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Application Note

# Testing SEL relays with sensor inputs

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Abstract

This application note explains the steps required for configuring a test for protection devices with inputs for Rogowski current sensors and voltage sensors using the *Test Universe* software. Therefore, the configuration of the test object and hardware-configuration is explained. The sensor specific settings for the correction factors of amplitude and propagation delay are also described.

# General information

# Table of contents

# 1 Safety instructions

This Application Note may only be used in conjunction with the relevant product manuals which contain all safety instructions. The user is fully responsible for any application that makes use of OMICRON products.

Instructions are always characterized by a ▶ symbol, even if they are included in a safety instruction.

**NOTICE**

**Equipment damage or loss of data possible**

- ▶ Carefully read and understand the content of this Application Note as well as the manuals from the systems involved before operating them.
- ▶ Please contact OMICRON support if you have any questions or doubts regarding the safety or operating instructions.
- ▶ Follow each instruction listed in the manuals, especially the safety instructions, since this is the only way to avoid the danger that can occur when working on high voltage or high current systems.
- ▶ Only use the equipment involved according to its intended purpose to guarantee safe operation.
- ▶ Existing national safety standards for accident prevention and environmental protection may supplement the equipment's manual.
- ▶ Before starting a test always check that the test signals are suitable for your system under test.

Only experienced and competent professionals that are trained for working in high voltage or high current environments may implement this Application Note. Additionally, the following qualifications are required:

- Authorization for working in environments of energy generation, transmission or distribution, and familiarity with the approved operating practices in such environments.
- Familiarity with the five safety rules.
- Proficiency in working with the CMC test sets.

## 2 Introduction

Some versions of the SEL 700 series protection relays are available with Rogowski current sensor inputs or LPCTs and voltage sensor inputs instead of analog inputs for conventional instrument transformers. These sensor inputs use RJ45 connectors.

To test these protection relays, most CMC test sets are equipped with low-level output signals that can be connected to accessory boxes. The CMLIB A accessory and Easergy cables, pictured below in Figure 1, interface between the low-level signals and the relay. The Easergy cables have BNC connections for the CMLIB A ports on one end and an RJ45 connector on the other. These can be configured to carry the current or voltage signals.

The CMC 430 test set uses different accessories for the low-level signals with more control options, so the LLX1 accessory with the LSE2 cables can be used in the same manner and are pictured in Figure 2. Each LSE2 cable carries both the current and the voltage signals, and they are split into two RJ45 connectors per cable.

This application note explains the steps required for configuring a test for protection devices with sensor inputs using the *Test Universe* software.


Figure 1: CMLIB A accessory and Easergy cable


Figure 2: LLX1 accessory and LSE2 cable


Figure 3: SEL 751 relay

# 3 Connections at the relay

The sensor inputs for the SEL 700 series relays use RJ45 connectors. As can be seen in the rear panel layout for a 751 relay, there are 3 RJ45 connectors for current on the left and 3 for voltage on the right.

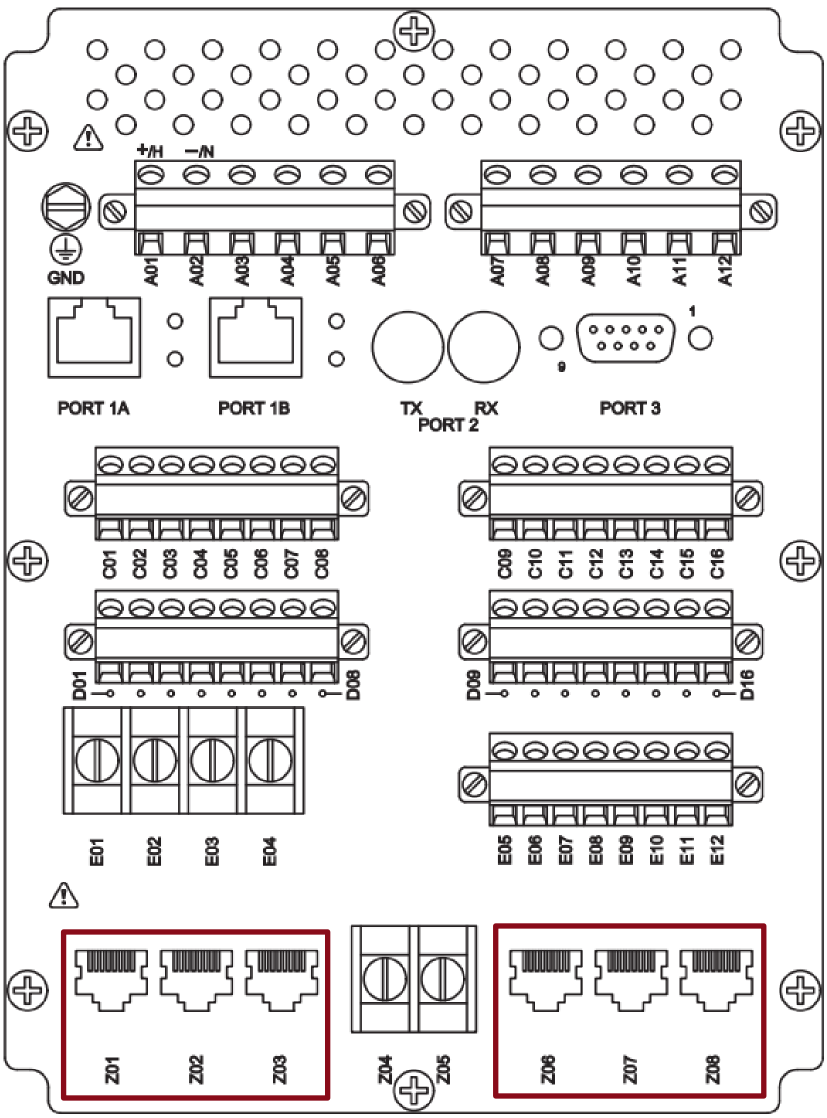



Figure 4: SEL 751 LEA Layout

Other relays might have 6 currents instead of the 3 currents and 3 voltages. The following hardware configurations can be modified in Test Universe to simulate two or more sets of current sensors in that case.

# 4 Test Equipment

## 4.1 CMC 356, CMC 256plus, CMC 353, or CMC 850

### 4.1.1 Required Equipment

These test sets have at least 6 built-in low-level outputs through the interface connectors that can be found on the back panel of the test set. With the LLO-2 option, the back panel interface will have an extra set of 6 low-level outputs labeled “LL out 7-12” directly below 1-6. These extra outputs can also be configured as described in this document.


Figure 5: Back panel of a CMC test set with interfaces “LL out 1-6”

The low-level interface will connect to the CMLIB A accessory. From there, the Easergy cables can be used to connect the CMLIB A accessory to the back of the SEL 700 series relay. The low-level output configuration will be done for each set of 3 in the hardware configuration section of Test Universe.

### 4.1.2 Test setup example

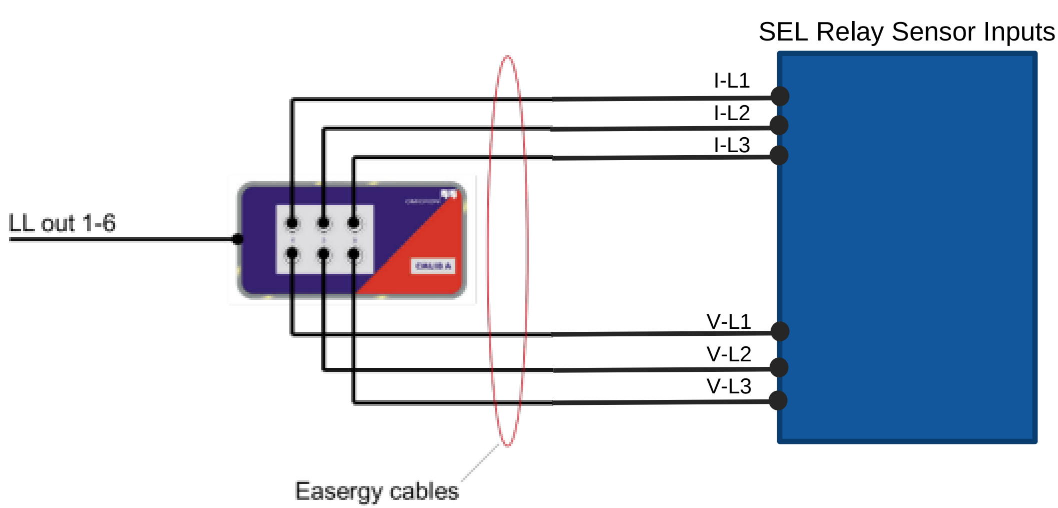



Figure 6: CMLIB A Connection Diagram

## 4.2 CMC 430

### 4.2.1 Required Equipment

LLX accessory units are used to expand CMC 430 test sets with six low level outputs. They are connected to one of the CMC 430s expansion ports, which powers and controls them.

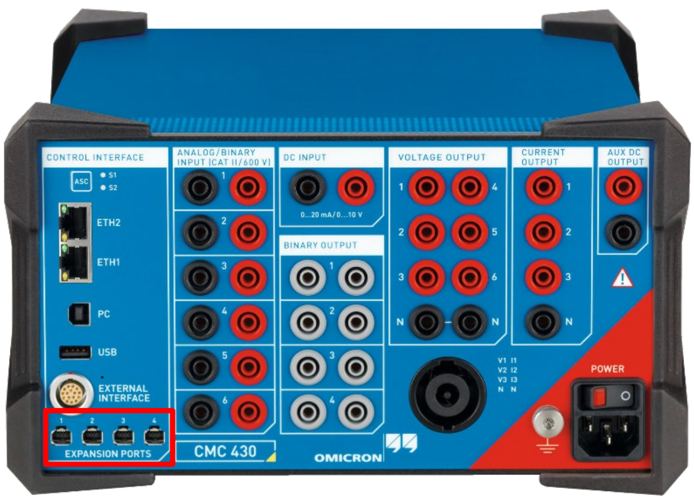



Figure 7: CMC 430 with expansion ports for accessories

The LLX1 is the right choice for testing devices with sensor inputs, such as SEL 700 series protection relays. A wide range of cables are available for easily connecting LLX1 to different devices that have specific connectors and pinouts.

The LSE2 cable type is available for testing SEL protection relays. The single end will connect to the LLX1 accessory, and it splits the current and the voltage into two separate RJ45 connectors. The cable end labeled “V V V” carries the signal configured for “LL out 1-3”. The other end, labeled “I I I”, carries the signal configured for “LL out 4-6”.

### 4.2.2 Test setup example

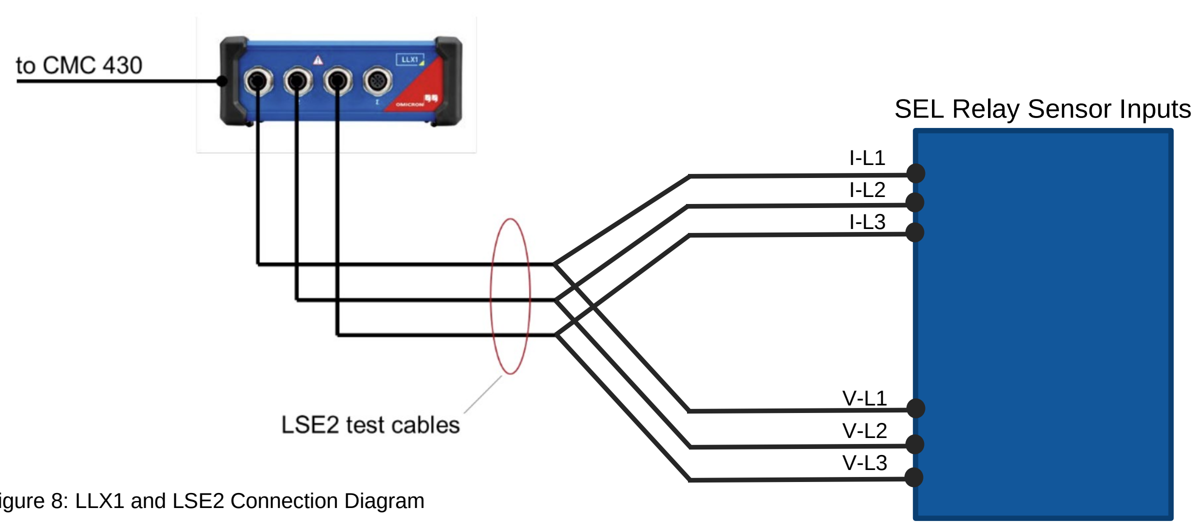
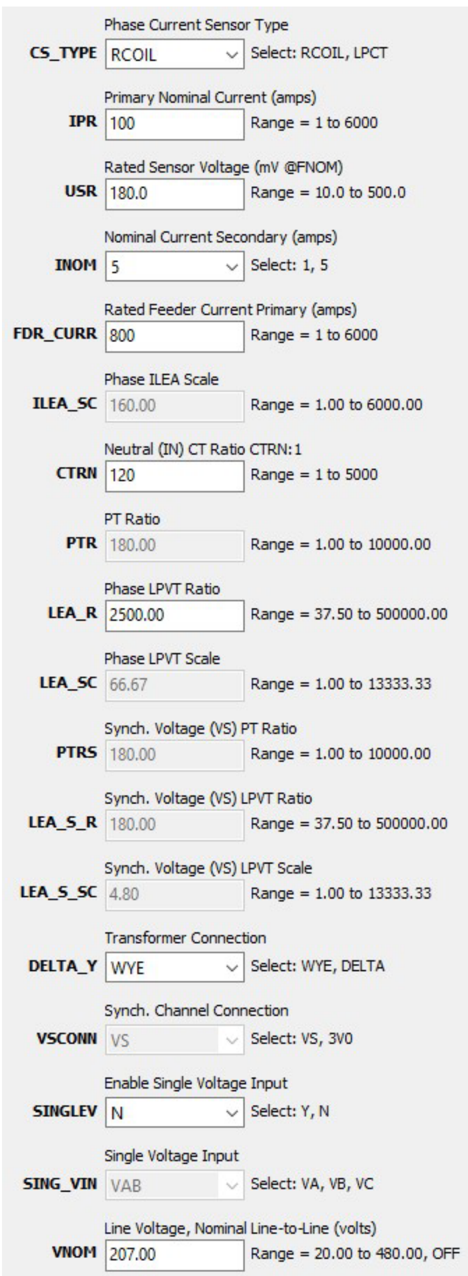



Figure 8: LLX1 and LSE2 Connection Diagram

# 5 Test configuration

## 5.1 Test object

Go to the Test Object and open Device settings by double-clicking the RIO/Device. The primary nominal values of the protected object have to be entered in the “Nominal Values” block. Sensors have a linear response covering a wide range. Therefore, the nominal primary values of the protected object and the rated primary values of the sensor can be significantly different. For the SEL 751 settings in Figure 9, the nominal sensor current is found in the IPR setting to be 100 A, but the rated feeder current is 800 A. The primary nominal voltage must be calculated using the setting information given. The secondary line to line voltage is given in the setting VNOM.



| Setting | Description | Value | Range / Select |
|---|---|---|---|
| CS_TYPE | Phase Current Sensor Type | RCOIL | Select: RCOIL, LPCT |
| IPR | Primary Nominal Current (amps) | 100 | Range = 1 to 6000 |
| USR | Rated Sensor Voltage (mV @FNOM) | 180.0 | Range = 10.0 to 500.0 |
| INOM | Nominal Current Secondary (amps) | 5 | Select: 1, 5 |
| FDR_CURR | Rated Feeder Current Primary (amps) | 800 | Range = 1 to 6000 |
| ILEA_SC | Phase ILEA Scale | 160.00 | Range = 1.00 to 6000.00 |
| CTRN | Neutral (IN) CT Ratio CTRN:1 | 120 | Range = 1 to 5000 |
| PTR | PT Ratio | 180.00 | Range = 1.00 to 10000.00 |
| LEA_R | Phase LPVT Ratio | 2500.00 | Range = 37.50 to 500000.00 |
| LEA_SC | Phase LPVT Scale | 66.67 | Range = 1.00 to 13333.33 |
| PTRS | Synch. Voltage (VS) PT Ratio | 180.00 | Range = 1.00 to 10000.00 |
| LEA_S_R | Synch. Voltage (VS) LPVT Ratio | 180.00 | Range = 37.50 to 500000.00 |
| LEA_S_SC | Synch. Voltage (VS) LPVT Scale | 4.80 | Range = 1.00 to 13333.33 |
| DELTA_Y | Transformer Connection | WYE | Select: WYE, DELTA |
| VSCONN | Synch. Channel Connection | VS | Select: VS, 3V0 |
| SINGLEV | Enable Single Voltage Input | N | Select: Y, N |
| SING_VIN | Single Voltage Input | VAB | Select: VA, VB, VC |
| VNOM | Line Voltage, Nominal Line-to-Line (volts) | 207.00 | Range = 20.00 to 480.00, OFF |

**EXAMPLE 4.3 Phase LEA Ratio Setting Calculations**

Consider a 13.8 kV feeder application where you have a 2500:1 ratio LEA sensor (connected in wye).

Set LEA_R := 2500/1 := 2500 and DELTA_Y := WYE.

**EXAMPLE 4.4 Clipping Voltage Calculation for Rogowski Coil**

Assume a Rogowski coil sensor with the following data and relay settings:

FNOM = 60 Hz
CS_TYPE = RCOIL
IPR = 100 A
USR = 180 mV at 60 Hz
INOM = 5 A
FDR_CURR = 800 A
ILEA_SC = 800/5 = 160, is auto-calculated
Sensor output voltage at 800 A = 180 mV/100 • 800 = 1.44 Vrms
Clipping Voltage = 1.44 Vrms • 30 = 43.2 Vrms

Figure 9: SEL 751 Set 1 Main Configuration Settings – From SEL Instruction Manual Examples 4.3 and 4.4

The interaction of the sensors and the SEL relays creates a virtual secondary level of voltage and current that is neither the current being injected into the relay nor the current going through the actual lines. There will be two ratios for both current and voltage that must be considered. The first is based on the ratio between the injection and the virtual secondary value, and the second is based on the ratio between the virtual secondary and the actual primary current or voltage.

For voltage, SEL settings use a 300 V base, but the low energy signals use an 8 V base. Any conversion between the two must use the factor 37.5, which is 300 divided by 8. The virtual secondary level is always created according to this factor, so the ratio between the injection and the virtual secondary is always 37.5. The ratio between the virtual secondary and the primary is determined by the LEA_R setting. This setting is directly the ratio between the injection and the primary value, so it must be divided by 37.5 to get the ratio between the virtual secondary and the primary.

For current, the FRD_CURR rated feeder current setting determines the ratio between the virtual secondary and primary current. This ratio is calculated as shown in Figure 9 by dividing FDR_CURR by the nominal secondary of the relay current channel, which is 5 A in this case. The auto-calculated setting is stored in ILEA_SC for reference.

To avoid confusion with the SEL settings in these virtual secondary values, enter the remaining nominal values based on the relay information. For example, the INOM setting in Figure 9 is 5 A, so the secondary nominal current is set to 5 A in the device settings shown in Figure 10. The primary current must be set to match the rated feeder current setting (FDR_CURR) from the relay. For the nominal voltage in Figure 10, the primary line to line value is calculated by multiplying the VNOM of 207 by the ratio LEA_R of 2500 and dividing by 37.5 (207*2500/37.5 = 13.8 kV).

Adapt the limits “V max” and “I max” to the suitable values for the virtual secondary by multiplying the maximum sensor input voltage from the relay specifications by the corresponding ratio.

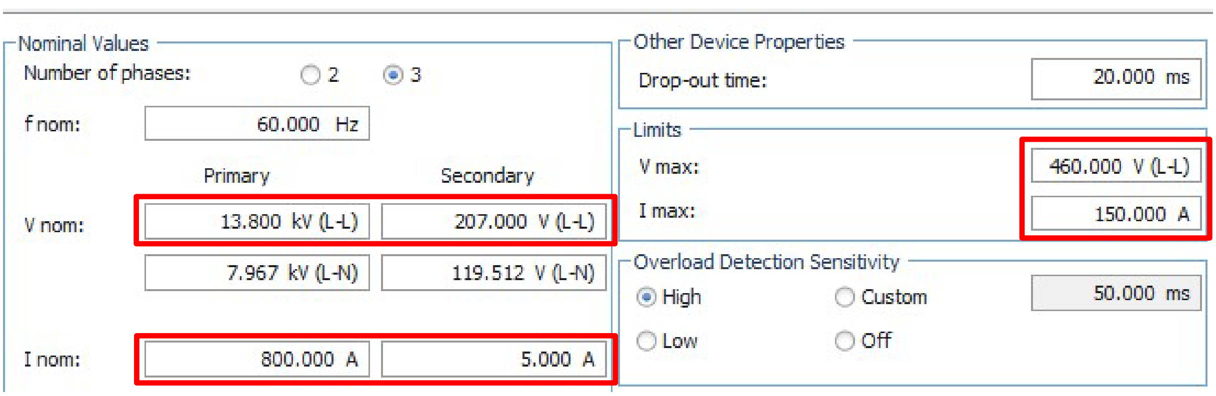



Figure 10: Device settings: Nominal Values and Limits

## 5.2 Hardware Configuration

First, it is recommended to set the number of **Voltage and current sources** to “0” to keep the existing mapping of the analog outputs.

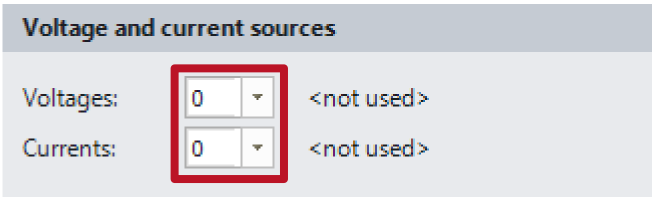



Figure 11: Configuration of the analog output sources

When using a CMC 430, the “LLX1“ accessory must be selected from the drop-down menu “Extension devices”.

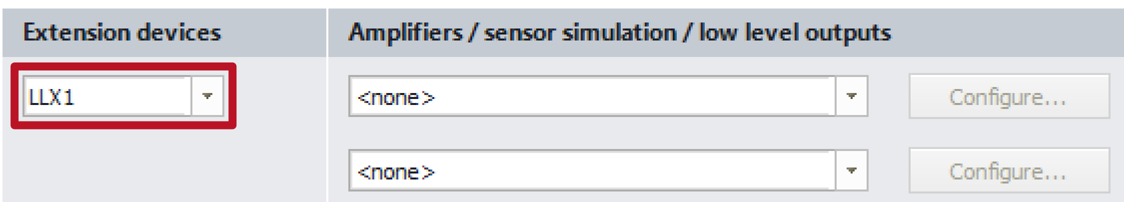



Figure 12: Selection of the extension device LLX1

### 5.2.1 Voltage sensor configuration

In the drop-down menu for “Amplifiers / sensor simulation / low level outputs”, select “Add voltage sensor”.

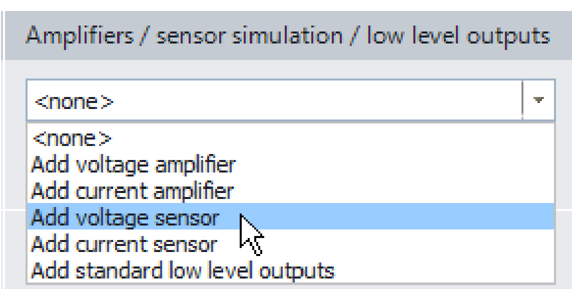



Figure 13: Adding of a voltage sensor

For “Low level output”, select “LL out 1-3”. Because of the virtual secondary discussed in section 5.1, the sensor ratio is always set to 37.5, as shown in Figure 14 below.

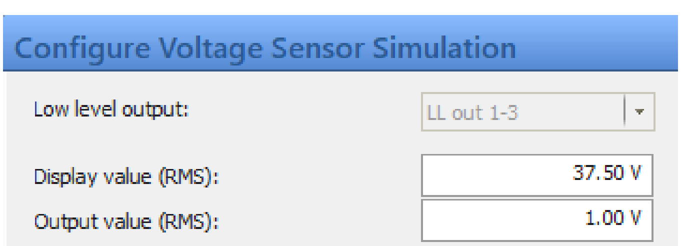



Figure 14: Voltage sensor configuration

The explanation on how to set the correction factors can be found in sections 6.2.1 and 6.2.2.

### 5.2.2 Current sensor configuration

In the drop-down menu for “Amplifiers / sensor simulation / low level outputs”, select “Add current sensor”.

For “Low level output” select “LL out 4-6”.

The “Output value (RMS)” is set to the rated sensor voltage (USR) of 180.00 mV, found in Figure 8. To get to the virtual secondary, the “Display value (RMS)” must be calculated based on the ratio between the primary nominal current and the rated feeder current. Using the settings shown in Figure 8, the display value is set to 0.625 A by dividing the primary nominal current of 100 A by the ILEA_SC setting of 160.

Additionally, select the sensor type based on the settings: “Rogowski” for Rogowski coils, “Linear” for LPCTs.

Finally, set the dynamic range to “High range”. The low range has a maximum output of 5.9 times the nominal current and can have a frequency up to 395 Hz. The high range goes up to 37 times nominal, but the frequency is limited to 60 Hz. For the CMC 430, the dynamic range selection is invisible and set to “High range” internally.

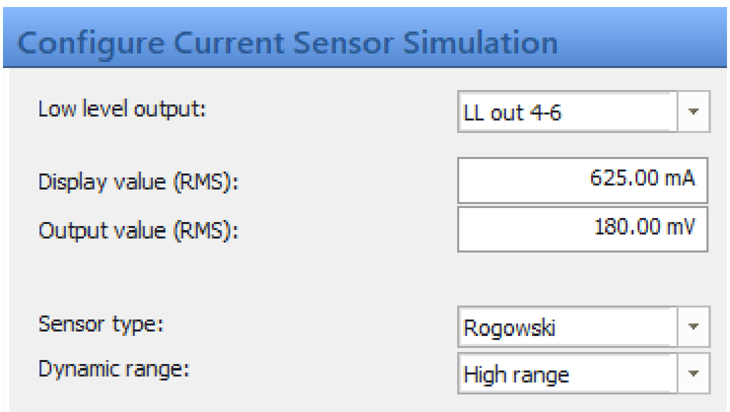


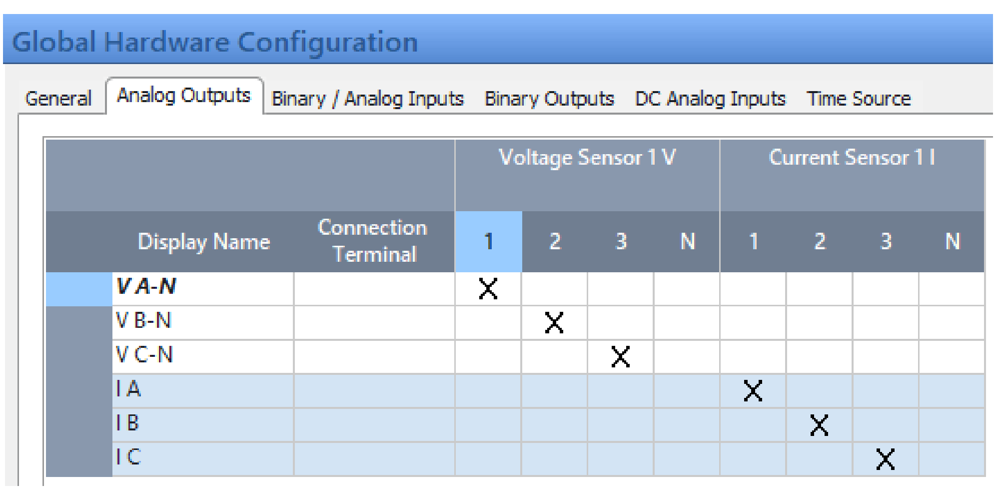

Figure 15: Current sensor configuration for CMLIB A

When using the LLX1, the signal type must be set to differential to match the SEL sensor inputs.

The explanation on how to set the correction factors can be found in sections 6.2.1 and 6.2.2.

### 5.2.3 Routing of analog outputs

Go to the analog output tab and check if all of the defined sensor inputs are routed properly.




| | | Voltage Sensor 1 V | | | | Current Sensor 1 I | | | |
|---|---|---|---|---|---|---|---|---|---|
| Display Name | Connection Terminal | 1 | 2 | 3 | N | 1 | 2 | 3 | N |
| ***V A-N*** | | X | | | | | | | |
| V B-N | | | X | | | | | | |
| V C-N | | | | X | | | | | |
| I A | | | | | | X | | | |
| I B | | | | | | | X | | |
| I C | | | | | | | | X | |

Figure 16: Analog output routing in hardware configuration

# 6 Correction factors

## 6.1 Definition

Sensor correction factors are determined by the manufacturer and can be found on the sensor's nameplate. These factors are set in the protection device's configuration to compensate for sensor inaccuracies and to meet the specified accuracy class.

### 6.1.1 Phase correction factor

The protection device adds the phase correction factor to the measured phase angle.

Accordingly, the phase correction factor has a:

- positive sign for a sensor with a lagging output signal
- negative sign for a sensor with a leading output signal

### 6.1.2 Amplitude correction factor

The protection device multiplies the measured amplitude by the amplitude correction factor.

Accordingly, the amplitude correction factor is:

- greater than 1 for a sensor with an output signal that is too small
- less than 1 for a sensor with an output signal that is too large

## 6.2 Usage in Test Universe

The correction factors for the current and voltage sensors can be set if the check box "Use correction factors" is ticked.

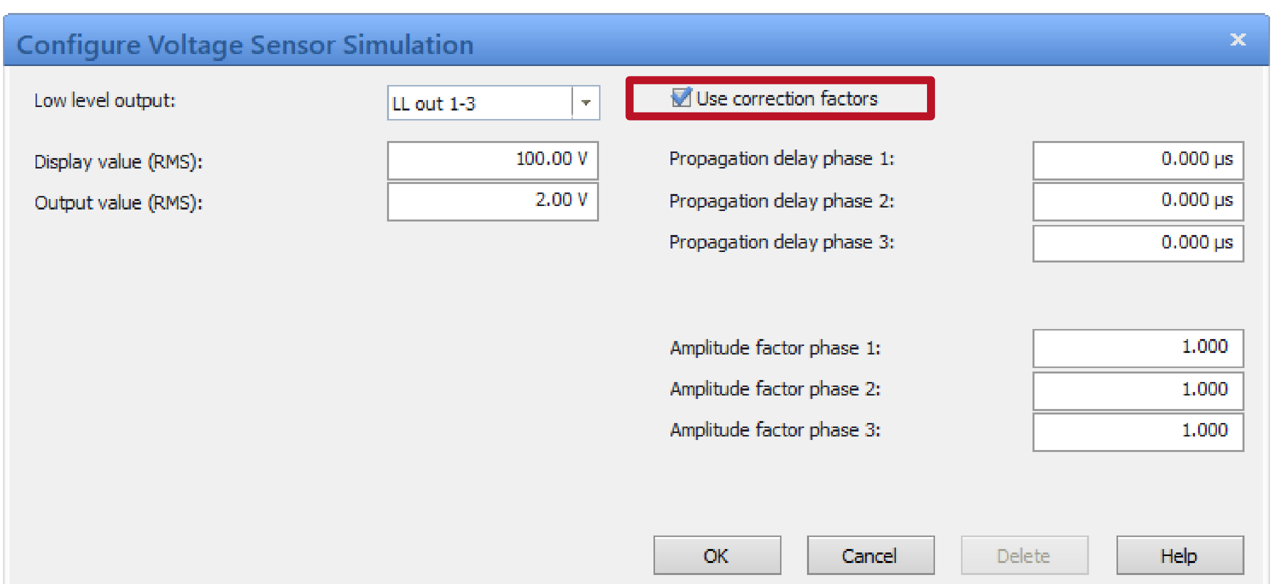



Figure 17: Correction factors for current and voltage sensors

### 6.2.1 Propagation time

The phase error of the sensor is simulated with “Propagation delay phase 1/2/3”. As the set propagation time is compensated by software, this is a correction factor. The phase correction factor of the sensor must be converted into a propagation delay that considers the rated frequency.

Example:

$$propagation\ delay = \frac{\mathrm{pI}}{f_r * 360°} = \frac{+0.0030°}{50\ Hz * 360°} = 0.17\ \mu s$$

Note: Type “u” to enter a value in microseconds.

Note that only positive values can be entered for propagation delays. Therefore, if one or more phase correction factors are negative, all phase correction factors must be adjusted so that none of them are negative.

Example:

The following phase correction factors

$$\mathrm{pU} = -0.0620°$$

$$\mathrm{pI} = +0.0030°$$

have to be adjusted as follows

$$\mathrm{pU} = -0.0620° - (-0.0620°) = 0°$$

$$\mathrm{pI} = +0.0030° - (-0.0620°) = +0.0650°$$

and afterwards converted into a propagation delay

$$V: propagation\ delay = \frac{\mathrm{pU}}{f_r * 360°} = \frac{0°}{50\ Hz * 360°} = 0\ s$$

$$I: propagation\ delay = \frac{\mathrm{pI}}{f_r * 360°} = \frac{0.0650°}{50\ Hz * 360°} = 3.61\ \mu s$$

### 6.2.2 Amplitude factors

The amplitude error of the sensor is simulated with “Amplitude factor phase 1/2/3”. Therefore, the reciprocal of the amplitude correction factor from the sensor’s nameplate must be formed.

Example:

$$amplitude\ factor = \frac{1}{\mathrm{aU}} = \frac{1}{1.0028} = 0.9972$$

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