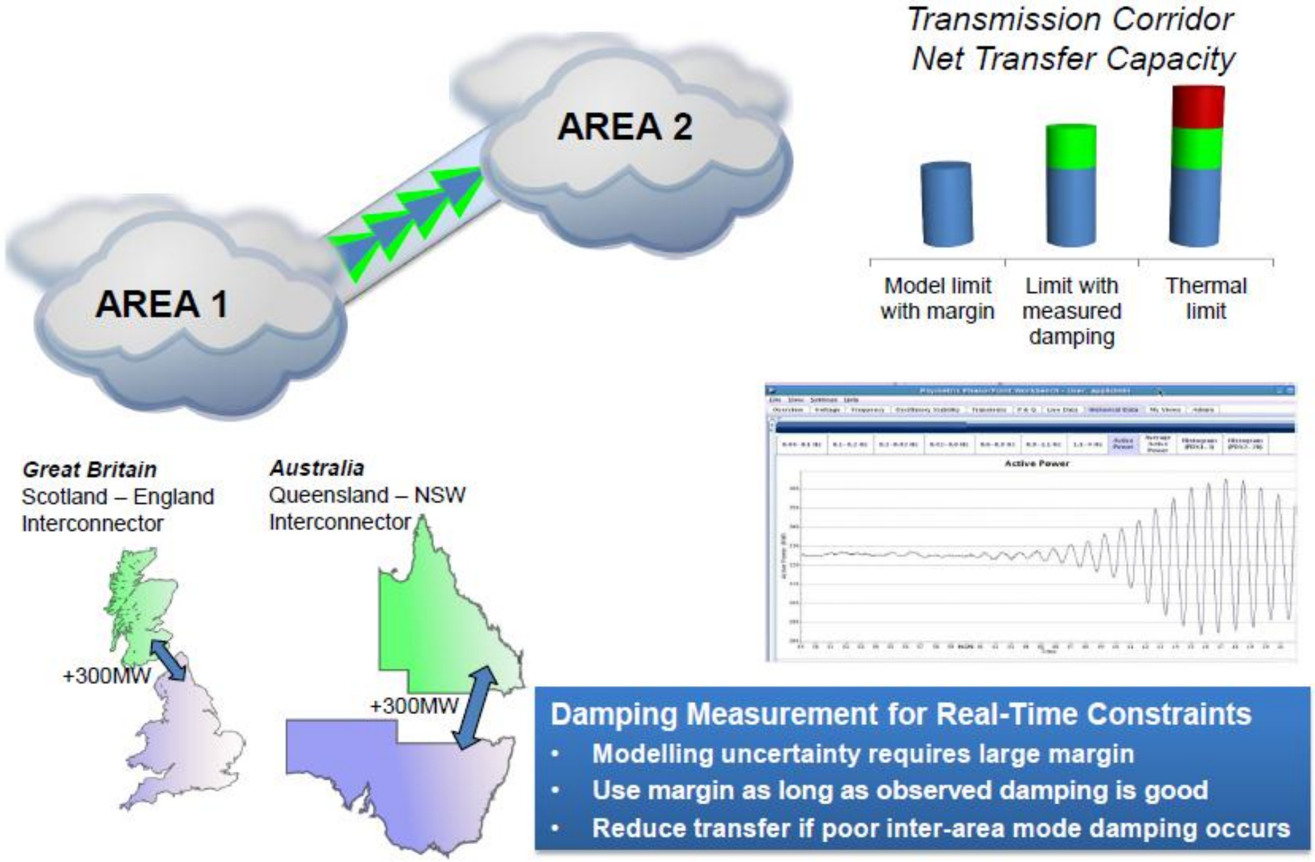
More power can be transferred with confidence with real time monitoring for the onset of power swinging enabled



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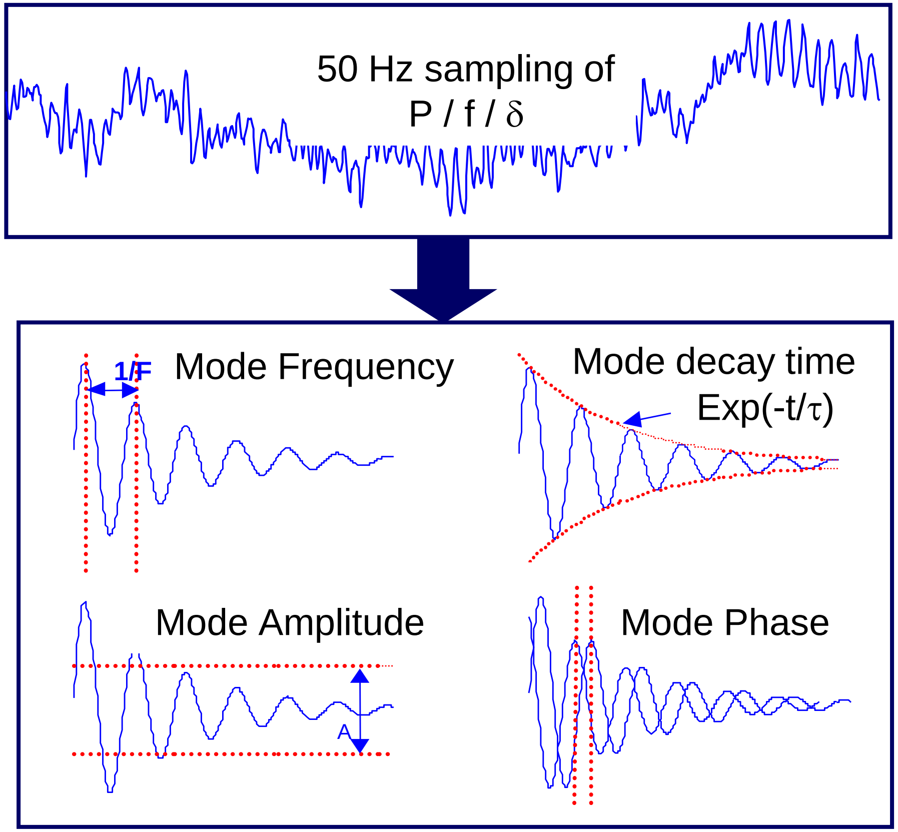
Parameters Defining Oscillations



allows extraction of low frequency dominant modes of oscillation (up to seven different modes between 0.03Hz – 5Hz)

- Four attributes of mode are – Damping (% or seconds), Amplitude , Frequency (Hz), Phase (degrees)

Damping and Amplitude are mode stability indicators. Mode must be damped

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The GCC Interconnection Project

- ❑50Hz 400 KV Interconnection
- ❑Saudi Arabia 60Hz, connected by back-to-back HVDC converter.
- ❑Long lines subject to oscillations.

Connects six countries with 400 and 220KV links

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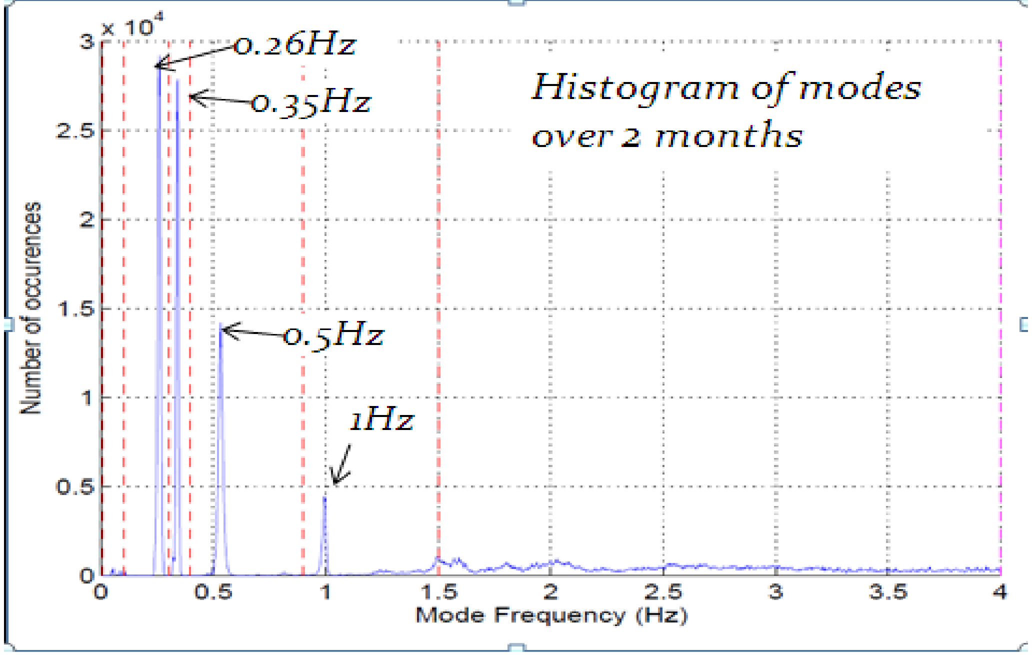
WAMS – System Oscillations

Mode	Average / Peak Decay Time	Average / Peak Amplitude	Comment
0.25 Hz	6 sec / 24 sec	2 MW / 30 MW	Interarea mode Moderate risk
0.35 Hz	8 sec / 35 sec	2 MW / 35 MW	Interarea mode Moderate risk
0.5,1Hz etc.	Well damped	Small	Low risk



- Summary of oscillations detected over a 2 month period and their possible effect on stability
- Inter-area mode at 0.26Hz is observed. The oscillations are in phase.

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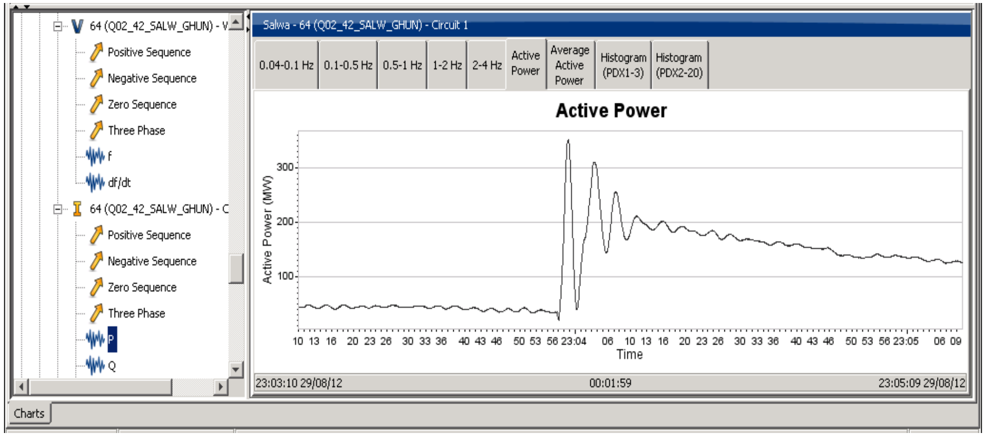
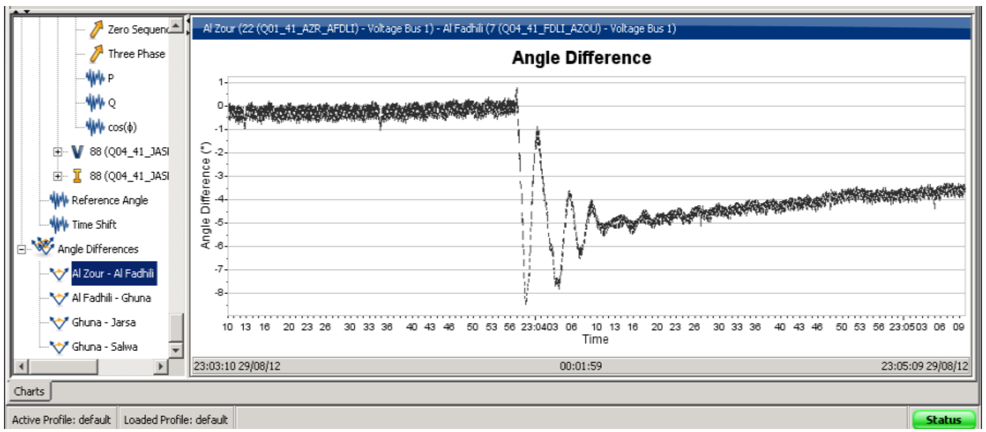
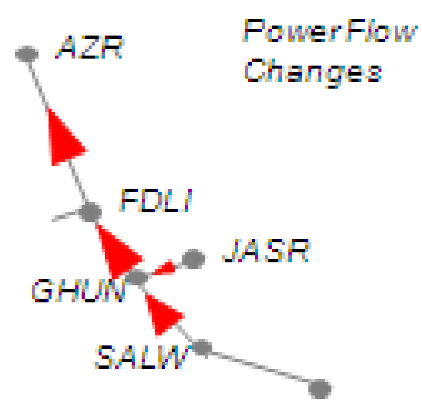
Loss of Generation in the North





- ❑Increase in active power at Salwa flowing North
- ❑Change in phase angle between Al Zour and AL Fadhili
- ❑Damped transient response with a dominant mode of 0.26Hz



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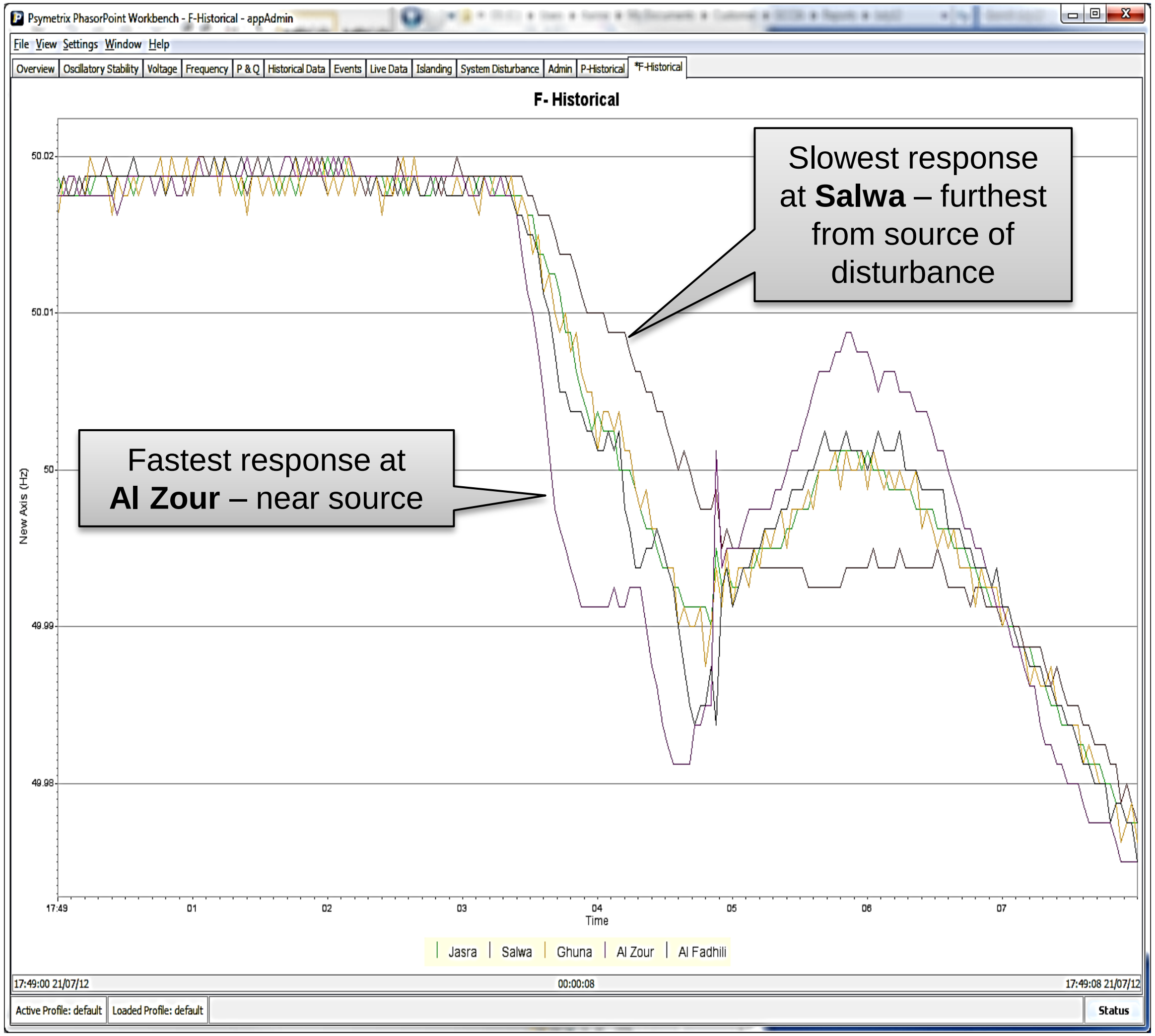
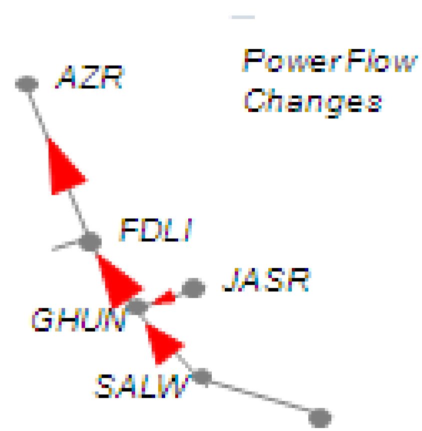
Loss of Generation in the North - freq



Frequency (and angle) records show earliest movement close to generation loss.

Frequency falls to 49.97Hz in just over 4 seconds



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International Standards - Update

- IEEE Standard 1344-1995
- C37.118-2005 IEEE Standard for Synchrophasors for Power Systems
- C37.118-1-2011 IEEE Standard for Synchrophasor Measurements for Power Systems
- C37.118-2-2011 IEEE Standard for Synchrophasor Data Transfer for Power Systems
- Later in 2012, IEC61850-90-5 Use of IEC61850 to Transmit Synchrophasor Information
- WIP - IEC61850-90-3 Object Models for Condition Monitoring

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IEEE C37.118 (2005) – PMU definition

The C37.118 (2005) is the standard universally used to define PMU performance. It covers:

- Time tagging of phasors referenced to GPS
- Accuracy limits
- Response to varying frequency and up to 10% injected harmonics
- The format of the ‘frames’ constituting the data stream to the PDC
- The speed of transmission – frame rate

Note that there is a new standard C37.118 (2011) that has just been released. All Vendors had difficulties meeting this spec. Revisions are being published.

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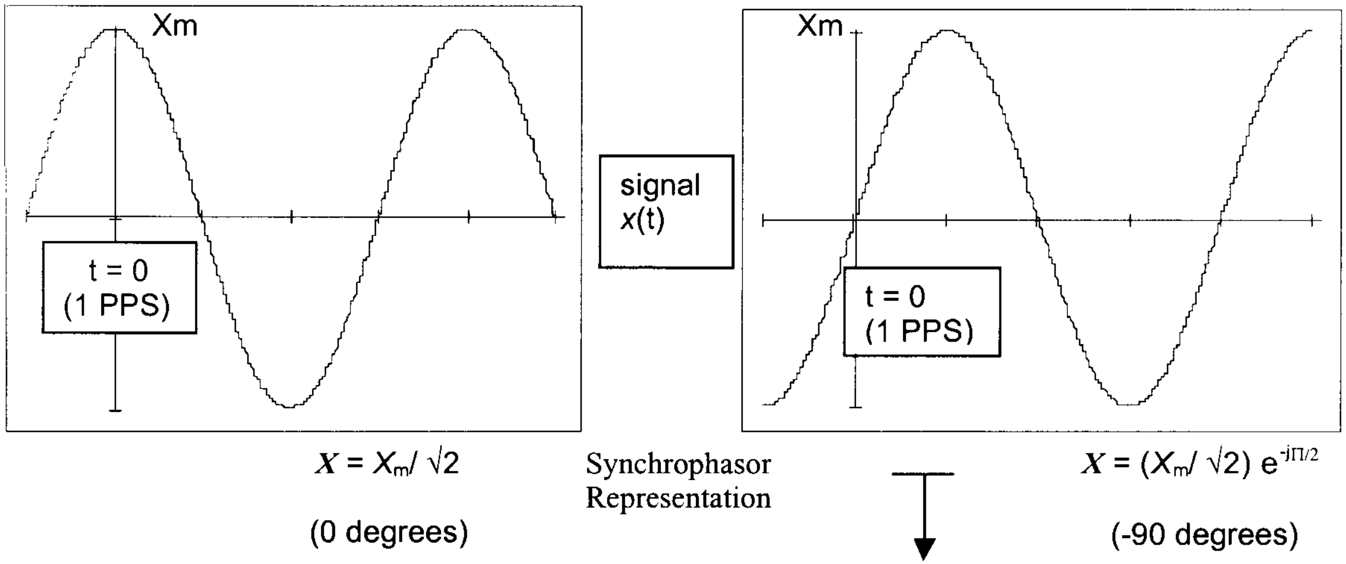
IEEE C37.118 (2005) – Time tagging

Magnitude (rms) and phase angle are logged on the 1pps edge marking a second boundary. Phase angle is zero if the positive peak aligns with this mark. Phase angle is -90 if a positive zero crossing aligns with this mark



Frame rates are integer values of system frequency. Phase angle remains constant for steady state signal at system frequency

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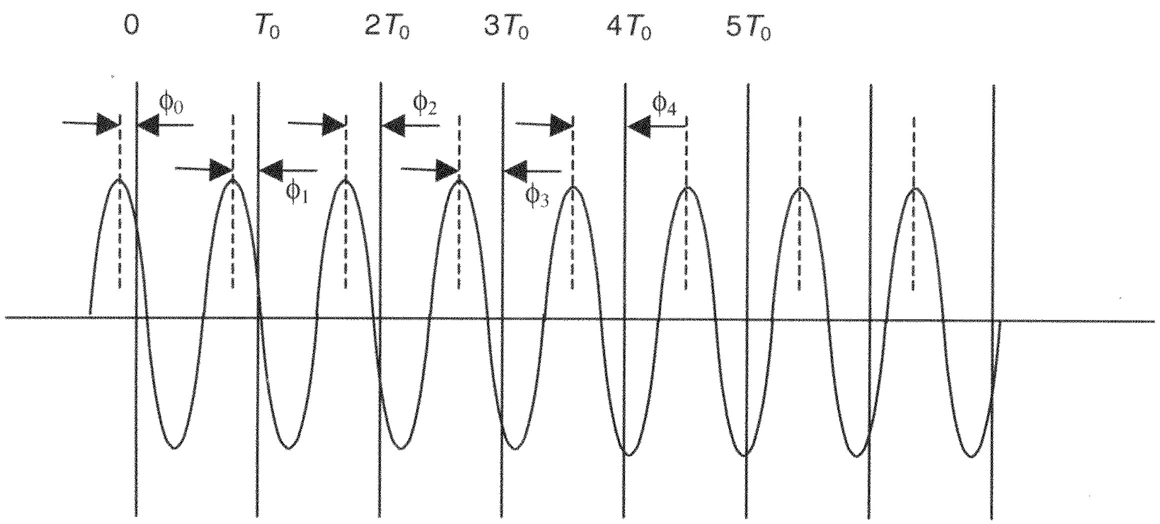
IEEE C37.118 (2005) – Time tagging

Reported phase angle will vary on successive measurements if frequency drifts from 50 or 60Hz



Note that the phase difference between two nodes will remain fixed for steady state values and identical frequency at each node

Phase angle accuracy linked to time accuracy – 1µs = 0.022 degrees at 60Hz and 0.018 degrees at 50Hz

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IEEE C37.118 (2005) – Accuracy & Frame Rate

Level 1

Performance

Phasor accuracy is expressed as % TVE (total vector error) and is therefore dependent on magnitude and phase

TVE must be ≤1% of measured value for inputs (voltage or current) from 10% to 120% of nominal over a frequency range of nominal +/- 5Hz

To avoid aliasing TVE must remain ≤1% when up to 10% of an 'out of band' frequency (fi) is present where **|fi – f0 | >Fs /2**. (f0 is nominal frequency and Fs is the frame rate)

Frame rates are shown in the table below. Note that the 50 and 60Hz rate are NOT mandatory in the spec.

Frequency (Hz)	50			60					
Report rates (Hz)	10	25	**50**	10	12	15	20	30	**60**

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IEEE C37.118 (2005) – Phasor data

- Phasors can be Sequence voltages and currents (+ve, -ve and zero) or Phase voltages and currents. Single phase phasors are best as the WAMS software has more options to calculate power and analyse unbalance. However it requires the greatest bandwidth on the communication channel. Some Utilities just rely on a single +ve seq phasor for voltage and current.
- Local frequency measured by PMU
- Local rate of change of frequency measured by PMU - the C37 spec gives no accuracy criteria for this measurement.
- Circuit breaker and switch status – digital inputs
- Analogue values calculated by the PMU, for example power or a transducer input
- Time stamp
- Time quality flags and other status information

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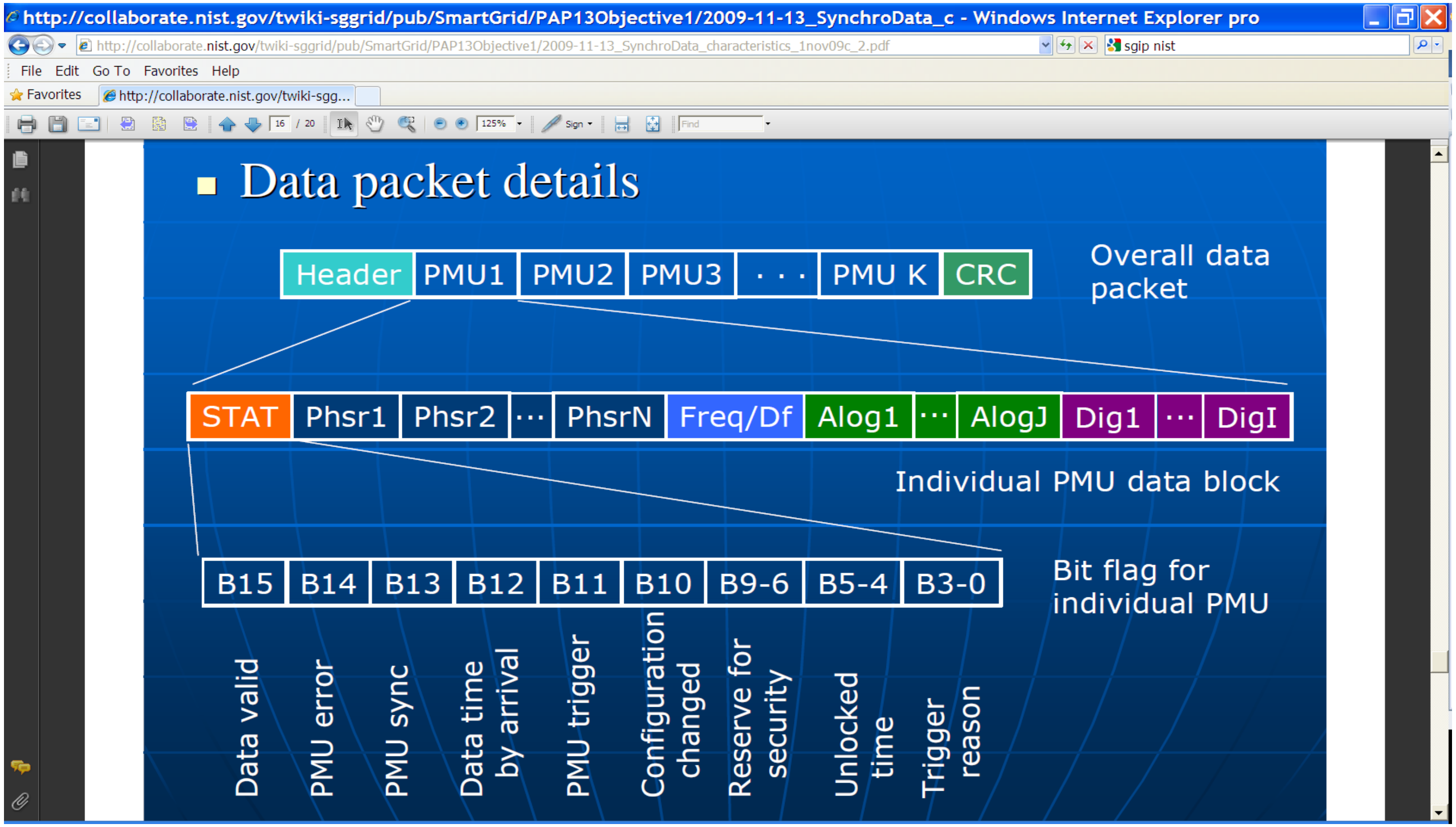
C37.118 frame format



Frames have a variable size depending on the number of phasors, analogue values and digital status

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IEEE C37.118 (2011) – Main Differences

- Frame rates must include 50/60 Hz
- 100/120Hz and the lower rate of 1Hz are encouraged.
- 1% TVE accuracy to be maintained on current inputs 10 to 200% of nominal
- 1.3% TVE allowed for out of band injection test
- Sets measurement algorithm and steady state accuracy criteria for the frequency (+/-5 mHz) and rate of change of frequency (10 mHz/s) measurement.
- Frequency accuracy relaxed for harmonic distortion and out of band interference testing. (25 mHz and 6Hz/s in some instances)

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IEEE C37.118 (2011) – Main Differences

- Two classes of performance – P (protection) and M (measurement)
- P is for fast response with no mandate for filtering. M is a slower response and will require filtering.
- Dynamic response time of the PMU to a 10% step change in the input. For phasors this is 2 cycles for P and 5 cycles for M
- Separates the communication aspect of phasors into a separate spec.
- Introduces an operating temperature range over which accuracy has to be retained of 0 to +50 ºC with measurements at 0, nominal (23 ºC) and 50 ºC.

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Summary

- Modern power systems are becoming harder to control due to increased loading, embedded generation and automated special protection schemes
- Real time state estimators can deliver better outcomes when using actual system data.
- Utility communication networks have evolved into high availability ethernet systems with low latency
- WAMS techniques (hardware and analysis software) have matured to allow the installation of practical systems.
- Result is the growing use of WAMS to assist in the real time control of power networks

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