Testing PMUs using the PMU Performance Analyzer (PPA)

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March 12, 2014

WASHINGTON STATE UNIVERSITY

World Class. Face to Face.

Outline

- *Motivation for PPA*
- *What is PPA*
- *Unique Capability of PPA*
- *Using PPA at WSU and SCE*
- *Testing Results*
- *Summary*

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Limitations of the conventional method of PMU testing and analysis –

(1) Needs complex test bed setup

(2) Requires specially trained person

(3) Very labor intensive

(4) Highly time taking

(5) Very costly

There is need of an automated / semi-automated method for testing and analyzing PMUs

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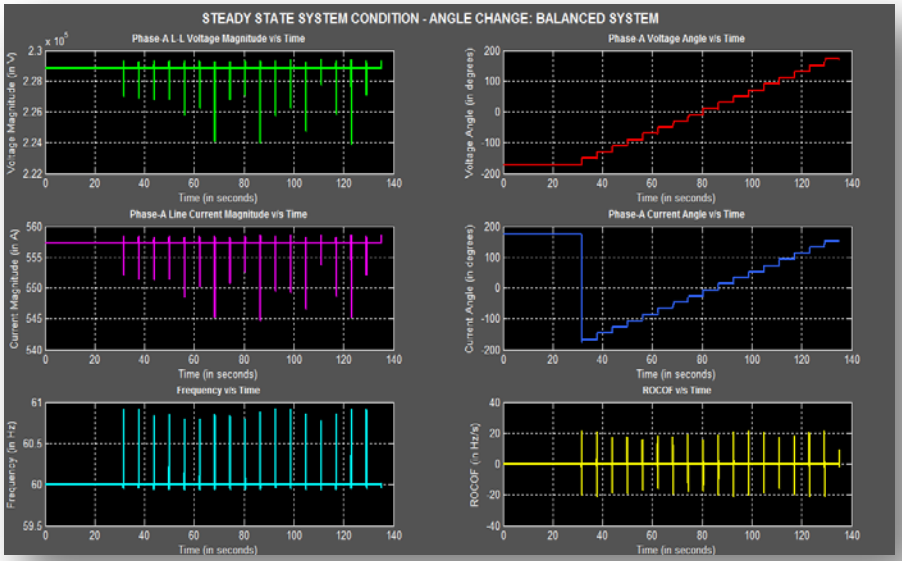
(1) It is an automated analysis tool for analyzing the performance of the test PMU under different test conditions

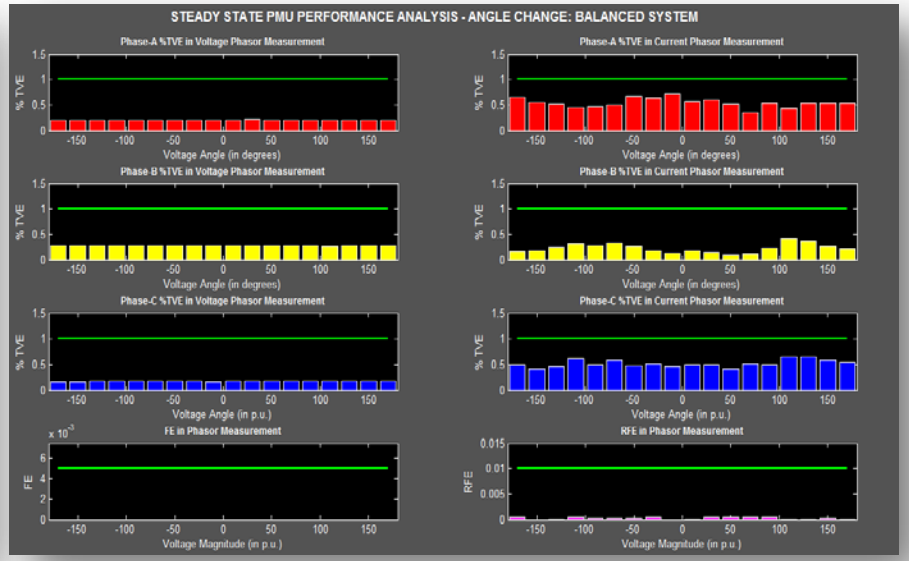
(2) It works with a Phasor Data Concentrator (PDC) and the Real Time Digital Simulator (RTDS)

Note – Substitute for the RTDS:

(i) High quality analog signal generator

(ii) High quality PMU (simulated / hardware)





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(1) Time aligns the synchrophasor data of the test PMU with the ideal PMU

(2) Automatically tracks the changes in the test conditions and finds the suitable data for test analysis

(3) Analyzes performance of test PMUs under different steady state and dynamic conditions as mentioned in the IEEE Standard for Synchrophasors C37.118.1

(4) Analyzes performance of test PMUs under other realistic conditions outside the IEEE Standard

(5) Allows the user to choose required tests from the suite of test configurations

(6) Provides visualization of test conditions and corresponding results in the form of figures while carrying out the analysis

(7) Automatically generates a detailed printer-friendly test report for the PMU instantly after the completion of test analysis

Characteristics

Parameters	PPA (2014)
No. of Tests	760
Reporting Rates supported by tool	10, 12, 15, 20, 25, 30, 50, 60
Type of PMU supported	Both P and M type
Supported Base Voltage	Any voltage given by user
Total Time Required to Test	90 Minutes (for one reporting rate and base voltage)

Suite of tests for PMU performance analysis –

Test Name/C37.118.1 section	Parameter	Settings	Reporting rates, (# of tests)	Input Frequency	Reported Quantities
Preliminary Tests					
1. Reporting rates w/ frequency range / 5.4.1 and 5.5.5	Reporting rate	45 Hz to 55 Hz in 0.5 Hz increments. 5 second duration.	10,(9 tests) 12,(11 tests) 15,(13 tests) 20,(17 tests)	f0±2.0 Hz for Fs ≤ 10 f0±Fs/5 for 10≤Fs20	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
		45 Hz to 55 Hz in 0.5 Hz increments. 5 second duration.	10,(9 tests) 25,(21 tests) 50,(21 tests)	*f*0±2.0Hz for *Fs* ≤10 *f*0±*Fs*/5 for 10≤*Fs*25 *f*0±5.0Hz for *Fs*≥25	
Steady-State performance					
1. Signal frequency range/ 5.5.5	Frequency	55 Hz to 65 Hz in 0.2 Hz increments, 5 second duration, 23°C±1°C	30,(51 tests) 60,(51 tests)	55 Hz to 65 Hz in 0.2Hz increments	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
2. Signal magnitude / 5.5.5	Magnitude	V: 10 % to 120 % nominal I: 10 % to 200 % nominal	30,(V:13 tests), (I:21 tests) 60,(V:13 tests), (I:21 tests)	60 Hz	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
3. Harmonic distortion / 5.5.5	10 % Harmonic	Each from 2nd to 50th. 5 second duration.	30,(49 tests) 60,(49 tests)	60 Hz	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
4. Out-of-band interference / 5.5.5	10 % of nominal amplitude out-of-band interfering signal	Fundamental freq at nominal and nominal ± 10 % of Nyquist Interharmonic: 10 Hz to 120 Hz in 1 Hz increments	30,(144 tests)	58.5 ,60, 61.5 Hz fundamental plus: • 10Hz to 20Hz • 22 Hz to 30 Hz • 31 Hz to 45 Hz • 75Hz to 89 Hz • 90 Hz to 100 Hz • 105 Hz to 120 Hz	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
			60,(93 tests)	57, 60, 63 Hz fundamental plus: • 10Hz to 20 Hz , • 21 Hz to 30Hz • 90Hz to 100 Hz • 102 Hz to 110Hz • 115 Hz to 120 Hz	

Test Name/C37.118.1 section	Parameter	Settings	Reporting rates, (# of tests)	Input Frequency	Reported Quantities
Dynamic performance					
1. Measurement bandwidth (amplitude modulation) / amended 5.5.6	0.1 amplitude mod. Index and 0.0 phase mod. index	Modulation frequencies: • 0.1Hz to 2.1 Hz, in 0.5 Hz increments. • 2.4 Hz to 3.9 Hz in 0.3 Hz increments • 4.1 to 10.1 Hz in 0.2 Hz increments.	30,(41 tests) 60,(41 Tests)	60 Hz	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
2.Measurement bandwidth (phase modulation) / 5.5.6	0.1 phase mod. Index and 0.0 amplitude mod. index	Modulation frequencies: • 0.1Hz to 2.1 Hz, in 0.5 Hz increments. • 2.4 Hz to 3.9 Hz in 0.3 Hz increments • 4.1 to 10.1 Hz in 0.2 Hz increments.	30,(41 tests) 60,(41 Tests)	60 Hz plus phase modulation	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
3. Frequency ramp / amended 5.5.7	Frequency	Linear ramp at +1 Hz/s from 55 Hz to 65 Hz, and then -1 Hz/s down to 55 Hz	30,(2 tests) 60,(2 tests)	Ramp from 55 Hz to 65 Hz and Ramp from 65 Hz to 55 Hz.	FE, RFE, VTVE, ITVE, and phasor magnitude & phase errors
4. Magnitude step / 5.5.8	Magnitude	+10% step and –10% step from 100% using equivalent time sampling technique over 10 iterations	30,(2 tests of 10 iterations each) 60,(2 test of 10 iterations each)	60 Hz	Response Times of voltage and current phasors, FE & RFE. Delay Time of voltage and current phasors, FE & RFE. Overshoot/undershoot of voltage and current phasors.
5. Phase step / 5.5.8	Phase	+10° step and –10° step using equivalent time sampling technique over 10 iterations.	30,(2 tests of 10 iterations each) 60,(2 test of 10 iterations each)	60 Hz	Mean, standard deviation, max & min of each of the following: Response Times of VTVE, ITVE, FE & RFE, Delay Time, Overshoot/undershoot
6. PMU latency / 5.5.9	Latency	Nominal frequency for 1000 report duration	30 (1 test), 60 (1 test)	60 Hz	Mean, standard deviation, max & min of Latency over 1000 reports

Table of Comparison –

Factors for Comparison	Conventional Methods	Method using *PMU Performance Analyzer*
Simplicity of Test Setup	Complex	Simple
Mode of Test Execution & Analysis	Mostly Manual	Mostly Automated
Requirement of Trained Person	Yes	No
Auto-generation of PMU Test Report	No	Yes
Time Required for Entire Process	Very High	Very Low (For 1 PMU: 90 minutes for all tests [in the test suite] conducted once for one reporting rate)
Cost of the Entire Process	Very High	Very Low

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A Typical Architecture for using the *PMU Performance Analyzer* –

RTDS

PMU

C37.118.1 Data

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e of Phasor Measurement Units (PMUs)
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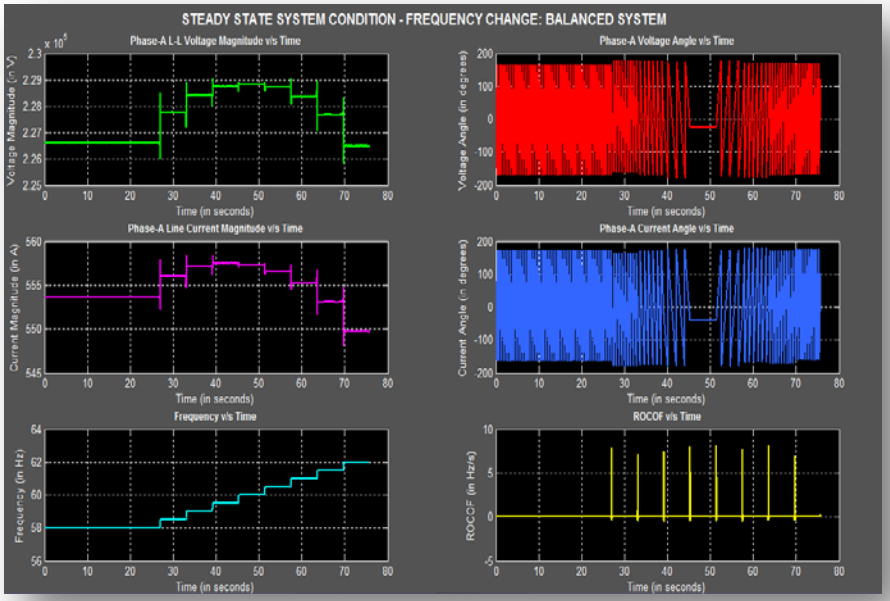
(1) A Sample of a Steady State Test Condition & Result

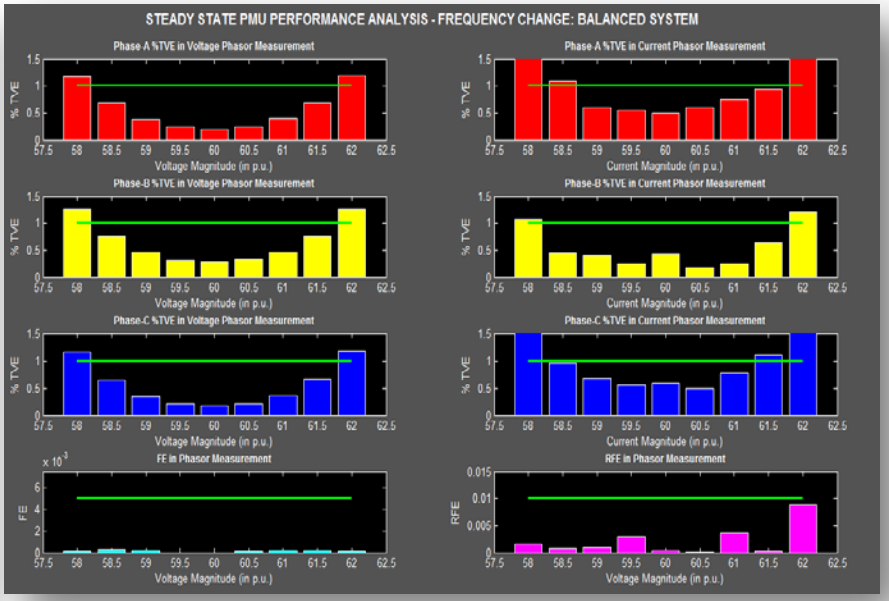
→ Quantity changed: Frequency

→ System condition during the change: Balanced System, No Harmonics

Test Condition



Test Results

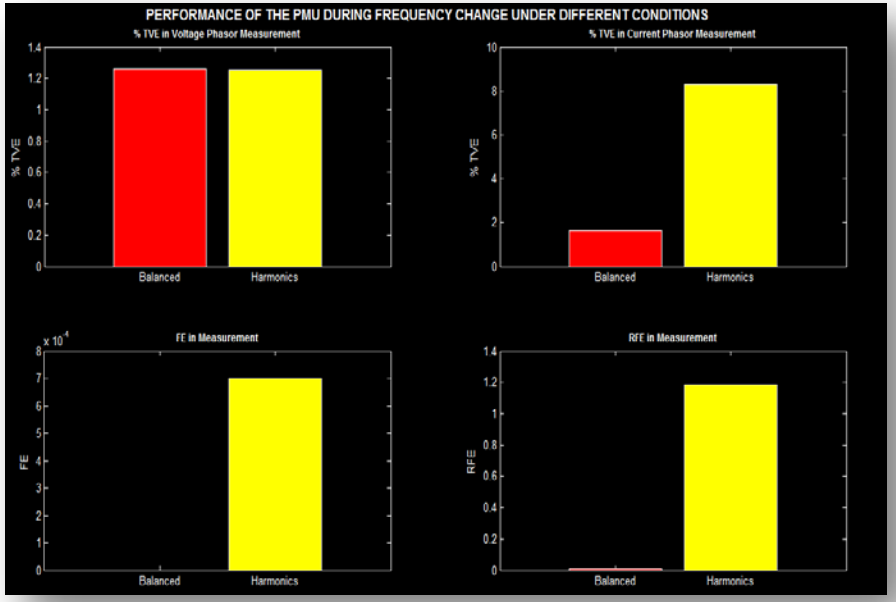


→ Detailed analysis of the test is available in the test report

(2) A Sample of a Difference in PMU Performance when test quantities are changed under different conditions –

→ Quantity changed: Frequency

→ System condition during the change: With & Without Harmonics



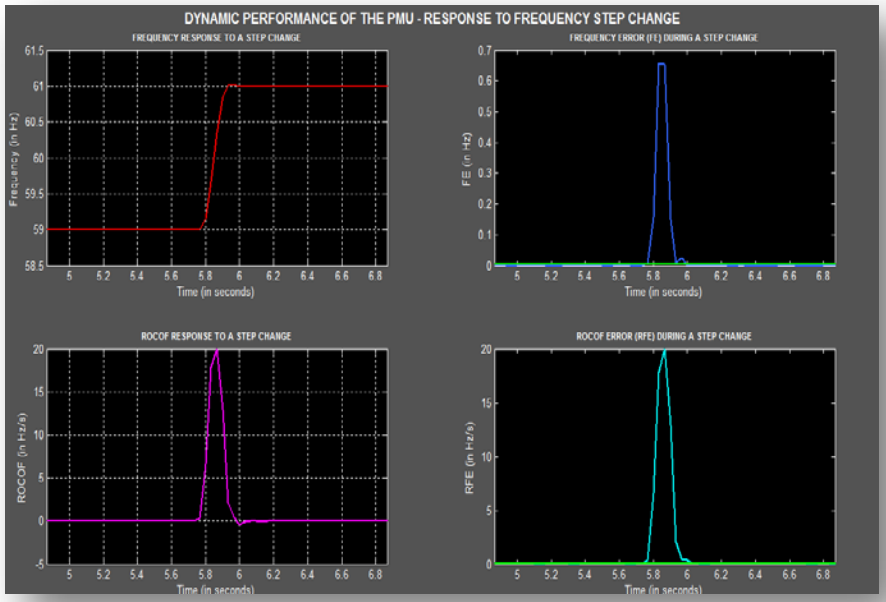
→ PMU performance varies drastically with system conditions for the same variation in the changing quantity

→ Detailed analysis of the test is available in the test report

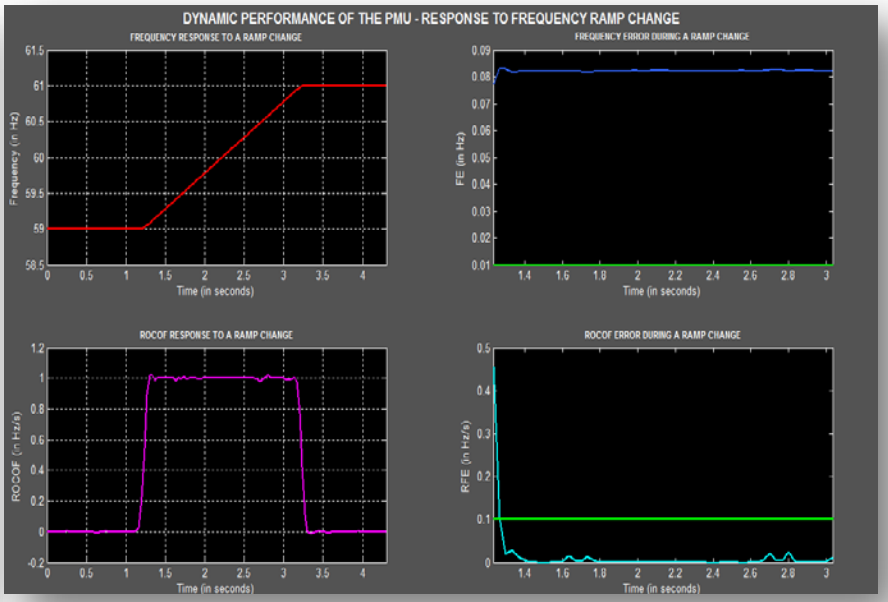
(3) A Sample of a Dynamic Test Condition & Result

→ Quantity changed: Frequency

Step Change in Frequency



Ramp Change in Frequency



→ Detailed analysis of the test is available in the test report

(4) A Sample of an Auto-generated PMU Test Report –

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Input Voltage Magnitude (in p.u.)	TVE of Phase-A (in percentage)	TVE of Phase-B (in percentage)	TVE of Phase-C (in percentage)
0.100	0.220	0.287	0.176
0.200	0.208	0.279	0.201
0.300	0.204	0.281	0.177
0.400	0.197	0.274	0.174
0.500	0.197	0.280	0.172
0.600	0.203	0.279	0.178
0.700	0.200	0.276	0.178
0.800	0.204	0.277	0.176
0.900	0.199	0.276	0.173
1.000	0.203	0.271	0.172
1.100	0.199	0.273	0.171
1.200	0.200	0.271	0.171
1.300	0.197	0.272	0.169
1.400	0.191	0.267	0.165
1.500	0.193	0.263	0.166
1.600	0.192	0.262	0.165
1.700	0.197	0.258	0.170
1.800	0.188	0.246	0.167
1.900	0.186	0.242	0.166
2.000	0.179	0.233	0.161

[A.2] Analysis of Average TVE in Voltage Phasor Measurement:

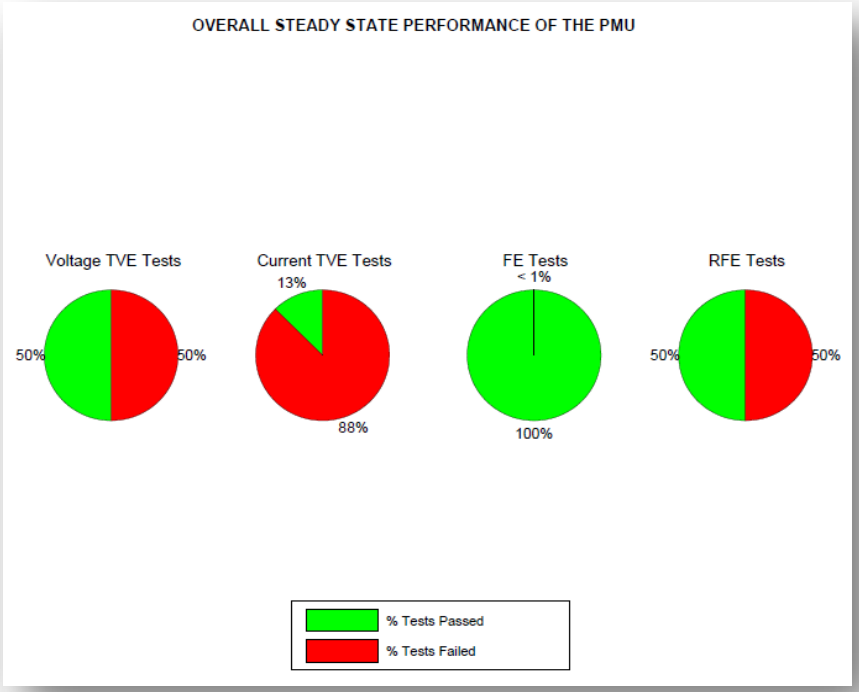
Average TVE of Phase-A (in percentage)	Average TVE of Phase-B (in percentage)	Average TVE of Phase-C (in percentage)	Standard Deviation of TVE of 3 Phases (in percentage)
0.198	0.268	0.172	0.042

[A.3] Analysis of Maximum TVE in Voltage Phasor Measurement:

Maximum TVE of Phase-A (in percentage)	Maximum TVE of Phase-B (in percentage)	Maximum TVE of Phase-C (in percentage)
0.220	0.287	0.201

[A.4] Verification of PMU Performance - Maximum TVE in Voltage Phasor Measurement:

Maximum TVE (in percentage)	Allowed Maximum TVE (in percentage)	Test Result (PASS / FAIL)
0.287	1.000	PASS



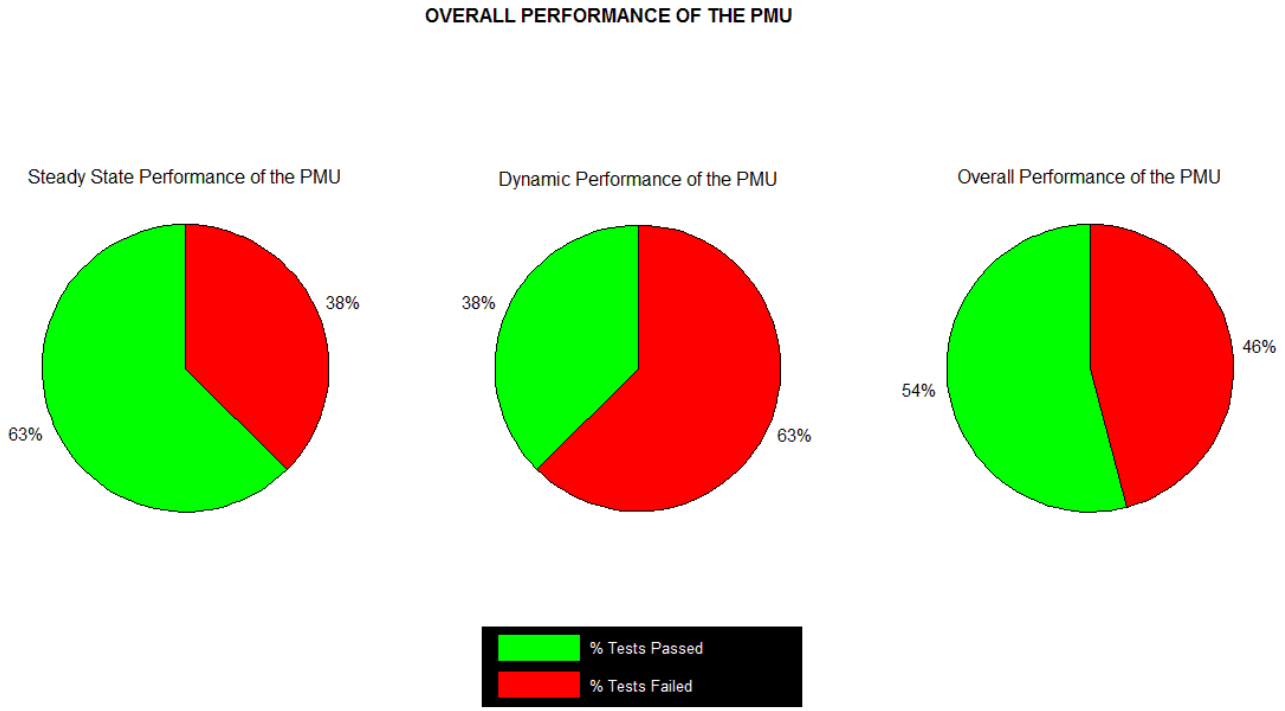
→ The PMU test report consists of:

(a) Detailed analysis of all the tests performed on the PMU in the form of text and corresponding figures

(b) Results in conformance with IEEE Standard C37.118.1

→ The PMU test report is very easy to interpret

(5) A Sample of the report showing Result of PMU test



[A.4] Verification of PMU Performance - Maximum TVE in Voltage Phasor Measurement:

Maximum TVE (in percentage)	Allowed Maximum TVE (in percentage)	Test Result (PASS / FAIL)
1.281	1.000	FAIL

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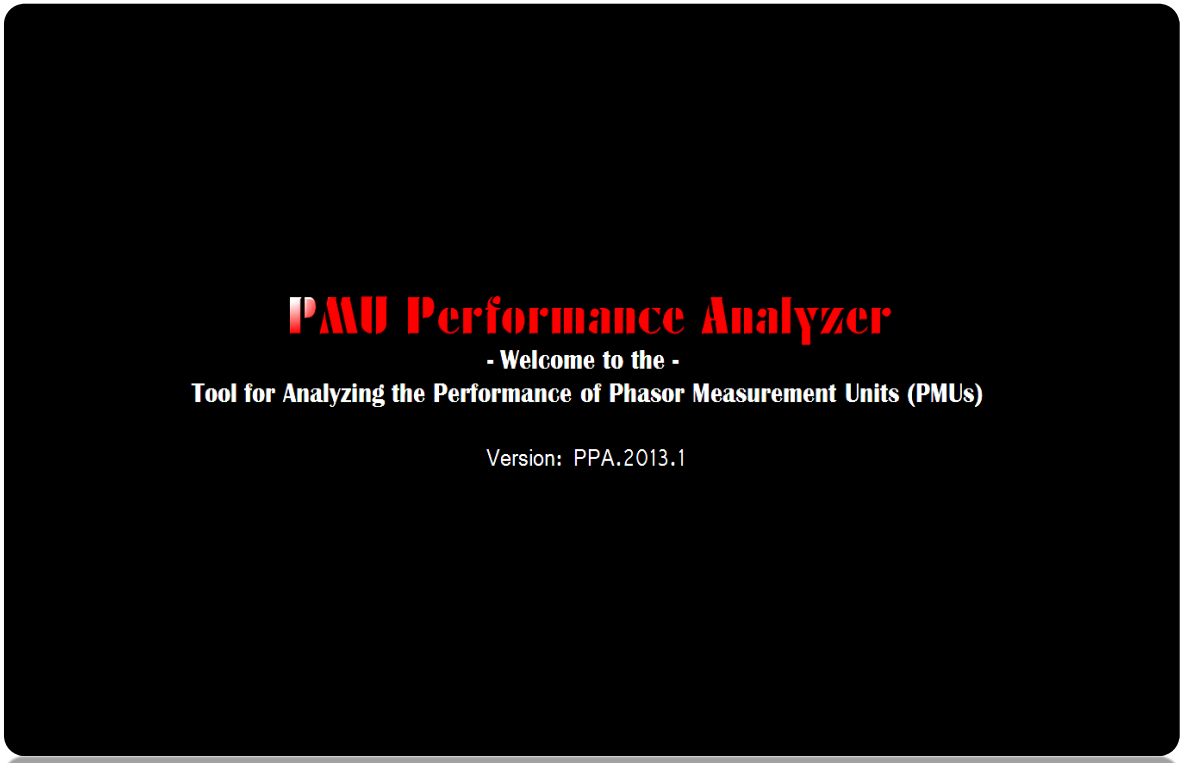
→ A new PMU performance testing tool has been developed

→ PPA can perform testing and reporting in very short time



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