Inaccurate Billing / Metering CTs and VTs: The Quickest Way to Gain (or Lose) Revenue!

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Why is CT and VT Accuracy So Important?

How much **annual revenue** does a utility gain (or lose), if energy consumption for a **10MVA** load is measured with an **0.2% error**?

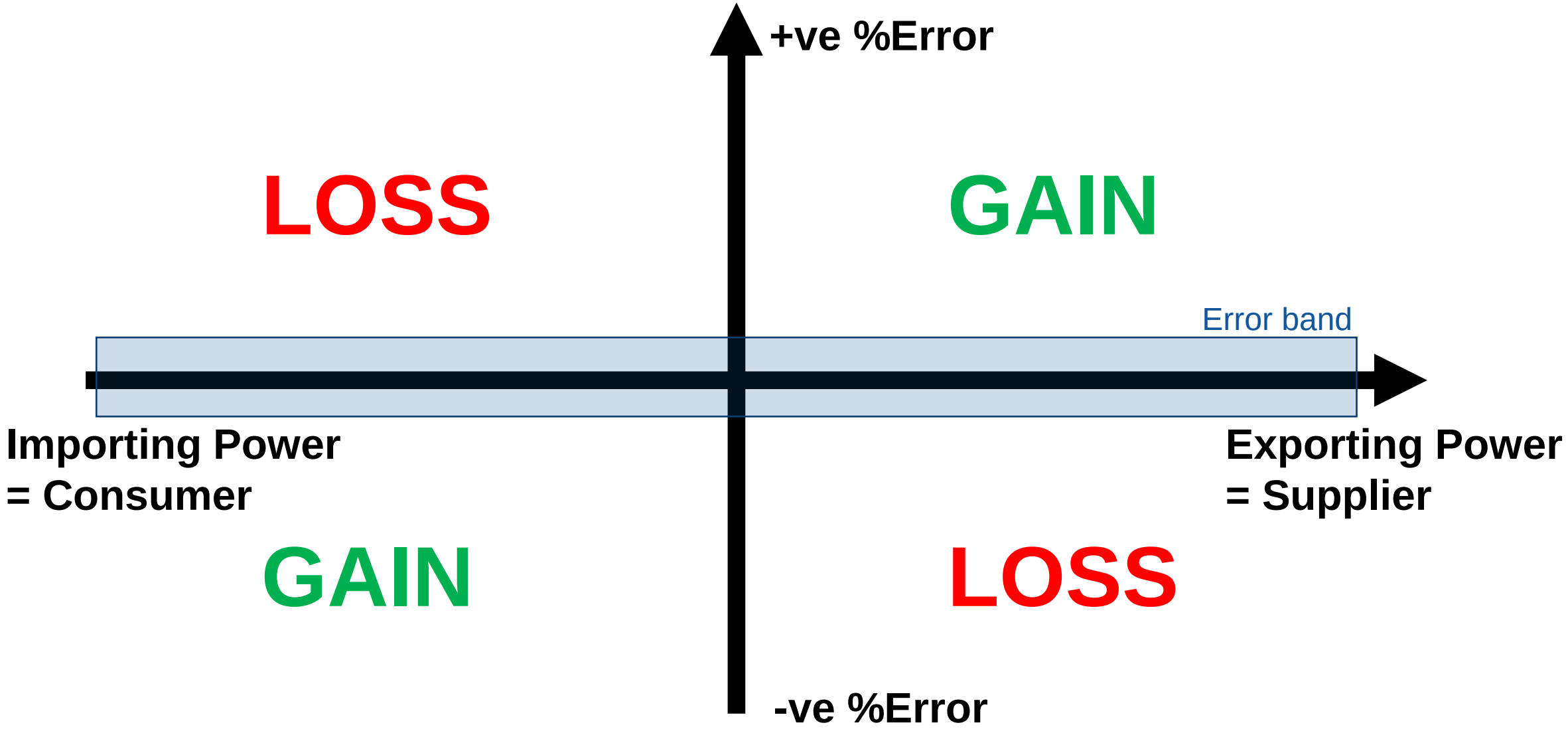
N$250,000

Daily energy consumed = **200MWh** = (1*16h + ½*8h)*10MVA
(Assumption: Full load for 16h/d; Half load for 8h/d)

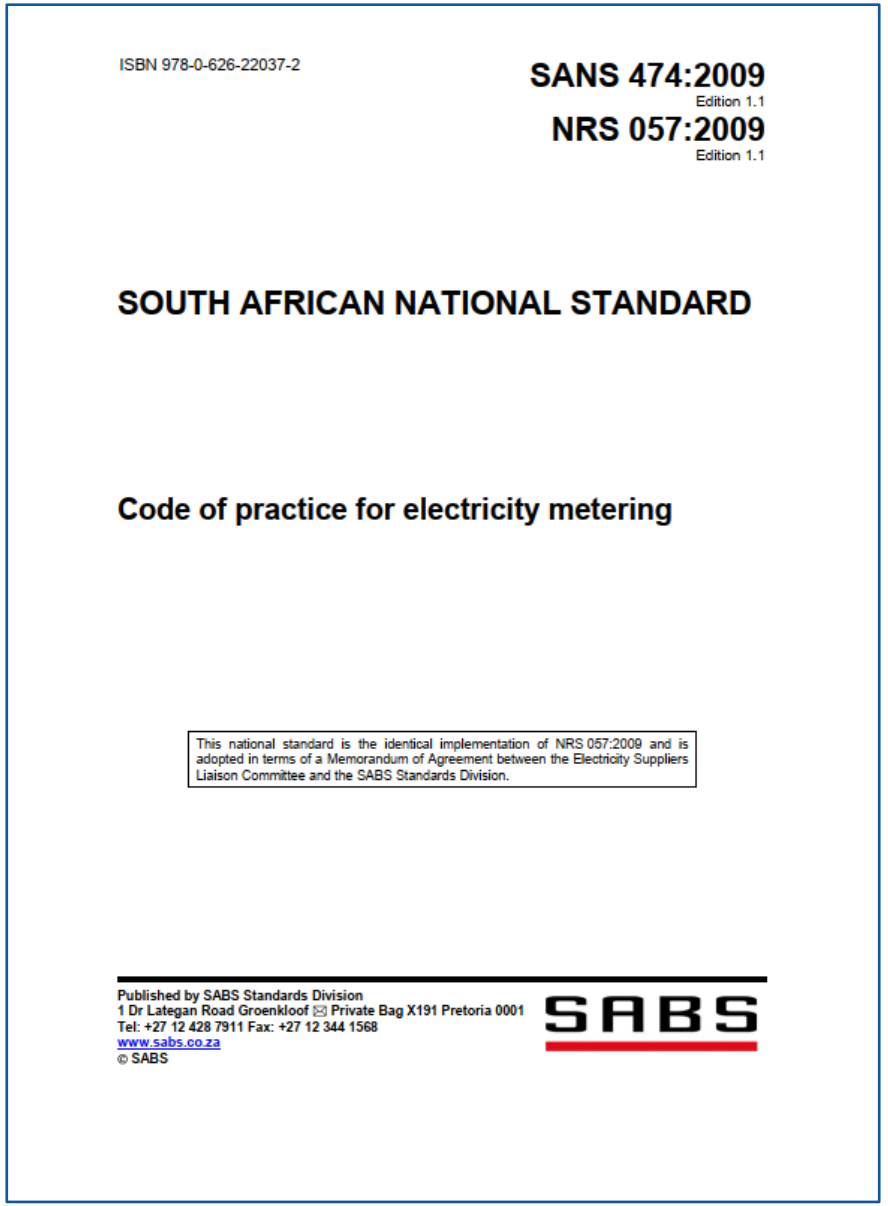
Annual revenue = **N$125Million** = 250d * N$2,500 1/MWh * 200MWh
(Assumption: 250 working days at N$2.50 1/kWh)

Total Annual Revenue gained/lost = **0.2%** * N$125Million = **N$250,000**

Where is a Positive (or Negative) Error Important?



SANS 474 / NRS 057



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SANS 474:2009
Edition 1.1
NRS 057:2009
Edition 1.1

SOUTH AFRICAN NATIONAL STANDARD

Code of practice for electricity metering

This national standard is the identical implementation of NRS 057:2009 and is adopted in terms of a Memorandum of Agreement between the Electricity Suppliers Liaison Committee and the SABS Standards Division.

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NRS 057 / SANS 474

- “Subsequent recalibration of metering system components requires the same full laboratory process as for new components. On-site testing and calibration is acceptable for this purpose as long as the requirements of this code of practise are complied with” (NRS 057:2009; Ch. 4.4.3.4)

- “Metering system components” consists of the energy meter(s) as well as the instrument transformer(s).
- Focus of this presentation is the verification of the current transformers (CTs) and voltage transformer (VTs).
- “Recalibration” means ‘comparison’ or ‘verification of accuracy’

- Calibration of inductive CTs - IEC 60044-1 / IEC 61869-2:
  Accuracy verification at 5%, 20%, 100% and 120% I_{nom} for 25% and 100% rated burden.
- Calibration of inductive VTs - IEC 60044-2 / IEC 61869-3:
  Accuracy verification at 80%, 100% and 120% V_{nom} for 25% and 100% rated burden – for all other windings unloaded AND fully loaded.

Customer Load	CT & VT Accuracy	Verification Interval
> 10MVA	class 0.2	5 years
100kVA to 10MVA	class 0.5	10 years
<100kVA	class 1	20 years

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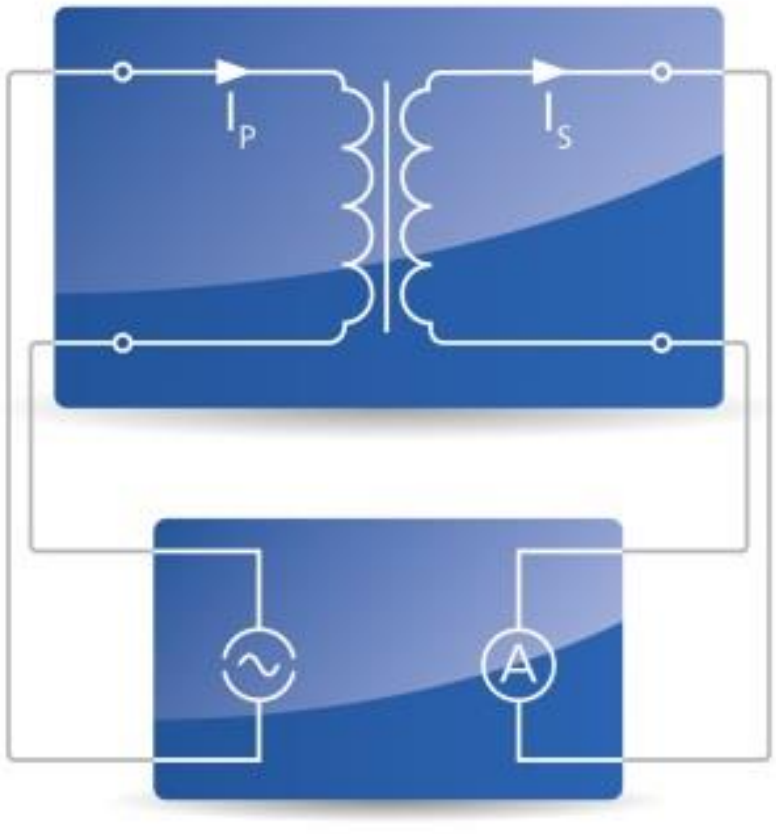
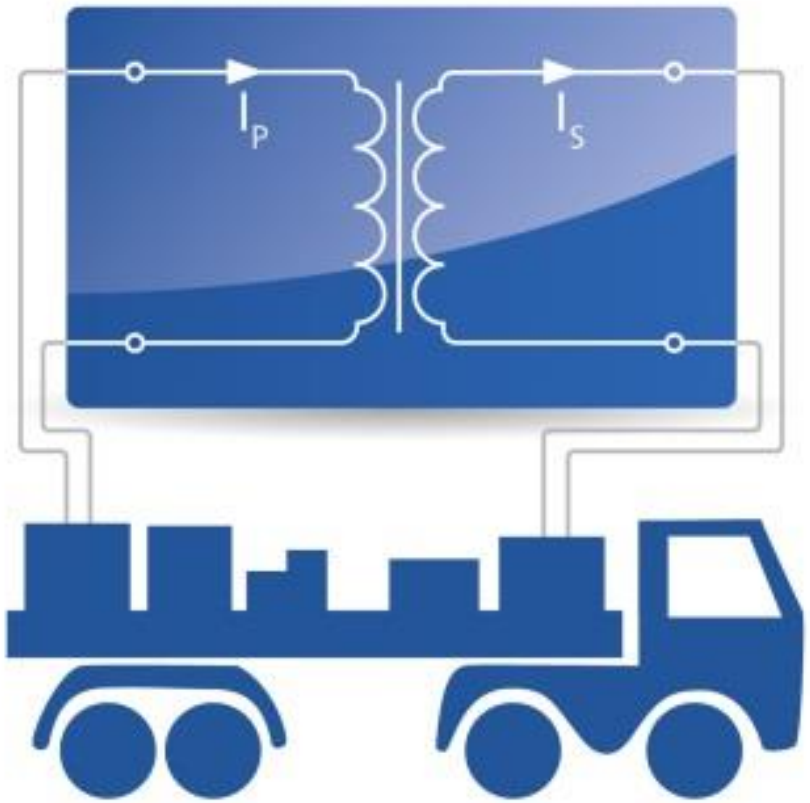
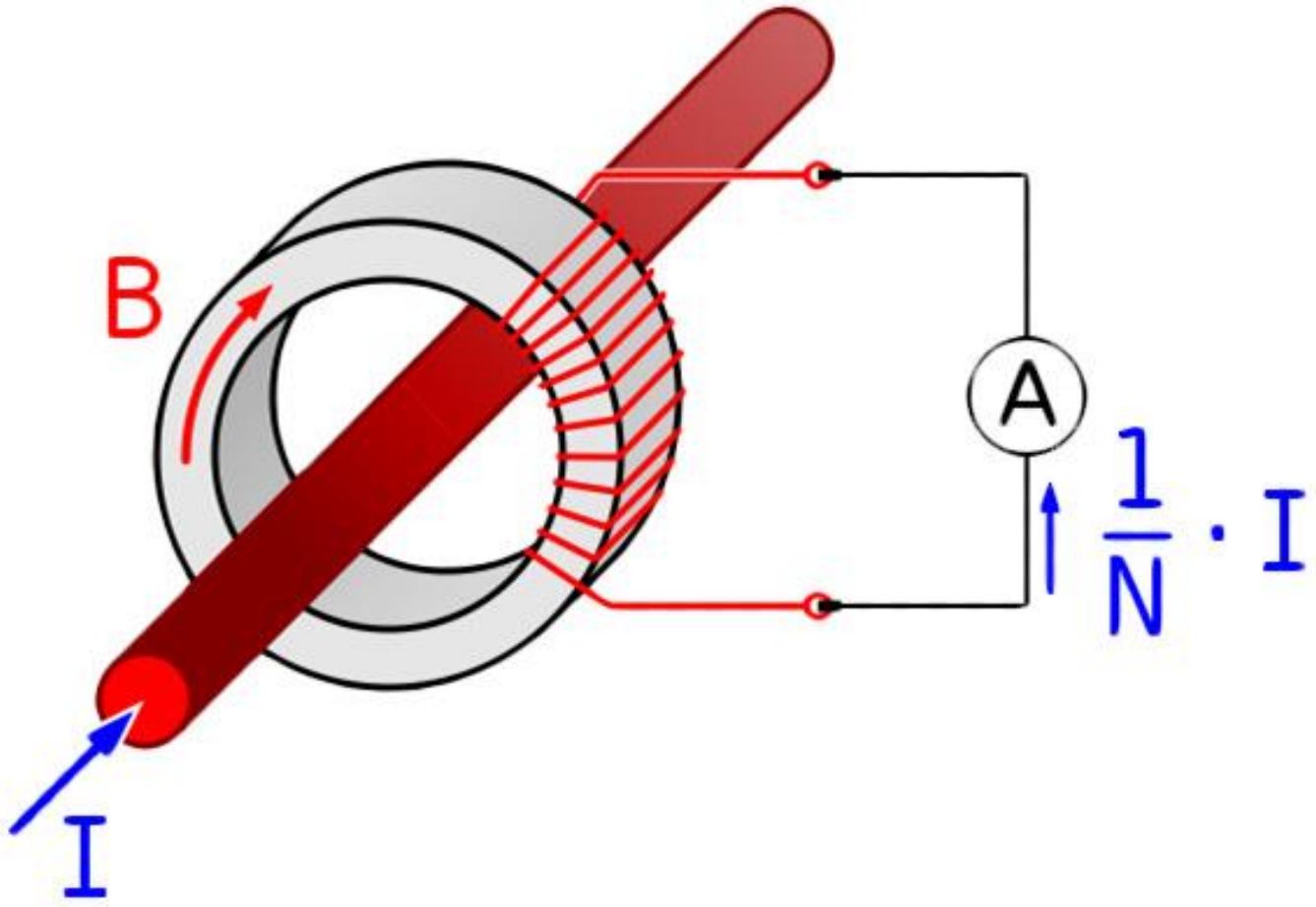
Conventional Verification by Primary Injection





Current Transformers (CT)

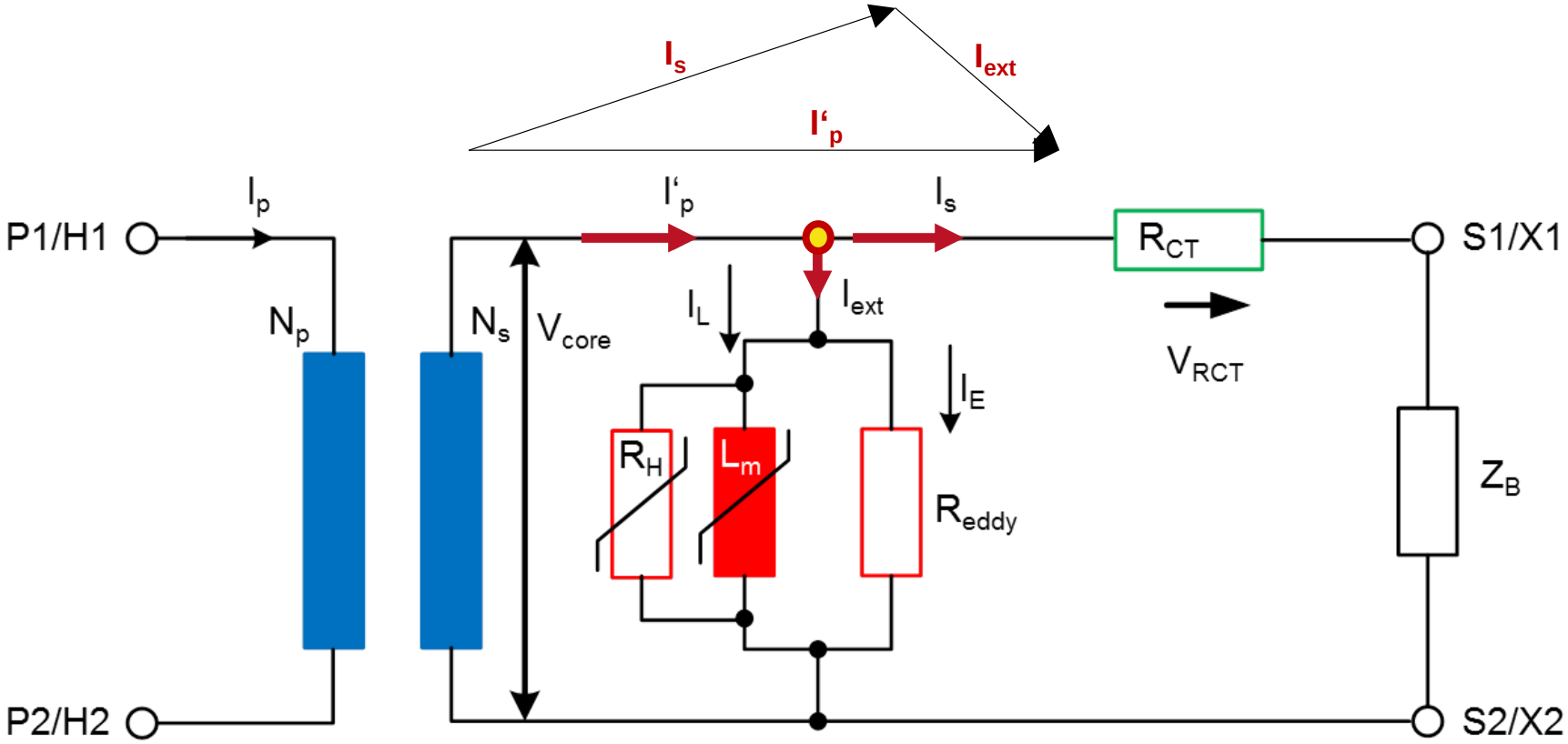
Ideal Current Transformer



Losses are not considered: $\Phi_1 = \Phi_2 \Rightarrow \ddot{u} = \frac{n_1}{n_2} = \frac{I_2}{I_1}$

Connected burden is not considered

Real Current Transformer (Detailed Electrical Model)



Parameters to determine:

- R_{CT} – secondary winding resistance
- Non-linear iron losses: Hysteresis losses R_H, magnetizing inductance L_m and the eddy losses R_{eddy}.
- Ideal transformation ratio N_p/N_s

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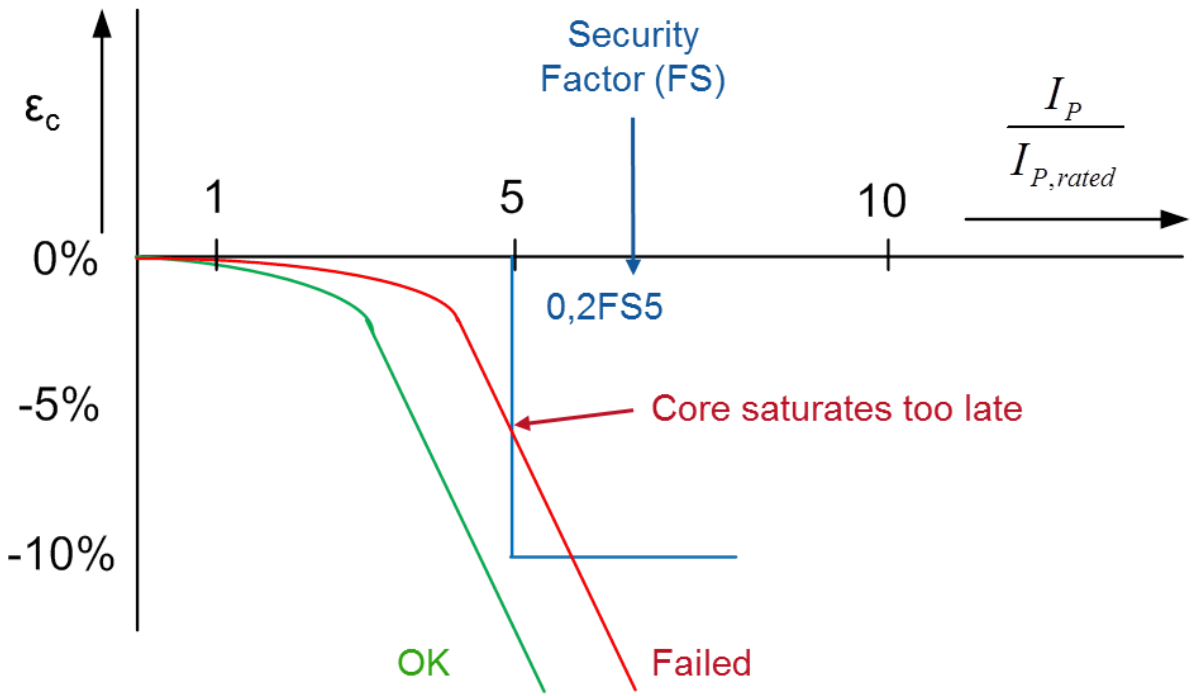
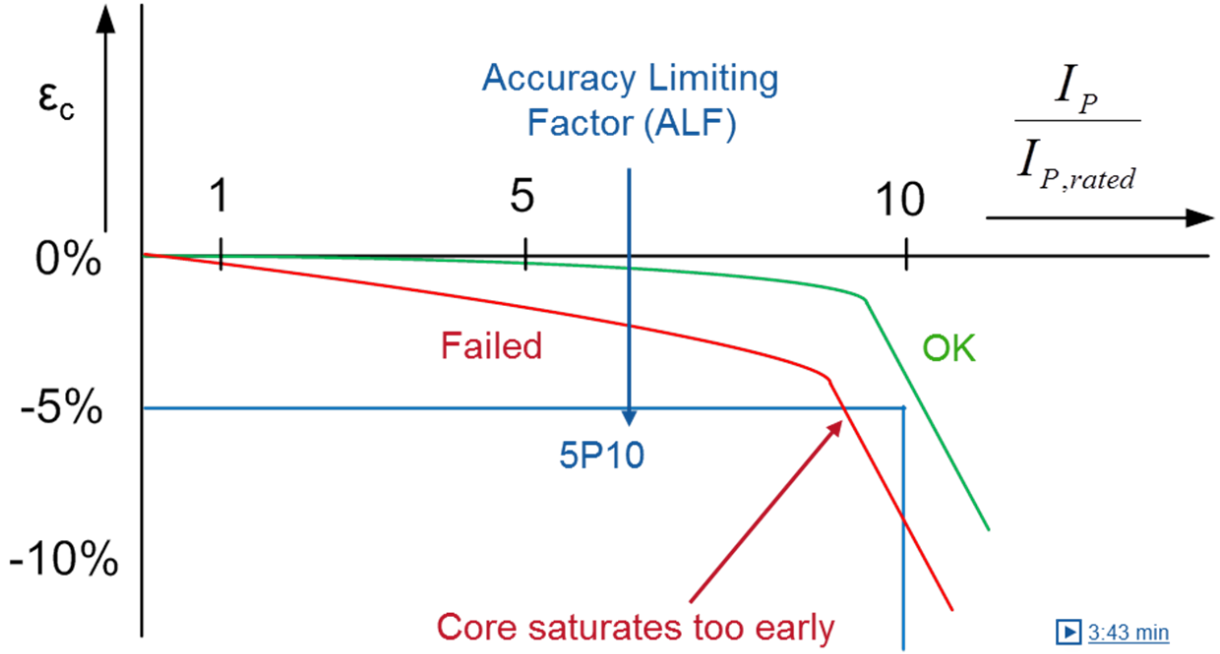
Accuracy Graph for a Metering / Protection CT

Metering Core:



Beware of underburdening a metering CT!

Protection Core:



Beware of overburdening a protection CT!

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OMICRON CT Analyzer for CT Calibrations

- Portable, compact size and low weight (< 8 kg)
- Field calibration of CTs up to the Class 0.1 accuracy class
- Fast testing time (<1min per core)

- Automatic result assessment as per IEC 60044-1and IEC61869-2 standards directly after the test
- Simulation and re-assessment with changed CT parameters

- Safety: max. 120 V output voltage
- Reliable: high noise immunity for on-site testing

- Multi-tap CTs can be tested with CT SB2 extension box (up to five taps)

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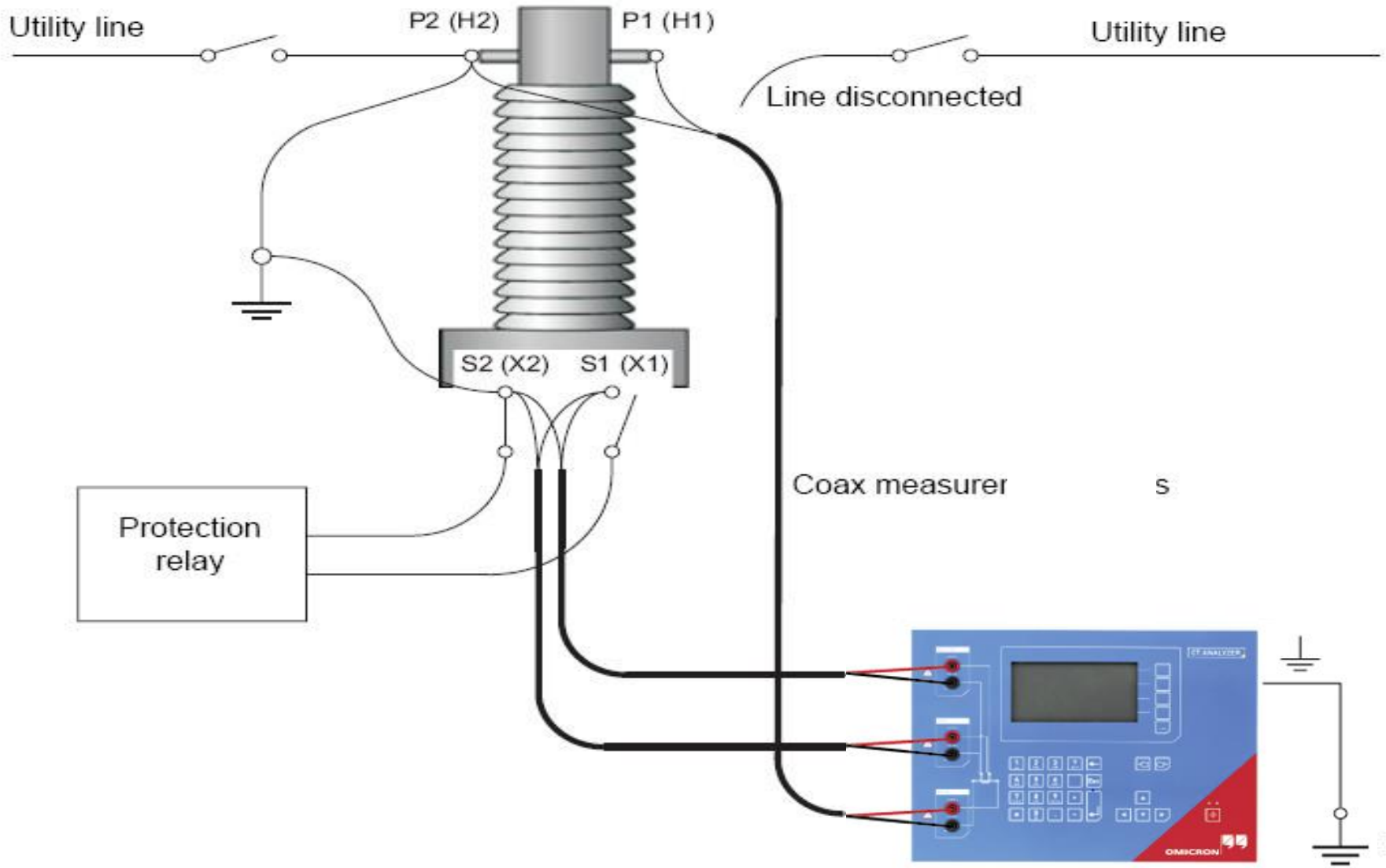
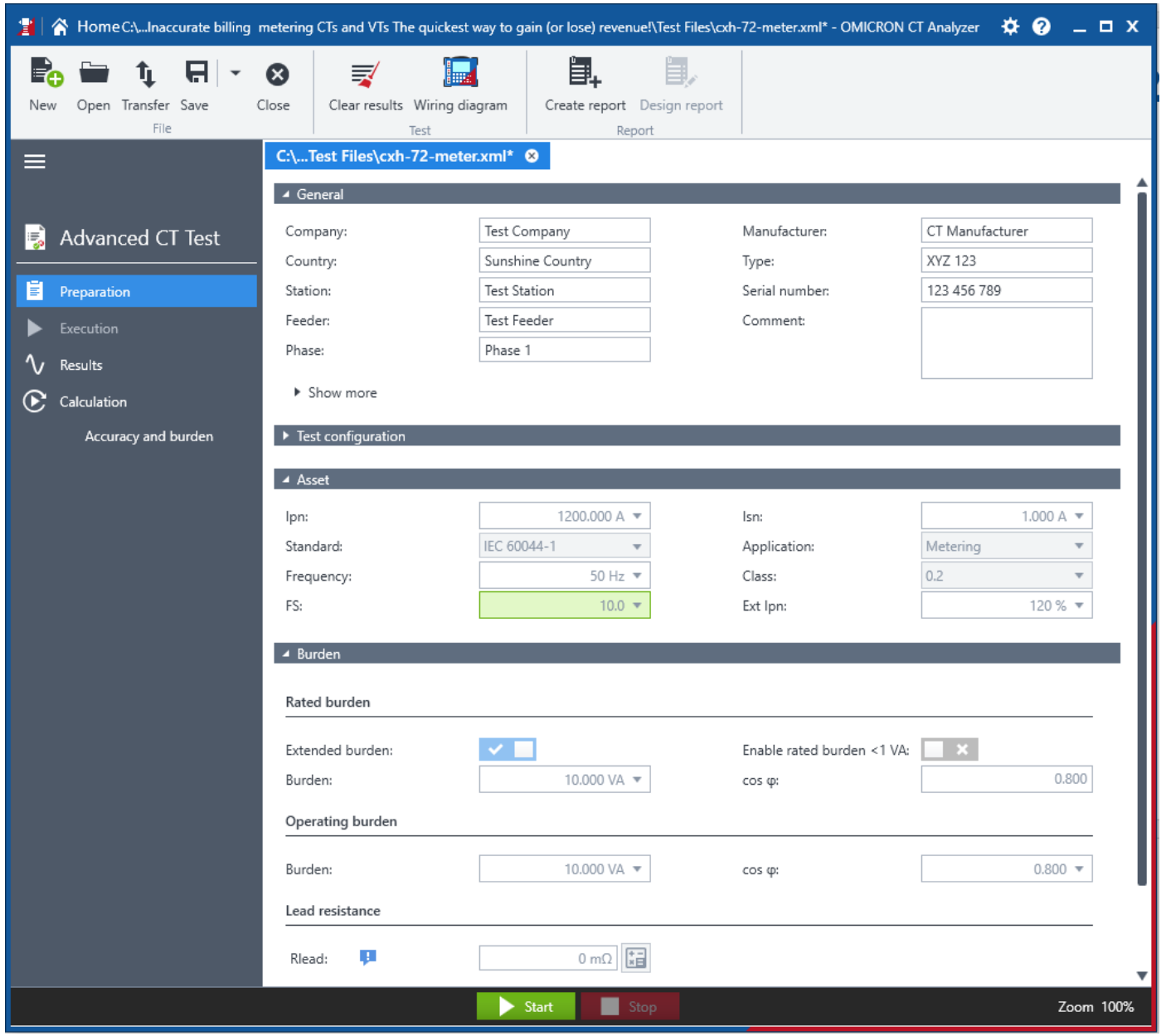
Case Study 1: Post Type CTs



Case Study 1: 66kV CT: 1200A:1A, 10VA, Class 0.2



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Case Study 1: 66kV CT: 1200A:1A, 10VA, Class 0.2

Test device			Date/Time	12/02/2016 09:58
Test device	CT-Analyzer		Device serial no	MB284K
File name	C:\Users\AlexanderDierks\Alectrix\Alectrix - Documents\2021\Trips\Digital Sessions\SAIEE Presentation 2021.02\Test Cases\cxh-72-meter.xml			
Overall assessement	OK			

Asset

Ipn	1200.0 A		Object		Location
Isn	1.0 A		Manufacturer		Company
Rated burden	10.0 VA /0.80		Type		Country
Operating burden	10.0 VA /0.80		Serial number		Station
Standard	IEC 60044-1		Core		Feeder
Application	Metering		Tap		Phase
Class	0.2		Optional		IEC-ID
Frequency	50.0 Hz		Comment		
Rct max	3.222 Ω	?			
FS	10.0	?			
Ext Ipn	120 %				

Secondary winding resistance				**Primary winding resistance**
R-meas (25.0 °C)	2.701 Ω	R-meas (25.0 °C)+Rlead	2.701 Ω	R-meas
R-ref (75.0 °C)	3.222 Ω	R-ref (75.0 °C)+Rlead	3.222 Ω	R-ref

Burden

Burden		cos ϕ:	Z
V-meas		I-meas	

Excitation

Ls	0.005587 H	Lm	149.925725 H	Results at rated burden (10.00 VA)			Results at operating burden (10.00 VA)		
Kr	75.1 %			FS	9.13	FSi 8.36	FS	9.13	FSi 8.36
Standard		IEC 60044-1		εci (@ FS=10)			εci (@ FS=10)		
V-kn	71.820 V	I-kn	0.002 A	Ts	13.360 s		Ts	13.360 s	

Ratio

Turns ratio	1199.3455			Results at rated burden (10.00 VA)			Results at operating burden (10.00 VA)		
εt	-0.0545 %			Ratio	1200.0 : 1.0001		Ratio	1200.0 : 1.0001	
Polarity	OK			ε	0.0124 %	Δϕ 0.42 min	ε	0.0124 %	Δϕ 0.42 min
				εc	0.0174 %		εc	0.0174 %	

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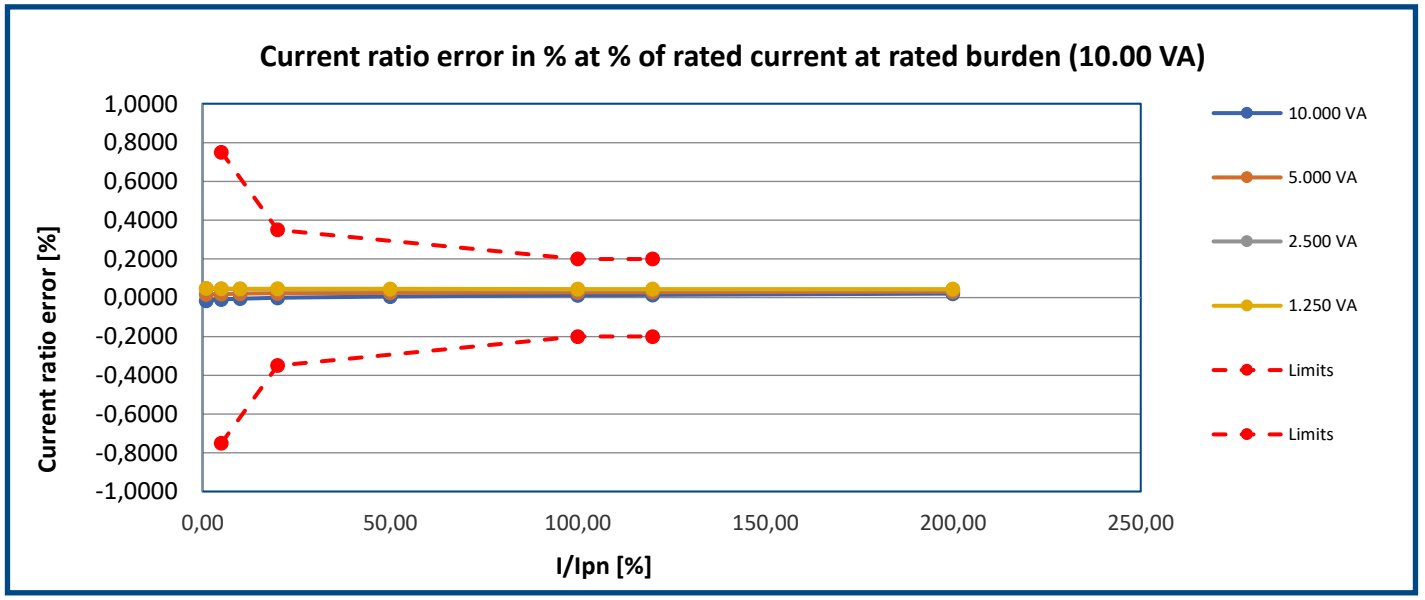
Case Study 1: 66kV CT: 1200A:1A, 10VA, Class 0.2

Current ratio error in % at % of rated current at rated burden (10.00 VA)								
VA/cos ϕ	1.00 %	5.00 %	10.00 %	20.00 %	50.00 %	100.00 %	120.00 %	200.00 %
10.00/0.80	-0.0158	-0.0087	-0.0049	-0.0007	0.0060	0.0124	0.0142	0.0206
5.00/0.80	0.0171	0.0185	0.0206	0.0223	0.0251	0.0276	0.0283	0.0310
2.50/1.00	0.0466	0.0449	0.0438	0.0431	0.0421	0.0416	0.0415	0.0415
1.25/1.00	0.0482	0.0475	0.0465	0.0461	0.0454	0.0449	0.0447	0.0445

Phase in min at % of rated current at rated burden (10.00 VA)								
VA/cos ϕ	1.00 %	5.00 %	10.00 %	20.00 %	50.00 %	100.00 %	120.00 %	200.00 %
10.00/0.80	2.8390	2.0821	1.7067	1.3320	0.8167	0.4245	0.3178	0.0777
5.00/0.80	1.9553	1.5272	1.2975	1.0700	0.7575	0.5115	0.4459	0.2650
2.50/1.00	1.6744	1.4116	1.2626	1.0915	0.8719	0.6916	0.6433	0.5033
1.25/1.00	1.2888	1.1112	1.0123	0.8800	0.7145	0.5804	0.5439	0.4400



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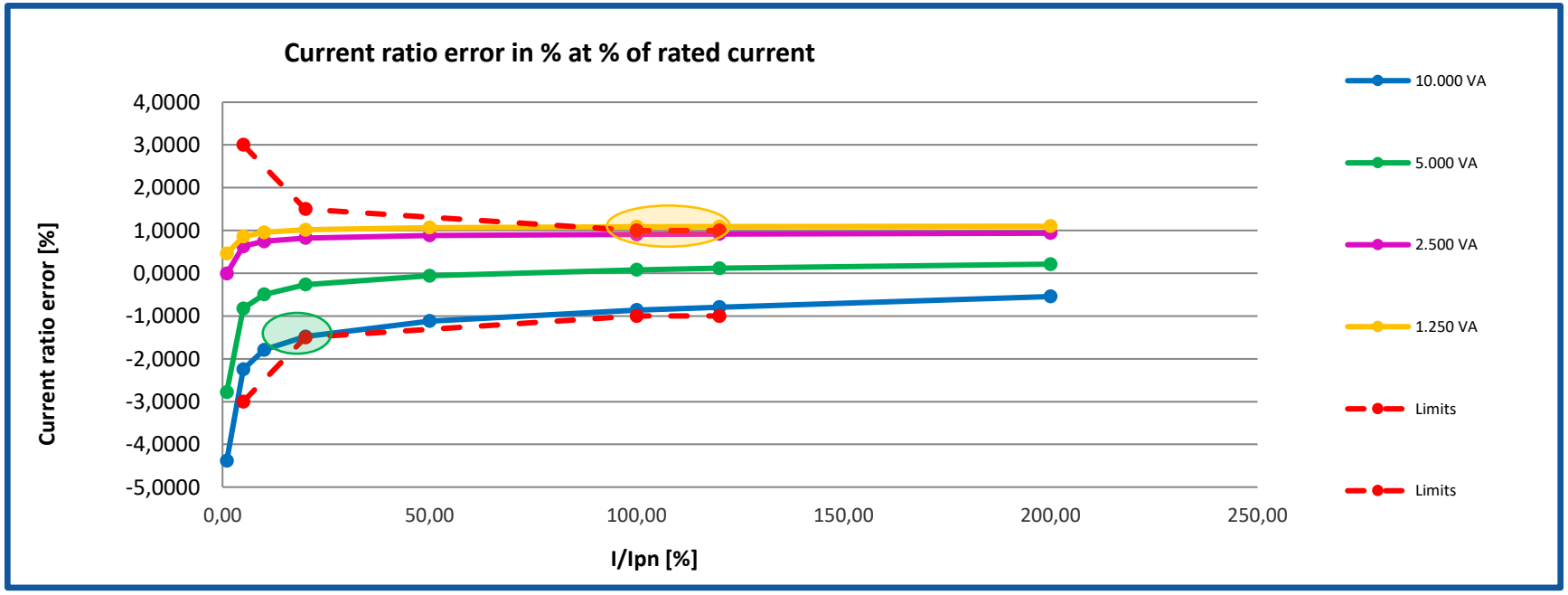
Case Study 2: 100A:1A, 10VA, Class 1

Current ratio error in % at % of rated current at rated burden (10.00 VA)

VA/cos ϕ	1.00 %	5.00 %	10.00 %	20.00 %	50.00 %	100.00 %	120.00 %	200.00 %
10.00/0.80	-4.3859	-2.2483	-1.7909	-1.4812	-1.1192	-0.8613	-0.7917	-0.5416
5.00/0.80	-2.7831	-0.8220	-0.4963	-0.2643	-0.0588	0.0806	0.1156	0.2126
2.50/1.00	-0.0087	0.6307	0.7460	0.8246	0.8850	0.9092	0.9170	0.9375
1.25/1.00	0.4590	0.8583	0.9540	1.0151	1.0666	1.0871	1.0914	1.1009

Phase in min at % of rated current at rated burden (10.00 VA)

VA/cos ϕ	1.00 %	5.00 %	10.00 %	20.00 %	50.00 %	100.00 %	120.00 %	200.00 %
10.00/0.80	115.2638	64.1793	53.3167	44.4075	33.6205	24.8930	22.0891	12.3455
5.00/0.80	97.7956	42.6187	35.0336	29.1495	22.6513	18.4887	17.3690	13.6873
2.50/1.00	131.6096	51.9136	41.5340	34.9057	28.6622	24.7641	23.8565	21.4562
1.25/1.00	112.6944	38.9152	28.5927	23.1707	18.6099	16.1587	15.5619	13.9497



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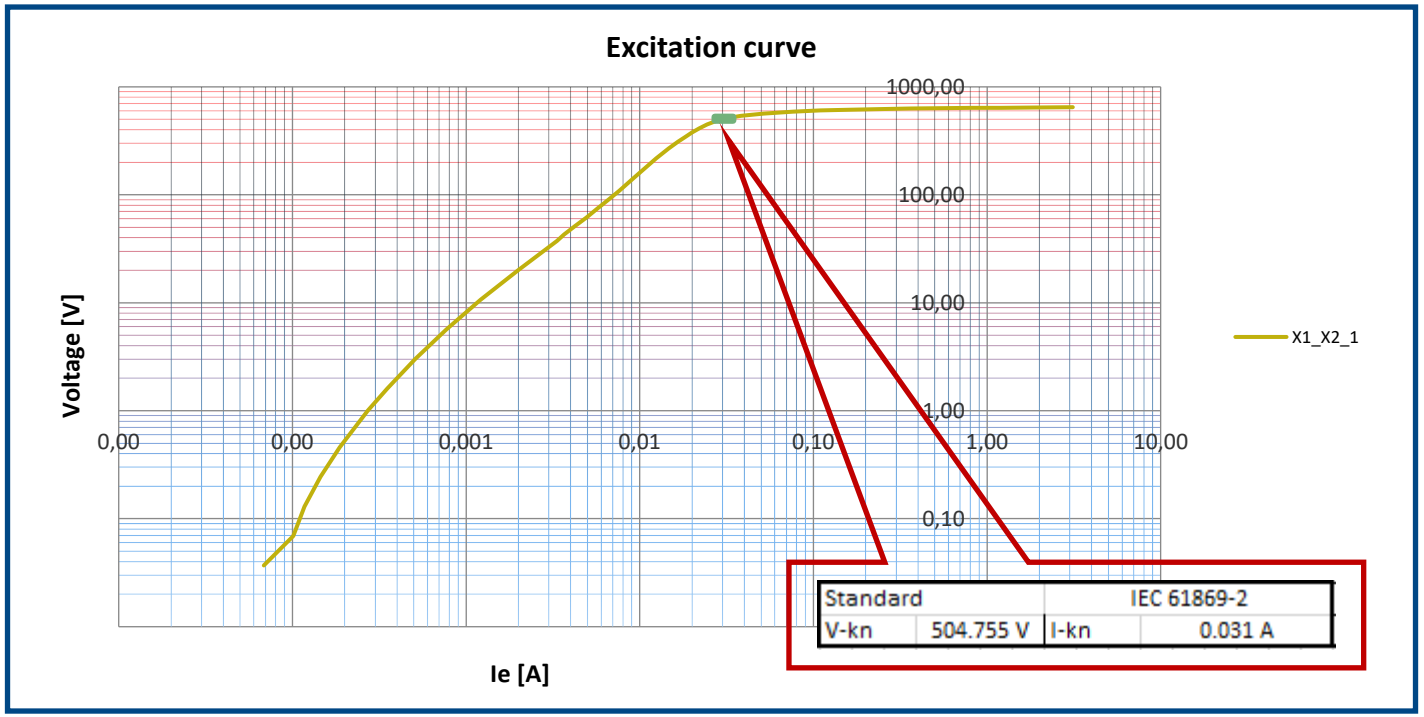
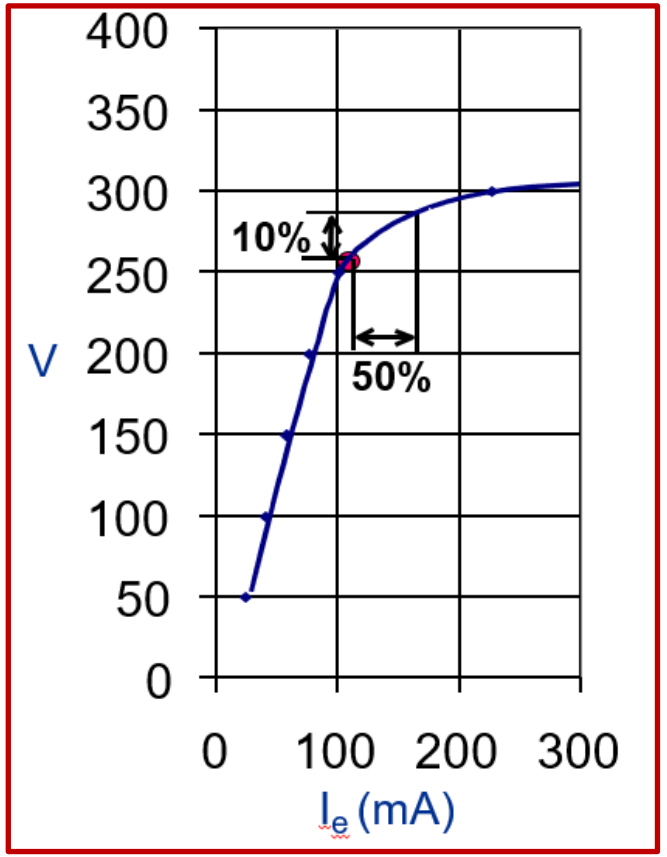
Case Study 3: 300:1, 15VA 5P30 Protection Core





Excitation							
Ls	0.003504 H	Lm	61.784285 H	Results at rated burden (15.00 VA)			
Kr	89.81 %			ALF	> 38.31	ALFi	37.41
Standard		IEC 61869-2		εci (@ ALF=30)		0.108 %	
V-kn	504.755 V	I-kn	0.0306 A	Ts	4.220 s		

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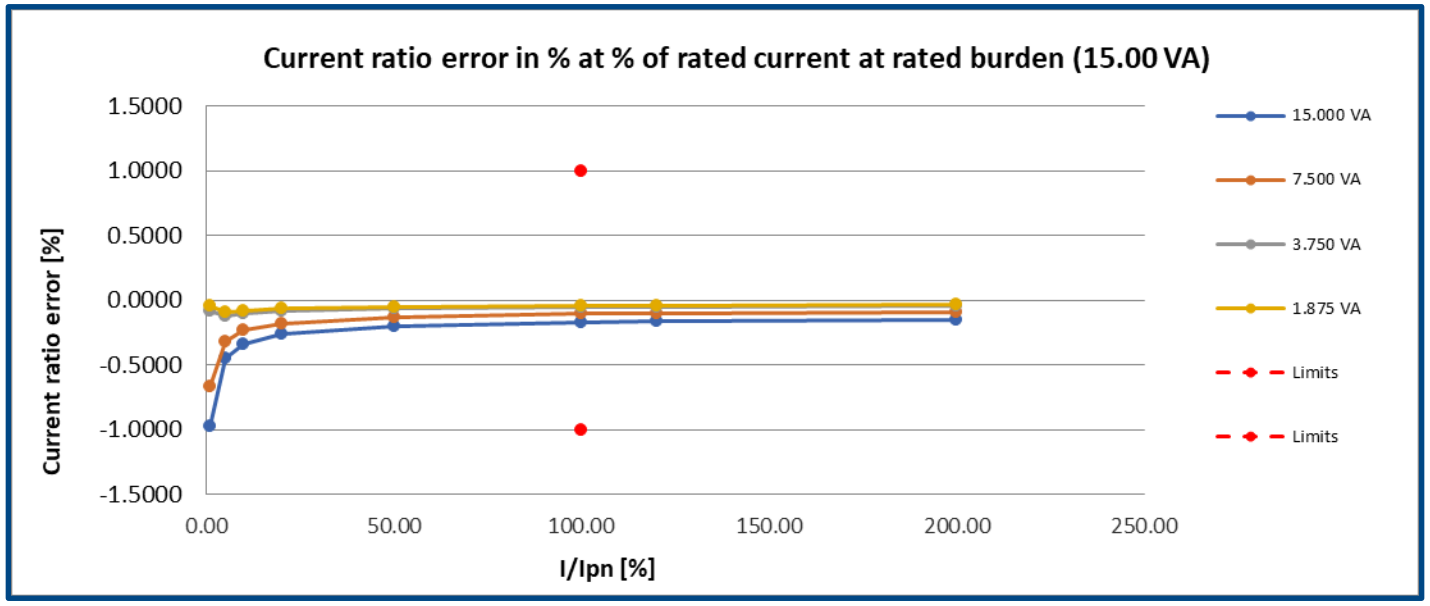
Case Study 3: 300:1, 15VA 5P30 Protection Core

Current ratio error in % at % of rated current at rated burden (15.00 VA)

VA/cos ϕ	1.00 %	5.00 %	10.00 %	20.00 %	50.00 %	100.00 %	120.00 %	200.00 %
15.00/0.80	-0.9686	-0.4505	-0.3389	-0.2603	-0.1962	-0.1674	-0.1613	-0.1485
7.50/0.80	-0.6677	-0.3179	-0.2321	-0.1768	-0.1274	-0.1045	-0.0999	-0.0899
3.75/1.00	-0.0795	-0.1239	-0.1038	-0.0848	-0.0642	-0.0523	-0.0500	-0.0443
1.88/1.00	-0.0402	-0.0896	-0.0800	-0.0651	-0.0500	-0.0404	-0.0383	-0.0336

Phase in min at % of rated current at rated burden (15.00 VA)

VA/cos ϕ	1.00 %	5.00 %	10.00 %	20.00 %	50.00 %	100.00 %	120.00 %	200.00 %
15.00/0.80	29.2857	7.7442	4.6430	3.1307	2.1521	1.7567	1.6715	1.4951
7.50/0.80	29.6845	7.3543	4.4448	2.8257	1.7791	1.3809	1.3037	1.1446
3.75/1.00	31.6301	10.0910	6.4642	4.3017	2.7528	2.1214	2.0104	1.7403
1.88/1.00	25.0714	8.9908	5.5939	3.6650	2.2555	1.6744	1.5615	1.3250



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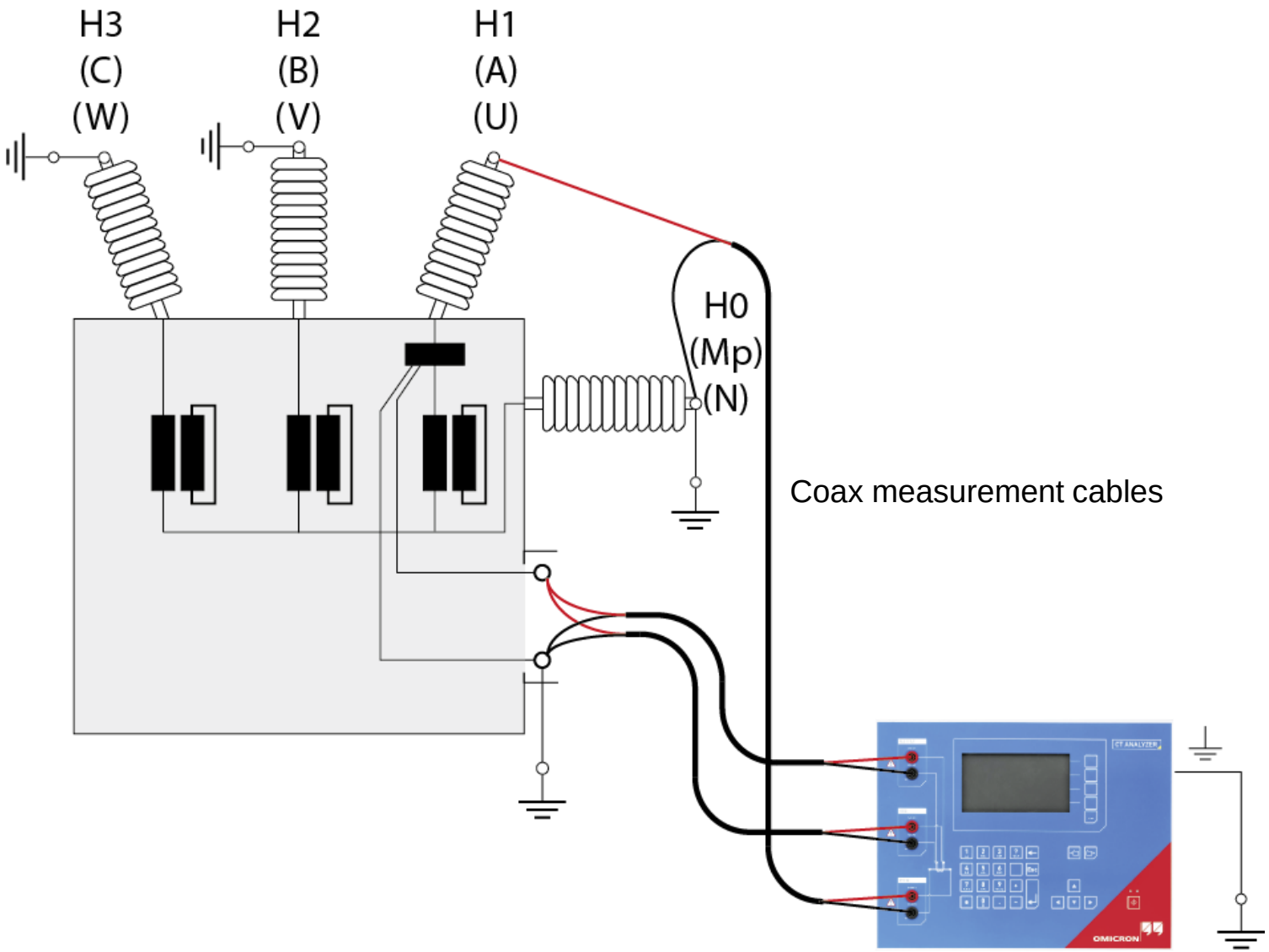
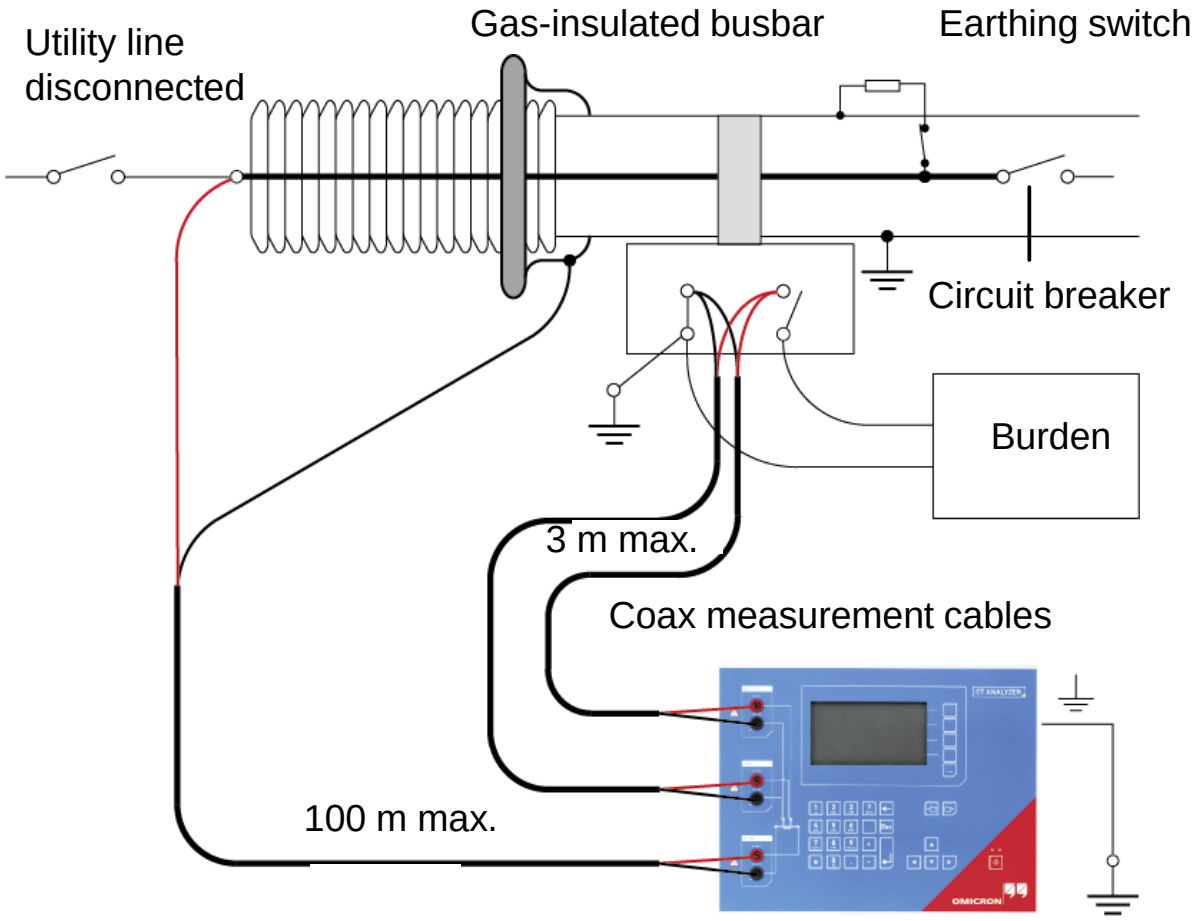
Special Applications: Bushing Type CTs

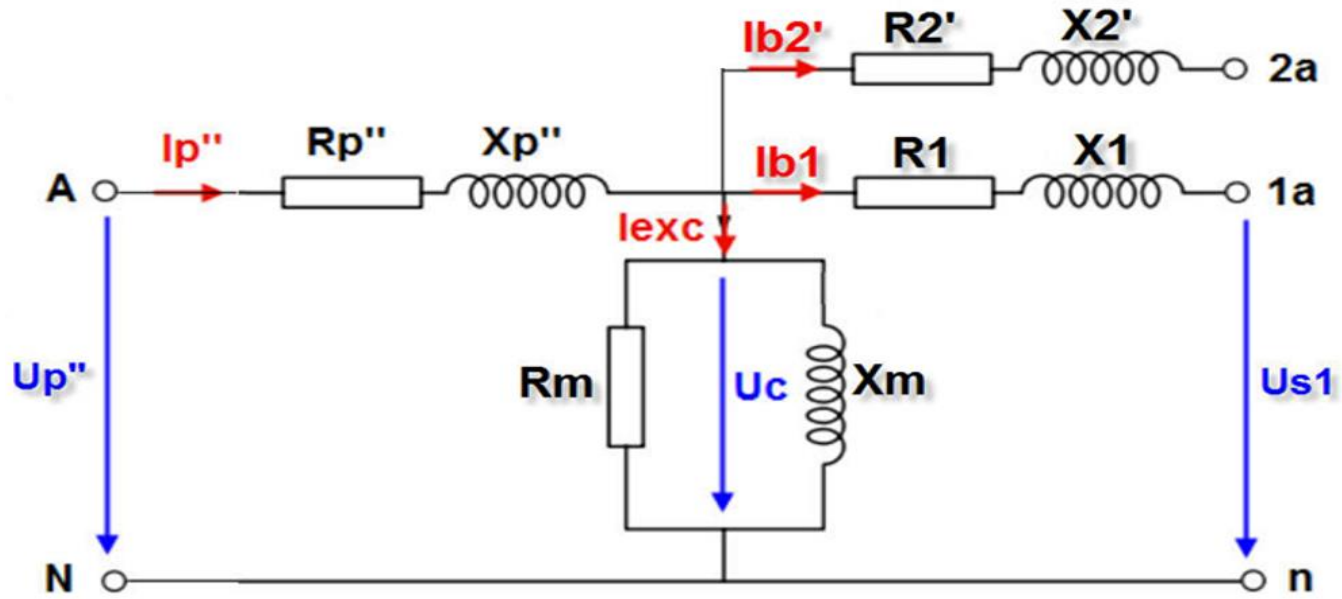


Special Applications: GIS



Voltage Transformers (VT)

Real Voltage Transformer (Detailed Electrical Model)



Parameters to determine:

1) Secondary winding resistance R_1 and R_2
2) Short circuit impedances yielding R_p", X_p", X_1 and X_2
3) Non-linear iron losses R_m and X_m

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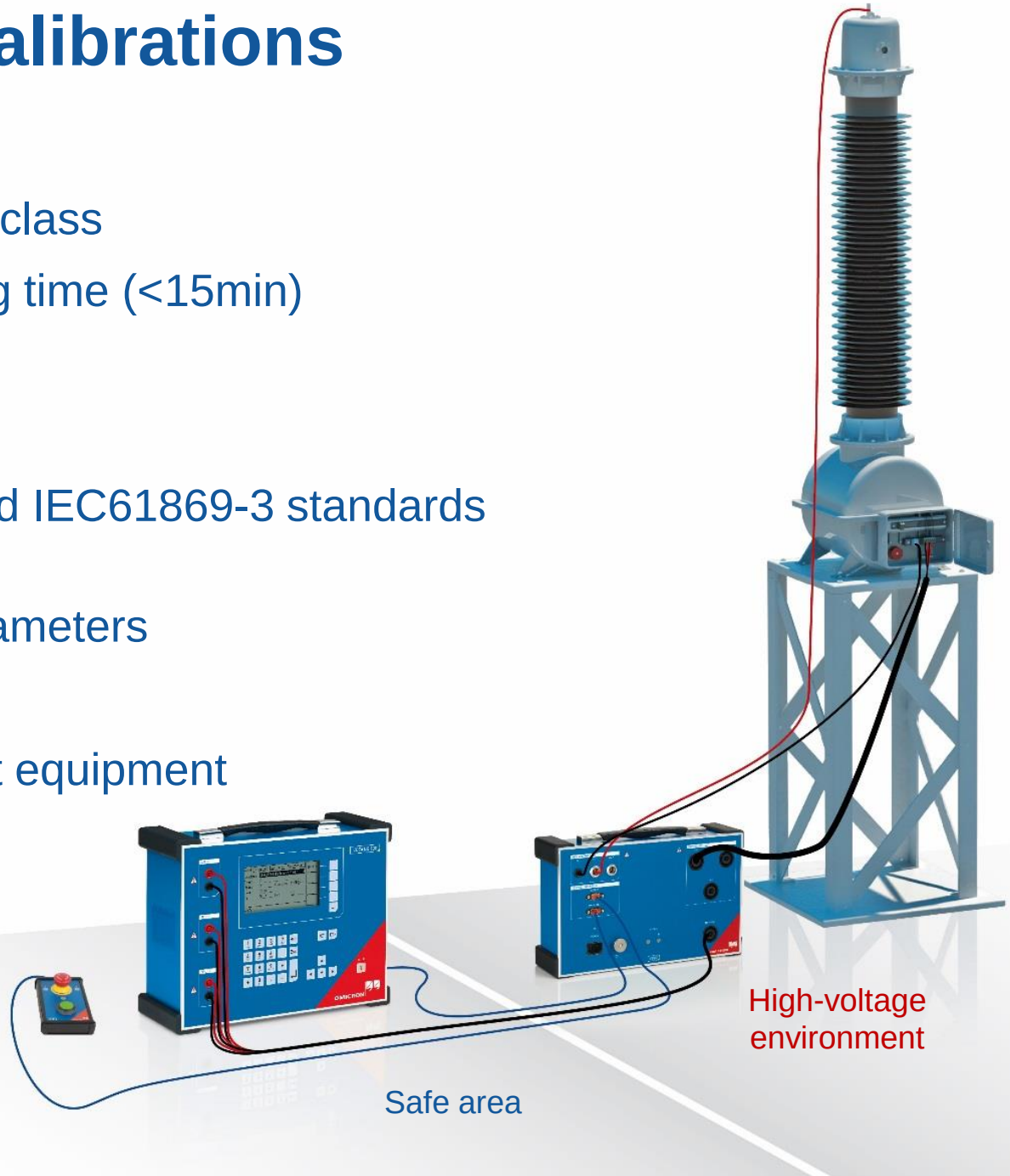
OMICRON VOTANO 100 for VT Calibrations

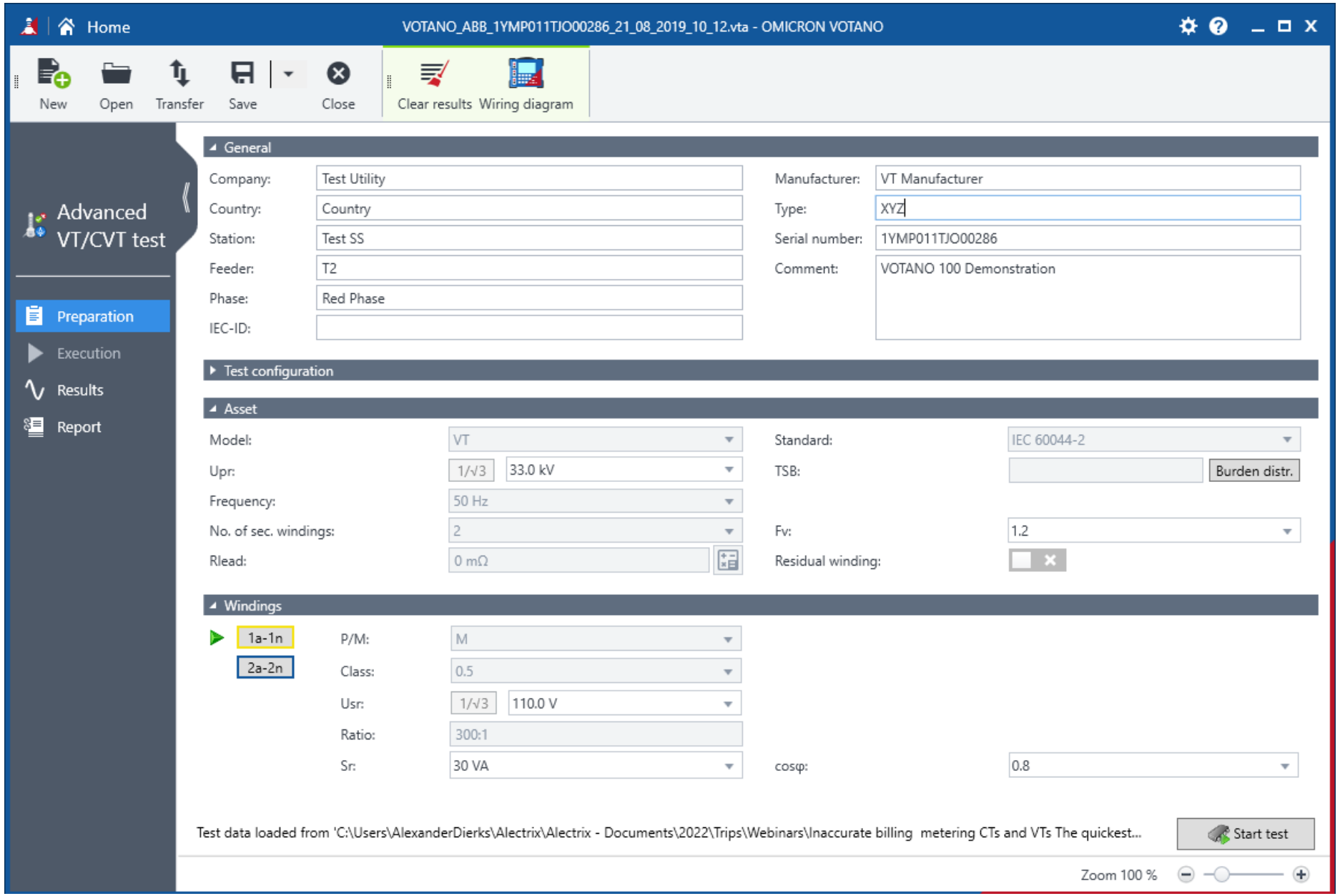
- Portable, compact size and low weight (8kg + 7kg)
- Field calibration of VTs up to the Class 0.1 accuracy class
- Software-guided test procedure ensures short testing time (<15min)
- VTs with up to five secondary windings

- Automatic result assessment as per IEC 60044-2 and IEC61869-3 standards directly after the test
- Simulation and re-assessment with changed VT parameters

- Safety: Local isolation between high voltage and test equipment
  Double action to start test; Emergency OFF button



Case Study 4: Two Winding 33kV:110V, 30VA; Class 0.5 / 3P



Case Study 4: Two Winding 33kV:110V, 30VA; Class 0.5 / 3P

VOTANO Advanced VT Test

Company	Test Utility
Company address	
Order number	

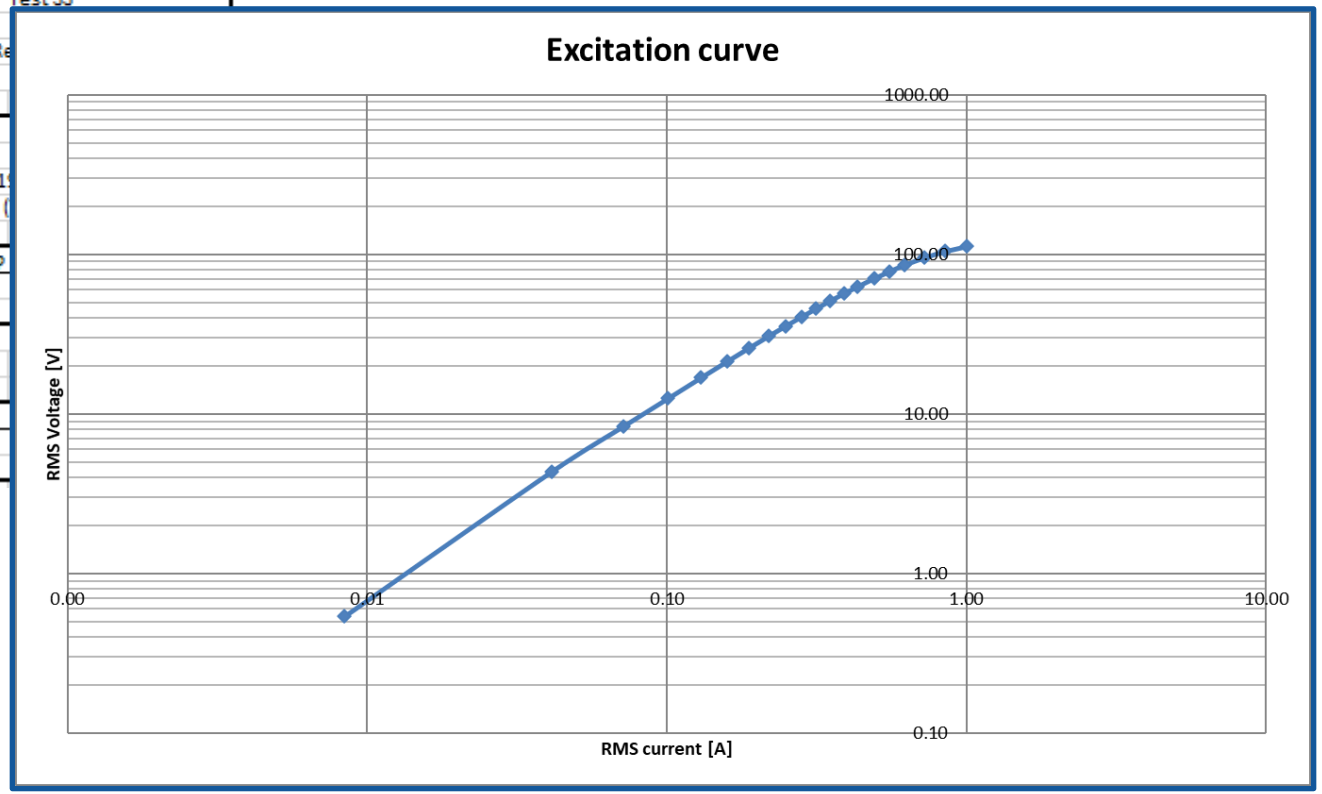
Object		Location	
Manufacturer	VT Manufacturer	Company	Test Utility
Type	XYZ	Country	Country
Serial number	1YMP011TJ000286	Station	Test SS
Comment		Feeder	
VOTANO 100 Demonstration		Phase	Re
		IEC-ID	

Model	VT	Type	
Rated primary voltage [V]	33000/√3	Serial number	
Applied standard	IEC 60044-2	Measurement saving time	201
Rated frequency [Hz]	50.00	Firmware version	2.10 (
Fv	1.2		

Winding	Rated sec. voltage [V]	Class	M-Class	Nom. Burden [VA]/cosφ
1a-1n	110/√3		0.5	30/0.8
2a-2n	110/√3	3P	n/a	30/0.8

Overall assessment	OK

Winding	Winding Resistance [Ω]	Ratio
1a-1n	0.1914	33000/√3 : 110.0081/√3
2a-2n	0.2956	33000/√3 : 109.9612/√3



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Case Study 4: Two Winding 33kV:110V, 30VA; Class 0.5 / 3P

Overview of ratio errors and phase displacements

				Burden							
Winding	Upr [kV]	Usr [V]	Freq. [Hz]	S1 [VA]	S2 [VA]	S3 [VA]	S4 [VA]	S5 [VA]	U [%]	Ratio error [%]	Phase error [min]
1a-1n	33/√3	110/√3	50	30/0.8					80%	0.0080	-0.50
									100%	0.0073	-0.47
									120%	0.0054	-0.43
				7.5/0.8					80%	0.1688	-0.55
									100%	0.1681	-0.52
									120%	0.1662	-0.49
				30/0.8	30/0.8				80%	-0.0701	-2.15
									100%	-0.0708	-2.12
									120%	-0.0727	-2.09
				7.5/0.8	30/0.8				80%	0.0905	-2.21
									100%	0.0899	-2.18
									120%	0.0879	-2.14
2a-2n	33/√3	110/√3	50		30/0.8				2%	-0.1157	1.04
									5%	-0.0822	1.16
									100%	-0.0353	1.20
									100*Fv%	-0.0372	1.23
					7.5/0.8				2%	0.0878	-0.49
									5%	0.1213	-0.37
									100%	0.1683	-0.33
									100*Fv%	0.1664	-0.30
				30/0.8	30/0.8				2%	-0.1966	-0.91
									5%	-0.1633	-0.80
									100%	-0.1164	-0.76
									100*Fv%	-0.1183	-0.73
				30/0.8	7.5/0.8				2%	0.0067	-2.45
									5%	0.0401	-2.33
									100%	0.0871	-2.29
									100*Fv%	0.0852	-2.26

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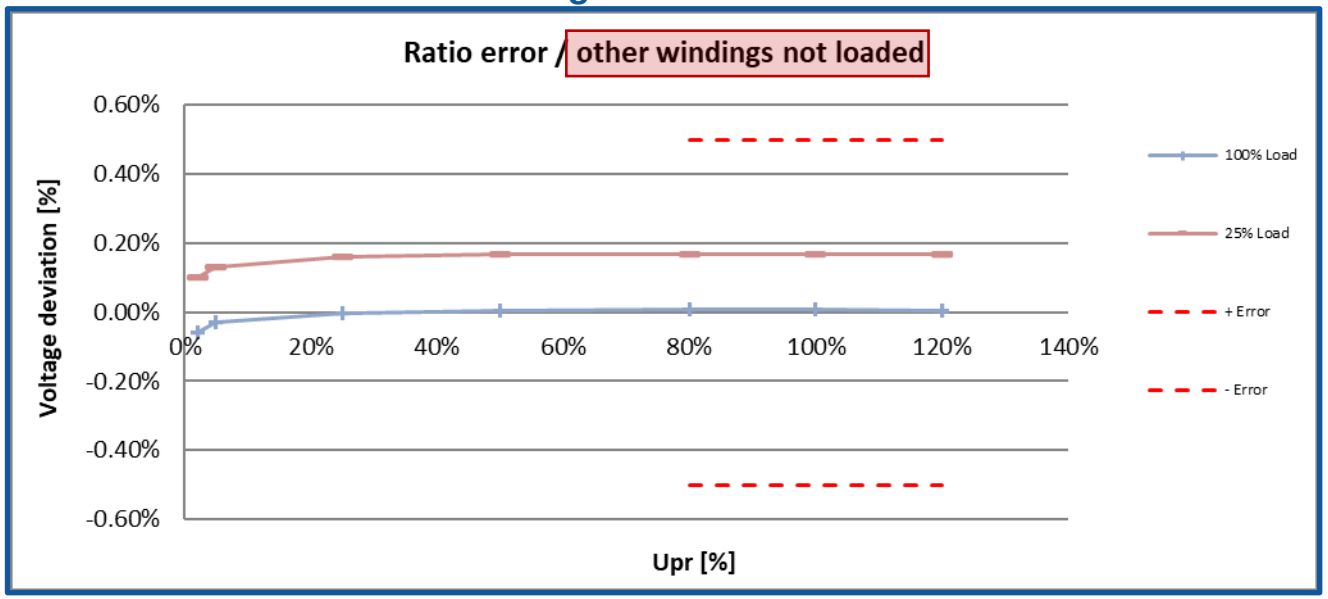
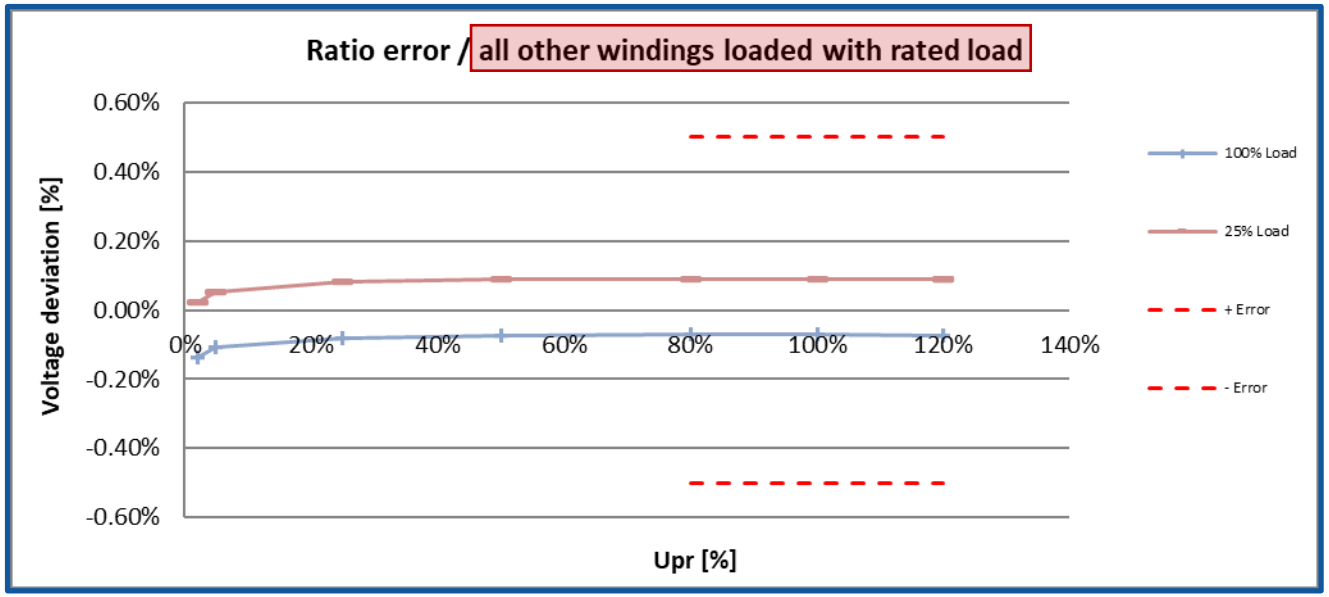
Case Study 4: Two Winding 33kV:110V, 30VA; Class 0.5 / 3P

Winding 1: Class 0.5





Case Study 5: Two Winding 66kV:110V, 100VA; Class 0.2 / 3P

VOTANO Advanced VT Test

Company	Test Utility
Company address	Test Workshop
Order number	

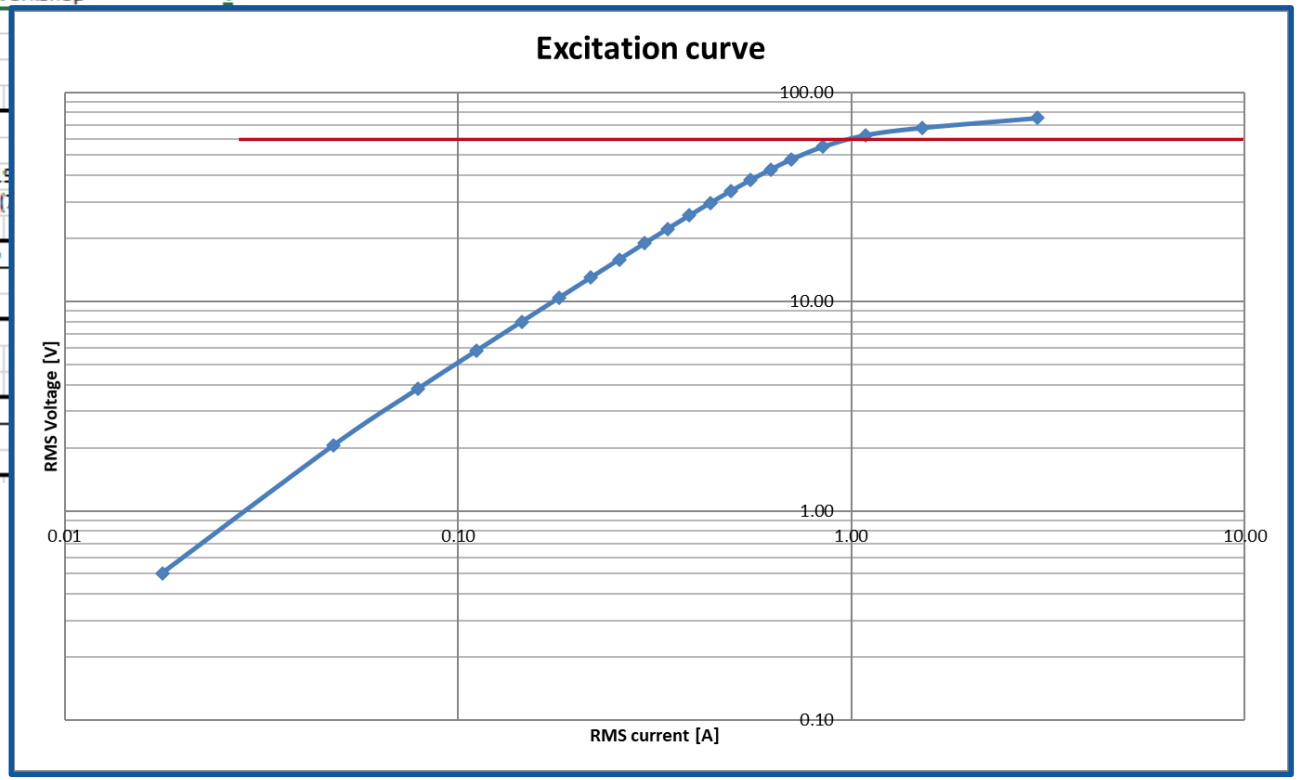
Object		Location	
Manufacturer	VT Manufacturer	Company	Test Utility
Type	JDCF-66W3	Country	Country
Serial number	14180256	Station	Workshop
Comment		Feeder	
VOTANO Demonstration		Phase	
		IEC-ID	

Model	VT	Type	
Rated primary voltage [V]	66000/√3	Serial number	
Applied standard	IEC 60044-2	Measurement saving time	201
Rated frequency [Hz]	50.00	Firmware version	2.10 (
Fv	1.2		

Winding	Rated sec. voltage [V]	Class	M-Class	Nom. Burden [VA]/cosφ
1a-1n	110/√3		0.2	100/0.8
2a-2n	110/√3	3P	n/a	100/0.8

Overall assessment	Failed

Winding	Winding Resistance [Ω]	Ratio
1a-1n	0.0278	66000/√3 : 110.0207/√3
2a-2n	0.0496	66000/√3 : 109.9348/√3



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Case Study 5: Two Winding 66kV:110V, 100VA; Class 0.2 / 3P

Overview of ratio errors and phase displacements

			Burden								
Winding	Upr [V]	Usr [V]	S1 [VA]	S2 [VA]	S3 [VA]	S4 [VA]	S5 [VA]	U [%]		Ratio error [%]	Phase error [min]
1a-1n	66/√3	110/√3	100/0.8					80%		0.0520	-6.15
								100%		0.0188	-6.09
								120%		-0.1629	-5.43
			25/0.8					80%		0.2027	-3.71
								100%		0.1690	-3.66
								120%		-0.0127	-3.00
			100/0.8	100/0.8				80%		-0.0850	-10.44
								100%		-0.1175	-10.39
								120%		-0.2994	-9.72
			25/0.8	100/0.8				80%		0.0654	-8.01
								100%		0.0324	-7.96
								120%		-0.1494	-7.29
2a-2n	66/√3	110/√3		100/0.8				2%		-0.1275	-6.88
								5%		-0.0840	-6.56
								100%		-0.0592	-6.45
								120%		-0.2426	-5.43
				25/0.8				2%		0.0774	-4.25
								5%		0.1210	-3.91
								100%		0.1453	-3.81
								120%		-0.0381	-2.80
			100/0.8	100/0.8				2%		-0.2692	-11.36
								5%		-0.2257	-11.03
								100%		-0.2002	-10.93
								120%		-0.3837	-9.90
			100/0.8	25/0.8				2%		-0.0645	-8.73
								5%		-0.0210	-8.40
								100%		0.0040	-8.30
								120%		-0.1796	-7.28

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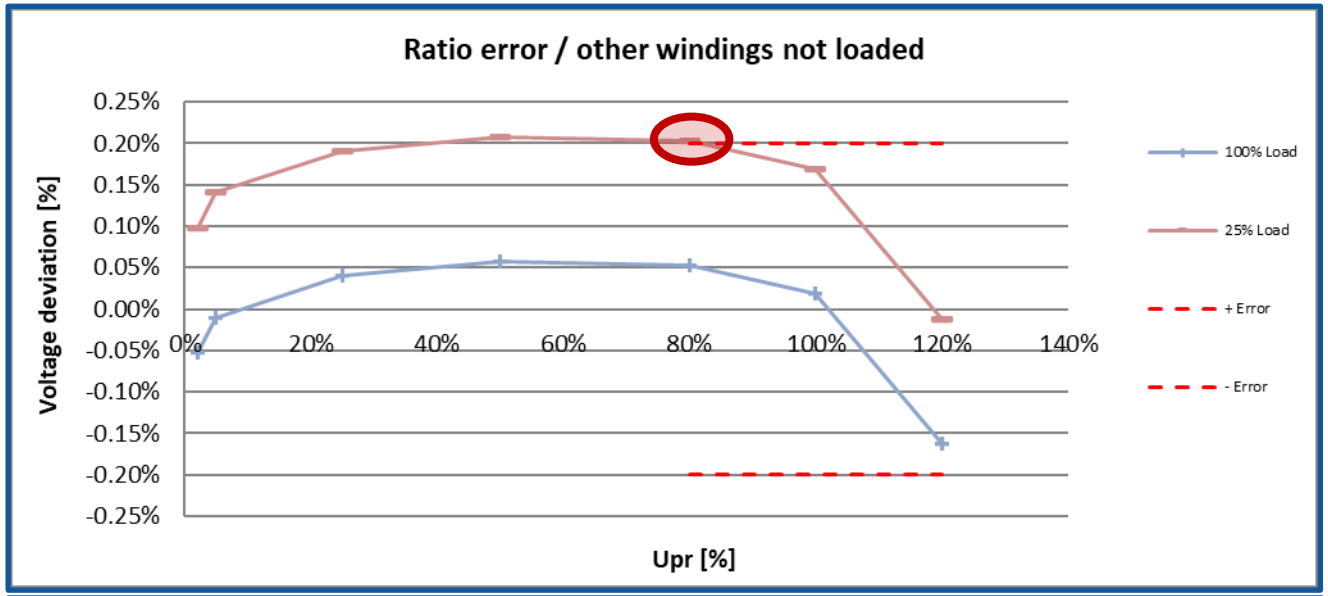
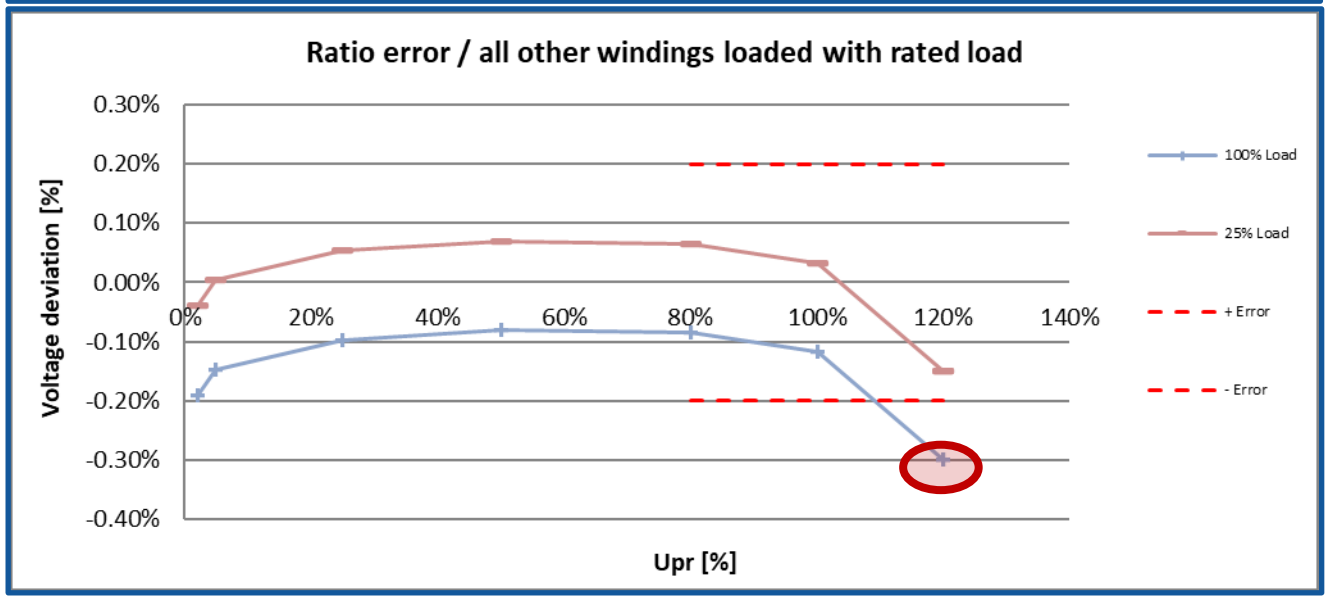
Case Study 5: Two Winding 66kV:110V, 100VA; Class 0.2 / 3P

Winding 1: Class 0.2





Certifications

Certified Accuracy of Calibration Equipment

Physikalisch-Technische Bundesanstalt

PTB

Seite 3 zum Kalibrierschein vom 2005-12-02, Kalibrierzeichen: 3403 PTB 05
Page 3 of calibration certificate of 2005-12-02, calibration mark: 3403 PTB 05

5. Messergebniss
Messurement results

In den folgenden Tabellen werden die Strommessabweichungen und Fehlwinkel bei Bemessungsübersetzungen in Abhängigkeit von der Bebürdung und dem Messpunkt angegeben. (ICE 60044-1).

Current errors and phase displacement indicated in the following tables are expressed as functions of the corresponding test point and rated ratio.(ICE 60044-1).

Sekundäre Bemessungsstromstärke (rated secondary current)			5A und 1A (and)	
Frequenz (frequency)			50 Hz und 60Hz (and)	
Primäre Bemessungsstromstärke (rated primary current) in A	Bürde (burden)	Prüfpunkt (test point)	ε_i	δ_i
5 A – 5000 A	0-10 VA	200 % - 1 %	0,02 %	1,0 min.

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Seite 4 zum Kalibrierschein vom 2016-04-11, Kalibrierzeichen: 21106 PTB 16 / 21107 PTB 16
Page 4 of the Calibration Certificate dated 2016-04-11, calibration mark: 21106 PTB 16 / 21107 PTB 16

Tabelle 2
table 2

Spannungswandler, Klasse 0,1, Betriebsbürde 50 VA *Voltage transformer, class 0,1, rated burden 50 VA*								
110 kV/√3 / 100 V/√3								
Bürde *Burden*	Messpunkt *Test point*	Referenz *Reference*		Ablesung *Displayed value*		Differenz *Difference*	
	in %	ε_u in %	δ_u in '	ε_u in %	δ_u in '	ε_u in %	δ_u in '
Leerlauf *No burden*	120	0,042	-0,6	0,060	-1,1	0,018	-0,5
	100	0,049	-0,8	0,065	-1,3	0,016	-0,5
	80	0,048	-0,9	0,062	-1,3	0,015	-0,5
	60	0,040	-0,9	0,054	-1,3	0,014	-0,4
	40	0,022	-0,7	0,030	-1,1	0,008	-0,4
	20	-0,021	-0,1	-0,024	-0,4	-0,004	-0,4
	10	-0,070	0,8	-0,086	0,5	-0,016	-0,3
	5	-0,126	1,6	-0,117	0,9	0,009	-0,7

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Summary

- Regular and accurate verification of instrument transformers, as required by the Code of Electricity Metering, can conveniently be conducted in the field by utilizing a modelling verification, instead of following a conventional primary injection calibration.
- The modelling approach consists of accurately characterizing the electrical model of a CT (or VT), then calculating the amplitude and phase angle accuracy of the device under test for the required burden 'connected' to the CT (or VT) and 'injecting' the required primary current (or primary voltage).

- Calibration of inductive CTs - IEC 60044-1 / IEC 61869-2:
  Accuracy verification at 5%, 20%, 100% and 120% I_{nom} for 25% and 100% rated burden.
- Calibration of inductive VTs - IEC 60044-2 / IEC 61869-3:
  Accuracy verification at 80%, 100% and 120% V_{nom} for 25% and 100% rated burden for all other windings unloaded AND fully loaded.
- Case studies for various metering and protection CTs (and VTs) – with both passed and failed results - have been presented and results discussed.

- The PTB (and other certification institutes) have certified the accuracy of the modelling verification approach of instrument transformers.

Thank You for Your Attention!