Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control

CIGRE REPORT

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ENGINEERING
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NASPI North American SynchroPhasor Initiative

Background about CIGRE

- Organization:
  - Conseil International des Grands Réseaux Électriques (International Council on Large Electric Systems)
  - Established in Paris in 1921; 15,000 members from over 90 countries
  - Study Committee B5 (Protection and Automation)
- WG groups of interest:
  - WG B5.62, Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control
  - WG C2.18, Wide Area Monitoring Protection and Control Systems – Decision Support for System Operators
  - JWG C4-C2.62-IEEE, Review of Advancements in Synchrophasor Measurement Applications

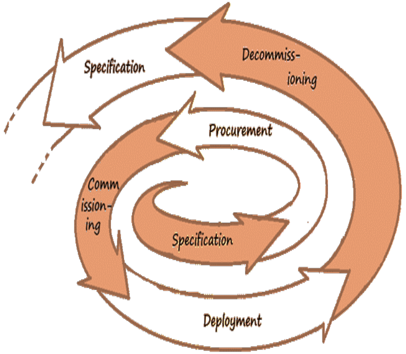
1. Introduction to Life-cycle Management
2. CIGRE WG B5.62
3. Standards and Practices
4. Integration Requirements
5. Life-cycle Requirements
6. Recommendations and Next Steps

Life-Cycle Management: Spiral Model

Why is needed?

- Equipment not tested before purchase
- Inappropriate installation
- Insufficient maintenance
- Improving monitoring, control and protection performance

How it looks?

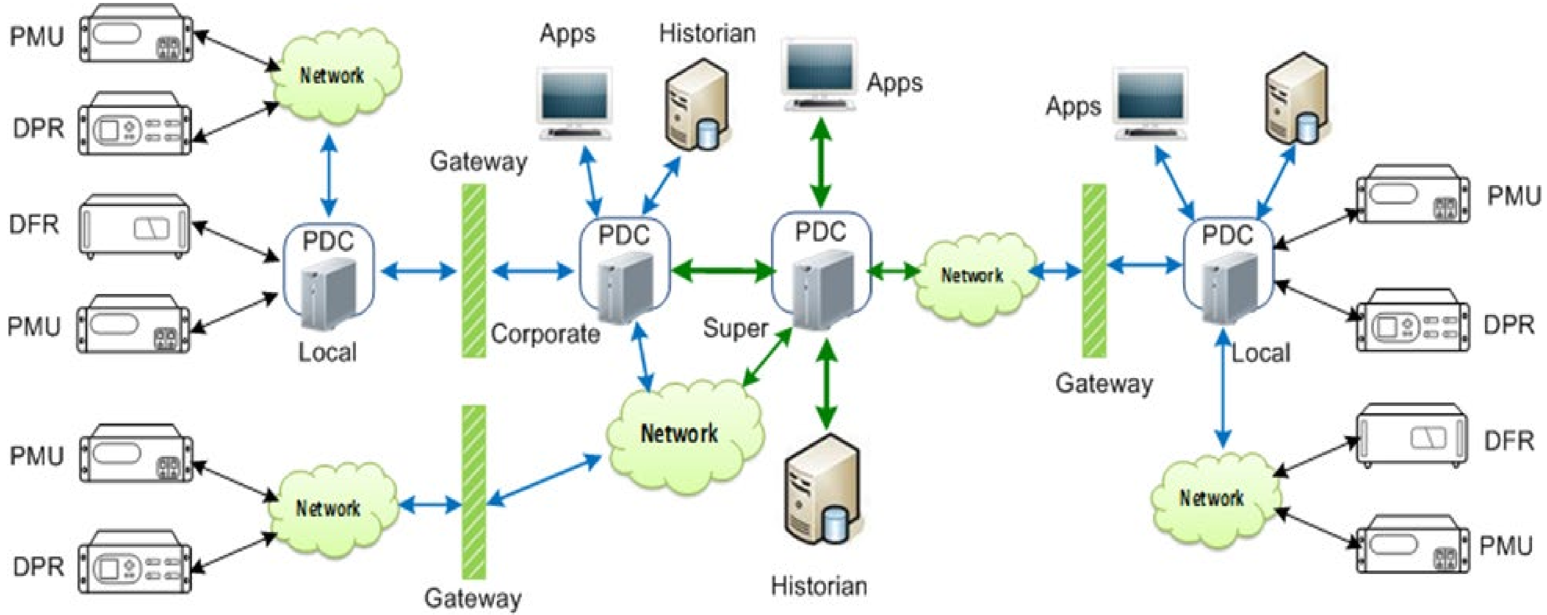


What it covers?

- Equipment testing and/or certification before purchase
- System commissioning
- Periodic field testing
- Continuous hidden failure checking
- Operator awareness of system *QoS* deterioration

Spiral Life-Cycle Management

Synhrophasor System: Architecture



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CIGRE WG B5.62

WG host: Study Committee B5 “Protection and Automation”

Working Group Members (report contributors):

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WG Activity: 2017-2020; Final Report and Electra article to be published in 2021

Relationship to IEEE work: PC37.242™/D5 “Draft Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control”

CIGRE WG B5.62: Terms of Reference-Questions

- What are the existing PMU and Synchrophasor system standards, and what is their impact on testing and certification?
- What is the importance of the concept of interoperability and why it matters?
- Why the certification may be needed and who is authorized to do it?
- How certification may be accomplished and what are associated costs?
- What are acceptance, commissioning, periodic maintenance and troubleshooting test procedures and how do they relate to the life-cycle management of synchrophasor systems?
- Why such life cycle test procedures matter and how they are implemented today?
- How to plan for the PMU certification and the lifecycle testing of PMUs and Synchrophasor Systems?

CIGRE WG B5.62: Terms of Reference-Deliverable

Discussion of the standards and interoperability requirements to be observed when implementing the testing and certification process.

The role of components and end-to-end testing of Synchrophasor Systems in the field and assessment of impact of errors on the synchrophasor applications

The role of testing, field evaluation and troubleshooting for PMUs and Synchrophasor Systems, as well as related support tools for the infrastructure lifecycle management

Guidelines for proposed testing requirements/specification

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Standards and Practices

Standards

- IEEE C37.118.1a-2014.
- IEC/IEEE 60255-118-1 Edition 1.0 2018-12.
- IEC/IEEE 61850-9-3-2016
- IEEE C37.238-2017
- IEEE P2030.101-2018
- IEEE C37.242-2013 (Rev 2021 was not discuss)

Practices

- Brazil
- China
- Finland
- India
- Russia
- USA

Practices-Brazil

EVOLUTION OF FIRMWARE OF A PMU				
ID	FIRST	SECOND	THIRD	Label
1				SteadyState/FreqResp/TVE
2				SteadyState/FreqResp/Fe
3				SteadyState/FreqResp/RFe
4				SteadyState/Harmonics/TVE
5				SteadyState/Harmonics/Fe
6				SteadyState/Harmonics/RFe
7				SteadyState/InterHarmonics/TVE
8				SteadyState/InterHarmonics/Fe
9				SteadyState/InterHarmonics/RFe
10				SteadyState/Mag/TVE
11				SteadyState/Mag/Fe
12				SteadyState/Mag/RFe
13				Ramp/ramp/TVE
14				Ramp/ramp/Fe
15				Ramp/ramp/RFe
16				Modulation/Phase/TVE
17				Modulation/Phase/Fe
18				Modulation/Phase/RFe
19				Modulation/Amplitude/TVE
20				Modulation/Amplitude/Fe
21				Modulation/Amplitude/RFe
22				Modulation/Combined/TVE
23				Modulation/Combined/Fe
24				Modulation/Combined/RFe
25				Step/Phase/PhasorRespTime
26				Step/Phase/PhasorDelayTime
27				Step/Phase/PhaseOvershoot
28				Step/Phase/FreqRespTime
29				Step/Phase/ROCOFRespTime
30				Step/Phase/FreqOverShoot
31				Step/Phase/ROCOFOvershoot
32				Step/Phase/AmplOvershoot
33				Step/Amplitude/PhasorRespTime
34				Step/Amplitude/PhasorDelayTime
35				Step/Amplitude/PhaseOvershoot
36				Step/Amplitude/FreqRespTime
37				Step/Amplitude/ROCOFRespTime
38				Step/Amplitude/FreqOverShoot
39				Step/Amplitude/ROCOFOvershoot
40				Step/Amplitude/AmplOvershoot
41				Latency

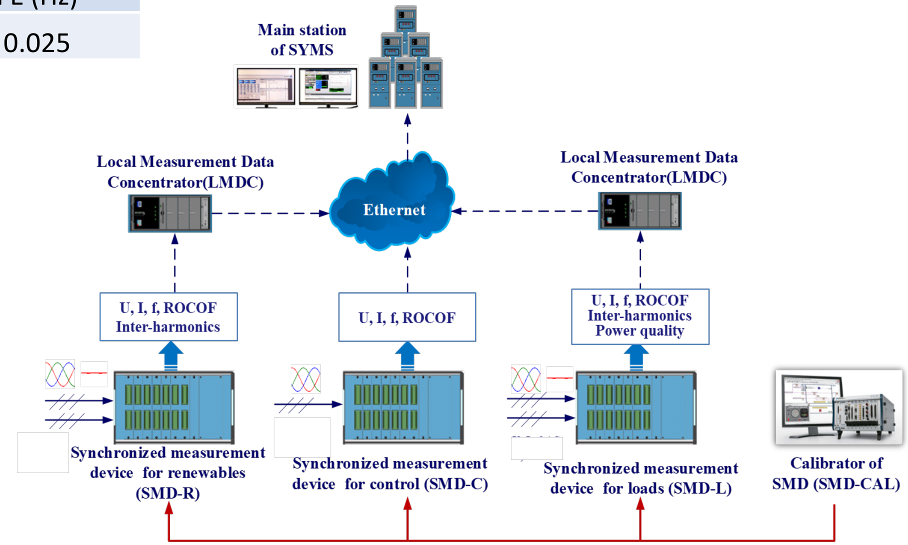
Practices-China

Δf (Hz)	AE (%)	PE (°) for voltage	PE (°) for current	FE (Hz)	RFE (Hz/s)
1	0.2	0.2	0.5	0.002	0.01
5		0.5	1		

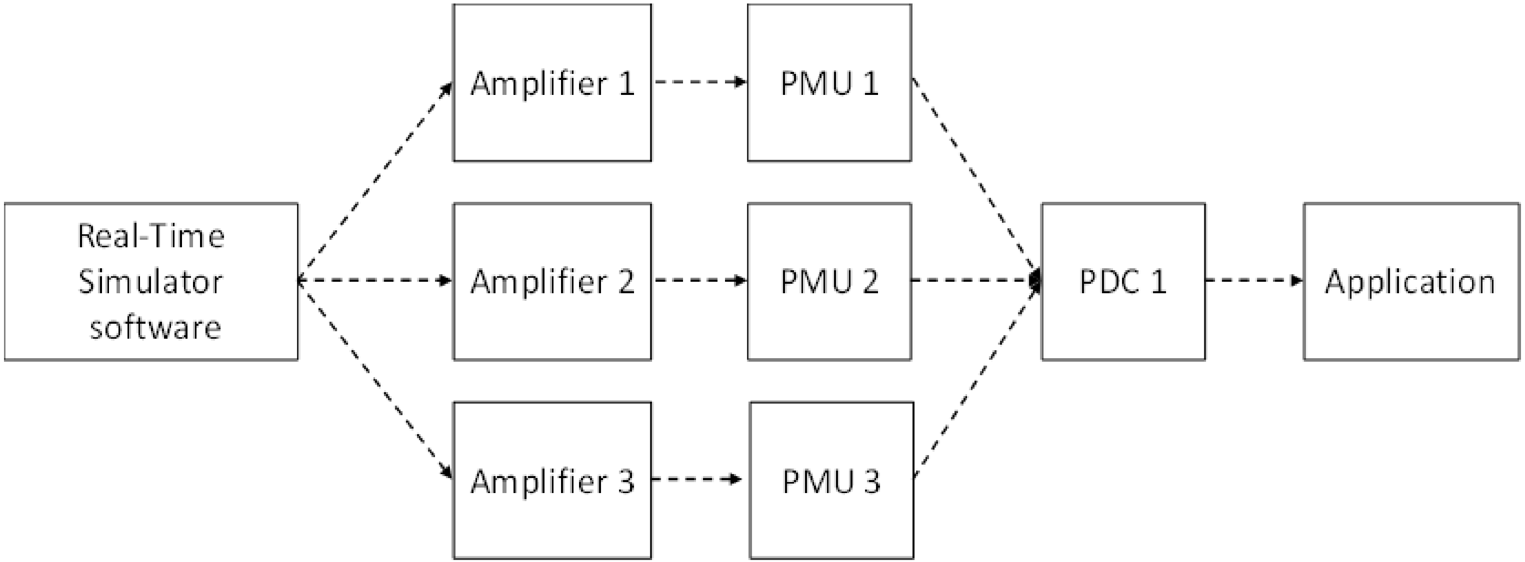
Report rate (Hz)	Out-of-band range (Hz)	AE (%)	PE (°)	FE (Hz)
100	100 ～150	0.5	1	0.025

Test conditions	AE (%)	PE (°)	FE (Hz)	RFE (Hz/s)
$0.0U_n \leq U < 0.5U_n$	0.2	0.5	0.002	0.01
$0.5U_n \leq U < 1.2U_n$		0.2		
$0.0I_n \leq I < 0.2I_n$	0.2	1	—	
$0.2I_n \leq I < 1.2I_n$		0.5		

Report rate (Hz)	Response time (ms)			
	Amplitude	Phase	Frequency	ROCOF
50	140	140	280	280
100	70	70	280	280



Practices-Finland



Practices-India

Test Nos	DESCRIPTION OF THE TEST	Type test	Routine test	Field test
	FUNCTIONAL TESTS FOR PMU			
1.	Check for BOQ, Technical details, Construction & Wiring as per PMU drawings	√	√	√
2.	Check for PMU database & configuration settings	√	√	√
3.	Check the operation of all Analog inputs, Digital and Status input points of PMU	√	√	√
4.	Check operation of all communication ports of PMU	√	√	√
5.	Check for communication between PMU and PDC	√		√
6.	Test for downloading of PMU database from PDC	√		√
7.	Test for PMU time synchronization from GPS	√		√
8.	Test Power Supply Voltage Margin, Ripple Levels and Short Circuit Protection	√		
9.	Test for PMU operation with DC power supply voltage variation	√		
10.	Check for auto restoration of PMU on DC power recovery after its failure	√	√	√
11.	Test for PMU diagnostic feature	√		
12.	Accuracy tests as per IEEE C37.118	√		
13.	Test for PMU internal Clock stability	√		
14.	Test for Peak-Peak variation in PMU measurement Noise: During each Step of the Steady State	√		

Practices-Russia

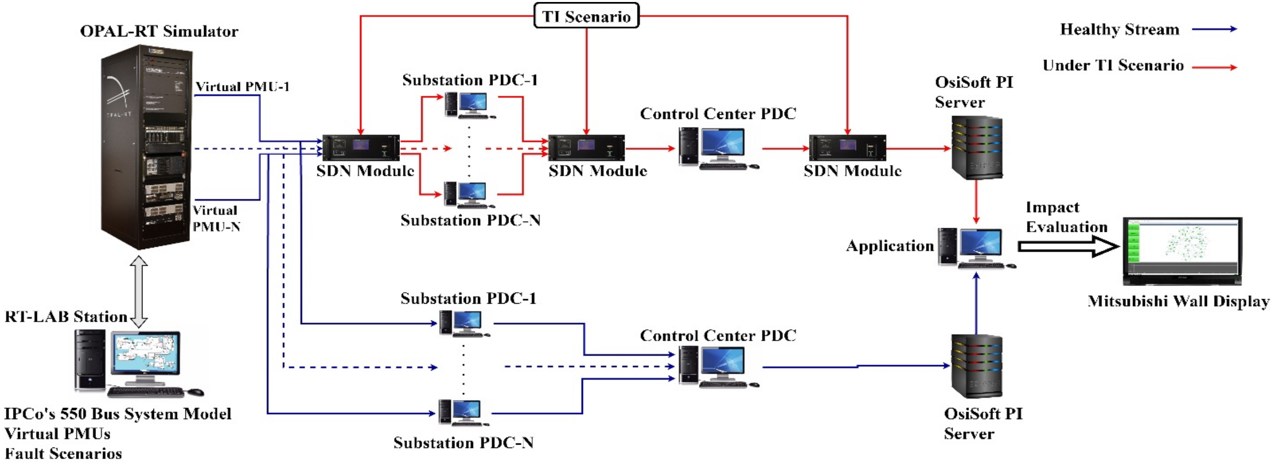
The PMU shall perform measurements of the following parameters:

- the phasors of phase-to-phase voltages, where the modulus is the effective value of the fundamental harmonic of the phase-to-phase voltage (U_a, U_b, U_c), and the phase angle is the corresponding absolute angle (δ_{Ua}, δ_{Ub}, δ_{Uc});
- the phase-to-phase phasors, where the modulus is the effective value of the fundamental harmonic of the phase-to-phase current (I_a, I_b, I_c), and the phase angle is the corresponding absolute angle (δ_{Ia}, δ_{Ib}, δ_{Ic});
- frequency of phase-to-phase and direct sequence (f_a, f_b, f_c, f_{U1});
- frequency change rate (df_a/ dt, df_b/dt, df_c/dt).

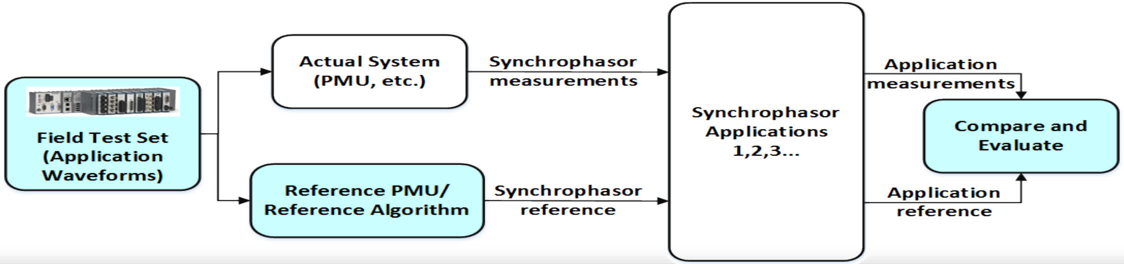
If it is necessary to measure the parameters of the generators excitation system, the following measurements shall be implemented:

- excitation voltage (rotor voltages) of the generator (U_f);
- excitation current (rotor current) of the generator (I_f);
- excitation voltage of the exciter (U_{ff});
- excitation current of the exciter (I_{ff}).

Practices-USA



Lab Tests



Field Tests

Integration Requirements

- Interoperability and interchangeability
- Calibration and certification
- Component and end-to-end testing
- Backward compatibility and interoperability
- Conclusions: Discussion at what lifecycle stage the above matters and how is it verified

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Life-cycle Requirements

Existing testing steps:

- China: Commissioning, periodic, troubleshooting
- Finland: commissioning, periodic
- Russia: System of Voluntary Certification
- Brazil: steady state, dynamic and latency tests

Existing testing practices:

- Some certification test were performed in all the countries

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Recommendations

Future Testing Protocols:

- The IEEE standard IEEE C37.242-2013 (revised in 2021) should be used. National standards with improved requirements should also be adopted

Future testing tools and methodologies:

- In-service testing tools are not fully available, and end-to-end testing procedures are not well defined

Staff training:

- In most instances, staff dedicated to synchrophasor system testing is very limited. Training programs in collaboration with academia are recommended

Distribution application of synchrophasor systems:

- This area is rapidly expanding and yet the performance requirements are quite different. Forming a WG to address this issues is recommended

Future Requirements

- Optical CT and PT with built-in PMUs
- Ultra-fast devices
- Higher reporting rate devices
- Include odd and even harmonics
- PMU with alternative/backup Timing Source
- Portable devices
- Non-contact measurement
- Multifunctional units

Next Steps

End users should persist in looking at the synchrophasor systems in a holistic way by defining the life-cycle test and calibration procedures. If such proceedings are not in place, they should be developed

Vendors should be ready to offer and perform interoperability tests as needed to verify that end-to-end legacy systems may be upgraded with a variety of products on the market going forward.

Standards organizations should develop procedures for application testing that will also encompass end-to-end testing of the underlying synchrophasor infrastructure.

Consultants, vendors, and academic researchers should look into the fundamentals needed to better understand the synchrophasor system performance under transient conditions and recommend adequate calibration and test procedures beyond what is currently defined in the standards.

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