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SUSTAINABLE DEVELOPMENT STRATEGIES FOR T&D

CONFERENCE 2025

How to Ensure that the Performance of ITs Meets the Challenges of Modern Power Grids?

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INSTRUMENT TRANSFORMERS

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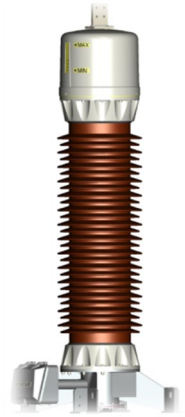
Introduction

KONČAR - Instrument transformers Inc.

CT type AGU

72,5 – 800 kV



IVT type VPU

72,5 – 550 kV

SSVT type VPT

72,5 – 550 kV / 10 – 333 kVA

CCVT type VCU

72,5 – 800 kV

CTVT type VAU

72,5 – 550 kV

Type VNP

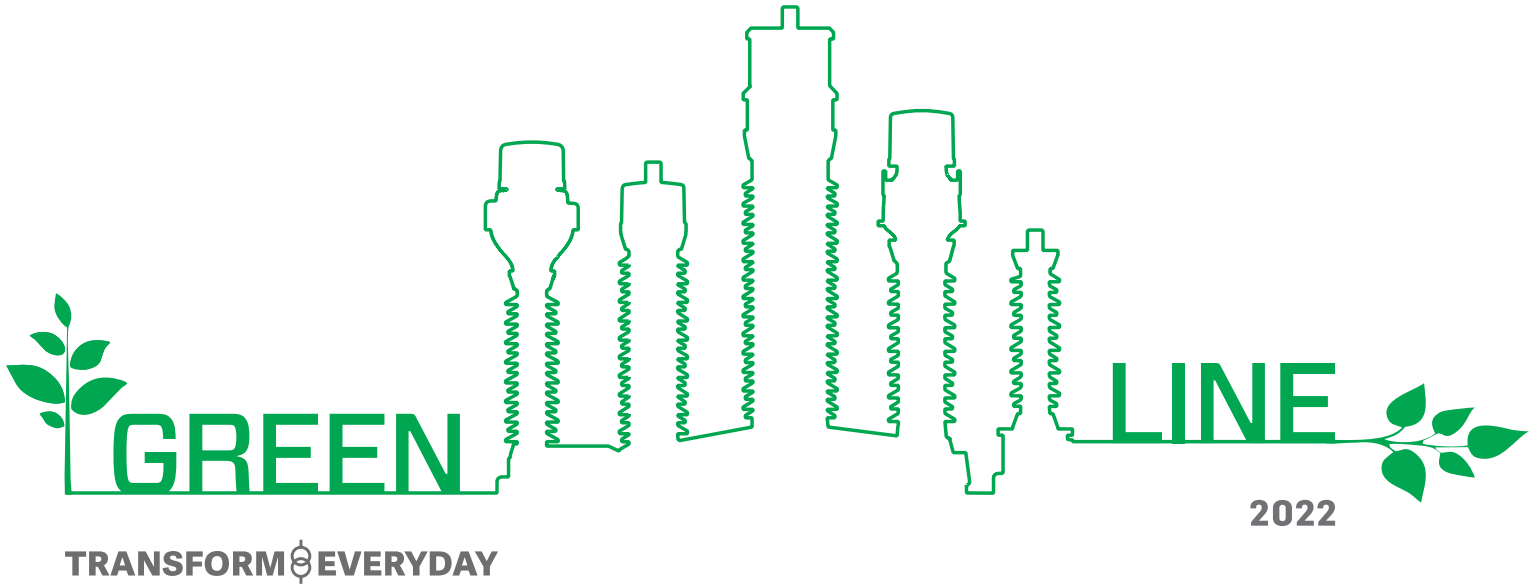
72,5 – 550 kV

Type SVE

123 kV / 50 kVA

- CT
- IVT
- SSVT

ALL


GREEN
LINE
2022
TRANSFORM EVERYDAY

Why new requirements? And are they really new?

- Ensuring in-service performance in modern power grids

- Requirements from TSOs, standards, and customers
  - Ferroresonance test – Type test in CVT transformers, Informative in IEC 61869-3 draft
  - Transmitted overvoltage test – Special test per IEC 61869-1:2007 and 2023
  - Accuracy class check at high frequencies – Extension for harmonics
  - Line discharge test – Requirement of TSOs, Informative in IEC 61869-3 draft
  - Repeated flashover test– Proposed addition to type tests
  - KONČAR - Instrument Transformers continuously aligns with changing standards
  - All mentioned tests are performed within the KONČAR Group

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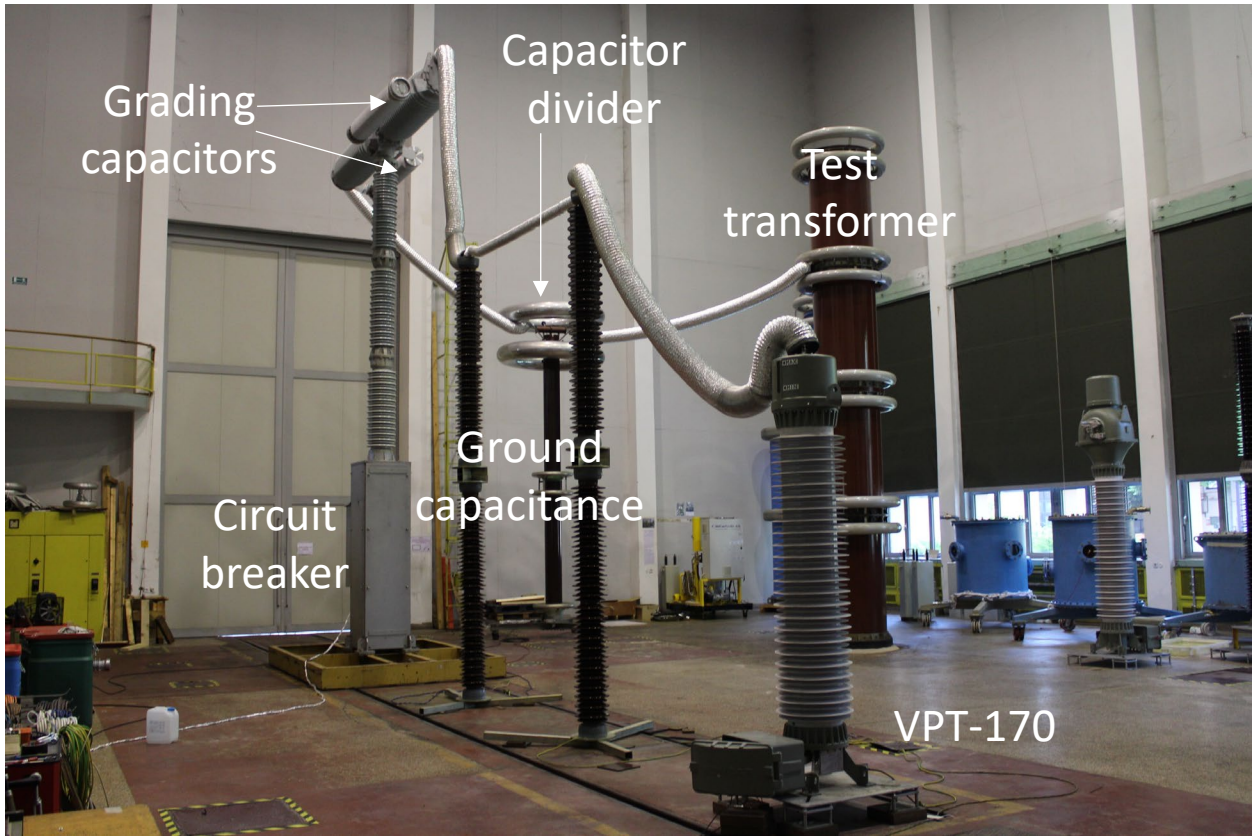
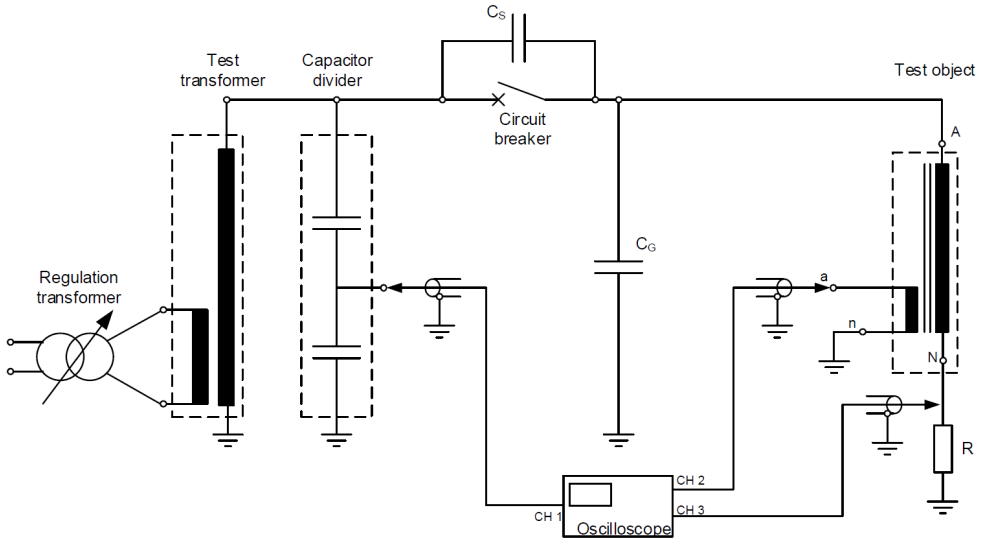
Ferroresonance

Ferroresonance test of inductive voltage transformers

- Oscillating phenomenon between a non-linear inductance and a capacitor
- Influence of line capacitance and grading capacitors
- Non-linear inductance - Inductive voltage transformer
- Capacitor - Grading capacitors in HV circuit breakers, conductor inter-phase capacitances, capacitance to ground of cables and long lines, series capacitors or shunt capacitor banks
- IEC 61869-3 (Draft 2024)- Considerations for ferroresonance performance qualification – Annex 3F – Informative
- Standard type test for CVTs, but not yet required for inductive voltage transformers
- Problem of a stable voltage source

Ferroresonance test of inductive voltage transformers

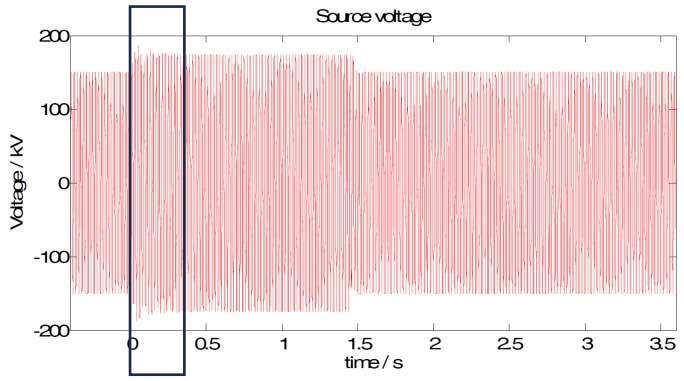


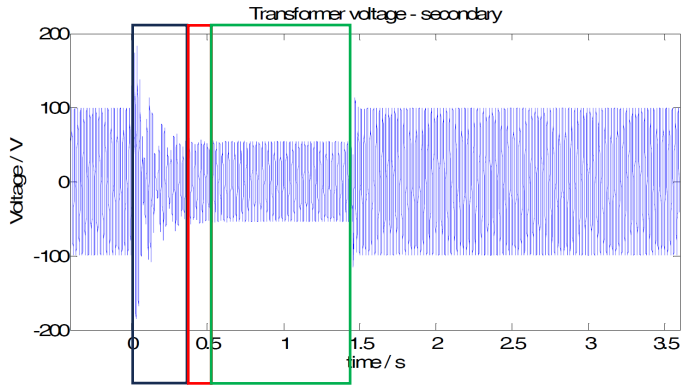


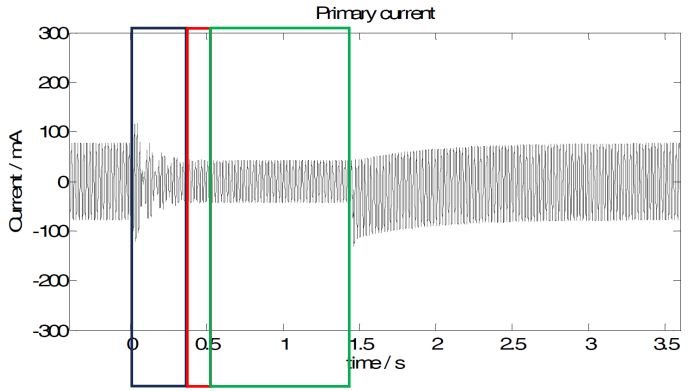
C_G – Ground capacitance
C_S – Grading capacitance
Test object – VPT-170

Ferroresonance test of inductive voltage transformers

- Performed as several combinations of capacitance *C*s and *C*g, with application of one switch-off/switch-on operation of a circuit breaker, at several voltage levels







- Circuit breaker operation transient state
- Transformer transient state
- Steady state of operation – NO FERRORESONANCE

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Transmitted Overvoltages

Transmitted overvoltage test

- Special test in IEC 61869-1
  - 2007 – LV method; T_1=0,50 µs ± 20 %
  - 2023 – HV method with minimum 50 kV impulse applied; 0,84 < T_1 < 1,3 µs
- Requirements:

$$U_{pref} = \frac{\sqrt{2}}{\sqrt{3}} \cdot U_m$$

$$50\ kV < U_{test} < U_{pref}$$

$$U_{tov} \leq 1{,}6\ kV$$

- Use of a standard impulse generator
- Oscillations in peak value due to circuit inductance – peak value is used for calculation

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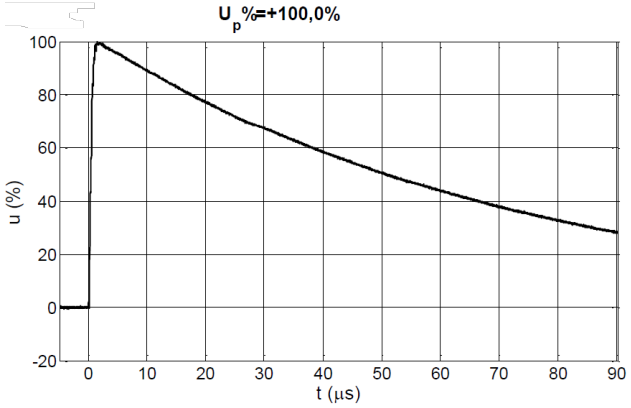
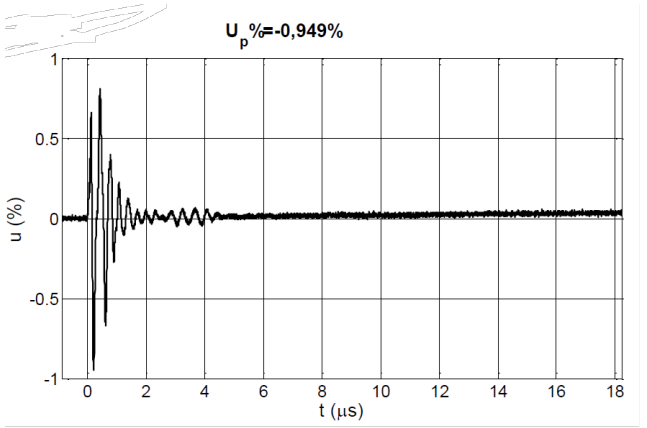
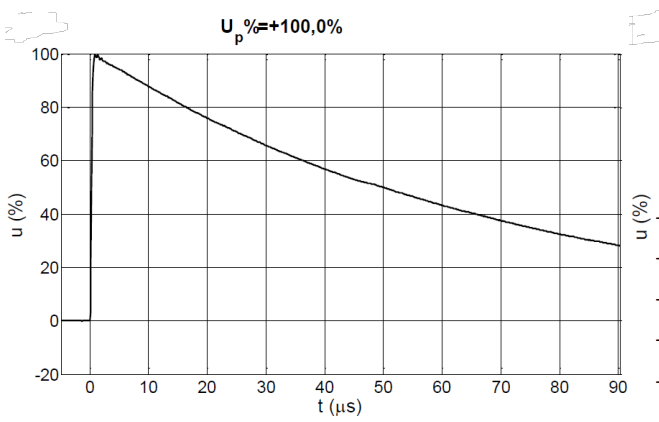
Transmitted overvoltage test

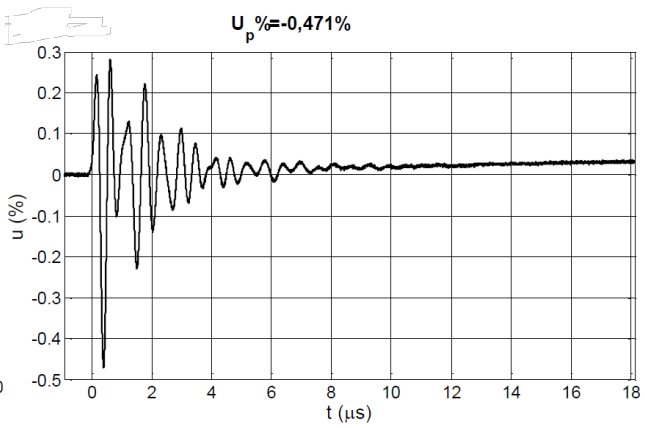




$U_{pref} = 118,4\ kV$
$U_{test} = 50kV$
$U_{TOV\%max} = 1,35\ \%$
$T_1 = 1,10\ \mu s$
$T_2 = 50,6\ \mu s$

PASSED





$U_{test} = 300\ V$
$U_{TOV\%max} = 1,35\ \%$
$T_1 = 0,57\ \mu s$
$T_2 = 50,3\ \mu s$

PASSED

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Power Quality

Accuracy tests at High Frequency

- Power quality measurement and protection applications
- Basic level WB0 (mandatory for LPIT) up to 13th harmonic, with wide bandwidth applications up to 100th harmonic
- Test performed up to 50th harmonic for class WB1

Accuracy class (at f_r)	Ratio error at low frequency		Ratio error at harmonics					Phase error at low frequency	Phase error at harmonics			
	%		%					± Degrees	± Degrees			
	0 Hz	1 Hz	2nd to 4th	5th and 6th	7th to 9th	10th to 13th	Above 13th	1 Hz	2nd to 4th	5th and 6th	7th to 9th	10th to 13th
0,05	+0,5 -100	+0,5 -30	±0,5	±1	±2	±4	+4 -100	45	0,5	1	2	4
0,1	+1 -100	+1 -30	±1	±2	±4	±8	+8 -100	45	1	2	4	8
0,2–0,2 S	+2 -100	+2 -30	±2	±4	±8	±16	+16 -100	45	2	4	8	16
0,5–0,5 S	+5 -100	+5 -30	±5	±10	±20	±20	+20 -100	45	5	10	20	20
1	+10 -100	+10 -30	±10	±20	±20	±20	+20 -100	45	10	20	20	20
3–5	–	–	–	–	–	–	–	–	–	–	–	–

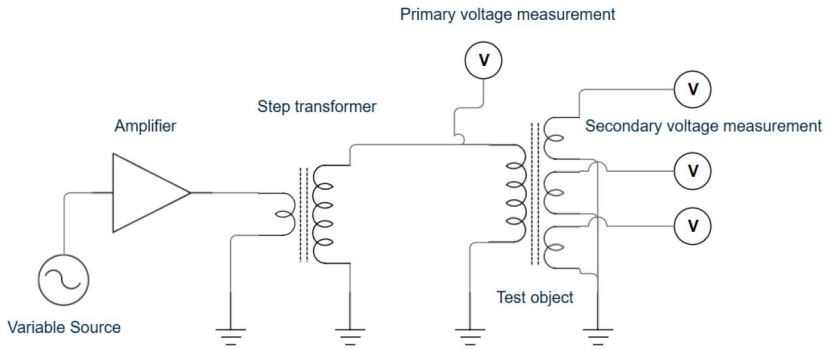
Accuracy classes		Ratio error (+/–) at frequencies shown below			Phase error (+/–) at frequencies shown below		
		%			Degrees		
	WB1	0,05 ≤f< 1 kHz	1 ≤ f< 1,5 kHz	1,5 ≤ f< 3 kHz	0,05 ≤ f< 1 kHz	1 ≤ f<1,5 kHz	1,5 ≤ f< 3 kHz
	WB2	0,05 ≤f< 5 kHz	5 ≤ f< 10 kHz	10 ≤ f< 20 kHz	0,05 ≤ f< 5 kHz	5 ≤ f<10 kHz	10 ≤f< 20 kHz
	WB3	0,05 ≤f< 20 kHz	20≤f<50 kHz	50≤f<150 kHz	0,05 ≤ f<20 kHz	20≤f<50 kHz	50≤f<150 kHz
	WB4	0,05 ≤f< 50 kHz	-	at 500 kHz	0,05 ≤ f<50 kHz	-	at 500 kHz
0,1		1 %	2 %	5 %	1	2	5
0,2 - 0,2S		2 %	4 %	5 %	2	4	5
0,5 - 0,5S		5 %	10 %	10 %	5	10	20
1		10 %	20 %	20 %	10	20	20
Protection		10 %	20%	30 %	-	-	-

Accuracy tests at High Frequency

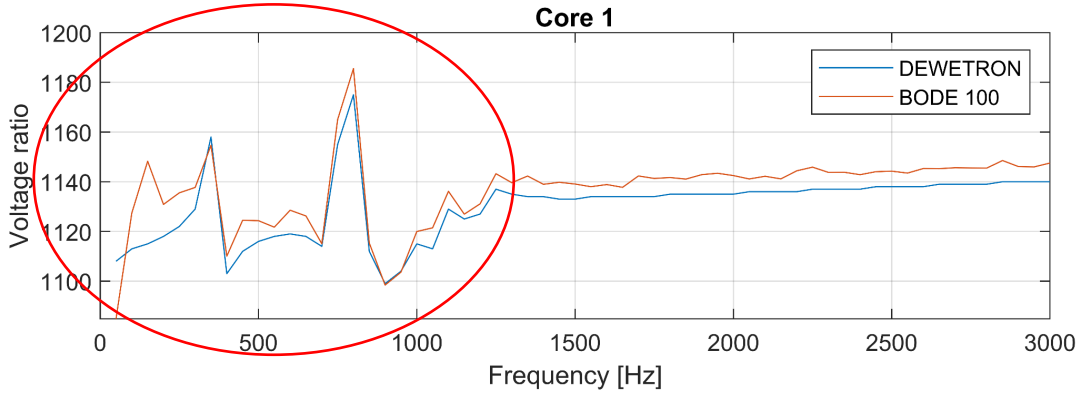
- Measurement of ratio error and phase displacement at high frequencies
- Unable to measure with standard accuracy bridges (50 or 60 Hz)
- Requires an instrument capable of detecting phase shift between two signals
- Preferred HV method – rated frequency + harmonics superimposed – LV method is acceptable

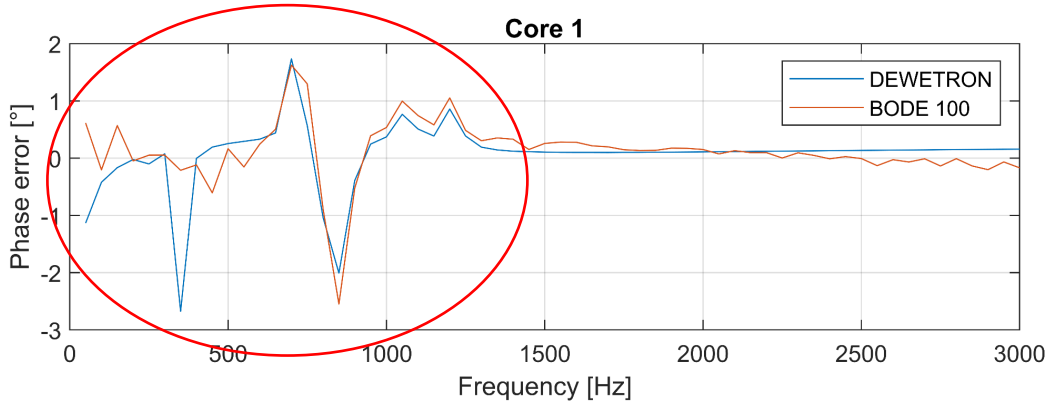
- Possible instruments:
  - Dewetron SIRIUS-XHS – acceptable accuracy
  - Vector Network Analyzer Bode 100 – susceptible to noise interference
  - Oscilloscope – limited usability due to user-unfriendly interface and questionable horizontal resolution

Accuracy tests at High Frequency



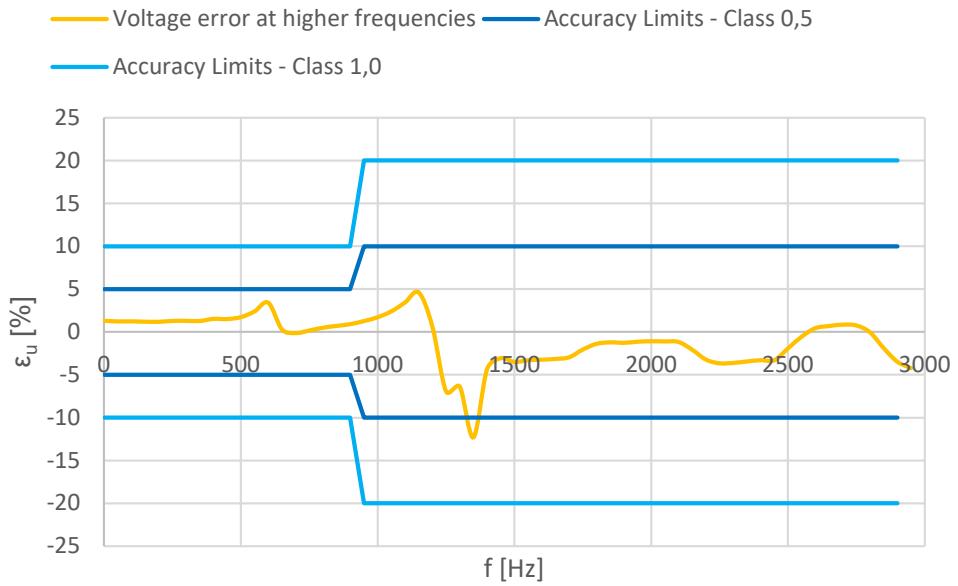
- Significant difference in lower frequency range between Bode and Dewetron
- Dewetron – more suitable solution (higher voltage)
- Variable source (AFG) and amplifier can be substituted with a single frequency converter

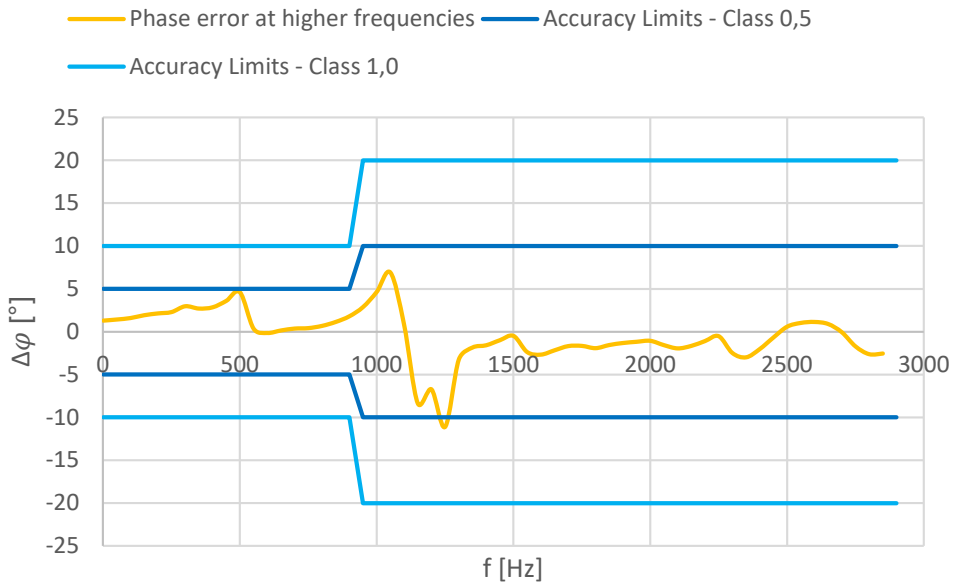




Accuracy tests at High Frequency

- Measurement example on SVE-123
- Ensures compliance with accuracy class 1.0 over class extension WB1, not optimized for transfer accuracy at higher harmonics





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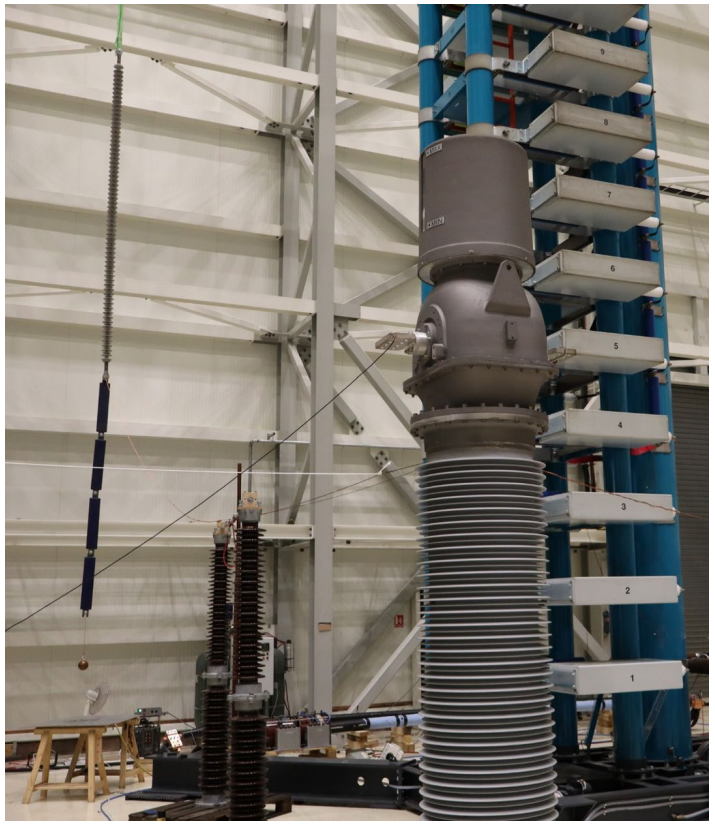
Line Discharge

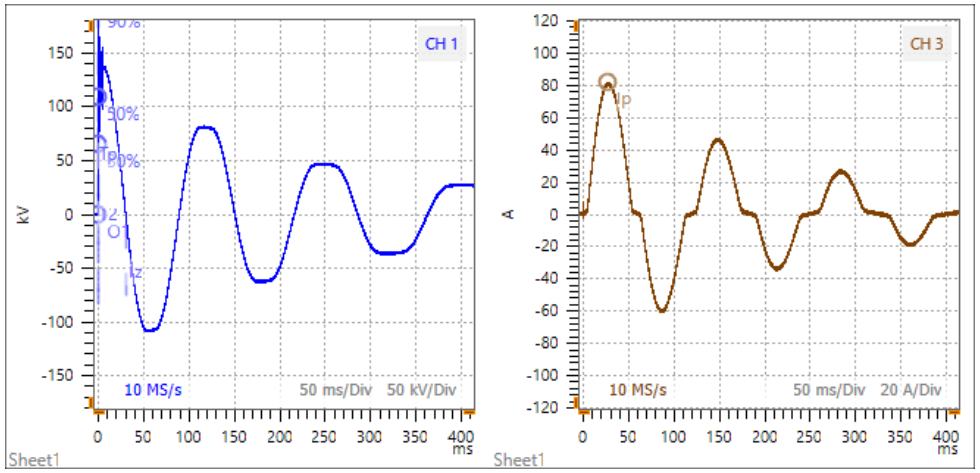
Line discharge test

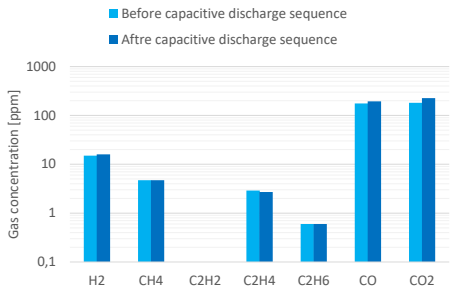
- IEC 61869-3 draft - Annex 3E – Informative, Requirement of TSOs
- Discharge of trapped line charge through high voltage winding of IVT's
- Combination of mechanical and thermal stresses
- Subject to multiple discharges during in-service period
- Impulse generator capacitance used as a line capacitance
- Tested across multiple capacitance values and system configurations
- Tested with 3 consecutive discharges, performed at the voltage corresponding to the rated voltage factor

Discharge capacitance C_L [µF]	2	4	6	8	10	12
Discharge voltage U_L [kV]	146,4					
Discharge current I_D [A]	37,8	52,2	63,0	71,7	79,2	85,9
Discharge energy E_D [kJ]	21,4	42,8	64,3	85,7	107,1	128,5
Winding temperature rise ΔT [K]	0,2	0,5	0,7	0,9	1,2	1,4
Total winding temperature θ_1 [K]	73,7	74,4	75,1	75,8	76,5	77,2

Line discharge test







- Following the discharge sequence, routine tests were conducted, including a DGA test
- Results confirm that the unit successfully completed the capacitive discharge sequence

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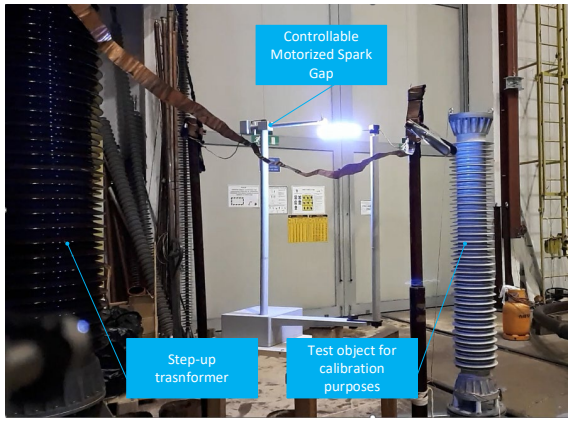
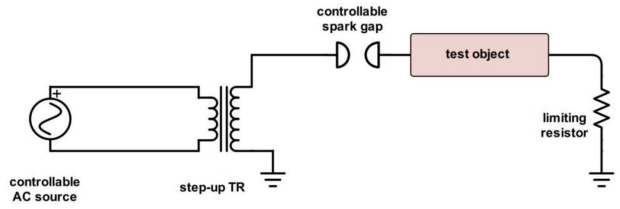
High-frequency Transients

Repeated flashover test

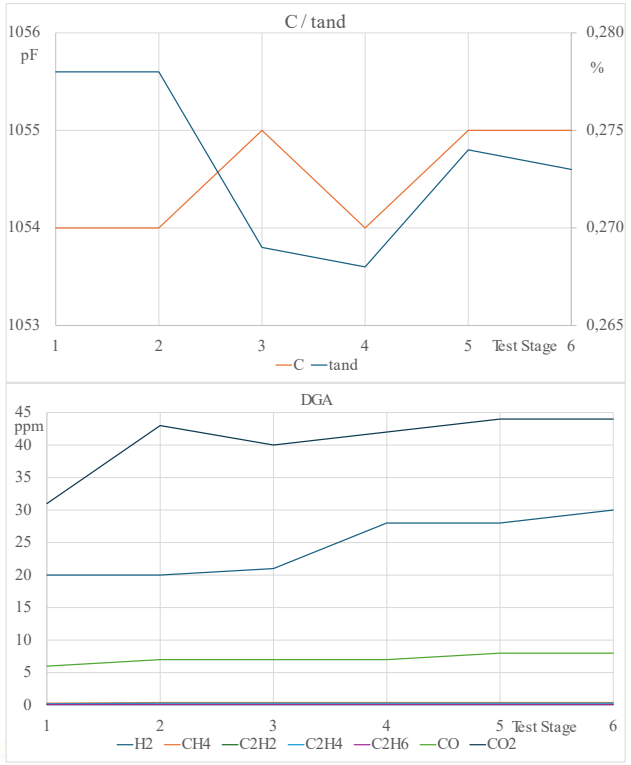
- Disconnectors – generate pre-strikes or re-strikes between contacts
- High rate of voltage rise
- Peak values range from 1.6 to 2.5 p.u.
- Effect simulation– deficiency of standardized test
- 15 min / 90 disconnector operations (3 min arching time) – pause 72 h / 6 stages

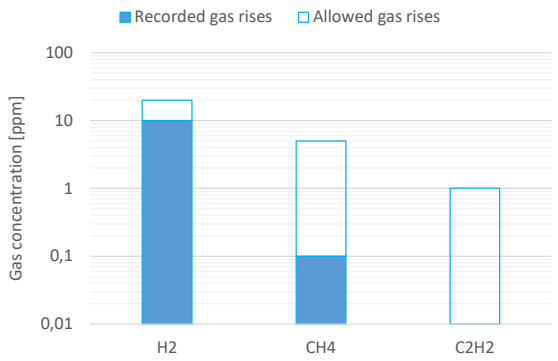




Repeated flashover test

- Verification of the insulation system
- tanδ, PD, DGA





- PD @1,2Um/√3 - 2 pC (1-6)
- PD @Um/√3 - 3 pC (1-6)
- PD @PFWV - <10 pC (1-6)
- No burn marks
- No graphite traces
- No treeing

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Conclusion

Conclusion

- Power system conditions are advancing beyond current standard requirements
- Common challenges include renewables, battery charging, cable systems, and two-way power flows impacting power quality...
- Several modern testing methods were presented
- All testing methods were developed and performed within the KONČAR Group
- A new product category has now been officaly launched

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