

GOALS

- Build/test a 120 V open-box **PMU** to investigate measuring, processing, and synchronizing synchrophasor data
- Implement a Phasor Data Concentrator (**PDC**) integrating data from project **PMUs** placed on the local distribution network
- ID & detect **SDQ** issues associated with **PMUs** and synchrophasor data networks
- Seek ways to mitigate/remedy **SDQ** issues

FUNDAMENTAL QUESTIONS/CHALLENGES

- Substantially reducing **PMU** per-unit cost, currently exceeding \$1,000
- Current **PMUs** do not fully comply with established IEEE standards¹
- Improve **PMU** performance to meet current and next-generation synchrophasor measurement IEEE c37.118 standards
- Can synchrophasor data from a local distribution network provide cost effective benefit to the local power provider?

6



Conformance Test Results

PMU	Class	Steady State Test												Dynamic State Test					
		Magnitude Variation			Phase Angle Variation			Frequency Variation			Measurement Bandwidth			Frequency Ramp			Step Change		
		TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	TVE	FE	RFE	RT	DT	MO			
A	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
A-1*	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
B	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
C	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
D	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
E	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
F	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
G	P	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	S	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
H	P	S	F	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F
M	M	S	F	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F

¹ Mladen Kezunovic, "Verifying Interoperability and Application Performance of PMUs and PMU-enabled IEDs at the Device and System Level," North American Synchrophasor Phasor Initiative Working Group Meeting, 5 Jun 12, Denver, CO.

*PMU A-1 is an upgraded firmware of PMU A. P: Class P; M: Class M.
TVE: total vector error; FE: frequency error; RFE: rate of change of frequency error;
RT: response time; DT: delay time; MO: maximum over/under shoot
S stands for "Satisfied"; F stands for "Failed".



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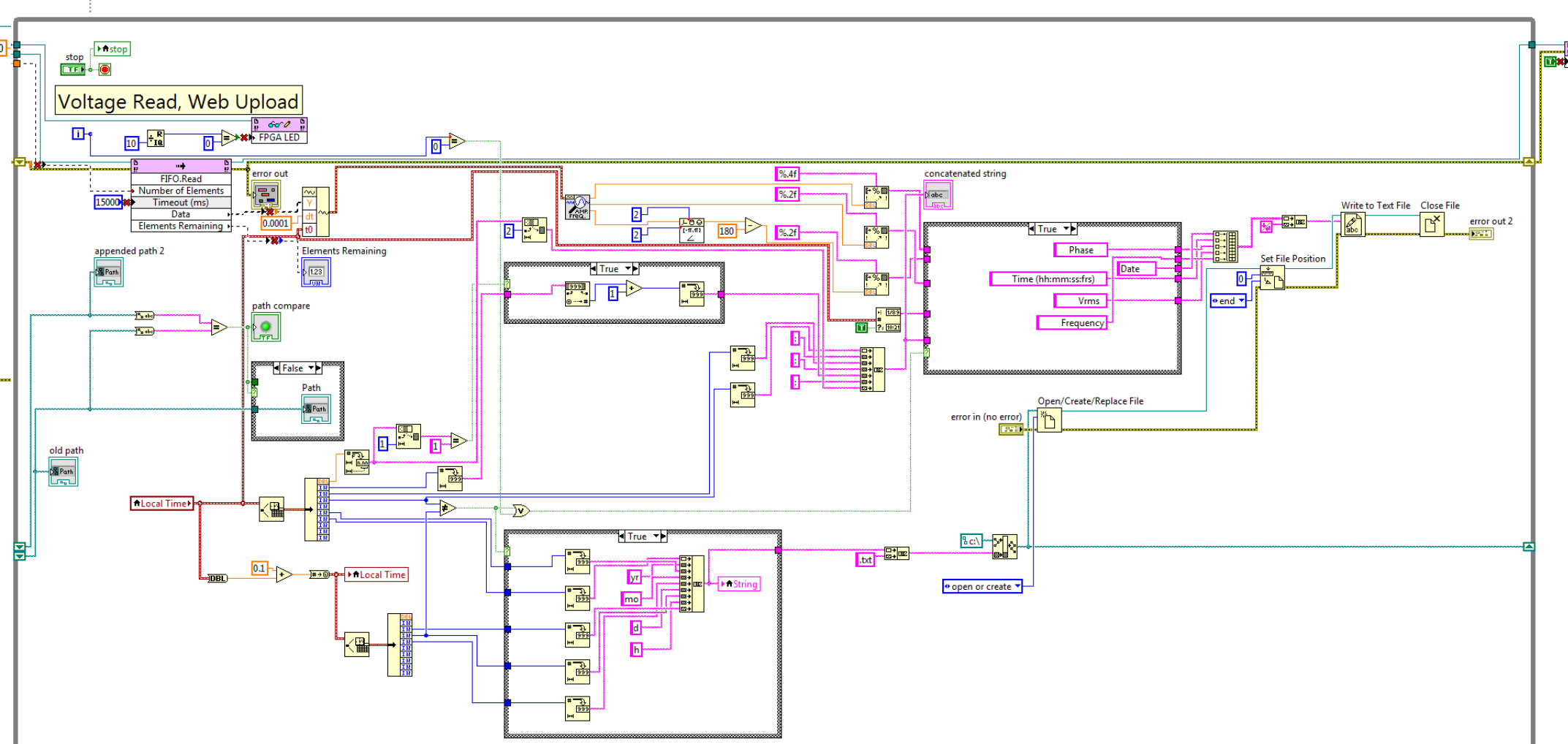
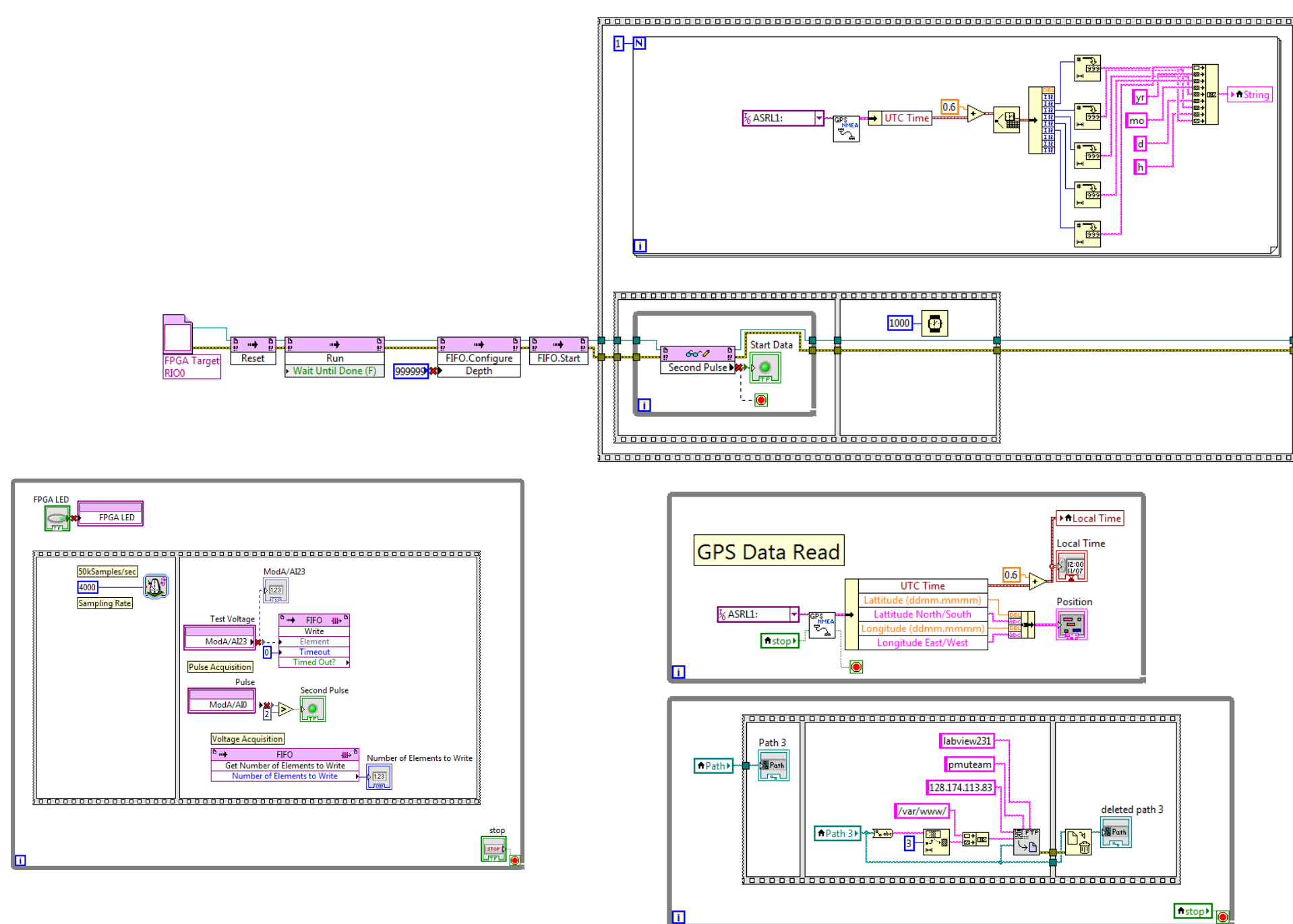


RESEARCH PLAN

- Complete **PMU** integration with an uninterruptible power supply (UPS), enabling synchrophasor data collection during power interruptions
- Implement a distribution level 10-**PMU** synchrophasor data network using the industry standard "openPDC" application set
- Develop and implement new algorithms for next-generation **PMUs**
- Explore next-generation **PMU** device requirements

BROADER IMPACT

- Gain detailed understanding of **PMU** measurement challenges, supporting overall synchrophasor data quality activity research
- Reduce **PMU** per-unit cost to ~\$350
- Investigate low-cost **PMUs** benefit to distribution system research



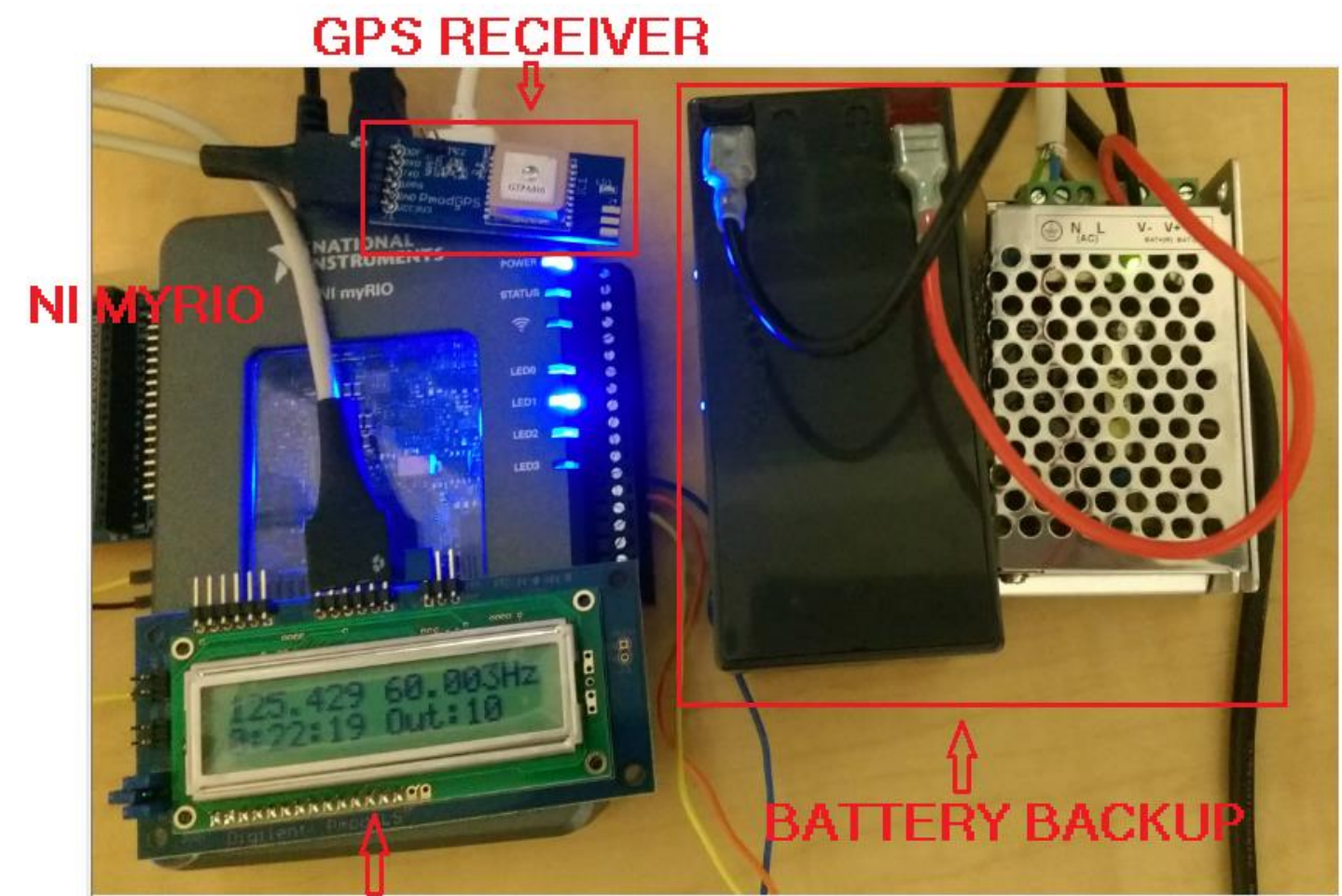
Virtual instrument logic, implemented with National Instruments hardware/software

INTERACTION WITH OTHER PROJECTS

- Apply the experience and insights gained to investigate synchrophasor data quality in real-world power systems
- Provide our **PMU** to the TCIPG testbed to assess GPS signal spoofing vulnerabilities

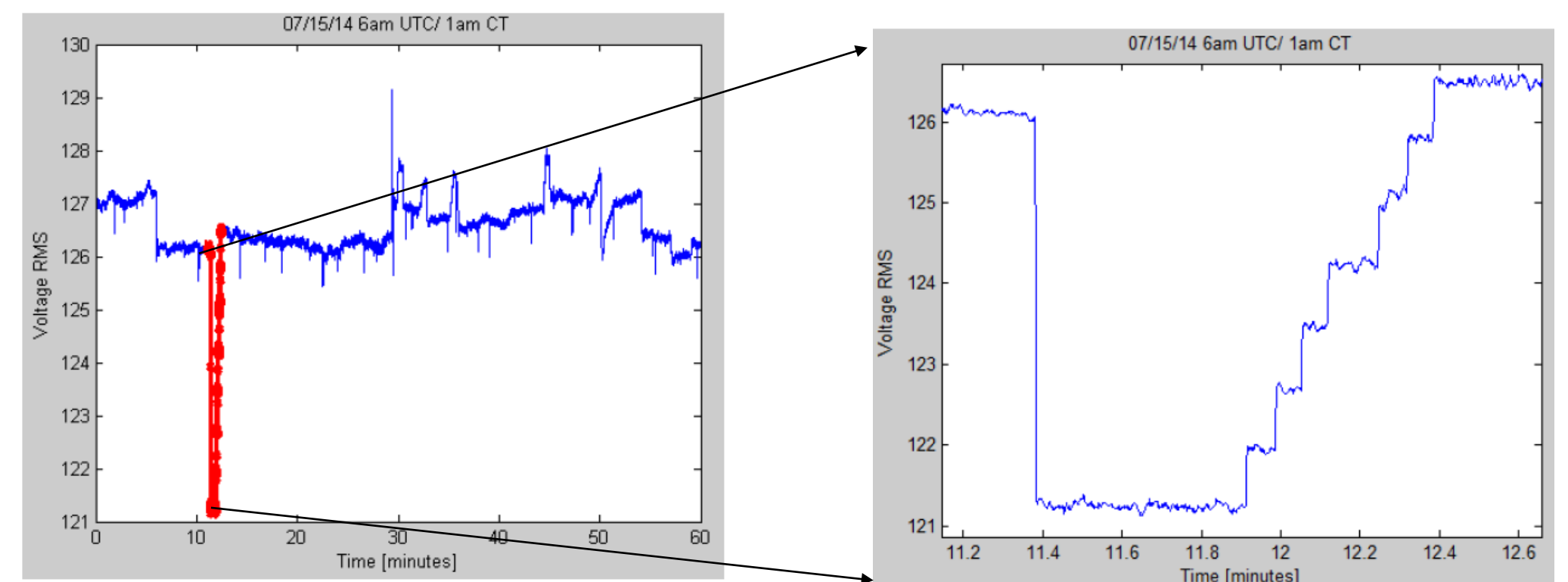
RESEARCH RESULTS

- Wall voltage sampled at 10 kHz
- 10/20 (user selectable) synchrophasors generated per second.
- Time-stamped using GPS time reference having 1 μs accuracy
- **PMU** implemented on NI's myRIO-1900
- Data buffered and transferred hourly via FTP to a remote server
- **PMU** device powered during grid instabilities by internal UPS



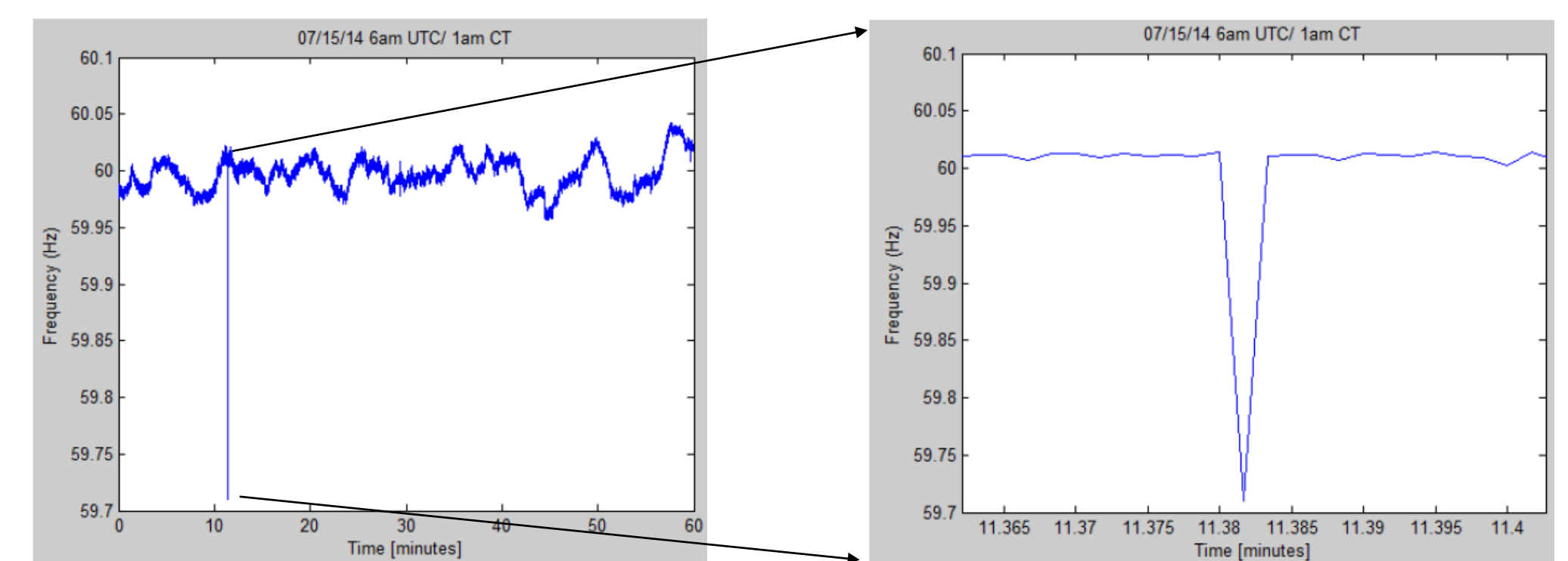
SDQ Activity PMU components

Synchrophasor data streams capturing distribution system events:



Sample hour long unusual voltage data

Zoom-in on the red voltage dip



Frequency during the same hour

Zoom-in on the frequency dip

FUTURE EFFORTS

- Improve SDQ Activity **PMU** performance to meet IEEE c37.118 synchrophasor standards
- Deploy 10 **PMU** network on the local power distribution system
- Set up the synchrophasor data network including the "openPDC" phasor data concentrator
- Apply knowledge gained to improve synchrophasor data quality