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DC Grids

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Test waveforms for DC PQ analysis tools

Yljon Seferi
yljon.seferi@strath.ac.uk

Brian Stewart
brian.stewart.100@strath.ac.uk

Institute of Energy and Environment
Department of Electronic and Electrical Engineering

Outline

- Introduction
- Research facility
- Experimental setup and measurement systems
- Generated signals
- PQ Metrics assessment
- Conclusions

Introduction

DC applications rapidly emerging

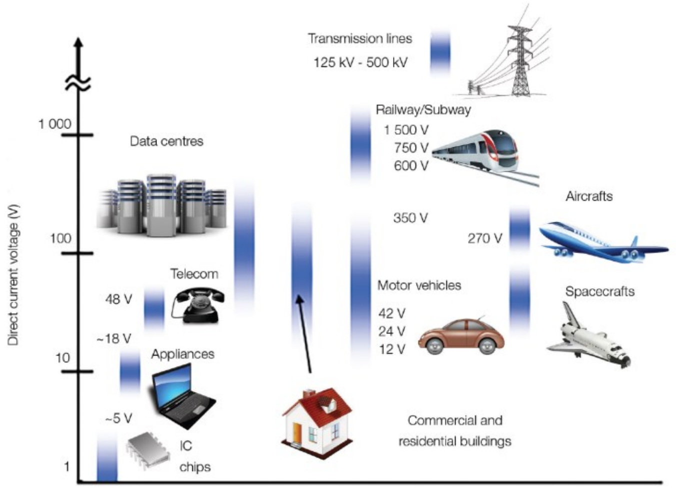
Benefits of DC over AC

- More power transfer capacity in DC
- Reduce losses in DC
- Reduced number of converters
- Improved efficiency

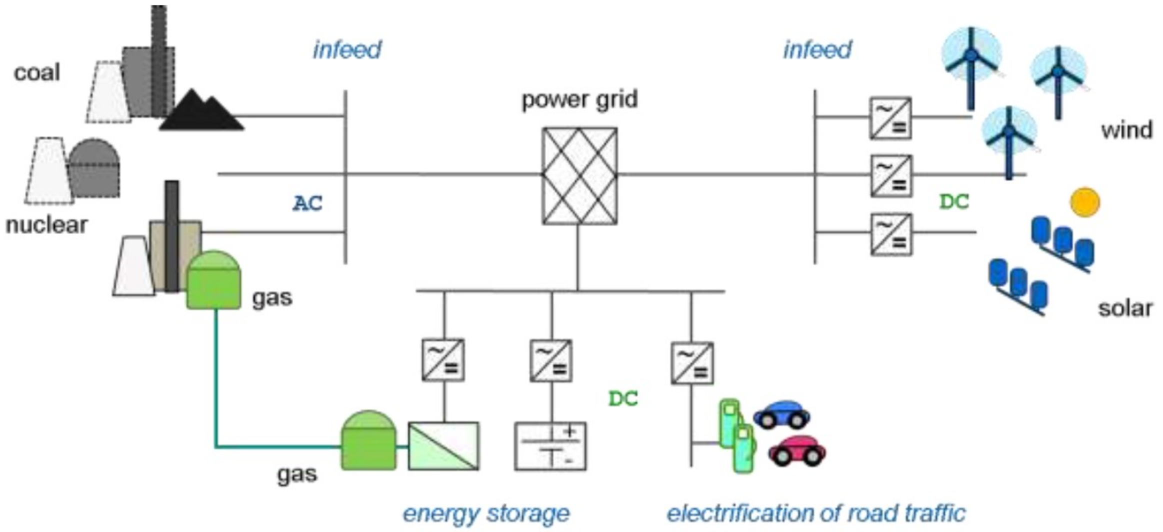
but limited knowledge on….

- PQ levels impacting immunity of equipment and insulation, planning, etc.
- Methods of analyses
- DC metrics use and their reliability
- Unified and acceptable measurement methods
- Lack of standardization

Transport application first to implement DC



More LVDC systems, technologies, and distribution grids



Source: CIRED WG – DC distribution networks 2019-1 http://www.cired.net/cired-working-groups/dc-distribution-networks-wg-2019-1
IEC – LVDC: Electricity for the 21st century https://www.iec.ch/basecamp/lvdc-electricity-21st-century

Introduction

- AC PQ parameters for modification into DC reviewed and proposed additional parameters for DC.

University of Strathclyde, University of Campania, TU Eindhoven

International standards and literature: EN 50160 , IEC 62749, IEEE 1159, IEC 61000, IEC 62586 & IEC TR 63282 LVDC systems.

→

PQ parameters and definitions

- Supply voltage, Voltage dips and swells, Voltage interruption, Under/over voltage
- Voltage Ripple, Spectral components, Transients (impulsive & osc.), Flicker,
- Supply voltage unbalance, Harmonics and Interharmonics, Fluctuation, RVC

→

Need for

- Analyses tools
- DC metrics evaluation
- Triggering mechanisms

Focus of the work: To emulate and record real DC voltages and currents, containing PQ events that are difficult to capture from the measurement campaigns, to allow lab-based reproduction for: testing of analysis tools, testing of DC energy meters, DC PQ analysis, PQ metrics assessment, trigger mechanisms validation, measurement methods, support DC PQ definitions.

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PNDC Research facility

Critical Validation & Testing Infrastructure

- Well resourced research infrastructures supporting bench to MW level R&D
- Focus spans fundamental to applied research & innovation, driving technology development, systems testing and validation

Diagram and Experimental setup

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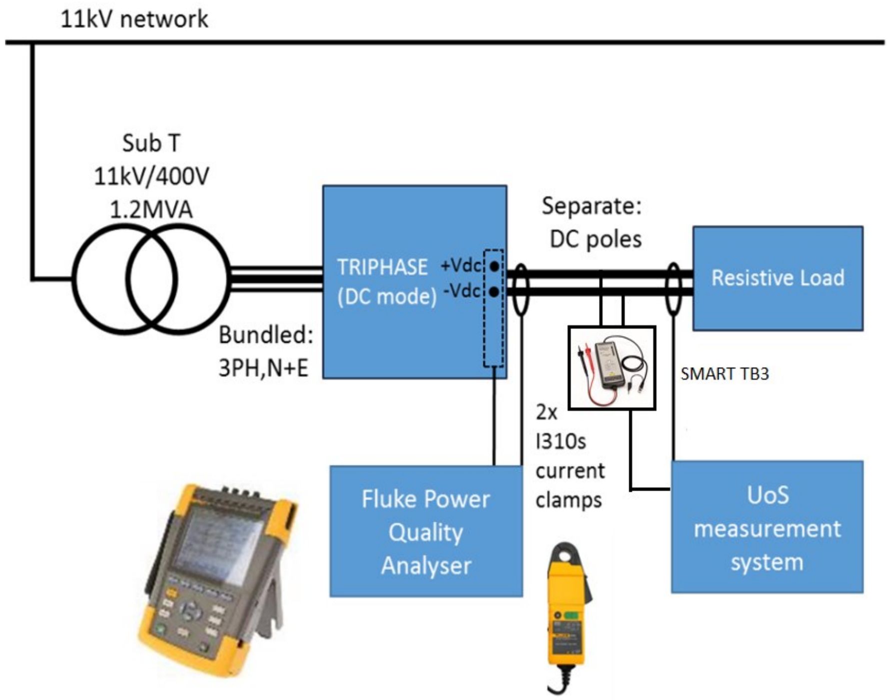
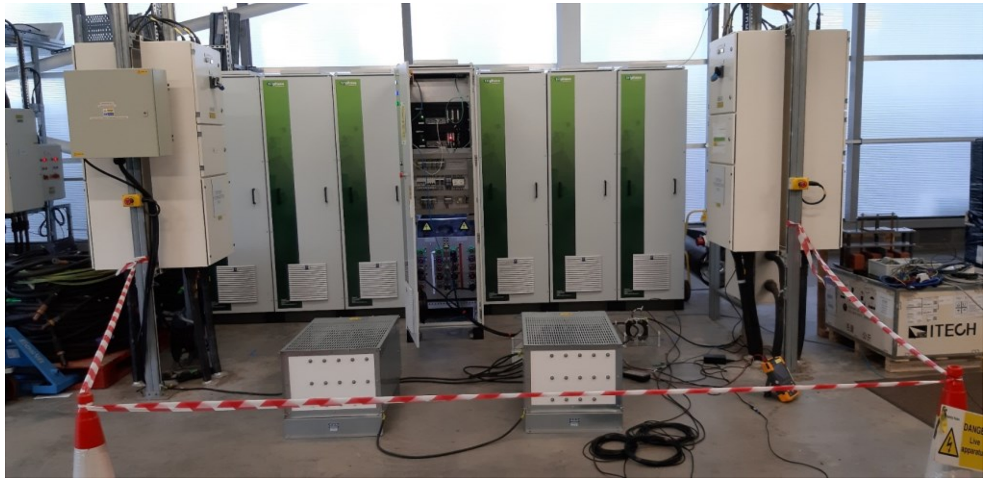
PNDC Tri-Phase System

- Emulation of DC grid waveforms
- Resistive loads employed
- Two measurement systems





Measurement system

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Two measurement systems installed to capture voltage and currents

HVPD Smart TB3
LF sensor (1 Hz – 200 kHz)
HFCT sensor (100 kHz – 30 MHz)
Up to 800A

PICO TA 044
(High Voltage Differential probe)
Up to 7 kV, ± 2%
(0 – 70 MHz)

Fluke i310s
(Hall-based effect)
Up to 300A, ± 1%
DC – 20 kHz

HBM Gen2tB DAQ
2 cards / 8 channels / 14 Bit
Up to 25 MS/s and 250 MS/s

Fluke i310s

Fluke 435 PQ Analyser
14 Bit
200 kS/s

Generated signals – different supply voltages

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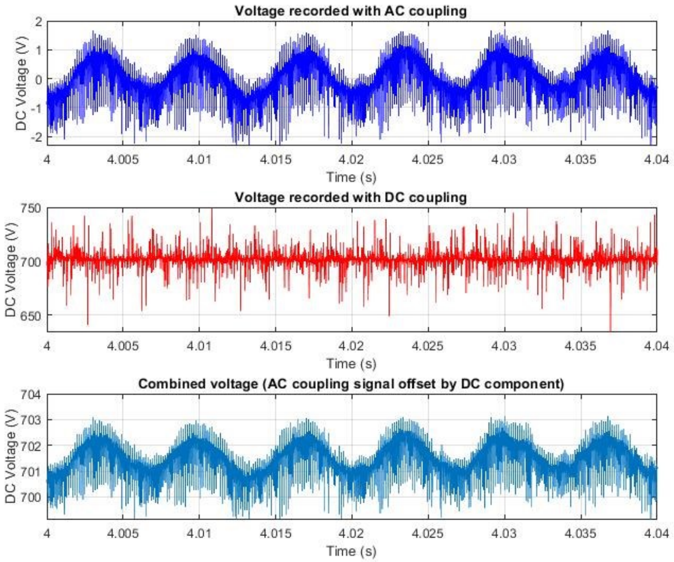
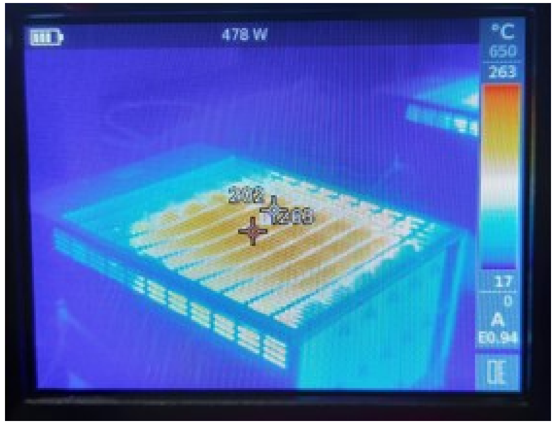
Supporting establishment of PQ with voltage levels relation.

- Signals measured with AC coupling in place (Ch. 1) and DC coupling (Ch. 2) for a better sensing/resolution of frequency components.
- Signals recorded with AC coupling offset by the DC component.



Different voltage levels

Tets ID	Applied voltage (V)	Load (Ω)	Sampling rate	Recording length (s)	Measured quantities and scaling coefficients of the voltage and current sensors			Coupling
					Voltage (DC - 70 MHz)	Current - 1 (0 - 20) kHz	Current - 2 (1 Hz - 200 kHz)	
Day_3_Test_1_1	100							
Day_3_Test_1_2	200							
Day_3_Test_1_3	300							
Day_3_Test_1_4	400							
Day_3_Test_1_5	500				100/1			
Day_3_Test_1_6	600							
Day_3_Test_1_7	700	7.83	400 kHz + 100 kHz BW filter	10		1 mV/1A	800A/1Vrms	AC & DC separately
Day_3_Test_1_8	800							
Day_3_Test_1_9	900							
Day_3_Test_1_10	1000							
Day_3_Test_1_11	1100							
Day_3_Test_1_12	1200				1000/1			
Day_3_Test_1_13	1300							



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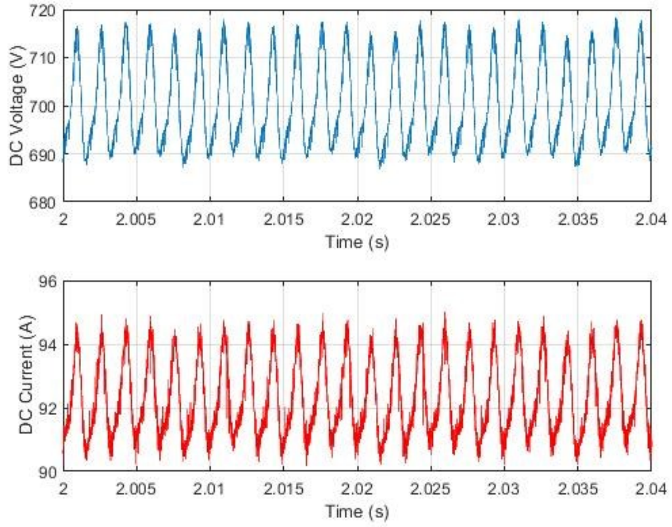
Generated signals – different ripple levels

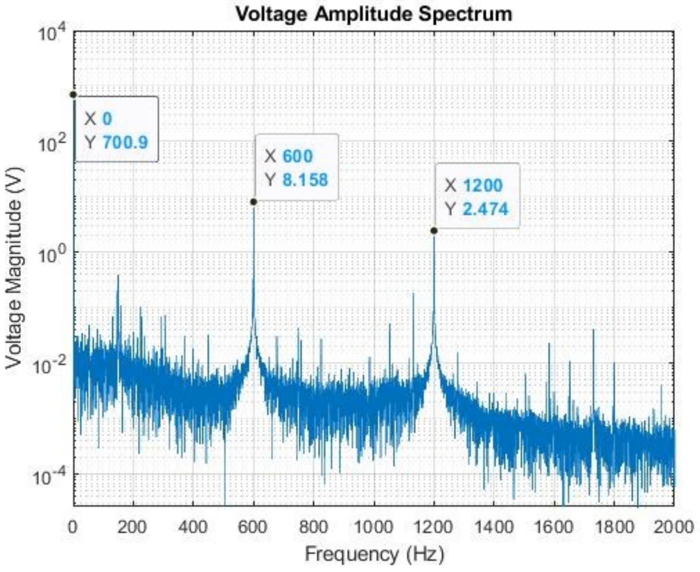
Presence of different converter systems emulated.

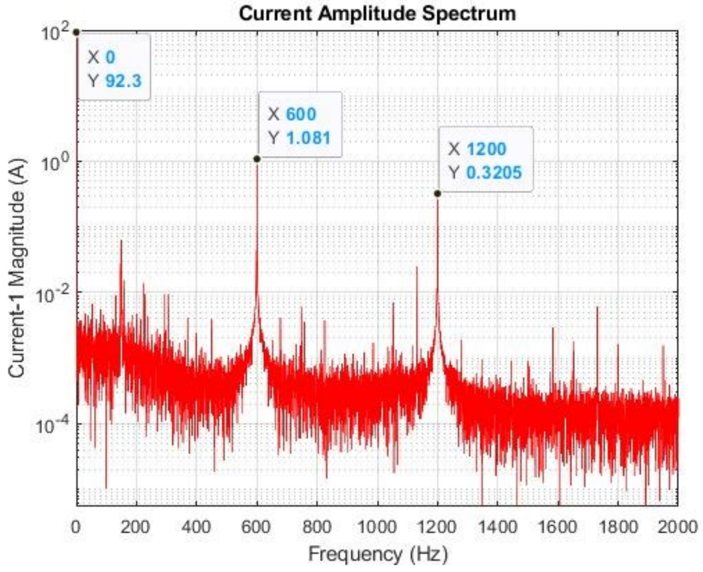
- Single and Three phase
- 6 and 12 pulse rectifiers
- 100, 200, 300, 600, 900, 1200 Hz

Different ripple levels

Tets ID	Applied voltage (V)	Load resistance (Ω)	Ripple frequency (Hz)	Additional frequency components (Hz)	Phase shift between frequency components (degrees)	Sampling frequency	Recording length (s)	Measured quantities and scaling coefficients of the voltage and current sensors			Coupling (Voltage Current_1 Current_2)
								Voltage (DC - 70 MHz)	Current - 1 (0 - 20) kHz	Current - 2 (1 Hz - 200 kHz)	
Day_3_Test_4_12	200		100	200, 300							
Day_3_Test_4_13	300		300	600, 900							
Day_3_Test_4_14	400		300	600, 900							
Day_3_Test_4_15	500		600	1200	0						
Day_3_Test_4_16	600	7.83	600	1200		400 kHz + 100 kHz BW filter	4	100/1	1 mV/1A	800A/1Vrms	AC coupling combined with DC component
Day_3_Test_4_17	700		600	1200							
Day_3_Test_4_18	500		600	1200							
Day_3_Test_4_19	600		600	1200	11.5						
Day_3_Test_4_20	700		600	1200							





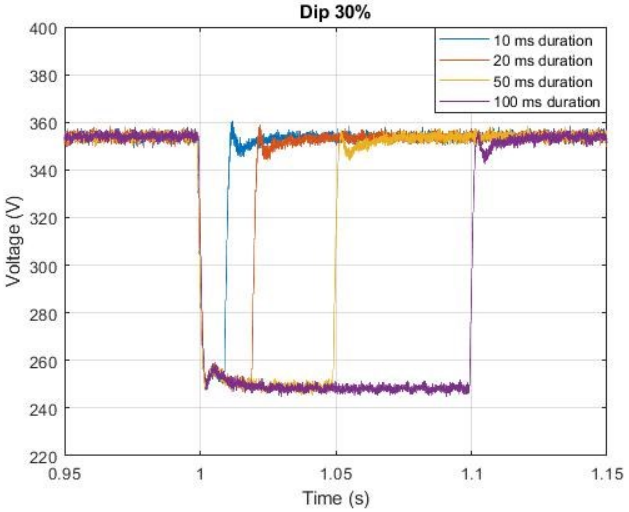


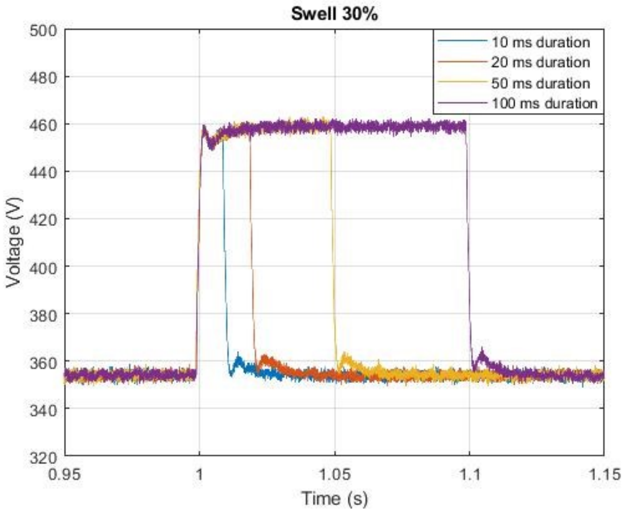
Generated signals – dips and swells events

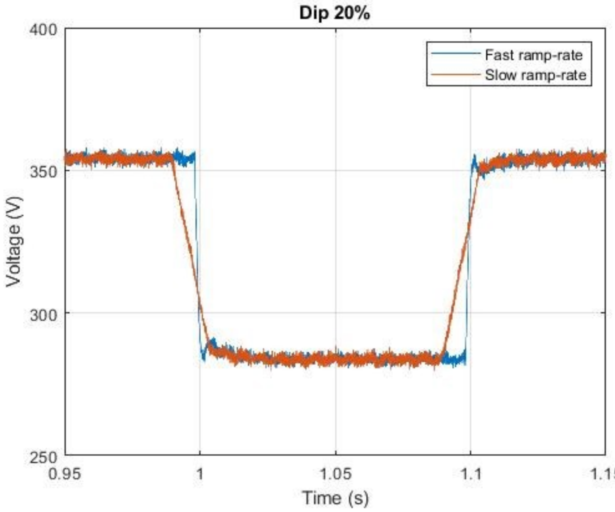
Voltage dips and swells generated, replicating events resulting from load changes and faults.

- Total of 58 tests
- Fast rate > 10 kV/s
- Slow rate < 5 kV/s

Swells and Dips												
Tets ID	Applied voltage (V)	Load resistance (Ω)	Ramp rate	Event duration (ms)	Voltage variation and magnitude	Sampling rate	Recording length (s)	Measured quantities and scaling coefficients of the voltage and current sensors			Coupling (Voltage and Current_1)	Coupling Current_2
								Voltage DC (DC - 70 MHz)	Current - 1 (0 - 20 kHz)	Current - 2 (1 Hz - 200 kHz)		
Day_2_Test_6_1	350	7.83	fast	10	Swell 10% 20 % 30%	1 MHz	4	100/1	1 mV/1A	800A/1Vrms	DC	AC
Day_2_Test_6_2			fast	20								
Day_2_Test_6_3			fast	50								
Day_2_Test_6_4			fast	100								
Day_2_Test_6_9			slow	10								
Day_2_Test_6_10			slow	20								
Day_2_Test_6_11			slow	50								
Day_2_Test_6_12			slow	100								
Day_2_Test_6_17			fast	10	Dip -10% -20% -30%							
Day_2_Test_6_18			fast	20								
Day_2_Test_6_19			fast	50								
Day_2_Test_6_20			fast	100								
Day_2_Test_6_25			slow	10								
Day_2_Test_6_26			slow	20								
Day_2_Test_6_27			slow	50								
Day_2_Test_6_28			slow	100								
Day_2_Test_6_51	700	7.83	fast	10	Swell 30%							
Day_2_Test_6_52			fast	20	Swell 30%							
Day_2_Test_6_53			fast	50	Swell 30%							
Day_2_Test_6_54			fast	100	Swell 30%							
Day_2_Test_6_55			fast	10	Dip -30%							
Day_2_Test_6_56			fast	20	Dip -30%							
Day_2_Test_6_57			fast	50	Dip -30%							
Day_2_Test_6_58			fast	100	Dip -30%							



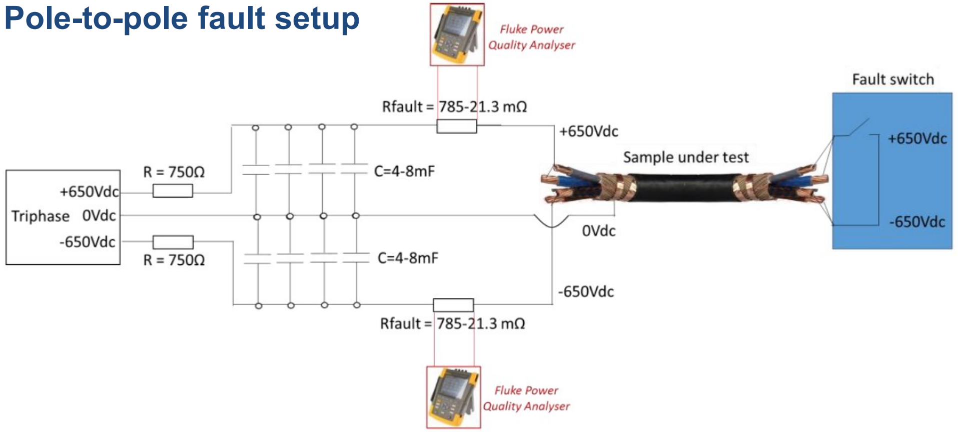




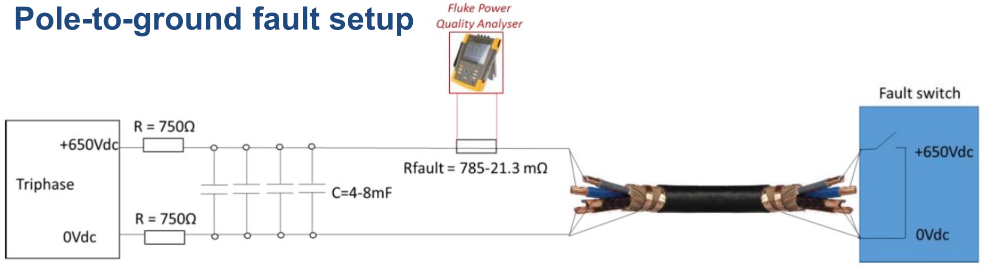
Generated signals – short circuit tests

Short circuit events occurring between two poles and pole to earth replicated.


Pole-to-pole fault setup

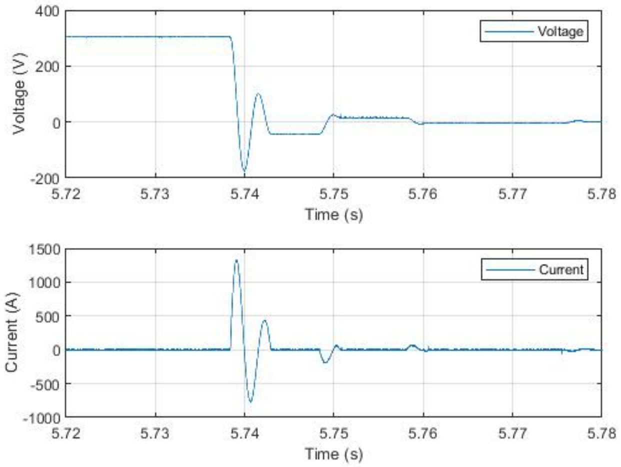


Pole-to-ground fault setup

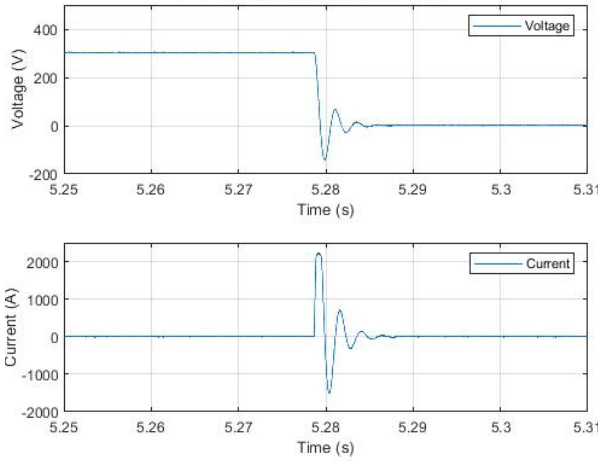


Short circuit										
Tets ID (ASCII format)	Applied voltage (V) (pole to pole)	Fault type	Rfault (mΩ)	Capacitors (mF) per pole	Sampling rate	Recording length (s)	Measured quantities and scaling coefficients of the voltage and current sensors			Coupling
							Voltage DC (DC - 70 MHz)	Current DC (0 - 20 kHz)	LF Current (1 Hz - 200 kHz)	
Day_3_Test_5_5	100	Pole to pole	21	6 mF (3 of 2mF in parallel)	400 kHz	10	100/1	1 mV/1A	800A/1Vrms	DC
Day_3_Test_5_6	200	Pole to pole	21							
Day_3_Test_5_7	300	Pole to pole	21							
Day_3_Test_5_8	400	Pole to pole	21							
Day_3_Test_5_9	500	Pole to pole	21							
Day_3_Test_5_10	600	Pole to pole	21							
Day_3_Test_5_11	700	Pole to pole	21							
Day_3_Test_5_20	50	Pole + to ground	21	6 mF (3 of 2mF in parallel)	400 kHz	10	100/1	1 mV/1A	800A/1Vrms	DC
Day_3_Test_5_21	100	Pole + to ground	21							
Day_3_Test_5_22	150	Pole + to ground	21							
Day_3_Test_5_23	200	Pole + to ground	21							
Day_3_Test_5_24	250	Pole + to ground	21							
Day_3_Test_5_25	300	Pole + to ground	21							
Day_3_Test_5_26	350	Pole + to ground	21							

Pole to pole fault at 300 V



Pole to ground fault at 300 V



PQ Metric assessment

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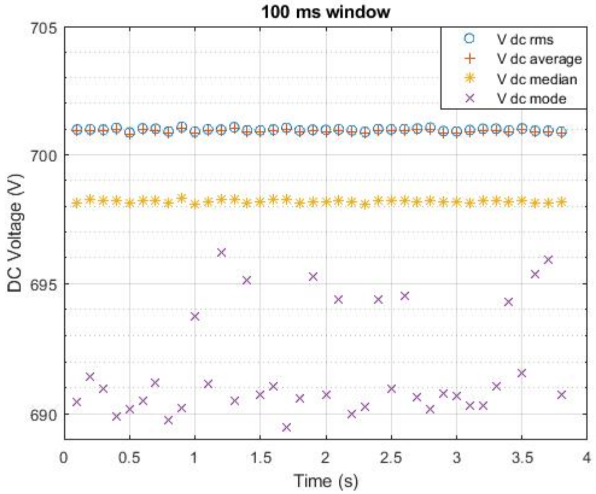
Estimating sampling rate and window size impact on PQ.

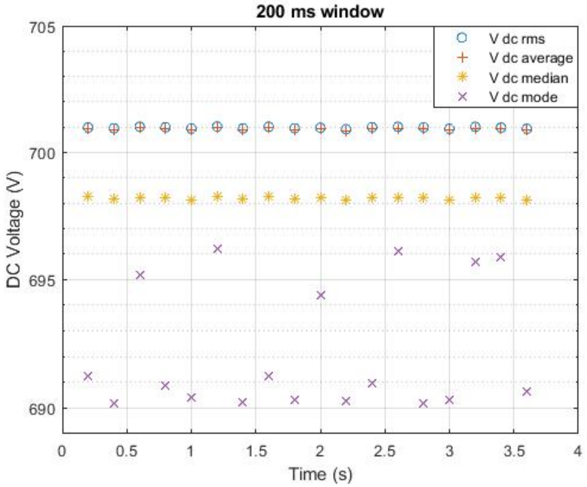
- Two measurement windows
- 6 sampling rates
- Several metrics

Peak to peak

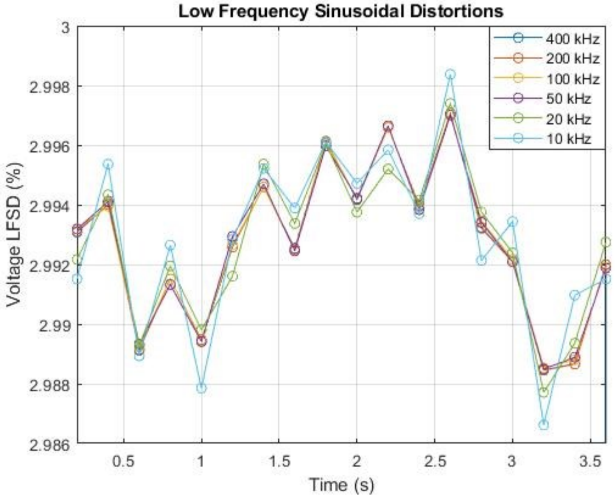
DC ripple rms $U_{ripple} = \sqrt{U_{rms}^2 - U_{avg}^2}$

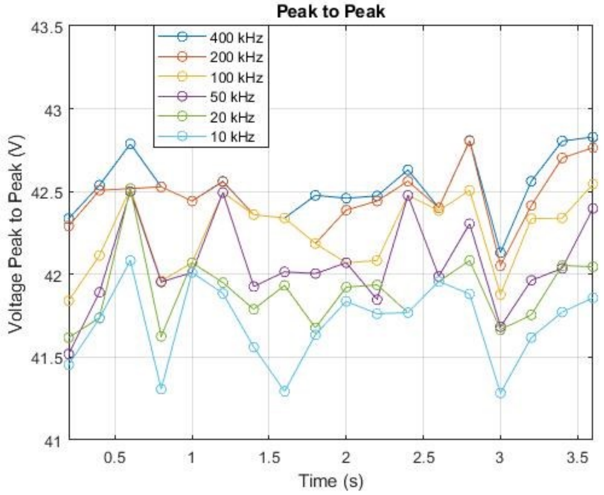
LFSD $D_{LFSD} = \sqrt{\sum_{k>0}^{k_{max}} \left(\frac{Q[k]}{Q[0]}\right)^2}$

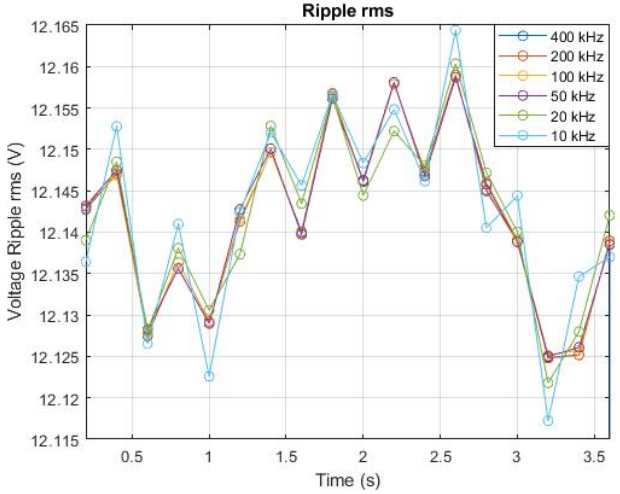




400V, 300 Hz ripple, added 600 Hz, 900 Hz







Conclusions

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Generated DC voltages, currents, and PQ events to support development and testing of analysis tools, measurement methods, DC PQ metrics and definitions.

- Replicated different supply systems.
- Emulated the presence of **different ripple levels** and converter systems.
- **Voltage dips** & **swells** various depth (10% – 30%), duration (10ms–100ms), and ramp rate.
- Pole to pole and poles to earth **faults**.

Data in text format uploaded to the Shearpoint A1.2.3 PNDC data

System conditions, sampling rate, scaling factors of measurement sensors explained.

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THANK YOU

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