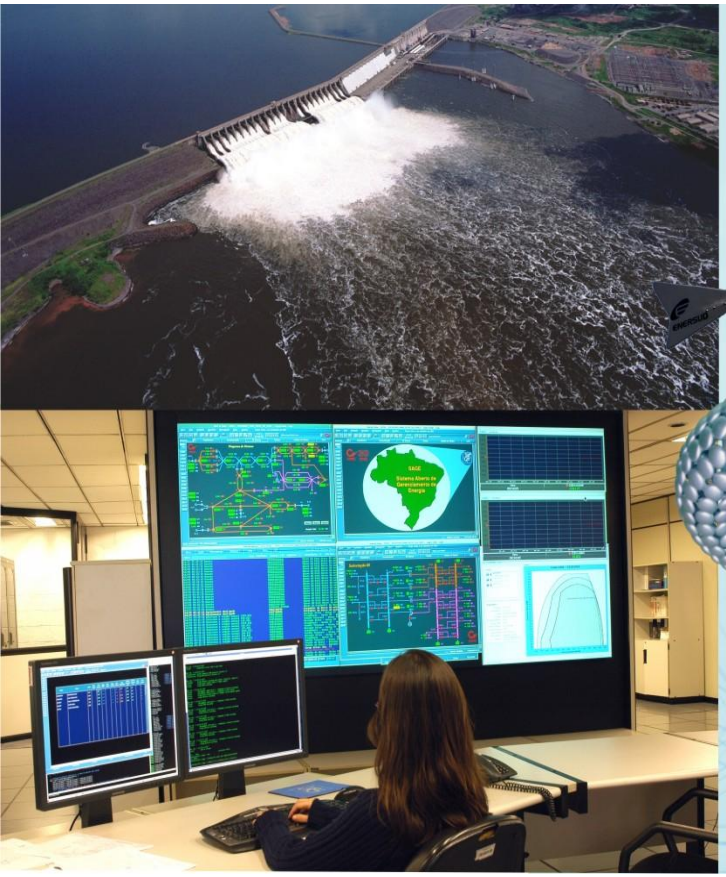
Electric Energy Research Center – Cepel



Performance Testing of Phasor Measurement Units at CEPEL's LabPMU

José Eduardo Alves Jr.

Distribution Technology Department - DTD

Prologue

When you have better measurements,

You will enhance the monitoring and control.

Prologue

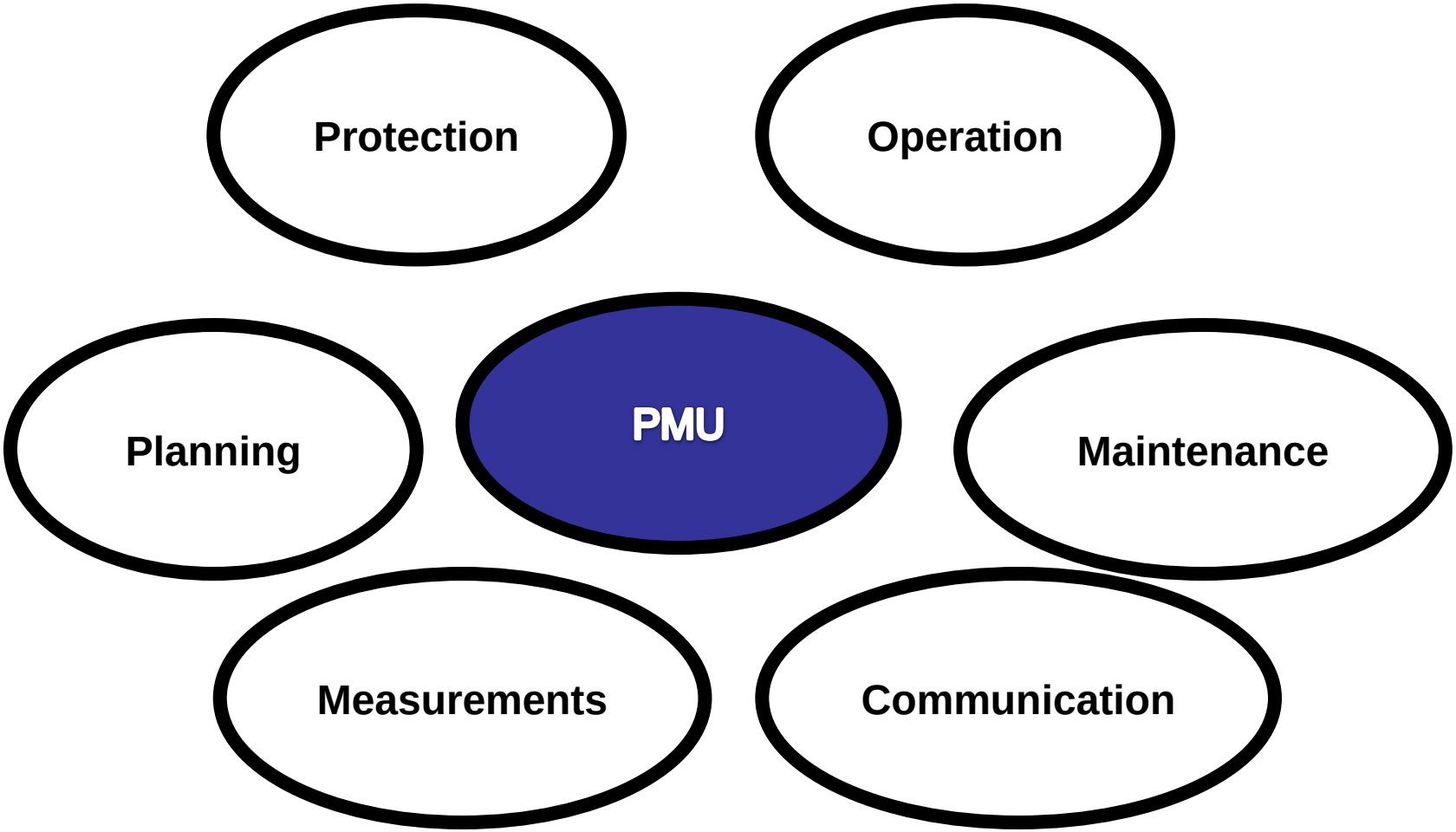

Protection
Operation
Planning
PMU
Maintenance
Measurements
Communication

Table of Contents

Introduction

Laboratory for studying Synchrophasor Systems

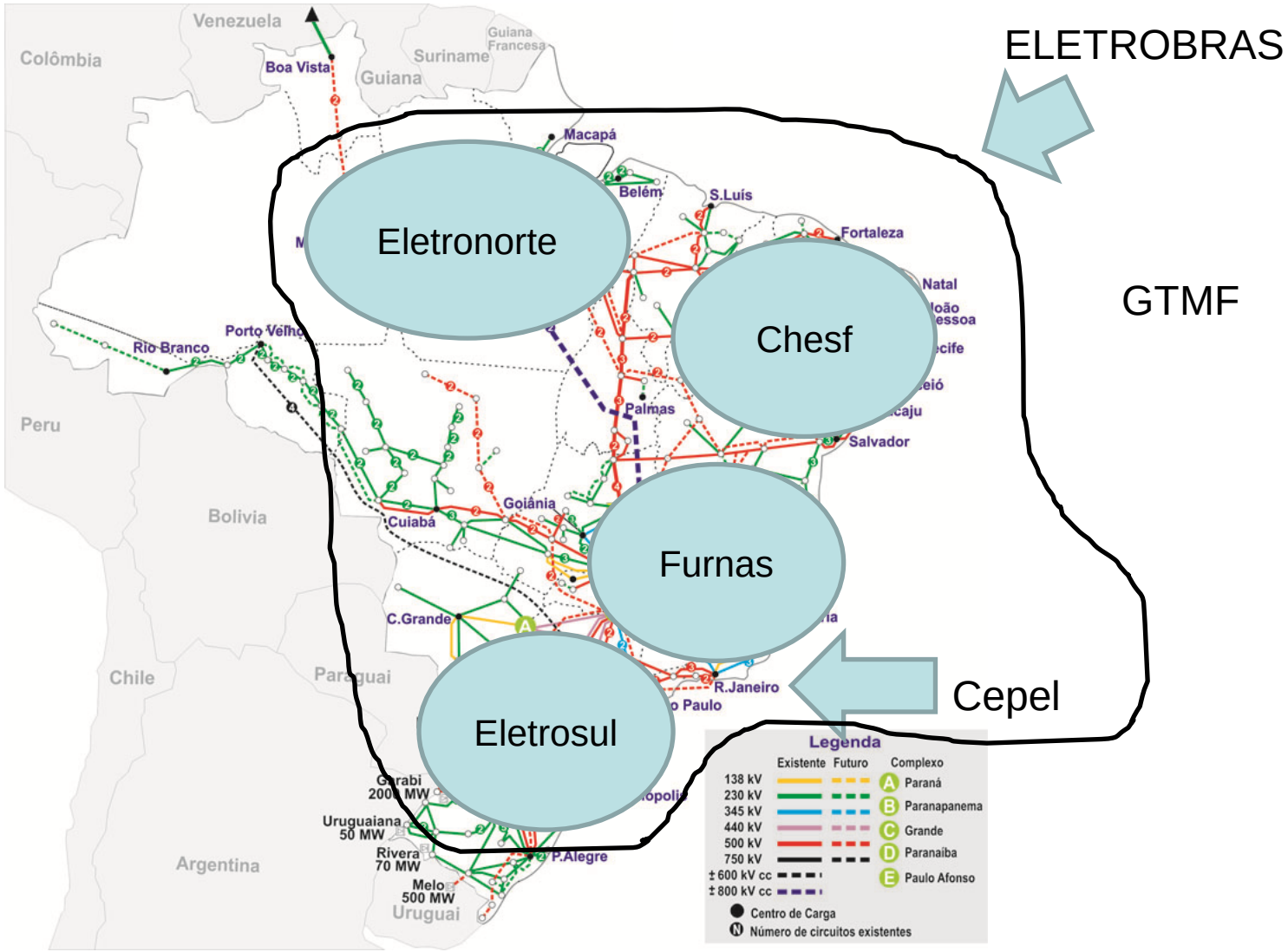
Introduction

Objective

- Enhance the degree of security and flexibility in the operation of the National Interconnected System, assisting the Ministry of Mines and Energy – MME, ELETROBRAS and other entities involved in the planning, operation and maintenance of generation and transmission electric network system.

Introduction

Brazilian Electric System



Benefits of LabPMU for ELETROBRAS

- The use of synchrophasors is a emerging technology that needs practical validation. In that sense LabPMU is helping GTMF (Grupo de Estudos de Medição Fasorial), a study group among ELETROBRAS transmission utilities dedicated to study Synchrophasor's Technology

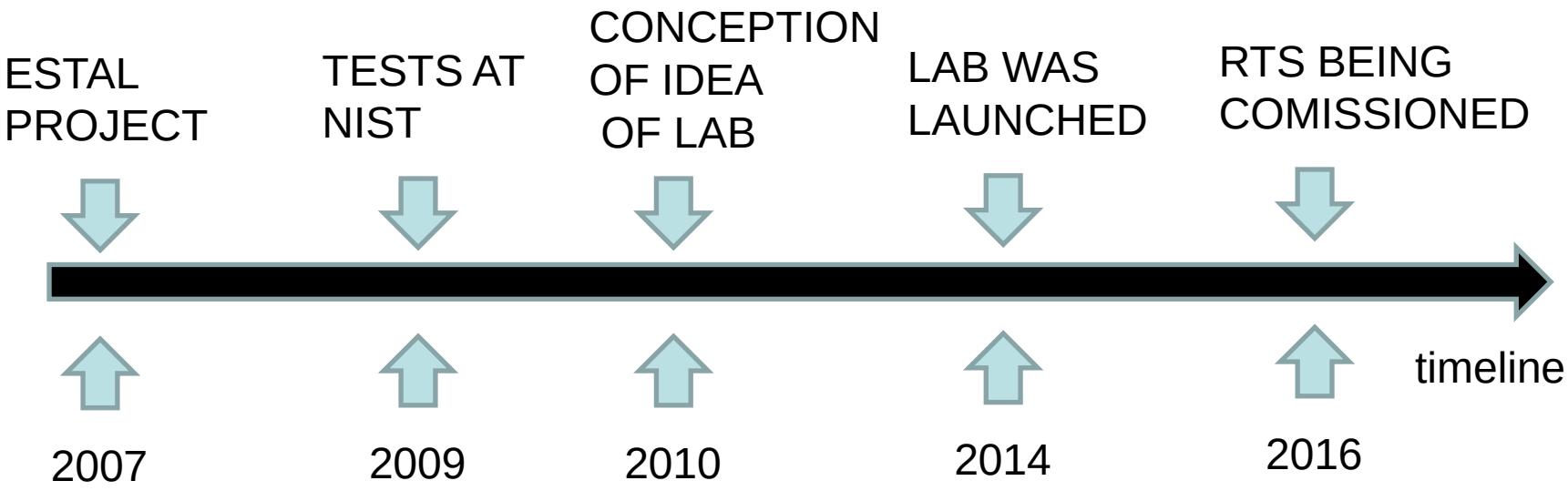
Eletrobras Cepel

Activities

- Provide a platform to verify the performance of PMUs units and their adequacy to the international standards (already in operation);
- Provide a platform to test computer applications developed by Cepel or by companies through various types of power system simulation;
- Explore the technology verifying new solutions based on existing synchronization by GPS.

Introduction

PMUs at Cepel



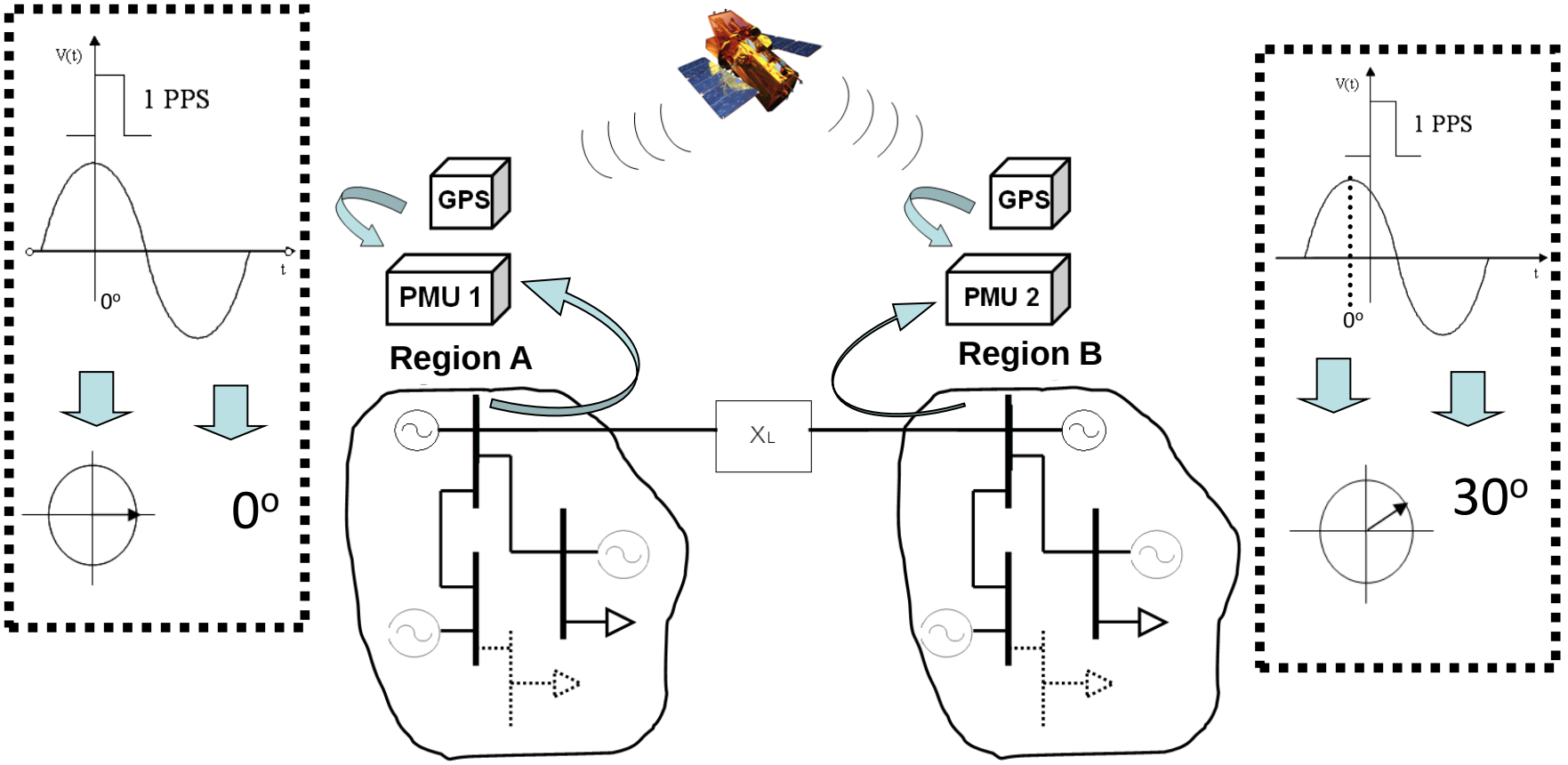
Concepts

Eletrobras Cepel

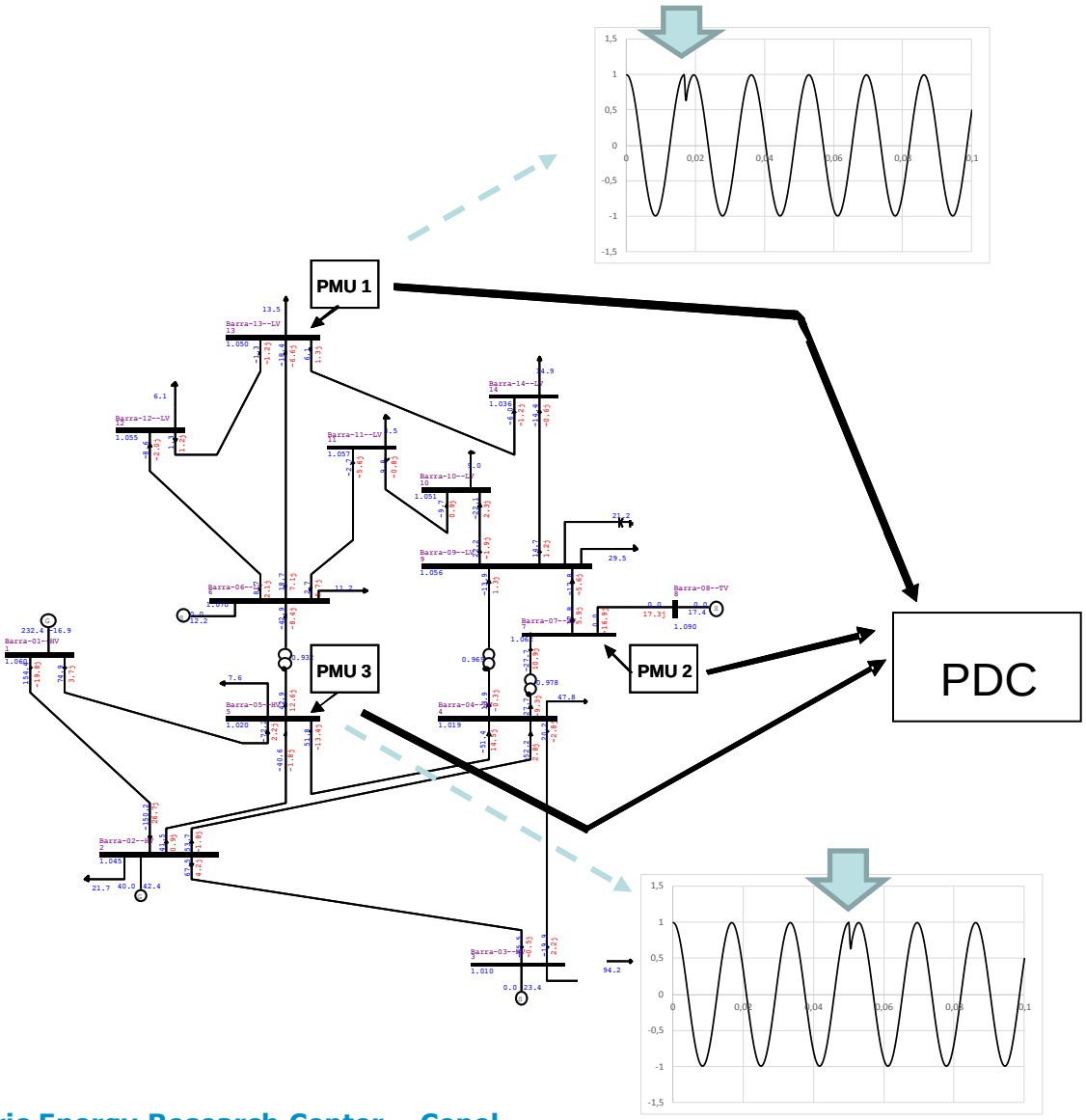
– Scope & Benefits Of Synchrophasors

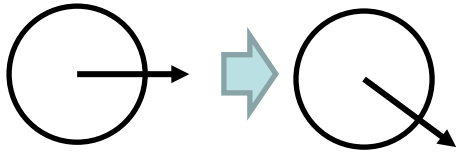
- The use of a robust and reliable system of area measurement (Wide-Area Measurement System – WAMS) is able to provide the system operator with better overview of the electric grid, based on synchrophasor measurements (situational awareness):
- Improve network safety and flexibility;
- Allow observability of oscillations in the power grid reducing the number of blackouts;
- Improve detection of dangerous situations;
- In the future the phasor generated by PMU units can be used in “Special Protection Systems” improving the protection of the network.

Concepts


V(t)
1 PPS
0º
t
0º
GPS
PMU 1
Region A
GPS
PMU 2
Region B
XL
V(t)
1 PPS
0º
t
30º

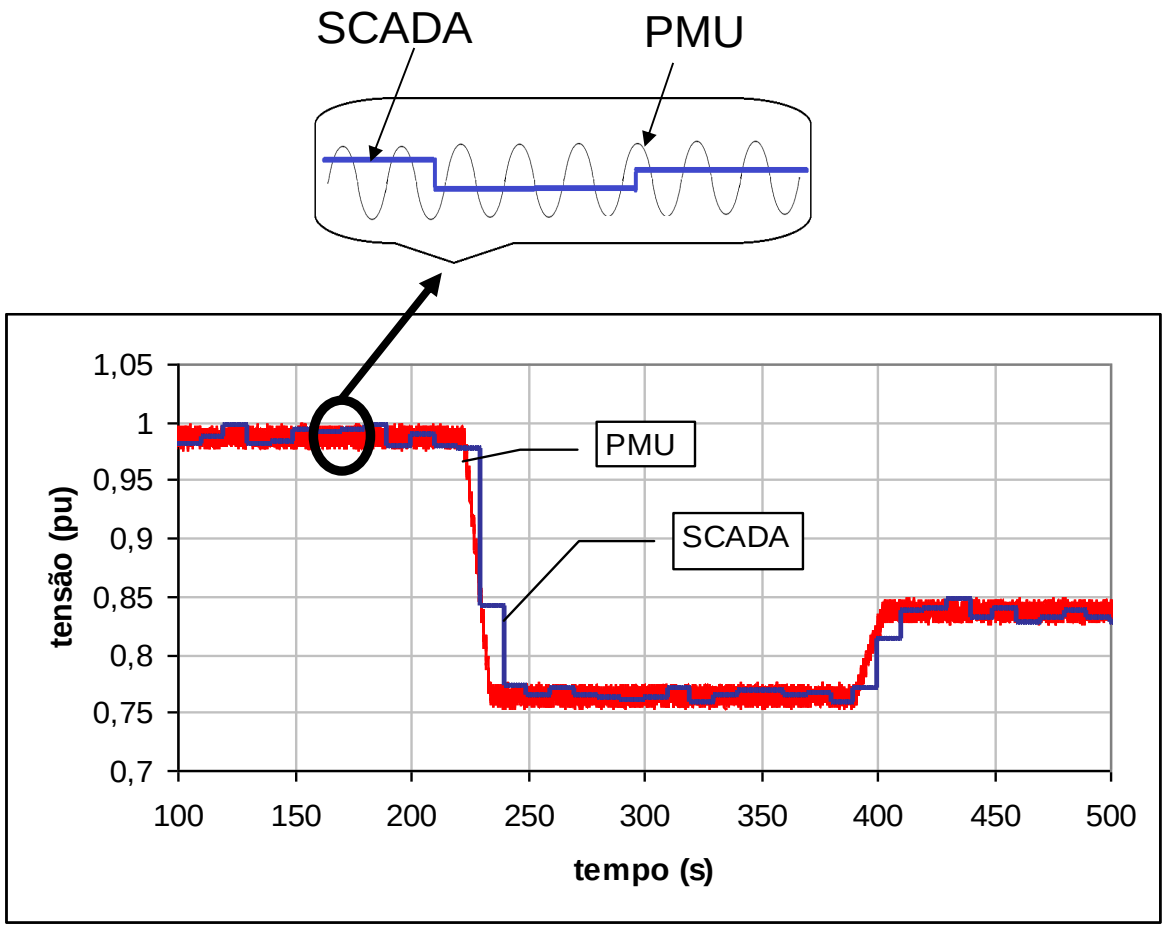
Concepts



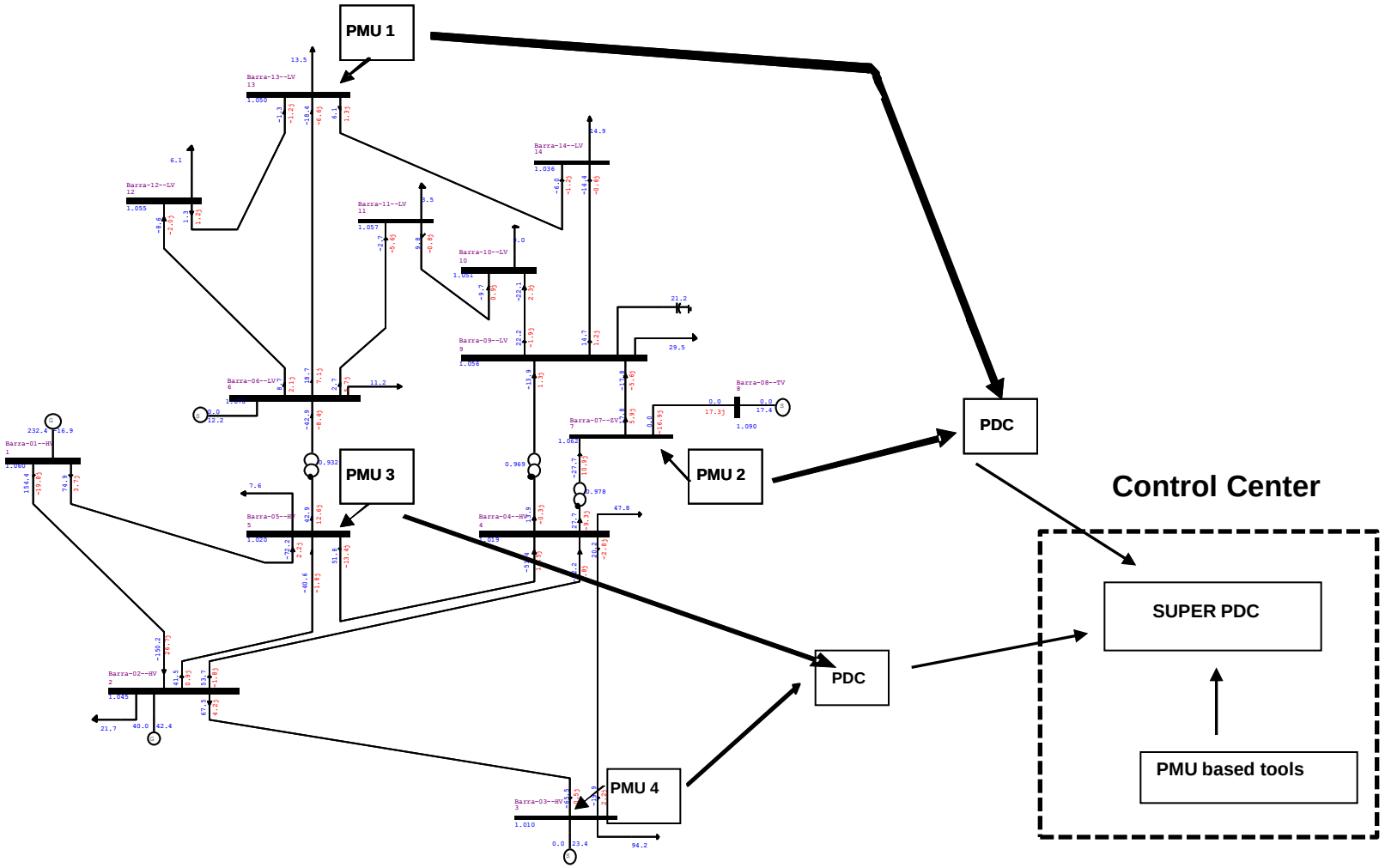


cycle	PMU 1	PMU 3
0	0	0
1	-60	0
2	-60	0
3	-60	-60
4	-60	-60

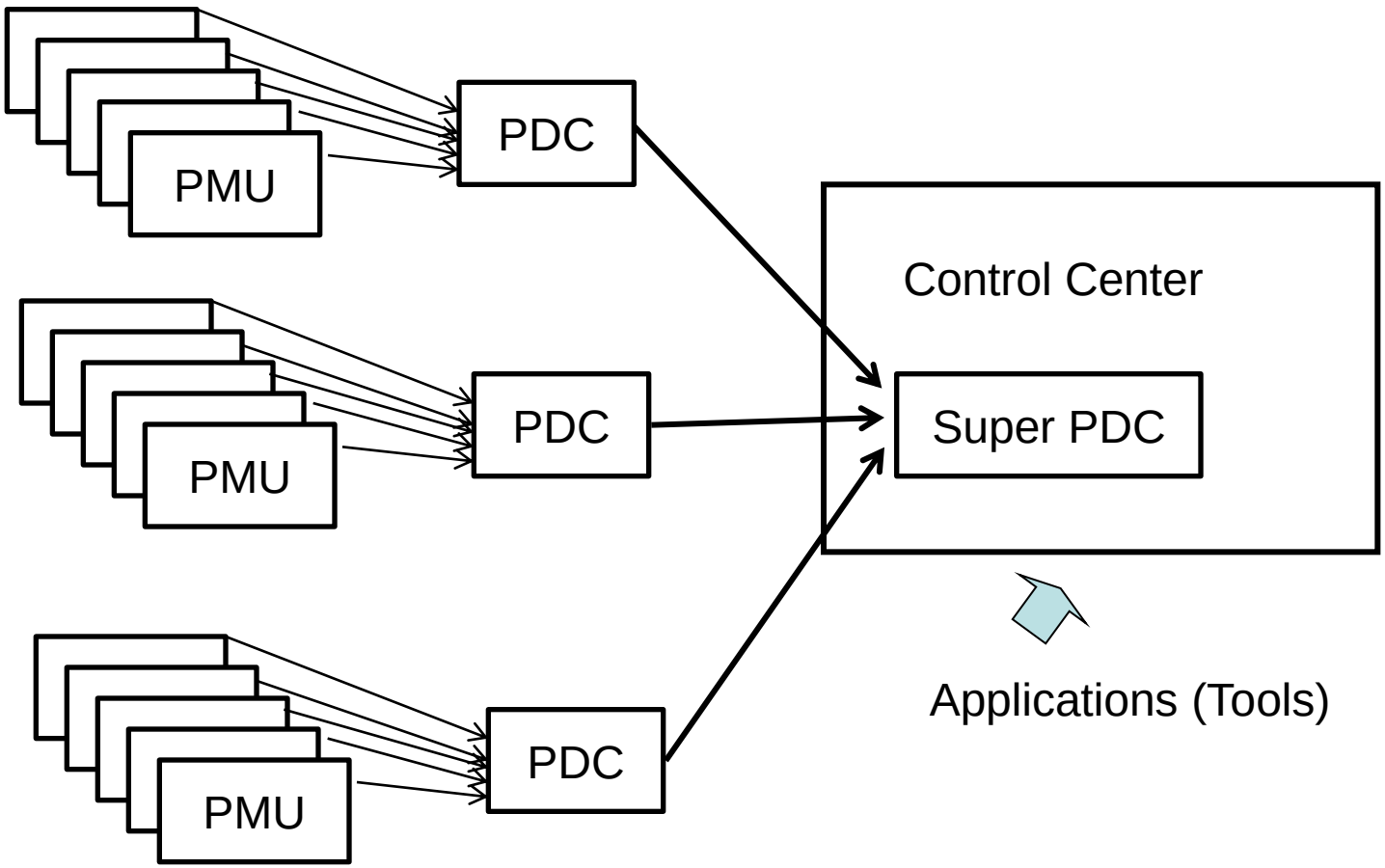
Concepts


SCADA
PMU
1,05
1
0,95
0,9
0,85
0,8
0,75
0,7
tensão (pu)
PMU
SCADA
100
150
200
250
300
350
400
450
500
tempo (s)

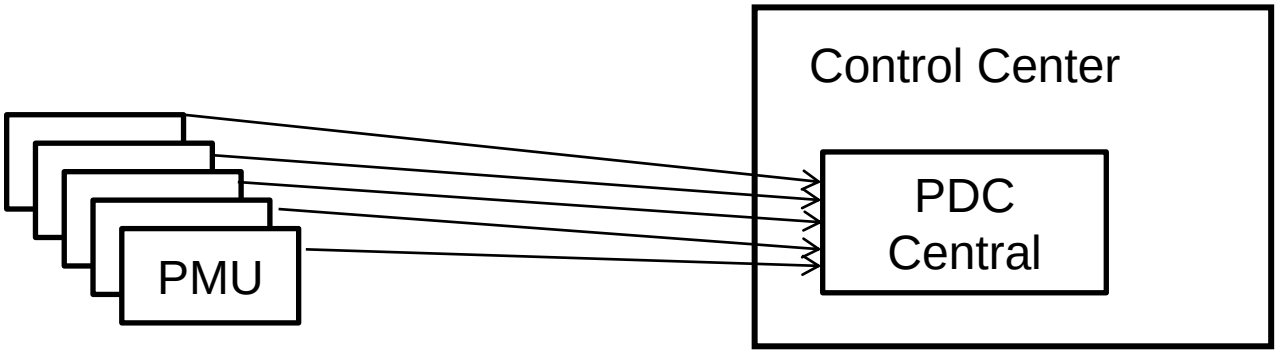
Concepts


PMU 1
PMU 2
PMU 3
PMU 4
PDC
PDC
Control Center
SUPER PDC
PMU based tools

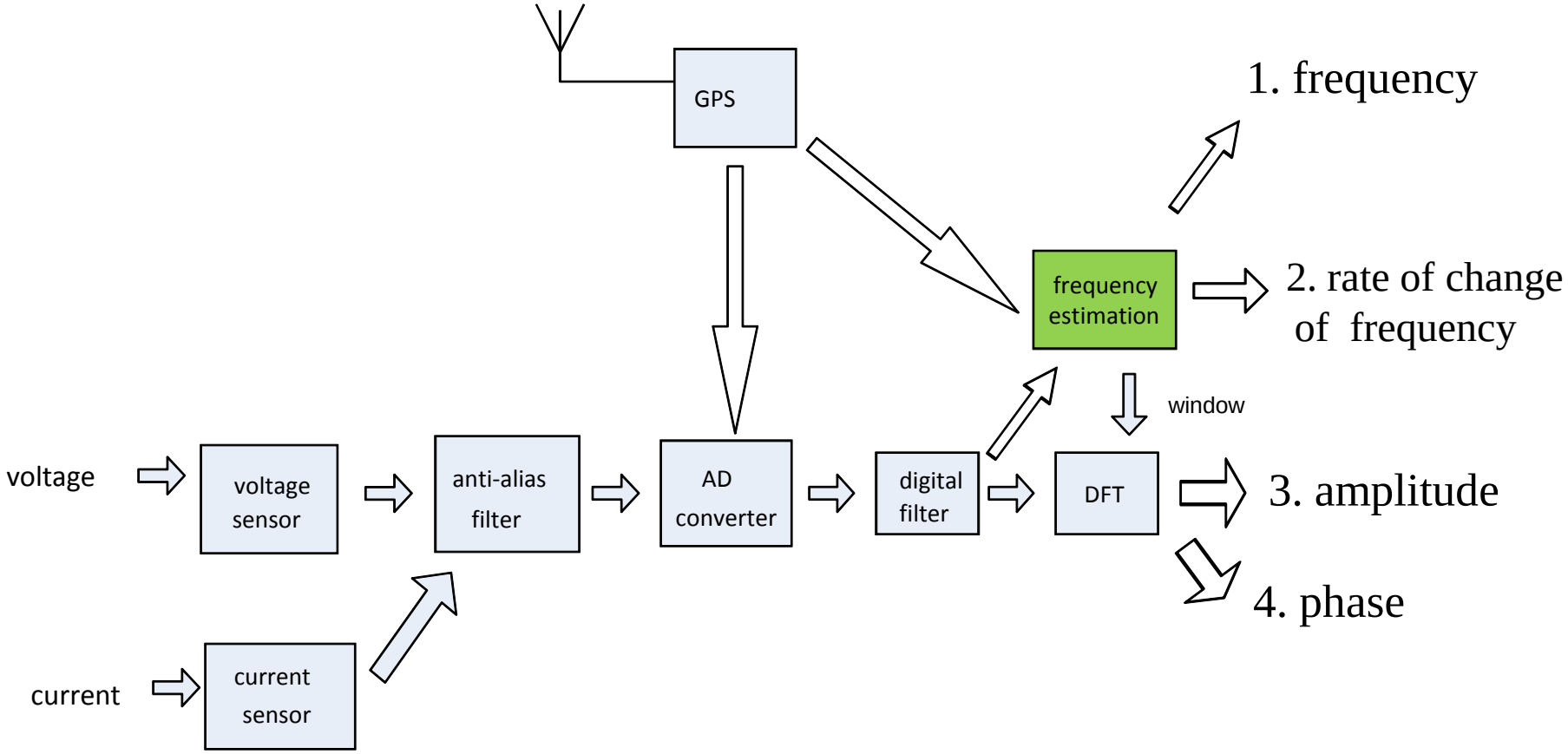
Concepts


PMU
PDC
PMU
PDC
PMU
PDC
Control Center
Super PDC
Applications (Tools)

Concepts



Concepts

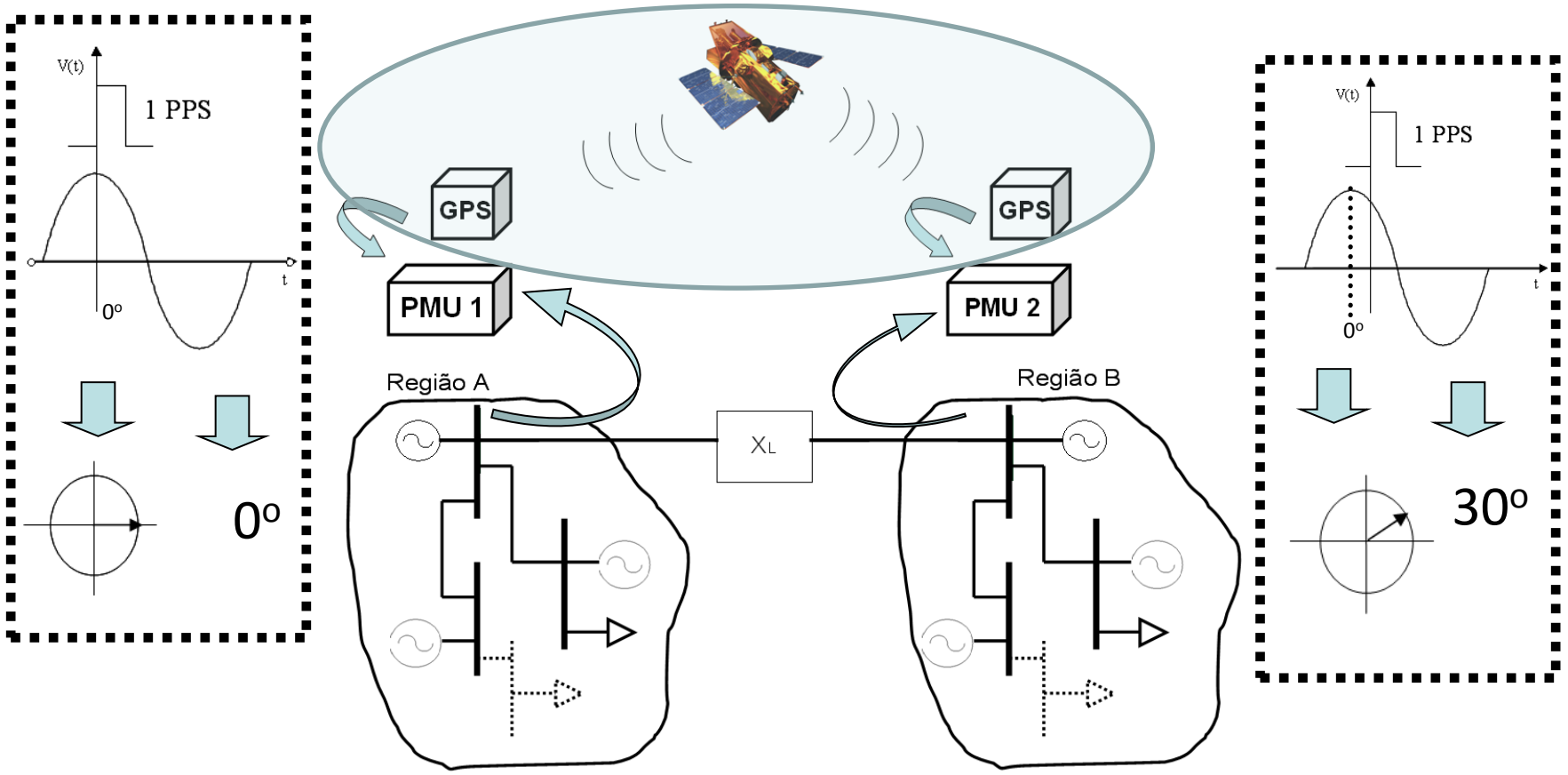

GPS
1. frequency
frequency estimation
2. rate of change of frequency
window
voltage
voltage sensor
anti-alias filter
AD converter
digital filter
DFT
3. amplitude
4. phase
current
current sensor

Concepts

1. Quality of Synchronism
2. Quality of PMUs
3. Quality of instrumentation channels
4. Quality of Communication
5. Quality of Phasor Data Concentrator
6. Quality of Applications

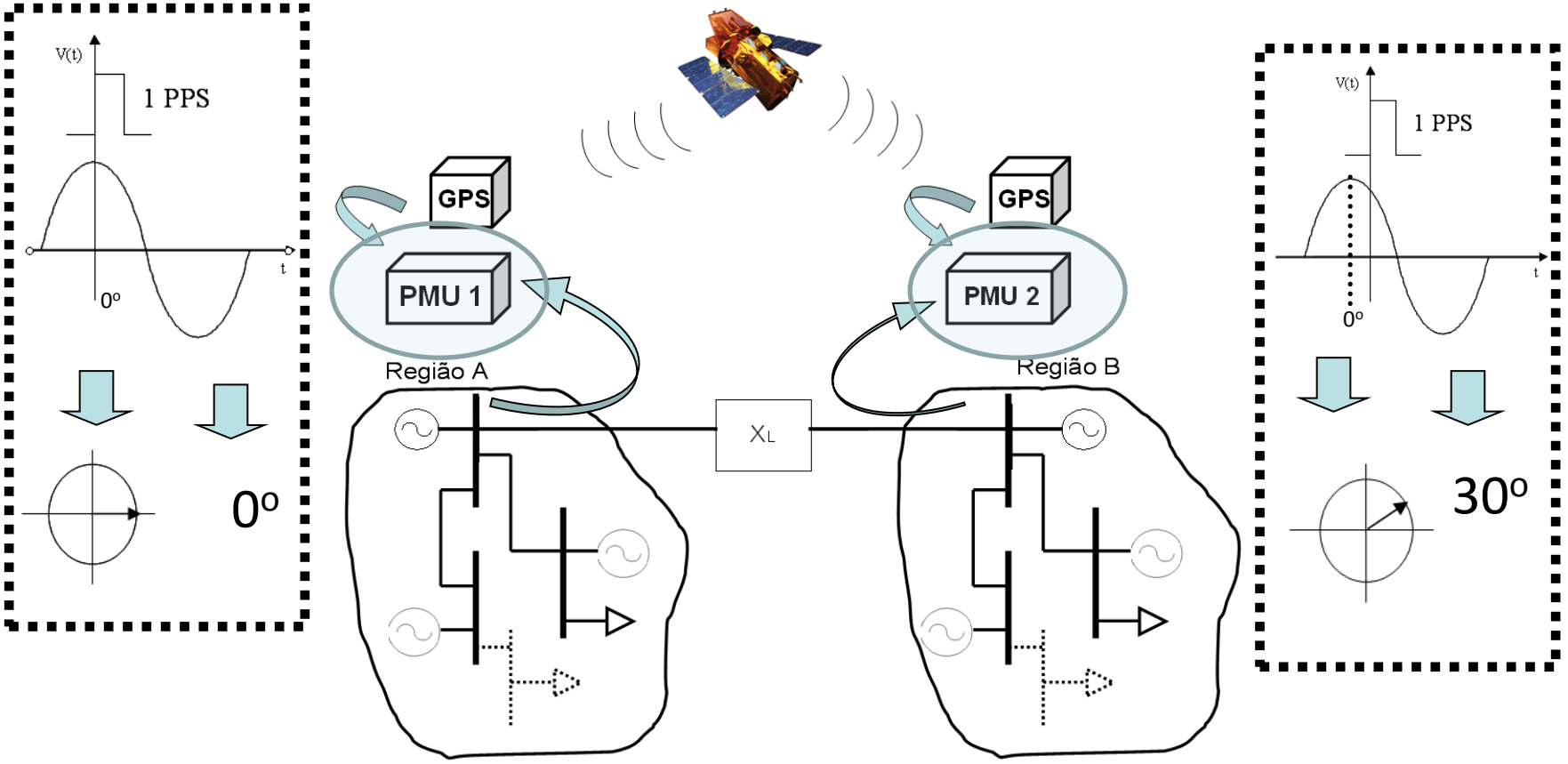
Concepts

1. Quality of Synchronism



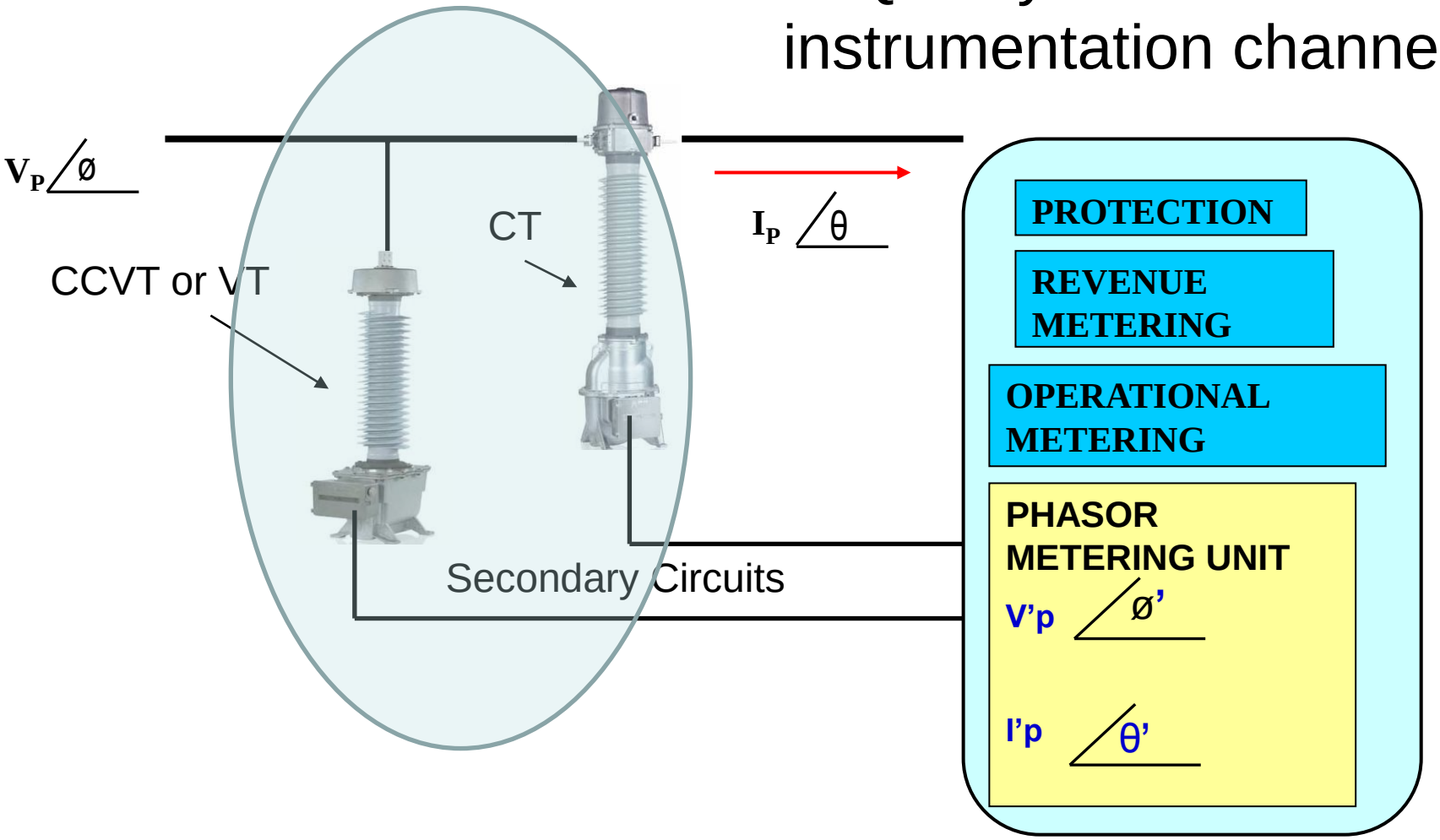
Concepts

2. Quality of PMUs



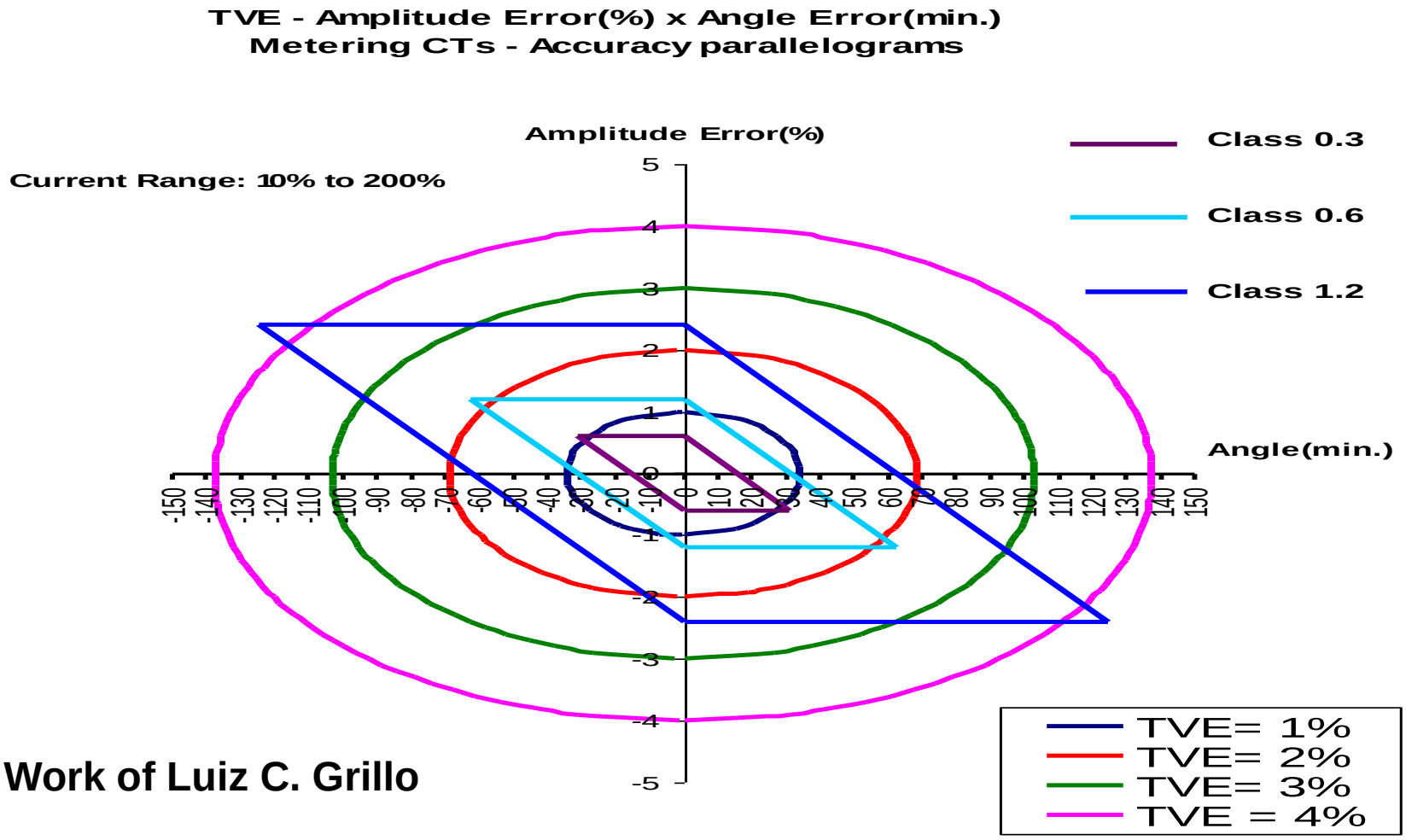
Concepts

3. Quality of instrumentation channels



Concepts

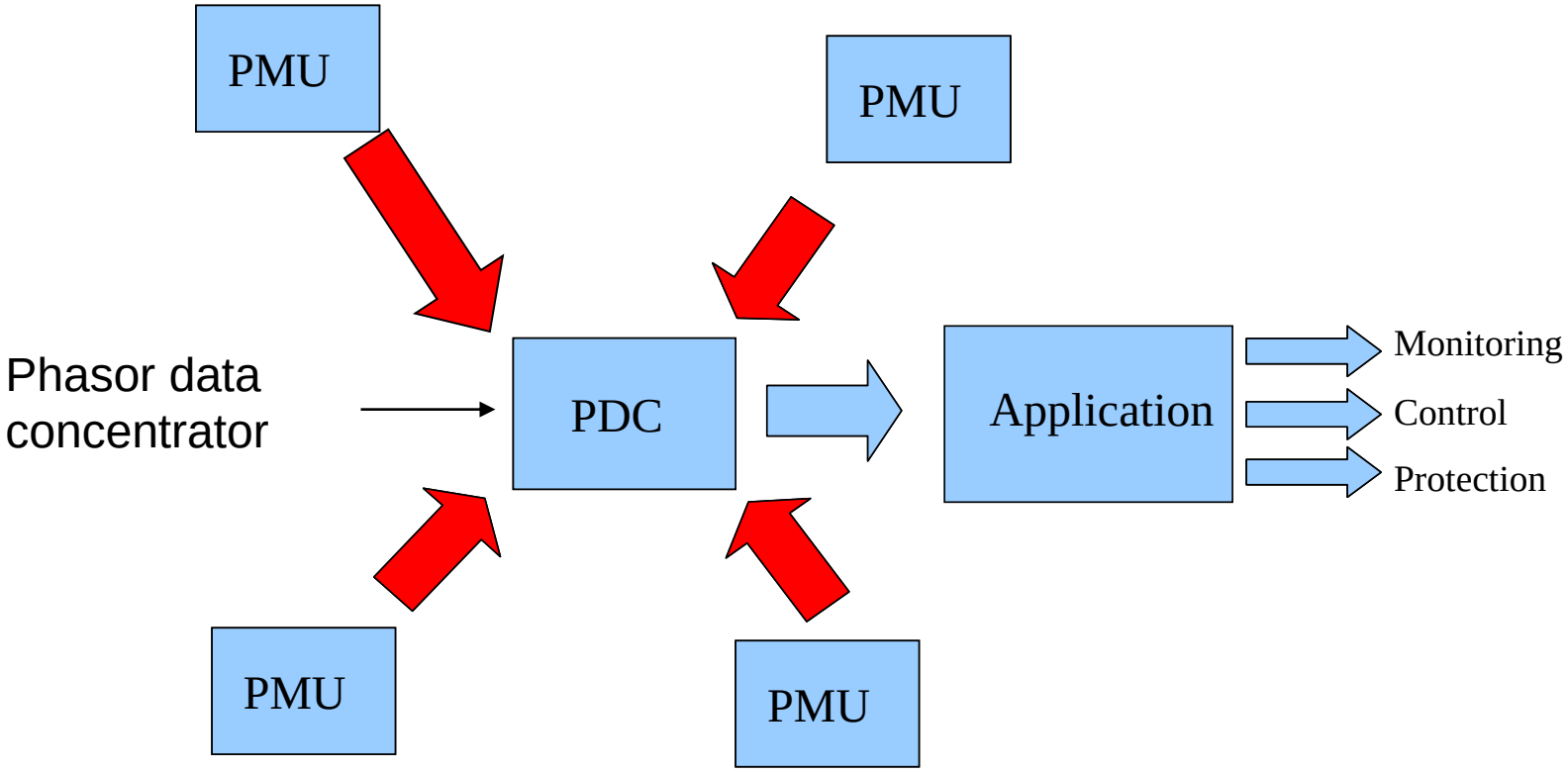
Comparison between TVE (%) and the parallelogram accuracy for *Metering CT.*



Work of Luiz C. Grillo

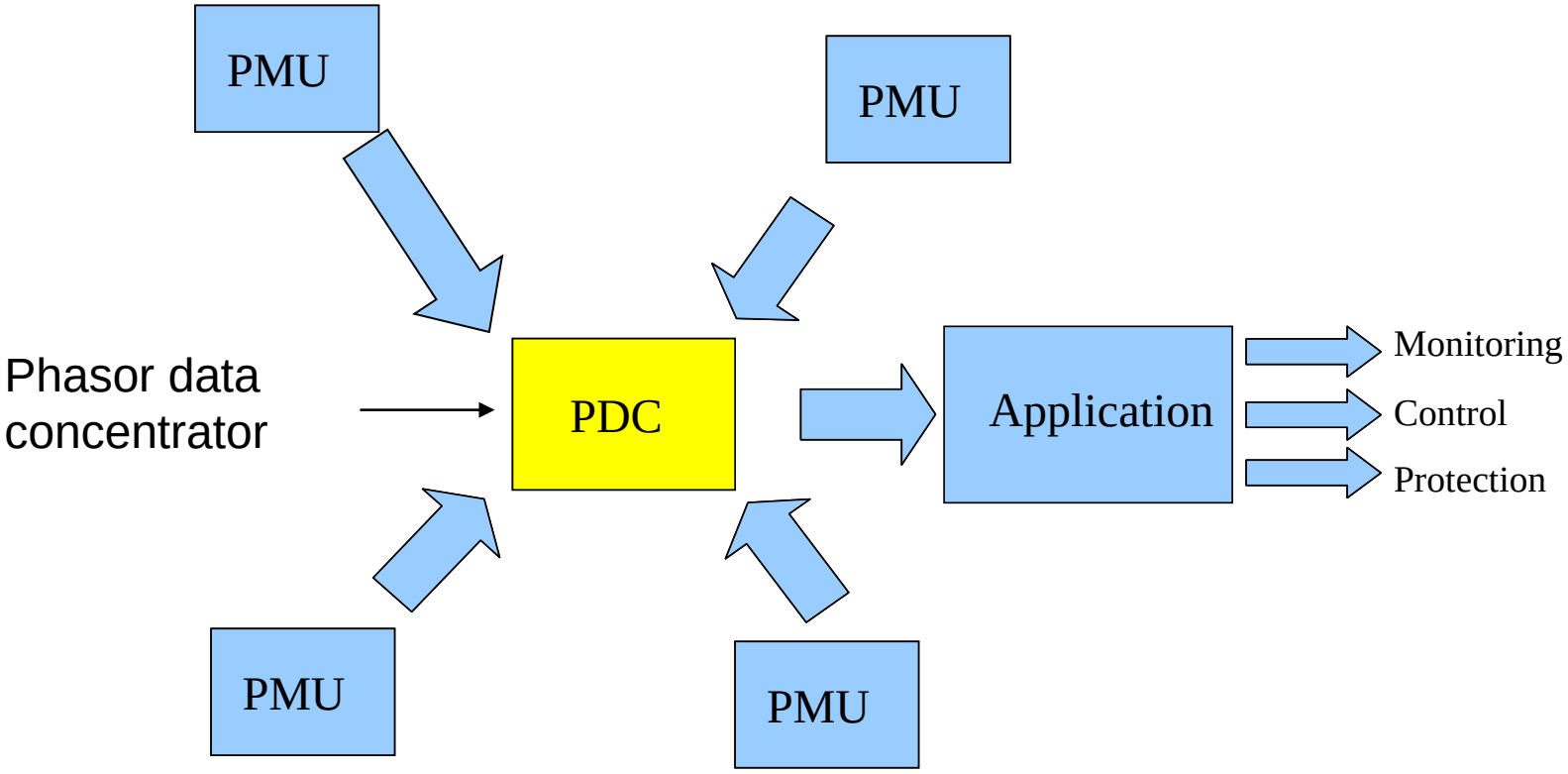
Concepts

4. Quality of Communication



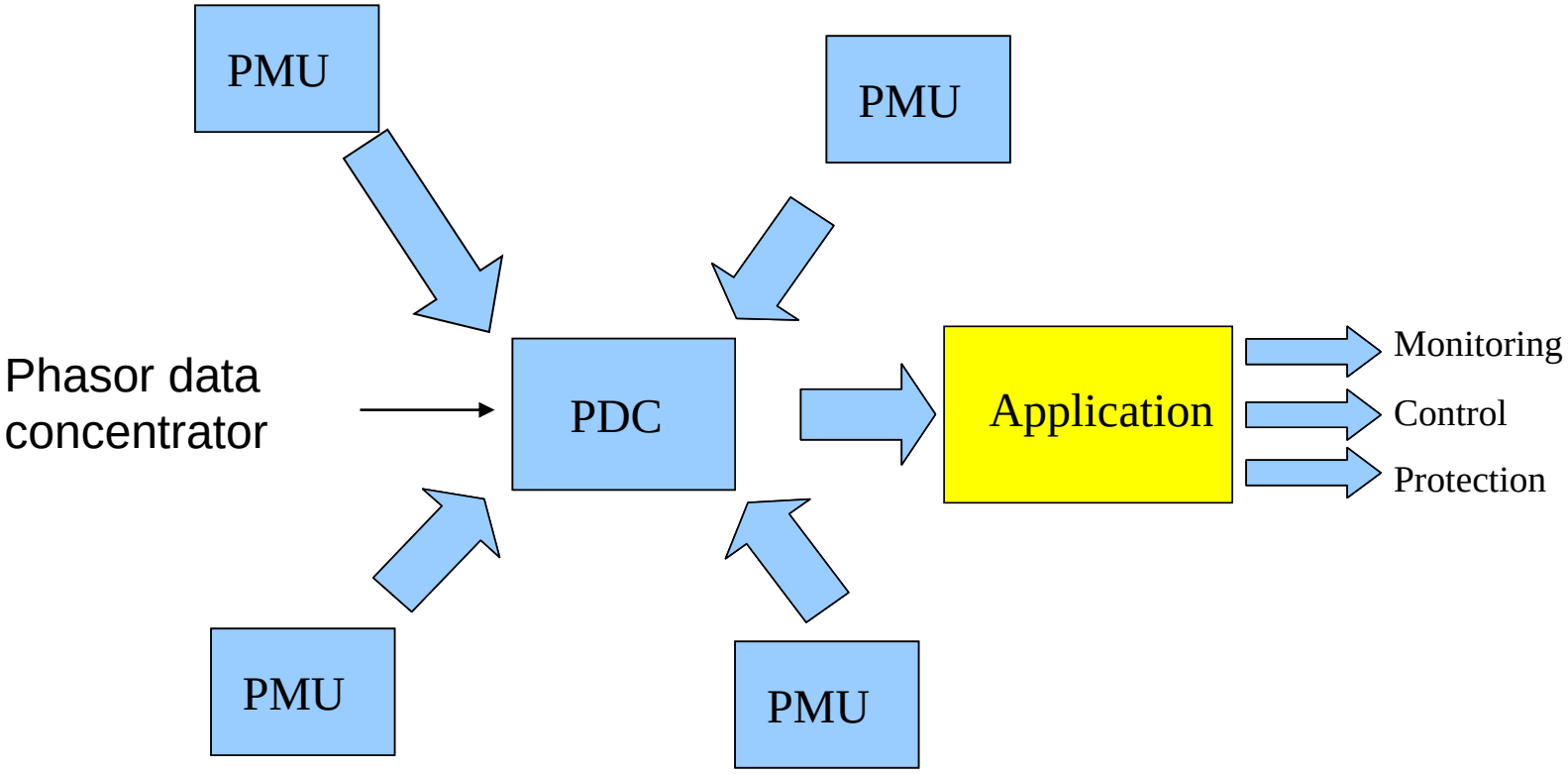
Concepts

5. Quality of Phasor Data Concentrator



Concepts

6. Quality of Applications

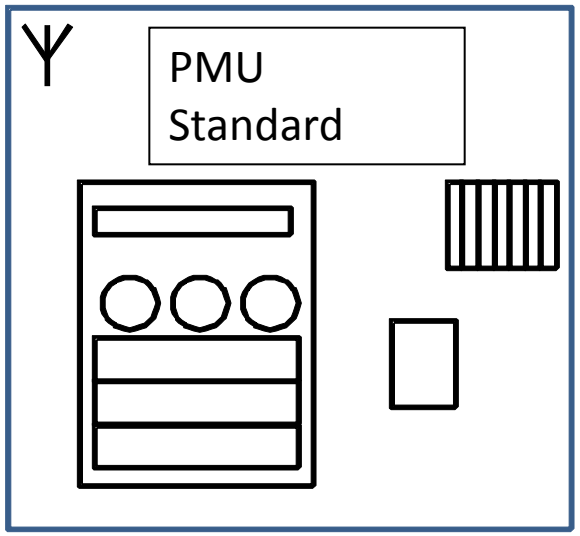


Concepts

1. Quality of Synchronism
2. Quality of PMUs
3. Quality of instrumentation channels
4. Quality of Communication
5. Phasor data concentrator quality
6. Quality of Applications

Performance of PMUs Units

Reference Tests according with standard IEEE C37.118.1



Generates voltage and current signals synchronized by GPS.

PMU under test

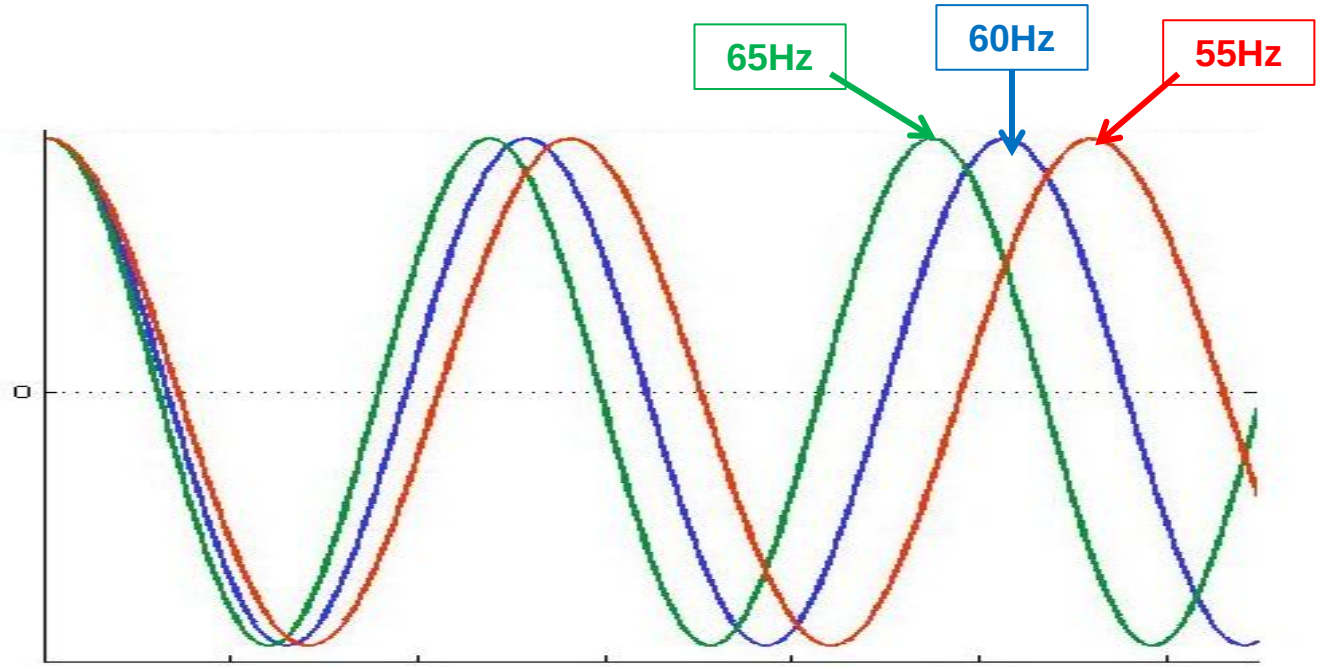
The phasors measured by PMUs are moved to the test bed and comparated with virtual standard PMU.

Performance of PMUs

- Classification of Tests:
  - Static
  - Dynamic
  - Latency

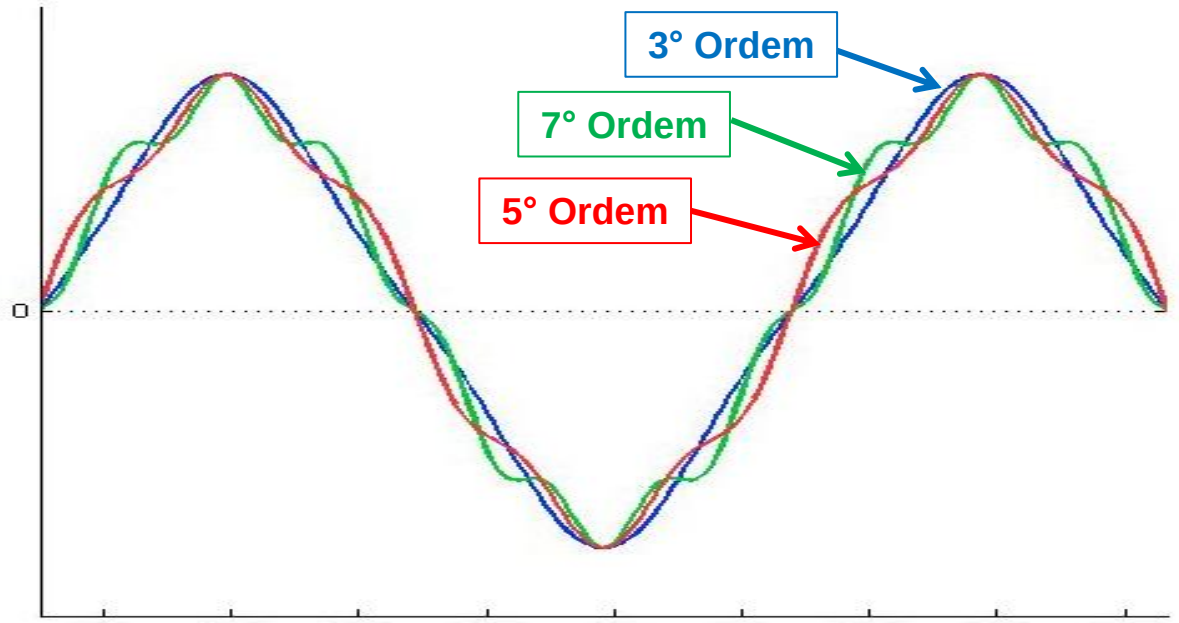
Performance of PMUs

- Static Tests (example):
  - **Signal Frequency**



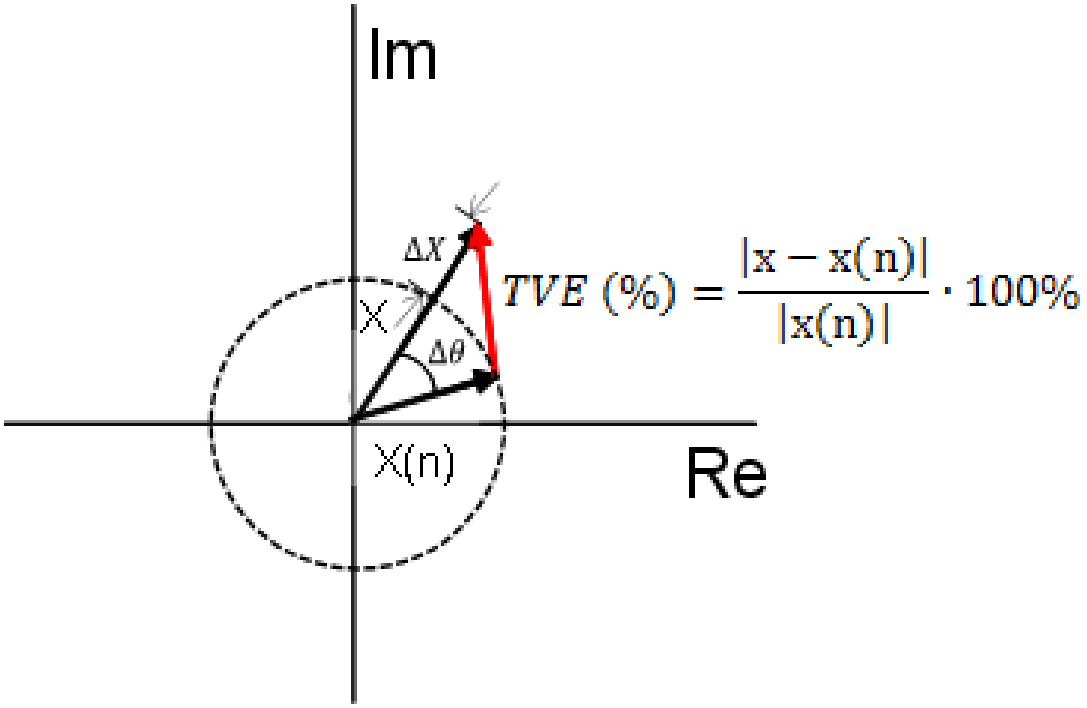
Performance of PMUs

- Static Tests (example):
  - **Harmonic tests**;



Performance of PMUs

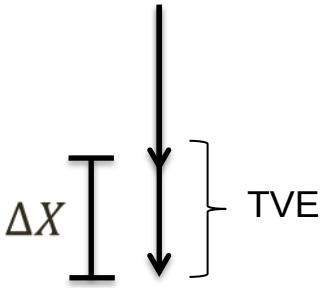
- Total Vector Error (TVE):



Performance of PMUs

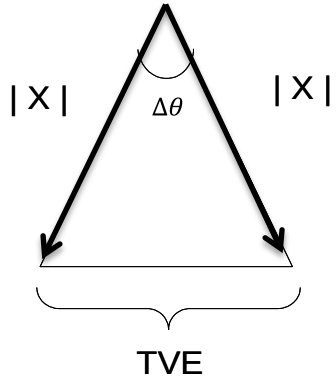
Total Vector Error (TVE):

- TVE < 1%
- Considering only amplitude error:



1% Error

- TVE < 1%
- Considering only phase error:



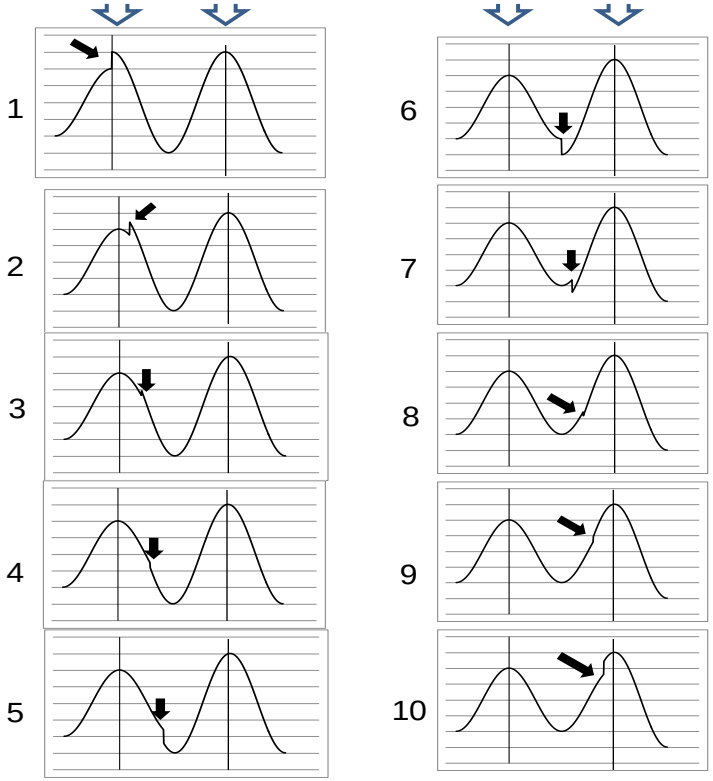
- 60 Hz:

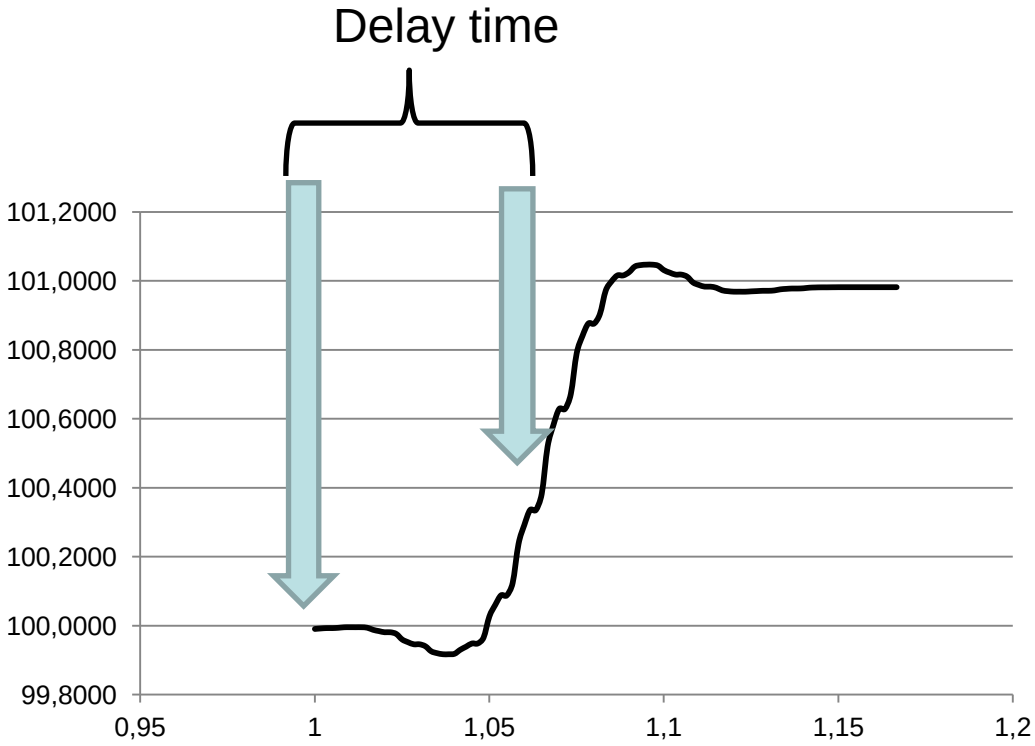
$$\Delta\theta \cong 0{,}57°$$

Delay ≤ 26 µs

Performance of PMUs

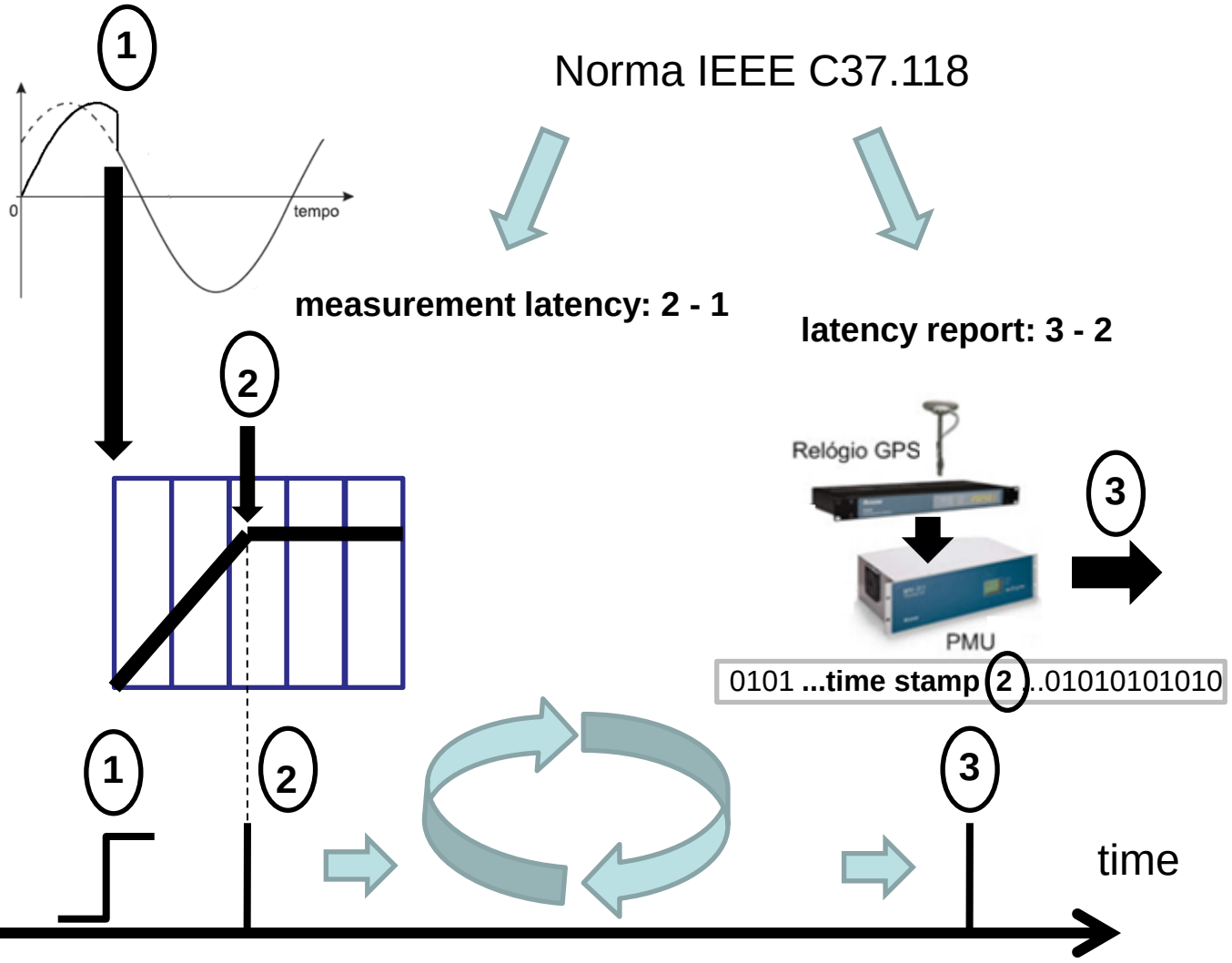
Dynamic Tests – example: Step Test



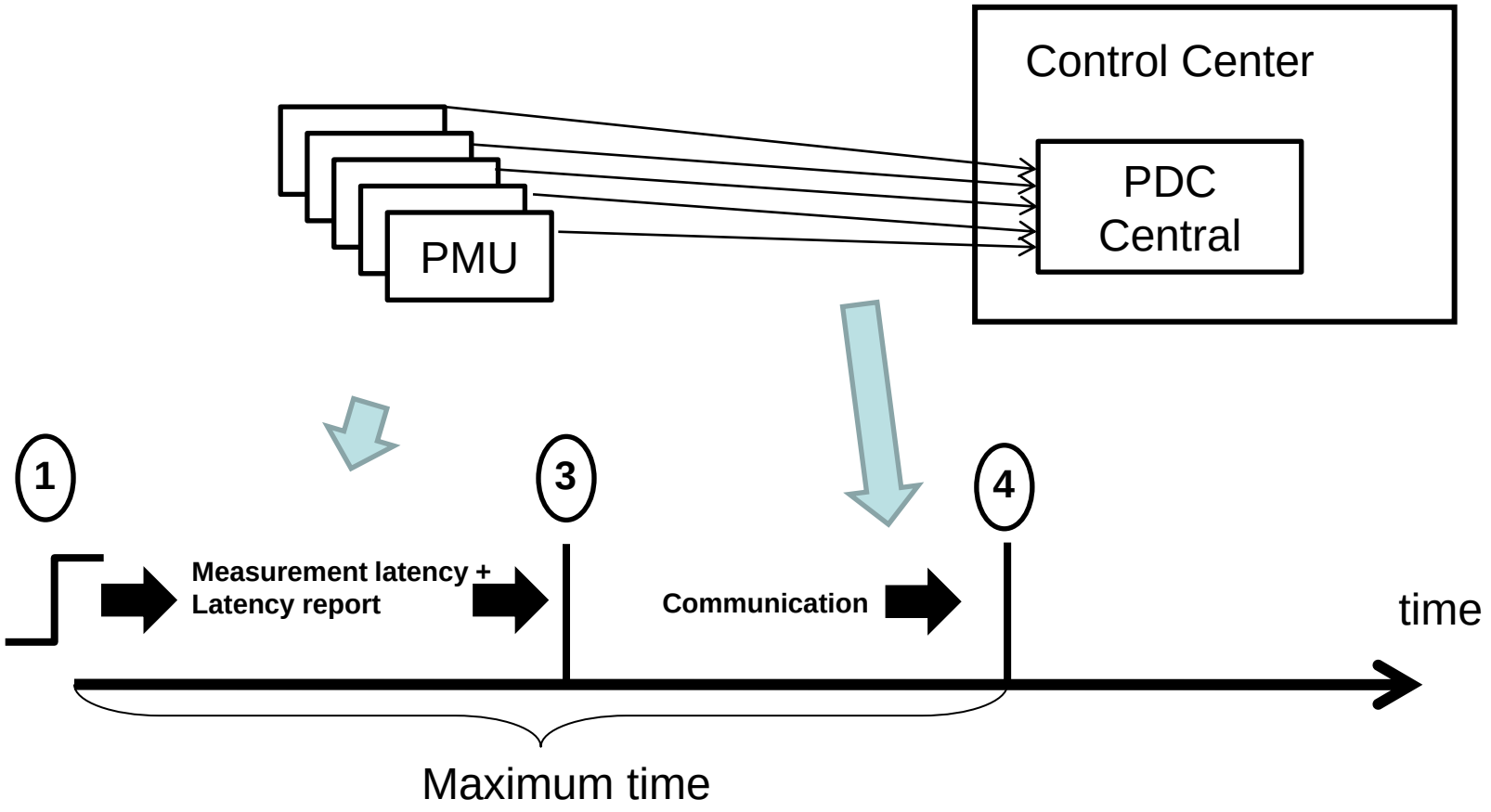


Performance of PMUs

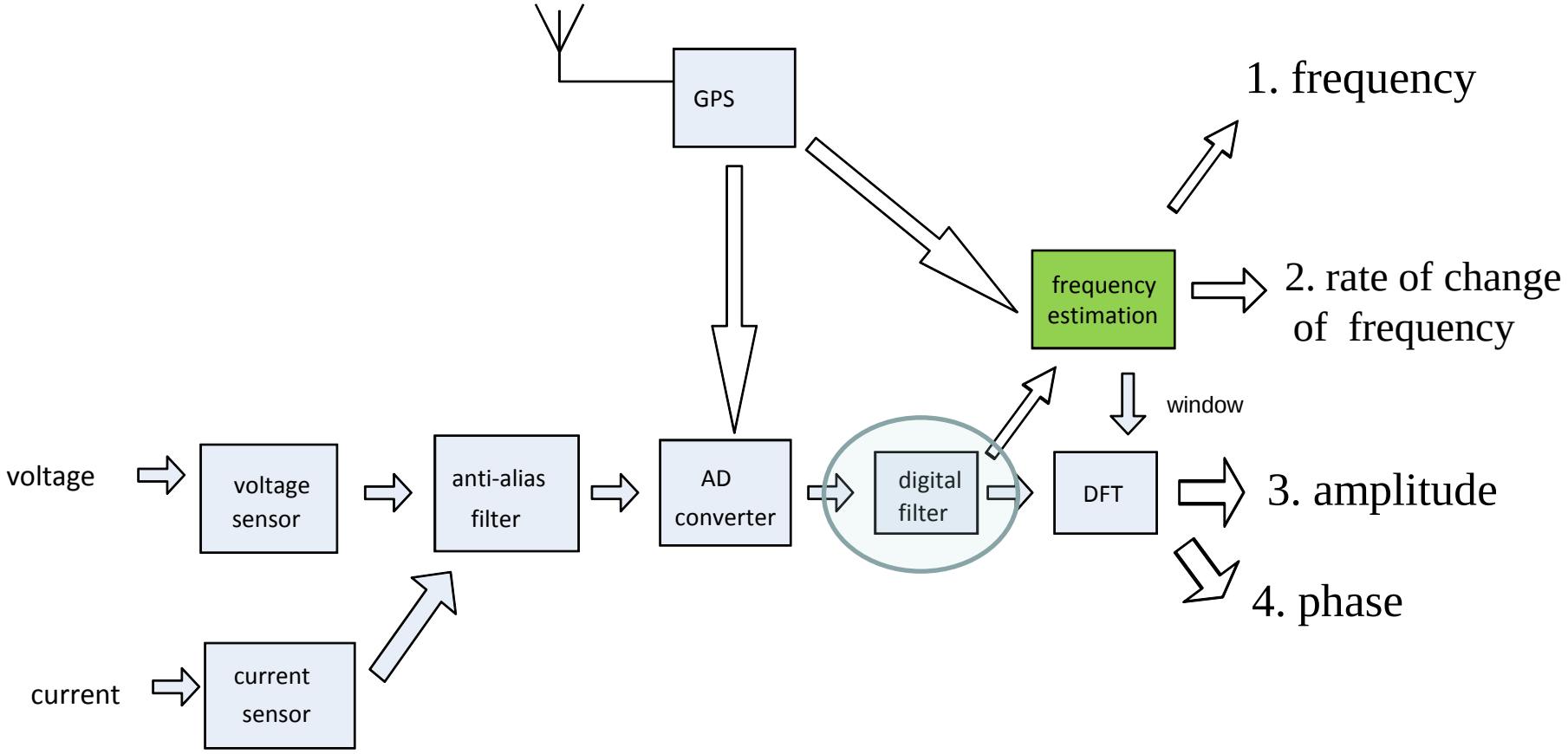
Latency



Performance of PMUs



Performance of PMUs

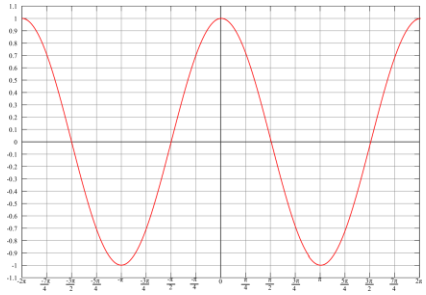


Performance of PMUs

Digital Filtering

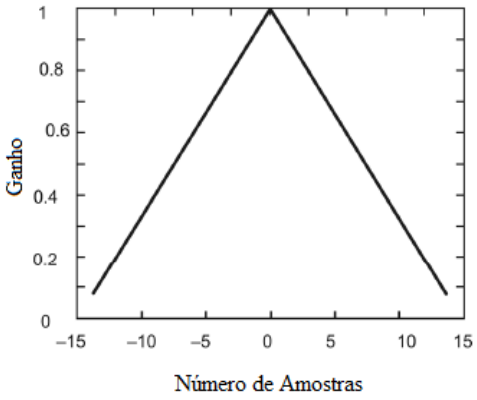
Time stamp

Input signal



×

Window



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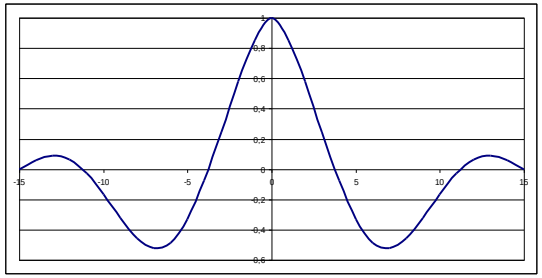
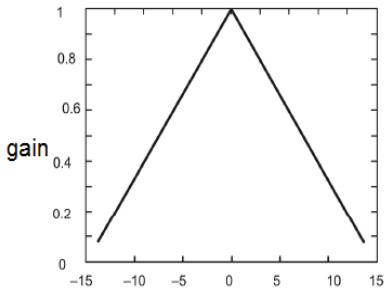


FFT

Performance of PMUs Units

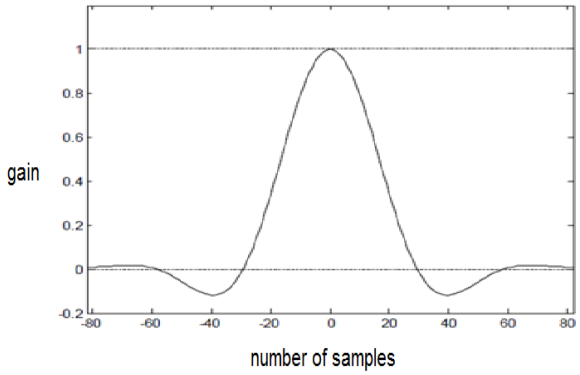
Eletrobras Cepel

Algorithms suggested by C37.118



2 cycles

PMU P



10 cycles

PMU M

Performance of PMUs

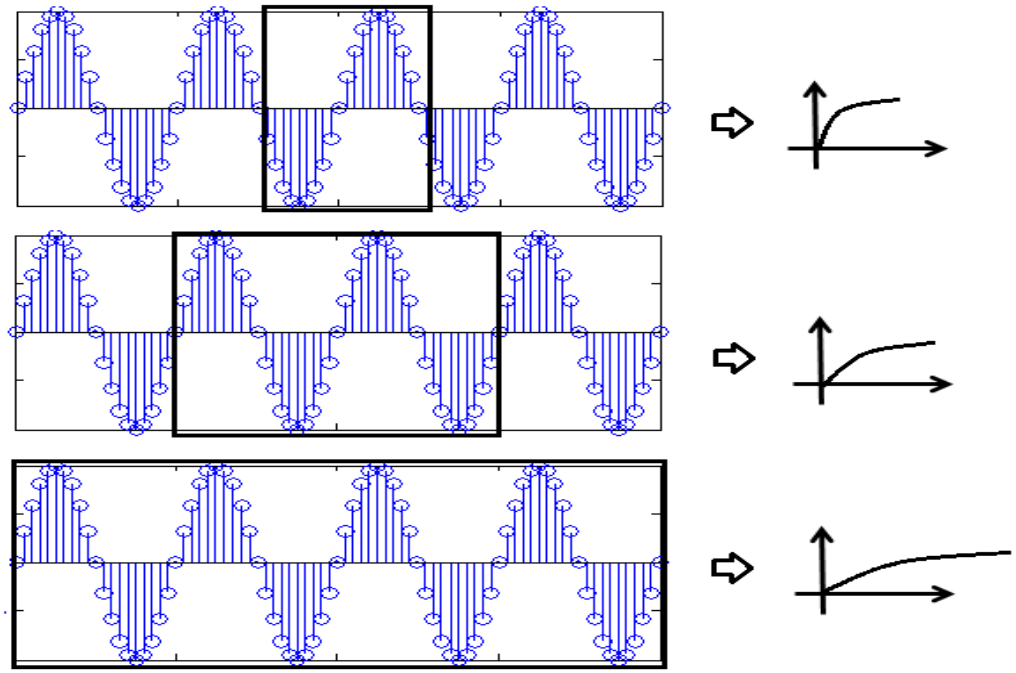
PMU class P → **2 cycle periods**

PMU class M → **10 cycle periods**

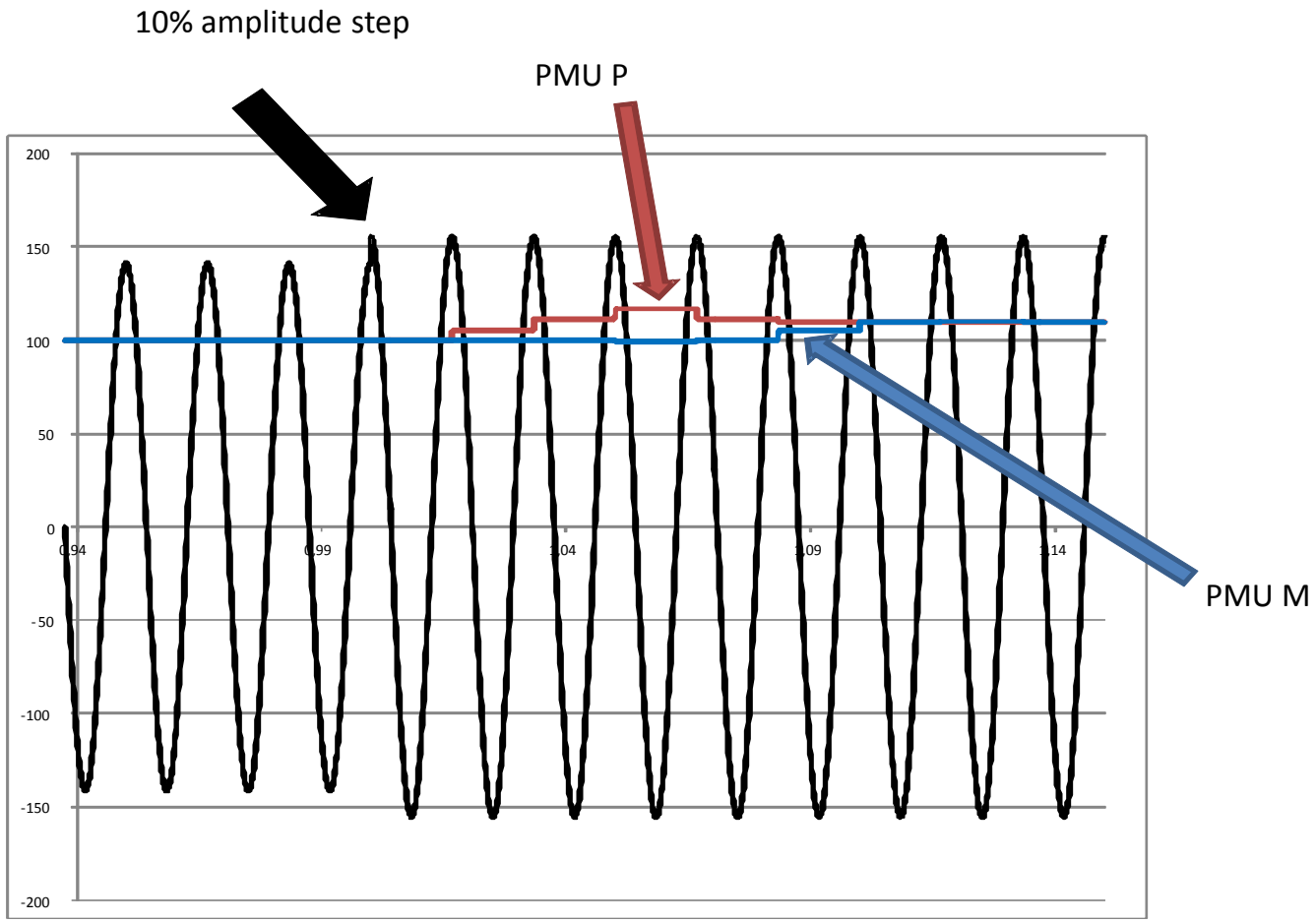
Filtering is better when the window is larger.

Performance of PMUs

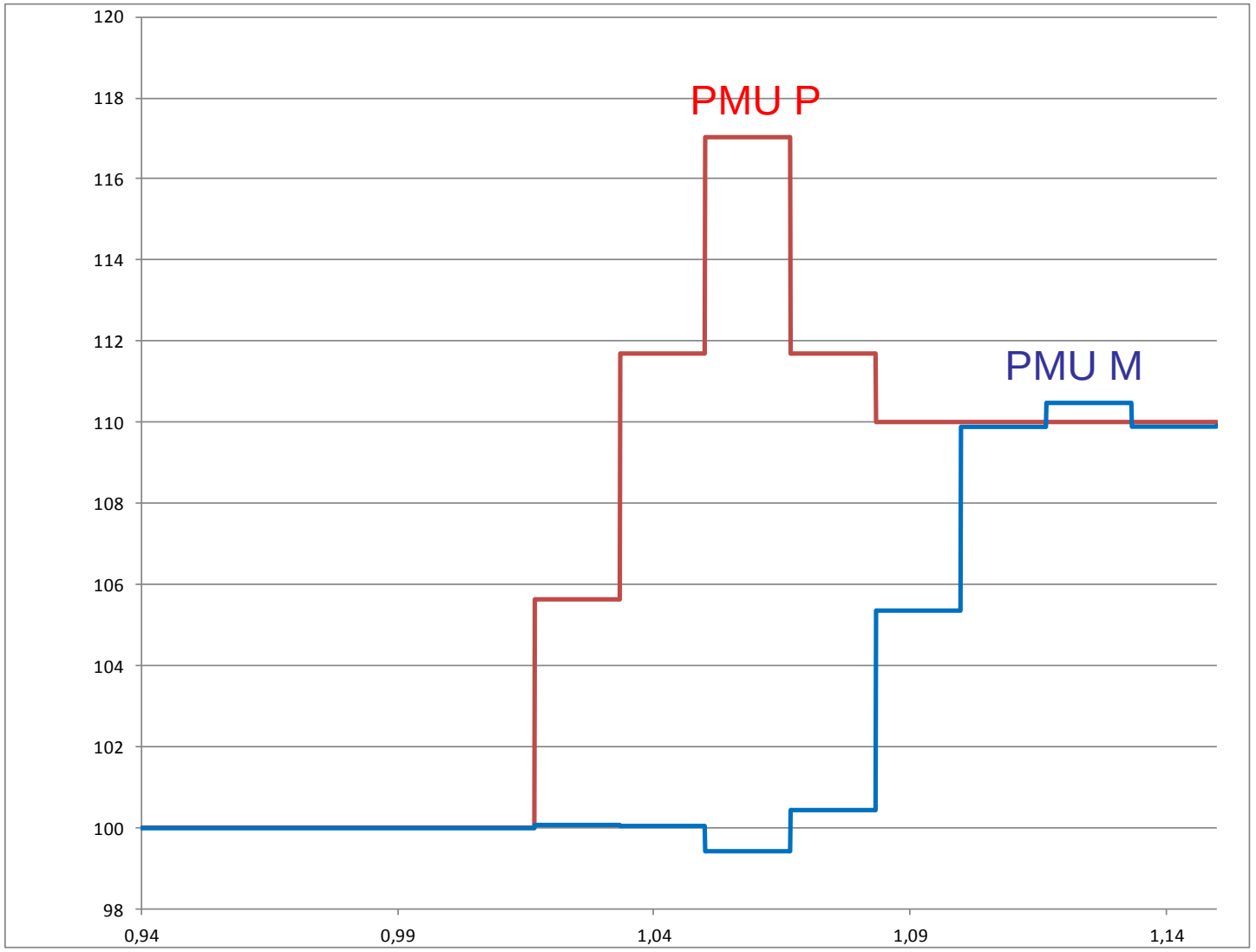
But the output will be slower!



Performance of PMUs



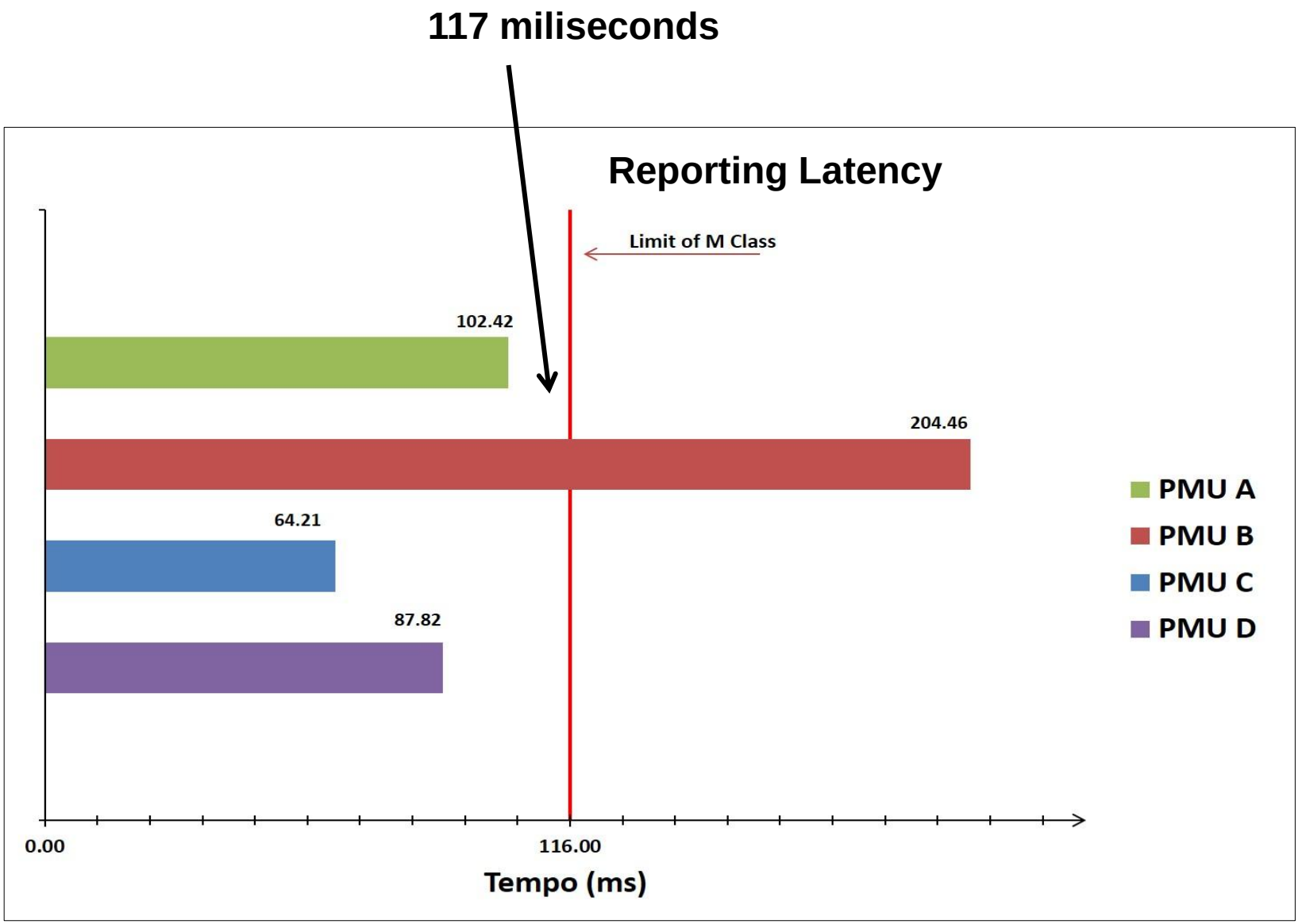
Performance of PMUs Units



Performance of PMUs

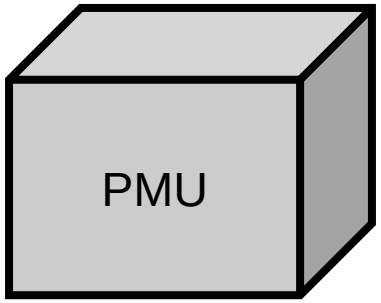
Filtering greatly influences PMU's response!

Performance of PMUs

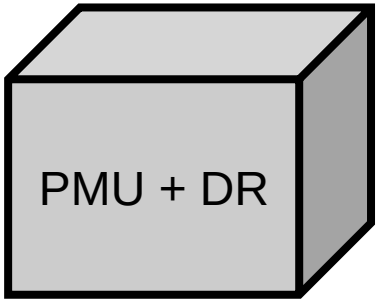


Performance of PMUs

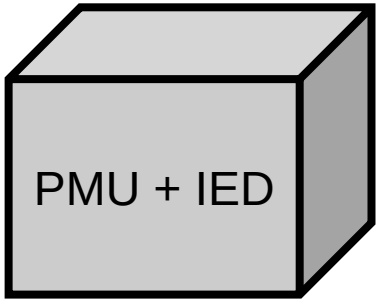
PLUs could be “standalone” or embedded together with other functions in the same case (receptacle)



Standalone PMU



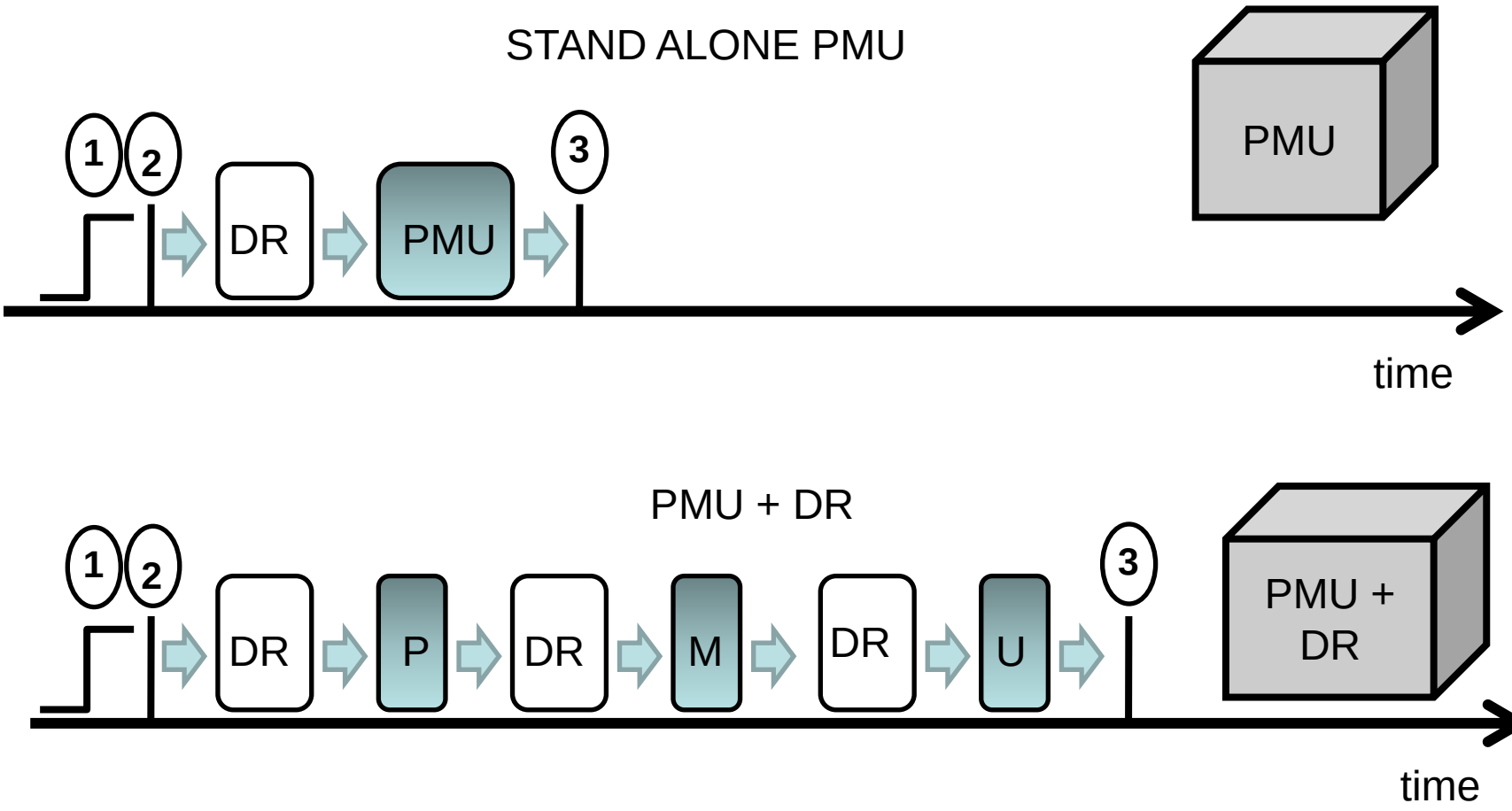
PMU + Digital Recorder (DR)



PMU + Intelligent Electronic Device

Performance of PMUs

Example of possible increasing latency because having to two functions being executed concurrently (PMU and DR)



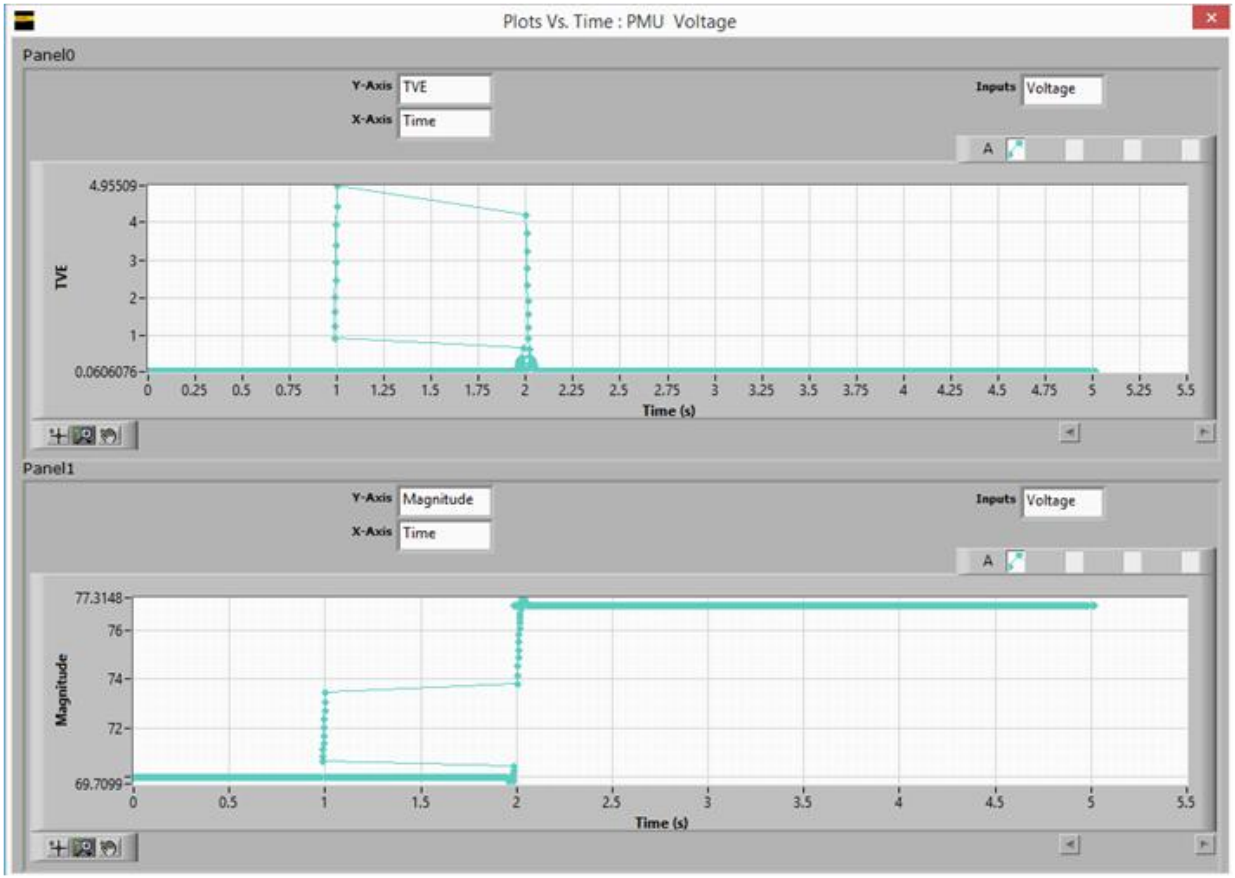
Influence of "firmware"

Eletrobras Cepel

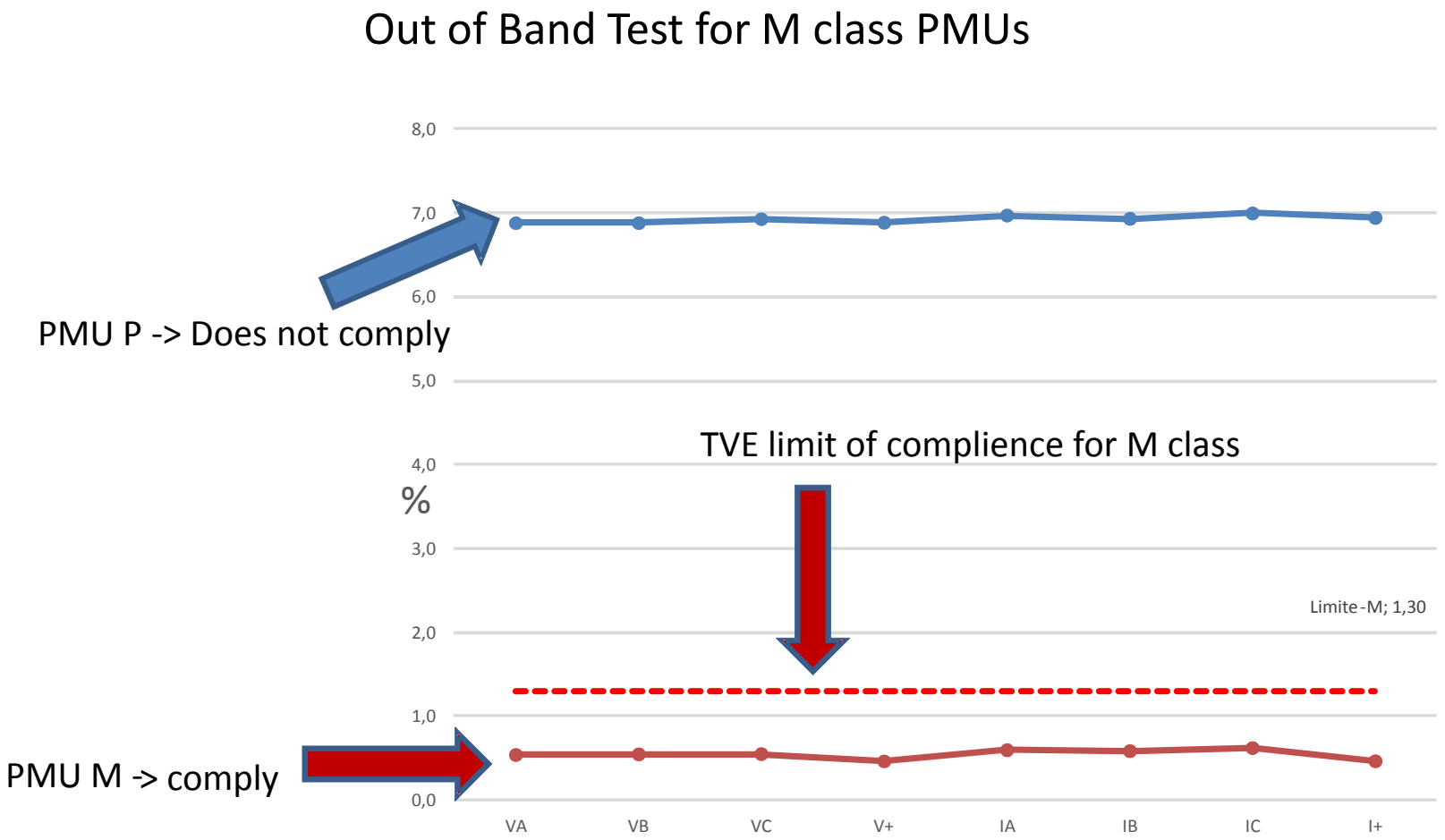
Evolution of Firmware

	Firmware			
ID	antigo	intermediário	novo	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

Influence of "firmware"

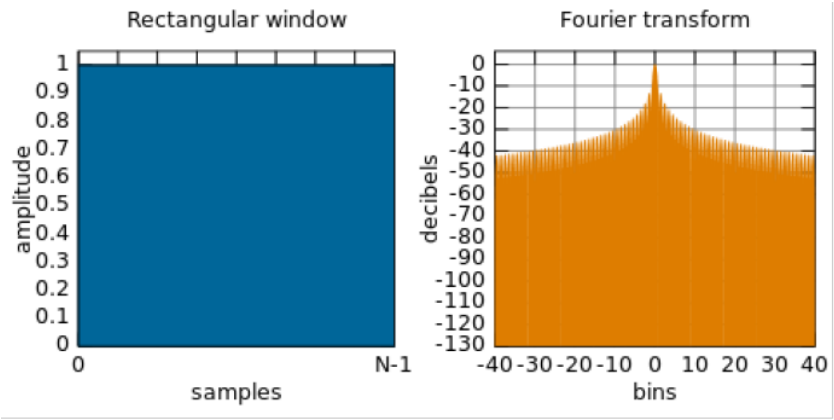


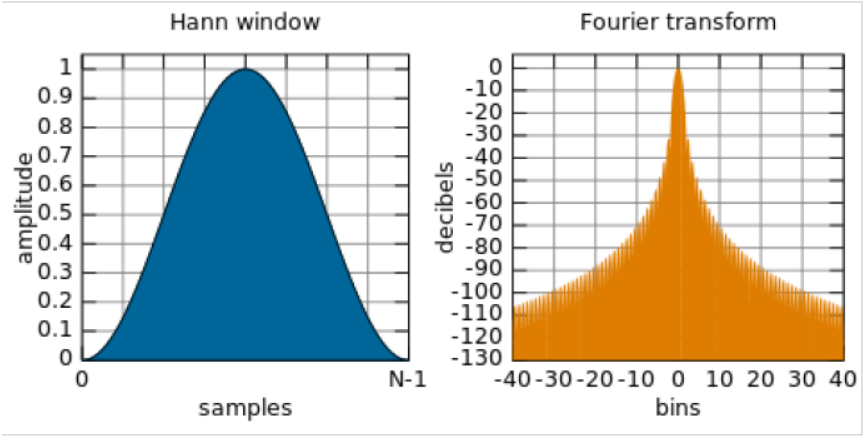
Influence of Configuration Parameters



Influence of Configuration Parameters

Different types of filtering

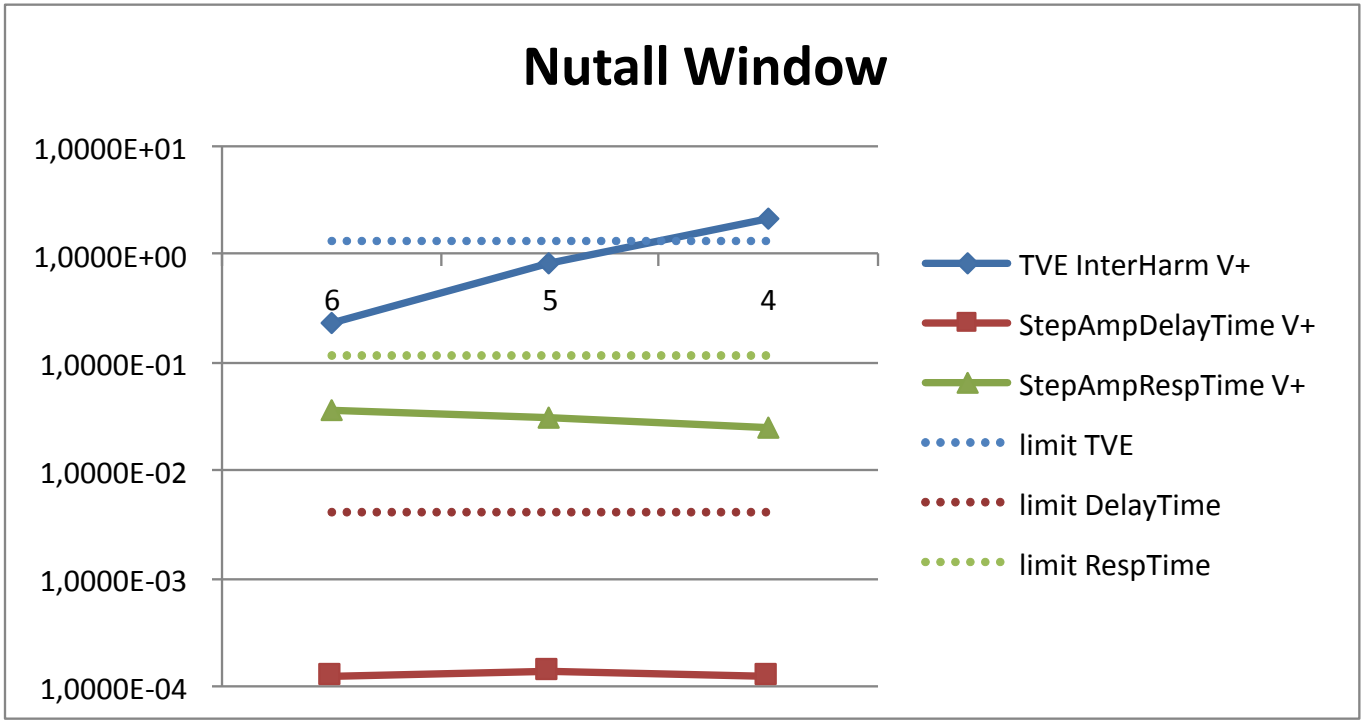




Influence of Configuration Parameters

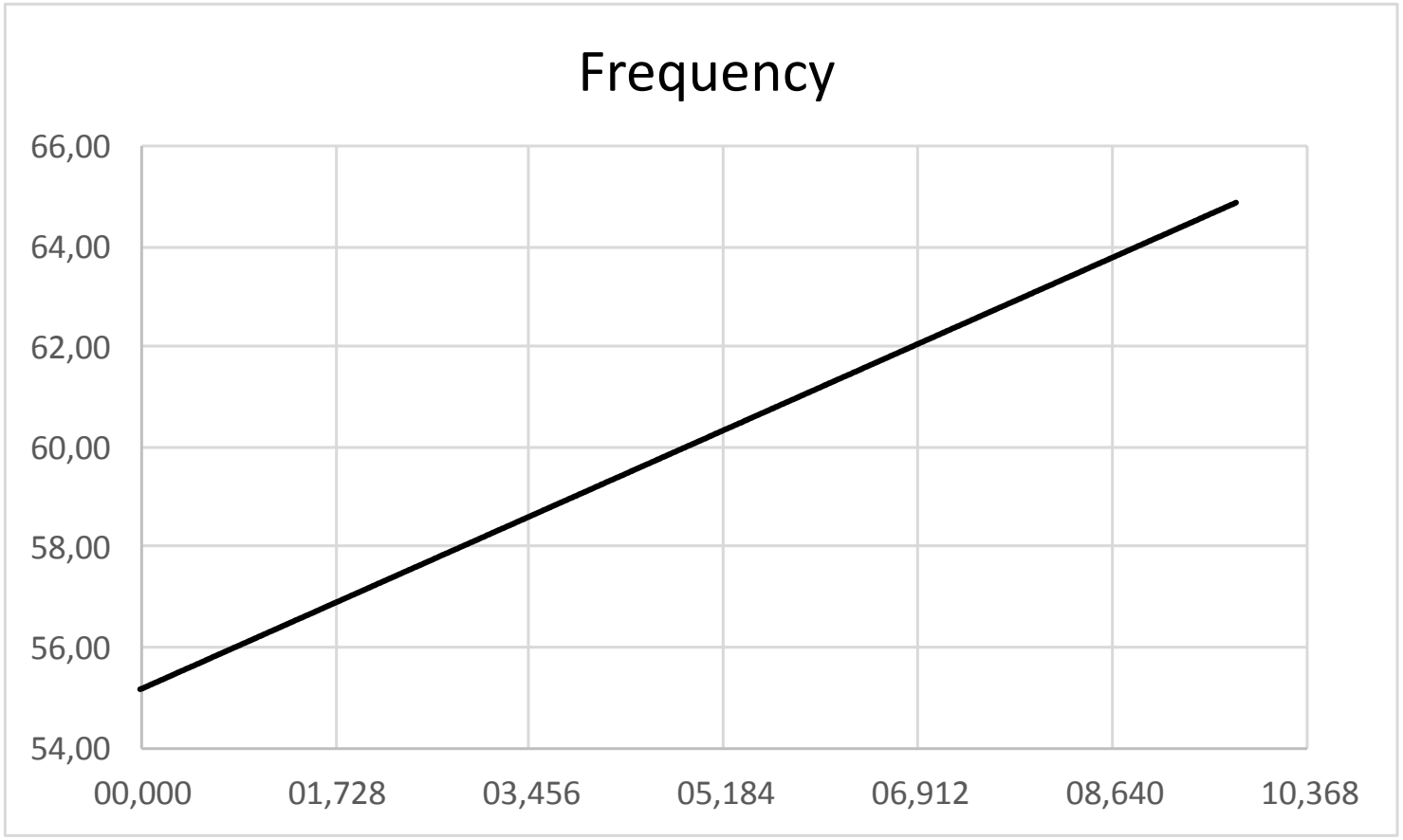
Eletrobras Cepel

Different types of filtering



Influence of Configuration Parameters

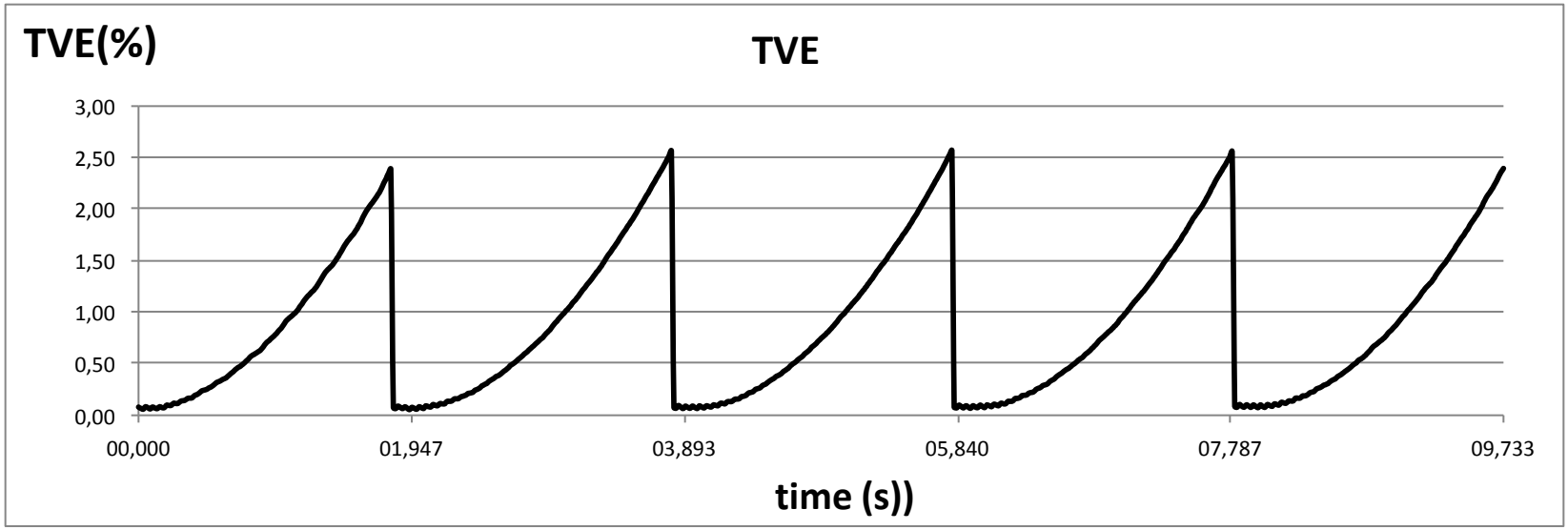
Adaptation to frequency variation



Influence of Configuration Parameters

Eletrobras Cepel

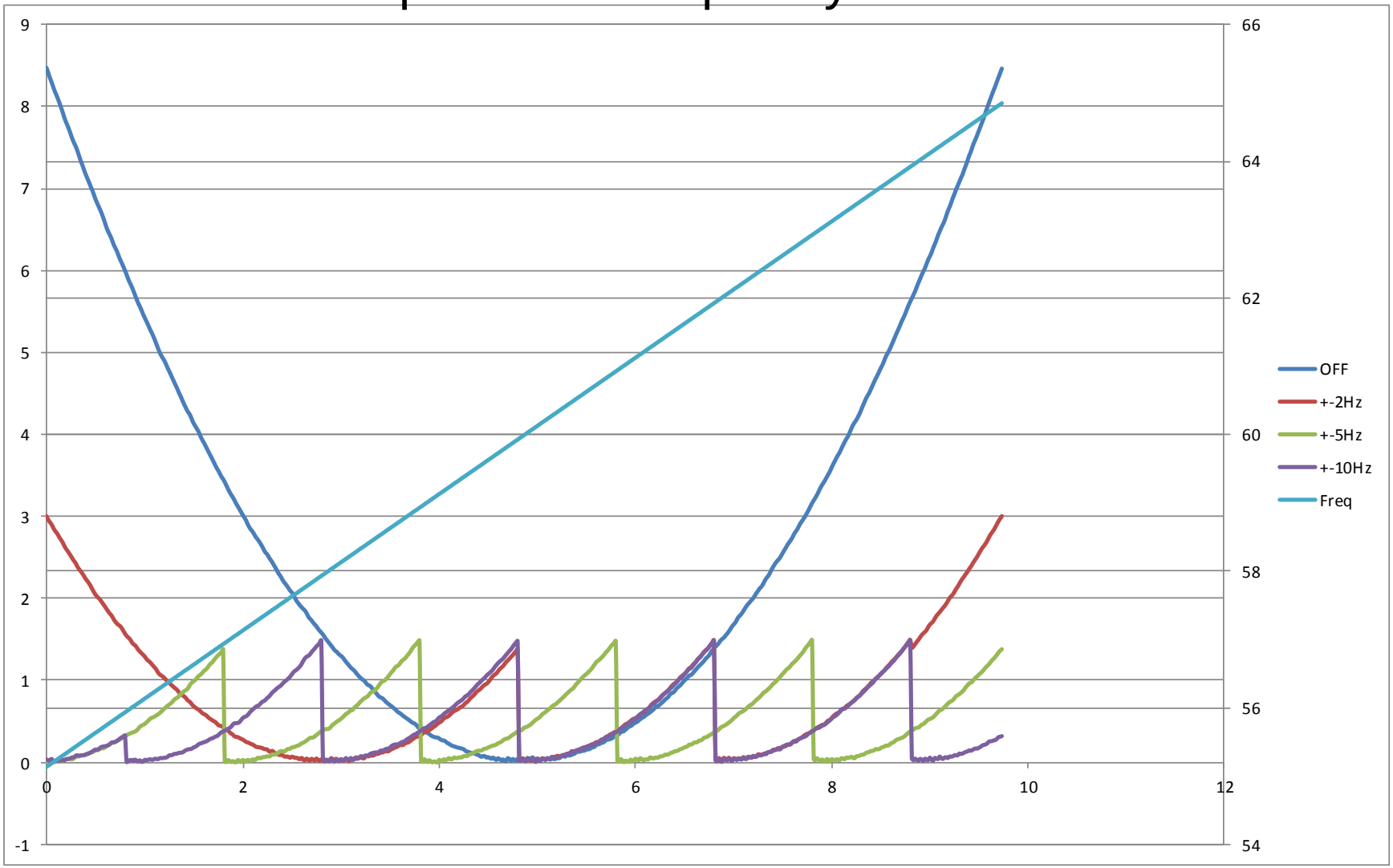
Adaptation to frequency variation



Influence of Configuration Parameters

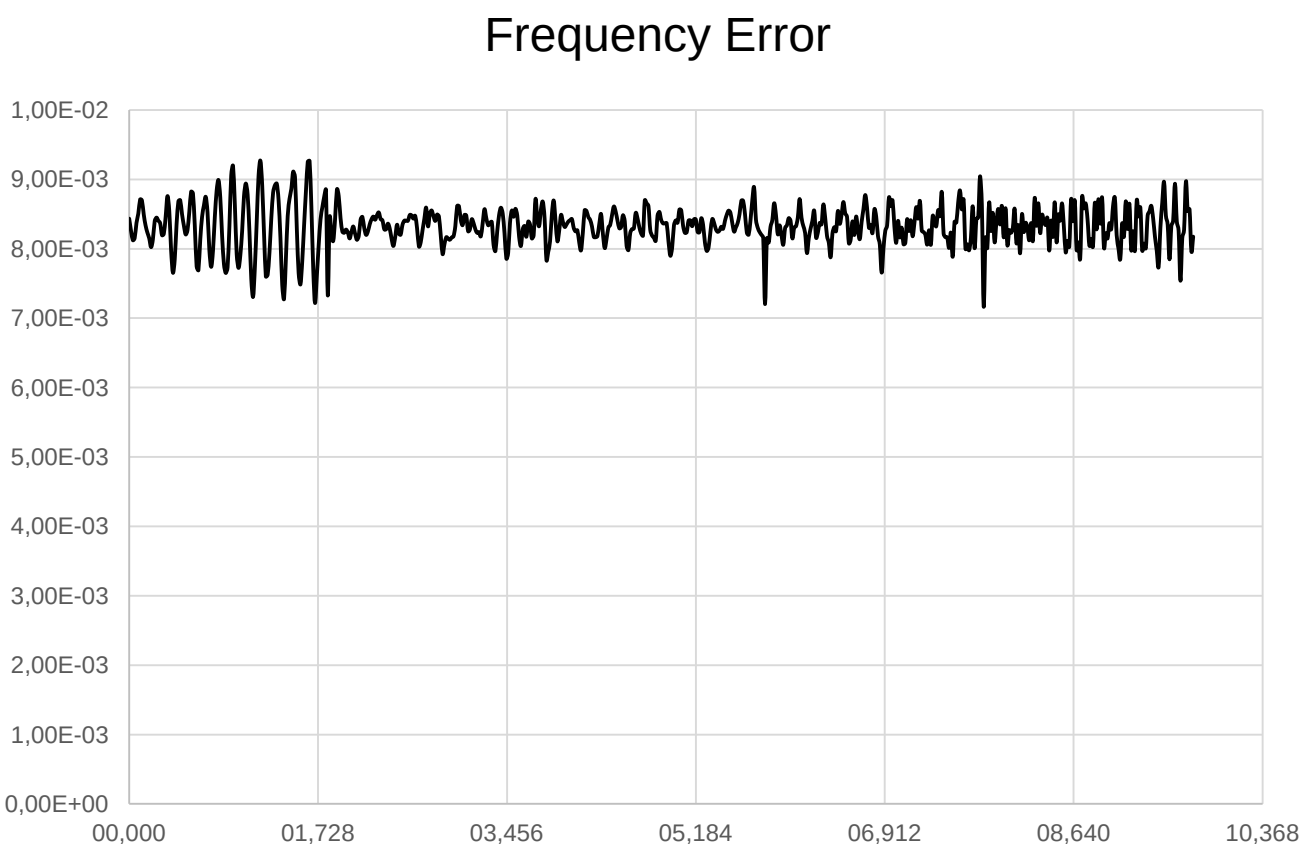
Eletrobras Cepel

Adaptation to frequency variation



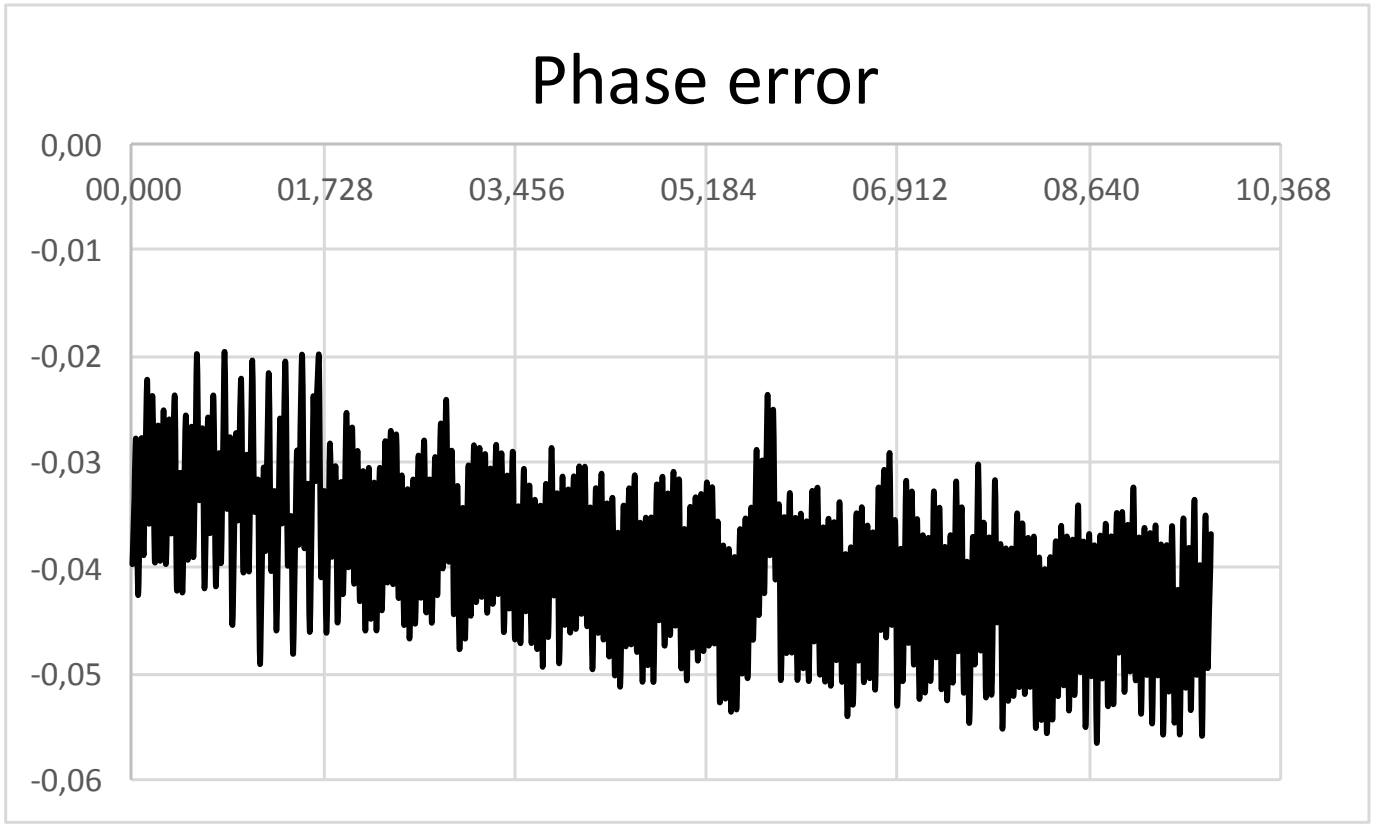
Influence of Configuration Parameters

Adaptation to frequency variation



Influence of Configuration Parameters

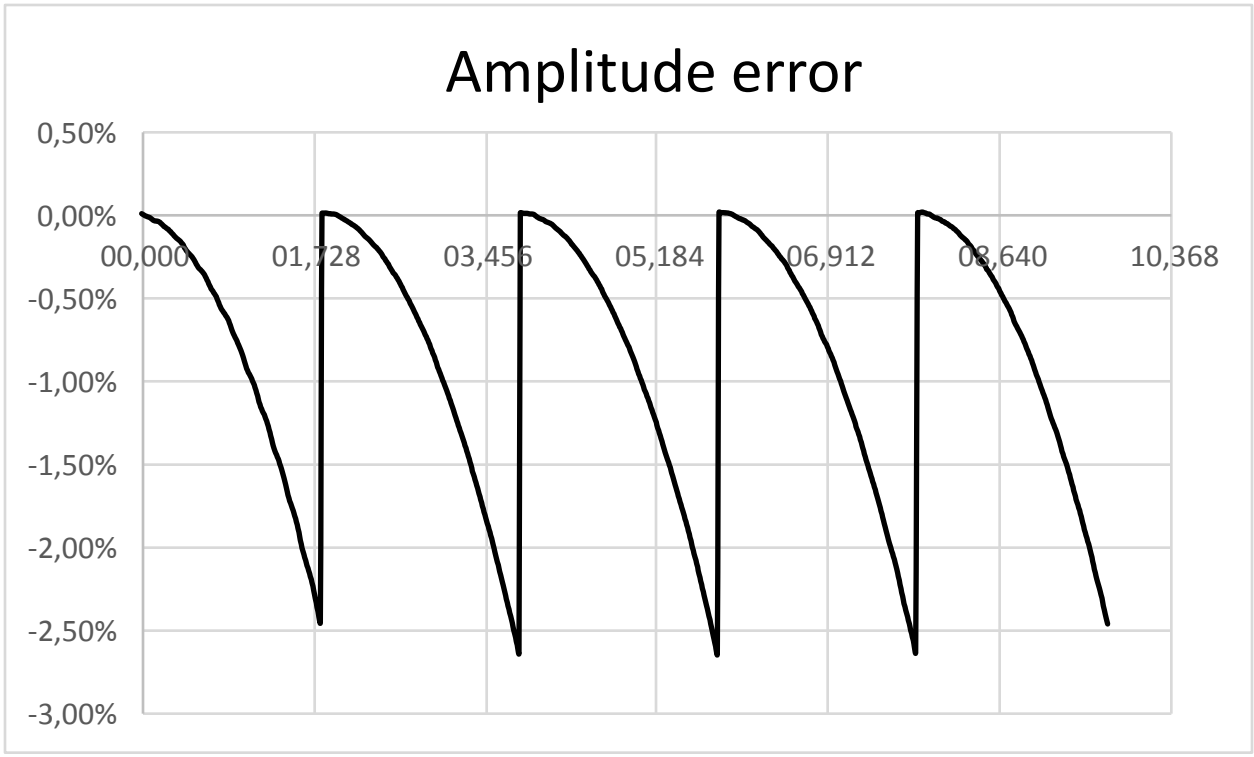
Adaptation to frequency variation



Influence of Configuration Parameters

Eletrobras Cepel

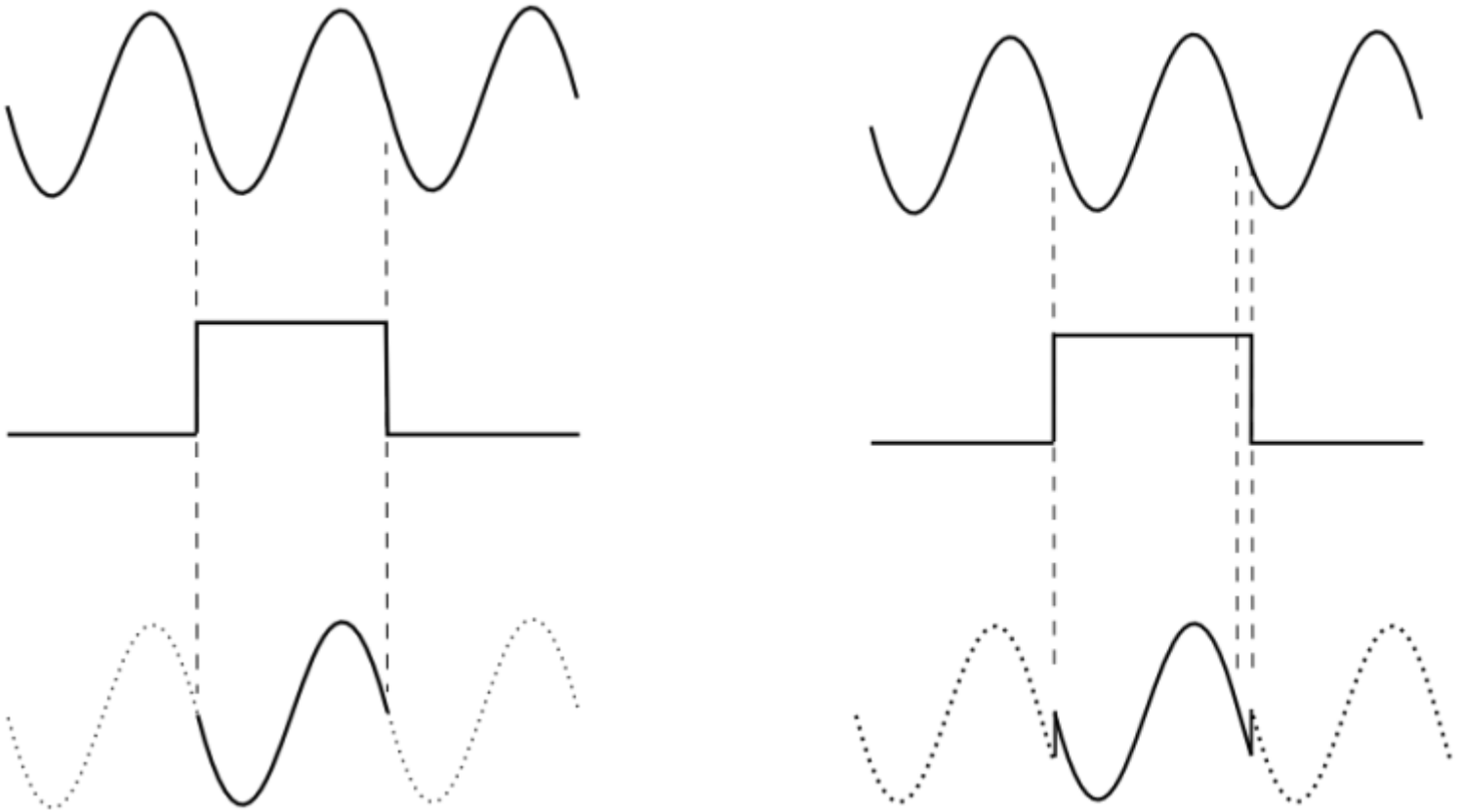
Adaptation to frequency variation



Influence of Configuration Parameters

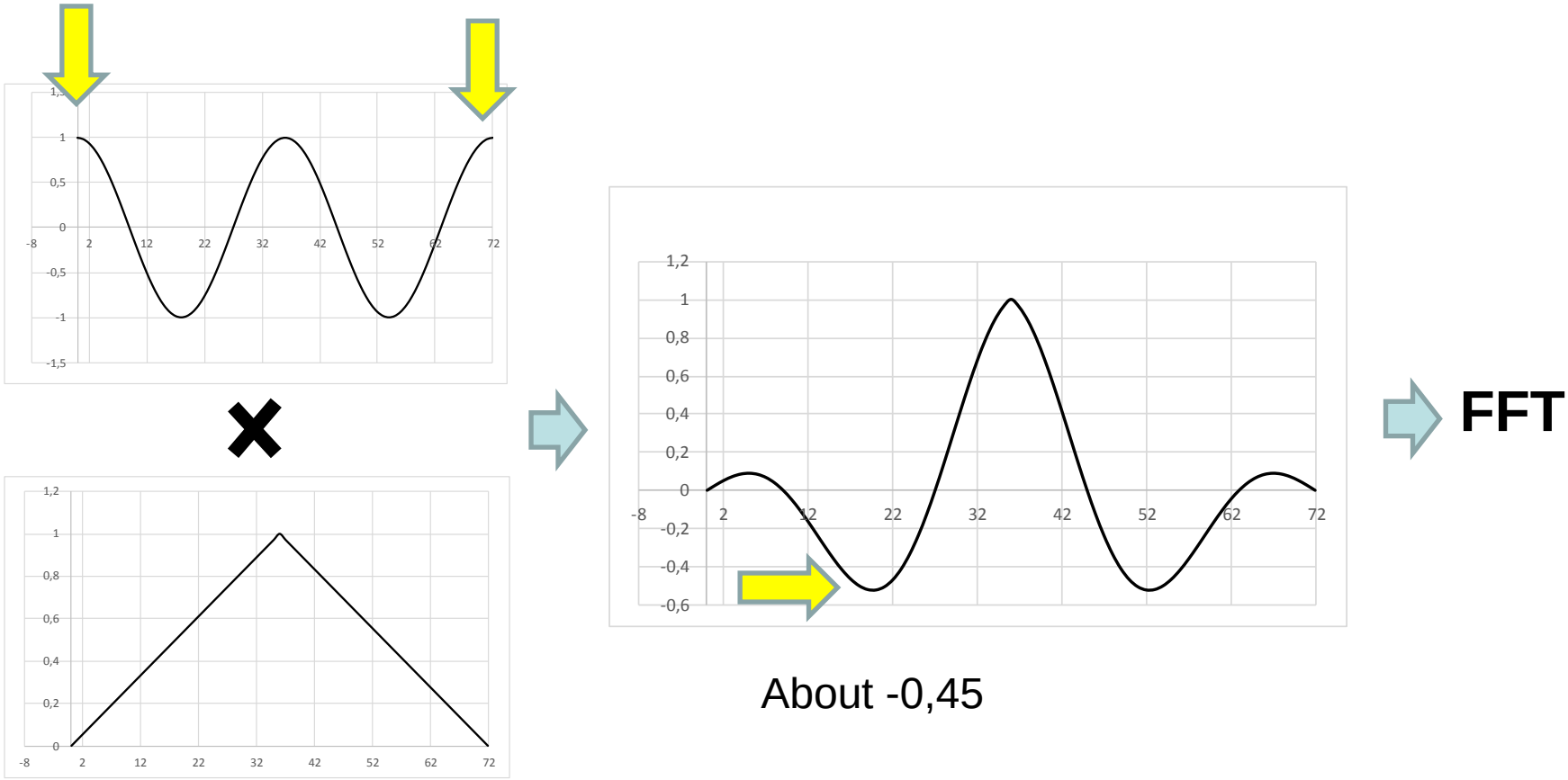
Eletrobras Cepel

Adaptation to frequency variation



Influence of Configuration Parameters

Adaptation to frequency variation

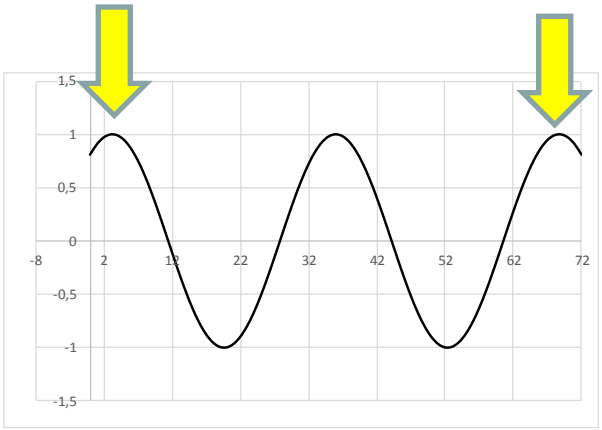


About -0,45

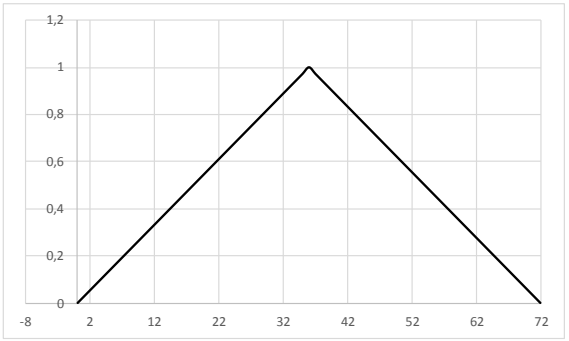
Influence of Configuration Parameters

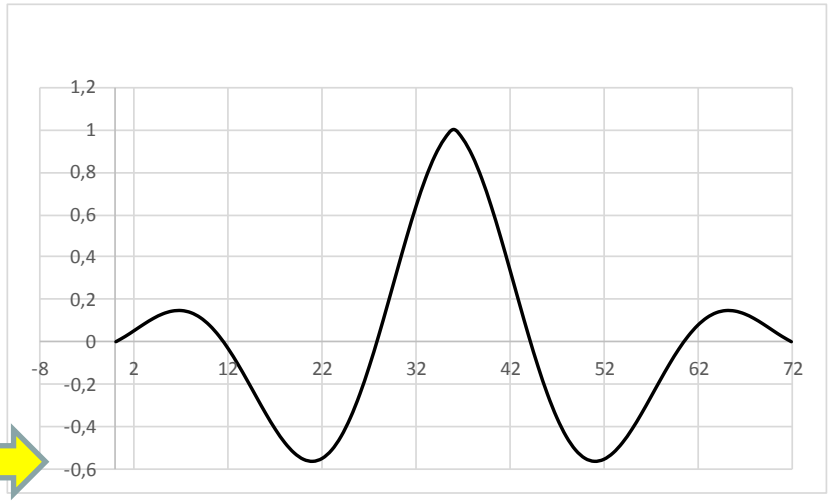
Eletrobras Cepel

Adaptation to frequency variation



×



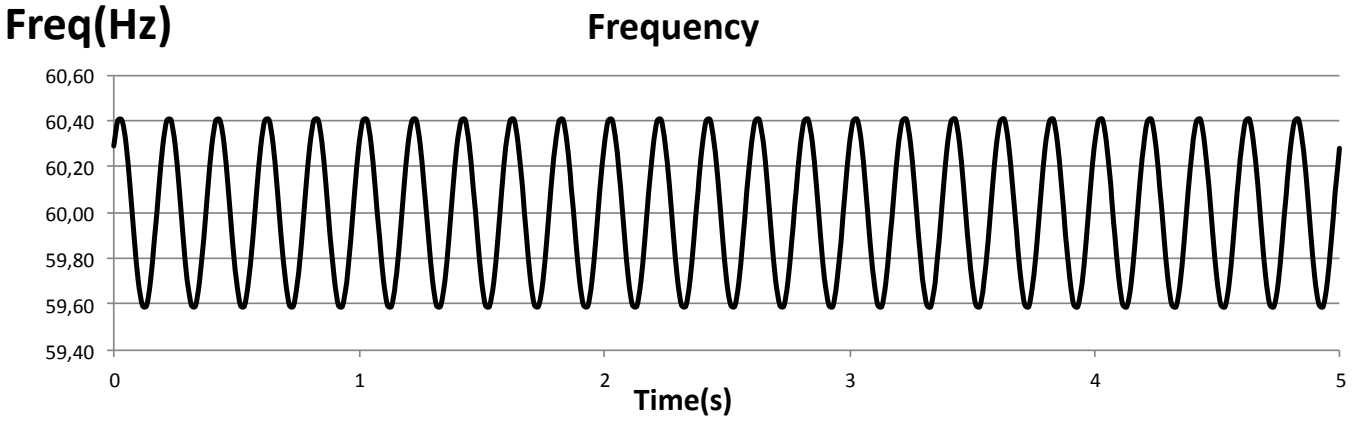


FFT

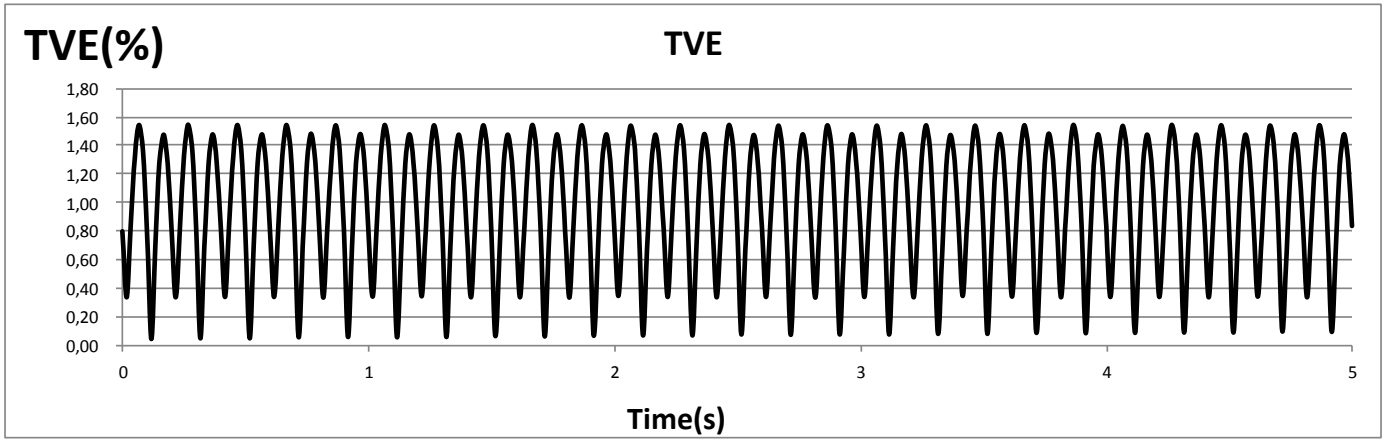
Almost -0,5

Influence of Configuration Parameters

Even though it passes on modulation tests!



Limit is 3% for this specific test !



Partial Conclusions

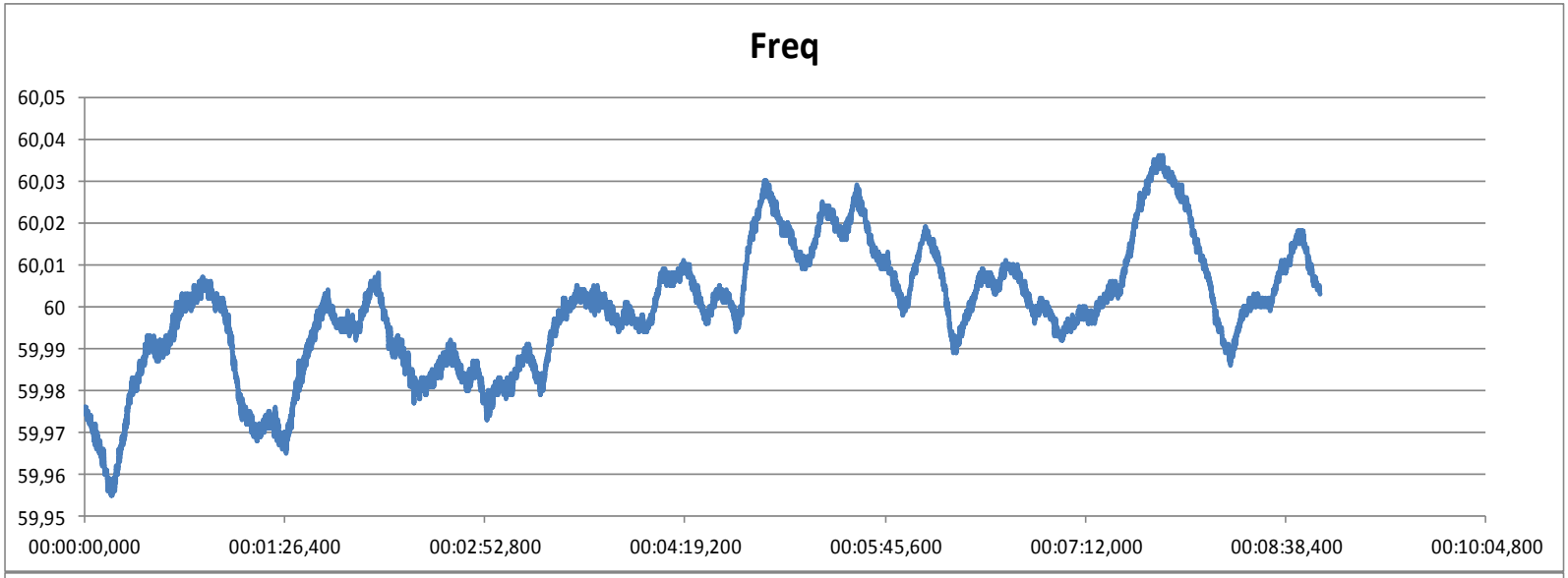
1. The performance of the PMU depends on the firmware loaded on that particular model.

2. The performance of the PMU depends on the configuration loaded in that particular model.

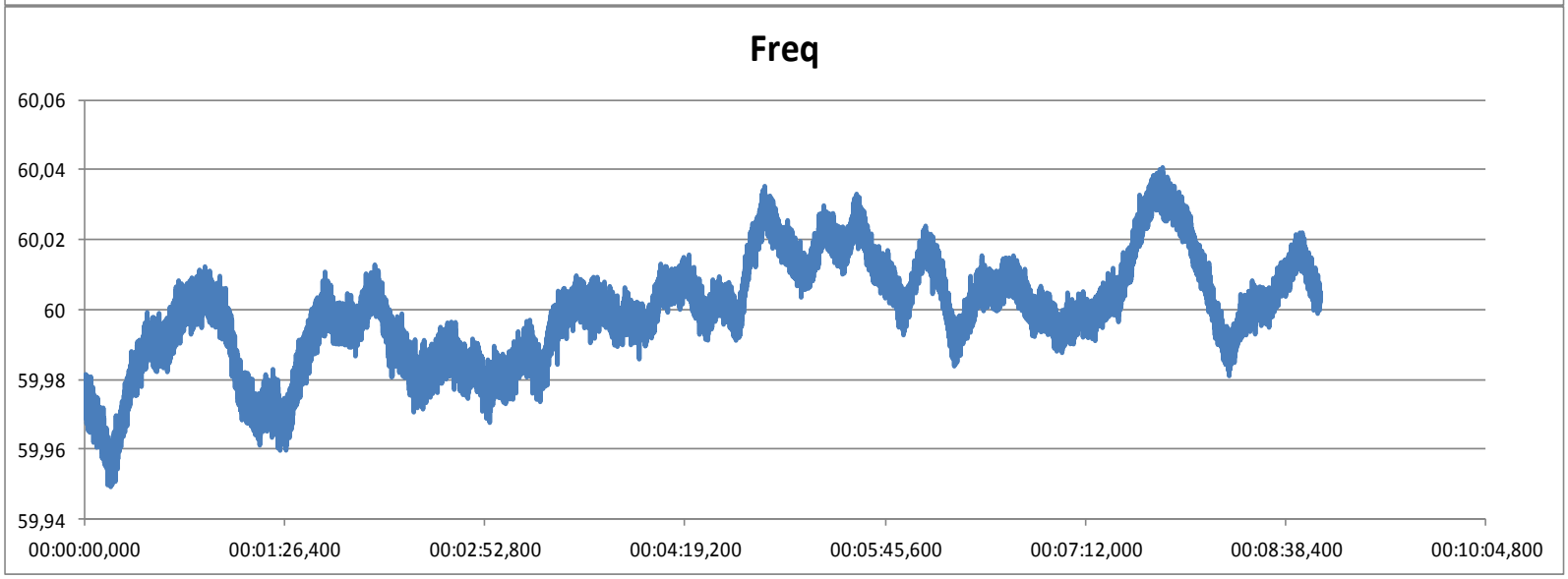
3. The PMUs, with regard to the firmware and configuration used, must be pre-checked in the laboratory before being used in the field.

PMUs in Practice – Outlet voltage

PMU 1

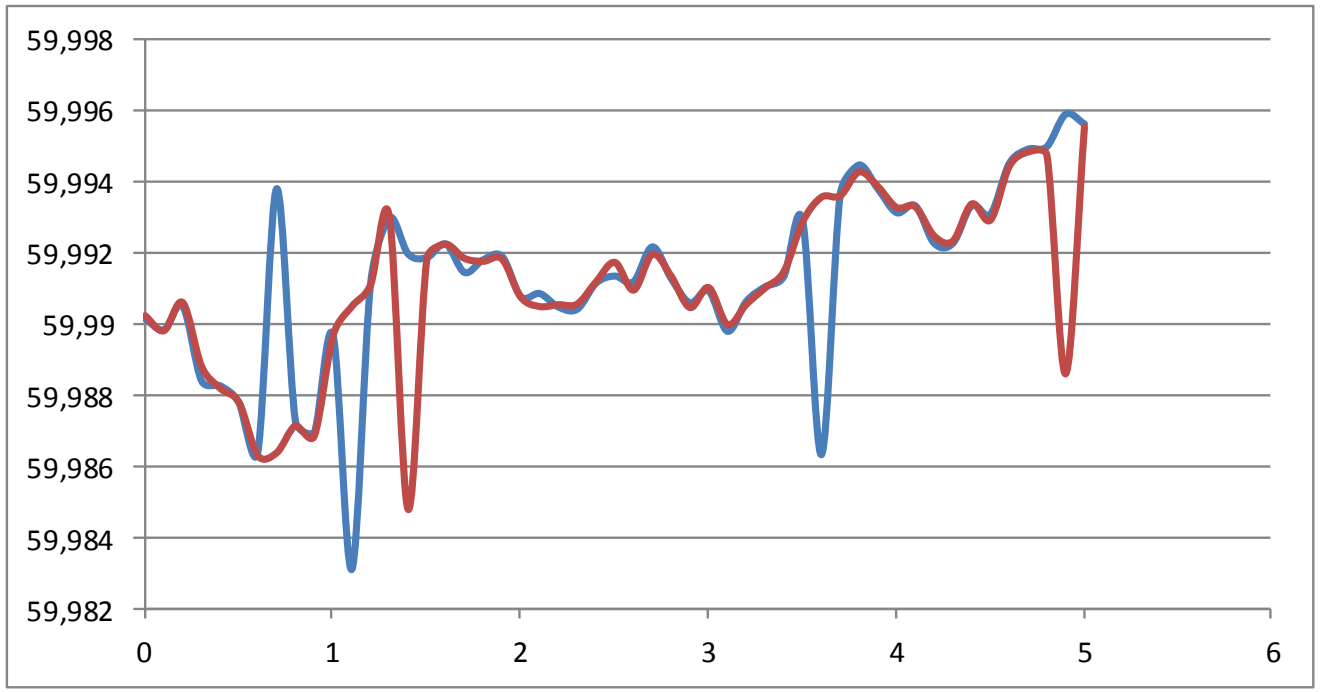


PMU 2



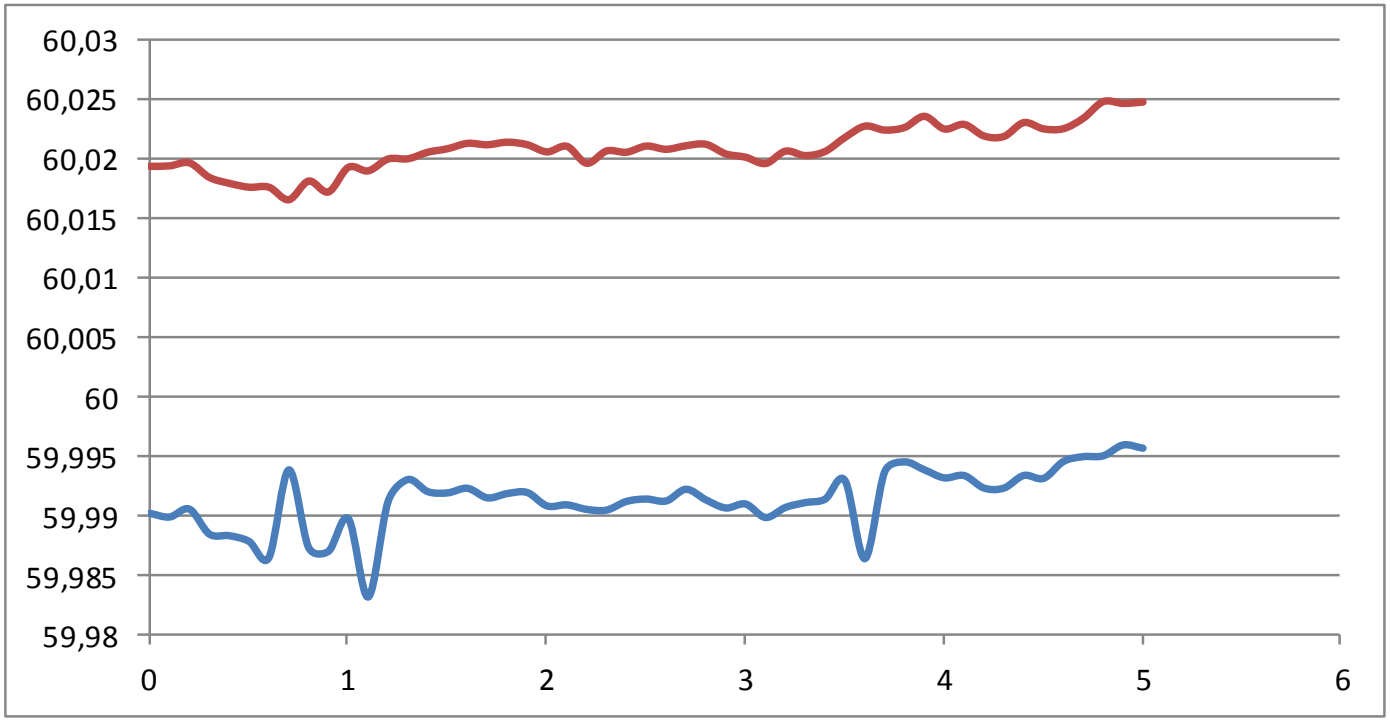
PMUs in Practice – Analysis 1

FIELD CONDITIONS: 2 PMUS should have same output



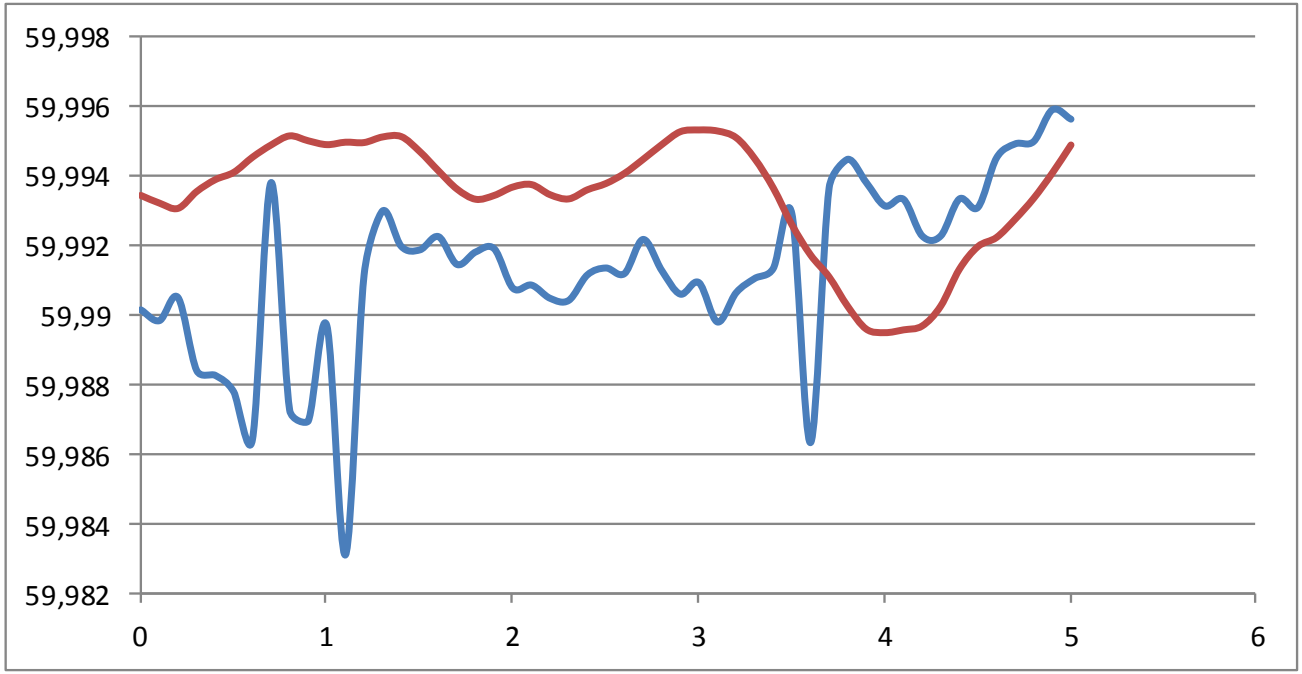
PMUs in Practice – Analysis 1

FIELD CONDITIONS: 2 PMUS should have same output



PMUs in Practice – Analysis 1

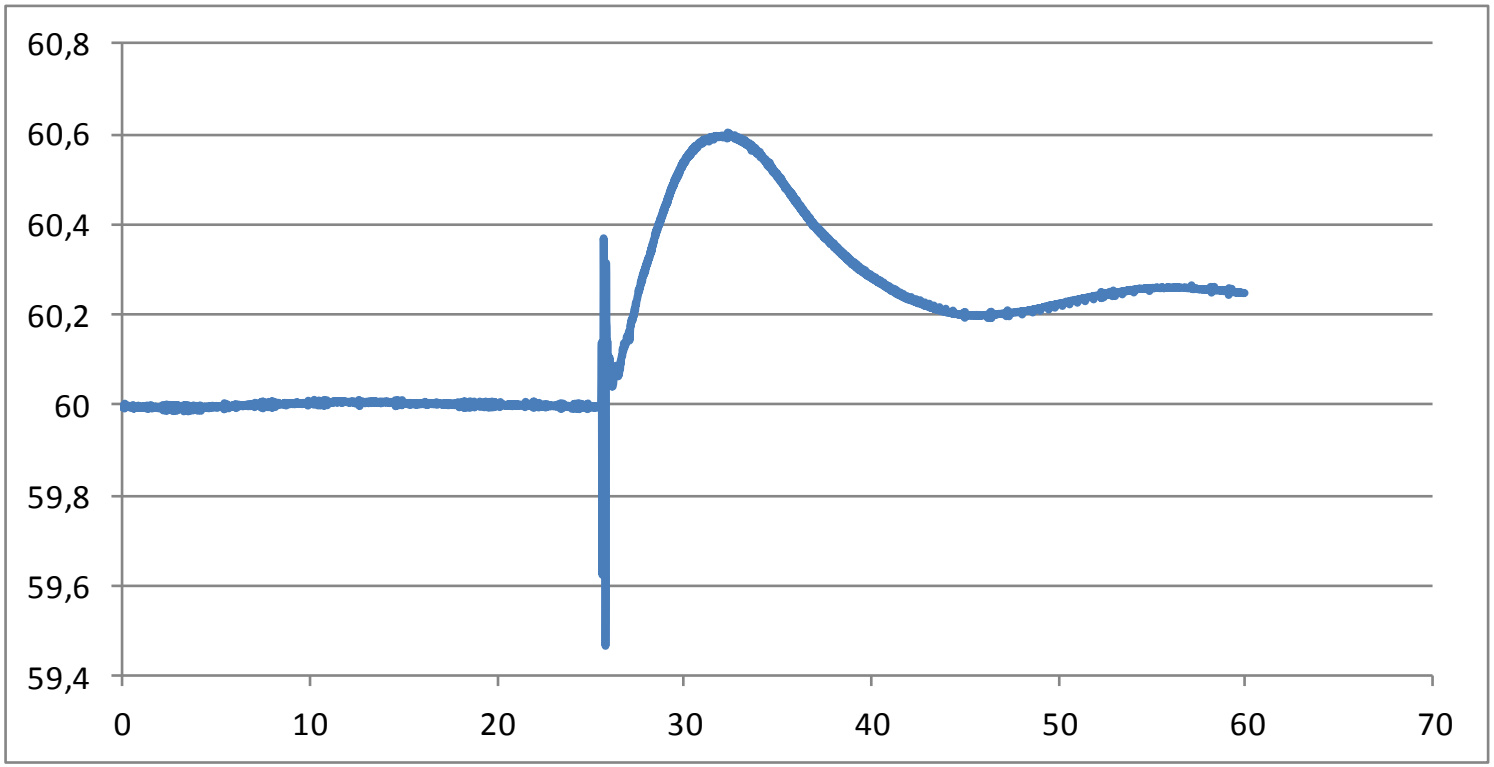
FIELD CONDITIONS: 2 PMUS should have same output



PMUs in Practice – Analysis 2

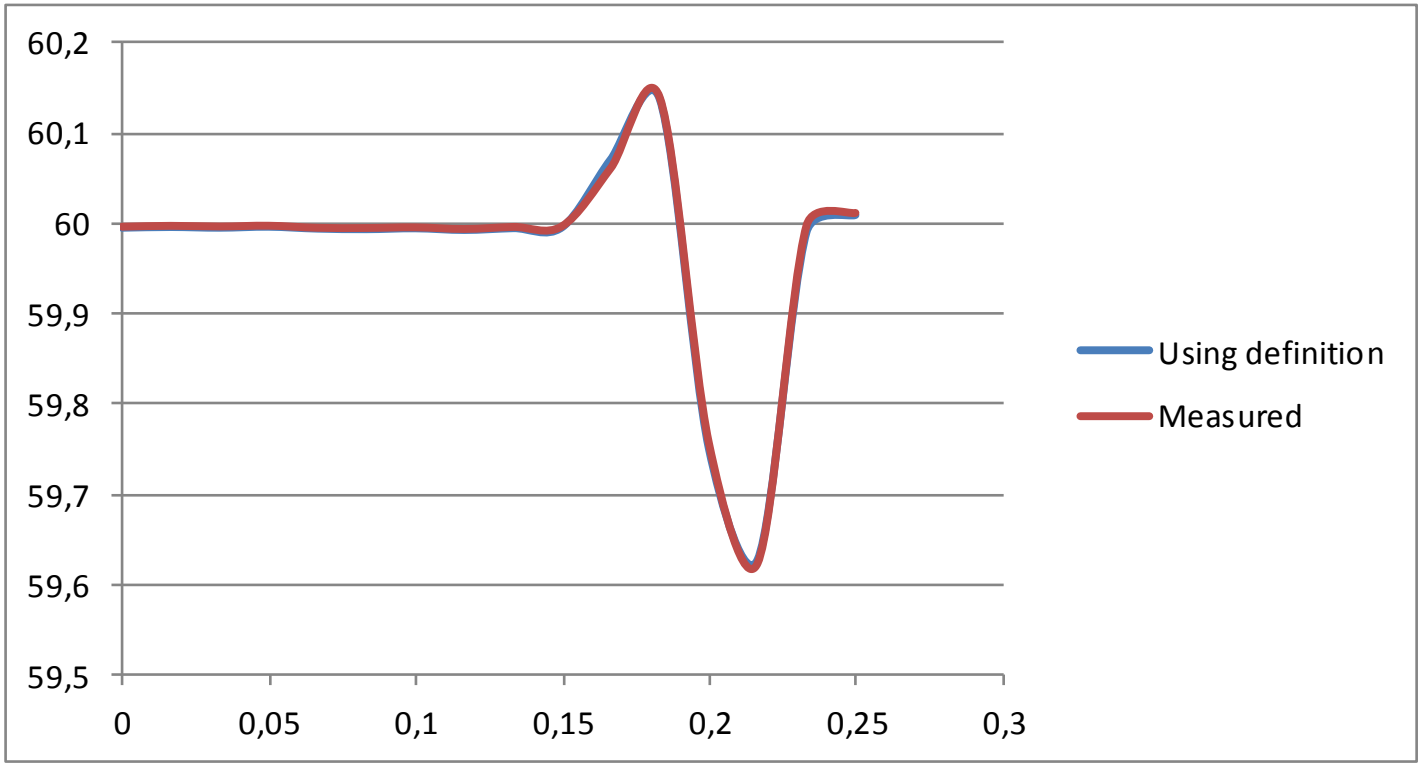
Eletrobras Cepel

Near location of a event



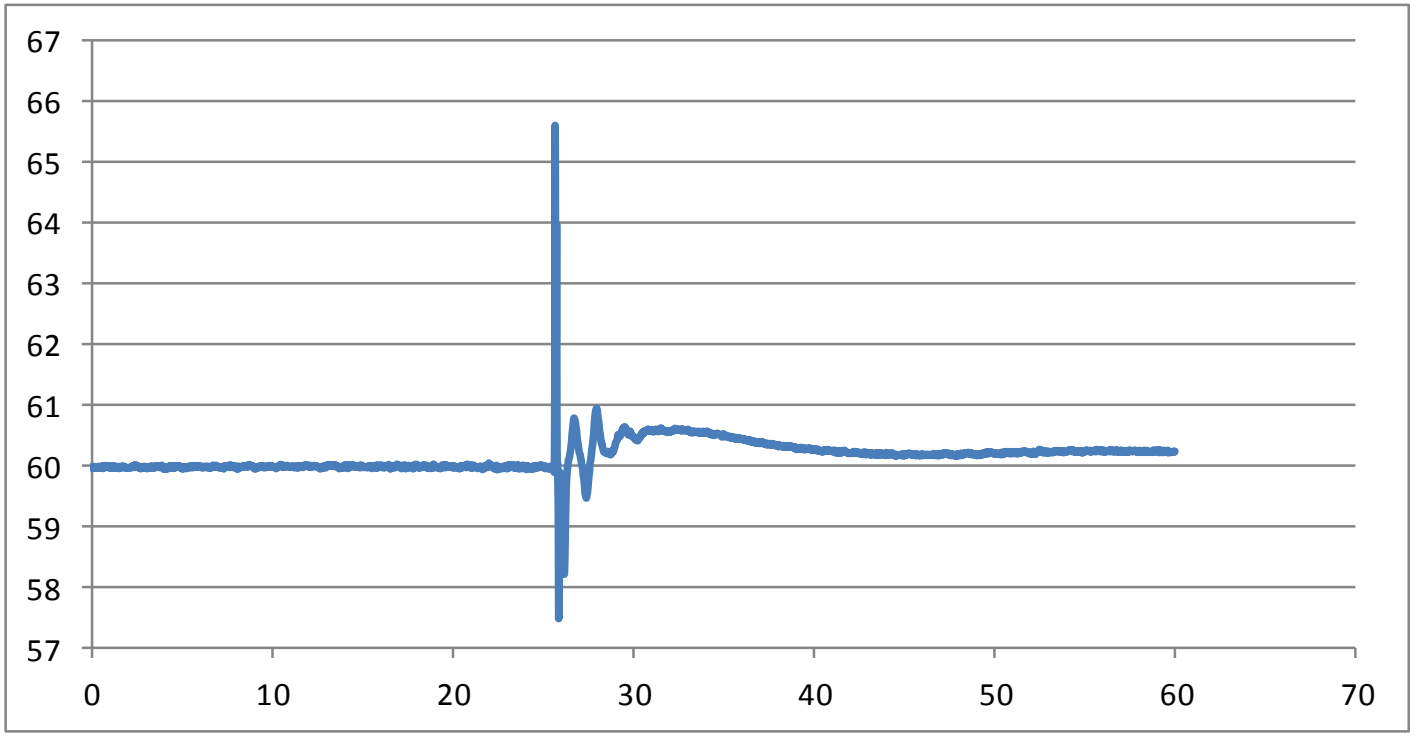
PMUs in Practice – Analysis 2

Near location of a event



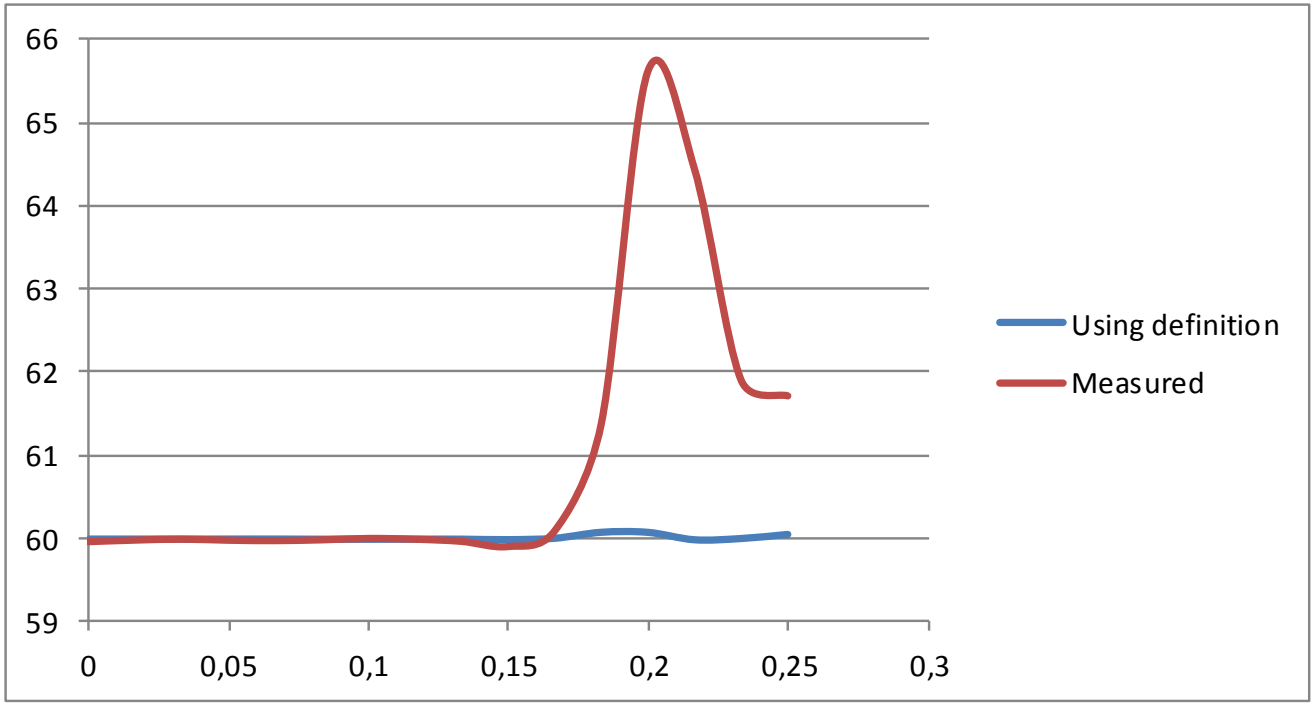
PMUs in Practice – Analysis 2

Distant location of the same event



PMUs in Practice – Analysis 2

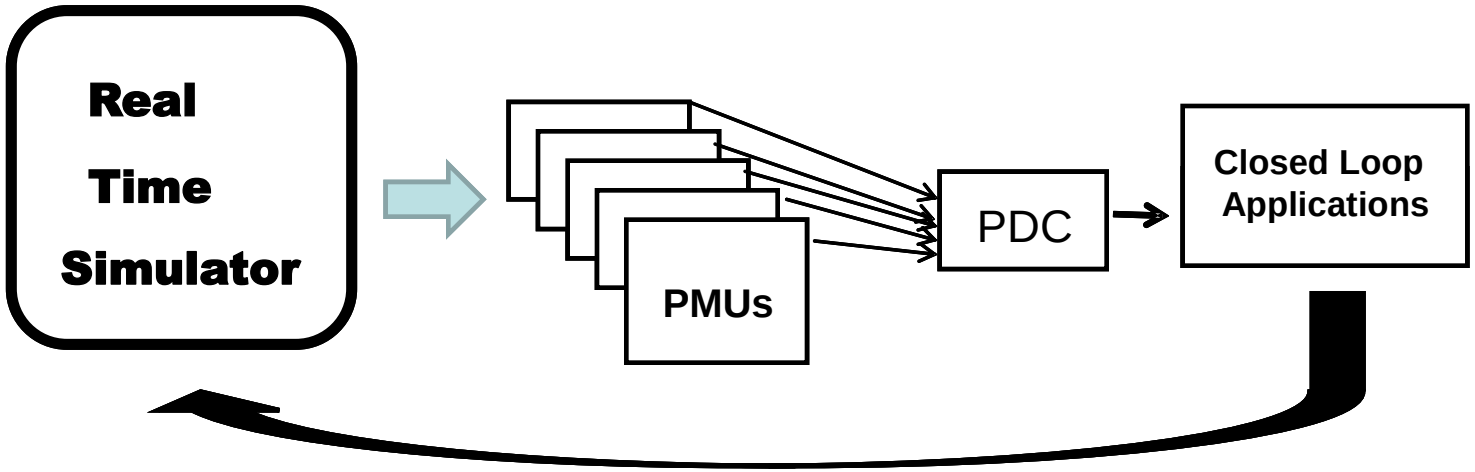
Distant location of a event



Next Steps

Planned Activities

• Computational platform for testing computer applications (research & development) in closed loops using real time PMU's simulation ("hardware in the loop").



Thanks!

alves@cepel.br

Eletrobras
Cepel