Shaft Current Protection

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Introduction

- Shaft overcurrent protection is an important generator protection issue
- Currents flowing in the shaft damage bearings
- Results in reduced operating time and financial losses

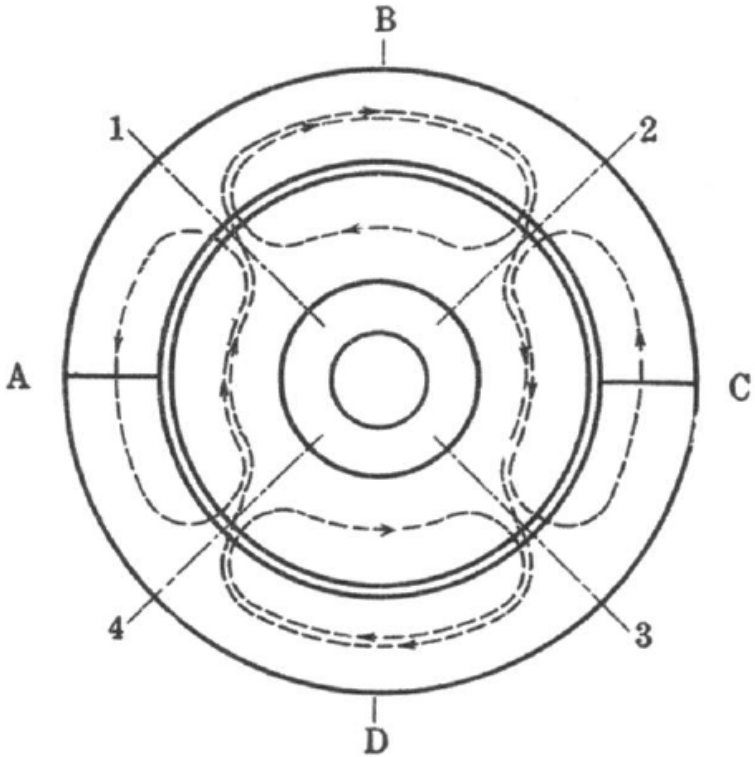
Shaft Voltage

"... in a perfectly constructed alternator both practice and theory tell us that no such vagabond current exists so that the cause must be looked for in constructive inequalities."

Buchannan, 1915

- Main cause of shaft currents are magnetic asymmetries in the stator core
- Magnetic asymmetry arises due to normal manufacturing processes

Shaft Voltage



Ratio is reduced to lowest terms:

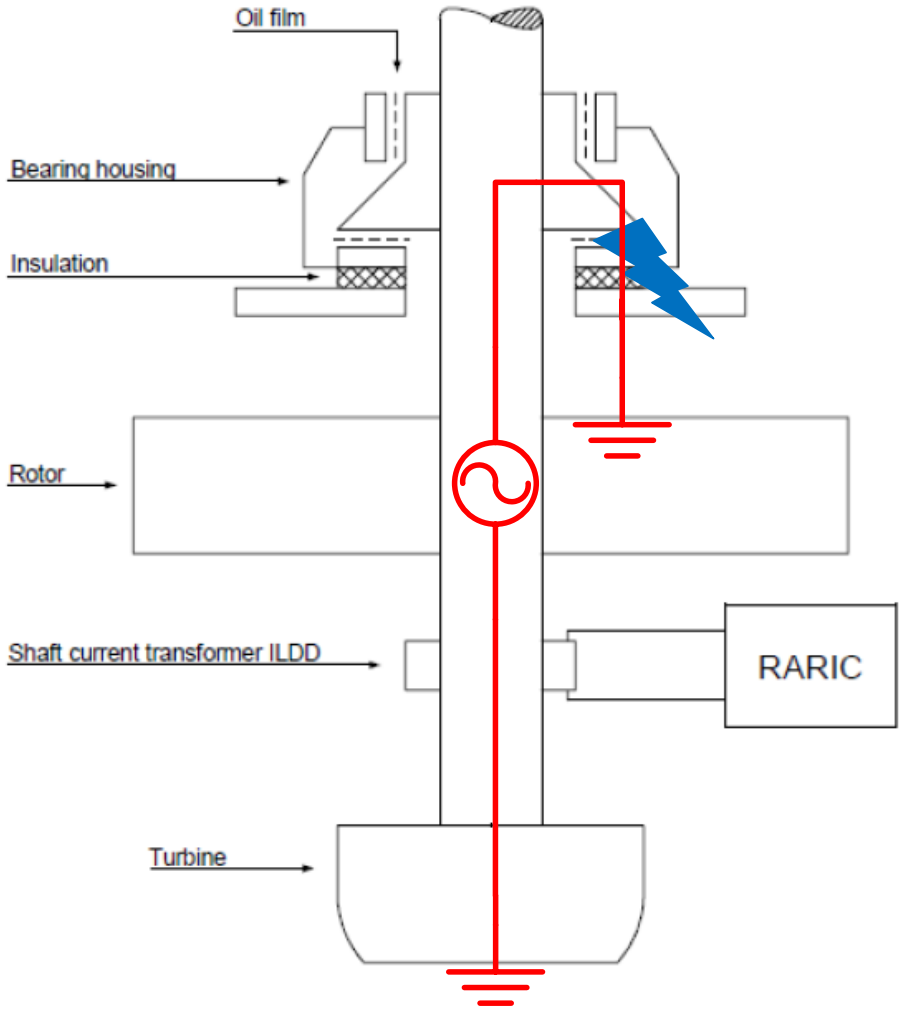
$$\frac{A}{B} = \frac{4 \times S}{P} \tag{1}$$

If A is odd number:

$$f_{shaft} = A \times f_{line} \tag{2}$$

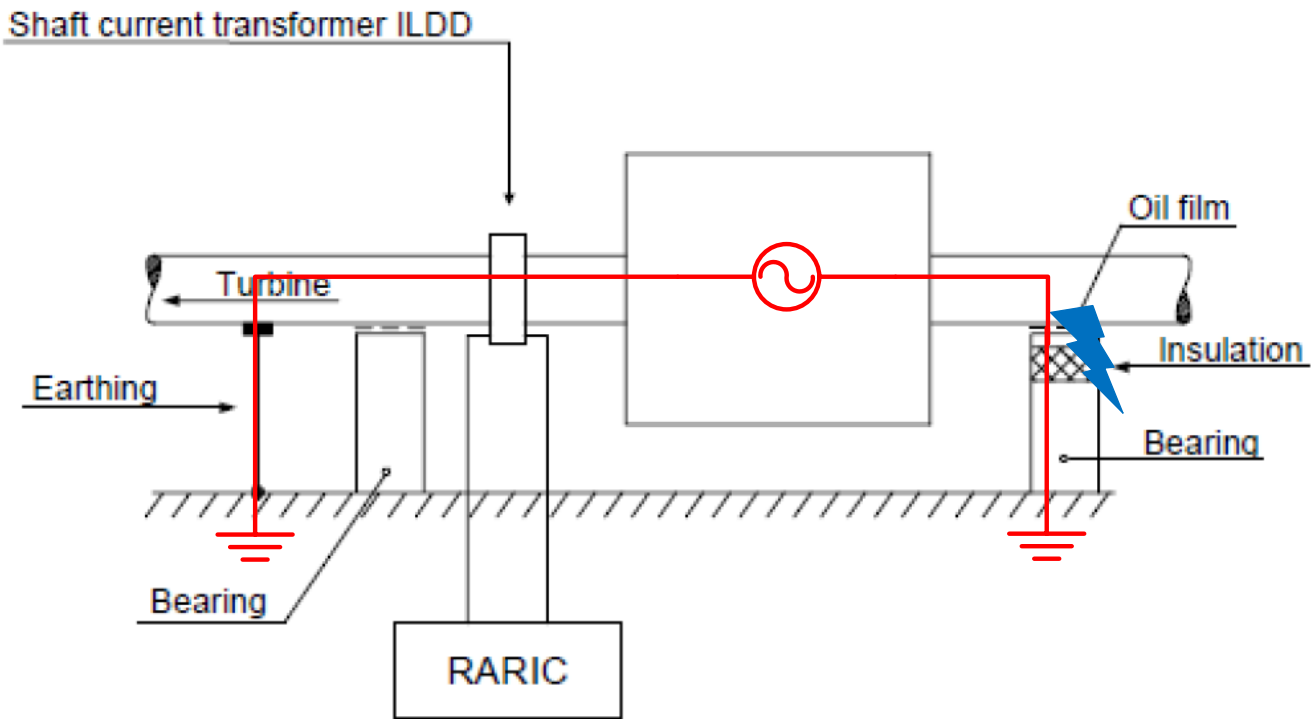
If A is even number, no shaft current exists.

Hydro generators



Problem and Literature Review

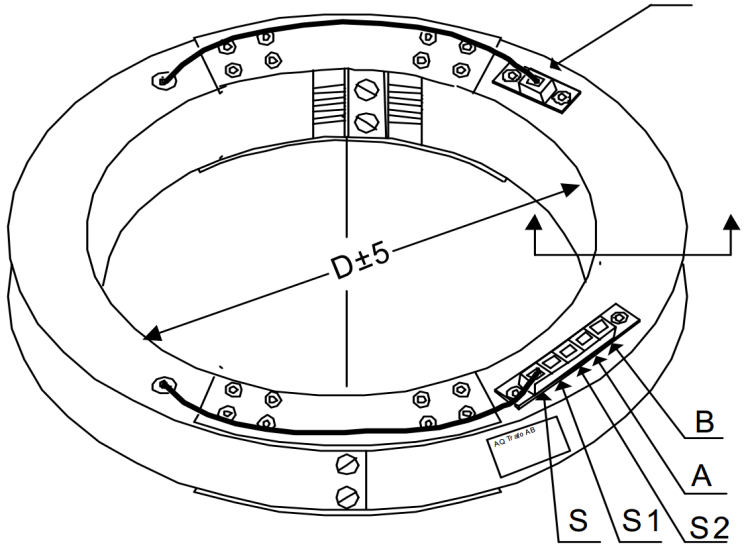
Turbo generators



Introduction

- Suitable sensor had to be used which satisfies mechanical and electrical requirements
  - Possible influence of stray flux from the generator
  - Installation requirements - space constraints
  - Low currents flowing in a large conductor (shaft)
- Numerical relay had to be used (REG670 Version 2.0)
  - Low output from measurement device had to be adapted

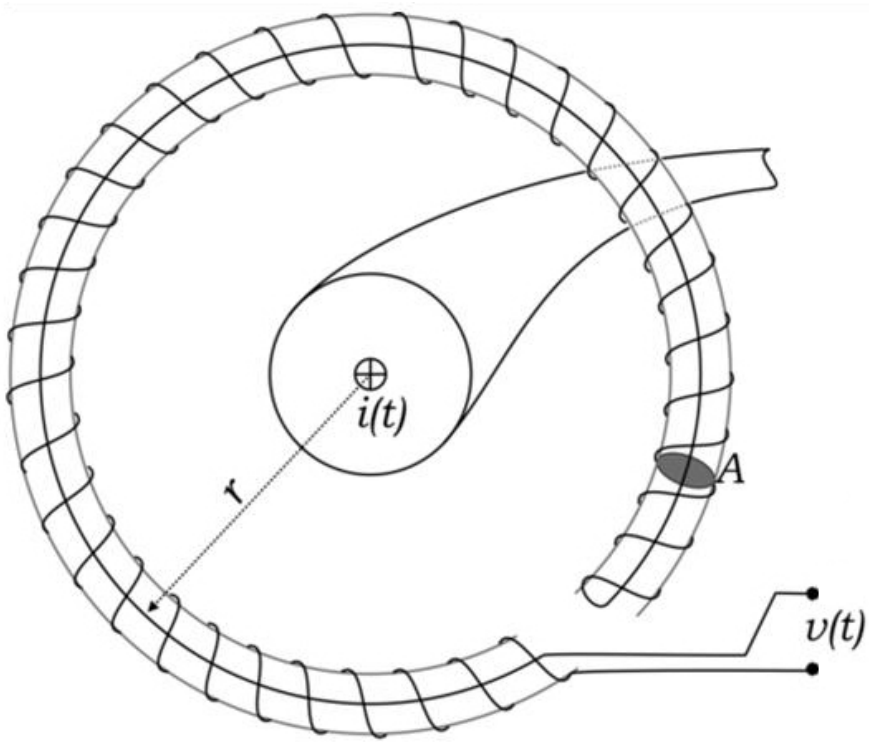
Current Transformer



- Made out of 2 or 4 parts depending on the size of the shaft
- Shaft is single primary winding
- Many secondary turns
- Low secondary voltage and current

Introduction

Rogowski coil



- Ampere's law

$$i(t) = \frac{1}{\mu_0} \oint \overrightarrow{B(t)} \cdot \vec{ds} \quad (3)$$

- Induced voltage

$$u(t) = N\frac{d\Phi}{dt} \quad (4)$$

- Current and voltage relation

$$u(t) = N\frac{A}{s} \cdot \mu_0 \cdot \vec{i(t)} \quad (5)$$

Rogowski coil

Advantages	Drawbacks
No iron core - linear, no saturation and magnetizing current	Necessity of integration circuit
Low production cost	Low voltage output
Mechanical fexibility, small size and weight	Low frequency noise from integrator circuit
Electrically safe when open	Sensitivity to conductor position
Wide bandwidth	Limited rejection of external fields
Non-disturbing for primary circuit	Inability to measure DC currents
Can endure large overload without damage	

Measurement Devices

- Three measurement devices
  - Rogowski coil
  - CT - ILDD 096
  - CT - Zelisko GWR3
- Focus is put on Rogowski coil
- ILDD 096 is used to demonstrate reduced magnetic performance
- Zelisko GWR3 is considered as a part of retrofit installation

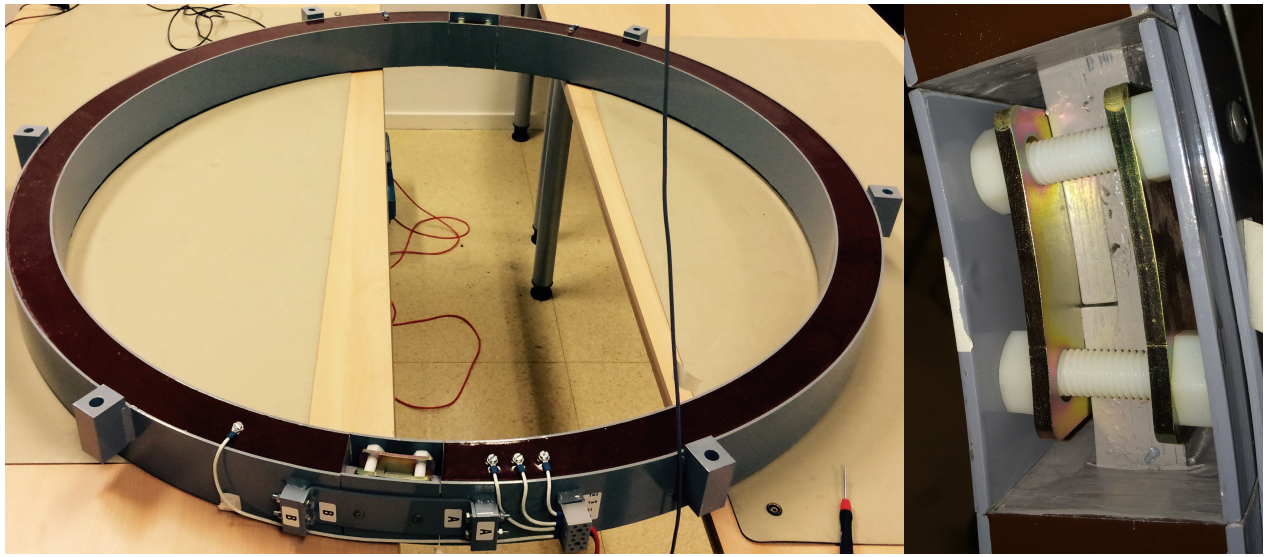
Measurement Devices

Rogowski coil

Sensitivity	200 mV/A	**Accuracy**	±0.3 %
Bandwidth	4 Hz to 40 kHz	**Linearity**	±0.05 %

Measurement Devices

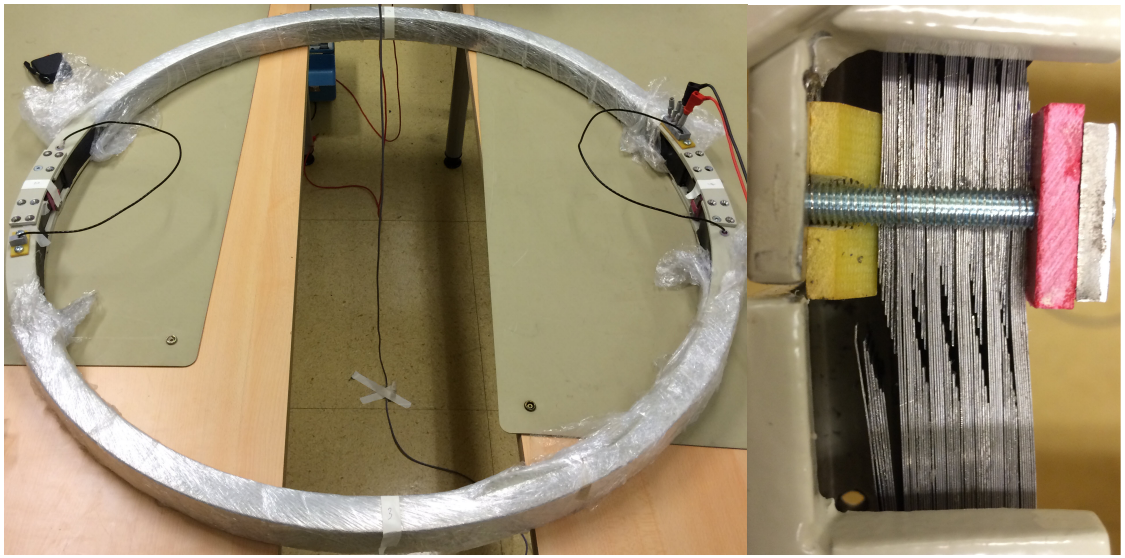
Zelisko GWR3



Name	Zelisko GWR3	**Primary Winding**	1 turn
Inner Diameter	DI = 990 mm	**Secondary Winding**	600 turns
Outer Diameter	DO = 1100 mm	**Test Winding**	2 turns

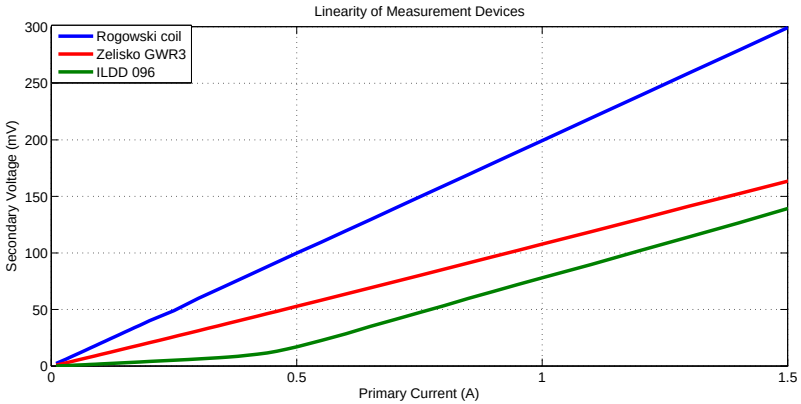
Measurement Devices

ILDD 096

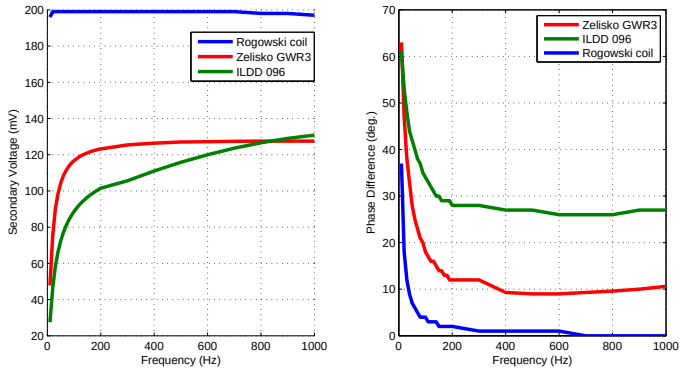


Name	ILDD 096	**Primary winding**	1 turn
Inner Diameter	990 mm	**Secondary winding**	500 turns
Outer Diameter	1030 mm	**Test winding**	4 turns

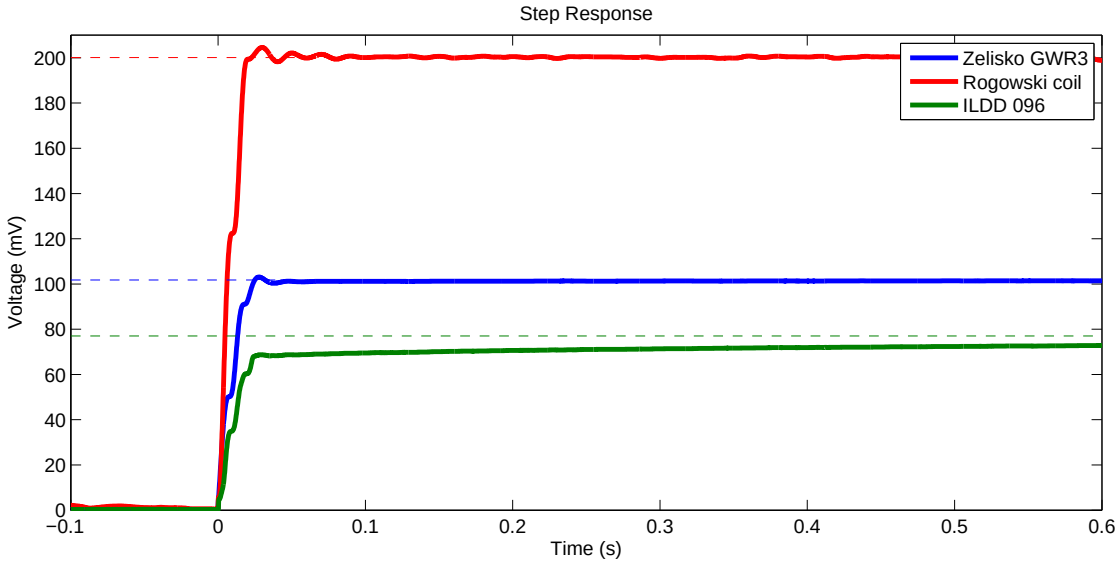
Test Measurements



(a) Linearity

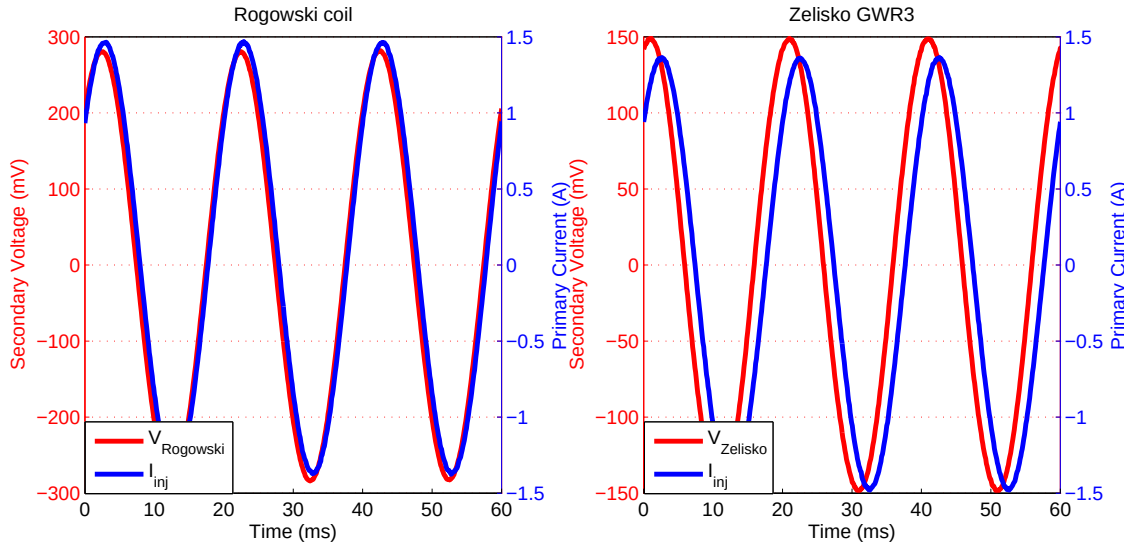


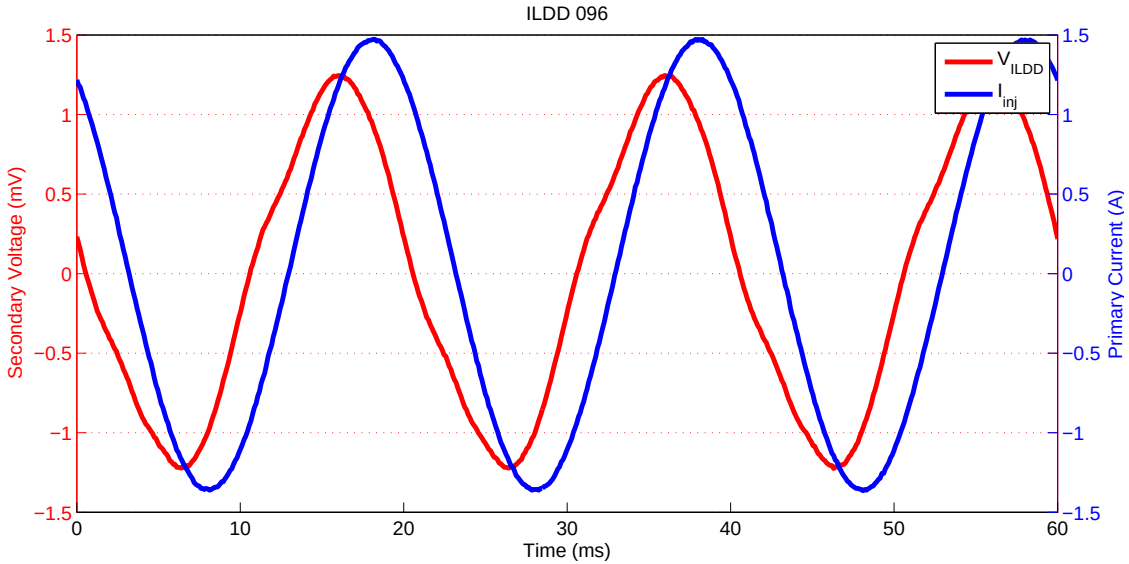
(b) Frequency Response



(c) Step Response

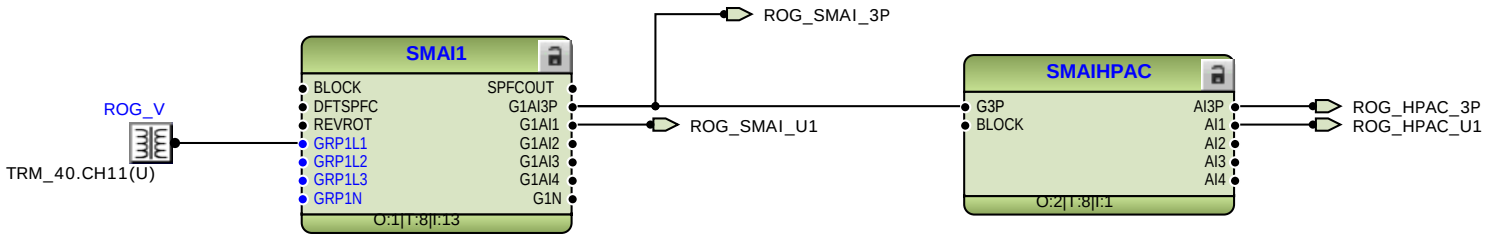
Waveform Recordings





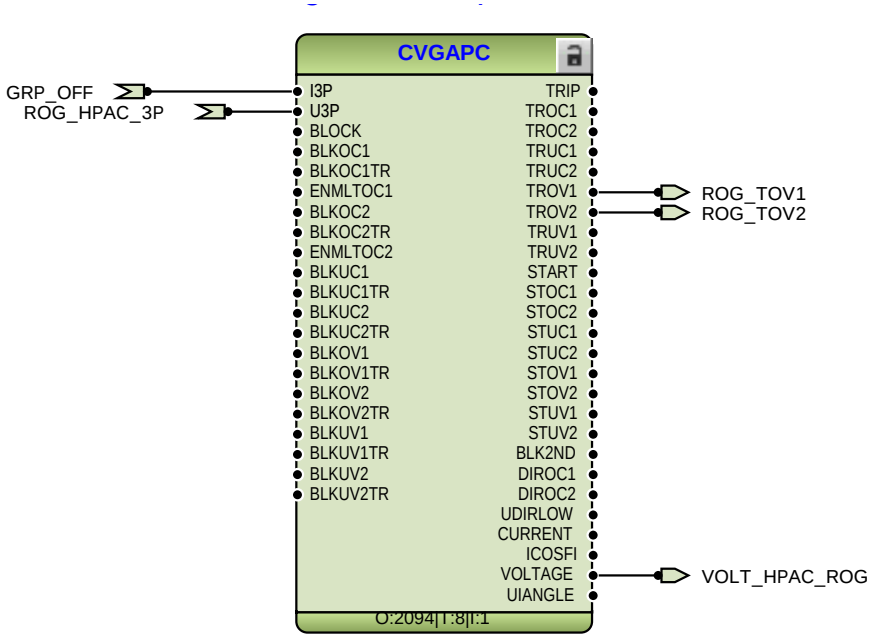
Protection Relay - REG670 2.0

Application Configuration - Analogue Inputs



Connection type	Ph-N
SetFrequency	50/150 Hz
FreqBandWidth	0.0 Hz
FilterLength	1.0 s
OverLap	20 %

Application Configuration - Protection Function



Protection Relay - REG670 2.0

Linearity and Accuracy of the relay

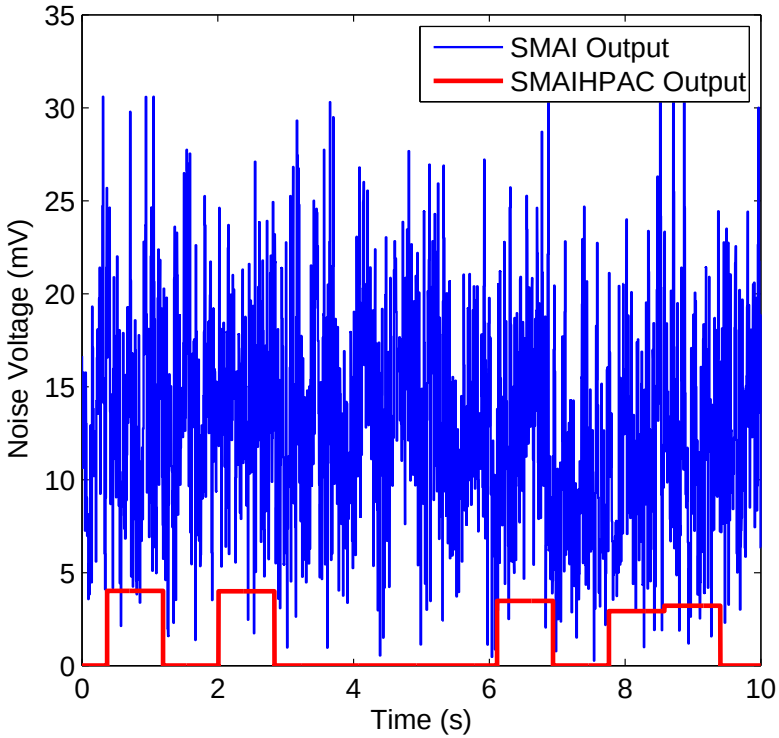
Quantity	**Rated Value**	**Nominal Range**
Current	$I_r = 1$ or $5A$	$(0.2 - 40) \times I_r$
Operative Range	$(0 - 100) \times I_r$	
AC Voltage	$U_r = 110$ V	$(0.5 - 288)$ V
Operative Range	$(0 - 340)$ V	

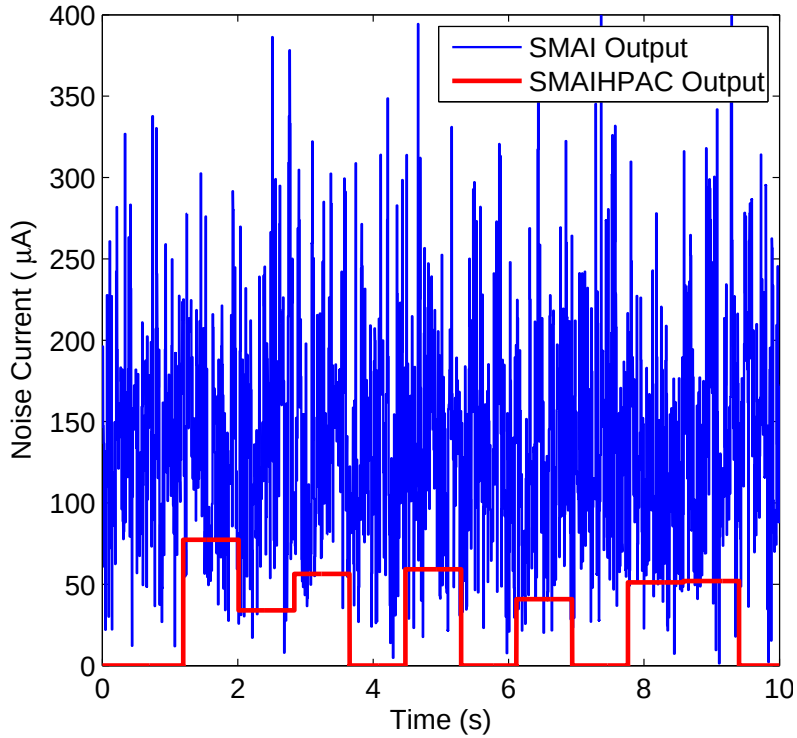
- Voltage and current outputs of measurement devices are below nominal range of the relay

Device	**Voltage at $I_{prim} = 1A$**	**Current at $I_{prim} = 1A$**
Rogowski coil	200 mV	X
Zelisko GWR3	104 mV	$\approx$ 1.5 mA
ILDD 096	90 mV	$\approx$ 1 mA

Protection Relay - REG670 2.0

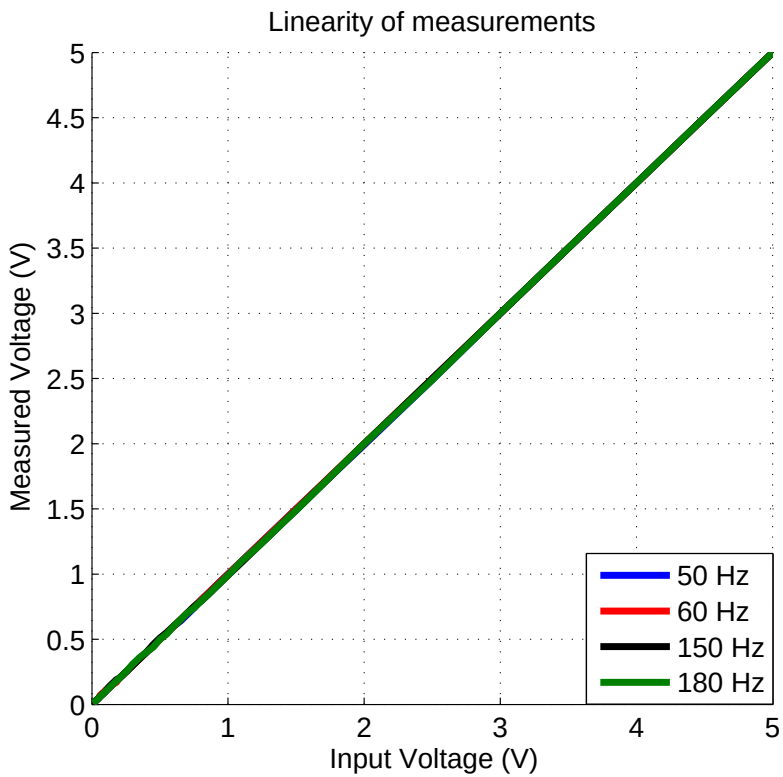
Linearity and Accuracy of the relay

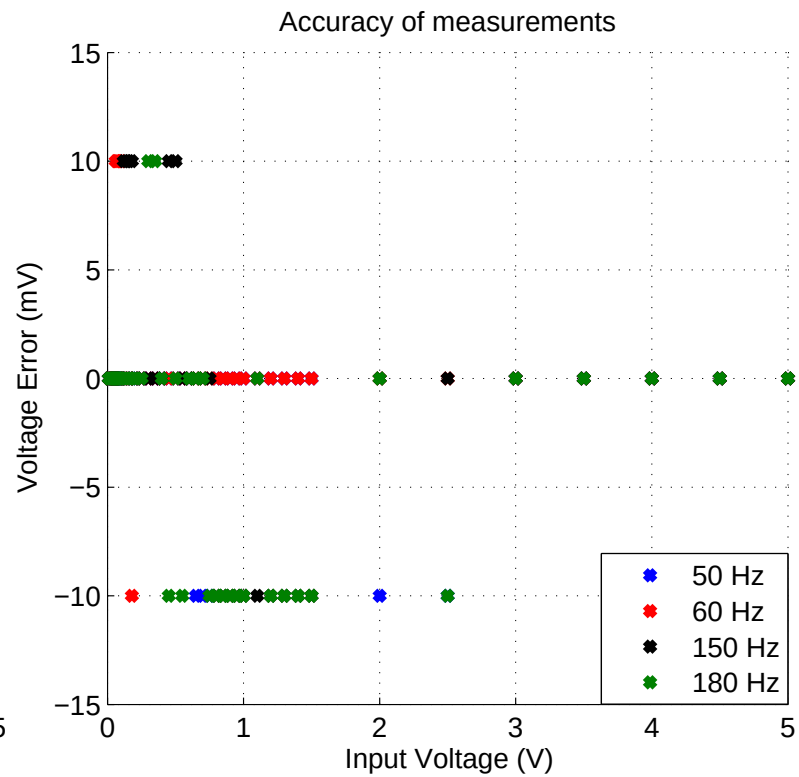




Protection Relay - REG670 2.0

Linearity and Accuracy of the relay



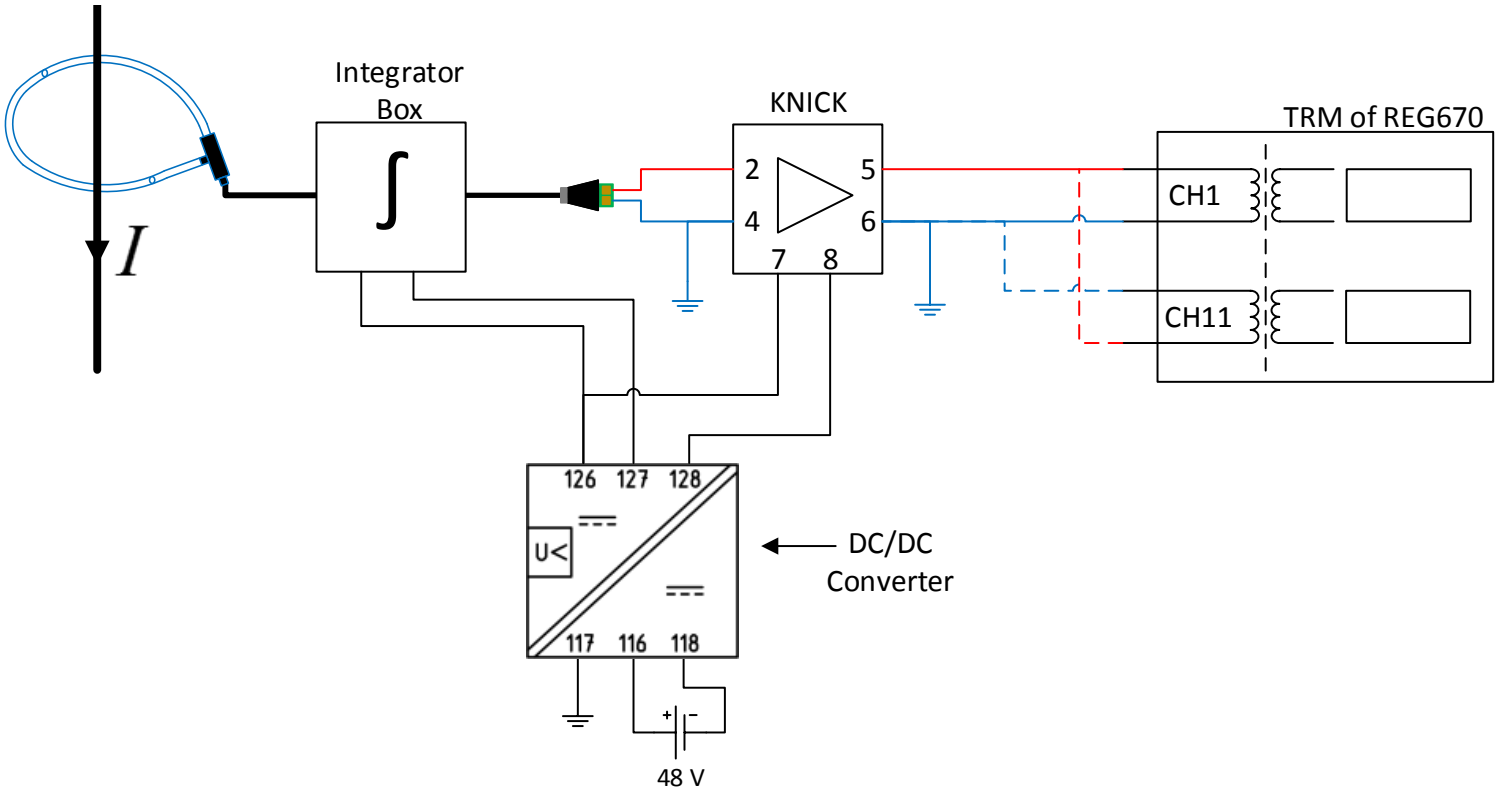


Amplifier Settings

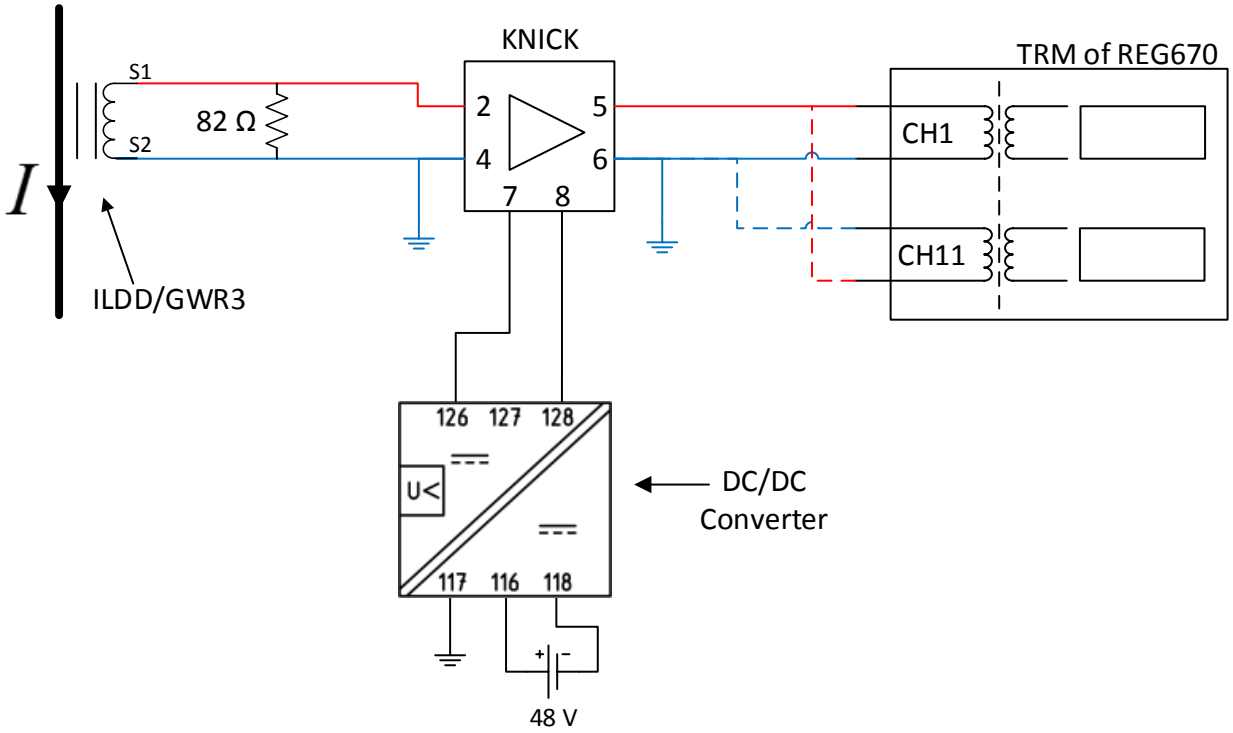
- Possibility of voltage or current input/output
- Every combination was chosen
- 2 voltage/voltage gains due to setting procedure
- Systems were also tested without an amplifier

	Setting 1	**Setting 2**	**Setting 3**	**Setting 4**
Input Range	0...250 mV	0...1 V	0...5 mA	0...5 mA
Output Range	0...10V	0...10 V	0...10 V	0...20 mA
Gain	40	10	2 V/mA	4

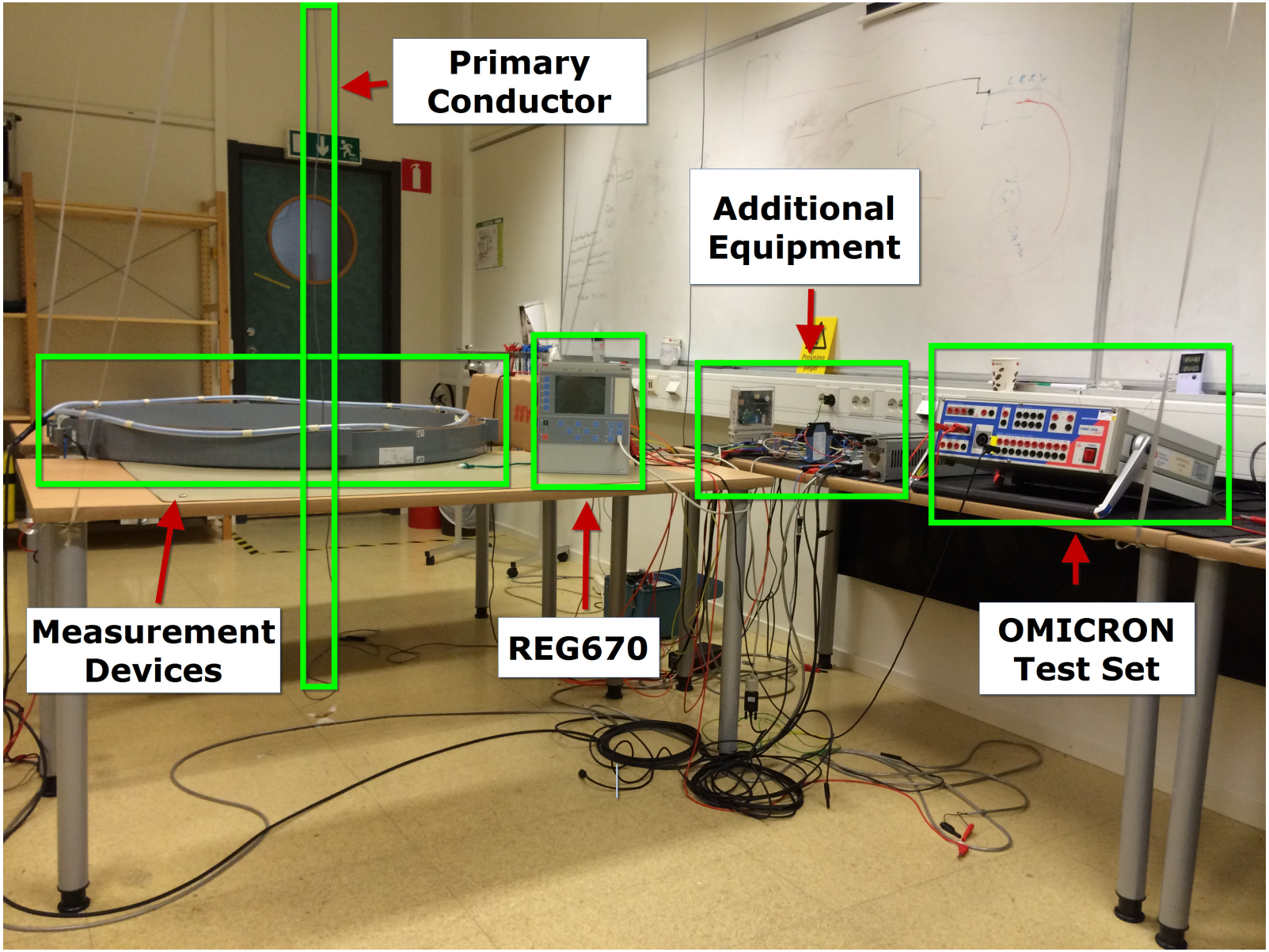
Protection System A



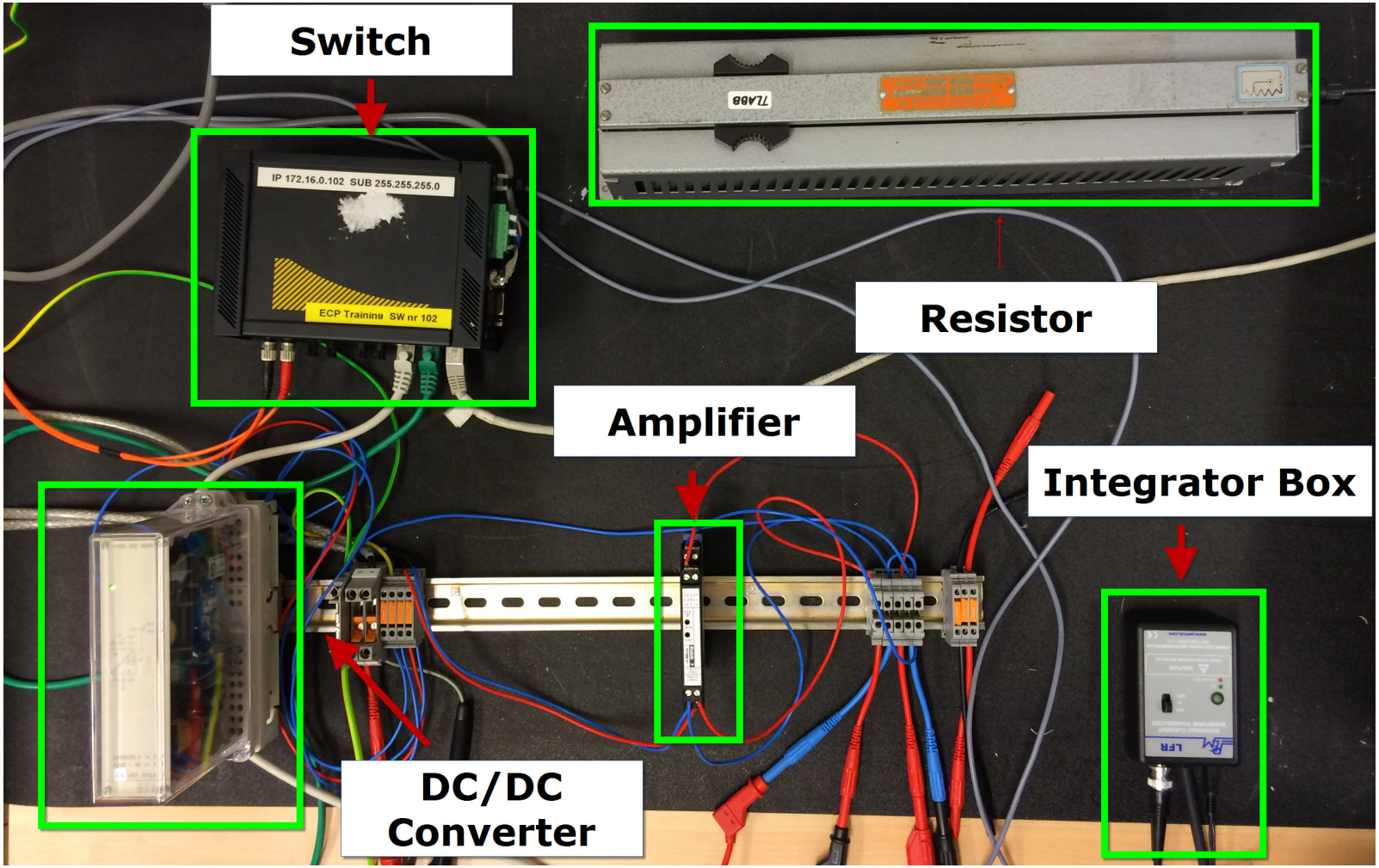
Protection System B



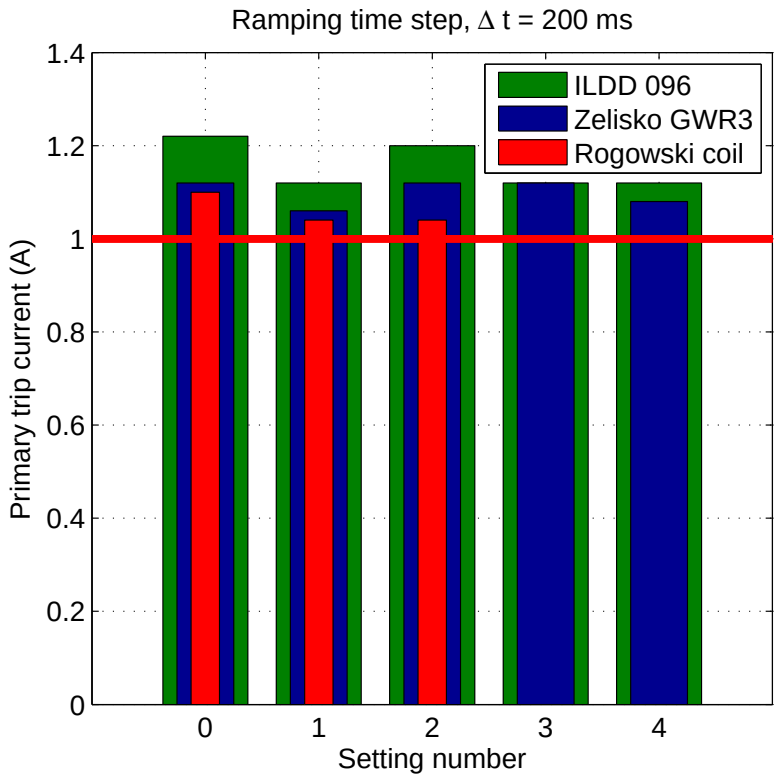
Protection Systems

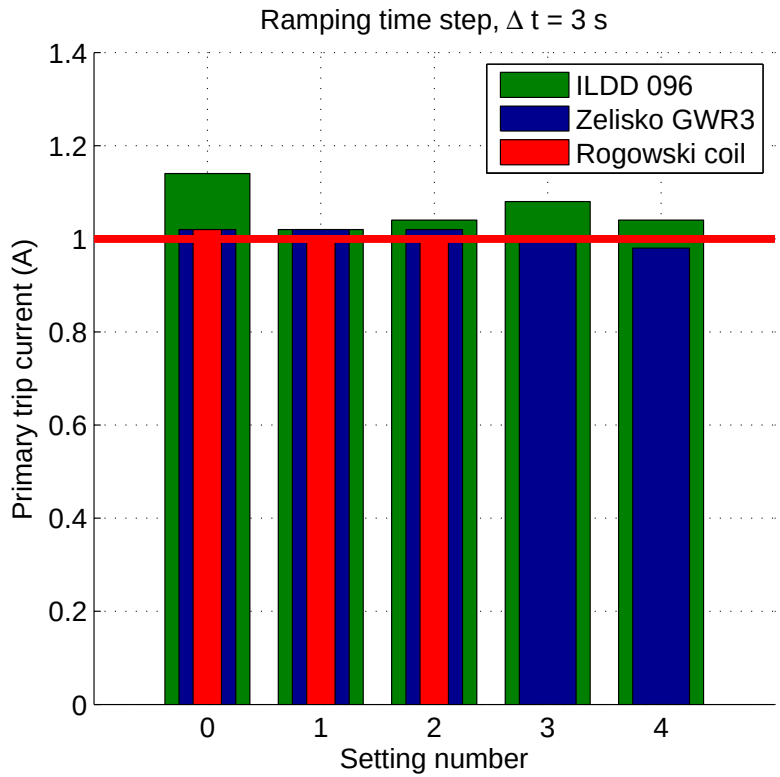


Protection Systems



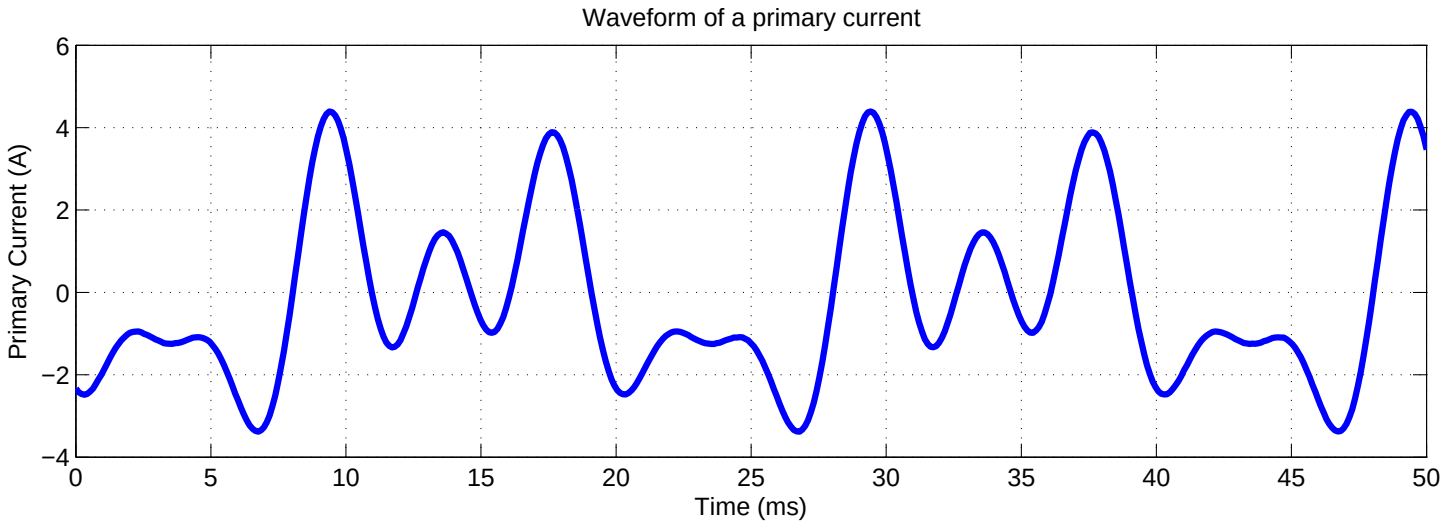
Ramping Tests





Protection Systems

Filtering Tests



Device	Set 0	Set 1	Set 2	Set 3	Set 4	I_{prim}
Rogowski coil	965 mA	1000 mA	970 mA	X	X	1 A
Zelisko GWR3	960 mA	914 mA	959 mA	980 mA	960 mA	
ILDD 096	925 mA	972 mA	950 mA	1081 mA	1100 mA	
Rogowski coil	500 mA	500 mA	500 mA	X	X	0.5 A
Zelisko GWR3	490 mA	458 mA	502 mA	505 mA	533 mA	
ILDD 096	620 mA	606 mA	563 mA	684 mA	725 mA	

Protection Systems

Summary

- More stable and accurate measurements with voltage than current signals
- Higher voltage results in more accurate measurements
- No amplifier is needed at currently set alarm and trip values
- Zelisko GWR3 and Rogowski coil can be used with REG670 2.0

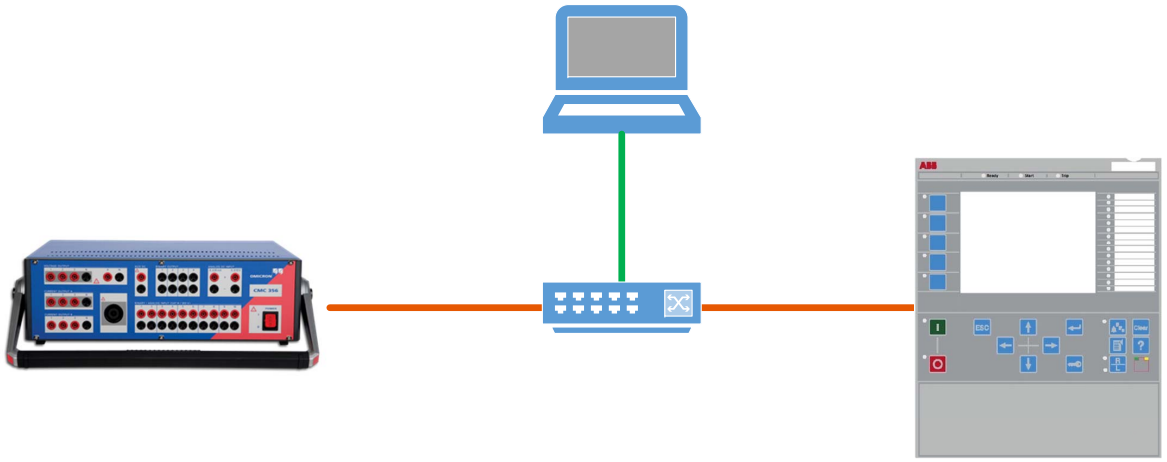
IEC61850-9-2 and MU

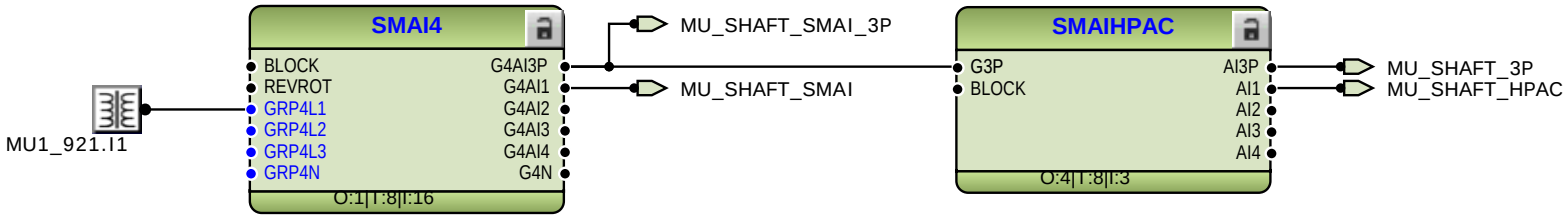
Advantages

- No input transformers on the SAM600 results in higher accuracy at low voltage levels
- Reduced wiring and EMI on the low level signal
- No need for dedicated voltage input channel on the TRM

IEC61850-9-2 and MU

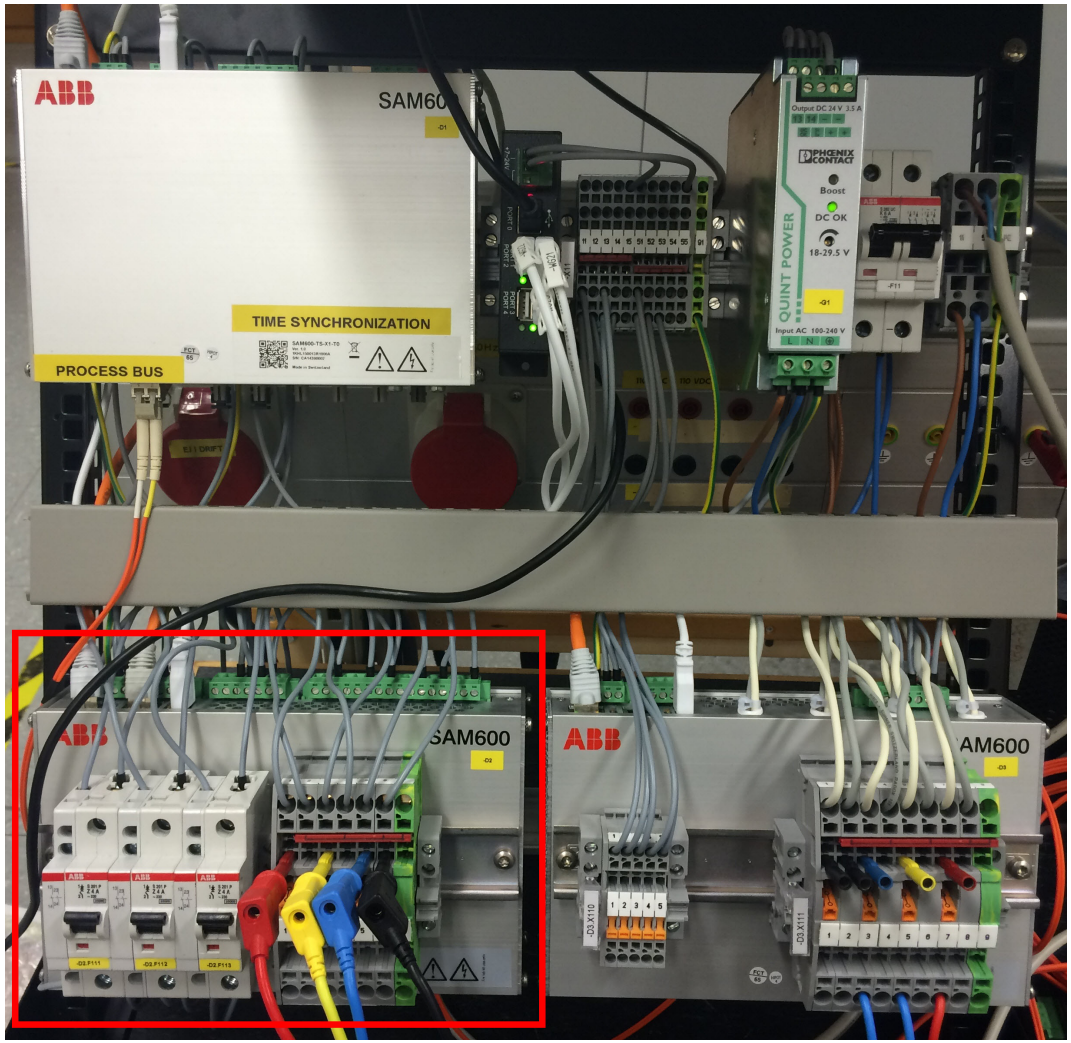
OMICRON set-up for IEC61850-9-2 test



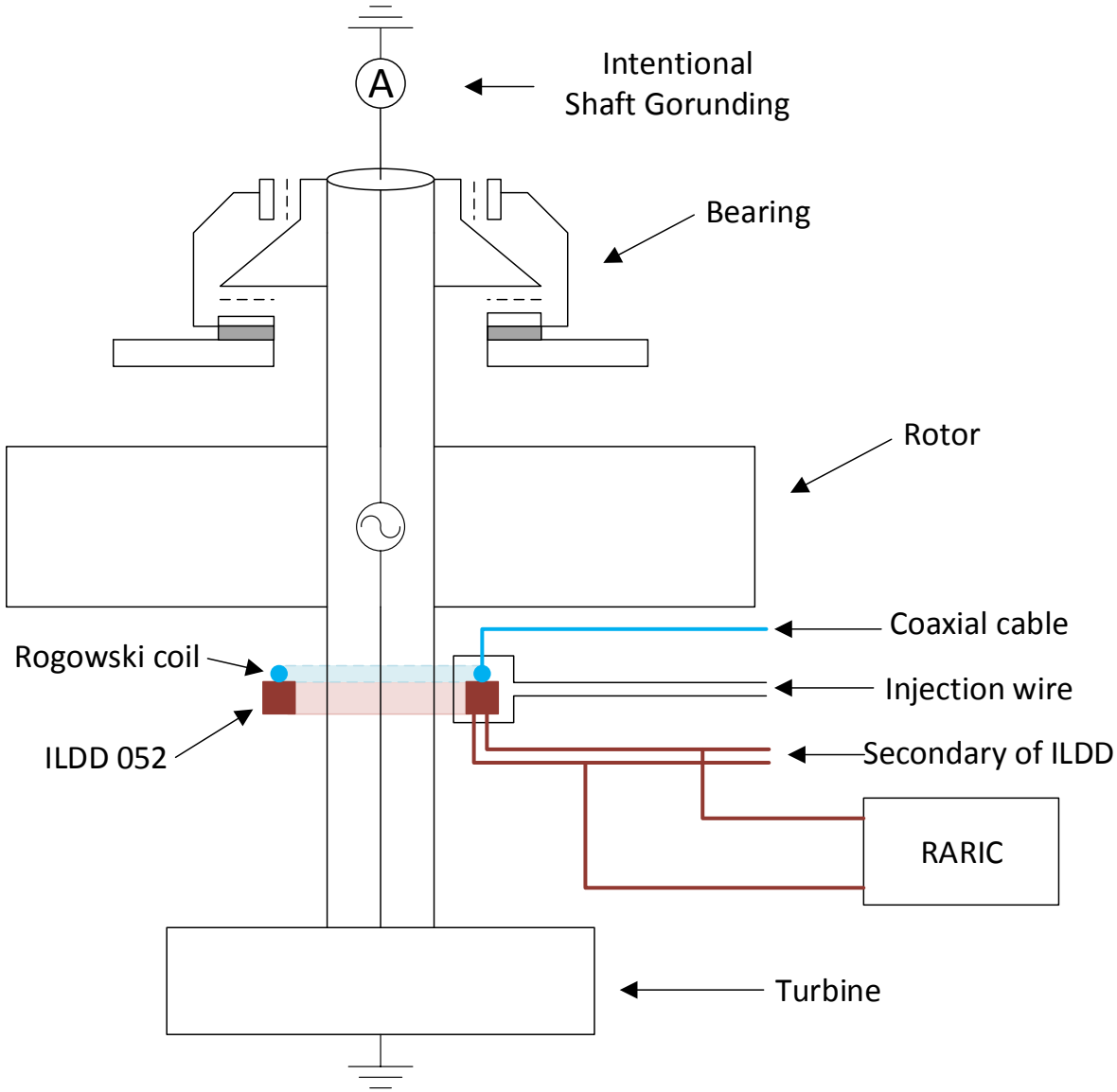


IEC61850-9-2 and MU

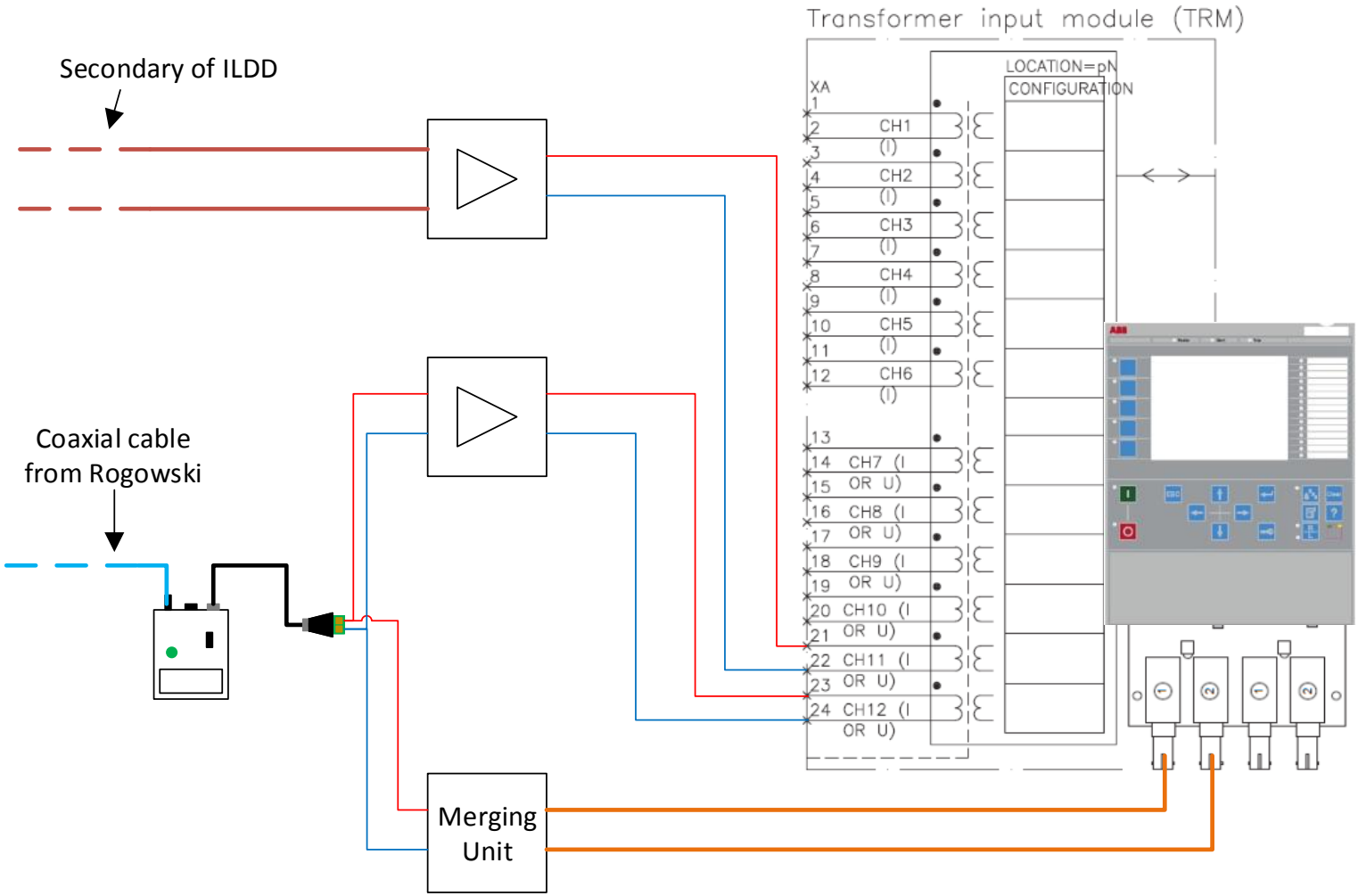
SAM600



Hallstahammar Installation



Hallstahammar Installation



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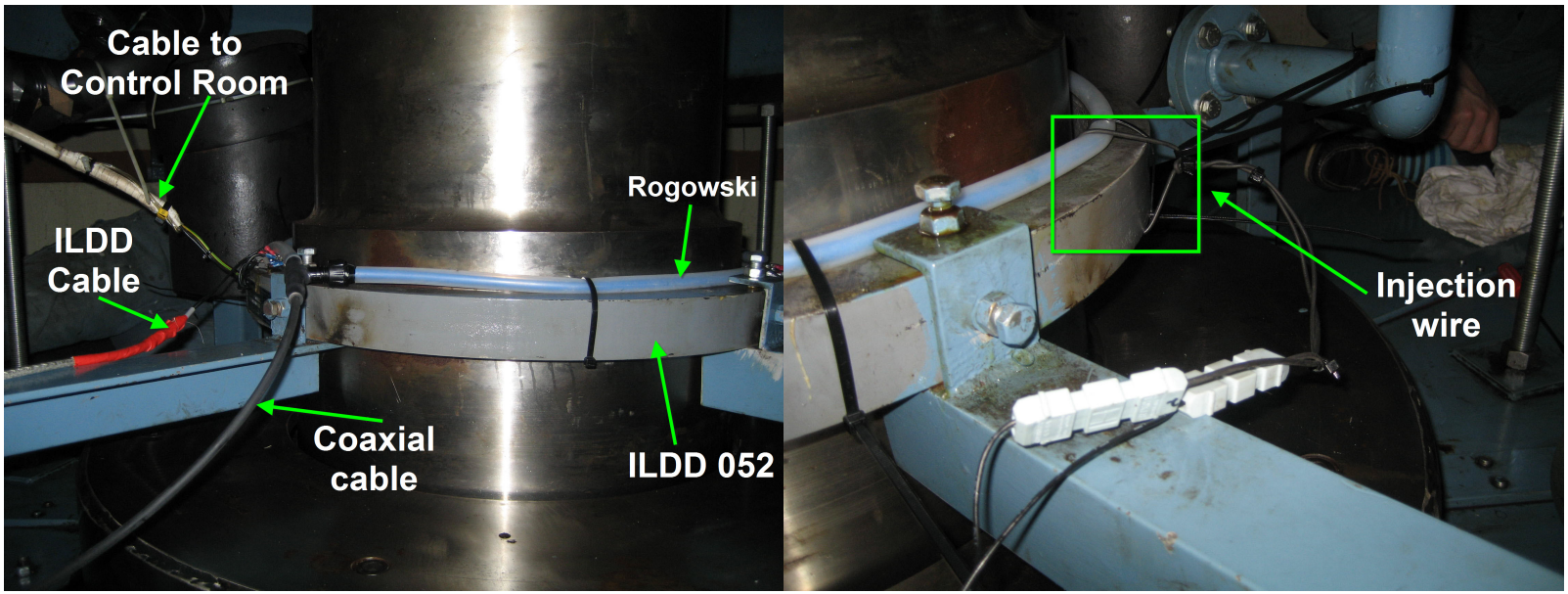
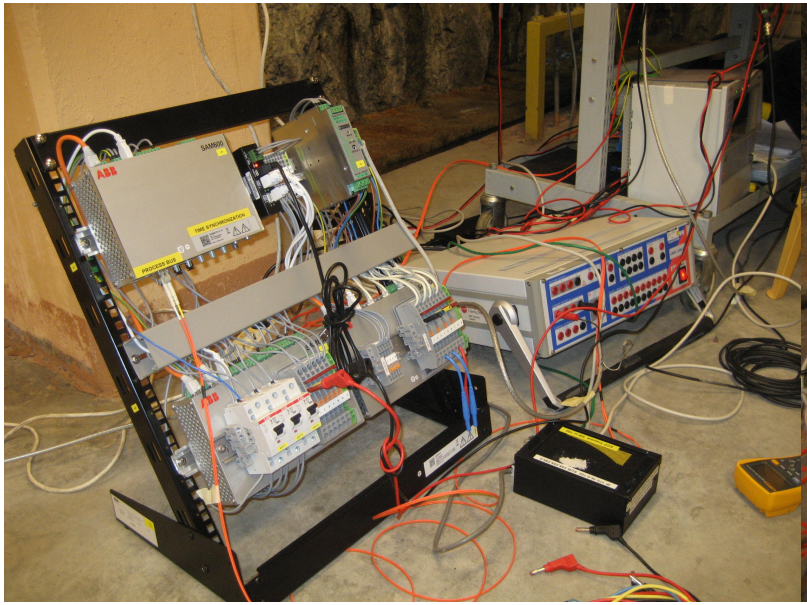
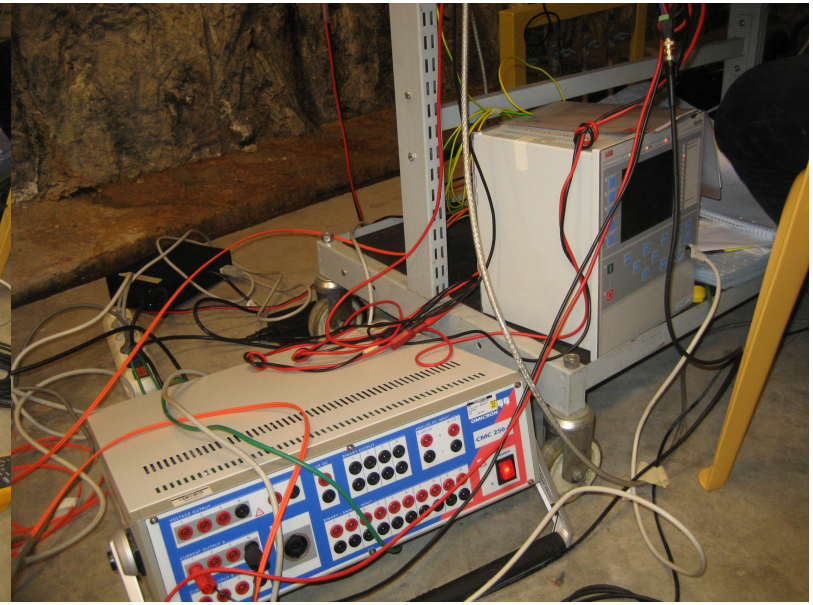
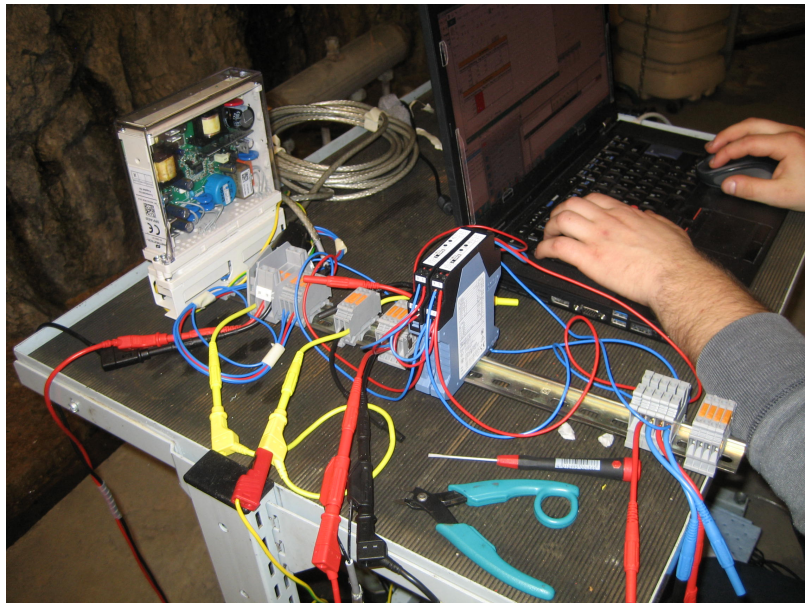


Hallstahammar Installation

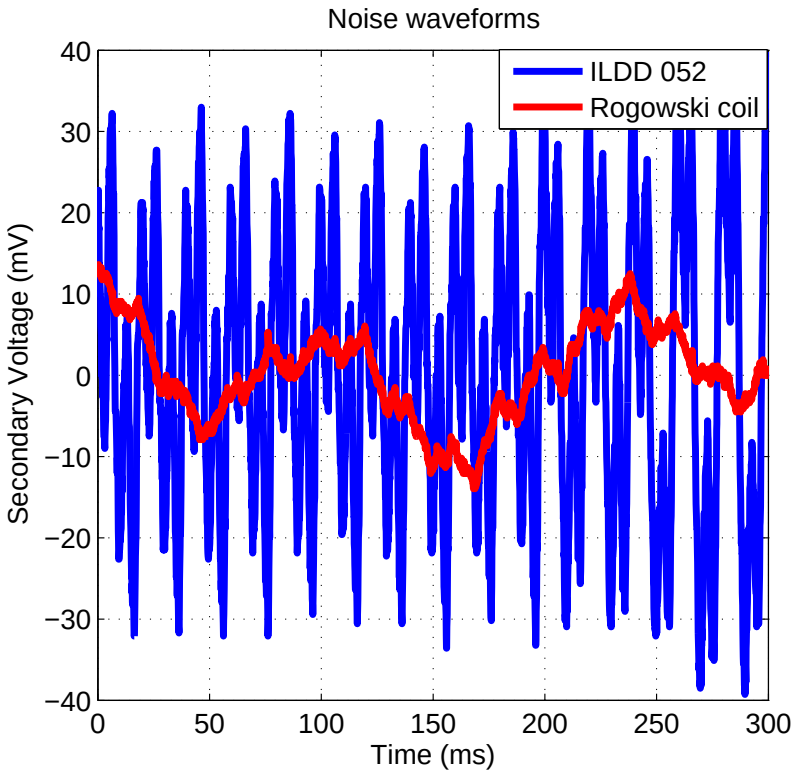


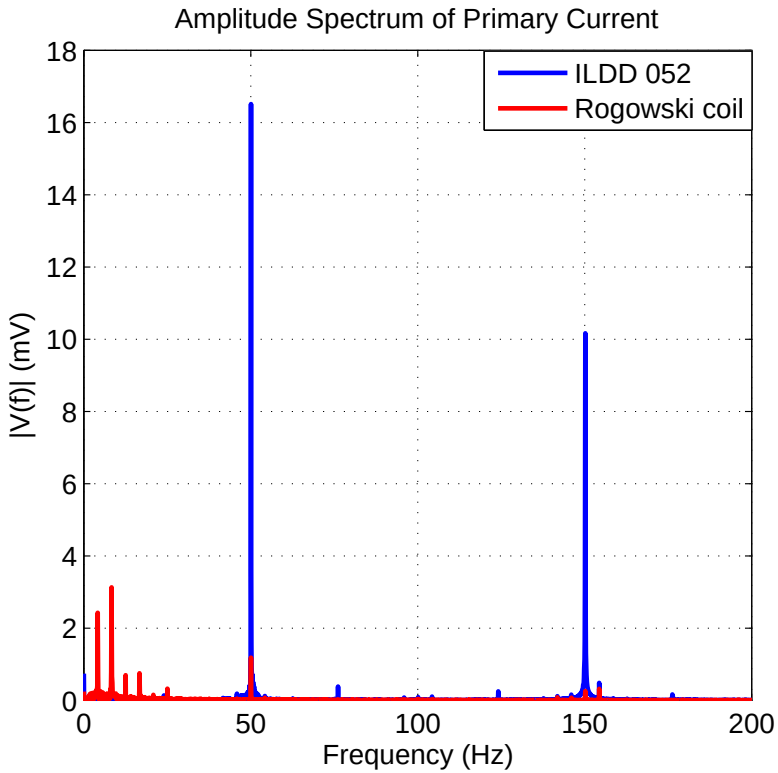




Hallstahammar Installation

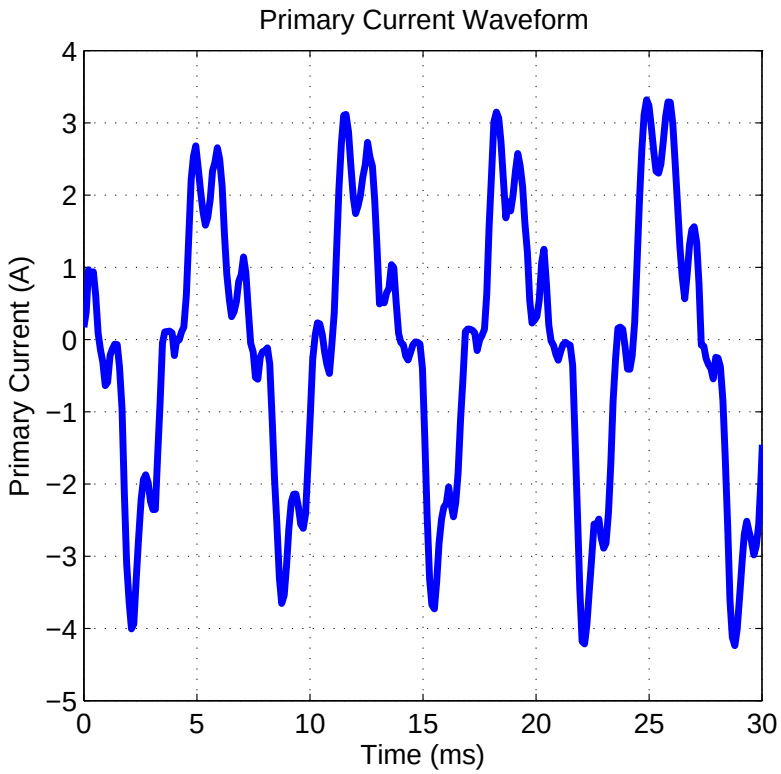
Stray flux

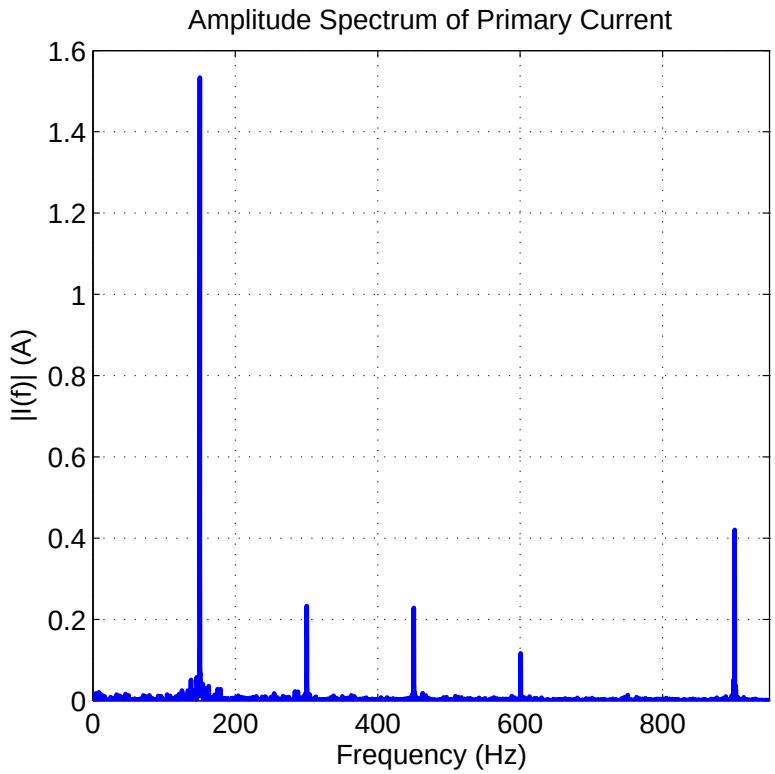




Hallstahammar Installation

Shaft Current





Hallstahammar Installation

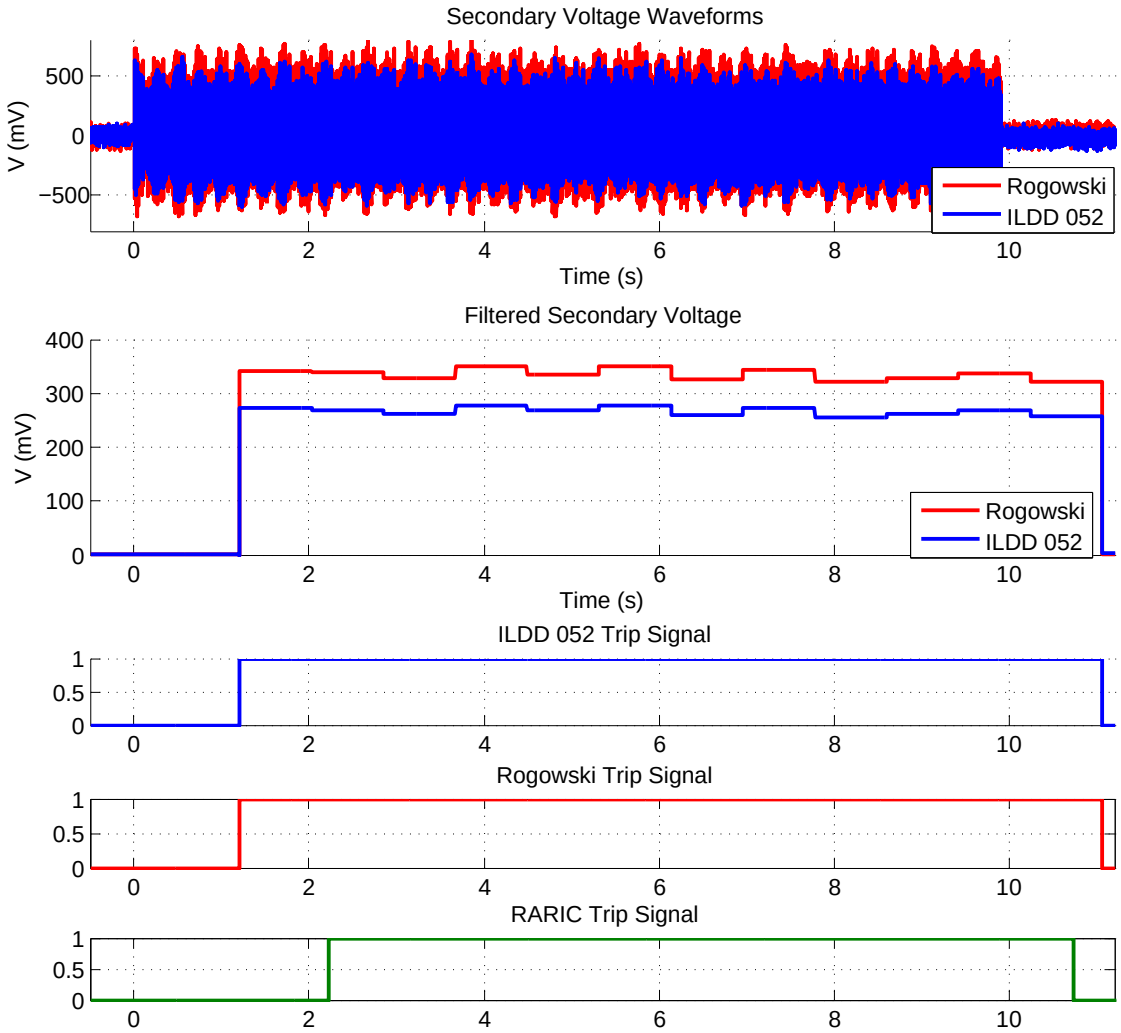
Trip and alarm level settings of REG670

- Four parts of the installation
  - Rogowski coil + MU + REG670 2.0
  - Rogowski coil + (Amplifier) + REG670 2.0
  - ILDD 096 + (Amplifier) + REG670 2.0
  - ILDD 096 + RARIC

System	Trip Value	Alarm Value
Rogowski (No Amp)	200 mV	100 mV
Rogowski (With Amp)	8 V	4 V
Rogowski (MU)	200 mV	100 mV
ILDD 096 (No Amp)	125 mV	62
ILDD 096 (With Amp)	5,2 V	2,6 V
ILDD 096 + RARIC	164 mV	X

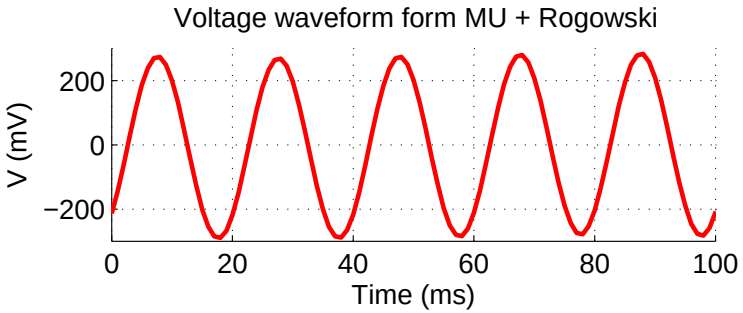
Hallstahammar Installation

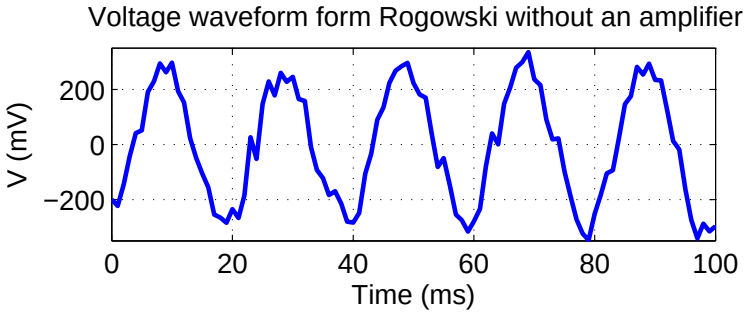
Shaft Current

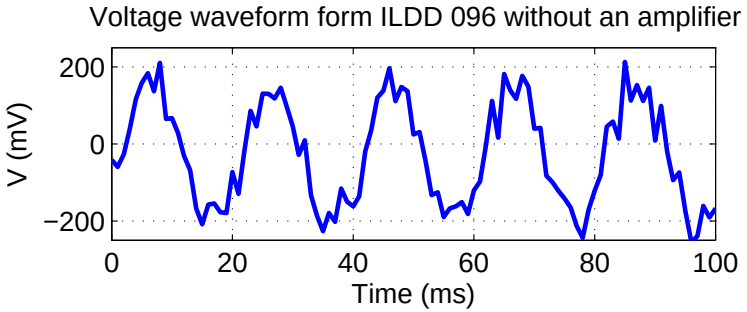


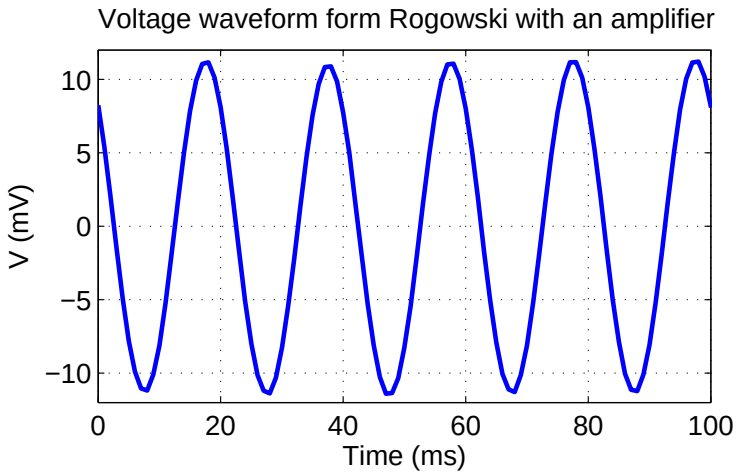
Hallstahammar Installation

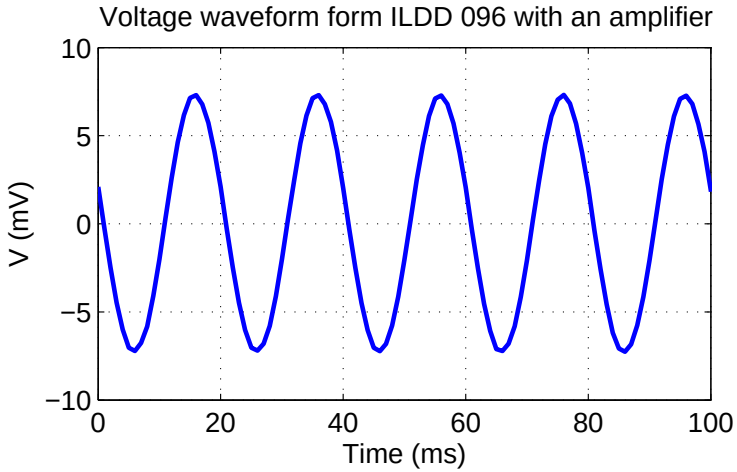
Waveforms











Conclusions

- Rogowski coil is a suitable choice for measurement of shaft currents due to its mechanical and electrical properties
  - Lightweight, flexible, easy to mount
  - Linear, no saturation, frequency independent, rejection of stray flux
- It can be used in pair with protection relay REG670 2.0
- Existing installations with ILDD or new installations with Zelisko GWR3 can be used with REG670 2.0
- If trip and alarm levels will be kept as they are, no amplifier is needed

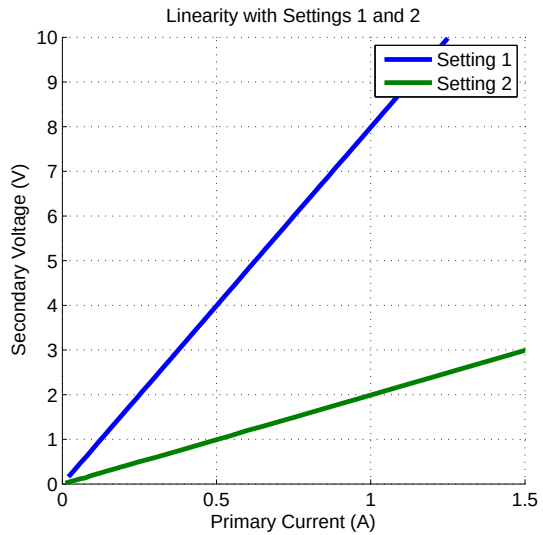
Conclusions

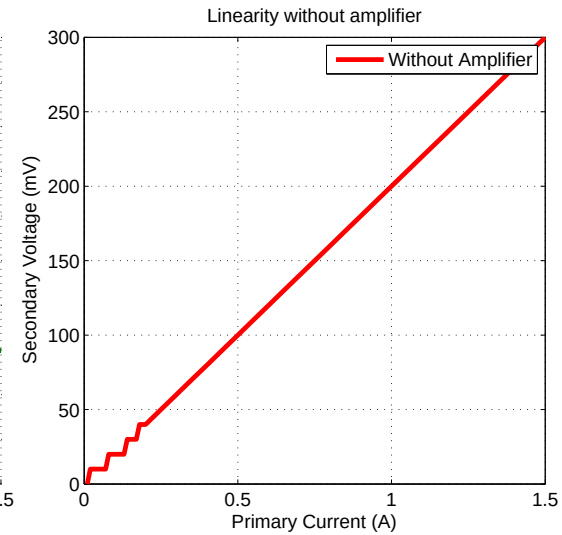
- Merging Unit has no input current transformers which results in a good performance even with low level signals
- No amplifier has to be used even if trip and alarm levels are reduced
- Since fiber optics are used, EMI on low level signals is eliminated

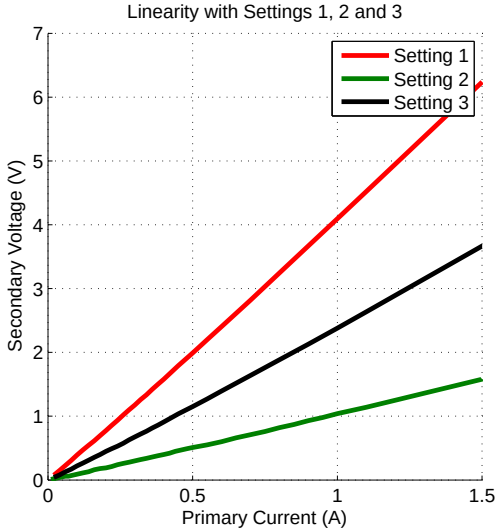
Questions?

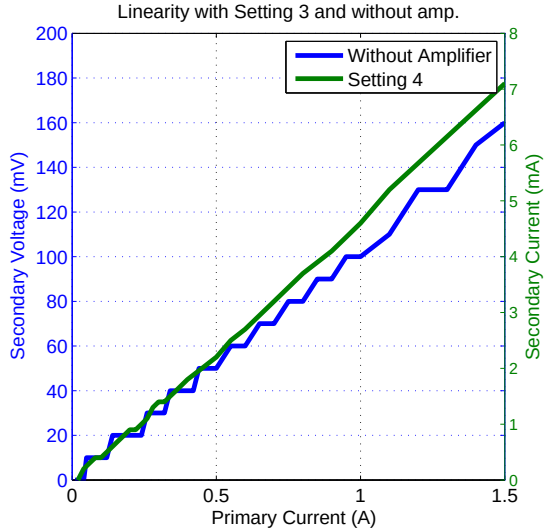
Protection Systems

Linearity - Systems A and B with Zelisko GWR3

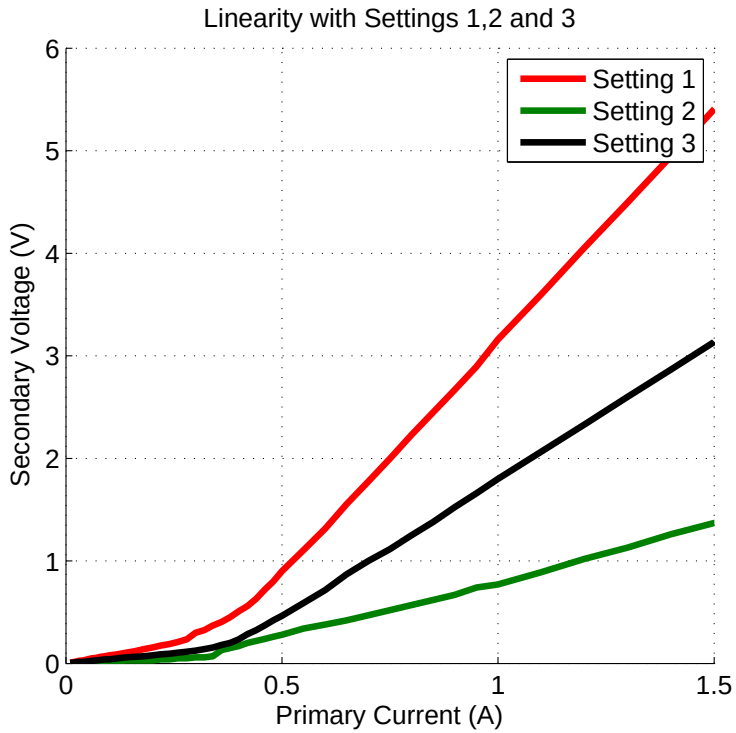


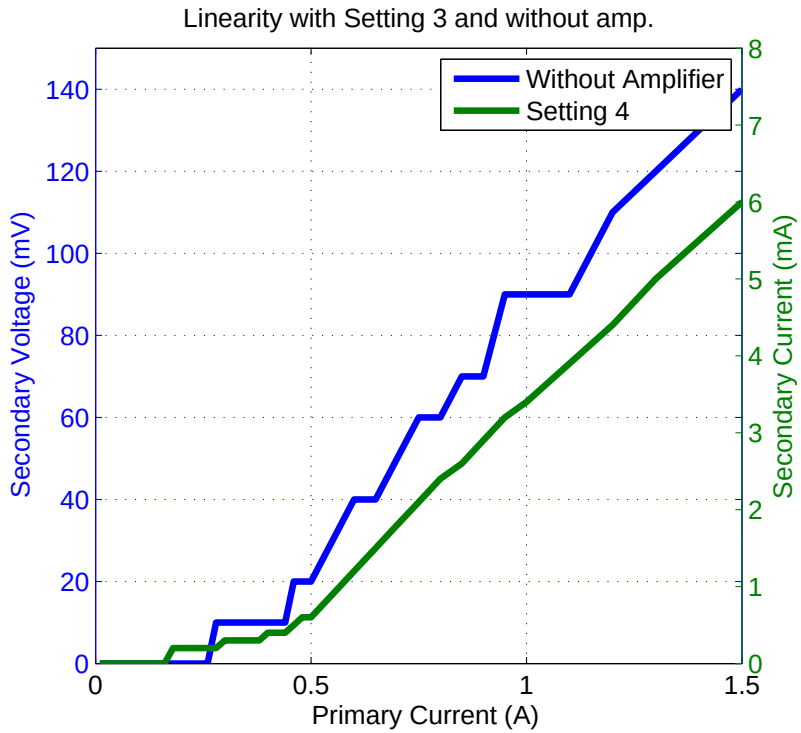






Linearity - System B with ILDD 096





Hallstahammar Installation

Linearity Measurements