



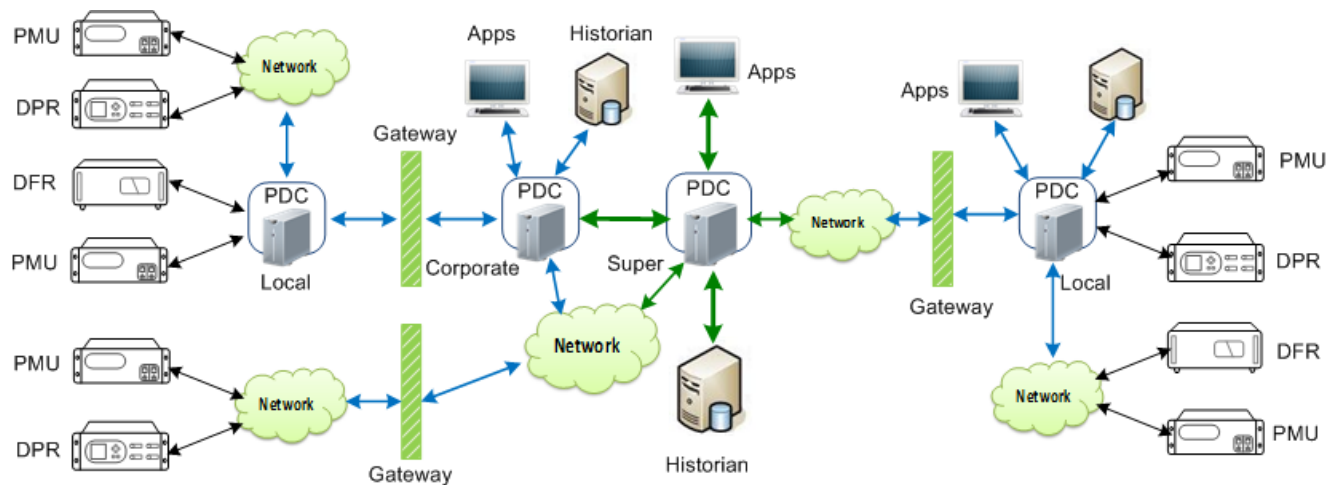
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Verifying Interoperability and Application Performance of PMUs and PMU-enabled IEDs at the Device and System Level

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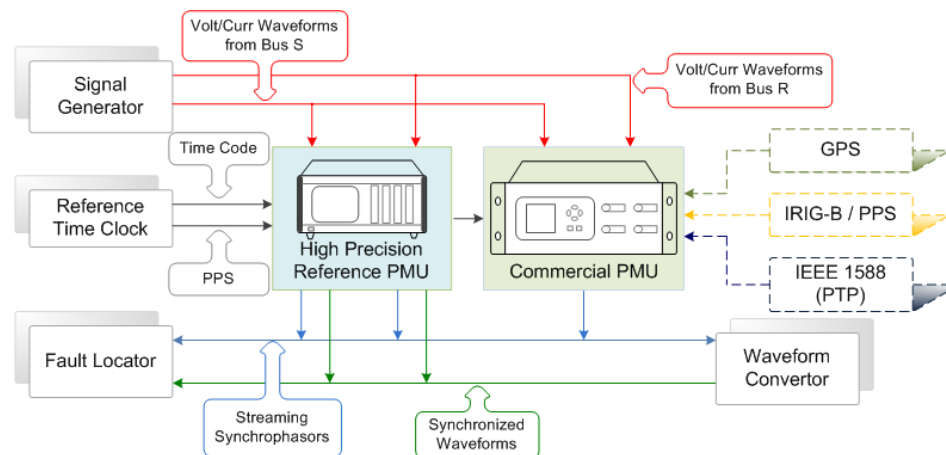
Project scope

- Interoperability issues
- Accuracy bounds for PMUs and PMU-enabled IEDs
- Test procedures for interoperability characterization
- Lab testing of commercial devices



Purpose of Testing

- Conformance Requirement
 - To industry standards (e.g., IEEE)
- Interoperability Issues
 - Between different vendors
- Application Performance
 - Fault location
 - State estimation





Types of Tests

- **Conformance Test**

- IEEE Standard for Synchrophasors for Power Systems, *IEEE Standard C37.118.1*, May 2011.
- IEEE Standard for Synchrophasors Data Transfer for Power Systems, *IEEE Standard C37.118.2*, May 2011.
- IEEE PC37.244. "Guide for Phasor Data Concentrator Requirements for Power System Protection, Control, and Monitoring", Jan 2012.

- **Interoperability Test**

- PMUs and PMU-enabled IEDs
- PDCs
- Time synchronization options

- **Application Test**

- Fault location
- State estimation



Product tested

- PMU and PMU-enabled IED
- PDC
- Time Synchronization devices

PMU and PMU-enabled IED	SEL 421x2, SEL 351, GE N60, ABB RES 521, SIMENS R, USI 2002, AMETEK, NI PMU
PDC	GPA OpenPDC, SEL 3373, EPG ePDC
Time Synchronization	Symmetricom Xli, RuggedCom 2288 AREVA P594, Hopf 6875



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	TVE	FE	RFE	RT	DT	MO
A	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	F	F
	M	S	S	S	S	S	S	F	S	S	S	F	S	F	F	F	S	F	F
A-1*	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	F
B	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	F	S
	M	S	S	S	S	S	S	S	S	S	F	F	S	F	F	F	S	F	S
C	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	S
	M	S	S	S	S	S	S	S	S	S	S	S	S	F	F	F	S	S	S
D	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	F	F
	M	S	S	S	S	S	S	S	S	S	F	F	S	F	F	F	S	F	F
E	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	F	S	F	F	F	S	S	F	F	S	S	F
F	P	S	S	S	S	S	S	F	S	S	S	F	S	F	F	F	S	S	S
	M	S	S	S	S	S	S	F	S	S	F	F	S	F	F	F	S	S	S
G	P	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	F	S	F
	M	S	S	S	S	S	S	S	S	S	S	F	S	S	F	F	S	S	F
H	P	S	F	S	S	F	S	S	F	S	S	S	S	S	F	F	S	S	S
	M	S	F	S	S	F	S	S	F	S	S	S	S	S	F	F	S	S	S

*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".



Interoperability Test Results

Interoperability test between PMUs and Time Synchronization Options

Device		Clock A				Clock B				Clock C				Clock D			
		C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4	C1	C2	C3	C4
PMU A-1	P	S	S	F	F	N	N	N	N	F	F	F	F	S	S	F	F
	M	S	S	F	F	N	N	N	N	F	F	F	F	S	S	F	F
PMU B	P	N	N	N	N	S	S	F	F	N	N	N	N	N	N	N	N
	M	N	N	N	N	S	S	F	F	N	N	N	N	N	N	N	N
PMU C	P	S	S	F	F	N	N	N	N	S	S	F	F	S	S	F	F
	M	S	S	S	F	N	N	N	N	S	S	F	F	S	S	S	F
PMU F	P	S	F	F	F	N	N	N	N	S	F	F	F	S	F	F	F
	M	S	F	F	F	N	N	N	N	S	F	F	F	S	F	F	F

C1 - C4: Amplitude Variation, Frequency Variation, Modulation, Frequency Ramp.

P: class P; M: class M.

S stands for "Satisfied"; F stands for "Failed"; N stands for "Not Functional".



Interoperability Test Results

Interoperability test between PMUs and PDCs

	PMU A	PMU A*	PMU B	PMU C	PMU D	PMU E	PMU F	PMU G	PMU H
PDC A	S	S	S	S	S	S	S	S	S
PDC B**	F	F	F	S	S	S	N	S	S
PDC C***	S	S	S	F	F	F	F	F	F

S stands for “Satisfied”; F stands for “Failed”; N stands for “Not Functional”.

* PMU A-1 is an upgraded firmware of PMU A.

** This PDC requires an additional adapter to support serial port communication.

*** This PDC only supports serial port communication, but it has two Ethernet ports available for upgrade to support Ethernet communication