Statistical Characterization of (Current) Waveform Parameters

MeterEmi
EMPIR
EURAMET
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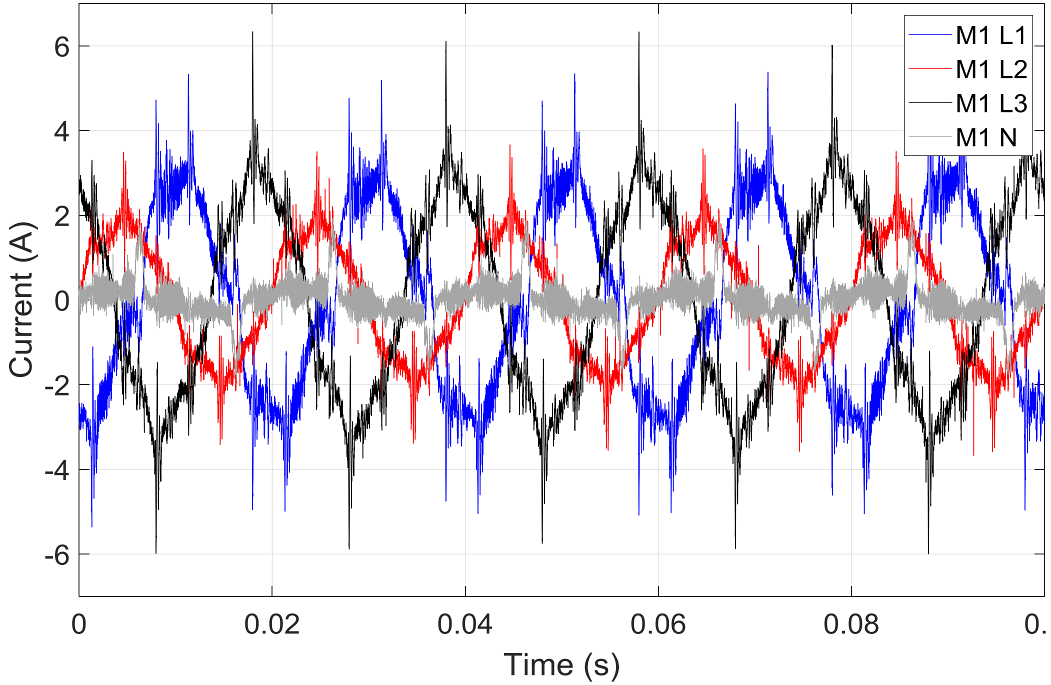
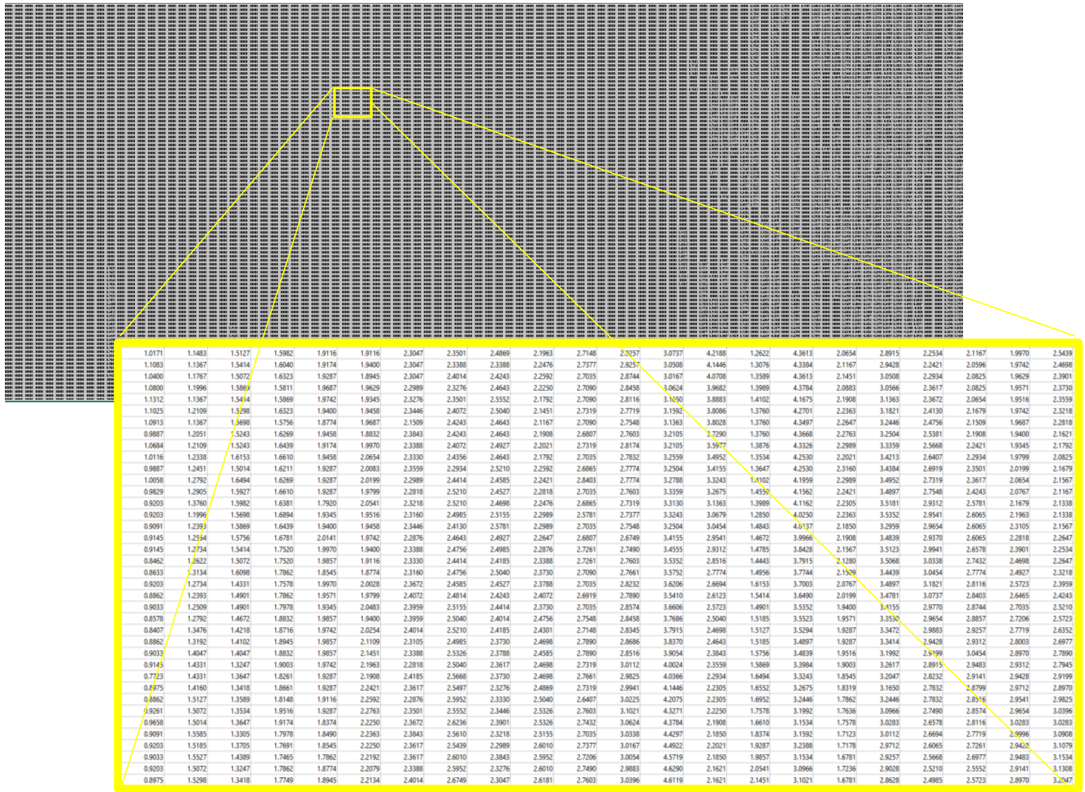
Introduction

When measuring complex waveforms, it is fundamental to ensure fidelity.



This means the signal has to be sampled at high-resolution, low distortion and at a sufficiently high sampling rate

Even if this waveform is usually displayed in the time-domain for facilitating the interpretation of the results…



This massive source of data can be further analyzed through statistical techniques

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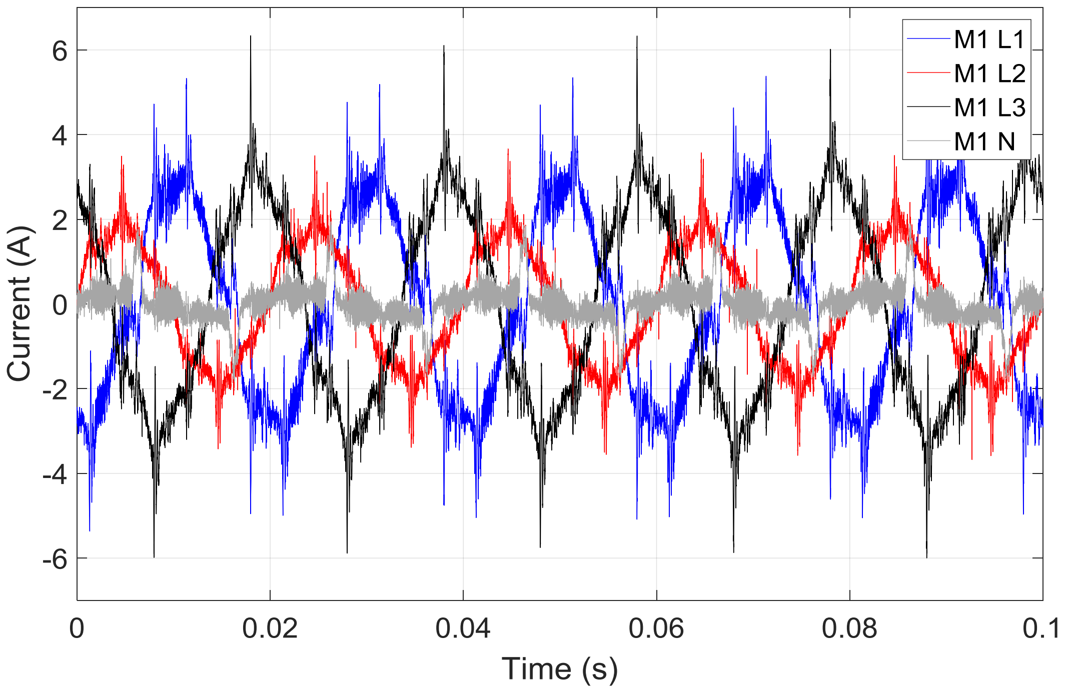
Introduction

Why should we explore the waveform statistics?



For finding answers to what is really causing the metering errors:

- Is it the amplitudes of the peaks/spikes in the waveform?
- Is it the distortion (harmonics, supraharmonics)?
- Is the error a function of di/dt?
- Is it the impulsiveness of the waveform?
- … Other hypothesis

The complexity of realistic current waveforms makes it difficult to reach a direct conclusion regarding its possible influence in generating metering errors in static meters.

Establishing causality of metering errors is a must

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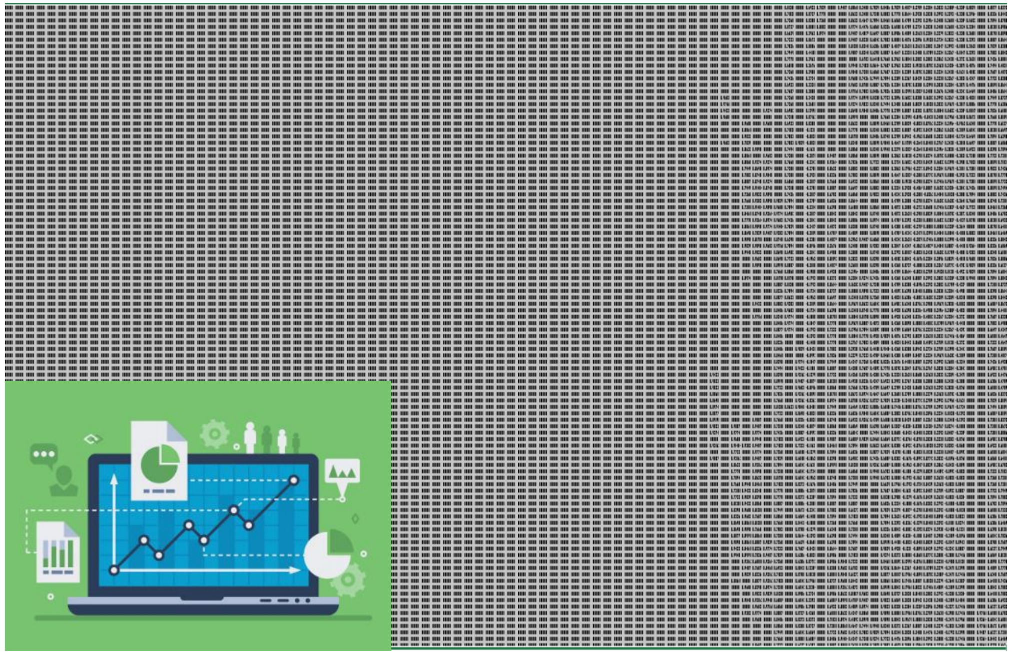
Introduction

<u>Which statistical techniques could be used?</u> ⟷ In fact, many approaches might be chosen. However, we have opted for two of them



Reducing the complexity is key for understanding the underlying root cause of the metering error

<u>Raw data -> Parameters</u>

Distribution analysis

Studying the distribution of the amplitude of an interference using the **APD detector** is useful for assessing and characterizing impulsive noise sources

Design of Experiments

Controlled experiments that allow identifying the waveform parameters that have a significant influence in metering errors.

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Amplitude Probability Distribution

What?

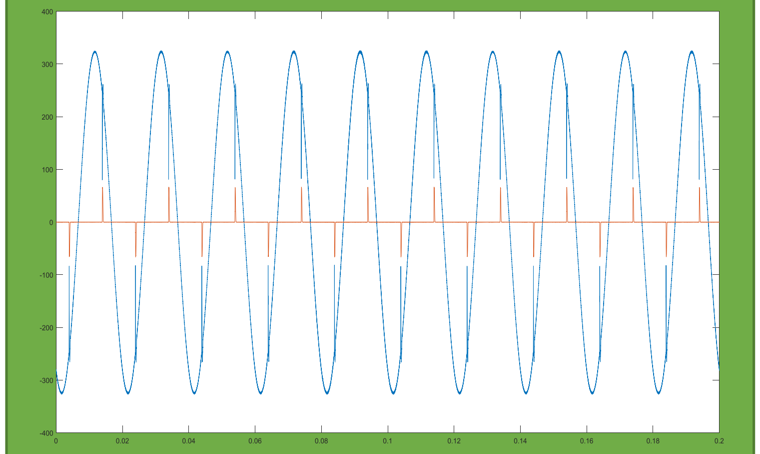
APD is defined as the amount of time the measured envelope of an interfering signal exceeds a certain level

$$APD_R(r) = 1 - F_R(r)$$

$$f_R(r) = \frac{d}{dr}F_R(r) = -\frac{d}{dr}APD_R(r)$$

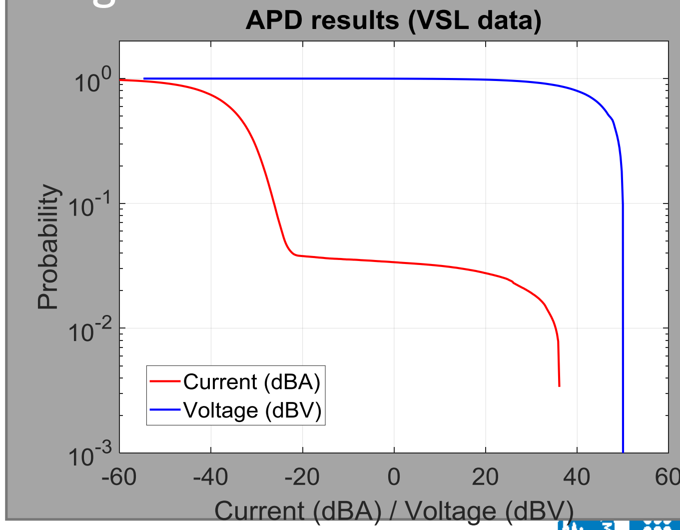
Why?

It allows to easily identify impulsive noise (heavy tailed distributions) from other types of noise (gaussian like)



How?

A convenient graphical representation enables an straightforward distinction between impulsive and gaussian-like noise sources



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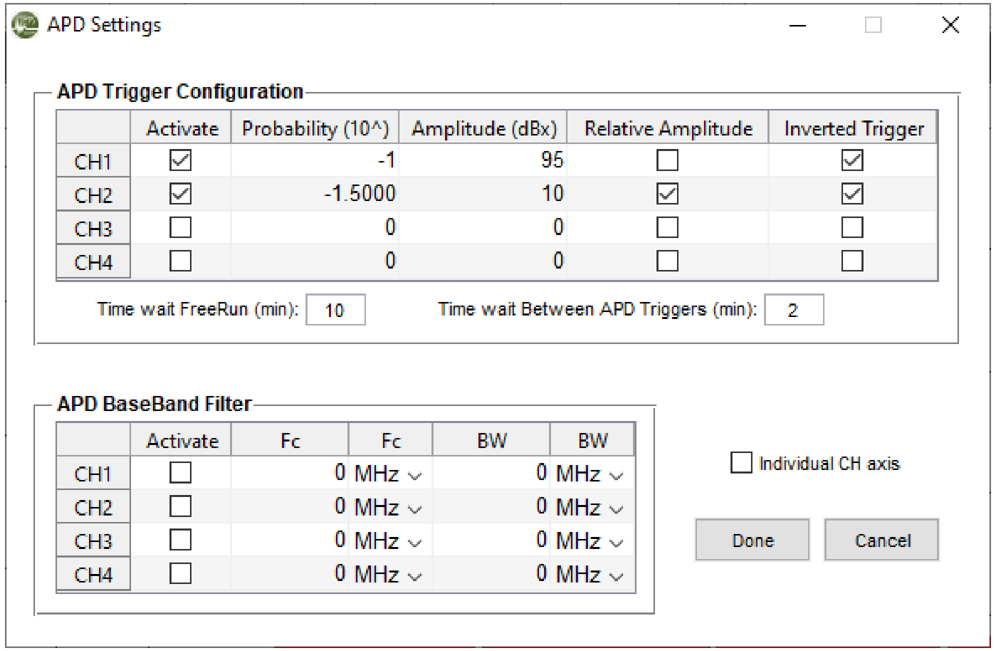
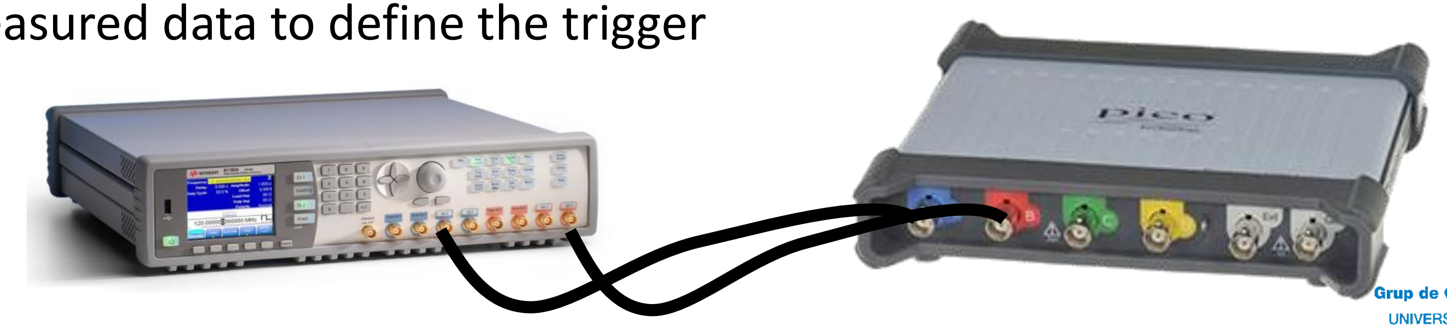
Amplitude Probability Distribution

- Define **APD** triggers at **each channel**
- Define **probability threshold**
- Define **Amplitude** (absolute or relative)
    - Relative to Probability < 1
- **Inverted** trigger to identify impulsive noise
- **Storage** interval
- Use more previously measured data to define the trigger





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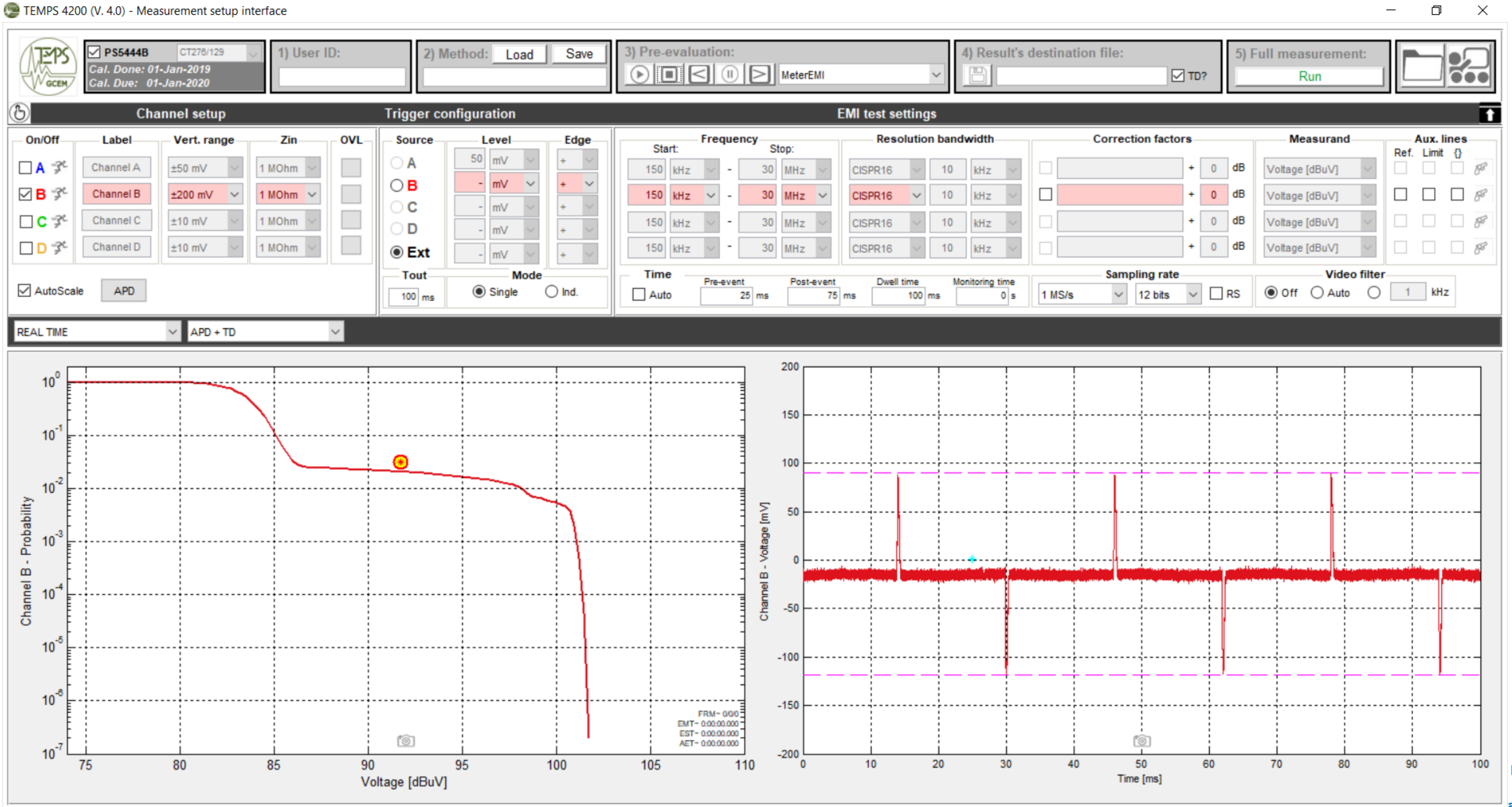
Amplitude Probability Distribution



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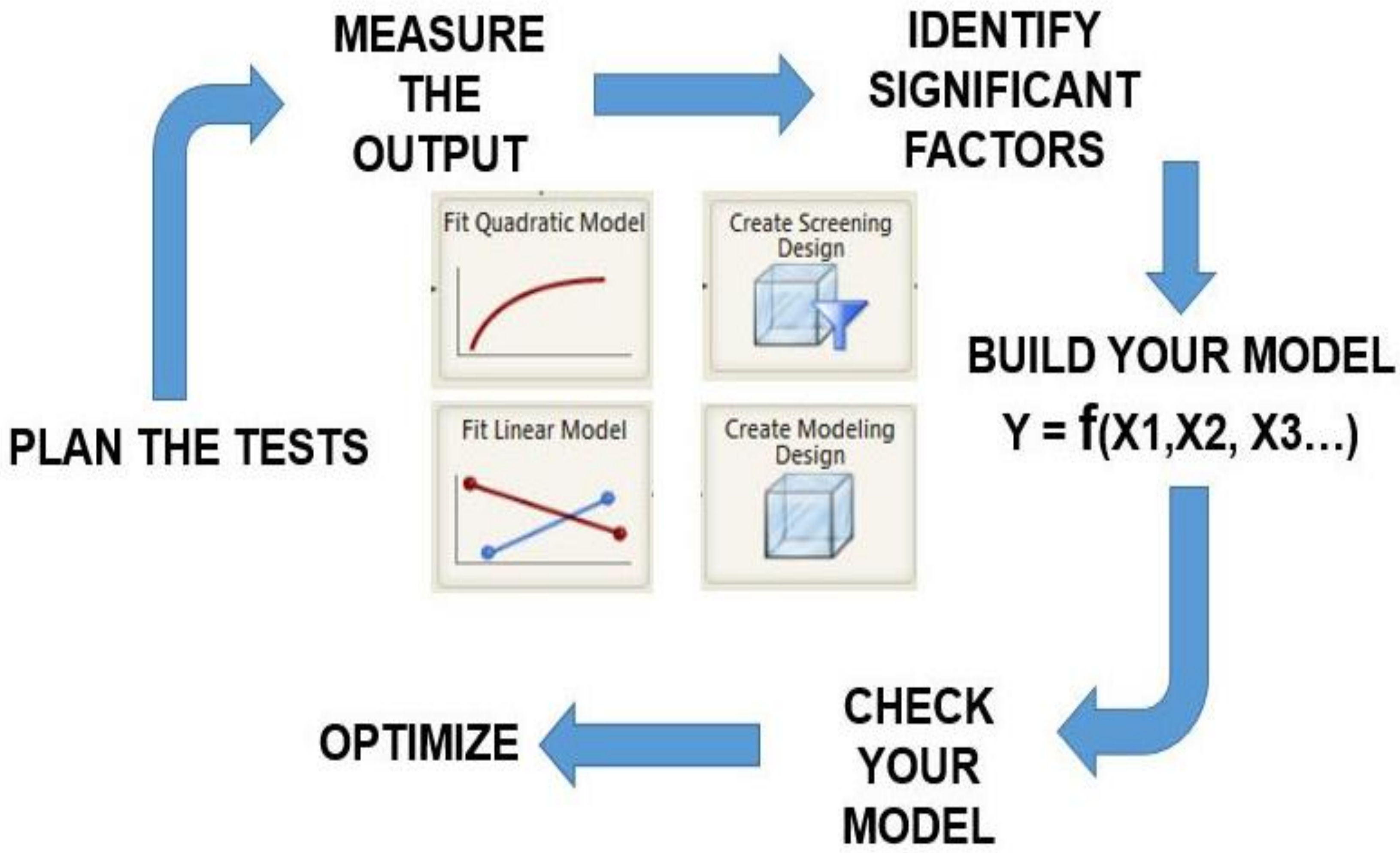
Design of the Experiment

DoE is defined as a branch of applied statistics that deals with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters.



Design of the Experiment

- **Objective:**

Determine which are the key (current) waveform parameters that have a significant influence in the measurement errors of static meters

- **Methodology:**
  - ✓ Full factorial design -> Robust experiment through repetitions under test standard conditions
  - ✓ Data complexity reduction. From time-domain waveform characterization to scalar waveform & statistical parameters
  - ✓ Multidimensional empirical (black box) model for the response of the static meter error
  - ✓ Analysis of variance (ANOVA) and sensitivity evaluation

Design of the Experiment

- **Expected outcome**
  - ✓Parametric characterization of the measured current waveforms
  - ✓Identify the critical waveform parameters causing errors in the static meters
  - ✓Obtain significant results through a robust statistical approach
  - ✓ Estimate the economic impact of the errors above
  - ✓ Predict if realistic waveforms are likely to produce errors in static meters

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Design of the Experiment

- **Experiment conditions**
  - Warm up time: 5 min
  - Pseudo-Randomized Test Sequence
  - Initial experiment calibration
  - Number of repetitions of each different experiment trial/run: 5
  - Trial/run time per experiment iteration: Depends on the energy consumed. A reasonable fixed value of energy will be defined based on a preliminary study.
  - Single-phase systems and EUTs
  - Reference power measurement instrument: Yokogawa Power Analyzer WT500

Design of the Experiment

- **The Sample**
  - 10 different models of static meters connected in series, simultaneously tested.

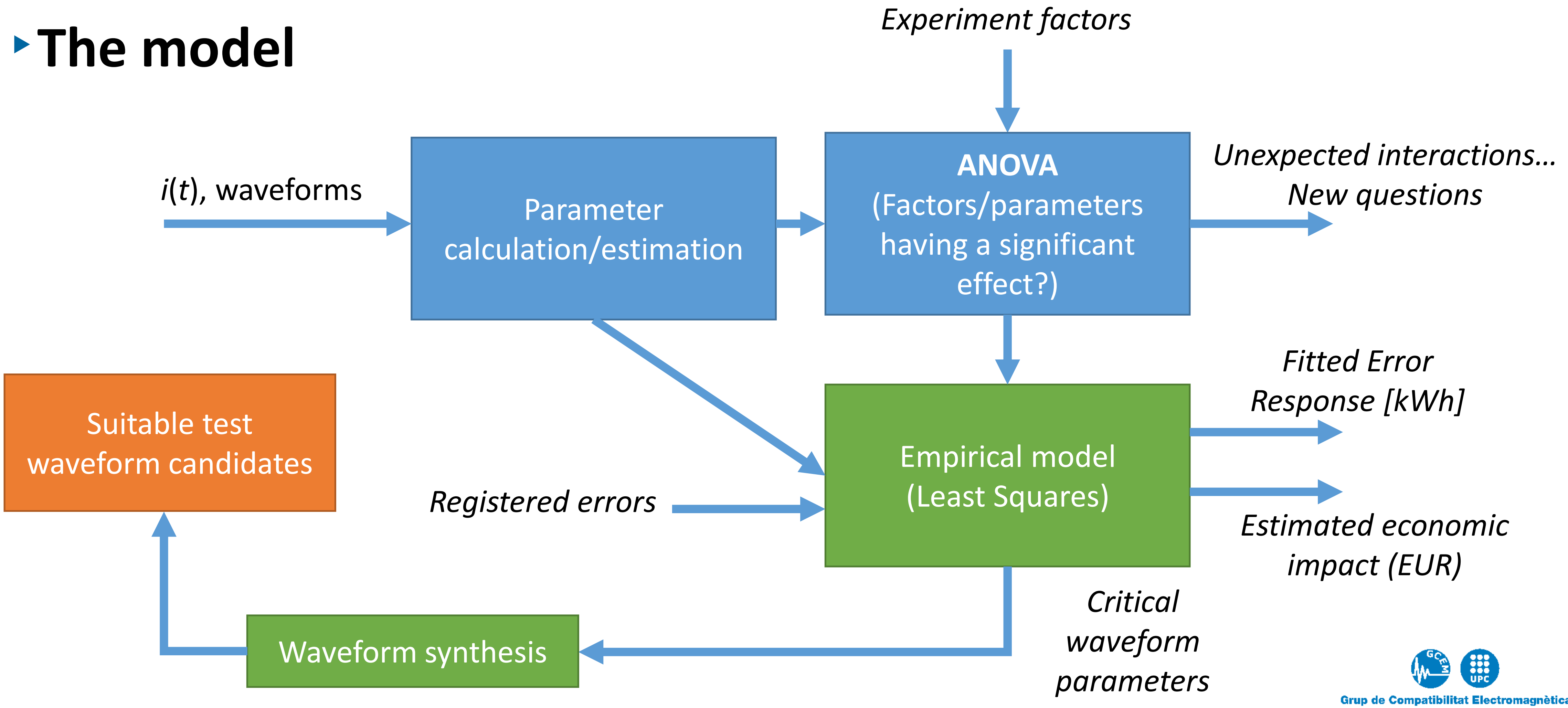
- **Experiment factors**
  - Oscilloscope Probe Type
    - Current Probe LF, Current Probe HF, Differential Voltage
  - Power Source
    - Pure Sine Wave
    - Distorted Sine Wave. Maximum allowed THD
    - Distorted Sine Wave. Half allowed THD
  - Load type
    - LED Light bulbs
    - CFL light bulbs
    - Waterpump + regulator. 5 types of regulators
      - Min
      - Middle
      - Max

Design of the Experiment

- Measurement settings
  - Multichannel time domain EMI with PS 5444D
  - Multiple probes for applying the extended frequency range current measurements
  - Oscilloscope sampling rate: 1 MSa/s
  - Acquisition (Dwell) time: 200 ms, that is, 10 cycles @ 50 Hz.
  - Vertical resolution: 12 bits
  - Number of acquisitions: 3 per trial/run one after the warm-up time, one at the middle of the experiment and, a final one just before finalizing the measurement.
  - Software: TEMPS 4.2 is going to be used
  - A predefined and validated method configuration files (.met) should be used

Design of the Experiment

- **The model**



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Design of the Experiment

- **Waveform parameters**
  - Rise-time
  - Fall-time
  - Duration
  - Amplitude
  - dI/dt
  - Impulsiveness ratio
  - Wavelet coefficient
  - …more can be added

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Design of the Experiment

- Experiment Validation
  - Additional waveform measurements should be performed of cases other than the ones in the experiment matrix (combination of factors and levels). Then, the model can be fed with the data and we can calculate the deviation in the predicted and the actual e
  - Some examples:
    - A Waterpump + regulator at a different dimming
    - A new load which is expected to induce reading errors
    - …
- Data management
  - The idea is to go with Open Data. https://ieee-dataport.org/submit-dataset
  - If the experiment is expanded, new data can be fed into the model
  - Data must be anonimyzed.

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