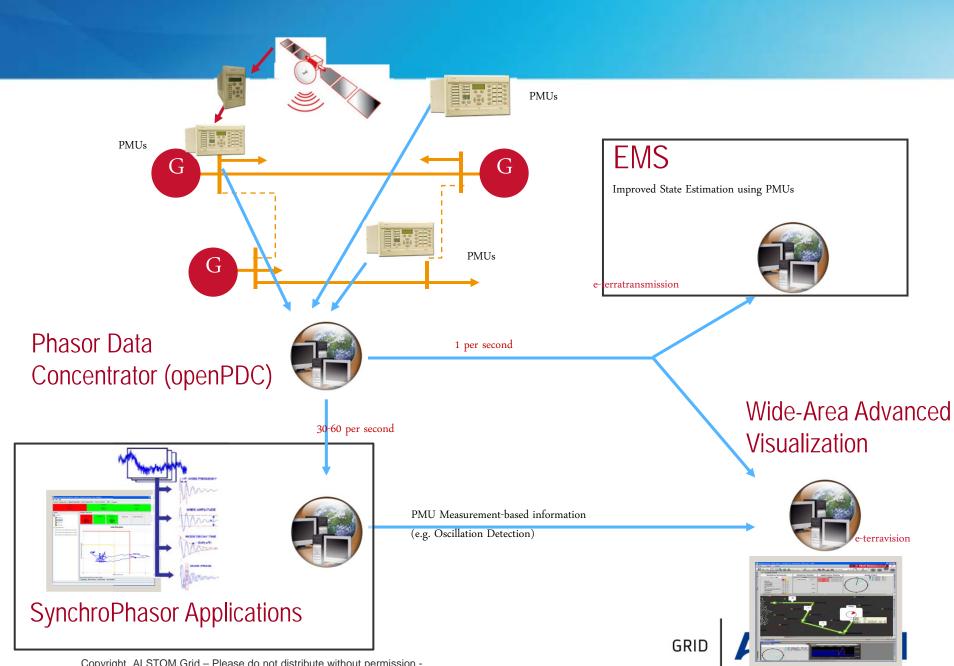
openPDC in the Control Center

August 22th, 2012

Barbara Motteler

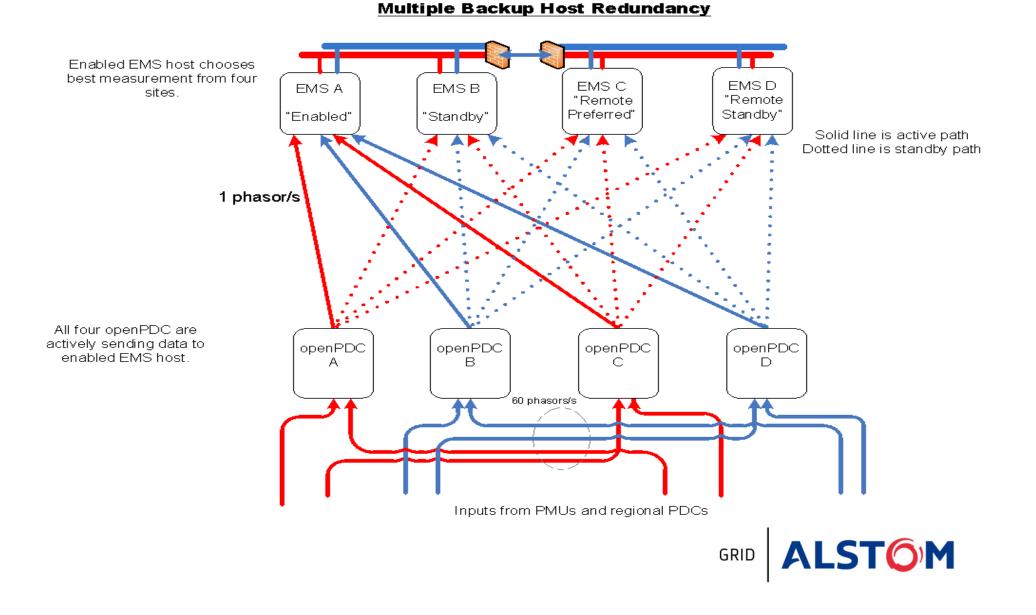


ALSTOM's Integrated SynchroPhasor Solution

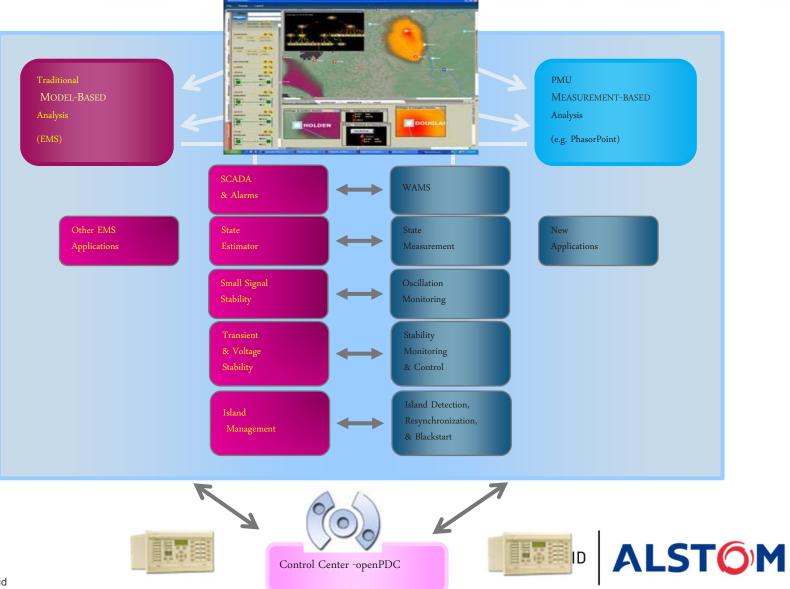


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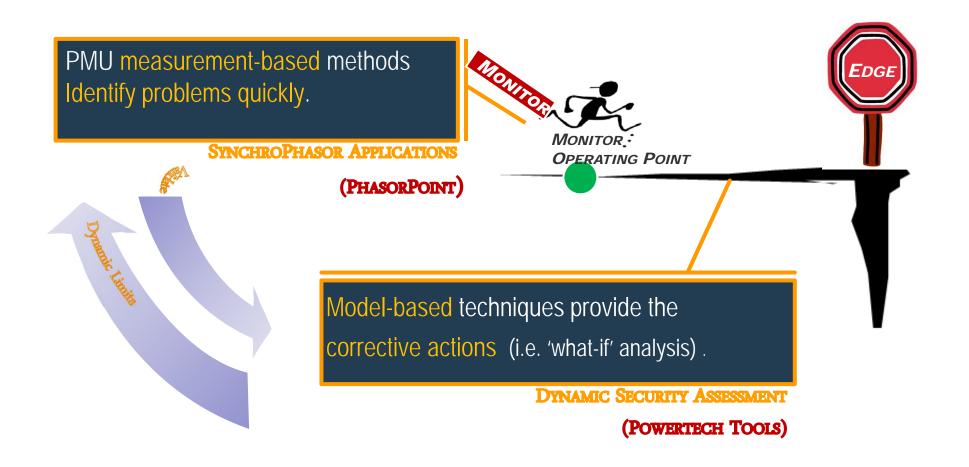
OpenPDC with Multi-Host Redundancy (ISD Link)



Our Vision for SynchroPhasors....

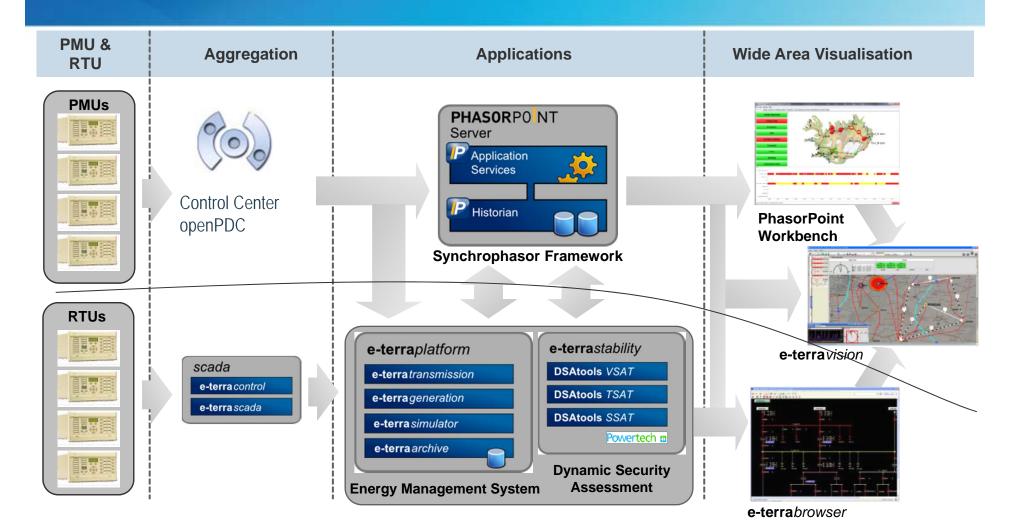


An Integrated *"measurement-based"* and *"model-based"* approach.....





Our Solution



GRID ALSTOM

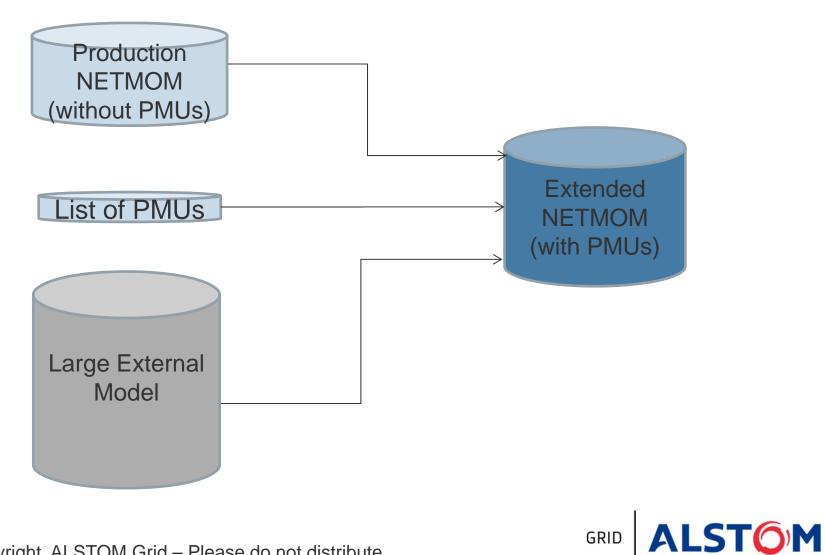
Integrating PMU based Applications

Philosophy: Complement Model based applications with Measurement based Applications

- Linear State Estimator (LSE)
- Substation Super Calibrator (GeorgiaTech)
- Fault Indicator
- Future:
 - Voltage Stability Predictor
 - Based on Singular Value
 Decomposition

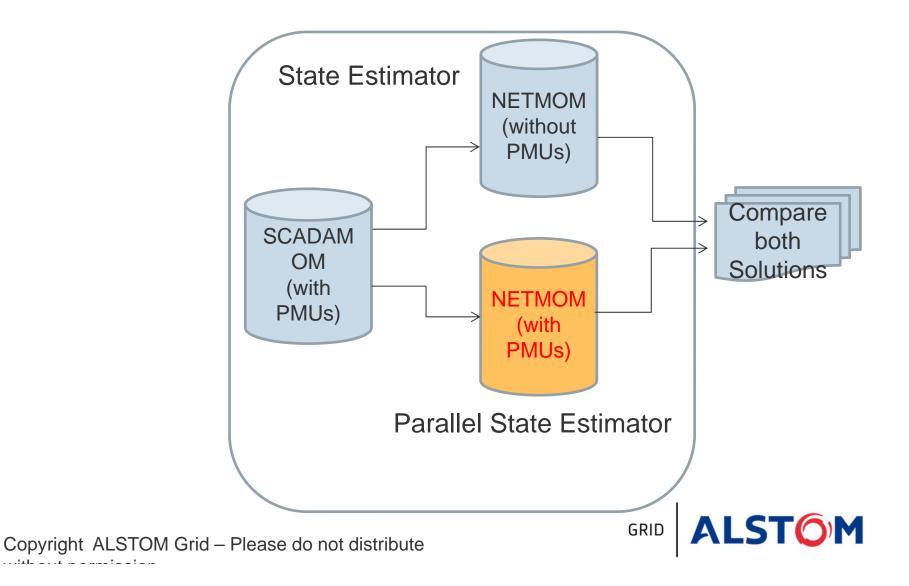
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Extended Network Model



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Framework – Parallel State Estimator



Enhanced EMS State Estimator with PMUs Uses PMU data at the 1 sample/sec rate

Utilization of PMU data (voltage & Current Phasors) in SE to improve round-the-clock reliability & robustness.

- Increase the number of 'Valid Solutions' \Rightarrow improved reliability
- Reduce dependency on 'Critical Measurements' \Rightarrow better observability
- Improved SE solution quality to minimize 'Variance of State'

 \Rightarrow higher accuracy

- Fewer SE iterations

 \Rightarrow faster performance

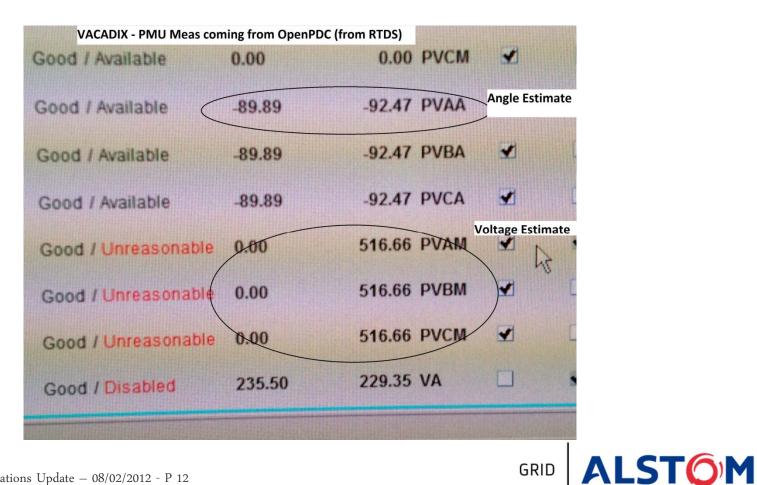
	🕛 - 🗙 I	🖾 - 🙆 🧇 - 🖛	es 🚺 🖆	* < 👻	💎 🔛 🔳				nov		
Telemetered PMU BUS Data											
Fime: 04	Jun-2007 1	15:01:48	RTNET REALTIME LOSSES CALC ED								
Station	Device Type	Device	Analog	QI SCADA	iality / Estimated	Valu SCADA	e / Estimated	Weighted Residual	Standard Deviation	Bias	
ASHE	BUS	PMU	PDEG	Good	/ Available	9.90	/ 9.45	0.504	0.044	0.400	Row
BELL	BUS	500_PMU	PDEG	Good	/ Available	25.80	/ 24.01	1.992	0.318	1.606	Row
BELL	BUS	230 PMU	PDEG	Good	/ Available	28.20	/ 26.18	2.248	0.307	1.875	Row
BIG_EDDY	BUS	500_PMU	PDEG	Good	/ Available	-2.90	/ -2.89	-0.015	0.104	-0.028	Row
BIG EDDY	BUS	230 PMU	PDEG	Good	/ Available	-7.10	/ -5.97	-1.254	0.065	-1.130	Row
CAPTJACK	BUS	PMU	PDEG	Good	/ Available	-17.00	/ -16.02	-1.089	0.319	-1.098	Row
CHIEF JO	BUS	500 PMU	PDEG	Good	/ Available	23.30	/ 22.81	0.545	0.307	0.312	Row
CHIEF JO	BUS	230 PMU	PDEG	Good	/ Available	26.10	/ 25.42	0.754	0.302	0.500	Row
CUSTER	BUS	500 PMU	PDEG	Good	/ Available		/ 8.98	-1.423	0.316	-1.369	Row
CUSTER	BUS	230 PMU	PDEG	Good	/ Available		/ 7.41	-1.563	0.320	-1.521	Row
GARRISON	BUS	500 PMU	PDEG	Estimated	/ Unavailable		/ 23.99				Row
GARRISON	BUS	230_PMU	PDEG		/ Unavailable		/ 21.79				Row
G_COULEE	BUS	500_PMU	PDEG	Good	/ Available		/ 22.97	0.704	0.201	0.568	Row
JOHN DAY	BUS	500_PMU	PDEG	Good	/ Available		/ -0.39	-0.172	0.010	0.002	Row
KEELER	BUS	500 PMU	PDEG	Good	/ Available		/ -5.30	-0.219	0.184	-0.254	Row
KEELER	BUS	230 PMU	PDEG	Good	/ Available		/ -7.61	-0.435	0.235	-0.473	Row
MALIN	BUS	PMU	PDEG	Good	/ Available		/ -16.03	-0.962	0.332	-1.084	Row
MAPLE VL	BUS	230 PMU	PDEG	Good	/ Available		/ 5.37	-0.522	0.227	-0.486	Row
MCNARY	BUS	500 PMU	PDEG	Good	/ Available		/ 8.58	0.466	0.391	0.159	Row
MCNARY	BUS	230 PMU	PDEG	Good	/ Available		/ 7.79	0.459	0.310	0.228	Row
SLATT	BUS	PMU	PDEG	Good	/ Available		/ 3.09	0.125	0.244	-0.002	Row
SUMMERLK	BUS	PMU	PDEG	Good	/ Available		/ -13.21	-0.769	0.305	-0.874	Row
COLSTRIP	BUS	500 PMU	PDEG	Good	/ Available		/ 34.66	3.936	0.258	3.306	Row
YELOWTLP	BUS	PMU	PDEG	- 2005 T - 10 - 12	/ Unavailable		/ 16.90	2.930	0.236	5.500	Row
DIABLOPG	BUS	PMU	PDEG	Good	/ Available		/ -16.68	-1.247	0.361	-1.452	Row
MIDWAYPG	BUS	500 PMU	PDEG	Good	/ Available	- 17.00	7 - 10.00	-1.247	0.001	- 1.4:32	TKOW .
MOSSLAND	BUS		PDEG	Gnod	/ Available			-1,108			
		500_PMU PMU				-	/ .28.70		0.378	- 3.2.4933	
PITSBURG TESLA	BUS		PDEG PDEG	Good	/ Unavailal to	inn	npar			\\ /1 t	
IESLA DEVERS	BUS	500_PMU PMU	PDEG		/ Available		ipal			VVILI	
		State of the second second	Contraction of the second	Good			383.592				
SYLMARS	BUS	230_PMU	PDEG	Good	/ Available		1 - 6 - 5 - 5 - 6				
VINCENT	BUS	PMU	PDEG	Good	/ Available		Resi	IITC		-1.385	
AULT	BUS	PMU	PDEG	Good			1031				
BEARS	BUS	PMU	PDEG	Good	/ Available			1.380	0.690	0.080	Elaw
SHIPROCK	BUS	PMU	PDEG	Good	/ Available		/ -2.16	Cou	rtesy Jim	Graffy (BPA)

Online SE with PMUs Co-funded project (Phase 2 - Completed in 2008)

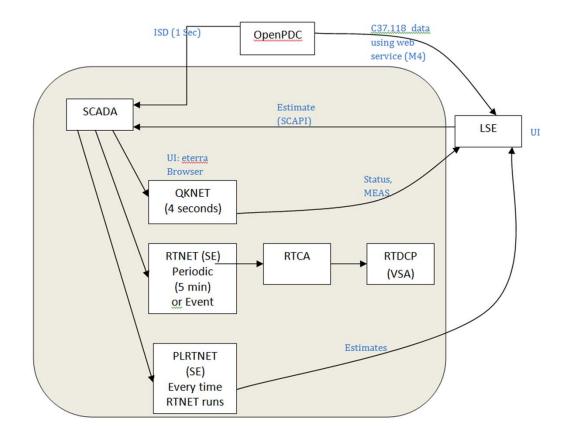
_	D11 💌										
	A Week	B %Valid SE Solutions with PMUs	C %Valid SE Solutions without PMUs	D Critical Measurements with PMUs	E Critical Measurements without PMUs	F Variance of the State with PMUs	G Variance of the State without PMUs	H Average of SE factorization (secs) with PMUs	Average of SE factorization (secs) without PMUs		
	April 1 to 8	99	93	130	130	0.01053	0.01071	1.548	1.891		
	April 1 to 16		88	136	139	0.01169	0.01244	1.857	1.861		
_	April 1 to 30	94	90	136	139	0.01221	0.01421	1.863	1.863		
		vement ⁴ in valid Improvement t 18 ₀ PMU m Solutions		Critical Measurements (ViSdim17,000) 18 PMUs	SCADA meas	State closer to urements)alue with 18 PMUs					
0000 0000 0000 0000 0000 0000	As PMU	J's Grow,	Benefits	will Increa	se						

Model Validation – Early Results

Preliminary Results - Only 2 PMU Voltage info is used for SE (NO field RTU meas is used)



LSE Application Context





Linear State Estimator – Benefits

The goal is to run SE at **subsecond** cycles using phasor measurements - Much faster than State Estimator

Validation of PMU data, including the possibility of topology error detection at substation level

Output of LSE can be used for RAS, SE - Estimated values (as opposed to raw inputs)

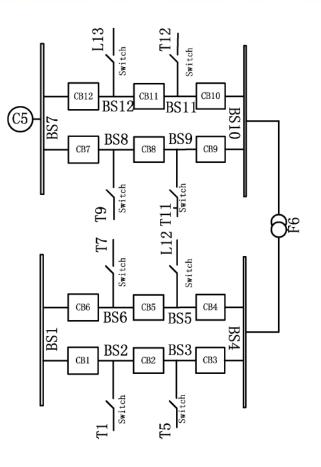


Substation Level LSE

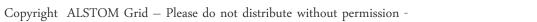
Analog State Estimation

- State:
 - Currents on Circuit Breakers
- Measurements:
 - Injection Currents to Nodes: Z_{inj}
 - Currents on Circuit Breakers: Z_{cb}
- Measurement Functions
 - Kirchhoff's Current Law
 - Identity Matrix
 - Formula:

$$z = \begin{pmatrix} Z_{inj} \\ Z_{cb} \end{pmatrix} = \begin{pmatrix} A_{KCL} \\ I \end{pmatrix} x + \begin{pmatrix} r_{inj} \\ r_{cb} \end{pmatrix} = Hx + r$$



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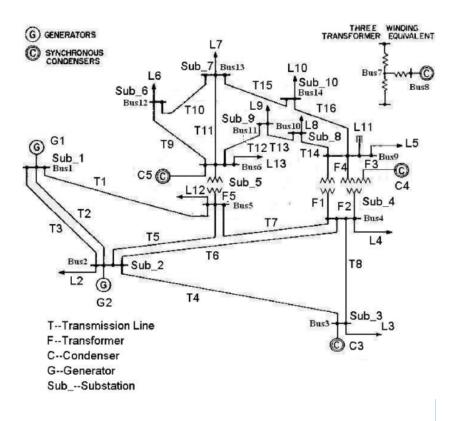


Control Center Level LSE

State Estimation

- States
 - Complex Bus Voltages
- Measurements (Phasor)
 - Bus Voltages: *V*_{bus}
 - Two Direction Branch Currents: *I*_{b1}, *I*_{b2}
 - Injection Currents: *I*_{inj}
- Measurement Functions

$$z = \begin{pmatrix} V_{bus} \\ I_{b1} \\ I_{b2} \\ I_{inj} \end{pmatrix} = Hx + r = \begin{pmatrix} I \\ Y_{b1} \\ Y_{b2} \\ Y \end{pmatrix} x + r$$



GRID

ALSTOM Involvement in SGIG Contracts

- Western Electricity Coordinating Council (WECC)
- Midwest ISO (MISO)
- Pacific Gas & Electric (PG&E)
- ISO New England (ISO-NE)
- Manitoba Hydro (MH)
- Florida Power & Light (FPL)
- Duke Energy
- Active proposals being submitted to others.....

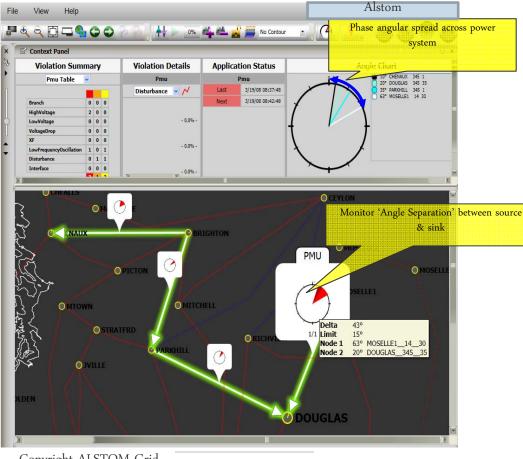




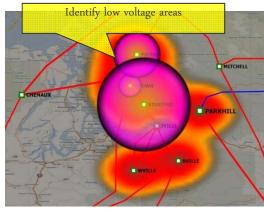
PMU Visualization within e-terravision

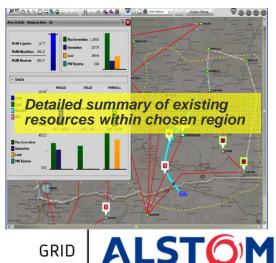
Monitor 'angular separation' as an indicator of increased grid stress due to:

- increased transmission path loading between 'Sources' & 'Sinks' of power
- sudden events such as line outages (i.e. weakening of the grid)



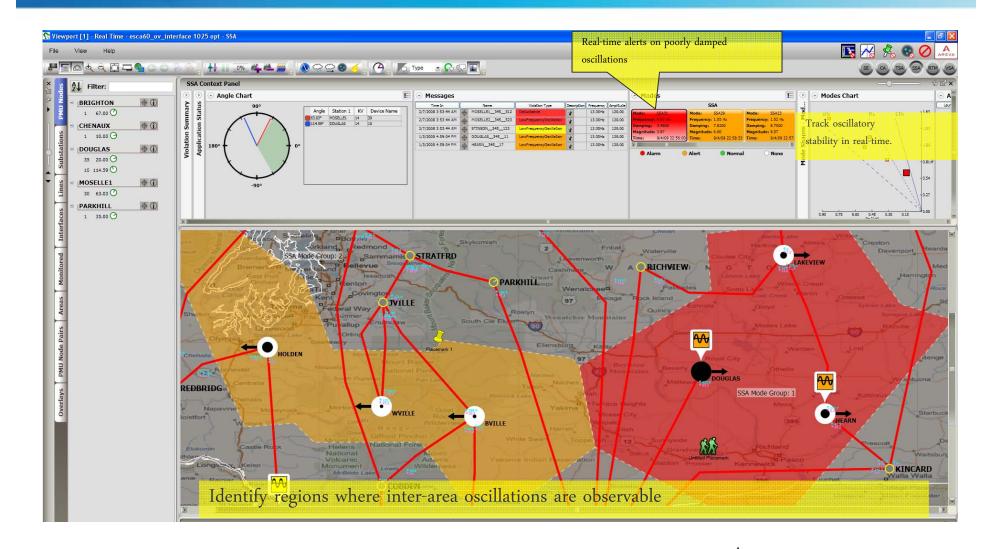
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Small Signal Stability Visualization in e-terravision

Modes shapes, amplitudes, damping, frequency, etc



GRID

ALSTOM SynchroPhasor Solutions





Our Implementation Unified Wide-Area Visualization e-terravision VISUALIZATION asorPoint DSA Tools UI Workbench Oscillatory Composite Enhanced Contingency Stability State Event Alarms Analysis Voltage Stability Management tion DATA MANAGEMENT Estimator Assessment **& APPLICATIONS** Islanding Line Parameter Alarm Resync, & DTS Estimation Management Blackstart Powertech Tools SynchroPhasor Platform EMS e-terraplatform Phasor High Speed PMU Data Historian Downsampled PMU Data (30-60 per second) (1 per second) **MEASUREMENT-BASED APPLICATIONS MODEL-BASED APPLICATIONS** Control Center openPDC DATA ACOUISITION **PMUs** G PMUs G & CONTROL Damping Substation **FACTS**

PMUs

PDC

CONITO