

Phasor Measurement Unit (PMU) Performance Test Report for TESLA 4000

IEEE C37.118.1 – 2011 (IEEE C37.118.1a – 2014)

Introduction

This report summarizes PMU performance test results for the TESLA 4000 Digital Fault Recording System. Its PMU function was tested as per the latest synchrophasor standard IEEE C37.118.1-2011 (with IEEE C37.118.1a -2014 amendments) [1-2]. Testing was carried out using the automated test suite (PMU utility) available in RTDS [3] for both steady-state and dynamic test scenarios defined in [4], as listed below.

- Signal frequency range test
- Signal magnitude test (voltage and current)
- Phase angle test
- Harmonic distortion test
- Out-of-band interference test
- Measurement bandwidth
- Frequency ramp test
- Step response test

RTDS - Test Setup

Fig. 1 shows the test setup used for PMU performance evaluation. Test waveforms generated by the RTDS are sent to the PMU via the analog output cards (GTAO) and voltage/current amplifiers. The PMU utility software provides interfacing for the RTDS and the PMU under test. More details about the RTDS PMU utility can be found in [3].

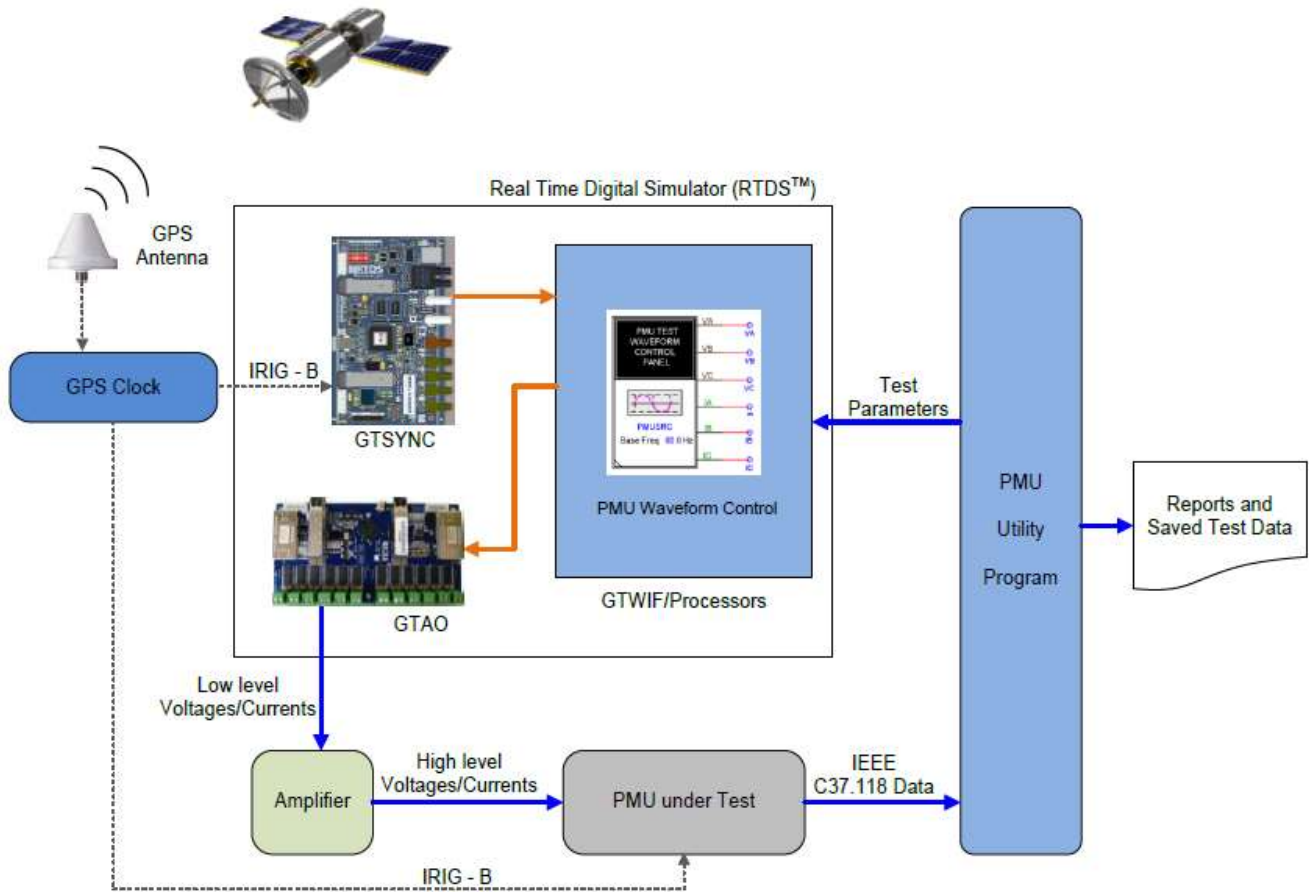


Fig.1: RTDS Test Setup [3]

Test Signals and Settings

Testing was performed for both 50Hz and 60 Hz signals. Basic test configurations and setting used during this testing are summarized in Table-1. Testing is repeated for both P class and M class case studies.

Table-1: Test Configurations and Settings

Description	50 Hz Settings	60 Hz Settings
Voltage (sec/primary)	69.0 V/ 69.0 kV	69.0 V/ 69.0 kV
Current(sec/primary)	5.0 A/ 5.0 kA	5.0 A/ 5.0 kA
PMU reporting rate	50 samples per sec	60 samples per sec
Signal sampling rate	128 samples per cycle	96 samples per cycle

Results

Steady-State Synchrophasor Measurement Test

Status: **Pass**

Table D.2: Steady-state synchrophasor measurement standard requirements and test results							
Influence quantity	Reference condition	Minimum range of influence quantity over which PMU shall be within given TVE limit					
		Performance – P class			Performance – M class		
		Range	Max. TVE %		Range	Max. TVE %	
			Standard Requirements	Results 50/60Hz		Standard Requirements	Results 50/60Hz
f_{dev} where $f_n = f_0 \pm f_{dev}$	Frequency = f_0 ($f_{nominal}$)	± 2.0 Hz	1	0.397-0.379/ 0.245-0.296	± 2.0 Hz for $F_s < 10$ $\pm F_s/5$ for $10 \leq F_s < 25$ ± 5.0 Hz for $F_s \geq 25$	1	0.508-0.655/ 0.210-0.256
Voltage	100% rated	80% – 120% rated	1	0.061-0.063/ 0.045-0.056	10% – 120% rated	1	0.663-0.039/ 0.69-0.059
Current	100% rated	10% – 200% rated	1	0.062-0.379/ 0.055-0.076	10% – 200% rated	1	0.023-0.047/ 0.0051-0.010
Phase angle	Constant or slowly varying angle	$\pm \pi$ radians	1	0.056/0.042	$\pm \pi$ radians	1	0.030/0.021
Harmonic distortion (single harmonic)	< 0.2% (THD)	1%. each harmonic up to 50 th	1	0.058-0.053/ 0.050-0.048	10% each harmonic up to 50 th	1	0.079-0.076
Out of band interference	< 0.2% of input signal magnitude		None	None	10% of input signal magnitude for $F_s \geq 10$. No requirement for $F_s < 10$.	1.3	1.018/1.033

Steady-State Frequency and ROCOF Test

Status: **Pass**

Table D.3: Steady-state frequency and ROCOF measurement requirements and test results									
Influence quantity	Reference condition	Error requirements for compliance							
		P class				M class			
Signal frequency	Frequency = f_0 (f_{nominal}) Phase angle constant	Range: $f_0 \pm 2.0$ Hz				Range: $f_0 \pm 2.0$ Hz for $F_s \leq 10$ $\pm F_s/5$ for $10 \leq F_s < 25$ ± 5.0 Hz for $F_s \geq 25$			
		Max. FE		Max. RFE		Max. FE		Max. RFE	
		Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz
		0.005 Hz	0.003/0.002	0.4 Hz/s	0.12/0.04	0.005 Hz	0.034/0.003	0.1 Hz/s	0.07/0.02
Harmonic distortion (single harmonic)	< 0.2% THD	Range: 1%. each harmonic up to 50 th				Range: 10%. each harmonic up to 50 th			
	$F_s > 20$	0.005 Hz	0.0008/0.001	0.4 Hz/s	0.102/0.02	0.025 Hz	0.0005/0.007	None	None
	$F_s \leq 20$	0.005 Hz	-	0.4 Hz/s	-	0.005 Hz	-	None	None
Out-of-band interference	< 0.2% of input signal magnitude	Range: No requirements				Range: Interfering signal 10% of signal magnitude			
		None	None	None	None	0.01 Hz	0.003	None	None

Table D.4: Synchrophasor measurement bandwidth requirements and test results using modulated test signals							
Modulation level	Reference condition	Minimum range of influence quantity over which PMU shall be within given TVE limit					
		P class			M class		
		Range	Max. TVE		Range	Max. TVE	
			Standard requirements	Results 50/60Hz		Standard requirements	Results 50/60Hz
$k_x = 0.1$ $k_a = 0$	100% rated signal magnitude. $f_{nominal}$	Modulation frequency 0.1 to lesser of $F_s/10$ or 2 Hz	3%	0.13/ 0.150	Modulation frequency 0.1 to lesser of $F_s/5$ or 5 Hz	3%	0.195/ 1.24
$k_x = 0$ $k_a = 0.1$	100% rated signal magnitude. $f_{nominal}$		3%	0.082/ 0.072		3%	0.2/ 0.4

Table D.5: Frequency and ROCOF performance requirements and test results under modulation tests										
F and ROCOF performance limits		Error requirements for compliance								
		P class				M class				
Reporting rate F_s Hz	F_r Hz	Max. FE		Max. RFE		F_r Hz	Max. FE		Max. RFE	
		Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz		Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz
50	2	0.06	0.002	2.3	0.061	5	0.30	0.192	14	10.41
60	2	0.06	0.011	2.3	1.45	5	0.30	0.015	14	1.56
Formulas	$\min(F_s/10.2)$	$0.03 \times F_r$		$0.18 \times \pi \times F_r^2$		$\min(F_s/5.5)$	$0.06 \times F_r$		$0.18 \times \pi \times F_r^2$	

Frequency Ramp Test

Status: **Pass**

Table D.6: Synchrophasor performance requirements and test results under frequency ramp tests							
Test signal	Reference condition	influence quantity test limits over which PMU shall be within given TVE limit					
		Ramp rate (Rf) (positive and negative ramp)	Performance class	Exclusion interval	Ramp range	Max. TVE	
						Standard req.	Results 50/60Hz
Linear frequency ramp	100% rated signal magnitude, and $f_{nominal}$ at a non-excluded point during the test	± 1.0 Hz/s	P class	Larger of $2/F_s$ or $2/f_0$	± 2 Hz	1%	0.377/ 0.314
			M class	Larger of $7/F_s$ or $7/f_0$	Lesser of $\pm(F_s/5)$ Hz or ± 5 Hz	1%	0.837/ 0.628

Table D.7: Frequency and ROCOF performance requirements and test results under frequency ramp tests										
Signal specification	Reference condition	Exclusion interval	Error requirements for compliance							
			P class				M class			
Ramp tests – Linear frequency ramp	100% rated signal magnitude and 0 radian base angle	Same as specified in Table 6	Max. FE		Max. RFE		Max. FE		Max. RFE	
			Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz
			0.01 Hz	0.001/ 0.001	0.4 Hz/s	0.392/ 0.201	0.01 Hz	0.009/ 0.008	0.2 Hz/s	0.083/ 0.053

Table D.8: Phasor performance requirements and test results for input step change													
Step change spec.	Ref. condition	Maximum response time, delay time, and overshoot											
		P class						M class					
		Response time (s)		Delay time		Max. Overshoot/undershoot		Response time (s)		Delay time		Max. overshoot/undershoot	
		Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz	Standard requirements	Results 50/60Hz
Magnitude = $\pm 10\%$. $k_x = \pm 0.1$. $k_a = 0$	All test conditions nominal at start or end of step	$2/f_0$	0.0025/ 0.01877	$1/(4 \times F_s)$	0.00212/ 0.00304	5% of step magnitude	0.65/ 0.33	Larger of $7/F_s$ or $7/f_0$	0.0282/ 0.024	$1/(4 \times F_s)$	0.002/0.0018	10% of step magnitude	3.63/ 3.71
Angle $\pm 10^\circ$. $k_x = 0$. $k_a = \pm \pi/18$	All test conditions nominal at start or end of step	$2/f_0$	0.023/ 0.02051	$1/(4 \times F_s)$	0.00041/ 0.00150	5% of step magnitude	0.25/ 0.21	Larger of $7/F_s$ or $7/f_0$	0.0332/ 0.038	$1/(4 \times F_s)$	0.0004/ 0.0013	10% of step magnitude	3.55/ 5.81

Table D.9: Frequency and ROCOF performance requirements and test results for input step change									
Signal specification	Reference condition	Maximum susceptibility response time							
		P class				M class			
		Frequency response time		ROCOF response time		Frequency response time		ROCOF response time	
		Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz	Standard req.	Results 50/60Hz
Magnitude test as in Table 8	Same as in Table 8	$4.5/f_0$	0.0839/ 0.063	$6/f_0$	0.016/ 0.075	Greater of $14/F_s$ or $14/f_0$	0.086/ 0.079	Greater of $14/F_s$ or $14/f_0$	0.093/ 0.085
Phase test as in Table 8	Same as in Table 8	$4.5/f_0$	0.086/ 0.058	$6/f_0$	0.017/ 0.049	Greater of $14/F_s$ or $14/f_0$	0.048793/ 0.121	Greater of $14/F_s$ or $14/f_0$	0.047/ 0.033

Table D.10: PMU reporting latency and test requirements		
Performance class	Maximum PMU reporting latency(s)	
	Standard requirements	Results 50/60Hz
P class	Greater of $2/F_s$ or $2/f_0$	< 2 cycles 40 ms (for 50 Hz, 50fps) 33.3 ms (for 60 Hz, 60 fps)
M class	Greater of $7/F_s$ or $7/f_0$	<6.5 cycles 130 ms (for 50 Hz, 50fps) 108.3 ms (for 60 Hz, 60 fps)
Note: Latency is limited by the need to include at least one cycle of the power system waveform for synchrophasor calculation.		

References

- [1] IEEE Standard for Synchrophasors for Power Systems, IEEE Standard C37.118.1-2011, Dec. 2011.
- [2] IEEE Standard for Synchrophasors for Power Systems (Amendment 1: Modification of Selected Performance Requirements), IEEE Standard C37.118.1a-2014, Apr. 2014.
- [3] D.Gurusinghe, D. Ouellette and R. Kuffel, "An Automated Test Setup for Performance Evaluation of a Phasor Measurement Unit", PAC World Conference 2016, Ljubljana, Slovenia.
- [4] IEEE Synchrophasor Measurement Test Suite Specification, IEEE Standard Association, Dec. 2014.