ACTUAL AND POTENTIAL PHASOR DATA APPLICATIONS

Shaded= actual usage

Not shaded = potential and anticipated use

RELIABILITY OPERATIONS		
APPLICATION	**DESCRIPTION**	**USES**
Wide-area grid monitoring and visualization	Use phasor data to monitor and alarm for metrics across entire interconnection (frequency stability, voltage, angle differences, MW and MVAR flows)	CAISO – using RTDMS to for WECC wide-area visualization and monitoring http://www.naspi.org/meetings/workgroup/2008_june/success/california_iso_synchrophasor_update_hawkins.pdf Entergy and AEP – dynamic security assessment http://www.naspi.org/meetings/workgroup/2008_october/presentations/11_asu_application_vittal_20081016.pdf China – using phasor network for wide-area visualization and fault analysis http://www.naspi.org/meetings/workgroup/2007_september/presentations/ecec_synchrophasor_act_hong09072007.pdf Power World for situational awareness http://www.naspi.org/meetings/workgroup/2008_june/vendor/powerworld_realtime_visualization_dahman.pdf Real Time Dynamics Monitoring System™ (RTDMS) alarming tools https://events.energetics.com/v&c08/pdfs/RC_RTDMS.pdf http://www.naspi.org/resources/oitt/naspi_oi_display_tool_conventions_standards_guidelines_010307.ppt http://www.naspi.org/resources/training/2008_0122/rtdms_training_package.pdf Hydro Quebec wide area monitoring and control http://www.ieee.org/organizations/pes/meetings/gm2006/html/slides/PESGM2006P-000401.pdf Prototype phasor-based real-time monitoring tool (training presentation) http://www.energy.ca.gov/2008publications/CEC-500-2008-049/CEC-500-2008-049-APE.PDF Line outage detection using phasor angle measurements http://www.pserc.wisc.edu/ecow/get/publicatio/2007public/tate_overbye_pes_nov2007.pdf New Zealand -- plan to use Psymetrix for oscillation monitoring http://www.electricitycommission.govt.nz/pdfs/advisorygroups/tag/21Feb08/Oscillatory-stability-monitoring.pdf SCE SMART software for visualization http://www.edison.com/files/0607_sce_phasrmt.pdf

Power plant monitoring and integration	Use real-time data to track and integrate power plant operation (including intermittent renewables and distributed energy resources	California Public Interest Energy Research in phasor measurement applications http://www.naspi.org/meetings/workgroup/2008_march/session_two/cpi_energy_research_brown.pdf CIEE- Transmission technology research for renewables integration http://uc-ciee.org/piertrans/documents/TransmissionTechnologyResearchforRenewablesFinalReport.pdf Denmark – monitoring wind power plant operation http://www.iceo.be/eow2007/calendar_site/info2.php?id=105&id2=162&ordre=77
Alarming for situational awareness tools	Use real-time data and analysis of system conditions to identify and alert operators to potential grid problems	RTDMS -- visualization, monitoring, alarming and reporting capabilities http://www.naspi.org/meetings/workgroup/2007_september/presentations/oitt_report_bilke09072007.pdf RDTMS – 2008 functional spec http://www.naspi.org/resources/oitt/naspi_rtdms_functional_spec_v6.pdf
State estimation	Use actual measured system condition data in place of modeled estimates	SDG&E –integrating phasor data into state estimator to better manage congestion http://www.naspi.org/meetings/workgroup/2008_march/session_two/sdge_enhance_state_estimation_kondragunta.pdf TVA – On-line state estimator using PMUs http://www.naspi.org/meetings/workgroup/2008_june/vendor/areva_activities_synchrophasor_giri.pdf Russia -- Improved EPS state estimation using SCADA and PMU data http://www.sei.irk.ru/articles/2006_10.pdf NYISO -- Augmenting state estimation with phasor measurements http://www.naspi.org/meetings/workgroup/2008_october/presentations/16_rpi_phasor_data_vanfretti_20081017.pdf
Inter-area oscillation monitoring, analysis and control	Use phasor data and analysis to identify frequency oscillations and initiate damping activities	BPA – real-time stability controls http://www.naspi.org/meetings/workgroup/2008_october/presentations/13_bpa_voltage_stability_kosterev_20081016.pdf TVA – oscillation monitoring http://www.naspi.org/meetings/workgroup/2008_march/session_one/tva_oscillation_monitoring_venkatasubramanian.pdf Prototype implementation of Oscillation Monitoring System at TVA http://www.naspi.org/meetings/workgroup/2008_october/presentations/08_wsu_oms_synchrophasors_mani_20081016.pdf SCE -- Power System Outlook off-line analysis tool to view MW, MVAR, voltage, currents, modal oscillations and their damping http://www.naspi.org/meetings/workgroup/2007_may/presentations/spms_monitor_trans_sce.pdf http://www.naspi.org/resources/training/2008_0122/rtdms_training_package.pdf Pacific DC line event identified and addressed based on phasor monitoring

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		http://www.naspi.org/meetings/workgroup/2009_february/presentations/quanta_phasor_measurements_wecc_martin_20090204.pdf Phasor Grid Dynamics Analyzer (PGDA) program to view and analyze modal oscillations and damping http://www.naspi.org/resources/training/2008_0801/phasor-grid_dynamics_analyzer_training080108.pdf
Automated real-time control of assets	Identify assets that can respond to specific local or wide-area grid problems and use real-time data to drive control of corrective measures for angular stability, voltage stability, low-frequency oscillations and thermal constraints	SCE – closed loop control of SVC http://www.naspi.org/meetings/workgroup/2008_march/session_one/sce_successful_utilization_johnson.pdf Static Var Compensation controlled via synchrophasors http://www.selinc.com/WorkArea/DownloadAsset.aspx?id=3487 Phasor data in protective relays for power system protection, control and analysis http://www.selinc.com/WorkArea/DownloadAsset.aspx?id=2613 Synchronized phasor measurement system for transmission reliability and capability http://www.naspi.org/resources/archive/olatt/pmu_acdc_paper_doe.pdf Real-time power system control using synchrophasors http://www.selinc.com/WorkArea/DownloadAsset.aspx?id=3503
Wide-area adaptive protection and system integrity protection	Real-time phasor data allow identification of grid events and adaptive design, execution and evaluation of appropriate system protection measures	Local and wide-area network protection systems http://www.naspi.org/resources/archive/prtt/waps_wprc04.pdf Status and key challenges of wide-area protection and control http://www.ee.iitb.ac.in/~npsc2008/NPSC_CD/Data/Oral/AIC2/p98.pdf Australia – stability monitoring avoided blackout http://www.naspi.org/meetings/workgroup/2008_october/presentations/07_psymetrix_oscillatory_modeshape_wilson_20081016.pdf Synchronized measurement technology (SMT) for real-time wide area monitoring, protection, and control (WAMPAC) http://www.quanta-technology.com/Documents/Grid%20Synchronization.pdf SCE -- synchronized phasor measurement system activities http://phasors.pnl.gov/Meetings/2006_may/presentations/minnicucci_bhargava_sce_eipp_051006.pdf
Planned power system separation	Improve planned separation of power system into islands when instability occurs, and dynamically determine appropriate islanding boundaries for island-specific load and generation balances.	Japan – PMUs for emergency islanding and management http://www.ieee.org/organizations/pes/meetings/gm2008/slides/pesgm2008p-001133.pdf Entergy – PMU use for islanding and restoration with Hurricane Gustav http://tdworld.com/overhead_transmission/role_phasor_data_emergency_operations_1208/ California Energy Commission: PMU Applications Business Case Study

		http://phasors.pnl.gov/Meetings/2006_september/tuesday/Business_Case_for_Phasor_Measurements.pdf Slow Coherency Based Controlled Islanding and Demonstration in WECC https://events.energetics.com/v&c08/pdfs/RC_Adaptive_Islanding_Demonstration.pdf
Dynamic line ratings and VAR support	Use PMU data to monitor or improve transmission line rating in real time	PMU-based voltage stability analysis of power transfer paths http://www.rpi.edu/~vanfrl/pdfs/PosterGallery/LV_2006IEEEGM.pdf ABB PSGuard system for angle difference monitoring, voltage stability monitoring, line thermal monitoring across corridors. http://phasors.pnl.gov/Meetings/2004%20March/Vendor%20Material/ABB/EIPP%20-%20Pres%20ABB%20PSGuard%20WAMS%20System.pdf Expected/Realized phasor data benefits http://www.phasorrtdms.com/downloads/presentations/PhasorTechResearchroadmap.pdf http://phasors.pnl.gov/Meetings/2006_may/presentations/imhoff_ercot_update.pdf http://pepei.pennnet.com/display_article/260824/17/ARTCL/none/none/1/Wider-acceptance-for-WAMS/
Day-ahead and hour-ahead operations planning	Use phasor data and improved models to understand current, hour-ahead, and day-ahead system operating conditions under a range of normal and potential contingency operating scenarios	EPRI -- Precursor signals of cascading outages based on visualization of PMU data http://www.naspi.org/meetings/workgroup/2008_october/presentations/03_epri_precursor_signals_lee_20081016.pdf Synchronized Phasor Measurement Systems (SPMS) vision and challenges http://www.naspi.org/meetings/workgroup/2007_may/presentations/spms_vision_challenge.pdf
Automatically manage frequency and voltage response from load	System load response to voltage and frequency variations	SCE/BPA - Load modeling and control http://www.energy.ca.gov/research/notices/2008-09-11_colloquium/presentations/06_Load_Modeling_and_Control.pdf
System reclosing and power system restoration	Use phasor data to bring equipment back into service without risking stability or unsuccessful reclosing attempts.	Entergy – used phasor data for restoration after Hurricane Gustav http://tdworld.com/overhead_transmission/role_phasor_data_emergency_operations_1208/index.html?smte=wr UCTE – used phasor data system for system restoration after October 2004 European blackout http://www.naspi.org/meetings/workgroup/2007_september/presentations/swissgrid_wam_sattinger09072007.pdf Salt River -- Generator black start validation phasor data http://www.apqa.org/aug2005.htm

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Protection system and device commissioning		Iceland – used phasor WAMS to commission and tune power system stabilizer http://www.naspi.org/meetings/workgroup/2008_june/success/landsnet_pmus_iceland_gústavsson.pdf Hydro Quebec -- Special Protections http://cigre2008.ece.umanitoba.ca/Session3B-Substation_Automation_&_Communication/562%20-%20Tholomier%20-%20The%20Future%20of%20Substation%20Automation.pdf Performance and Standards Task Team Progress Report: PMU Installation/Commissioning/Maintenance Guide Part II: Installation Procedures http://www.naspi.org/meetings/pstt/2007/pstt_progress_report_09072007.pdf
MARKET OPERATION		
APPLICATION	**DESCRIPTION**	**USES**
Congestion analysis	Synchronized measurements make it possible to operate the grid according to true real-time dynamic limits, not conservative limits derived from off-line studies for worst-case scenarios.	California Institute for Energy and Environment (CIEE):Phasor Measurement Application Study http://www.naspi.org/resources/dnmtt/ciee_pmufinalreport_october06.pdf SDG&E – working to integrate phasor data into state estimator to better manage congestion (http://www.naspi.org/meetings/workgroup/2008_march/session_two/sdge_enhance_state_estimation_kondragunta.pdf) Path flow (MW/MVAR) configuration http://eetd.lbl.gov/certs/pdf/cec-500-2008-049-apf.pdf Using phasors to enhance transmission reliability and capability http://phasors.pnl.gov/resources_offline/PMU_ACDC_paper_DOE.pdf SCE -- Synchronized Phasor Measurement System (SPMS) for monitoring transmission http://www.oe.energy.gov/DocumentsandMedia/Synchronized_Phasor_Movement_Bhargava.pdf
PLANNING		
APPLICATION	**DESCRIPTION**	**USES**
Static model benchmarking	Use phasor data to better understand system operations, identify errors in system modeling data, and fine-tune power system models for on-line and off-line applications (power flow, stability, short circuit, OPF, security assessment, modal frequency response, etc.).	PMU-Based Distributed State Estimation with the SuperCalibrator http://www.pserc.org/cgi-pserc/getbig/generalinf/presentati/psercsemin1/4psercsemin/meliopoulos_pserc_tele-seminar_pmu-dse_june17_2008.pdf SCE Synchronized Phasor Measurement System activities http://phasors.pnl.gov/Meetings/2006_may/presentations/minnicucci_bhargava_sce_eipp_051006.pdf
Dynamic model benchmarking	Phasor data record actual system dynamics and can be used to validate and calibrate	WECC Dynamic Probing Tests: Purpose and Results http://www.naspi.org/meetings/workgroup/2008_october/presentations/12_mttech_wecc_dynamic_trudnowski_20081016.pdf

(dynamic models.)		BPA Power System Stability Controls http://www.naspi.org/meetings/workgroup/2008_october/presentations/13_bpa_voltage_stability_kosterev_20081016.pdf Model parameter calibration using recorded dynamics http://www.naspi.org/meetings/workgroup/2008_october/presentations/14_pnnl_modelvalidation_huang_20081016.pdf California Institute for Energy and Environment (CIEE): Phasor Measurement Application Study http://www.naspi.org/resources/dnmtt/ciee_pmufinalreport_october06.pdf
Generator model validation		Model parameter calibration using phasor data for WECC's Palo Verde model http://www.naspi.org/meetings/workgroup/2008_october/presentations/14_pnnl_modelvalidation_huang_20081016.pdf
Stability model validation		PhasorPoint - Oscillatory Stability Monitoring by Psymetrix (Vendor) http://www.naspi.org/toolRepository/tool_details.aspx?tid=65 http://www.psymetrix.com/products/phasorpoint-applications/oscillatory-stability-monitoring.html
Performance validation	Use phasor data to validate planning models, to understand observed system behavior and predict future behavior under assumed conditions.	Staged System Tests for Validation of WECC System Performance and Modeling http://www.transmission.bpa.gov/business/operations/SystemNews/HVDCprobesAug08_SummaryReportD.doc http://www.naspi.org/meetings/workgroup/2007_may/presentations/wecc_wams.pdf
OTHER		
APPLICATION	**DESCRIPTION**	**USES**
Forensic event analysis	Use phasor data to identify the sequence of events underlying an actual system disturbance, to determine its causes.	UCTE – used phasor data to analyze November 2006 European disturbance http://www.naspi.org/meetings/workgroup/2007_september/presentations/swissgrid_wam_sattinger09072007.pdf NERC – used phasor data to analyze Florida 2007 disturbances http://www.nerc.com/news_pr.php?npr=36 http://www.naspi.org/meetings/workgroup/2008_march/session_two/vt_online_event_location_liu.pdf

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		WECC WAMS -- examples of WECC event and observations from PMU data http://www.naspi.org/meetings/workgroup/2009_february/presentations/quanta_phasor_measurements_wecc_martin_20090204.pdf Thailand -- Wide Area Monitoring System http://www.actapress.com/Abstract.aspx?paperId=30318 Phasor Grid Dynamics Analyzer (PGDA) program for offline analysis http://www.naspi.org/resources/training/2008_0801/phasor-grid_dynamics_analyzer_training080108.pdf Line outage detection using phasor angle measurements http://www.pserc.wisc.edu/ecow/get/publicatio/2007public/tate_overbye_pes_nov2007.pdf
Phasor applications vision, road- mapping & planning		Roadmap for Capability Evolution Indicating Time to Achievement, Priority of Industry Need, and Severity of Deployment Challenge http://www.naspi.org/resources/esg/2007_nov/research_roadmap_20071130.pdf California Energy Commission: PMU Applications Business Case Study: Results and Recommendations http://phasors.pnl.gov/Meetings/2006_september/tuesday/Business_Case_for_Phasor_Measurements.pdf Phasor Technology Research Road Map to Improve Grid Reliability and Market Efficiency (2005) http://www.phasorrtdms.com/downloads/presentations/PhasorTechResearchroadmap.pdf Synchronized Phasor Measurement Systems (SPMS) Vision and Challenges http://www.naspi.org/meetings/workgroup/2007_may/presentations/spms_vision_challenge.pdf

table 1. PMU deployment in different parts of the world.

PMU Applications	North America	Europe	China	India	Brazil	Russia
Post-disturbance analysis	√	√	√	P	T	√
Stability monitoring	√	√	√	P	P	√
Thermal overload monitoring	√	√	√	P	P	√
Power system restoration	√	√	√	P	P	P
Model validation	√	√	√	P	T	√
State estimation	P	P	P	P	P	P
Real-time control	T	T	T	P	P	P
Adaptive protection	P	P	P	P	P	P
Wide area stabilizer	T	T	T	P	P	P

T = Testing phase; P = Planning stage

Source – Chakrabarti, Kyriakides, Bi, Cai and Terzija, "Measurements Get Together," IEEE Power & Energy, January-February 2009, at http://www.ieee.org/portal/cms_docs_pes/pes/subpages/publications-folder/07mpe01-chakrabarti-mo.pdf