Wide area monitoring, analysis, protection and control in smart grid using synchronized phasor measurements: a review

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Introduction

Future challenges in Smart Grid

- Increasing need for power transmission and energy storage
- Distributed energy resources integration
- Increased situational awareness and flexibility
- Real-time grid reliability management

New possibilities with Phasor Measurement Units (PMUs) in Wide Area Systems

The first PMUs were developed in Virginia Tech by A. G. Phadke and J. S. Thorp [1].

Attributes [1-3]:

- **Time stamped data:** The PMU hardware is primarily a digital relay with added advantage of providing time stamped measurements using global positioning system (GPS) signals.
- **Direct measurements**: PMU measures sinusoidal voltage and current signals in the network and provides phasor equivalent (both magnitude and phase angle) of the signals and frequency information.
- **High resolution:** PMUs sample at speeds of 30-60 observations per second.
- **Current standards:** IEEE C37.118 (2011) - Synchrophasors for power systems
  IEC 61850 (2003) - Substation automation and transmission device communications
  IEC 61588 (2009) & IEEE 1588 (2008) - Time synchronization

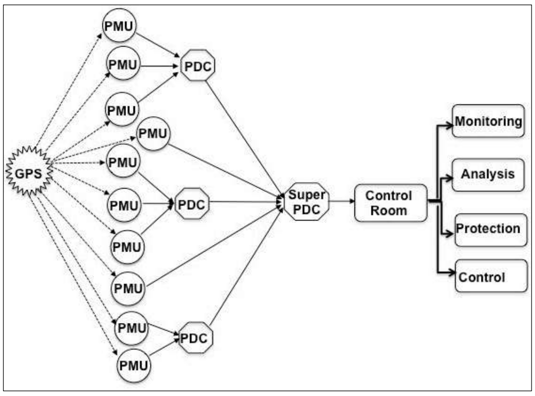

Figure 1 Wide area monitoring and control system (PDC: Phasor data concentrator)

Current PMU applications

Table I Summary of current applications of PMUs [4-5]

Applications	State estimation	Frequency stability monitoring	Power oscillation monitoring	Voltage monitoring	Event detection	System model calibration and validation	Load characterization	Resource integration	Special protection schemes and islanding	Automated protection	Phase angle monitoring	Wide area visualization	Post Event Analysis
Functionalities	Integrate phasor data and phase angle measurements in state estimators	Track system frequency Detect generation and load loss events	Oscillation detection and mode meter Display oscillation energy Decision support tools to deal with poorly dampened oscillations	Identify changes in system conditions with relation to current operating point	Review of data to determine normal range of Operation Indicate operation outside identified normal conditions Identify problem and react in a timely manner	Adopt processes for system model validation using tools to compare actual event data to study results	Estimate system load sensitivity to frequency Estimate real-time load sensitivity to voltages Measure and analyze dynamic load response	Dynamic issues identified through the use of historical data Identify issues related to resource specific behavior	Identify events that would trigger the need for islanding and allow for manual or planned separation. Manage islanding	Identify crucial outages of a transmission and/or generation component	Warn operators when system stress is increasing Accelerate the reclosing of tie lines	Provide dynamic operating details Enhanced monitoring and diagnostic capabilities	Analyze disturbances and large-scale system events, providing better understanding of their causes event reconstruction
Increased system reliability	High	High	High	High	High	High	High		High	High	High	High	
Increased Asset management		High				High	High		High	High	High		High
Increased organizational efficiency	High				High	High		High				High	High
Priority to Real-time operations	High	High	High	High	High					High	High	High	
Priority to Day-ahead operations		High				High	High						

R & D opportunities and challenges

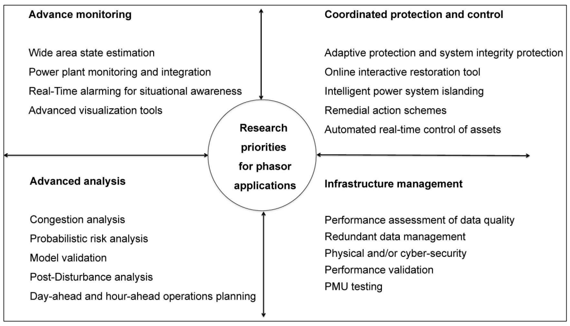

Figure 2 Emerging phasor applications

Challenges

- Updated technical standards for PMU performance and interoperability testing
- Physical and/or cyber-security: confidentiality, security and integrity of data
- Data Management: acquisition, consolidation, storage, quality and sharing, data validation methods and tools, latency requirement, analysis and visualization, privacy, and interoperability
- Information & communication technology: availability, reliability, redundancy, and security
- Critical interdependence and cascading phenomena between power grid and communication network

Summary and future work

PMUs have emerged as the most effective sensors for wide area monitoring, trending and prediction, automated control strategies, and wide-area special protection schemes.

PMUs provide full observability of the system conditions. If system operators could in real-time assess the information from PMU data, counteraction might be taken to avoid a cascade of outages and an eventual system blackout.

Future research efforts:

- Study PMU reliability and evaluate ICT challenges and constraints
- Develop PMU model and validation
- Vulnerability analysis using PMU
- Implementation and test in laboratory
- Identify technology transfer opportunities

References

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