Trigger mechanisms to detect DCPQ events and distortions

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DC Grids

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Introduction

DC grids and Power Quality Indices

- DC grids have been proposed as solution to current problems in the power systems having some advantages over traditional AC grids.
- PQ indices are very well documented for AC grids in international standards, but almost nothing done yet in DC grids.
- The definition of PQ indices in DC grids requires real-life data which will allow for determining reference levels, thresholds, sampling rates, integration (time) windows, etc.

Introduction

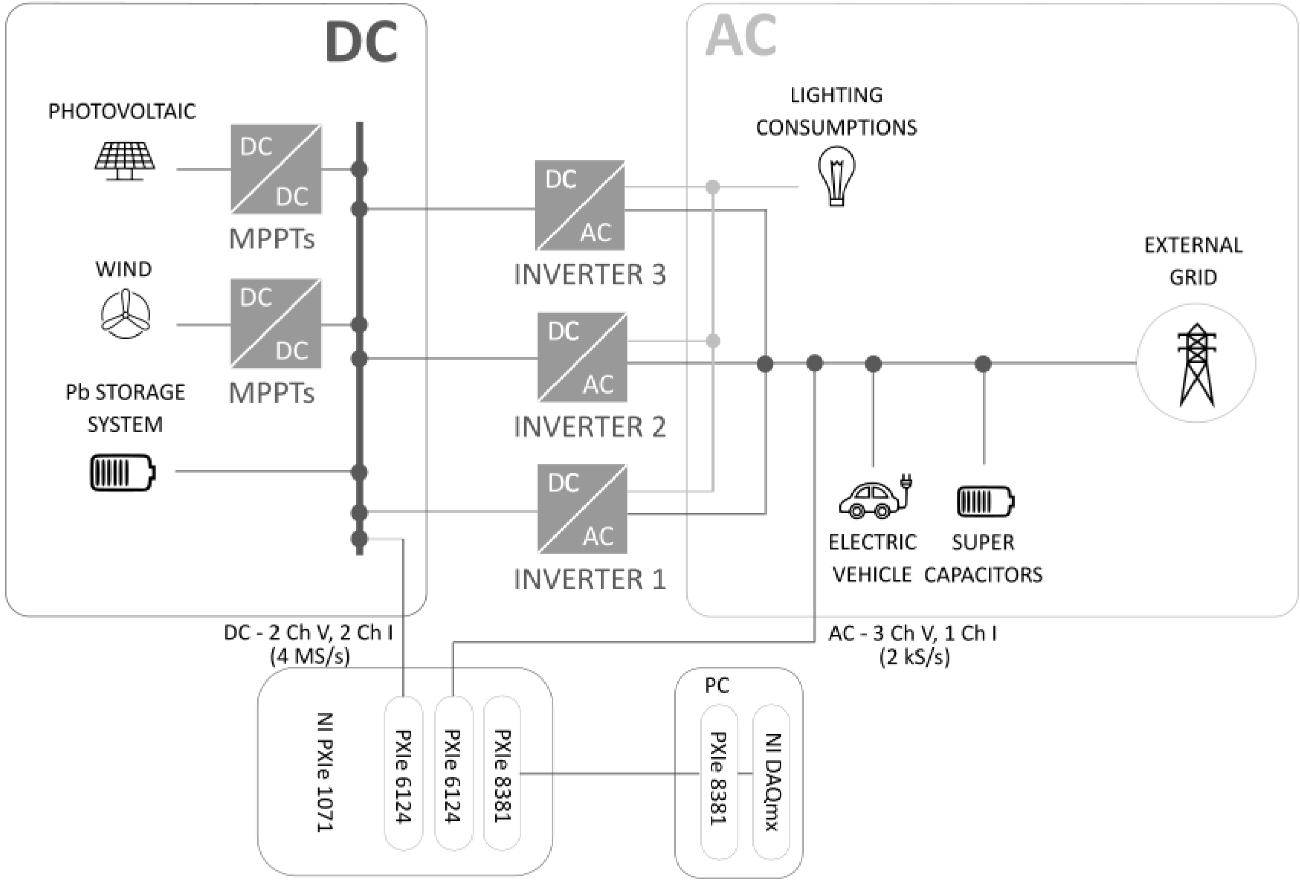
DC grids and Power Quality Indices

- These data consist of waveforms obtained in measurement campaigns which should be performed in real working micro-grids.
- The capture of the waveforms requires the development of appropriate triggers in order to record only data including interesting phenomena.
- Specific DC triggers have been developed for that task.

Micro-Grid Description and Experimental Setup

Description of the micro-grid

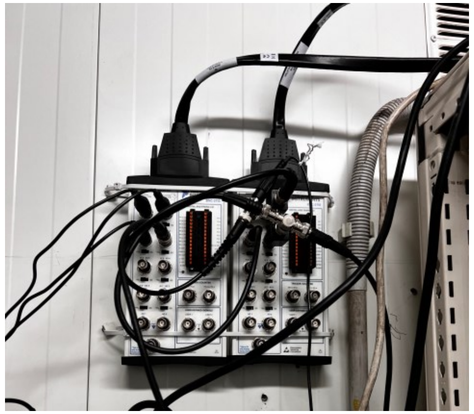
- 1 small wind turbine (600 W)
- 9 micro-wind turbines powering street lamps (300 W)
- 10 street lamps with PV panels (950 Wp in total)
- 1 PV power plant (9 kWp)
- 1 Vehicle to grid charger (10 kW)
- Some storage systems combining batteries and supercapacitors (50 kW)

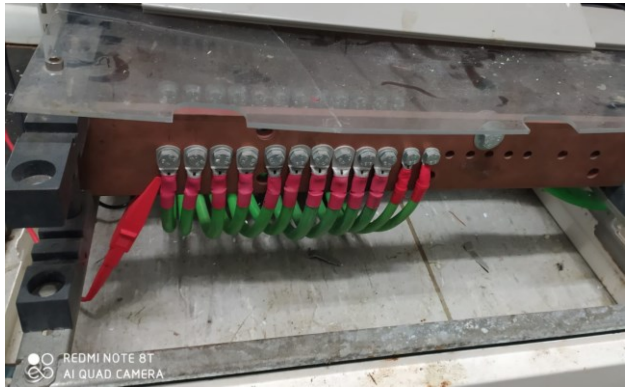


Micro-Grid Description and Experimental Setup

Measurement system

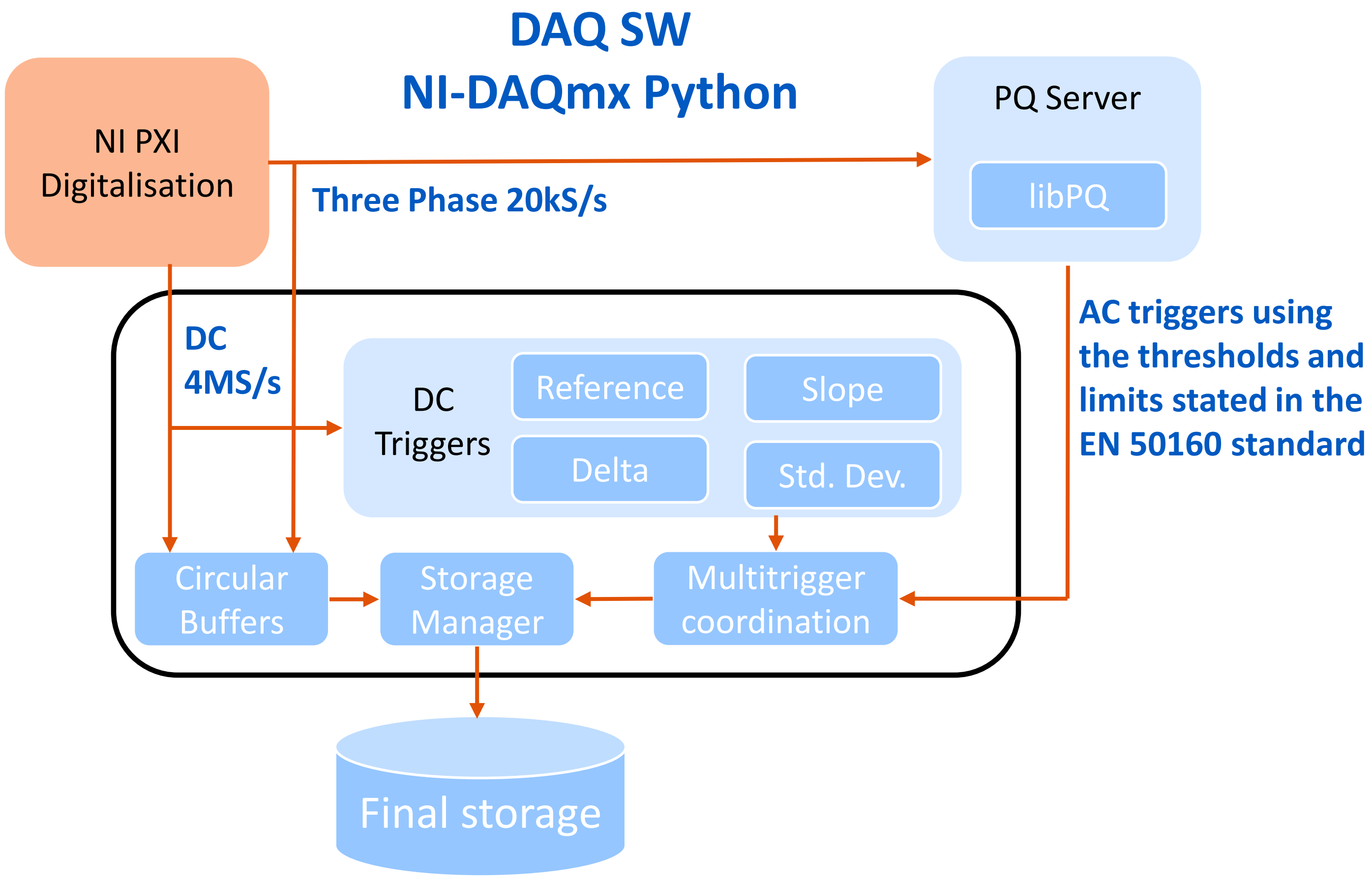
- NI PXIe 1071 chassis with three PXI boards
- 2 PXIe-6124 data acquisition boards
    - 4 simultaneous sampling analogue channels
    - 16 Bits, 4 MS/s
- PCIe-8381 for the PXI/PCI connection
- Hioki P9000 voltage probes
- Signaltec CT200 AC/DC current transducers combined with MCTS II plug-on burden resistors





Software design

- Acquisition software and triggering processes designed to facilitate the recording of interesting waveforms
- Intel i5-11400 processor 6 cores (12 threads) and 128 Gb RAM, OS Ubuntu 20.04.4 LT
- Circular buffers to store the temporarily sampled values in memory.
- Triggers, running in real time, provide the appropriate signals to store data permanently before overwriting the buffered samples.
- The performance of the triggers must be tuned, as they have to run at the same speed as the acquisition threads.
- Software designed to run unattended, recording the triggered waveforms for later offline analysis.



DC trigger mechanisms

DC Reference trigger

- The **DC Reference trigger** uses the subsampled (200 kS/s from 4 MS/s) DC signal to compute the average of the data in a configured time window.
- The subsampling has been implemented for a lighter and more agile performance.
- Once the average is obtained, the threshold value is easy to choose, considering the nominal value of the DC bus for the voltage channel and the maximum expected current for the current channel.
- An adjustable tolerance is added to both thresholds to allow certain signal variations.

```
function DC_REFERENCE_TRIGGER
    wf_ref_accumulated := wf_ref_accumulated + subsampled_waveform_sample
    if wf_index mod window_ref_size = 0 then  ◃ window accumulated completely
        computed_mean := wf_ref_accumulated/window_ref_size
        wf_ref_accumulated := 0
        if computed_mean < threshold_lo or computed_mean > threshold_hi then
            return True
        end if
    end if
    return False
end function
```

DC Grids

DC trigger mechanisms

DC Delta trigger

- The **DC Delta trigger** calculates the mean values for two consecutive equal-length time windows of samples.
- Same subsampling as the **DC Reference trigger.**
- Compares the difference between both average values, firing the trigger when this difference is bigger than a configurable threshold value.

```
function DC_DELTA_TRIGGER
    wf_delta_accumulated := wf_delta_accumulated + subsampled_waveform_sample
    if wf_index mod window_delta_size = 0 then  ◃ window accumulated completely
        computed_mean := wf_delta_accumulated/window_delta_size
        wf_delta_accumulated := 0
        if ABS(computed_mean − previous_mean) > threshold_delta then
            previous_mean := computed_mean
            return True
        end if
        previous_mean := computed_mean
    end if
    return False
end function
```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DC trigger mechanisms

DC Slope trigger

- The **DC Slope trigger** has been implemented modularly with a call to a generic derivative function which uses as parameters the waveform data and the time value when computing the derivative.
- Modularity allows different approaches to calculate the derivative of noisy signals.
- Optimised Sampling Frequency (OSF) approach, 2-points and 5-points derivatives have been used.
- Width of the time window is selected, considering the noise present in the actual signals. A wider window will give a better noise rejection at the expense of a delay in the triggering.

```
function DC_SLOPE_TRIGGER
        current_value := waveform(time_now)
        current_derivative := DERIVATIVE(waveform, curent_value)
        if ABS(current_derivative) > threshold_derivative then
                return True
        end if
        return False
end function
```


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DC trigger mechanisms

DC Scatter trigger (Standard Deviation)

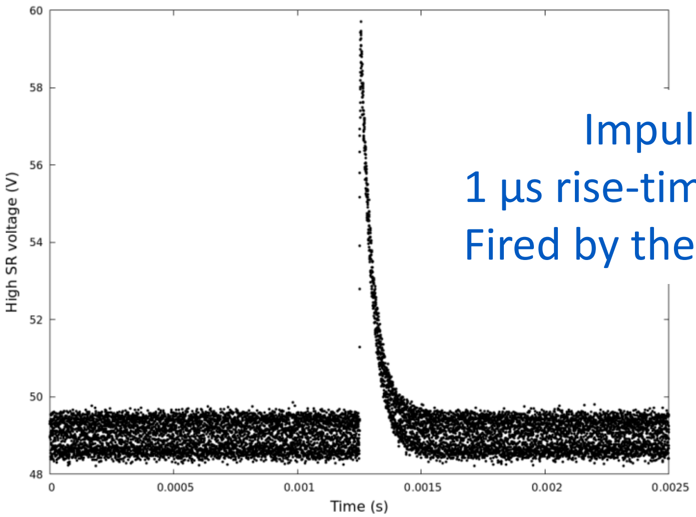
- The **DC Scatter trigger** calculates the standard deviation values for consecutive equal-length time windows of samples.
- Same subsampling as the **DC Reference trigger.**
- Once the standard deviation is obtained, a threshold value is chosen based on the dispersion (noise) of the signal.
- An adjustable tolerance is added to the thresholds to discard random noise.

```
function DC_STDDEV_TRIGGER
        wf_stddev_accumulated := wf_stddev_accumulated + subsampled_waveform_sample
        if wf_index mod window_stddev_size = 0 then ▷ window accumulated completely
                computed_mean := wf_stddev_accumulated/window_stddev_size
                wf_stddev_accumulated := 0
                wf_stddev2_accumulated := 0
                for t := time_now − window_stddev_time ; t <= time_now;  t := t + subsampled_time do
                        wf_stddev2_accumulated := wf_stddev2_accumulated + (waveform[t] - computed_mean)**2
                end for
                computed_stddev := SQRT(wf_stddev2_accumulated/(window_stddev_size - 1))
                if computed_stddev > threshold_stddev
                        return True
                end if
        end if
        return False
end function
```

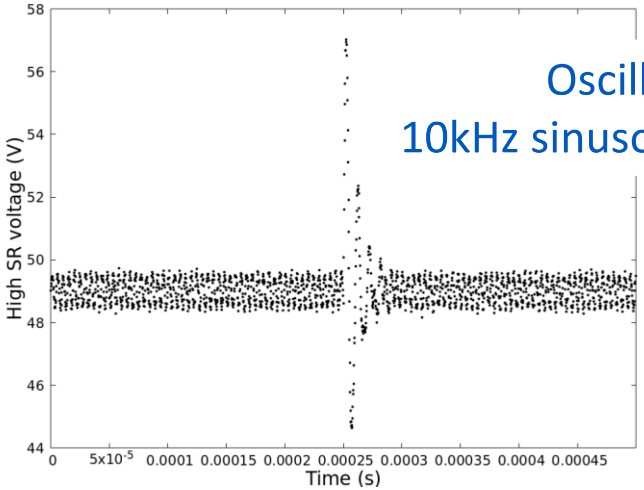
DC trigger mechanisms

Testing with synthetic signals

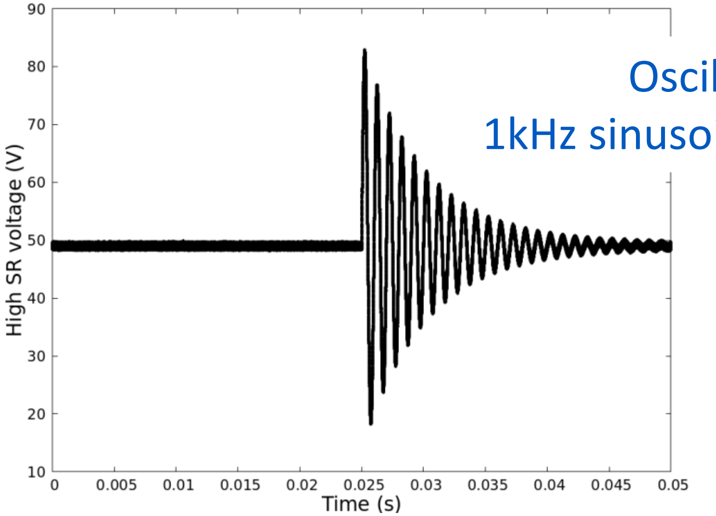
- Several signals including transients were prepared to test the triggers.
- The performance tests were repeated with different noise levels, showing satisfactory results for all triggers.
- Over-imposed noise assumed to be Gaussian.



Impulsive transient
1 µs rise-time, 250µs duration
Fired by the DC SLOPE trigger

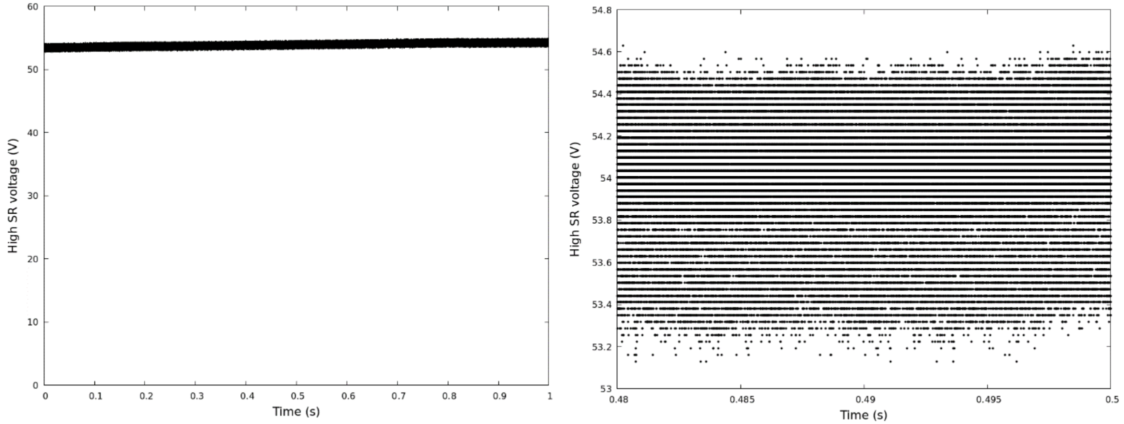


Oscillatory transient
10kHz sinusoidal, 10µs duration

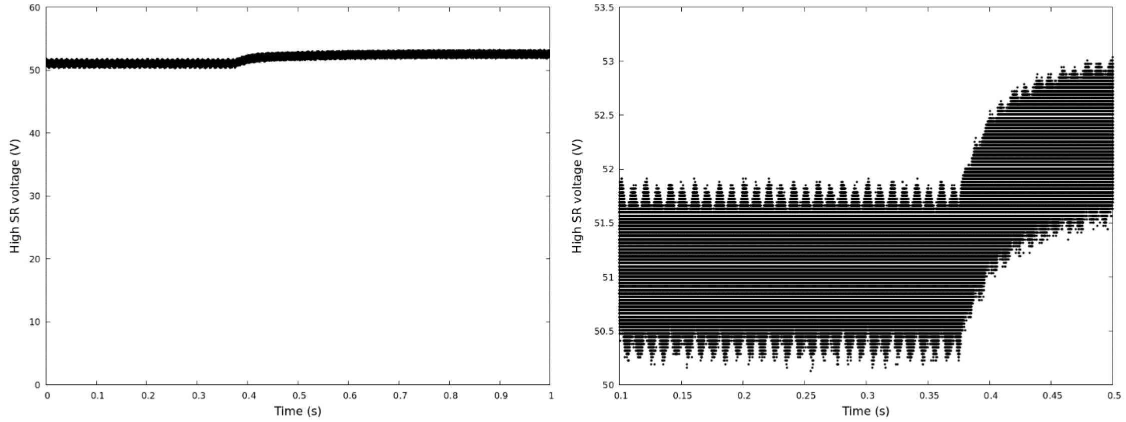


Oscillatory transient
1kHz sinusoidal, 5ms duration

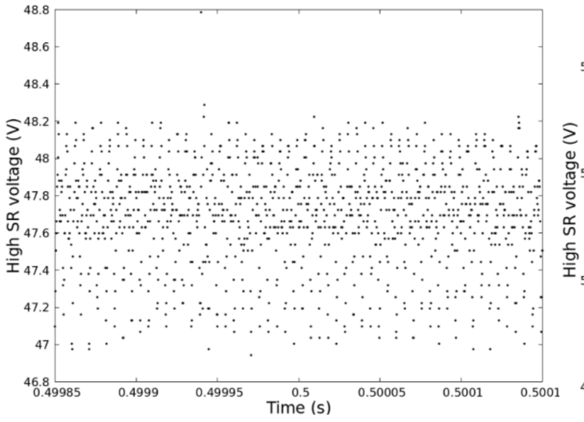
On-line waveform processing (Málaga, 4MS/s)



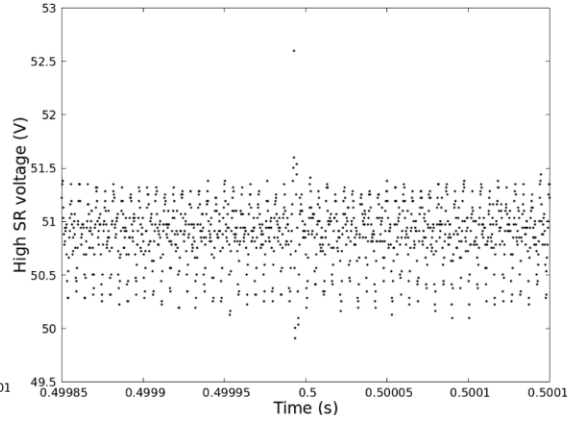
REFERENCE (LEVEL) TRIGGER, Threshold: 54.0 V



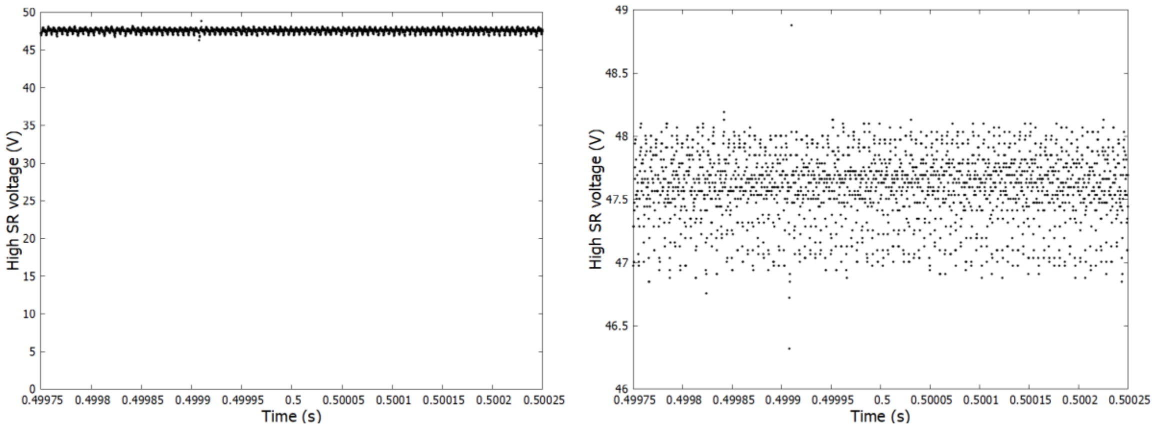
DELTA TRIGGER, Threshold: 1.43 V



DERIVATIVE (SLOPE) TRIGGER,
Thres.: 162.48 V/ms (2 points)



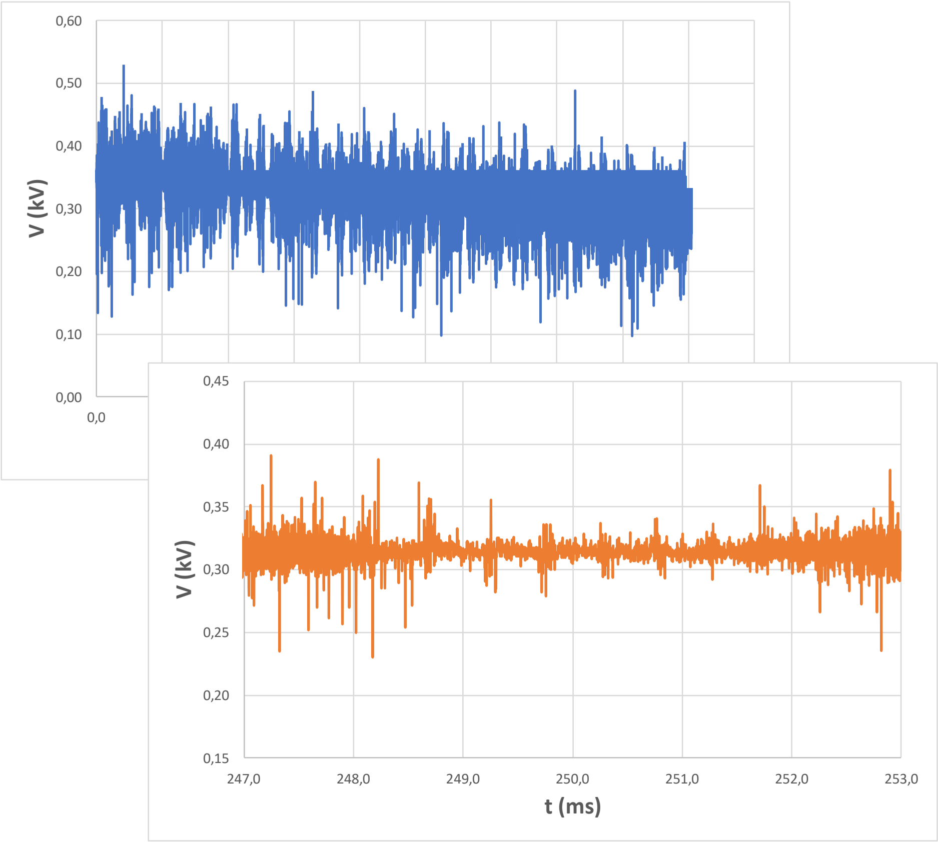
DERIVATIVE (SLOPE) TRIGGER,
Thres.: 440.56 V/ms (5 points)



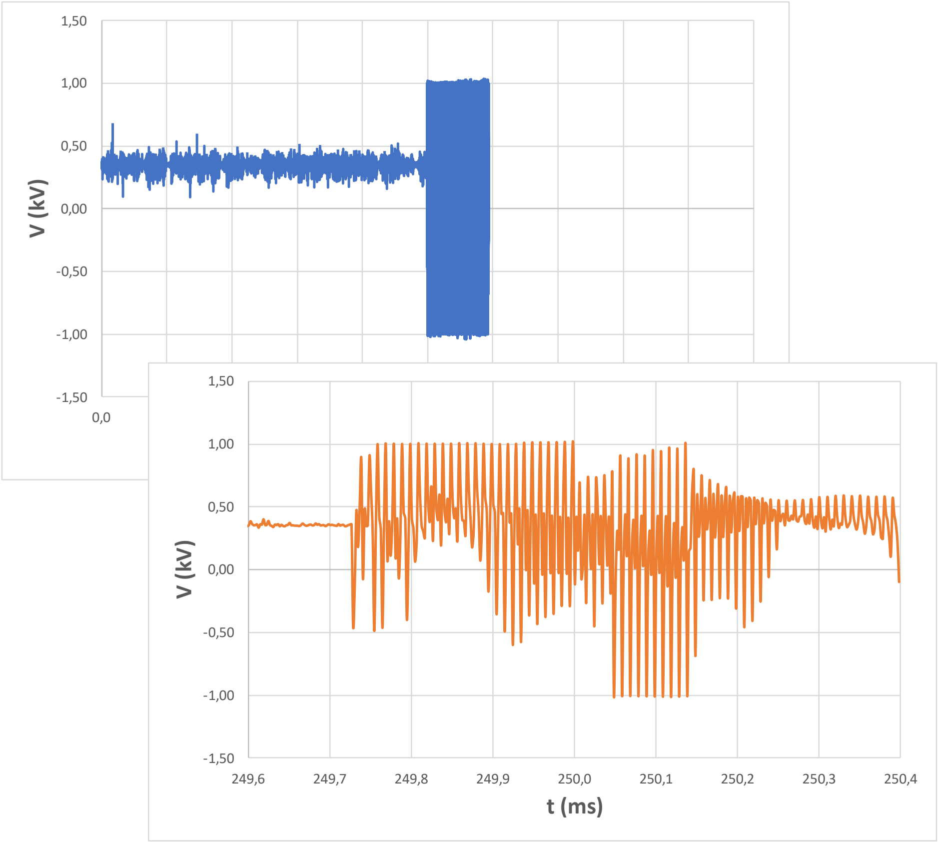
SCATTER (Standard deviation) TRIGGER, Threshold: 0.4457 V

Off-line waveform processing

Delft Microgrid **500 kS/s**



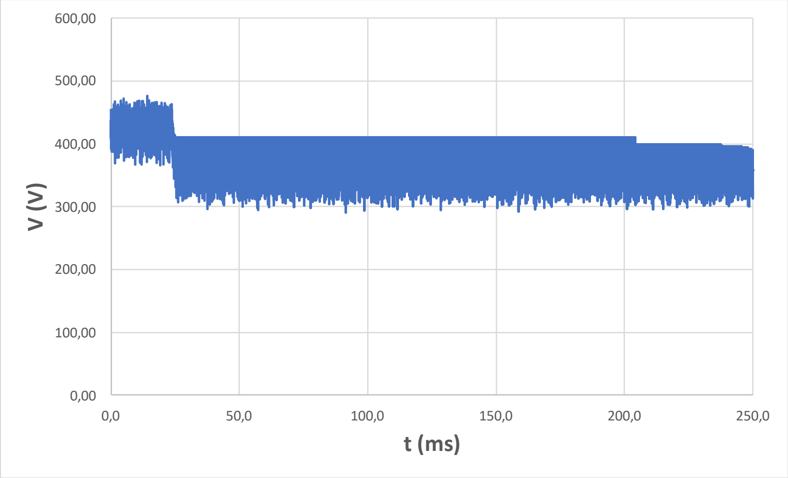
REFRENCE (Level) TRIGGER, Threshold: 288 V



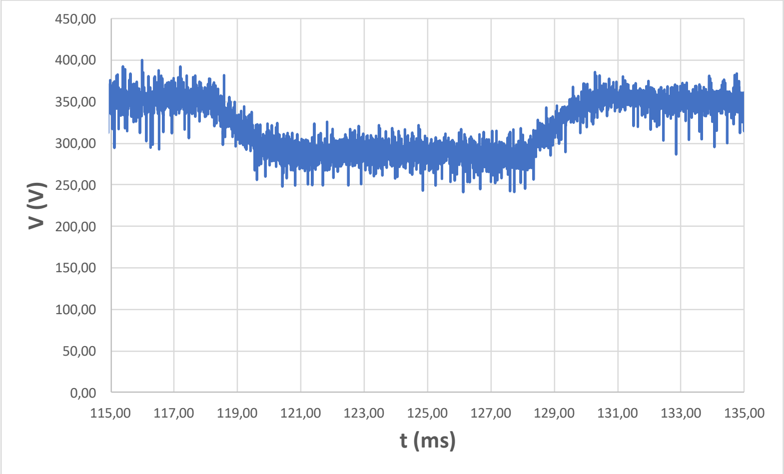
SCATTER (Standard deviation) TRIGGER, Threshold: 100 V

Off-line waveform processing (PNDC 1MS/s)

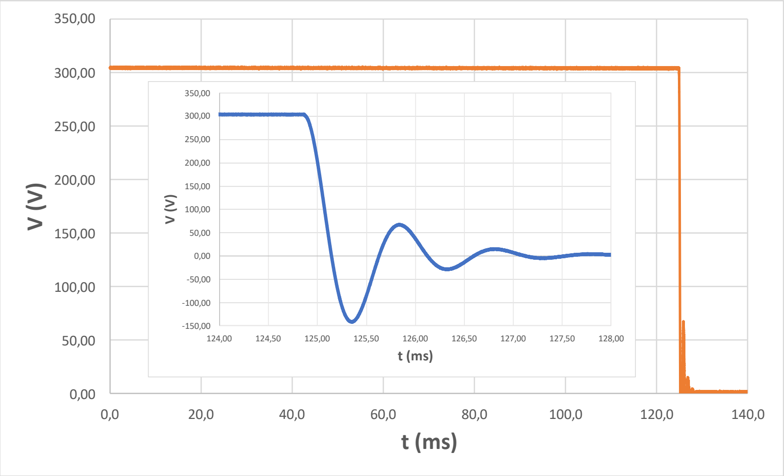
DC Grids



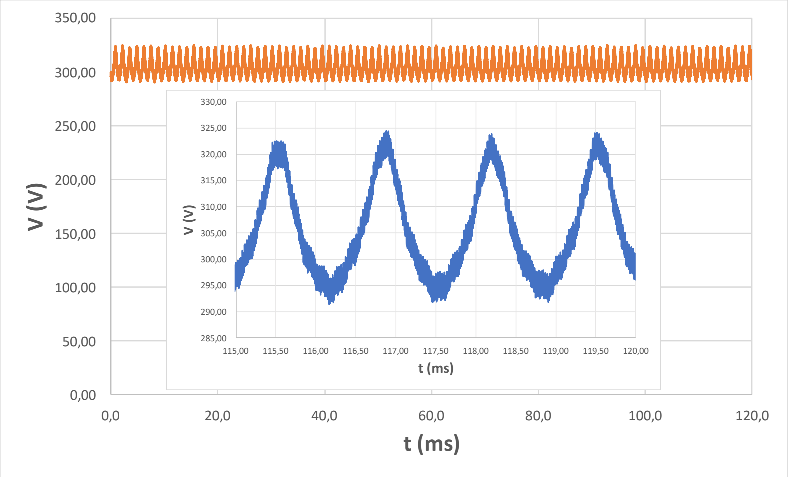
DELTA TRIGGER, Threshold: 10 V



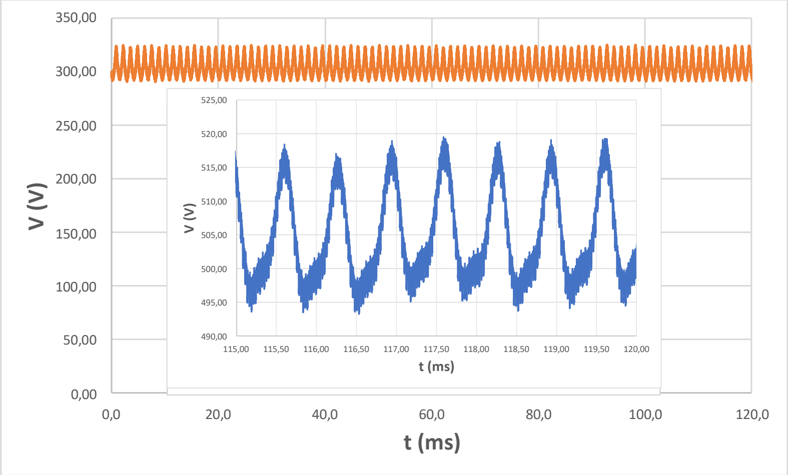
REFERENCE (LEVEL) TRIGGER, Threshold: 315 V



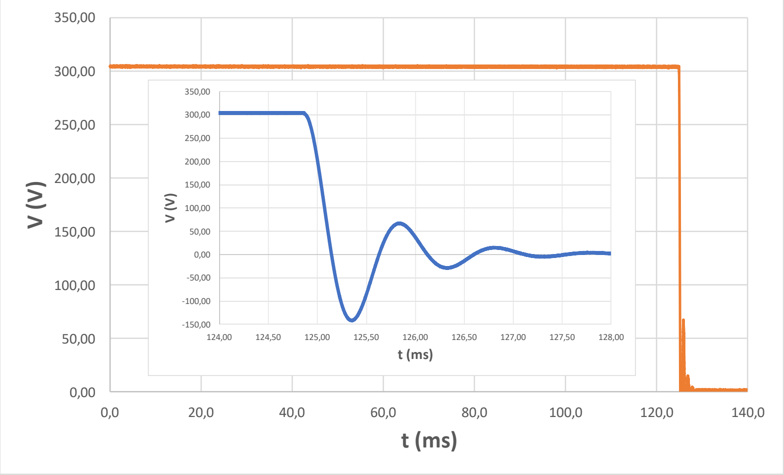
REFERENCE (LEVEL) TRIGGER, Threshold: 270 V



DERIVATIVE (SLOPE) TRIGGER, Thres.: 1000 V/ms



DERIVATIVE (SLOPE) TRIGGER, Thres.: 1000 V/ms



SCATTER (Std dev) TRIGGER, Threshold: 23 V

20NRM03 DC grids

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CONCLUSIONS

- Simple but effective trigger mechanisms have been developed.
- Performance tested with synthetic signals.
- Capable of working on-line to capture selected waveforms from raw measurements.
- Work off-line to extract events from saved raw measurements.
- Capable of detect dips, swells, interruptions and ripple (frequency) events.
- Easy to adapt to post-processed waveforms to capture PQ events.
- Published:

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