OMICRON

CP CU1

User Manual

Manual Version: ENU 1030 05 05

The product information, specifications, and technical data embodied in this manual represent the technical status at the time of writing and are subject to change without prior notice.

We have done our best to ensure that the information given in this manual is useful, accurate and entirely reliable. However, OMICRON does not assume responsibility for any inaccuracies which may be present.

The user is responsible for every application that makes use of an OMICRON product.

OMICRON translates this manual from the source language English into a number of other languages. Any translation of this manual is done for local requirements, and in the event of a dispute between the English and a non-English version, the English version of this manual shall govern.

Contents

About this manual

This Reference Manual provides detailed information on how to use the *CP CU1* coupling unit safely, properly and efficiently. The CP CU1 User Manual contains important safety instructions for working with the *CP CU1*, gets you familiar with operating the *CP CU1*, and provides typical application examples. Following the instructions in this Reference Manual will help you to prevent danger, repair costs and possible down time due to incorrect operation.

The CP CU1 User Manual always has to be available at the site where the *CP CU1* is used. It must be read and observed by all users of the *CP CU1*.

Reading the CP CU1 User Manual alone does not release you from the duty of complying with all national and international safety regulations relevant to working with the *CPC 100* and *CP CU1*. The regulation EN 50191 "The Erection and Operation of Electrical Test Equipment" as well as all the applicable regulations for accident prevention in the country and at the site of operation has to be fulfilled.

Safety symbols used

In this manual, the following symbols indicate safety instructions for avoiding hazards.

DANGER

Death or severe injury will occur if the appropriate safety instructions are not observed.

WARNING

Death or severe injury can occur if the appropriate safety instructions are not observed.

CAUTION

Minor or moderate injury may occur if the appropriate safety instructions are not observed.

NOTICE

Equipment damage or loss of data possible

Related documents

The following documents complete the information covered in the CP CU1 User Manual:

Title	Description
CPC 100 User Manual	Contains information on how to use the *CPC 100* test system and relevant safety instructions.
CPC 100 Reference Manual	Contains detailed hardware and software information on the *CPC 100* including relevant safety instructions.
HGT1 User Manual	Contains information on how to use the FFT voltmeter *HGT1* and relevant safety instructions.

1 Safety instructions

1.1 Operator qualifications

Working on overhead lines is extremely dangerous. Testing and measuring with the *CP CU1* must be carried out only by qualified, skilled and authorized personnel. Before starting to work, clearly establish the responsibilities.

Personnel receiving training, instructions, directions, or education on the *CP CU1* must be under constant supervision of an experienced operator while working with the equipment.

1.2 Safety standards and rules

1.2.1 Safety standards

Testing and measuring with the *CP CU1* must comply with the relevant national and international safety standards listed below:

- EN 50191 (VDE 0104) "Erection and Operation of Electrical Equipment"
- EN 50110-1 (VDE 0105 Part 100) "Operation of Electrical Installations"
- IEEE 510 "IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing"
- LAPG 1710.6 NASA "Electrical Safety"

Moreover, additional relevant laws and internal safety standards have to be followed.

Before operating the *CP CU1* and its accessories, read the safety instructions in this User Manual carefully.

Do not turn on the *CP CU1* and do not operate the *CP CU1* without understanding the safety information in this manual. If you do not understand some safety instructions, contact OMICRON before proceeding.

Maintenance and repair of the *CP CU1* and its accessories is only permitted by qualified experts at OMICRON service centers (see "Support" on page 80).

1.2.2 Safety rules

Always observe the five safety rules:

► Disconnect completely.

► Secure against re-connection.

► Verify that the installation is dead.

► Carry out grounding and short-circuiting.

► Provide protection against adjacent live parts.

1.2.3 Safety accessories

OMICRON offers a range of accessories for added safety during the operation of our test systems. For further information and specifications, refer to the corresponding Supplementary Sheet or contact OMICRON Support.

1.3 General

- ► Do not touch any terminals without a visible connection to ground.
- ► Before handling the *CP CU1* or *CPC 100* in any way, connect them with a solid connection of at least 6 mm^2 cross-section to ground. Ground the *CP CU1* as close as possible to the *CPC 100*.
- ► Use the *CP GB1* grounding box to connect the *CP CU1* to overhead lines and power cables. For detailed information, see 3 "Connecting the CP CU1 to a power line" on page 23.
- ► When using the *CP GB1*, ground it near the place where the connection to the test object is made. Make sure that the grounding stud is in good condition, clean and free of oxidation.
- ► Make sure that all studs and cables of the *CP GB1* are screwed tight.
- ► Do not open the *CP CU1*'s or *CP GB1*'s housing.
- ► Do not repair, modify, extend, or adapt the *CP CU1*, *CP GB1* or any accessories.
- ► Use only original accessories available from OMICRON.
- ► Use the *CP CU1*, *CP GB1* and their accessories only in a technically sound condition and when its use is in accordance with the regulations. In particular, avoid disruptions that could in turn affect safety.
- ► Do not use the *CP CU1* if you have a cardiac pacemaker. Before operating the *CP CU1* make sure that there is no person with a cardiac pacemaker in the immediate vicinity of the measurement setup.

1.4 Operating the measurement setup

- ► Before operating the *CP CU1*, *CPC 100*, and *CP GB1* ground them as described in 3 "Connecting the CP CU1 to a power line" on page 23.
- ► When using the *CP GB1*, ground it near the place where the connection to the test object is made. Make sure that the grounding stud is in good condition, clean and free of oxidation.
- ► Life threatening voltages up to 600 V can appear on all *CP GB1*'s contacts and on all clamps and cables connected to the *CP CU1* during the test. Keep safe distance from them.
- ► Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).
- ► Power the *CP CU1* only from the *CPC 100*'s EXT. BOOSTER output. Use only booster cables supplied by OMICRON.
- ► Ensure that the short-circuit bar is always plugged in the *CP CU1*'s I AC output whenever the output is not connected to the I AC input of *CPC 100*.
- ► Connect the *CP CU1*'s I AC output exclusively to the I AC input of the *CPC 100*.
- ► Before connecting the *CP CU1* with the *CPC 100*, turn off the *CPC 100* either by the POWER ON/OFF switch or the Emergency Stop button.
- ► Set the current range switch on the *CP CU1*'s front panel only when the *CPC 100* is turned off and the test object is grounded.
- ► In addition to the above safety rules follow the application-specific instructions in chapters 4 and 5.

1.5 Orderly measures

The CP CU1 User Manual or alternatively the e-book in PDF format has always to be available on site where the *CP CU1* is being used. It must be read and observed by all users of the *CP CU1*.

The *CP CU1* may be used only as described in chapters 3, 4 and 5. Any other use is not in accordance with the regulations. The manufacturer and/or distributor is not liable for damage resulting from improper usage. The user alone assumes all responsibility and risk.

Following the instructions provided in this User Manual is also considered part of being in accordance with the regulations.

1.6 Disclaimer

If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

1.7 Compliance statement

Declaration of conformity (EU)

The equipment adheres to the guidelines of the council of the European Community for meeting the requirements of the member states regarding the low voltage directive (LVD) and the RoHS directive.

1.8 Recycling

This test set (including all accessories) is not intended for household use. At the end of its service life, do not dispose of the test set with household waste!

For customers in EU countries (incl. European Economic Area)

OMICRON test sets are subject to the EU Waste Electrical and Electronic Equipment Directive 2012/19/EU (WEEE directive). As part of our legal obligations under this legislation, OMICRON offers to take back the test set and ensure that it is disposed of by authorized recycling agents.

For customers outside the European Economic Area

Please contact the authorities in charge for the relevant environmental regulations in your country and dispose the OMICRON test set only in accordance with your local legal requirements.

2 Introduction

2.1 Designated use

The *CP CU1* is a coupling unit designated for measurements with the *CPC 100* test system mainly on overhead lines and power cables.

Typical applications include:

- Line impedance and k factor measurements at overhead lines and power cables
- Mutual coupling measurements on double and multi-circuit lines
- Ground impedance measurements
- Step & touch voltage measurements
- Reduction factor measurements
- Measurement of coupling into signal cables

The *CP GB1* grounding box (see 2.4 "CP GB1 grounding box" on page 12) is a surge arrestor unit protecting the operating staff and equipment from high-voltage hazards during measurements on overhead lines and power cables in case of unexpected events on the power line.

The *CP CU1* works as an add-on device to the *CPC 100*. Do not connect the *CP CU1* to any other device. Do not use the accessories for applications not indicated in this reference manual.

Any other use of the *CP CU1* but the one mentioned above is considered improper use, and will not only invalidate all customer warranty claims but also exempt the manufacturer from its liability to recourse.

2.2 Circuit diagram of the *CP CU1*

Figure 2-1 below shows the principal circuit diagram of the coupling unit.

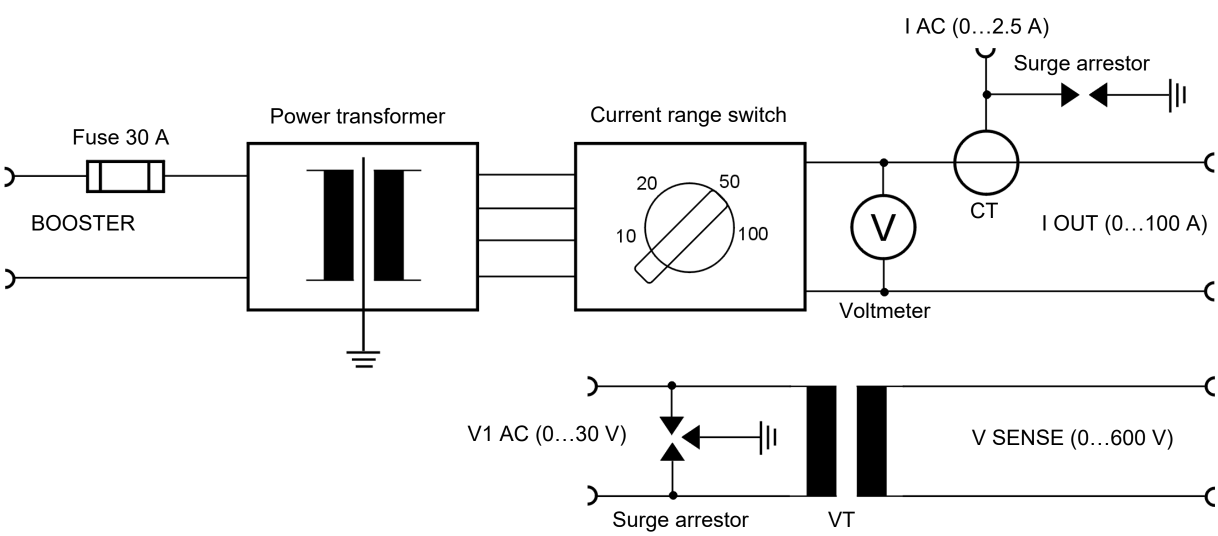


Figure 2-1: Circuit diagram of the *CP CU1*

2.3 Operating controls of the *CP CU1*

- The front panel of the *CP CU1* provides the following functional elements:
- BOOSTER input for connecting with the *CPC 100*'s EXT. BOOSTER output
- Current range switch for setting the current range of the *CP CU1*
- Voltmeter for measuring the voltage at the test object's terminals
- I OUT current output
- I AC output for measuring the output current using a CT (current transformer) with the 100 A : 2.5 A transformation ratio. The output is to be connected with the I AC input of the *CPC 100*.
- V SENSE input for measuring the voltage at the test object's terminals
- V1 AC output for measuring the voltage at the test object's terminals using a VT (voltage transformer) with the 600 V : 30 V transformation ratio. The output is to be connected with the V1 AC input of the *CPC 100*.
- Short-circuit bar for shorting the I AC output whenever the output is not connected to the I AC input of the *CPC 100*
- Equipotential ground terminal for grounding the *CP CU1* close to the position of the operating staff

Figure 2-2 below shows the *CP CU1*'s functional elements.

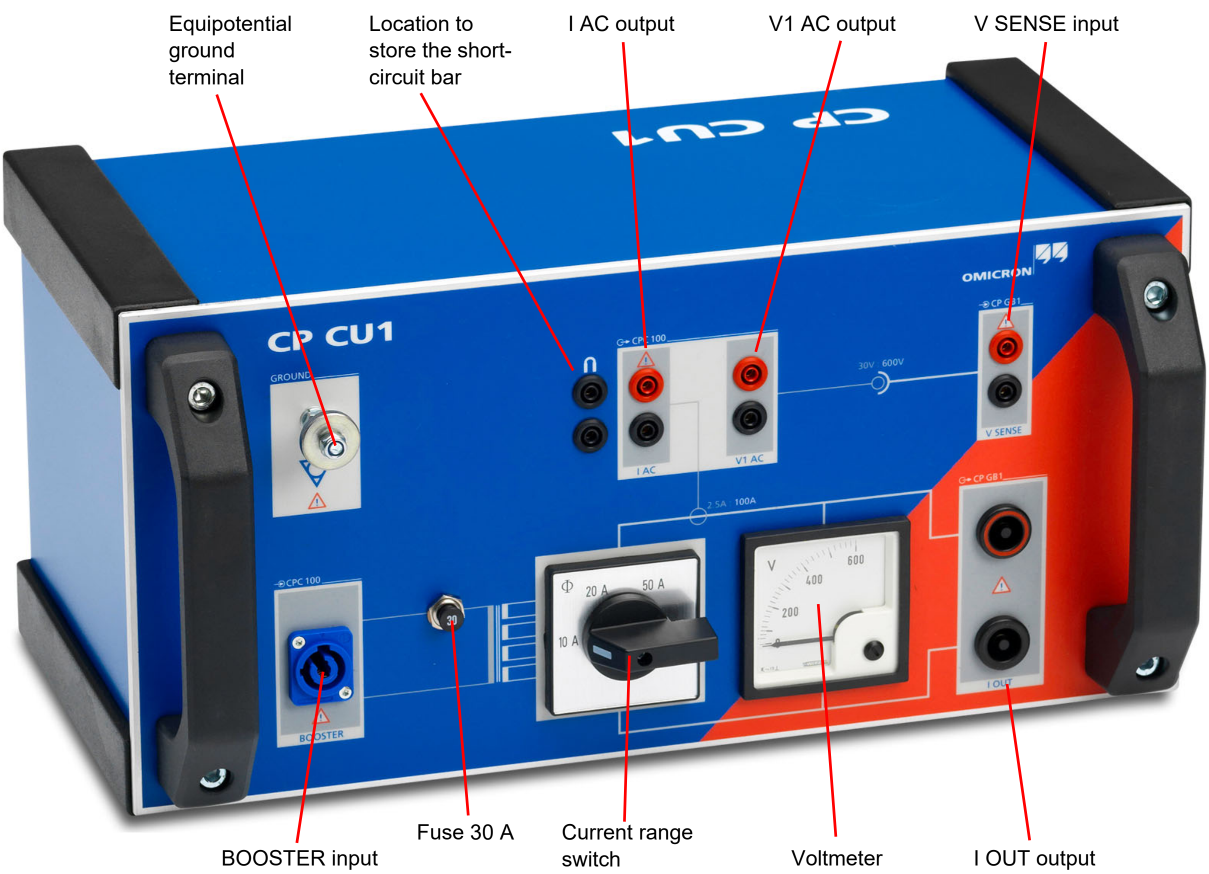


Figure 2-2: Front panel of the *CP CU1*

2.4 *CP GB1* grounding box

2.4.1 Description

The *CP GB1* grounding box (see Figure 2-3 below) is a surge arrestor unit for connecting the *CP CU1* to the test object. If high voltage appears for a short time on the test object's terminals, an arc discharges the voltage and exstinguishes without destroying the grounding box. If the arc persists for a longer time period, the surge arrestor insulator melts and the terminals are short-circuited to ground, thereby protecting the operating staff, *CP CU1* and *CPC 100*.

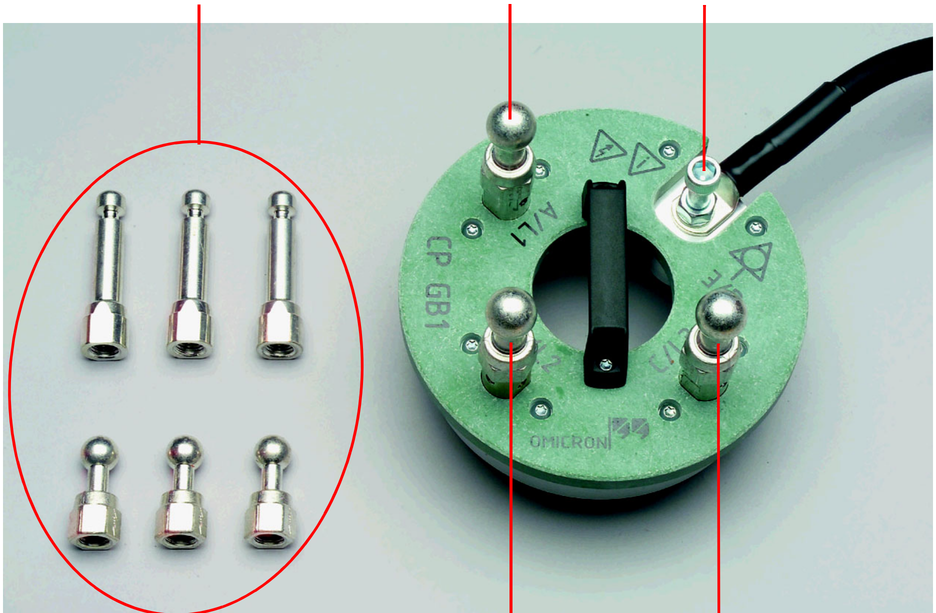


Figure 2-3: *CP GB1* grounding box

The scope of delivery for the *CP GB1* includes 16 mm cylindrical grounding studs as well as 20 mm and 25 mm ball grounding studs as seen in Figure 2-3 above

.

WARNING

Death or severe injury caused by high voltage or current possible

► The *CP GB1* grounding box must be used for measurements on overhead lines or power cables.

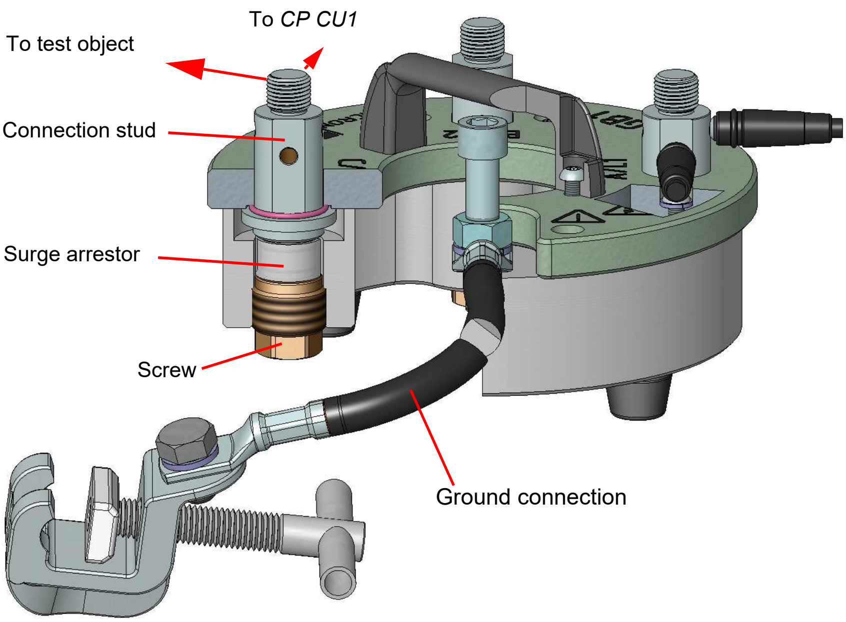


Figure 2-4: Cross-sectional view of the *CP GB1*

WARNING

Death or severe injury caused by high voltage or current possible

Insufficient grounding due to missing surge arrestors.

► Before connecting the *CP GB1* to a power line, always check whether it is equipped with surge arrestors. The following signs could indicate missing surge arrestors:

- The screws for the installation of the surge arrestors appear to be more recessed than usual (due to a missing surge arrestor above the respective screw).
- The connection studs are loose and "wobbling".

The *CP GB1* grounding box is suitable for three different ground connection types: cylindrical grounding studs of 16 mm diameter or ball studs of 20 mm and 25 mm (1 inch) diameter. The grounding socket clamp is needed for secure ground connection of the *CP GB1* to the substation ground. The grounding socket clamps compatible with the grounding studs in the substation are given in Table 2-1 below.

WARNING

Death or severe injury caused by high voltage or current possible

Connecting socket clamps of one type to a grounding point of another system is highly dangerous on both the connection of the grounding set to the *CP GB1* and the connection of the *CP GB1* to the grounding point in the substation.

► Depending on the type of grounding studs in the substation, the appropriate connection set and socket clamp have to be used.

The 16 to 20 mm socket clamps are designed and tested for fault currents up to 26.5 kA, the 25 mm (1 inch) socket clamp for fault currents up to 30 kA, both for a maximum duration of 100 ms.

► On locations where higher fault currents are possible, the *CP CU1* and *CP GB1* must not be used!

Table 2-1: To be used grounding stud / socket clamp combinations

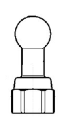
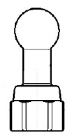
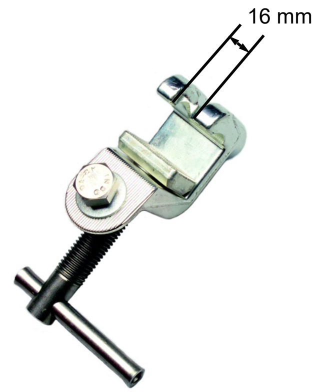
Grounding stud in the substation		Proper grounding socket clamp
16 mm cylindrical grounding stud		16…20 mm grounding socket clamp (if the *CP GB1*'s 16 mm cylindrical or 20 mm ball studs are used) 
20 mm ball grounding stud		

Table 2-1: To be used grounding stud / socket clamp combinations

Grounding stud in the substation		Proper grounding socket clamp
25 mm ball grounding stud		25 mm grounding socket clamp (if the *CP GB1*'s 25 mm studs are used) 

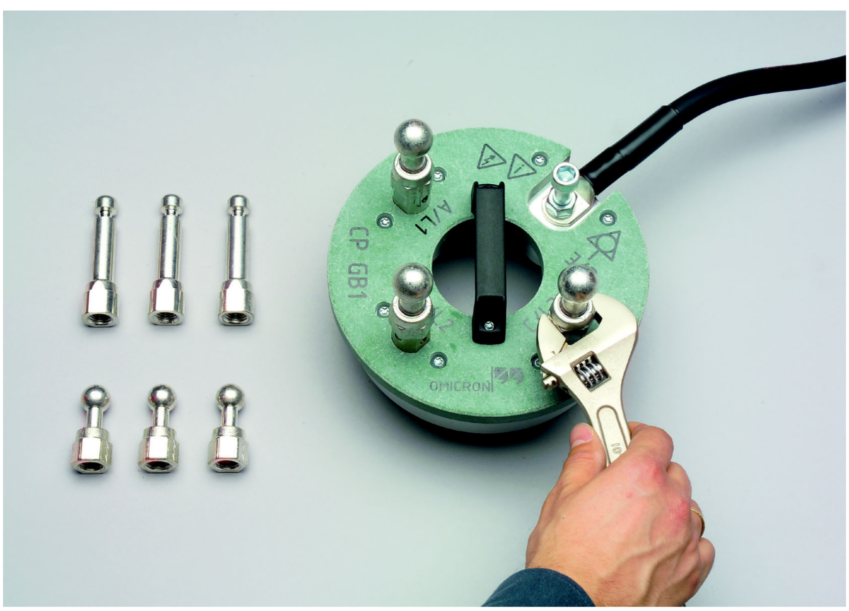


Figure 2-5: Screwing on the *CP GB1*'s grounding studs

For transportation, the *CP GB1*'s grounding studs are usually removed. If this is the case, mount them onto the *CP GB1* using the delivered wrench and screw them tight (see Figure 2-5 above).

2.4.2 Shorting the phases

A three-lead cable is delivered with the *CP GB1* for shorting all phases for L1||L2||L3-E measurements.

See:

- Figure 4-9: "Clamp connections for measurement loops 2 to 7" on page 39
- Figure 4-11: "Clamp connections and state of near end grounding switch for measurement loops 2 to 8" on page 43
- Figure 5-5: "Ground impedance measurement setup" on page 50
- Figure 5-15: "Step and touch voltage measurement setup" on page 59
- Figure 5-28: "Reduction factor measurement setup" on page 69
- Figure 6-3: "Coupling into signal cables measurement setup for the line-to-ground measurement" on page 75
- Figure 6-4: "Coupling into signal cables measurement setup for the line-to-ground calibration" on page 76

Figure 2-6: Three-lead cable

To short the phases, connect the line studs of the *CP GB1* as shown in Figure 2-7 below.

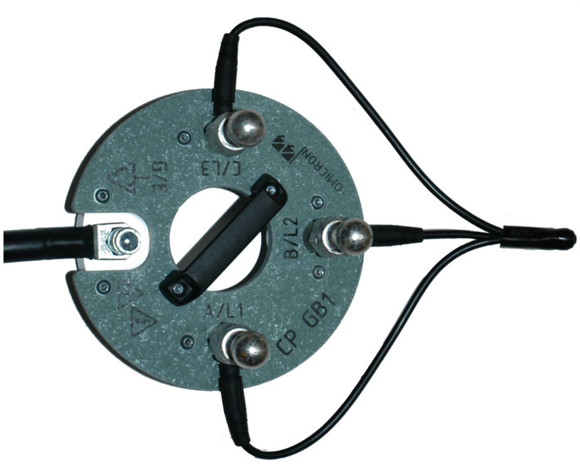


Figure 2-7: Shorting the phases

2.4.3 Changing the surge arrestors

The surge arrestors of the *CP GB1* can permanently short-circuit the *CP GB1*'s terminals to ground if overvoltage appears on the terminals. Even short transients can cause a discharge and, if the energy is too high, possibly damage the surge arrestor. Defective surge arrestors can result in erroneous measurement results. If the measurement results obtained using the *CP GB1* differ considerably from the expected values, check the surge arrestors using the *CPC 100* as follows.

Surge arrestor testing with the VWithstand test card

Apply a voltage of 500 V for at least 10 seconds using the **VWithstand** test card from the resistance test cards. Set a test current of 0.01 A. If the current is exceeded, an error message is displayed. In this case, the surge arrestor under test is defective and you have to replace it. If no message is displayed, the surge arrestor is intact. For detailed information on this test, see the CPC 100 Reference Manual. Repeat the test for all three studs A/L1, B/L2 and C/L3.

Surge arrestor testing with the sequencer test card

Note: Depending on the license package you purchased with your *CPC 100*, the **VWithstand** test card might not be available (it is for example not part of the *CPC 100* + *CP CU1* package, since it is not needed for the *CP CU1*-related measurements). In this case the *CPC 100*'s sequencer test card can be used alternatively.

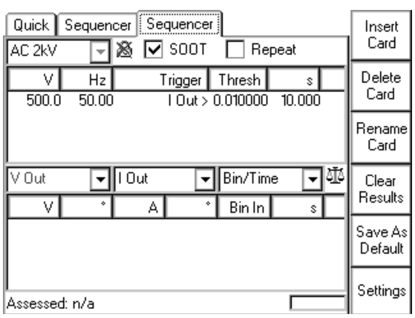


Figure 2-8: Setup of the sequencer test card for surge arrestor testing

In case you plan to use the sequencer test card, perform the steps below. Also see Figure 2-8 above.

1. Open the sequencer test card as described in the CPC 100 User Manual.
2. Set the output range selection to **AC 2kV**.

The measurement channels are set to **V Out** and **I Out** automatically.

3. Select **Bin/Time** from the combo box next to the measurement channel combo boxes.
4. Set the voltage to 500 V and the frequency to 50 Hz.
5. Set the trigger to **I Out** and the threshold to 0.01 A.
6. Set the time limit to 10 s.
7. Activate the **SOOT** (**Switch off on trigger**) check box.
8. Perform the test for all three studs A/L1, B/L2 and C/L3.

If the **I Out** threshold of 0.01 A is exceeded before the measurement is over (10 s), the respective surge arrestor is defective.

Replace defective surge arrestors only with spare parts from OMICRON (see Figure 2-9 below). For ordering information, contact OMICRON sales office.

Figure 2-9: Surge arrestors

To replace a surge arrestor:

1. Disconnect the *CP GB1* completely and observe the five safety rules in 1.2.2 "Safety rules" on page 7.
2. Open the surge arrestor chamber using a 22 mm wrench by removing the contact screw (see Figure 2-10 below).

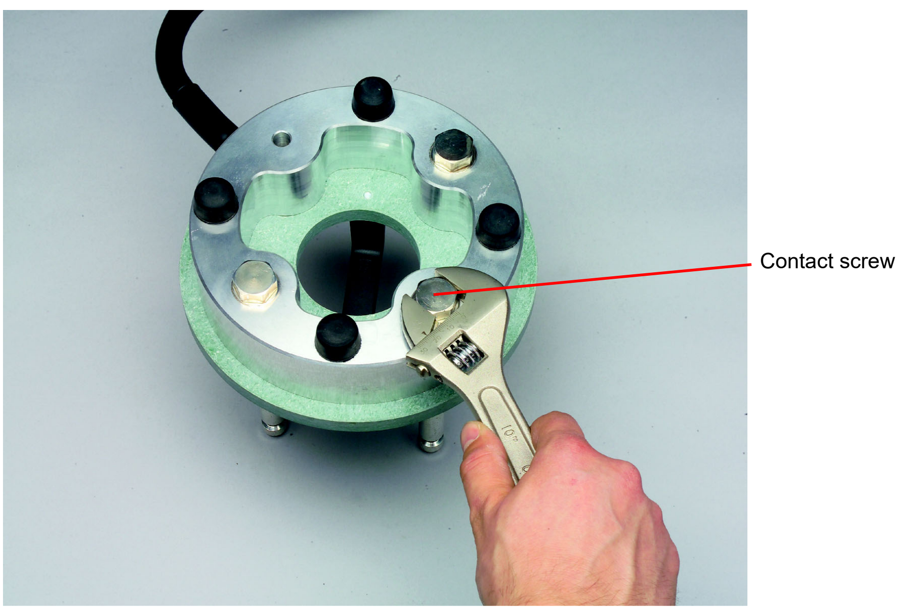


Figure 2-10: Opening the surge arrestor chamber

3. Turn the *CP GB1* upright and move the stud over the surge arrestor chamber until the surge arrestor falls out.
4. Replace the defective surge arrestor by the spare one.
5. Screw the contact screw very tight (torsional moment of 15…20 Nm).

2.5 Clamp-on ammeter

A clamp-on ammeter for AC 50/60 Hz (see Figure 2-11 below) is available from OMICRON as an accessory. For ordering information, contact OMICRON sales office. This is a third party device. For further information on the device refer to the product documentation delivered with it.

Figure 2-11: Clamp-on ammeter (symbolic picture)

2.6 Cleaning

WARNING

Death or severe injury caused by high voltage or current possible

► Prior to cleaning disconnect the device.

► To clean one of the devices described in this document, use a cloth dampened with isopropanol alcohol or water.

2.7 Working principle of the *CP CU1*

2.7.1 Safety concept

The *CP CU1* has been designed for measurements on overhead transmission lines and power cables. In order to provide safety, the *CP CU1* comes with a matching transformer, a CT and a VT which provide galvanic insulation between the operator and the line under test (marked by the orange dashed line in Figure 2-12 below). Furthermore, the *CP GB1* protects the *CP CU1* and the operator from unexpected events on the line by being capable of diverting high short-circuit currents. The insulation of the *CP CU1* is designed to withstand far higher voltages than the *CP GB1*'s surge arrestors do.

Note: This is only guaranteed if the danger zone is respected by the user!

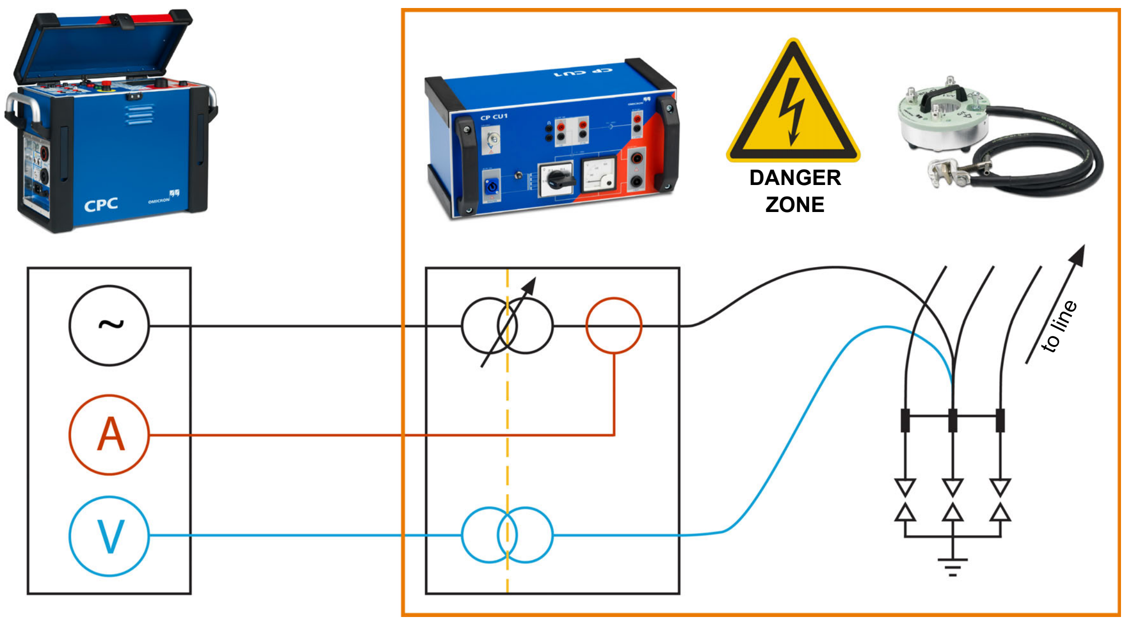


Figure 2-12: Test setup consisting of *CPC 100*, *CP CU1* and *CP GB1*.

2.7.2 Measurement methodology

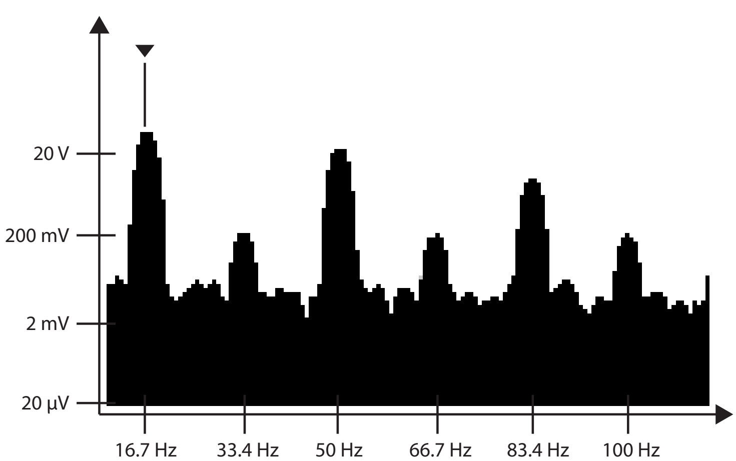


Figure 2-13: Interference in railroad environment (rated frequency at 16.7 Hz)

Measurements on Power Lines involve high interference from parallel live systems. Figure 2-13 above shows the frequency spectrum for the open line voltage of loop L1-E of a line which is running in parallel to a railway transmission line. From this diagram it is quite obvious that interference must be carefully considered for an accurate measurement.

The noise suppression method applied by the *CPC 100* is called frequency-selective measurement, which means that the frequency of the measurement current differs from any frequency which is generated by interference.
By default, all *CP CU1*-related templates use 30 and 70 Hz (or 40 and 80 Hz respectively if the mains frequency is 60 Hz). On top of that a digital filter is applied, with its mid-frequency matching the frequency of the test current, which suppresses interference above and below the measurement current's frequency. Refer to the CPC 100 Reference Manual to get more information on the characteristics of the applied filter.

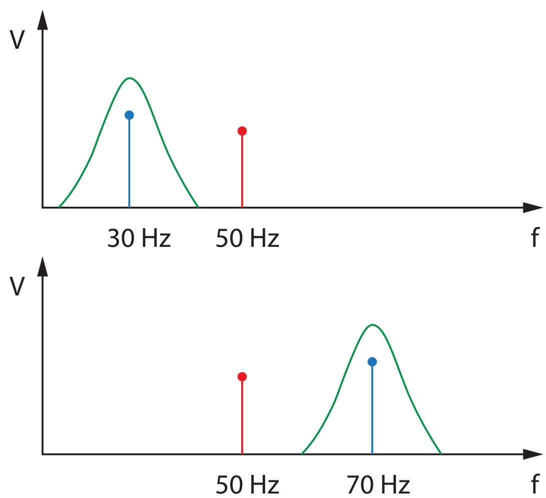


Figure 2-14: Frequency-selective measurement

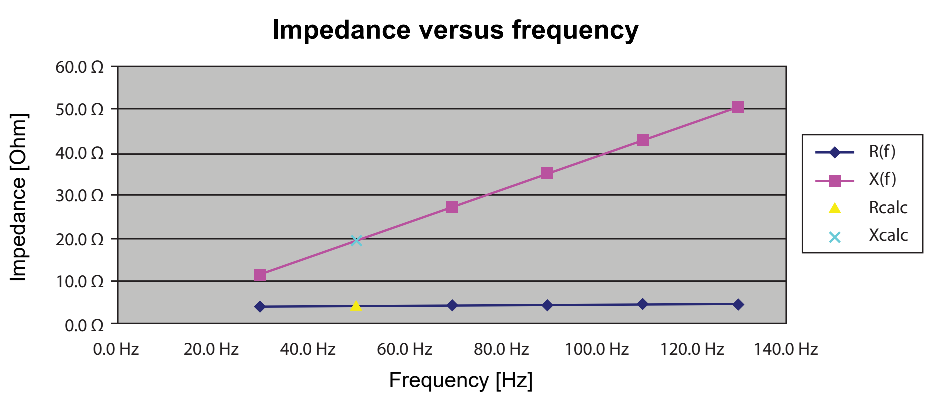


Figure 2-15: Interpolation to rated frequency

In order to obtain the values corresponding to 50 Hz, the 30 Hz and 70 Hz measurement results are linearly interpolated, as shown in Figure 2-15 above. As can also be seen in Figure 2-15, additional measurements are conducted at frequencies higher than 70 Hz to check the interpolation for plausibility.

For a reliable and accurate measurement it is however also required to facilitate a rather high signal-to-noise ratio. Therefore, in order to inject maximum power, the *CP CU1* comes with a switchable matching transformer with four different current ranges, which allow impedance matching for short and long power lines.

Table 2-2 below illustrates currents and voltages related to the four *CP CU1* ranges.

Table 2-2: *CP CU1* current range characteristics

***CP CU1* Range (Max. Current)**	**Max. Voltage**	**Turns Ratio *CP CU1* Matching Transformer**	**Range of Impedance with Max. Possible Current**
100 A	50 V	1:5	< 1 Ω
50 A	100 V	2:5	1 Ω...5 Ω
20 A	250 V	1:1	5 Ω...25 Ω
10 A	500 V	2:1	> 25 Ω

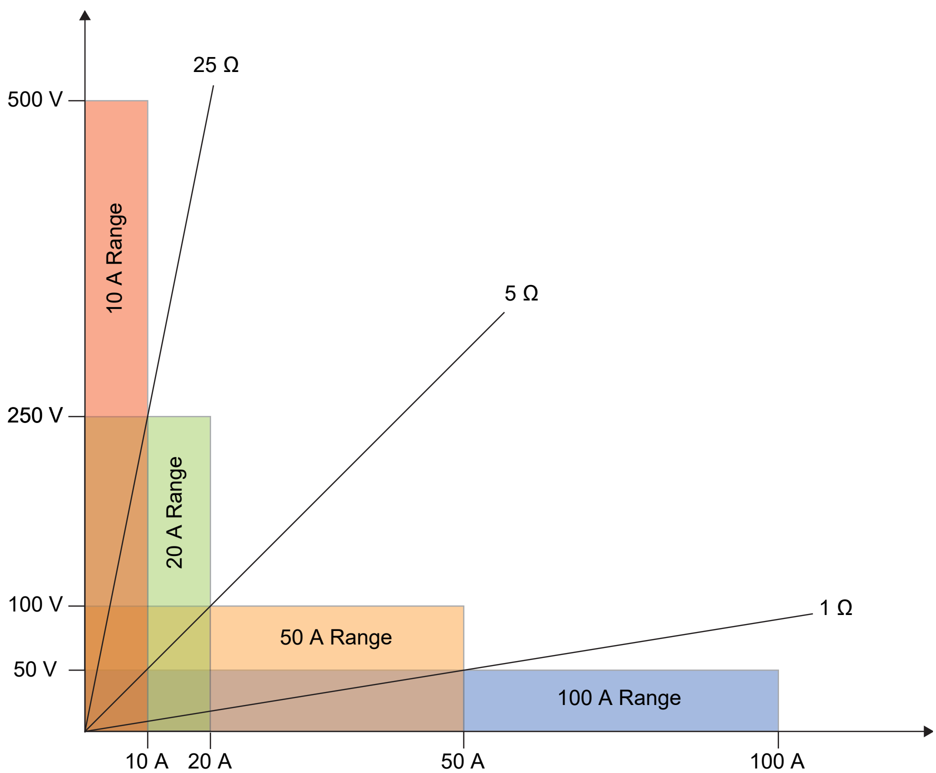


Figure 2-16: Load diagram of the *CP CU1*

Considering 5 kVA as maximum power of the *CPC 100* in conjunction with the *CP CU1*, the load diagram in Figure 2-16 above applies. For impedances smaller than 1 Ω, the 100 A range offers the highest possible test current. In contrast, for impedances higher than 25 Ω, the 10 A range offers the highest possible test current and therefore the best signal-to-noise ratio.

3 Connecting the *CP CU1* to a power line

WARNING

Death or severe injury caused by high voltage or current possible

▶ For measurements on overhead lines or power cables the *CP CU1* must be connected to the test object through the *CP GB1* grounding box.

For line impedance testing, as well as grounding system testing, the *CP CU1* must be connected to an overhead line or a power cable. Due to the fact that the near end of the line must be disconnected from ground, there is a high danger potential and the risk for persons and test equipment to be exposed to hazardous voltages. The following scenarios are leading to voltages which are diverted to ground by the *CP GB1* to protect the test equipment and operating staff:

- The line under test could carry high voltage due to interference from adjacent live systems.

WARNING

Death or severe injury caused by high voltage or current possible

- Due to miscommunication, the grounding switch at the far end could be opened accidentally.
- Due to miscommunication, the line could also be energized from the far end.

  Note: This is a severe violation of the safety rule “Secure against re-connection”!

▶ Establish the responsibilities of everybody working on the asset under test.

▶ Make sure that everybody is made aware of the measurement on the respective power line.

▶ Provide two-way communication between the near and far ends of the power line.

- The line could also be exposed to lightning strike.

WARNING

Death or severe injury caused by lightning discharge to the power line possible

▶ Check the weather forecast for the area the line is located in!

▶ Do not connect the measurement setup to overhead lines if there is a possibility of a thunderstorm over any part of the line to be measured!

▶ Abort the measurement at the slightest indications of lightning!

In order to estimate the interference and find an adequate current range on the *CP CU1*, the following steps are recommended for preparation of the measurement. All together, four criteria have to be checked:

- Line length
- Estimated open-line voltage
- Measured open-line voltage
- Injected test current

Note: It is now also possible to check the four criteria using the Line Impedance test card. See 3.5 "Using the Line Impedance test card to check the four criteria" on page 30.

3.1 First criterion: Line length

► Select the *CP CU1*'s current range by following the assignment in Table 3-1 below and continue with the next criterion: 3.2 "Second criterion: Estimated open-line voltage" on page 24.

Table 3-1: Selection of current range, according to line length

Line Length	0...2 km	2...10 km	10...50 km	> 50 km
	0...1.5 mi	1.5...6 mi	6...30 mi	> 30 mi
CP CU1 Current Range	100 A	50 A	20 A	10 A

3.2 Second criterion: Estimated open-line voltage

Figure 3-1 below illustrates the estimation of the open-line voltage. In principal, the circular current which is caused by the interference of a parallel system is measured in all three phases.

WARNING

Death or severe injury caused by high voltage or current possible

► Before grounding a power line, make sure that the line is not powered with the life-dead-life test as follows:

1. Use a certified voltage tester, approved for the voltage tests to be performed.
2. Verify on a life system that the voltage tester is operational.
3. Verify on the line to be unpowered that it is dead, using the voltage tester.
4. Verify on the life system again that the voltage tester is still working.

► When grounding a power line, observe the five safety rules as described in 1.2.2 "Safety rules" on page 7.

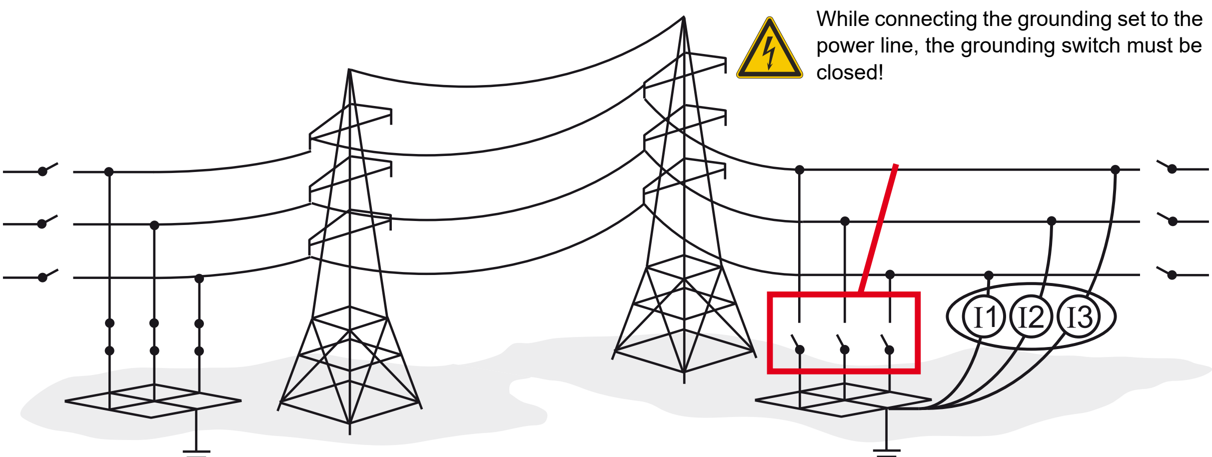


Figure 3-1: Estimating the open-line voltage

In order to allow a circular current, both ends of the line must be grounded. With a standard current clamp it is usually not possible to measure the current directly at the grounding switch. Therefore, the following procedure by using a grounding set is recommended:

1. Switch off, short-circuit and ground the power line on both sides, using an installed grounding switch or, if no grounding switch is available on site, using grounding cables (further on, the grounding switch or these extra grounding cables are referred to as grounding switch).
2. Make sure that the connection to ground at the far end of the power line is not removed during the complete test procedure.
3. In addition to the grounding switch, ground the line at the near end, using a grounding set consisting of three cables rated for the maximum short-circuit current possible on the line. Now the circular current is split between the near grounding switch and the grounding set.
4. Open the near grounding switch in order to measure the entire circular current via the grounding set.
5. Then measure the current in each of the three phases of the grounding set with a common current clamp and note the values. Depending on the geometry of the line the values for the currents could slightly differ.
6. Close the grounding switch again.
7. Disconnect the grounding set from the power line and ground.

Alternatively, the circular currents can also be measured directly at the grounding switch by using a Rogowski coil or other suitable measuring devices. Then the grounding set is not needed for the measurement of the circular currents. One advantage of the measurement is the possibility to detect contact problems at the grounding switch. If one of the measured currents is much lower than the others, this could indicate a contact problem at the grounding switch of that respective phase (this of course only refers to the measuring method using a Rogowski coil).

DANGER

Death or severe injury caused by high voltage or current

► Make sure all the contacts at the grounding switch are in good condition (free of oxidation). **Note:** If no voltage is measured on any of the phases, this does not necessarily mean that the grounding switch is working properly!

The estimated voltage can now be calculated according to equation Eq. 3-1 or 3-2 below by using the highest of the three measured currents.

Note: If line length is measured in kilometers use Eq. 3-1. For miles use Eq. 3-2.

$$V_{est} = l_{line} \cdot 2 \cdot 0{,}4 \cdot \frac{\Omega}{km} \cdot \max(I_{1,2,3}) \qquad \text{(Eq. 3-1)}$$

$$V_{est} = l_{line} \cdot 2 \cdot 0{,}64 \cdot \frac{\Omega}{mi} \cdot \max(I_{1,2,3}) \qquad \text{(Eq. 3-2)}$$

Table 3-2: Selection of current range, according to estimated voltage

Calculated Voltage (V_{est})	0...50 V	50...100 V	100...250 V	250...500 V
CP CU1 Current Range	100 A	50 A	20 A	10 A

► Select the *CP CU1*'s current range according to Table 3-2 above. Do not select a higher current range than selected according to line length! Only select a lower range if necessary.

Note: If the calculated voltage exceeds 500 V, the measurement cannot be performed, since the *CP CU1* is designed for a maximum working voltage of 500 V! If this is the case, please consider the following options:

- Try to reduce the interference from parallel lines by
  a) reducing the load flow on parallel lines,
  b) de-energizing parallel systems.
- Perform the measurements at another time, when load flow is lower.
- For overhead lines: Perform measurement on the most remote phase of the parallel system if the coupled voltage is lower than 500 V.

Note: If none of the above mentioned options is sufficient and you still need to conduct a measurement, contact OMICRON customer support. There is a special application available for such cases. For security reasons, this specific option is only performed by OMICRON engineers and is not offered as an official application to customers.

3.3 Third criterion: Measured open-line voltage

After the estimation of the open-line voltage, the *CP CU1* can now be connected to the line under test, in order to measure the actual open-line voltage and verify the estimation.

► Set up the *CP CU1* and the *CP GB1* according to Figure 3-2 below. The Kelvin clamps on the grounding box must be connected to the phase where the highest circular current has been measured and ground.

In the example in Figure 3-2 the *CP CU1* is connected to L2 and ground.

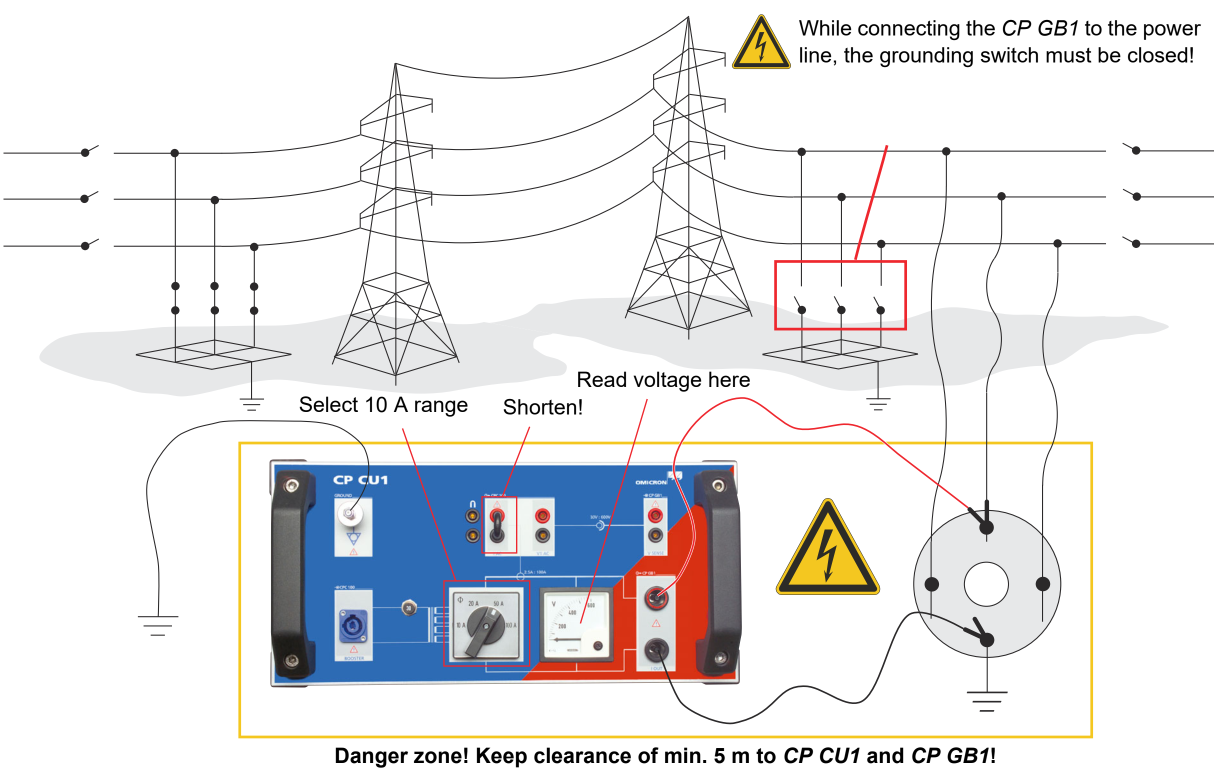


Figure 3-2: Measuring the coupled voltage with the *CP CU1*

To measure the open-line voltage, perform the following steps:

1. Make sure the grounding switch is closed!

WARNING

Death or severe injury caused by high voltage or current possible

Connecting grounding socket clamps of one type to a grounding point of another type is highly dangerous on both the connection of the grounding set to the *CP GB1* and the connection of the *CP GB1* to the grounding point in the substation. The 16 to 20 mm grounding socket clamp is designed and tested for fault currents up to 26.5 kA, the 25 mm (1 inch) grounding socket clamp for fault currents up to 30 kA, both for a maximum duration of 100 ms.

- ► Make sure to use the proper grounding socket clamp and that the grounding stud is in good condition, clean and free of oxidation!
- ► On locations where higher fault currents are possible than the grounding socket clamps are designed for, the *CP CU1* and the *CP GB1* must not be used!

2. Connect the *CP GB1* to ground near the place where the connection to the power line is made. Use the cable delivered with the *CP GB1* and the proper grounding socket clamp.
3. Connect the cables of the grounding set used for estimating the open-line voltage (see step 3. on page 25) to the *CP GB1*. (See Figure 3-2: on page 26).
4. Connect the other ends of the grounding set to the three phases of the power line.

WARNING

Death or severe injury caused by high voltage or current possible

- ► Position the *CP CU1* at a minimum distance of 5 m/15 ft from the *CP GB1*.
- ► Mark the area around the *CP GB1* in the range of at least 5 m/15 ft and around the *CP CU1* in the range of at least 2 m/6 ft as danger zone.

Note: Since the *CP CU1* is located within the danger zone, it must be positioned in a way to be able to read the voltage.

5. Ground the *CP CU1*, using a cable of at least 6 mm^2 cross-section, close to the position of the operator.
6. Connect the *CP CU1* with the *CP GB1* as shown in Figure 3-2: on page 26.
7. Select the 10 A range (500 V) on the *CP CU1* and shorten the **I** AC output.
8. Leave the danger zone and open the grounding switch.

WARNING

Death or severe injury caused by high voltage or current possible

- ► If you see or hear anything uncommon in the test equipment, for example, noise of electrical discharge or lightening of surge arrestors in the *CP GB1*, close the grounding switch before touching the measurement setup.

9. Read the voltage at the voltmeter of the *CP CU1* from outside the danger zone.
10. Close the grounding switch again!

11.Select the *CP CU1*'s current range according to Table 3-3 below. Do not select a higher current range than selected according to line length! Only select a lower range if necessary.

Note: If the measured voltage exceeds 500 V, the measurement cannot be performed, since the *CP CU1* is designed for a maximum working voltage of 500 V! If this is the case, please consider the options given in the previous section on page 26.

Table 3-3: Selection of current range, according to measured voltage

Measured Voltage	0...50 V	50...100 V	100...250 V	250...500 V
CP CU1 Current Range	100 A	50 A	20 A	10 A

Note: Furthermore, the safety concept of the *CP CU1* must be explained at this stage, since a higher voltage than the permissible voltage could be measured under particular circumstances. The insulation of the *CP CU1* is designed to withstand far higher voltages than the *CP GB1*'s surge arrestors do. Hence, there is no risk potential for the user if the actual voltage is higher than the calculated voltage as long as the safety clearance is respected.

3.4 Fourth criterion: Injected test current

The fourth and last criterion is the injected test current. Now the *CPC 100* needs to be connected to the *CP CU1* to be able to inject current and perform measurements.

Figure 3-3 below shows the measurement setup of the *CP CU1* and *CPC 100*. A more detailed overview over the necessary connections between the two units is given in Figure 3-4: on page 29.

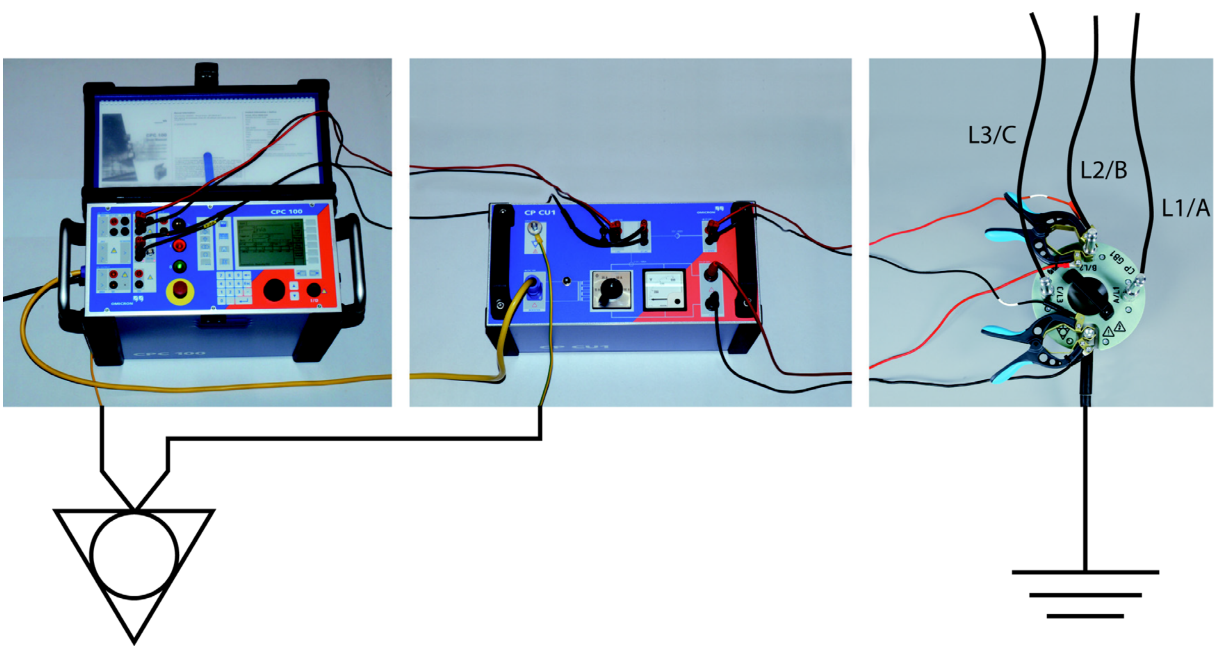


Figure 3-3: *CP CU1* measurement setup with *CPC 100* and *CP GB1*

To connect the *CPC 100* to the *CP CU1* perform the steps below. Keep in mind that you need to enter the previously mentioned danger zone to get access to the *CP CU1*'s front panel.

1. Make sure the grounding switch is closed and the *CPC 100* is switched off!
2. Position the *CPC 100* outside the danger zone, at least 5 m/15 ft away from the *CP CU1* and at least 10 m/30 ft away from the *CP GB1* respectively.
3. Ground the *CPC 100*, using a cable of at least 6 mm^2 cross-section, close to the position of the operator.
4. Connect the *CPC 100* to the *CP CU1* according to Figure 3-4 below.
   a) Connect the *CPC 100*'s EXT. BOOSTER output with the *CP CU1*'s BOOSTER input, using the yellow Booster Cable.
   b) Connect the *CP CU1*'s I AC output with the *CPC 100*'s I AC input, using a banana cable. Plug in the cable according to the color coding (red/black).
   c) Optional (for line impedance measurements only): Connect the *CP CU1*'s V1 AC output with the *CPC 100*'s V1 AC input, using the V1 AC coax. cable. Plug in the cable according to the color coding (red/black).

Note: If the *CP CU1*'s I AC output is not in use, shorten it with the short-circuit bar!

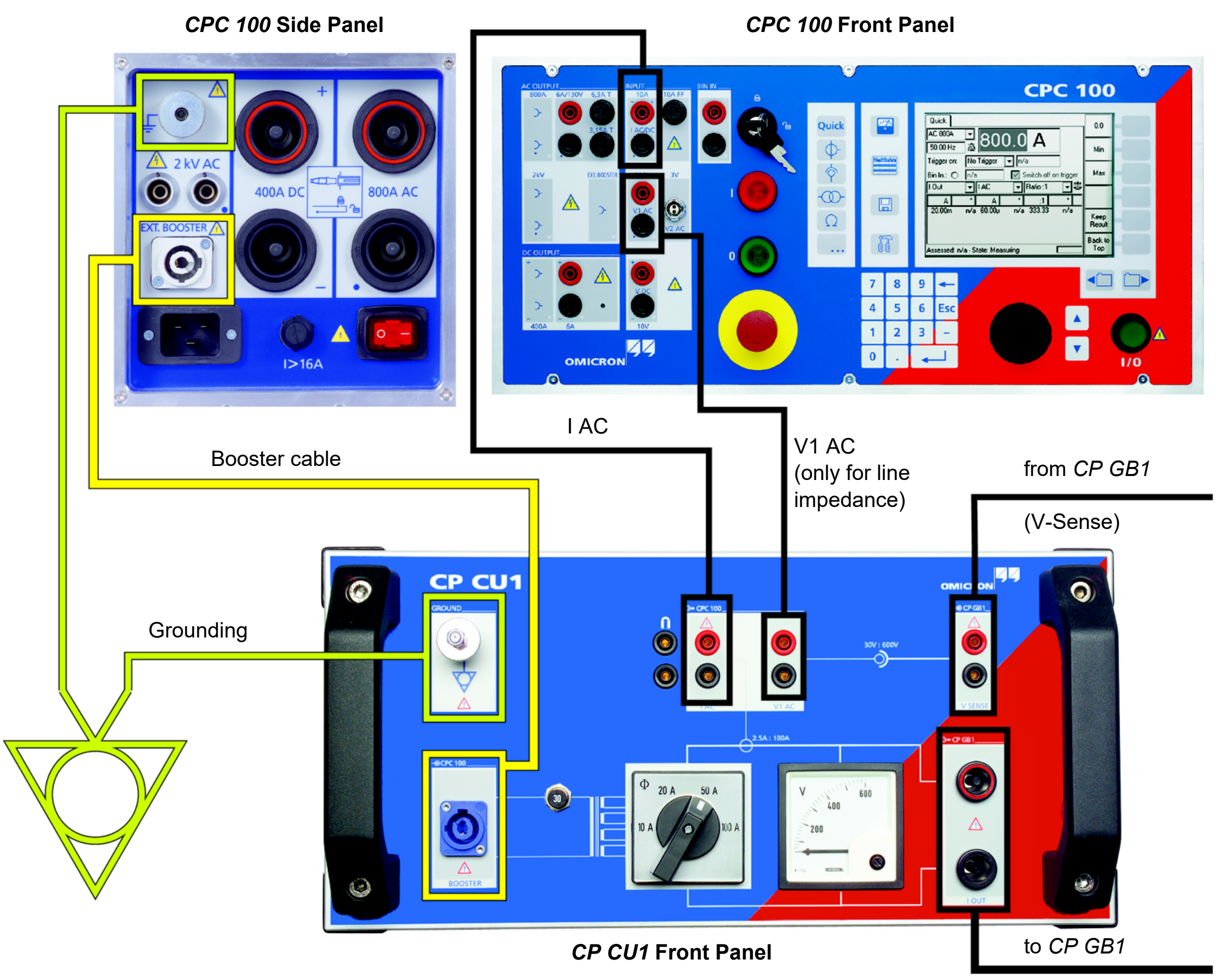


Figure 3-4: Connecting the *CPC 100* to the *CP CU1*

If the *CPC 100* is not capable of injecting the required current, the shape of the current is getting distorted. The distortion of the current causes harmonics. These harmonics can be suppressed effectively by frequency-selective measurement if the degree of distortion is small. It is recommended to inject at least 60 % of the required current if using one of the four *CPC 100* templates for 10 A, 20 A, 50 A and 100 A. If this isn't possible, select a smaller current range on the *CP CU1* and load the corresponding template. In case it is not possible to inject 6 A in the 10 A current range, set the current in the *CPC 100* template to a lower value. However, if possible, try to inject at least 1 A to get reliable test results.

Based on experience, it is mostly phase-ground loops on overhead lines and phase-phase loops on power cables which have the highest loop impedance. Therefore, these loops should be taken for assessing the *CP CU1*'s ability of current injection.

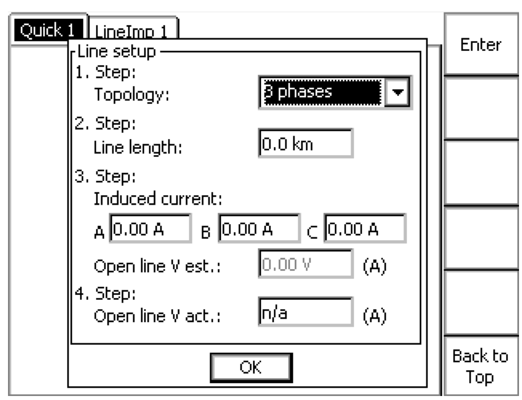
3.5 Using the Line Impedance test card to check the four criteria

If you want to perform line impedance measurements with the new **Line Impedance** test card, you should use the work-flow of the new **Line Impedance** template (which includes the new test card) to check the four criteria.

If you need to check the criteria before performing grounding system or coupling into signal cables measurements, you could use the test card to check criteria 1 to 3 but would have to perform the manual check of the fourth criterion as described in 3.4 "Fourth criterion: Injected test current" on page 28.

Note: If you just plan to use the Line Impedance test card for checking the first three criteria, you can open it directly by pressing the **Resistance** accelerator key situated left of the *CPC 100*'s display.

For a description of the Line Impedance test card refer to 4.1 "Line Impedance test card" on page 35.



1. Open the Line Impedance template on the *CPC 100* by following this path in the file operations view: Templates > Cable & Transmission Line > **Line Impedance 1/2/3-Phase** or **Mutual Coupling** (depending on the asset under test).

   Note: The **Line Setup** sub-window is opened automatically.
2. Select the asset type under **1. Step: Topology**.
   Note: For measurements on double-circuit lines select **3 phases, coupled (mutual coupling)**.
3. Enter the length of the line you want to measure under **2. Step: Line length**.
4. Measure the circular currents at the grounding switch at the near end of the line or alternatively at a grounding set you connected to the line. For a description of the procedure refer to 3.2 "Second criterion: Estimated open-line voltage" on page 24.
5. Enter the results under **3. Step: Induced current**.
   The test card will then calculate the estimated open-line voltage (**Open line V est**).
6. Connect the *CP CU1* to the power line as described in 3.3 "Third criterion: Measured open-line voltage" on page 26 to measure the actual line voltage and verify the estimation.
7. Enter the measurement result under **Open line V act**. Then press **OK** to conclude line setup.

The system will calculate the needed current range for the *CP CU1* and display it in a new sub-window. The suggested current range needs to be selected via the current range switch at the front panel of the *CP CU1*. Additionally, the needed current range is automatically set in the main page of the Line Impedance test card.
If the measurement is not possible, because the criteria to conduct a safe and reliable measurement were not met, an error message is shown.

Note: The fourth criterion (Injected test current) is checked in each measurement loop of the line impedance measurement. If the actually injected test current does not reach 60 % of the set current, an error message is displayed. In this case the current setting needs to be decreased accordingly.

4 Line impedance measurements

Distance protection relays require accurate line parameters in order to ensure selectivity and to avoid zone under- or overreach respectively. The fault locator as well requires correct line parameters to be able to determine the fault location accurately. In general, distance protection relays consider the line as balanced by employing the line model shown below, which is characterized by the impedances $\underline{Z}_1$ and $\underline{Z}_E$. Please note that $\underline{Z}_1$ is sometimes also called $\underline{Z}_L$. The purpose of the line impedance measurement is to determine the line model's parameters.

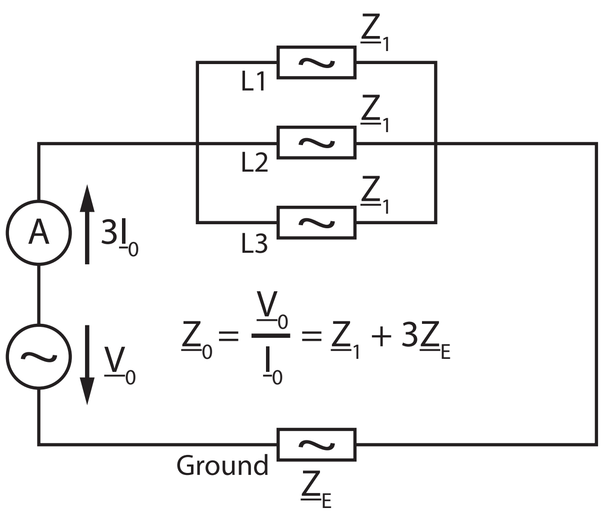


Figure 4-1: Zero-sequence impedance definition

The performance of most distance protection relays depends on the positive-sequence reactance X_1 and the k factor. X_1 is used to define the zone reach, which is crucial for the relay to decide in which zone a fault occurs. If it is a phase-to-phase fault, the reactance of the fault loop is divided by two and compared to X_1. If the fault reactance, divided by two, is smaller than X_1, the fault is supposed to occur in zone 1 and the relay trips immediately. If it is a phase-to-ground fault, the impedance of the fault loop is processed by using the k factor. The resulting reactance is then compared to X_1 in the same way as in case of a phase-to-phase fault. Therefore, distance protection relays only operate selectively if the correct settings for X_1 and k factor are used!

Note: The above paragraph describes the distance protection working principle strongly simplified. The algorithms implemented in a distance protection relay are much more complex and shall not be commented any further here.

The following three k factor formats are commonly used in distance protection relays:

1. The complex ratio of the ground impedance $\underline{Z}_E$ and the line impedance $\underline{Z}_L$:

$$\underline{k}_L = \frac{\underline{Z}_E}{\underline{Z}_L} = \frac{\left(\frac{\underline{Z}_0}{\underline{Z}_1} - 1\right)}{3} \qquad \text{(Eq. 4-1)}$$

   Note: $\underline{Z}_1 = \underline{Z}_L$

2. the complex ratio of the zero-sequence impedance and the positive-sequence impedance (see Figure 4-1: "Zero-sequence impedance definition" on page 32):

$$\underline{k}_0 = \frac{\underline{Z}_0}{\underline{Z}_1} \qquad \text{(Eq. 4-2)}$$

3. and a couple of real values

$$k_R = \frac{R_E}{R_L} \qquad \text{(Eq. 4-3)}$$

$$k_X = \frac{X_E}{X_L} \qquad \text{(Eq. 4-4)}$$

where R_E and X_E are the real and imaginary parts respectively of the ground impedance and R_L and X_L are the real and imaginary parts respectively of the line impedance.

Measurements have shown that in a significant number of cases the k factor of the measured lines is set more than 20 % from its actual value. This is because $\underline{Z}_E$ and $\underline{Z}_0$ respectively cannot be accurately determined by calculation since the properties of the soil are not known. Therefore, a line impedance test has to be performed in order to obtain correct values and allow fast, reliable and selective distance protection.

Figure 4-2 below illustrates the zone reaches of zone 1 for all 6 possible fault loops, in a typical example of an accurately calculated line impedance but a drastically miscalculated k factor. The actual k factor derived by measurement was 1.45, whereas a k factor of 0.65 was used to set the protection relay.

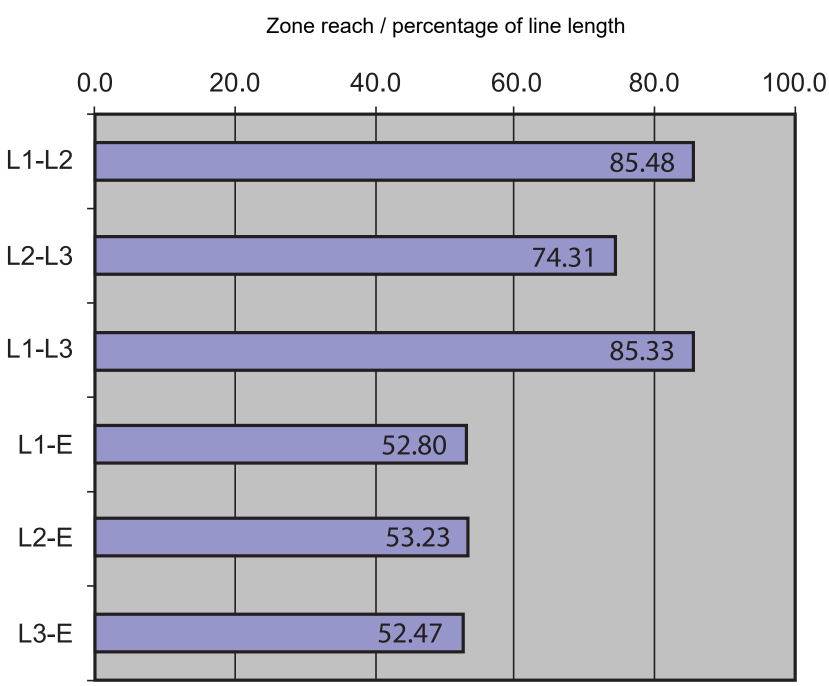


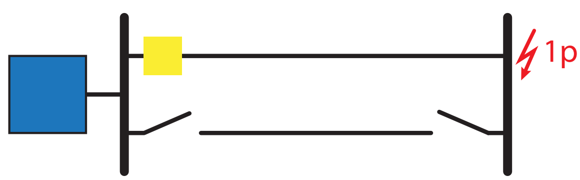
Figure 4-2: Zone reaches

However, the k factor does not only depend on the soil's properties. For double-circuit lines, mutual coupling effects must be taken into account, which also have an impact on the k factor. There are various configurations of double or multi-circuit lines where mutual coupling has to be considered in different ways. In this manual mutual coupling shall only be considered for the following configurations:

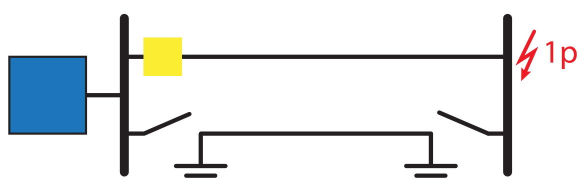
- Only single infeed, either via the local or the far end of the line.
- $\underline{I}_0$ of System II is not measured. If this current was measured, the portion of the voltage, which is caused by mutual coupling, could be determined by employing the mutual coupling impedance $\underline{Z}_{0M}$. Therefore, the k factor corresponding to the case where no coupling is existing (parallel circuit de-energized and not grounded) can be used here.
- Only real double-circuit lines are considered here. This means that both circuits are interconnecting the same busbars / substations.

It is useful to focus on the 4 following cases for the above mentioned configurations:

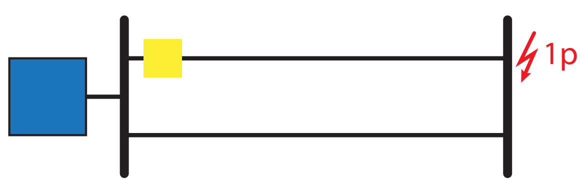
- Case 1: No coupling from parallel line is considered. The parallel line is de-energized and not grounded on both ends.



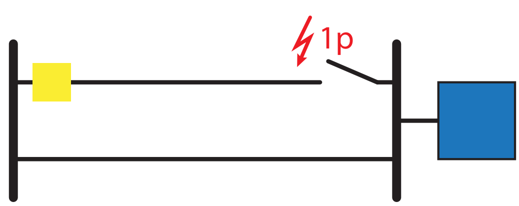
- Case 2: The parallel line is grounded on both ends. The fault impedance of a single-phase fault is smaller than for case 1. This is because the current induced in the parallel line is flowing into the opposite direction of $\underline{I}_0$. The higher $\underline{Z}_{0M}$ is, the lower is the fault impedance.



- Case 3: The parallel line is in operation. The fault impedance of a single-phase fault is higher than for case 1. This is because $\underline{I}_0$ in the parallel line is flowing into the same direction as in line I. The higher $\underline{Z}_{0M}$ is, the higher is the fault impedance.



- Case 4: The fault is fed via the far end of the parallel line. Here the fault impedance is even lower than in case 2 as $\underline{I}_0$ in line I and II have the same amplitude but are flowing into opposite directions.



For more complex line configurations an appropriate combination of the four cases must be considered, in order to find the correct parameter setting for the k factor.

Note: The OMICRON software *RelaySimTest* allows to simulate phase-to-ground faults for complex line configurations, by considering mutual coupling effects. This allows simple and accurate determination of the k factor for all network scenarios.

For measuring the mutual coupling impedance $\underline{Z}_{0M}$, the template requires two measurements. The advantage here is that no measurement is required on system II. Rather, all measurements are conducted on system I. In the first measurement, system II is separated from the ground on at least one end. Consequently, no current can flow through system II. The result is the zero-sequence impedance $\underline{Z}_{01}$ for the case that no current can flow in system II. For the second measurement, both ends of the line have to be grounded to ensure a flow of current. However, the voltage in system II becomes zero. The result of this measurement is the zero-sequence impedance $\underline{Z}_{02}$. The mutual coupling impedance $\underline{Z}_{0M}$ is now calculated from $\underline{Z}_{01}$ and $\underline{Z}_{02}$:

$$\underline{Z}_{0M} = 3\sqrt{(\underline{Z}_{01} - \underline{Z}_{02}) \cdot \underline{Z}_{01}} \qquad \text{(Eq. 4-5)}$$

4.1 Line Impedance test card

Additionally to the **Line Impedance** template, there now is also a **Line Impedance** test card optionally available (for more information contact OMICRON customer support).

Ω The test card is accessible via the **Resistance** accelerator key situated left of the *CPC 100*'s display. The **Line Impedance** test card can then be selected from a list.

4.1.1 Set-Up/Guidance

Upon opening the **Line Impedance** test card, the **Set-Up** sub-window is automatically shown. It is used to determine the current range that needs to be used for the respective test object.

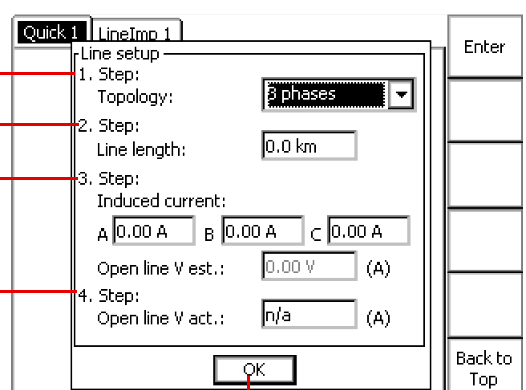
1. Step: Select the asset type. The options are:

- **3 phases**
- **3 phases, coupled** (mutual coupling)
- **2 phases**
- **1 phase**

2. Step: Line Length: Enter the length of the line to be measured. (See 3.1 "First criterion: Line length" on page 24).

3. Step: Induced Current: Enter the short-circuit currents measured for each phase when connecting the *CP CU1* to a power line.
(See 3.2 "Second criterion: Estimated open-line voltage" on page 24).

4. Step: Open Vclamp: Enter the open-line voltage measured when connecting the *CP CU1* to a power line. (See 3.3 "Third criterion: Measured open-line voltage" on page 26).



The recommended current range for the *CP CU1* is calculated and provided in a new sub-window. If the measurement is not possible because the criteria to conduct a safe and reliable measurement were not met, an error message is shown.

Figure 4-3: **Guidance** sub-window

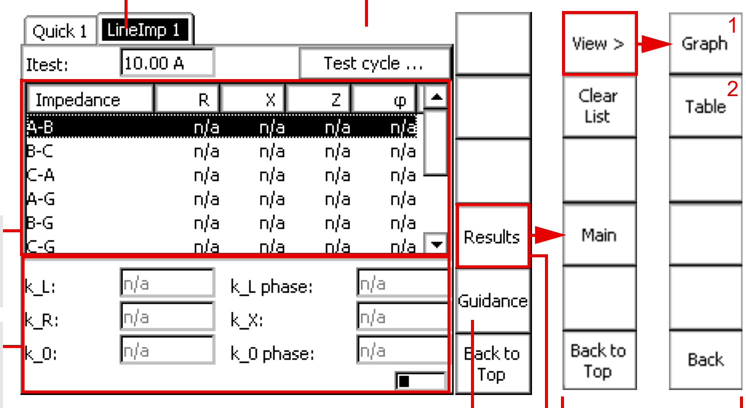
4.1.2 Main page

After the **Set-Up** sub-window is closed by clicking **OK**, the main page of the **Line Impedance** test card is accessible.

The measurement current recommended in the **Set-Up** sub-window.

Note: After the first measurement loop is concluded the **Line Impedance** test card prohibits any change of the measurement current that would necessitate to switch to another current range.
Example: If the first measurement loop was conducted with a current of 12.5 A (20 A current range), it is not possible to change the measurement current to 10 A as currents below 10.01 A are part of the 10 A current range.

Opens the **Test Cycle** sub-window. (See 4.1.3 "Test Cycle" on page 36).



Measurement loops. The number of loops depends on the selection under **Step 0** in the **Set-Up** sub-window. (See 4.1.1 "Set-

k factor values calculated from the line impedance measurement results. k factor results are shown as soon as enough data is available and get more precise with every measurement loop concluded.

Note: If too few measurement loops are conducted k factor calculation is not possible and no results will be shown.

Opens the **Set-Up** sub-window. (See 4.1.1 "Set-Up/Guidance" on page 35).

Shows the measurement results in more detail. Either as **Graph**[1] (see 4.1.4 "Results – Graph" on page 37) or in a **Table**[2] (see 4.1.5 "Results – Table" on page 37).

Figure 4-4: Main page of the **Line Impedance** test card

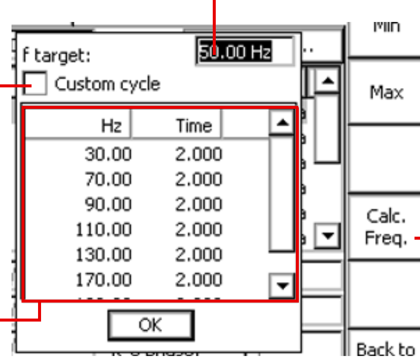
4.1.3 Test Cycle

In the **Test Cycle** sub-window the frequency sweep of a measurement loop can be adjusted.

In the **Target Freq.** text field mains frequency can be set. By default the *CPC 100* uses the frequency that was set under **Default freq.** in the **Device Setup** page of the **Options** menu.

Note: If the mains frequency setting is changed, the frequency sweep will be altered accordingly.

When activated, a custom frequency sweep can be defined in the area below the check box.



Resets the frequency sweep to the settings recommended by OMICRON.

The frequencies used in the current frequency sweep.

Figure 4-5: **Test Cycle** sub-window

4.1.4 Results – Graph

The **Graph** page is accessible via the buttons **Results/View >/Graph**.

Note: It is possible to perform measurements from within the **Results** pages (**Graph** and **Table**). For this purpose the respective measurement loop needs to be selected from the **Loop** check box at the top of the **Graph** or **Table** page. After the necessary connections at the *CP CU1* and the *CP GB1* have been made, the measurement loop can be started via the **I/O** button of the *CPC 100*.

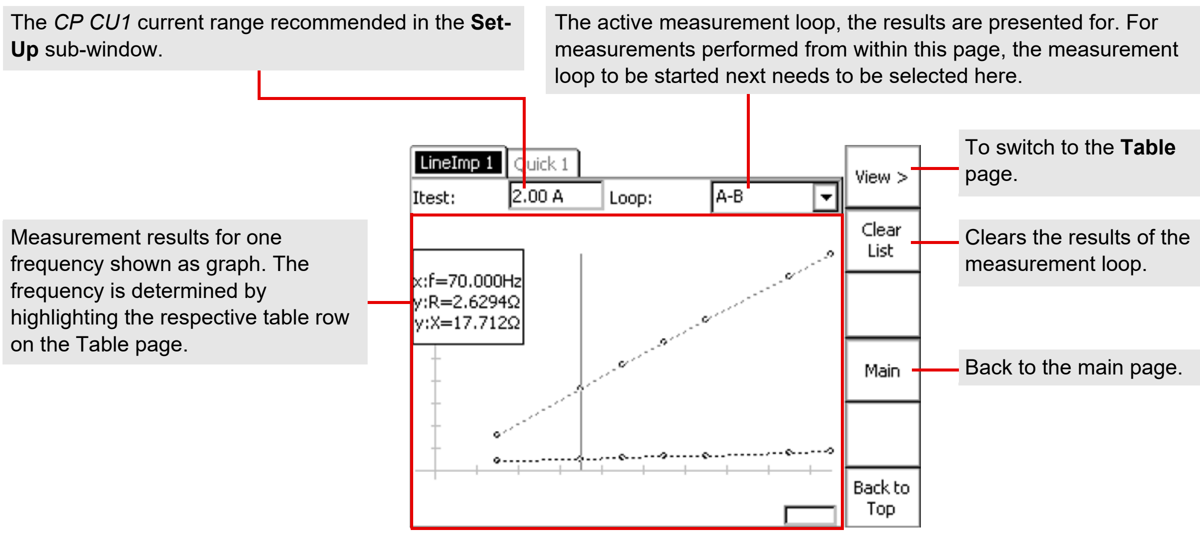


Figure 4-6: **Graph** page (**Results**)

4.1.5 Results – Table

The **Table** page is accessible via the buttons **Results/View >/Table**.

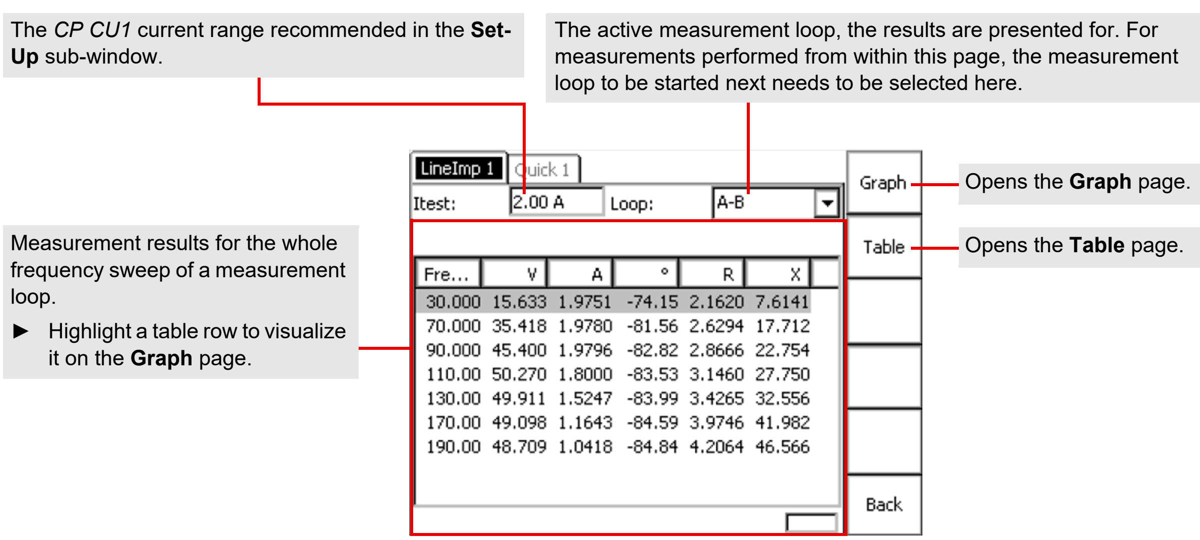


Figure 4-7: **Table** page (**Results**)

4.2 Line impedance measurement on single-circuit lines

Please note that this measurement only applies to a single-circuit line where no mutual coupling to parallel lines must be considered. This is the case for overhead transmission lines without any parallel system and most of the power cables no matter if there is another cable in parallel to it. There, however, can be seldom cases of mutual coupling in cables.

WARNING

Death or severe injury caused by high voltage or current possible

► Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test and check the four criteria either using the Line Impedance test card (see 3.5 "Using the Line Impedance test card to check the four criteria" on page 30) or manually as described in sections 3.1 to 3.4 (starting on page 24).

As an example, Figure 4-8 below shows the connection of the *CP CU1* to the *CP GB1* for measurement loop L1-L2.

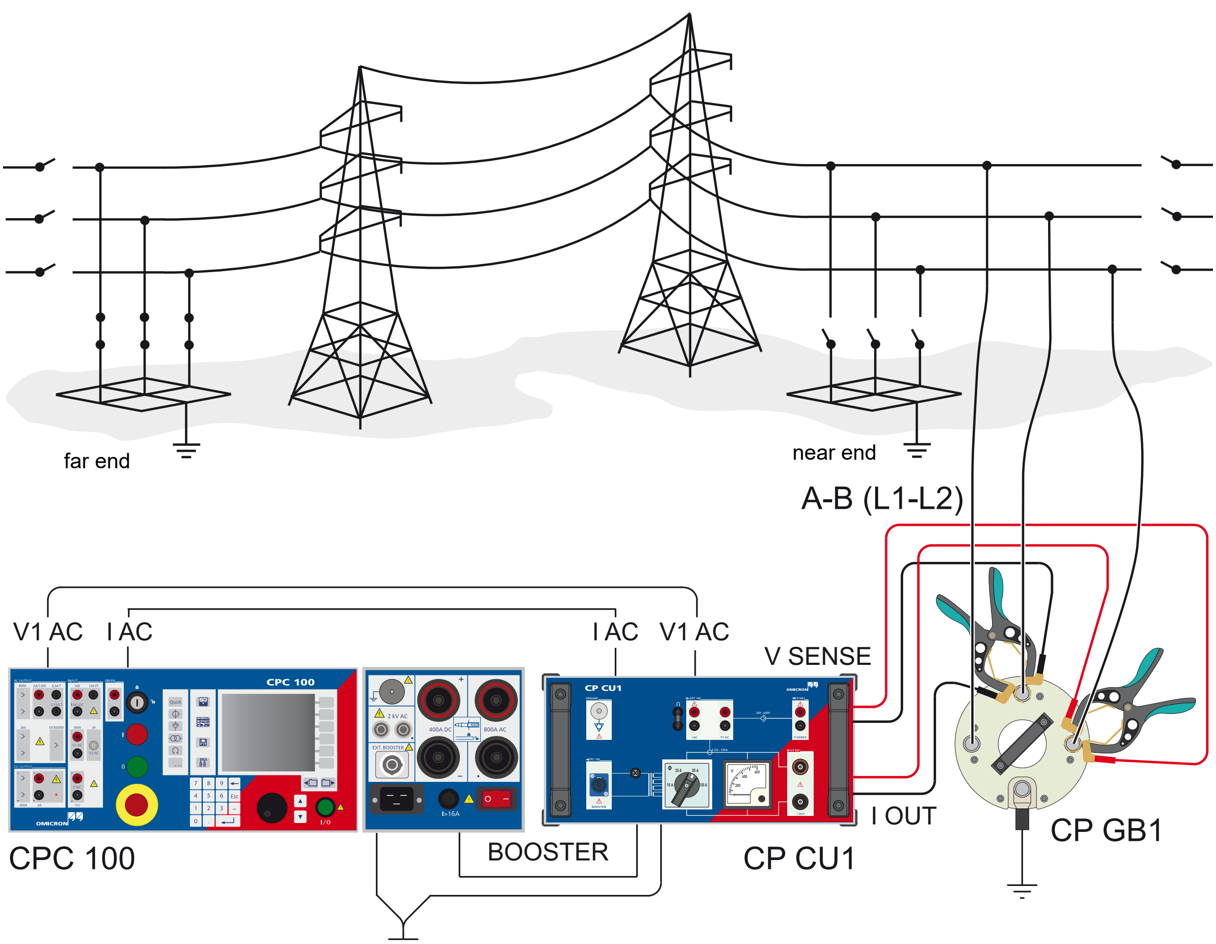


Figure 4-8: Line impedance measurement loop A-B (L1-L2)

2. Change the connection accordingly for all other test loops as shown in Figure 4-9 below.
3. Use the three-lead cable (see 2.4.2 "Shorting the phases" on page 16) to shorten the three phases for the last test loop **L1L2L3-E**.

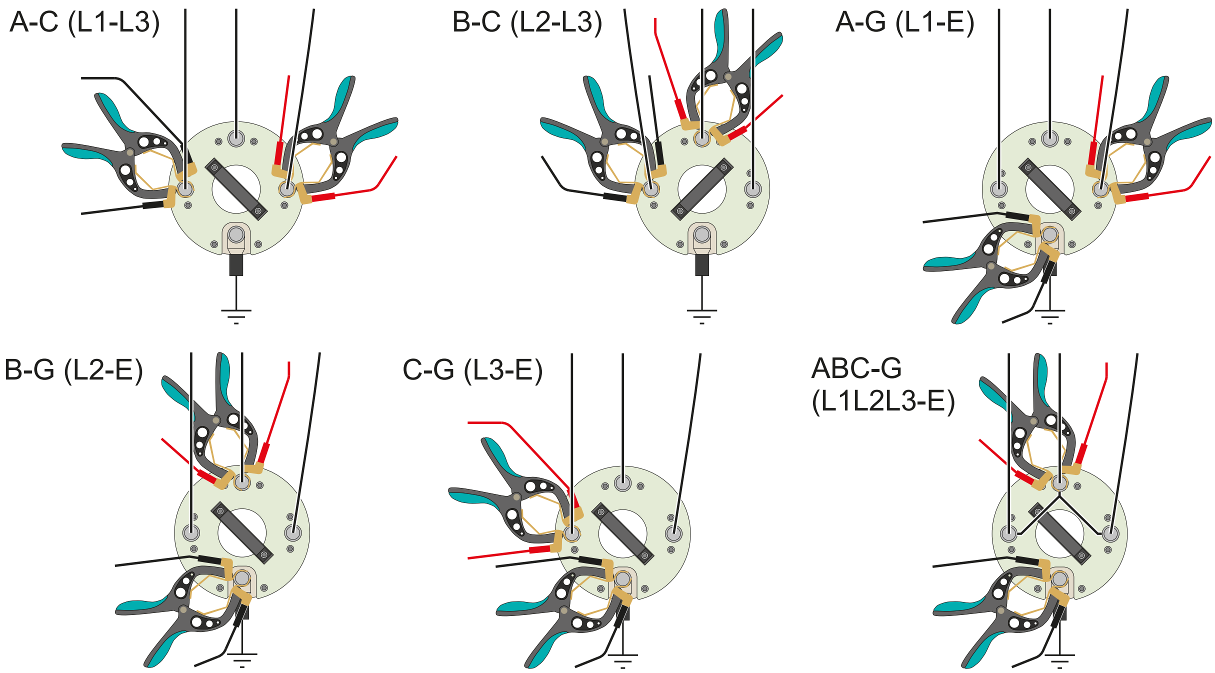


Figure 4-9: Clamp connections for measurement loops 2 to 7

4.2.1 Using the *CPC 100*'s Sequencer test card to perform the line impedance measurement

1. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Other > **Line Impedance**

2. Choose the template matching the current range selected on the *CP CU1*.

The template contains the following test cards:

- **Schema L1-L2** (comment test card, showing the necessary connections)
- **L1-L2** (sequencer test card - the actual measurement)
- **Schema L1-L3**
- **L1-L3**
- **Schema L2-L3**
- **L2-L3**
- **Schema L1-E**
- **L1-E**
- **Schema L2-E**
- **L2-E**
- **Schema L3-E**
- **L3-E**
- **Schema L1L2L3-E**
- **L1L2L3-E**
- **Version** (version check for Excel template)

The **Schema** test cards are comment test cards, which show how to connect the clamps to the *CP GB1*. The measurement is then performed in the sequencer test card which is following the **Schema** test card.

3. Press the **I/O Button** on the *CPC 100*'s front panel to start a measurement after you have connected the clamps to the *CP GB1* according to the respective **Schema** test card as well as Figure 4-8: "Line impedance measurement loop A-B (L1-L2)" on page 38 and Figure 4-9: "Clamp connections for measurement loops 2 to 7" on page 39.

The measurement is stopped automatically after the sequence has terminated.

Note: The near end of the line must not be grounded during the injection of the test current! Ground the line immediately after the measurement!

It is recommended to save the test file on the *CPC 100* after each individual test loop to prevent loss of data in the event of an unexpected outage.

4. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Line Imp.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

4.2.2 Using the Line Impedance test card to perform the line impedance measurement

After you checked the first three criteria using the Line Impedance test card (see 3.5 "Using the Line Impedance test card to check the four criteria" on page 30) and confirmed the current range notification, the main page of the **Line Impedance** test card is opened. The needed current range for the test card is already automatically set under **Itest**.

Note: It is recommended to use the new **Line Impedance** template.

1. Press the **I/O Button** on the *CPC 100*'s front panel to start a measurement after you have connected the clamps to the *CP GB1* according to the respective **Schema** test card as well as Figure 4-8: "Line impedance measurement loop A-B (L1-L2)" on page 38 and Figure 4-9: "Clamp connections for measurement loops 2 to 7" on page 39.

The measurement is stopped automatically after the sequence has terminated.

Note: The near end of the line must not be grounded during the injection of the test current! Ground the line immediately after the measurement!

It is recommended to save the test file on the *CPC 100* after each individual test loop to prevent loss of data in the event of an unexpected outage.

2. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Line Imp 1-phase.xlt, Line Imp 2-phase.xlt or Line Imp 3-phase.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

4.3 Line impedance measurement on double-circuit lines (mutual coupling)

If mutual coupling to a parallel line must be considered, the test described in this section must be performed. Please note that the template only considers real double-circuit lines, which means that both circuits are interconnecting the same busbars.

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test and check the four criteria either using the Line Impedance test card (see 3.5 "Using the Line Impedance test card to check the four criteria" on page 30) or manually as described in sections 3.1 to 3.4 (starting on page 24).

WARNING

Death or severe injury caused by high voltage or current possible

► Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

As an example, Figure 4-10 below shows the connection of the *CP CU1* to the *CP GB1* for measurement loop A-B.

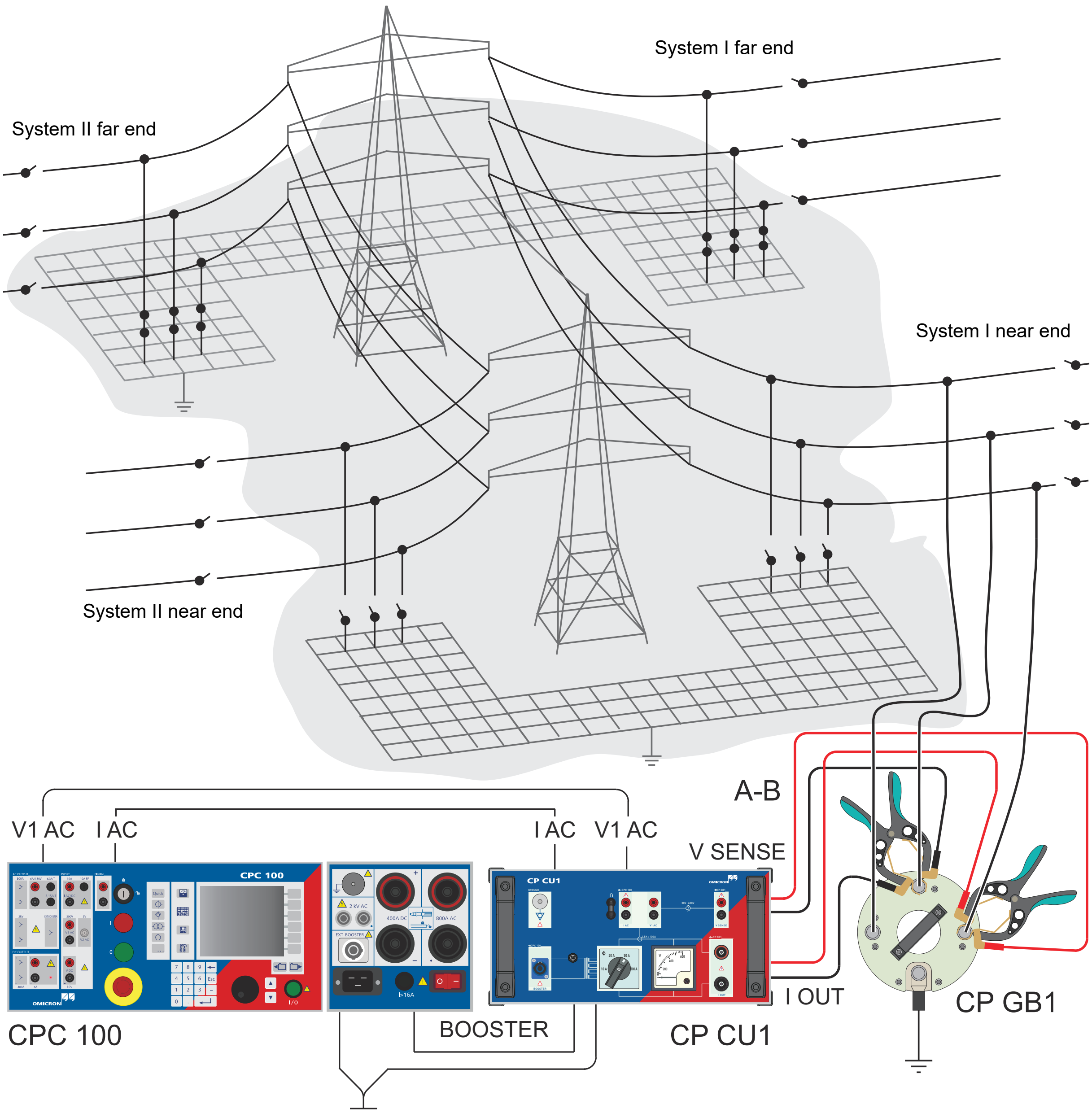


Figure 4-10: Mutual coupling measurement loop A-B

2. Change the connection accordingly for all other test loops as shown in Figure 4-11 below. Also note the state of the parallel system's grounding switches at the near end of the line.
3. Use the three-lead cable (see 2.4.2 "Shorting the phases" on page 16) to shorten the three phases for the last two test loops **Syst II grounded** (ABC-G) and **Syst II open** (ABC-G).

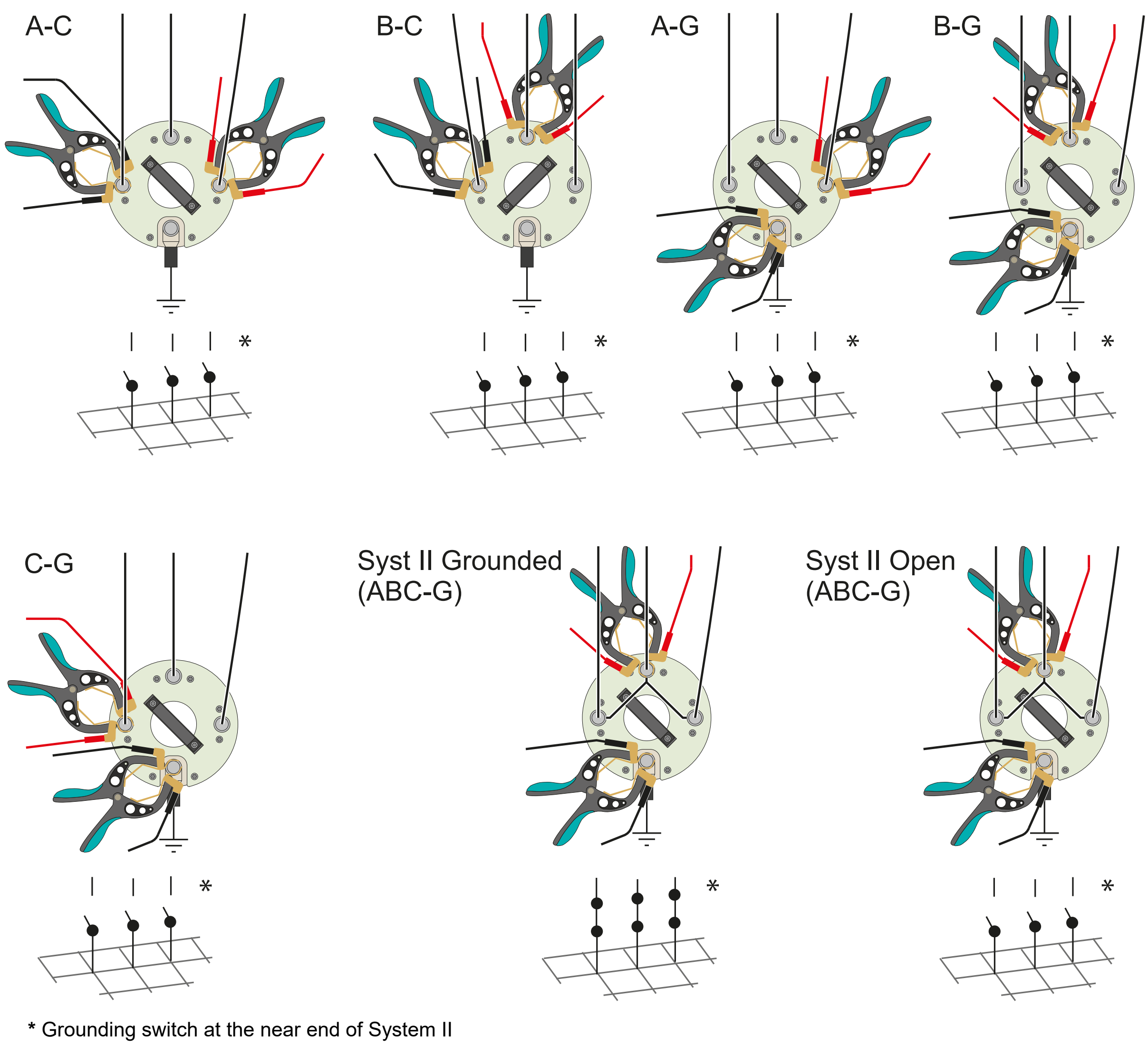


Figure 4-11: Clamp connections and state of near end grounding switch for measurement loops 2 to 8

4.3.1 Using the *CPC 100*'s Sequencer test card to perform the line impedance measurement on a double-circuit line

1. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Other > **Mutual Coupling**

2. Choose the template matching the current range selected on the *CP CU1*.

The template contains the following test cards:

- **Schema A-B** (comment test card, showing the necessary connections)
- **A-B** (sequencer test card - the actual measurement)
- **Schema A-C**
- **A-C**
- **Schema B-C**
- **B-C**
- **Schema A-G**
- **A-G**
- **Schema B-G**
- **B-G**
- **Schema C-G**
- **C-G**
- **Schema Syst II grounded** (ABC-G)
- **Syst II grounded** (ABC-G)
- **Schema Syst II open** (ABC-G)
- **Syst II open** (ABC-G)
- **Version** (version check for Excel template)

The **Schema** test cards are comment test cards, which show how to connect the clamps to the *CP GB1*. The measurement is then performed in the sequencer test card which is following the **Schema** test card.

3. Press the **I/O Button** on the *CPC 100*'s front panel to start a measurement after you have connected the clamps to the *CP GB1* according to the respective **Schema** test card as well as Figure 4-10: "Mutual coupling measurement loop A-B" on page 42 and Figure 4-11: "Clamp connections and state of near end grounding switch for measurement loops 2 to 8" on page 43.

The measurement is stopped automatically after the sequence has terminated.

Note: The near end of the line must not be grounded during the injection of the test current! Ground the line immediately after the measurement!

It is recommended to save the test file on the *CPC 100* after each individual test loop to prevent loss of data in the event of an unexpected outage.

4. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Mutual Coupling.xlt) from the *CPC 100* Start Page in the section Test Templates. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

4.3.2 Using the Line Impedance test card to perform the line impedance measurement on a double-circuit line

After you checked the first three criteria using the Line Impedance test card (see 3.5 "Using the Line Impedance test card to check the four criteria" on page 30) and confirmed the current range notification, the main page of the **Line Impedance** test card is opened. The needed current range for the test card is already automatically set under **Itest**.

Note: It is recommended to use the new **Line Impedance** template.

1. Press the **I/O Button** on the *CPC 100*'s front panel to start a measurement after you have connected the clamps to the *CP GB1* according to the respective **Schema** test card as well as Figure 4-10: "Mutual coupling measurement loop A-B" on page 42 and Figure 4-11: "Clamp connections and state of near end grounding switch for measurement loops 2 to 8" on page 43.

The measurement is stopped automatically after the sequence has terminated.

Note: The near end of the line must not be grounded during the injection of the test current! Ground the line immediately after the measurement!

It is recommended to save the test file on the *CPC 100* after each individual test loop to prevent loss of data in the event of an unexpected outage.

2. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Mutual Coupling 3-phase.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

5 Grounding system measurements

This User Manual complies with the following three standards related to AC grounding system safety and measurements:

- EN 50522:2011 - Earthing of power installations exceeding 1 kV a.c.
- IEEE 80-2013 - Guide for Safety in AC Substation Grounding
- IEEE 81-2012 - Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System

In the following, they are referred to as EN50522, IEEE 80 and IEEE 81.

During a ground fault the current returns to the neutral of the network. In order to establish a low-ohmic return path for the fault current, grounding systems allow a conductive, low-ohmic connection between the soil and the neutral of the network. In principal, a grounding system consists of conductive elements, such as wires, rods, etc. These elements have direct contact to soil, which allows a current between the soil and the neutral. The more conductive elements are brought into the ground, the better (resp. low-ohmic) the grounding system is.

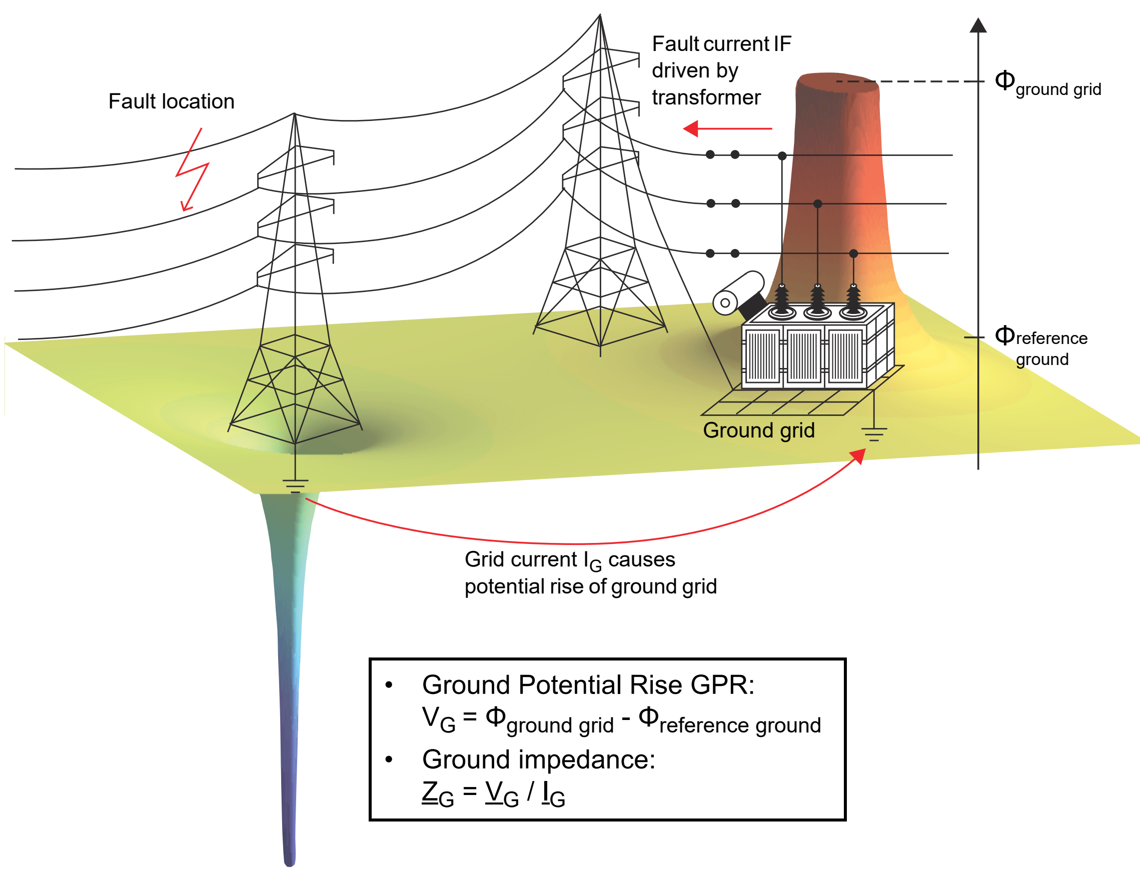


Figure 5-1: Potential during a ground fault

Figure 5-1 above shows the potential in the event of a ground fault on a line. The return current through soil causes a potential rise of the grounding system with regard to reference ground. The reference ground potential is represented by the green flat plain. In the vicinity of the grounding system the return current causes a cone-shaped potential rise V_G according to electromagnetic field theory.

The ground potential rise is considered as the voltage between the grounding system and an infinitely remote location. Practically the potential of this location is represented by the flat part around the grounding system's potential rise. This zone is considered as not being directly influenced by the grounding system anymore. Furthermore, the ground impedance Z_G is introduced, which represents the impedance between the grounding system and reference ground.

$$\underline{Z}_G = \frac{\underline{V}_G}{\underline{I}_G} \qquad \text{(Eq. 5-1)}$$

A high potential rise reveals a "bad contact" to reference ground and a high ground impedance respectively. In order to reduce the ground impedance, the grounding system must be extended by additional conductive elements or rotten conductive elements must be replaced.

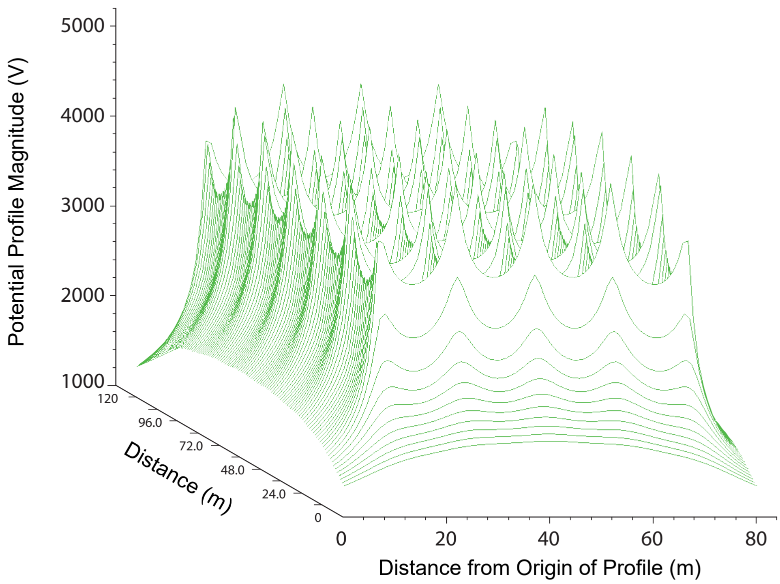


Figure 5-2: Potential contours of a ground grid

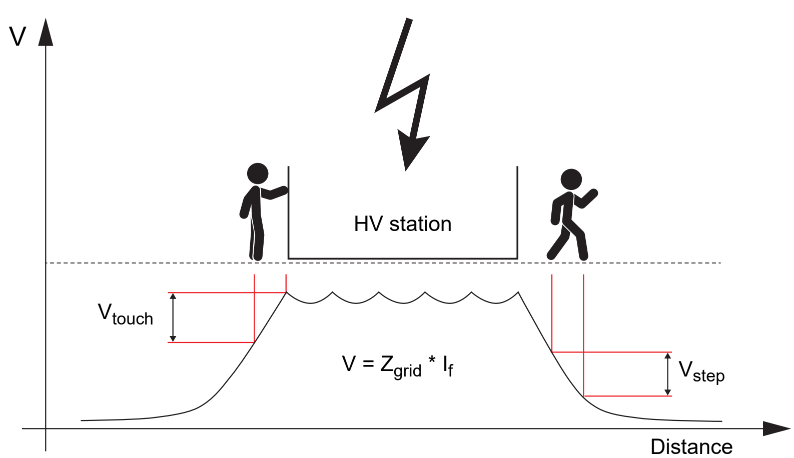


Figure 5-3: Step and touch

Figure 5-2 and Figure 5-3 on the previous page illustrate the potential rise of a ground grid in detail. In opposite to the simplified illustration in Figure 5-1, on page 46, the potential contour inside the grounding system is not flat. Therefore, step and touch voltages have to be considered in and outside the substation for personal safety.

A touch voltage is defined as the difference in potential between a grounded metallic structure and a location 1 m apart in the event of a ground fault. This scenario represents the worst case scenario for a person touching this object as a maximum arm span of 1 m is assumed.

A step voltage is defined as the difference in potential between two locations 1 m apart from each other in the event of a ground fault. This scenario represents the worst case scenario for a person being exposed to a step voltage by standing with his feet 1 m apart.

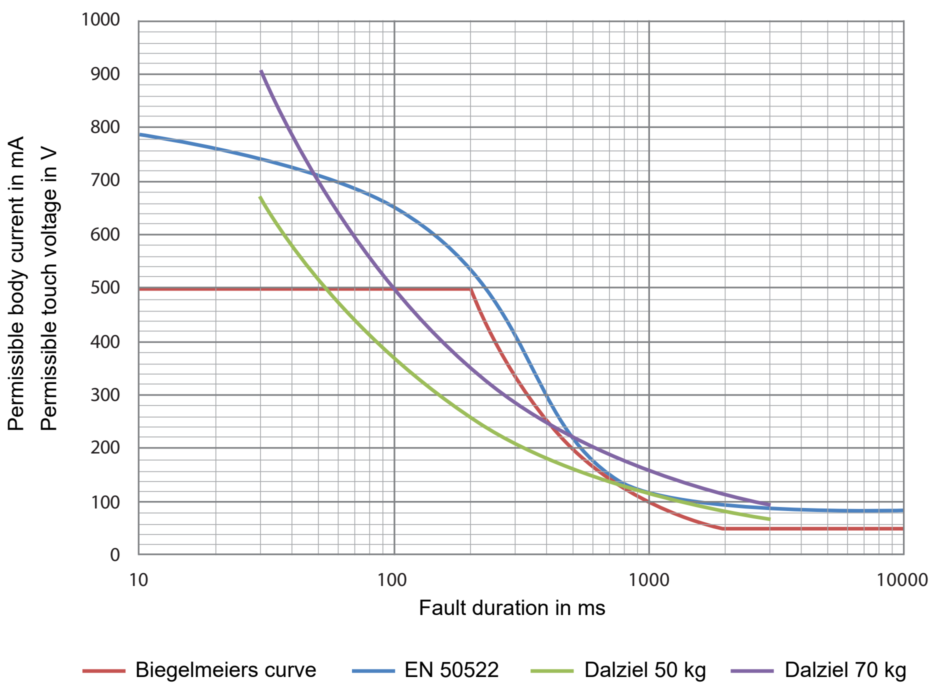


Figure 5-4: Permissible body currents from EN 50522 and IEEE 80

EN 50522 and IEEE 80 define permissible body currents as shown in Figure 5-4 above. IEEE 80 even proposes three different limits (Dalziel and Biegelmeier) but doesn't recommend any explicitly. These body currents depend on the maximum fault duration. The higher the fault duration is, the lower the permissible body current is. The body impedance is considered as 1 kΩ in both standards, which means that the permissible touch voltage is the same value in Figure 5-4 as the body current, just in V. However, for the measurement and the assessment of step and touch voltages the two standards define different approaches.

EN 50522 recommends a method simulating the human body, by measuring the touch voltage across a 1 kΩ resistor and using a metal plate, which is simulating bare feet. EN 50522 also recommends to wetten the soil underneath the metal plate, in order to simulate the worst case. IEEE 81 recommends to measure step and touch voltage with a high-ohmic volt meter and a rod, which is driven at least 8 inches (about 20 cm) into soil. Hereby the prospective touch voltage measured is higher than the touch voltage a person would be exposed to. Therefore, IEEE 80 also considers additional resistances for the assessment of step and touch voltages. The Excel template for step and touch voltage determines the permissible touch voltage for each of the two standards by respecting the fault duration and, if necessary, additional resistances.

Overhead transmission lines are usually equipped with a ground wire, whereas power cables are equipped with a shield. Both the ground wire and the cable shield reduce the grid current in the event of a ground fault, which causes lower step and touch voltages than in the case that none of them were present. In order to prove that a certain amount of the entire fault current returns via the ground wire (or shield) the reduction factor (also called current split factor) can be measured.

5.1 Ground impedance measurement

5.1.1 Measurements without *PTM* (stand-alone)

WARNING

Death or severe injury caused by high voltage or current possible

▶ Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test.
2. If criterion 3 is met, establish the measurement setup as shown in Figure 5-5 below.

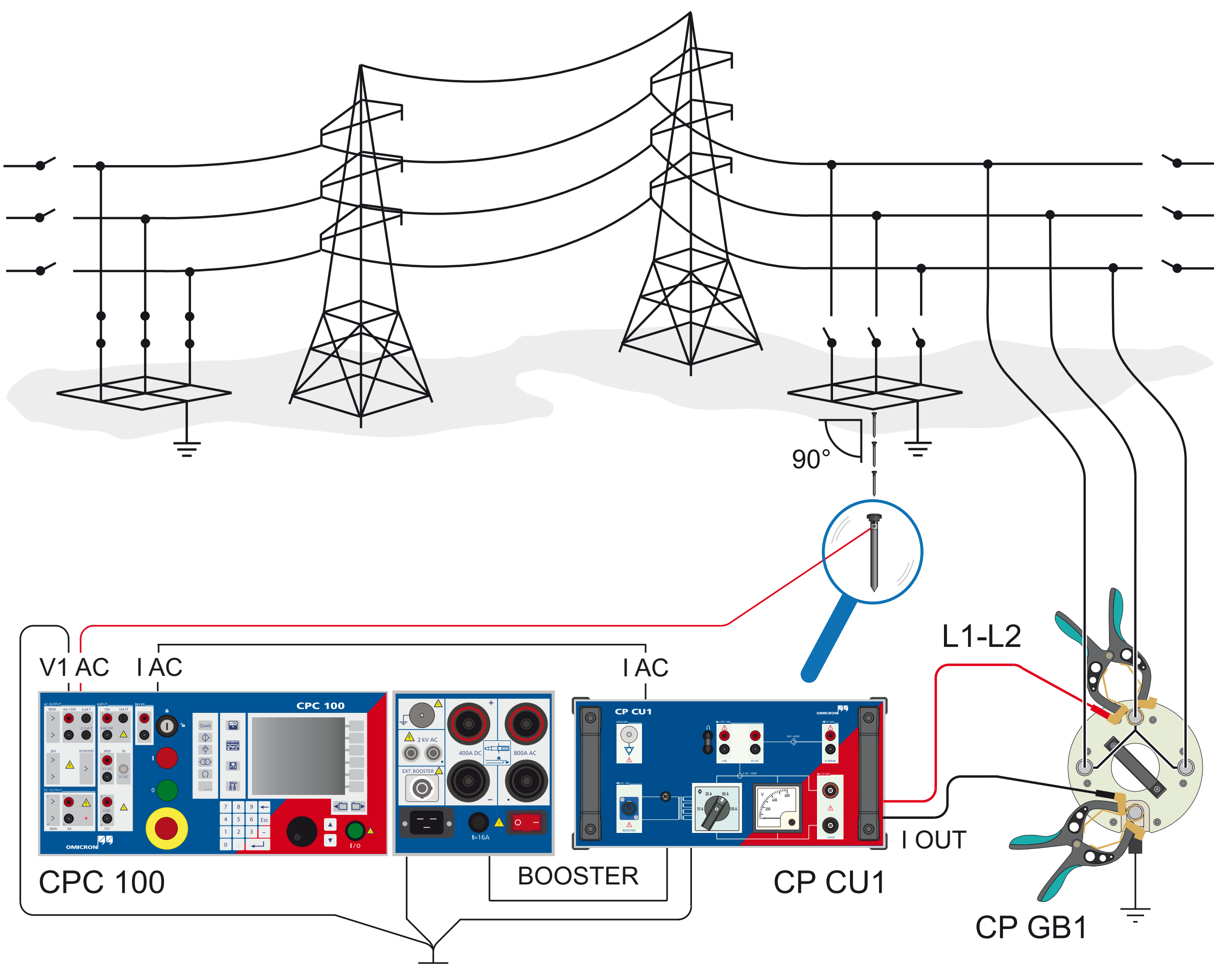


Figure 5-5: Ground impedance measurement setup

Note: In order to measure valid ground impedance values, the distance between the grounding system under test and the remote substation must be taken into account. IEEE 81 recommends a minimum distance of five times the maximum dimensions of the grounding system to avoid overlapping of the ground potential rise of both the grounding system and the current probe. EN 50522 recommends a distance of minimum 5 km, no matter the size of the grounding system.

In general, the setup must represent worst case conditions, which could occur during a single line fault. This must be clarified for each individual grounding system.

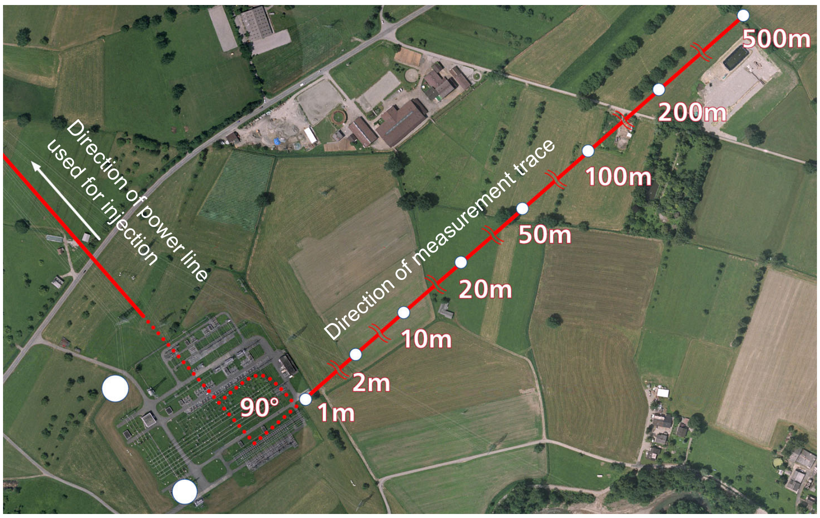


Figure 5-6: Direction of measurement trace

According to EN 50522 and IEEE 81 the angle between the line which is used for injection and the measurement trace must be 90° in order to avoid coupling effects, which might disturb the measurement. In cases this is not possible due to topographical or man-made obstacles in the surroundings of the substation, an angle of at least 60° should be maintained.

The measurement trace is realized by the use of ground rods that are placed at certain distances from the grounding system. The following distances can be taken as a guideline: 1 m, 2 m, 5 m, 10 m, 20 m, 50 m, 100 m, 150 m, 200 m, then increase in increments of 100 m.

WARNING

Death or severe injury caused by high voltage or current possible

In case of a fault, high voltage can occur at the far end of the measurement cable.

► It is recommended to unplug the test lead to the ground rod right at the V1 AC input of the *CP CU1* if no measurement is performed and the field crew moves to the next location. This is to avoid transferring potential to the remote end of the test lead in the event of a fault in the substation.

3. Follow the examples in Figure 5-6 above and Figure 5-5: on page 50, by connecting the black pin of the V1 AC input with any grounded part in the substation and the red pin with the rod, which is used as test electrode.

4. Place the ground rod at the distance from the grounding system you want to start the measurement from. In the present example this would be 1 m.

CAUTION

Minor or moderate injury caused by tripping on the measurement cable possible

► If the measurement cable crosses obstacles like roads or walkways, make sure to warn approaching persons about the cable to prevent accidents caused by tripping.

5. Press the **Options** view button to the left of the *CPC 100*'s display to enter the **Options** menu.

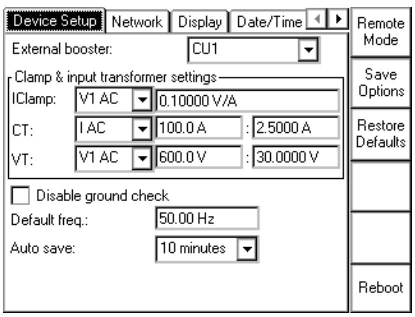


Figure 5-7: **Device Setup** tab of the *CPC 100* **Options** menu

6. Check whether "CU1" is set as booster under **External booster**.
7. If this is not the case, select "CU1" as booster.

The CT and VT settings are set according to the built-in current and voltage transformers automatically.

8. Press the **Testcard View Button** on the *CPC 100*'s front panel to switch to the test card view.
9. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Grounding Systems > **Ground Impedance**

10. Choose the template matching the current range selected on the *CP CU1*.

The template contains the following test cards:

- **Instruction**
- **Enter Distance** (sequencer test card). It has to be renamed according to the distance the measurement is started at. As the measurement is progressing, further test cards have to be added and named accordingly.
- **Version** (version check for Excel template)

11. Select the **Enter Distance** test card, by choosing the respective tab at the top of the template.

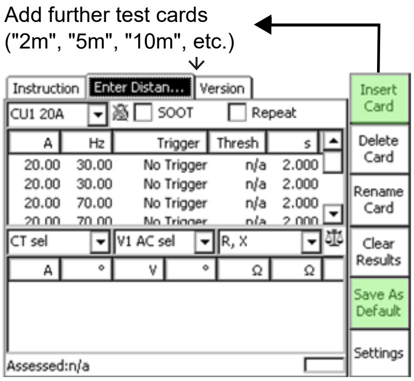


Figure 5-8: **Enter Distance** test card of the **Ground Impedance** template on the *CPC 100*

12. Press **Rename Card** from the right-hand toolbar to rename the **Enter Distance** test card to, for example, "1m" if you start the measurement trace at 1 m from the grounding system.

    Note: There must be no space between the numeral and the character, since the Excel template cannot handle it. So be sure to use "1m". Alternatively, you can use "ft" instead of "m".

13. Press **Save As Default** to overwrite the default settings for new sequencer test cards.

    Note: This way, your settings will be automatically applied to new sequencer test cards you need to add as the ground impedance measurement is progressing.

14. Press the **I/O** button on the front panel of the *CPC 100* to start the first measurement cycle.
15. After the measurement cycle is finished, move the ground rod to the next desired position. For example, this could be 2 m.
16. Press **Insert Card** to add a new sequencer test card.
17. Press **Rename Card** to rename the new test card according to the ground rod distance.
18. Press the **I/O** button on the front panel of the *CPC 100* to start the next measurement cycle.
19. Repeat the previous four steps until the ground impedance is not changing anymore and the flat part of the profile is reached.

It is recommended to save the test after each individual test point.

20. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Ground Imp.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

Applied Standard:		EN 50522:2011		Max. Fault Duration:		600 ms	
Reduction Factor of test current		Magnitude	Phase	Max. Current to Earth		900 A	
		0,60	0,00°				
“Permissible” Ground Potential Rise:				350 V			
Rated Frequency:		50,0 Hz					
Distance / m	Comment	R / Ω	X / Ω	Z / Ω	φ / °	V_{Step} / V/m	V / V
1		0,023	0,006	0,024	14,55		21,20
2		0,034	0,009	0,035	14,20	10,60	31,80
10		0,126	0,032	0,130	14,22	10,63	116,83

Figure 5-9: Ground impedance Excel template

The following information can be entered into the template:

- Applied Standard
- Maximum Fault Duration
- Reduction Factor of Test Current
- Rated Frequency

The template returns the following data in tabularized and graphical form:

- Ground Impedance
- Ground Potential Rise
- Step Voltage

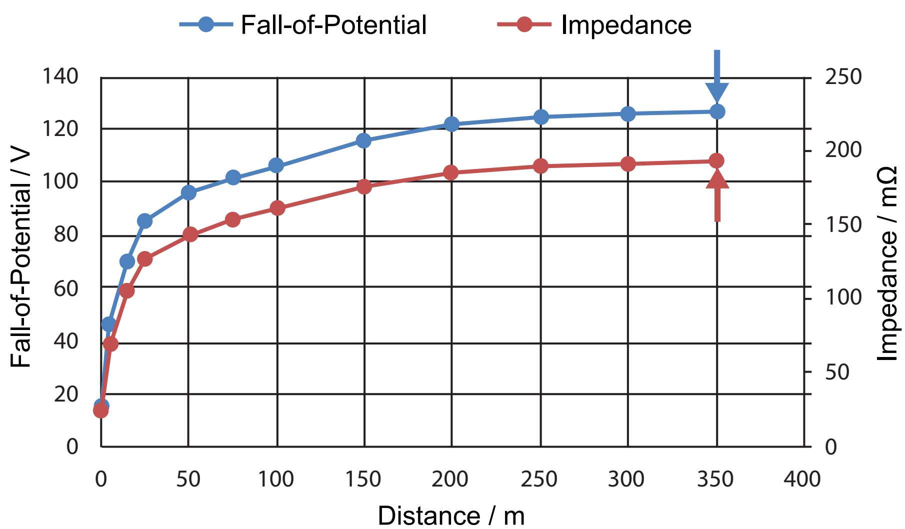


Figure 5-10: Impedance and voltage profile

The diagrams in Figure 5-10 above show the ground impedance and the ground potential rise. The value of the flat part of the curve is, respectively, the ground impedance and the ground potential rise of the grounding system under test. The two arrows mark the final measurement result.

According to EN 50522, the step and touch voltage measurement can be skipped if the ground potential rise is smaller than the permissible touch voltage multiplied by two. This value is also indicated in the template, as shown above. IEEE 80 does not mention any limit for ground potential rise or ground impedance.

5.1.2 Measurements with PTM (using a Windows tablet)

WARNING

Death or severe injury caused by high voltage or current possible

► Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test.
2. If criterion 3 is met, establish the measurement setup as shown in Figure 5-11 below.

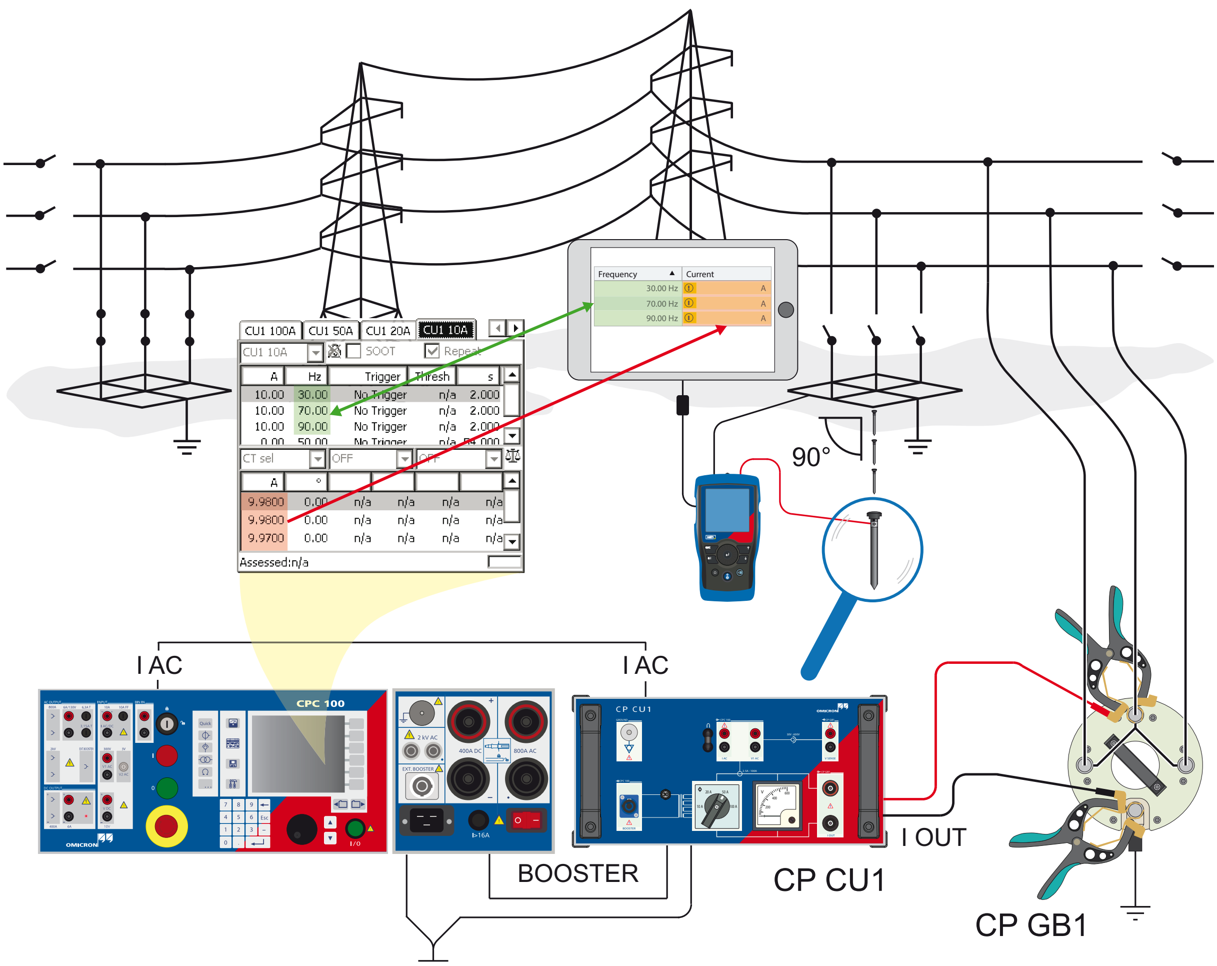


Figure 5-11: Ground impedance measurement setup when using *PTM* on a tablet

Note: In order to measure valid ground impedance values, the distance between the grounding system under test and the remote substation must be taken into account. IEEE 81 recommends a minimum distance of five times the maximum dimensions of the grounding system to avoid overlapping of the ground potential rise of both the grounding system and the current probe. EN 50522 recommends a distance of minimum 5 km, no matter the size of the grounding system.

In general, the setup must represent worst case conditions, which could occur during a single line fault. This must be clarified for each individual grounding system.

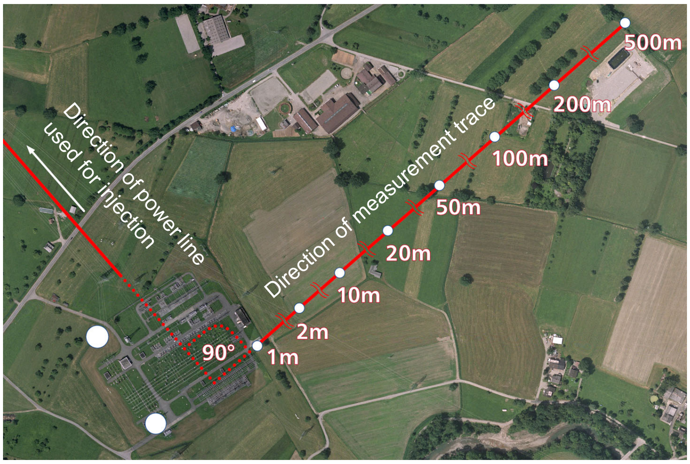


Figure 5-12: Direction of measurement trace

According to EN 50522 and IEEE 81 the angle between the line which is used for injection and the measurement trace must be 90° in order to avoid coupling effects, which might disturb the measurement. In cases this is not possible due to topographical or man-made obstacles in the surroundings of the substation, an angle of at least 60° should be maintained.

The measurement trace is realized by the use of ground rods that are placed at certain distances from the grounding system. The following distances can be taken as a guideline: 1 m, 2 m, 5 m, 10 m, 20 m, 50 m, 100 m, 150 m, 200 m, then increase in increments of 100 m.

3. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Grounding Systems > **PTM**

4. Open the file corresponding to your power frequency and navigate to the test card matching the current range selected on the *CP CU1*.

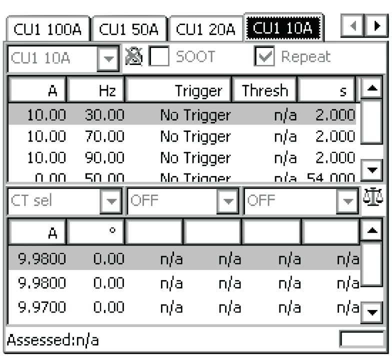


Figure 5-13: **CU1 10** test card of the **PTM** template on the *CPC 100*

Figure 5-13 shows settings in the **CU1 10** test card of the **PTM** template. The sequence consists of 4 states, which are applied in an endless loop, since **Repeat** is activated in the test card:

- Injection of the test current at 30 Hz for 2 s (measuring touch voltage at a distinct location at 30 Hz)
- Injection of the test current at 70 Hz for 2 s (measuring touch voltage at a distinct location at 70 Hz)
- Injection of the test current at 90 Hz for 2 s (measuring touch voltage at a distinct location at 90 Hz)
- No injection for 54 s (to be able to move to the next measurement location in the substation)

5. Start the injection by pressing the **I/0** button on the *CPC 100*.
6. Start *PTM* on the tablet and enter the *CPC 100*'s current readings for each defined frequency under **Settings and Conditions**. Also verify that the frequency selections in the sequencer test card and under **Settings and conditions** match.

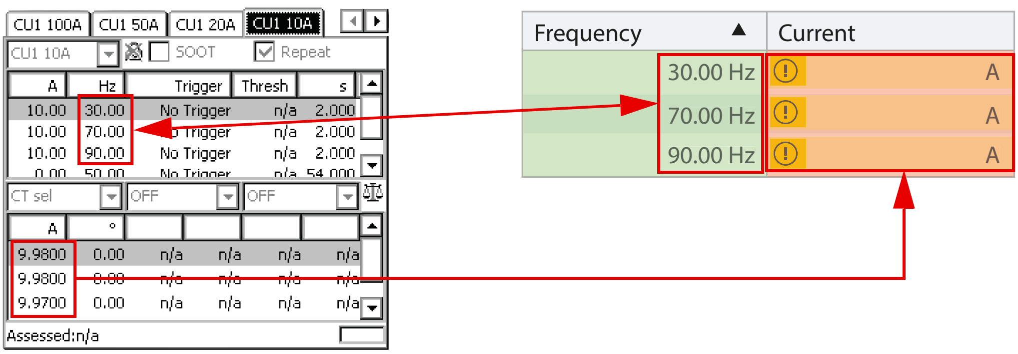


Figure 5-14: Enter the current readings under the **Settings and Conditions** section in *PTM*

7. Set the *HGT1*'s **USB mode** to **COM port** to enable communication with the tablet running *PTM*.
8. Connect the *HGT1* to the tablet using the *HGT1*'s USB connector and the delivered USB cable.

WARNING

Death or severe injury caused by high voltage or current possible

► Never connect the *HGT1* to the tablet without using the provided USB isolator.

As soon as the *HGT1* is recognized by *PTM*, it is locked and cannot be operated via its buttons any longer.

9. Follow the examples in Figure Figure 5-11: on page 55 and Figure 5-12: on page 56, by connecting the black input of the *HGT1* with any grounded part in the substation and the red input with the rod, which is used as test electrode.

WARNING

Death or severe injury caused by high voltage or current possible

In case of a fault, high voltage can occur at the far end of the measurement cable.

► It is recommended to unplug the test lead to the ground rod right at the *HGT1*'s red input if no measurement is performed and the field crew moves to the next location. This is to avoid transferring potential to the remote end of the test lead in the event of a fault in the substation.

10. Place the ground rod at the distance from the grounding system you want to start the measurement from. In the present example this would be 1 m.

CAUTION

Minor or moderate injury caused by tripping on the measurement cable possible

► If the measurement cable crosses obstacles like roads or walkways, make sure to warn approaching persons about the cable to prevent accidents caused by tripping.

11. Press the **I/O** button on the front panel of the *CPC 100* to start the first injection cycle.
12. Start the measurement in *PTM* section **Measurement**.
13. After the measurement is finished, move to the next location (for example 2 m) and start the next injection cycle and take measurements in *PTM* section **Measurement**.
14. Repeat the previous step until the ground impedance is not changing anymore and the flat part of the profile is reached.

According to EN 50522, the step and touch voltage measurement can be skipped if the ground potential rise is smaller than the permissible touch voltage multiplied by two. This value is also indicated in the template, as shown above. IEEE 80 does not mention any limit for ground potential rise or ground impedance.

5.2 Step and touch voltage measurement

5.2.1 Measurements without *PTM* (stand-alone)

WARNING

Death or severe injury caused by high voltage or current possible

▶ Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test.
2. If criterion 3 is met, establish the measurement setup as shown in Figure 5-15 below.

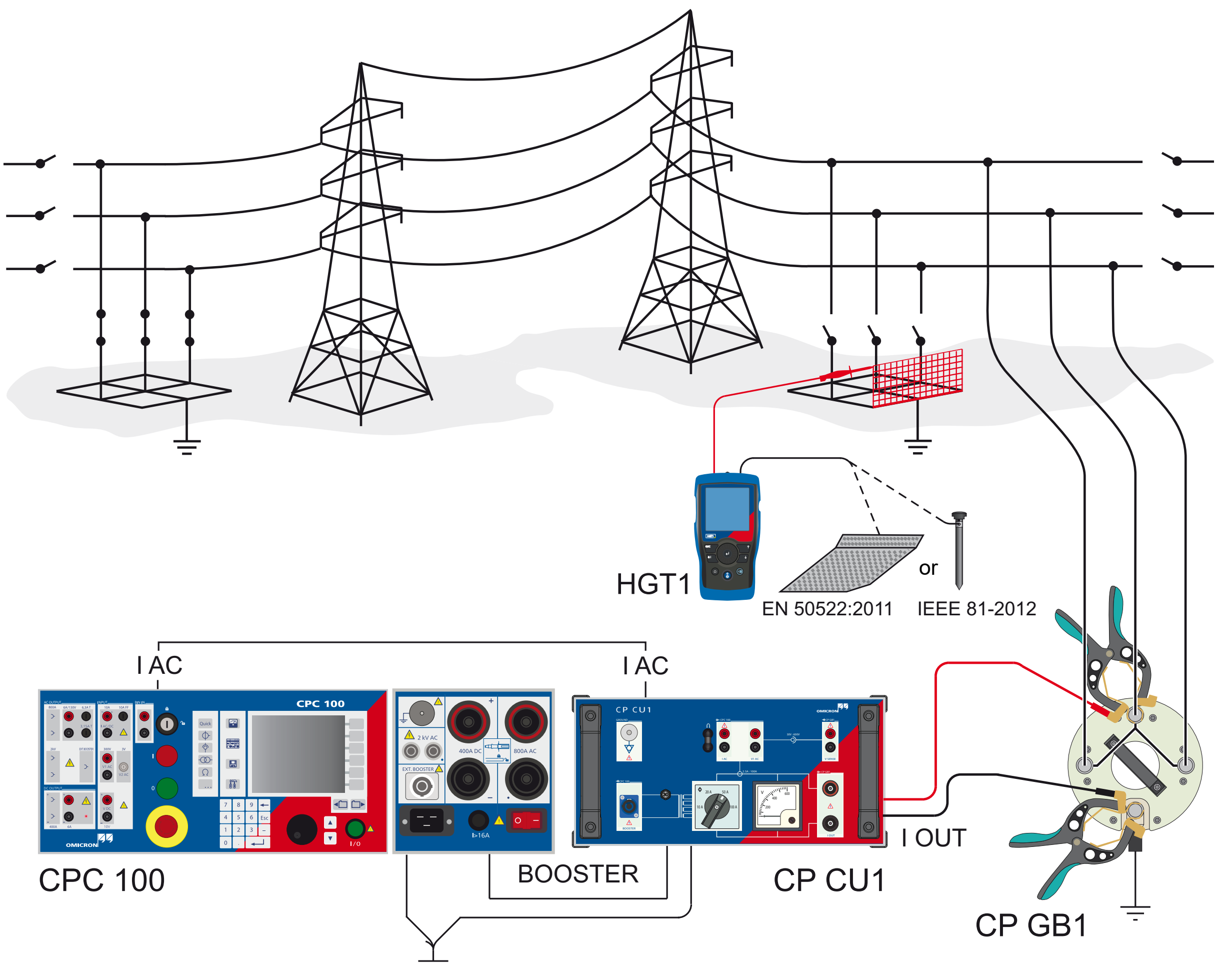


Figure 5-15: Step and touch voltage measurement setup

Note: In order to measure valid step and touch voltage values, the distance between the grounding system under test and the remote substation must be taken into account. IEEE 81 recommends a minimum distance of five times the maximum dimensions of the grounding system to avoid overlapping of the ground potential rise of both the grounding system and the current probe. EN 50522 recommends a minimum distance of 5 km, no matter the size of the grounding system. In general, the setup must represent worst case conditions, which could occur during a single line fault. This must be clarified for each individual grounding system.

3. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Grounding Systems > **Step&Touch using HGT1**

4. Choose the template matching the current range selected on the *CP CU1*.

The template contains the following test cards:

- **Connection** (comment test card, showing the necessary connections)
- **Output** (sequencer test card, used for the injection of the test current)
- **Version** (version check for Excel template)

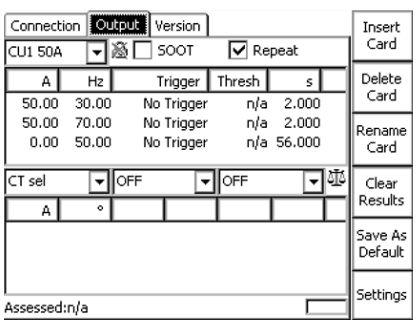


Figure 5-16: **Output** test card of the **Step&Touch using HGT1** template on the *CPC 100*

Figure 5-16 above shows settings in the **Output** test card of the **Step&Touch using HGT1** template. The sequence consists of 3 states, which are applied in an endless loop, since **Repeat** is activated in the test card:

- Injection of the test current at 30 Hz for 2 s (measuring touch voltage at a distinct location at 30 Hz)
- Injection of the test current at 70 Hz for 2 s (measuring touch voltage at a distinct location at 70 Hz)
- No injection for 56 s (to be able to move to the next measurement location in the substation)

In order to save time, the injection of the test current can also be remote-controlled by adapting the sequencer test card accordingly as shown in Figure 5-18 below. In the second column, additional measurement of voltage at the DC input is activated.

► Optional: Connect a walkie-talkie, which is used as a receiver, to the *CPC 100*'s VDC input, by using an adapter as shown in Figure 5-17 below.

Note: This is no accessory available from OMICRON!

Figure 5-17: Adapter for the connection of a walkie-talkie to the *CPC 100*

► Plug the headphone jack into the walkie-talkie’s headphone socket and connect the banana plugs to the *CPC 100*’s VDC input.

In the example shown in Figure 5-18 below, the voltage at the headphone socket was about 1 V when pressing the talk button on the walkie-talkie that was used as a sender. Hence, a threshold level of 0.5 V is reasonable. By pressing the talk button on the sender walkie-talkie, the measurement sequence starts from the first state again and the voltage at a distinct location can be measured instantly, without waiting for state 3 of the **Output** test card to complete.

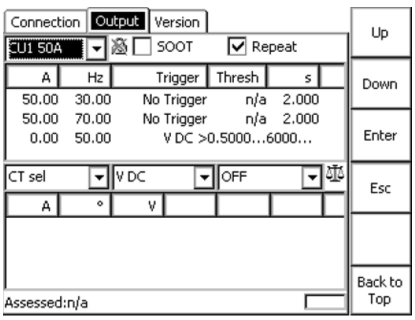


Figure 5-18: **Output** test card of the **Step&Touch using HGT1** template on the *CPC 100*, adapted for remote-controlled current injection

EN 50522 and IEEE 81 consider different ways of testing step and touch voltage. Table 5-1 below illustrates the differences.

Table 5-1: Step and touch measurements according to EN 50522 and IEEE 81

Standard	Measurement	Ground electrode	Input imped.
EN 50522:2011	Touch voltage	20 cm X 20 cm metal plate loaded with min. 50 kg, 1 m apart from grounded structure. Wetten the soil underneath the plate.	1 kΩ[1]
	Step voltage	This standard assumes that the limits for step voltage are much higher than for touch voltage. Therefore, step voltage measurements are considered obsolete.	-
IEEE 81-2012	Touch voltage	Rod (6 mm diameter) driven 150 mm into moist subsoil, 1 m apart from grounded structure.	High Z
	Step voltage	Two rods (6 mm diameter) each driven 150 mm into moist subsoil, 1 m apart from each other.	High Z

1. This standard also proposes to consider additional resistances for the assessment of the measurement, which requires a high ohmic input impedance.

As an example, Figure 5-19 below shows the touch voltage measurement according to EN 50522.

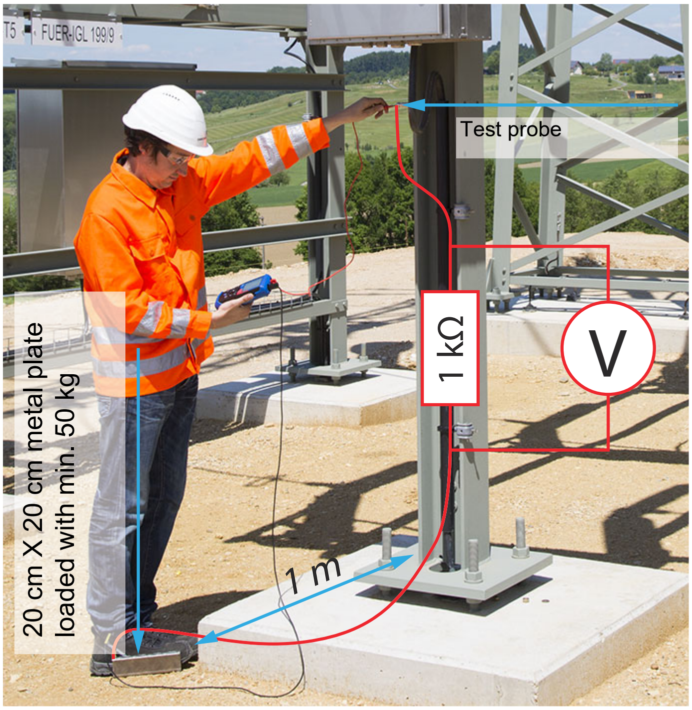


Figure 5-19: Touch voltage measurement according to EN 50522

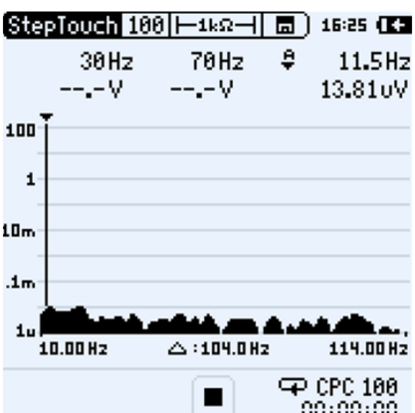


Figure 5-20: *HGT1* settings according to EN 50522

Figure 5-20 shows the settings to be considered when measuring step and touch voltage with the *HGT1*:

The 100 Hz range (10 – 114 Hz) is recommended, since frequencies higher than 100 Hz are not important for the measurement.

In the above example, 1 kΩ is selected as input impedance according to the EN 50522 recommendation for touch voltage measurements.

► If required, select an alternative setting, for example **High Z**, in order to measure the prospective touch voltage.

Note: The **High Z** setting is needed for measurements according to IEEE 81.

- ► Check if the two settings for the detection frequency equal the frequency of the injected current.
- ► Refer to the chapter 5.1 "Frequency range selection" on page 17 for information on how to adapt the frequency.

Now the step and touch voltage at distinct locations can be measured according to Figure 5-19: on page 62. The automatic detection of step and touch voltages requires the following workflow in order to avoid a faulty measurement:

5. Depending on the standard you follow, connect the metal plate (EN 50522) or the ground rod (IEEE 81) to the *HGT1*, using the black banana cable.
6. Connect the probe to the *HGT1*, using the red banana cable.

Figure 5-21: *HGT1* hardware setup according to EN 50522

7. Start the current injection loop by pressing the **I/O** button on the front panel of the *CPC 100*.
8. a) If you measure according to EN 50522, place the metal plate on the ground and step on it.

   b) If you measure according to IEEE 81, drive the ground rod approximately 150 mm into the ground, one meter away from the object under test.
9. Connect the probe to the object under test.

   Note: It is important to establish a good contact to the object. This could sometimes be cumbersome if the object is painted with an insulating layer. One option is to remove the layer with a file. The *HGT1*'s filter adapts to the connected impedance. The adaption results in a temporary increase of the voltage over the entire frequency spectrum. Hence, by starting the measurement BEFORE the probe is connected to the object, faulty values could be measured, since the values during adaption of the filter could be higher than the values actually caused by the injected current.
10. Start the measurement on the *HGT1*.

    Note: Make sure that the filter is only being adapted once in the duration of the measurement. A deteriorated probe could cause connection problems, resulting in several adaptions of the filter during the measurement. By using a proper, pointed probe, this problem can be avoided.
11. Either trigger the *CPC 100*'s next current injection with the walkie-talkie as described before or wait for the next current injection loop to begin.

    Current is injected for 2 seconds at 30 Hz and 70 Hz respectively. The highest measured value is kept by the *HGT1* for every frequency.

    Note: If the mains frequency is 60 Hz, the current is injected at 40 Hz and 80 Hz respectively.
12. Stop the measurement on the *HGT1* as soon as the highest value has been detected at 70 Hz.

13.Remove the probe from the object under test.

14.Save the measurement point on the *HGT1*.

15.Move to the next location and repeat steps 8 to 14.

16.After all tests have been performed, open the *CPC 100* file (xml-file) and the txt-file from the *HGT1* with the corresponding Excel template (Step&Touch using HGT1.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

Maximum Fault Duration:	300 ms	
Additionally considered resistance:	0 Ω	
Permissible Touch Voltage:	416 V	
Required Input Impedance during measurement:	1 k	
Reduction Factor of Test Current:	1,00	
Frequency of Test Current:	30,0 Hz	70,0 Hz
Amplitude of Test Current at corresponding Frequency:	30 A	30 A
Maximum Current to Earth:	10000 A	

ID	Location	Impedance Selection	HGT1 Results / V		Calculated Touch Voltage / V	Assessment
			30,0 Hz	70,0 Hz		
1	fence@gate	1 k	0,00581V	0,00430V	1,68V	OK
2	transformer	1 k	0,00276V	0,00432V	1,18V	OK
3	VT1housing	1 k	0,00421V	0,00613V	1,72V	OK
4	MyLocation	1 k	0,00298V	0,00311V	1,01V	OK
5	fence@trafo	1 k	0,00669V	0,00337V	1,67V	OK
6	entryFence	1 k	0,00341V	0,00385V	1,21V	OK
7	trafo2	1 k	0,00232V	0,00500V	1,22V	OK
8	VT2housing	1 k	0,00815V	0,00577V	2,31V	OK
9	CT2housing	1 k	0,00115V	0,00577V	1,15V	OK
10	CT1housing	1 k	0,00298V	0,00311V	1,01V	OK

Figure 5-22: Step and touch (using *HGT1*) Excel template (with the EN 50522 tab active)

5.2.2 Measurements with *PTM* (using a Windows tablet)

WARNING

Death or severe injury caused by high voltage or current possible

► Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test.
2. If criterion 3 is met, establish the measurement setup as shown in Figure 5-23 below.

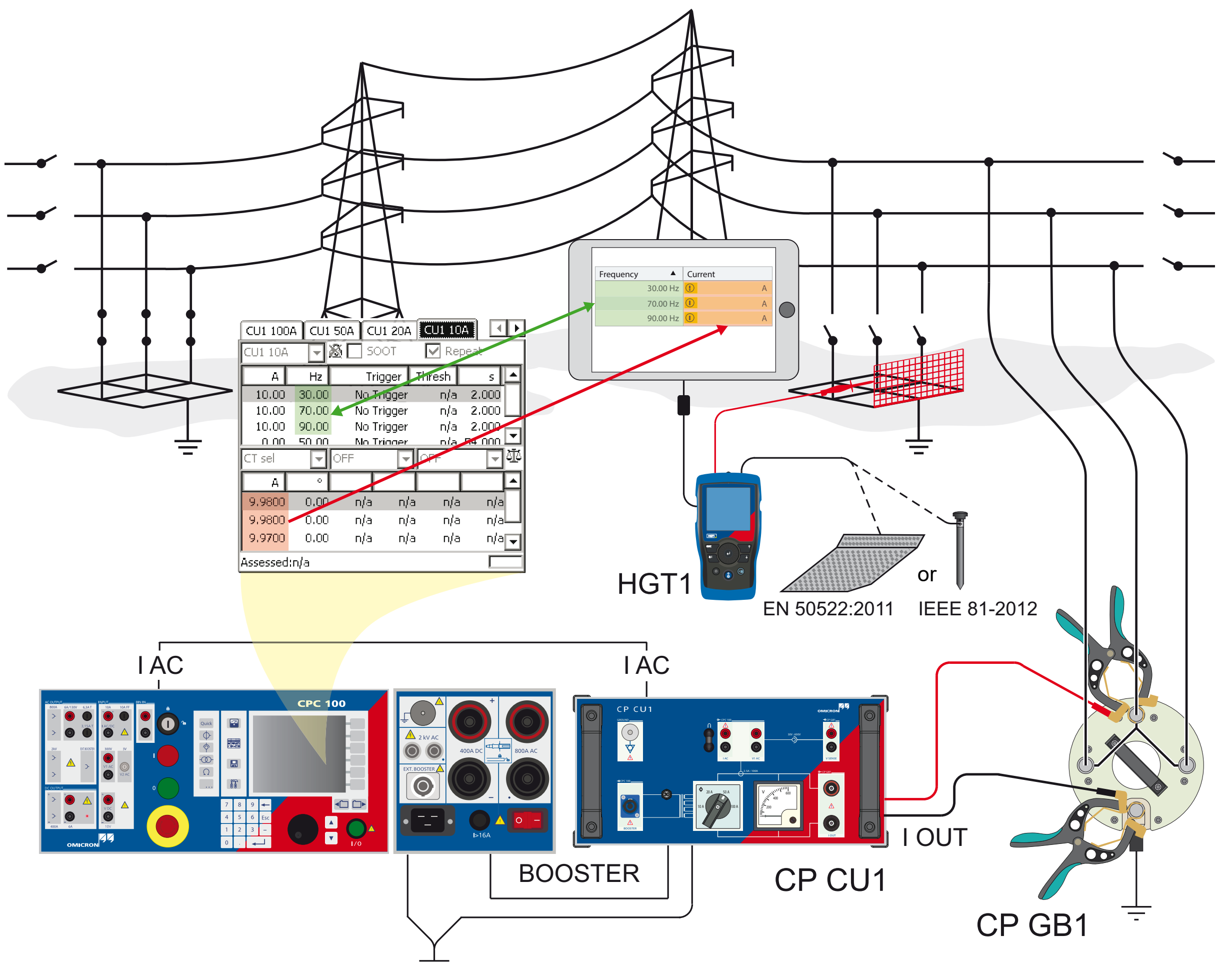


Figure 5-23: Step and touch voltage measurement setup when using *PTM* on a tablet

Note: In order to measure valid step and touch voltage values, the distance between the grounding system under test and the remote substation must be taken into account. IEEE 81 recommends a minimum distance of five times the maximum dimensions of the grounding system to avoid overlapping of the ground potential rise of both the grounding system and the current probe. EN 50522 recommends a minimum distance of 5 km, no matter the size of the grounding system. In general, the setup must represent worst case conditions, which could occur during a single line fault. This must be clarified for each individual grounding system.

3. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Grounding Systems > **PTM**

4. Open the file corresponding to your power frequency and navigate to the test card matching the current range selected on the *CP CU1*.

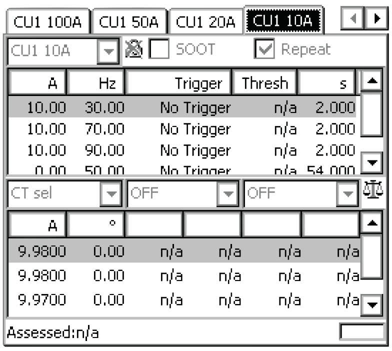


Figure 5-24: **CU1 10** test card of the **PTM** template on the *CPC 100*

Figure 5-24 above shows settings in the **CU1 10** test card of the **PTM** template. The sequence consists of 4 states, which are applied in an endless loop, since **Repeat** is activated in the test card:

- Injection of the test current at 30 Hz for 2 s (measuring touch voltage at a distinct location at 30 Hz)
- Injection of the test current at 70 Hz for 2 s (measuring touch voltage at a distinct location at 70 Hz)
- Injection of the test current at 90 Hz for 2 s (measuring touch voltage at a distinct location at 90 Hz)
- No injection for 54 s (to be able to move to the next measurement location in the substation)

5. Start the injection by pressing the I/0 button on the *CPC 100*.
6. Start *PTM* on the tablet and enter the *CPC 100*'s current readings for each defined frequency under **Settings and Conditions**. Also verify that the frequency selections in the sequencer test card and under **Settings and conditions** match.

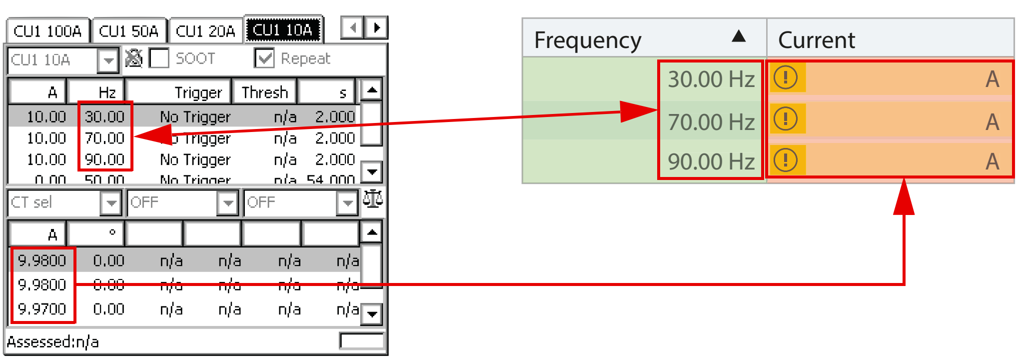


Figure 5-25: Enter the current readings under the **Settings and Conditions** section in *PTM*

EN 50522 and IEEE 81 consider different ways of testing step and touch voltage. Table 5-1 below illustrates the differences.

Table 5-2: Step and touch measurements according to EN 50522 and IEEE 81

Standard	Measurement	Ground electrode	Input imped.
EN 50522:2011	Touch voltage	20 cm X 20 cm metal plate loaded with min. 50 kg, 1 m apart from grounded structure. Wetten the soil underneath the plate.	1 kΩ[1]
	Step voltage	This standard assumes that the limits for step voltage are much higher than for touch voltage. Therefore, step voltage measurements are considered obsolete.	-
IEEE 81-2012	Touch voltage	Rod (6 mm diameter) driven 150 mm into moist subsoil, 1 m apart from grounded structure.	High Z
	Step voltage	Two rods (6 mm diameter) each driven 150 mm into moist subsoil, 1 m apart from each other.	High Z

1. This standard also proposes to consider additional resistances for the assessment of the measurement, which requires a high ohmic input impedance.

As an example, Figure 5-26 below shows the touch voltage measurement according to IEEE 81.

Figure 5-26: Touch voltage measurement with *PTM* (tablet) according to IEEE 81

7. Set the *HGT1*'s **USB mode** to **COM port** to enable communication with the tablet running *PTM*.
8. Connect the *HGT1* to the tablet using the *HGT1*'s USB connector and the delivered USB cable.

WARNING

Death or severe injury caused by high voltage or current possible

► Never connect the *HGT1* to the tablet without using the provided USB isolator.

As soon as the *HGT1* is recognized by *PTM*, it is locked and cannot be operated via its buttons any longer.

Now the step and touch voltage at distinct locations can be measured according to Figure 5-26: on page 67. The automatic detection of step and touch voltages requires the following workflow in order to avoid a faulty measurement:

9. Depending on the standard you follow, connect the metal plate (EN 50522) or the ground rod (IEEE 81) to the *HGT1*, using the black banana cable.
10. Connect the probe to the *HGT1*, using the red banana cable.

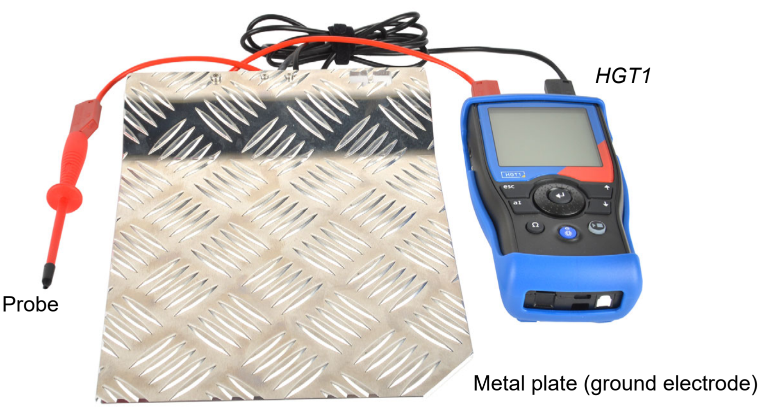


Figure 5-27: *HGT1* hardware setup according to EN 50522

11. Start the current injection loop by pressing the **I/O** button on the front panel of the *CPC 100*.
12. a) If you measure according to EN 50522, place the metal plate on the ground and step on it.

    b) If you measure according to IEEE 81, drive the ground rod approximately 150 mm into the ground, one meter away from the object under test.
13. Connect the probe to the object under test.

    Note: It is important to establish a good contact to the object. This could sometimes be cumbersome if the object is painted with an insulating layer. One option is to remove the layer with a file. The *HGT1*'s filter adapts to the connected impedance. The adaption results in a temporary increase of the voltage over the entire frequency spectrum. Hence, by starting the measurement BEFORE the probe is connected to the object, faulty values could be measured, since the values during adaption of the filter could be higher than the values actually caused by the injected current.
14. Start the measurement in *PTM* section **Measurement**.
15. After the measurement is finished, move to the next location and and take measurements whenever test current is injected.

5.3 Reduction factor measurement

WARNING

Death or severe injury caused by high voltage or current possible

▶ Use a grounding set to ground the power line at the near end whenever you handle the measurement setup inside the danger zone (for example when changing connections at the *CP GB1* between measurement loops).

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test.
2. If criterion 3 is met, establish the measurement setup as shown in Figure 5-28 below.

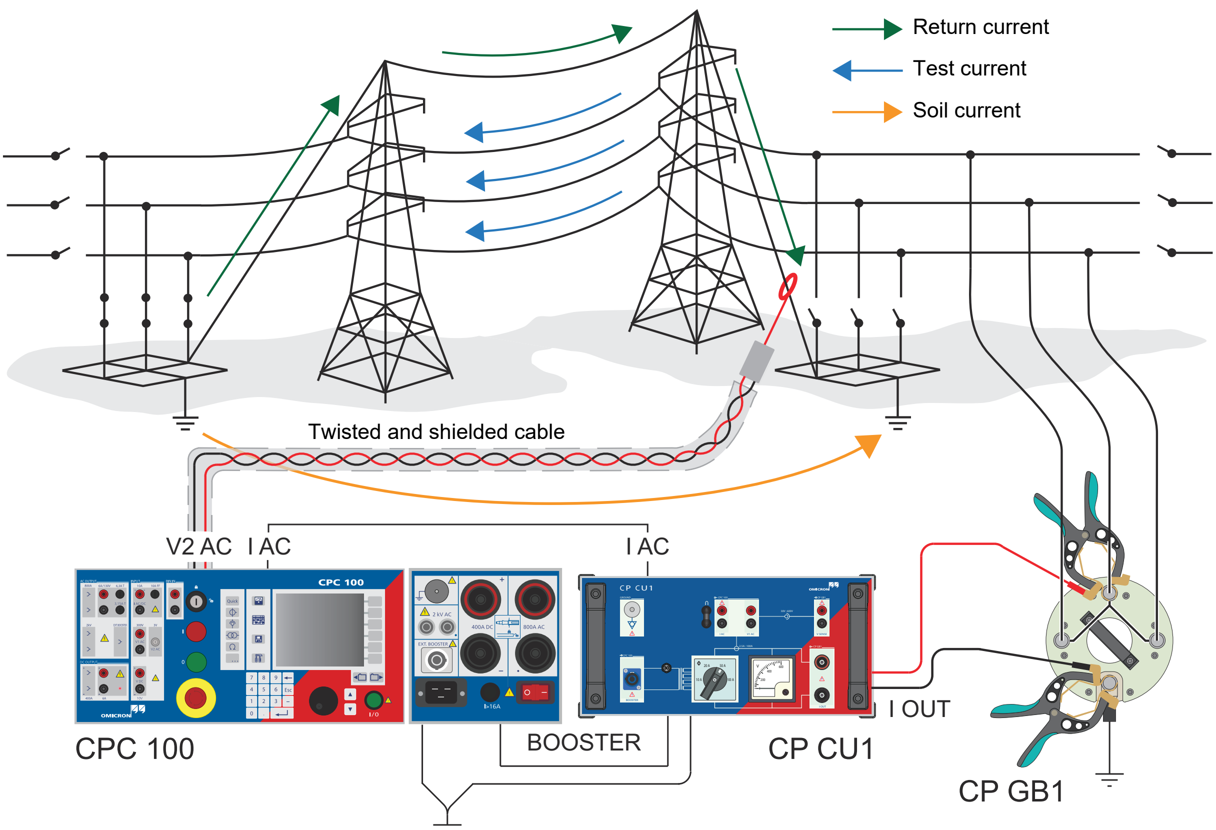


Figure 5-28: Reduction factor measurement setup

Note: Use a twisted and shielded cable to connect the Rogowski coil to the *CPC 100*'s V2 AC input.

3. Press the **Options** view button to the left of the *CPC 100*'s display to enter the **Options** menu.

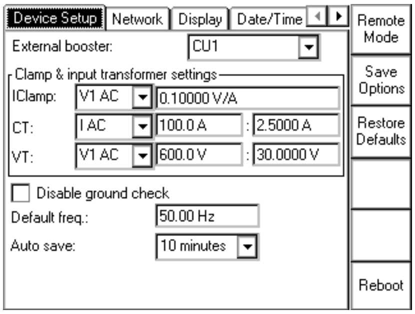


Figure 5-29: **Device Setup** tab of the *CPC 100* **Options** menu

4. Check whether "CU1" is set as booster under **External booster**.
5. If this is not the case, select "CU1" as booster.

The CT and VT settings are set according to the built-in current and voltage transformers automatically.

6. Press the **Testcard View Button** on the *CPC 100*'s front panel to switch to the test card view.
7. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Template > Grounding Systems > **Reduction Factor**

8. Choose the template matching the current range selected on the *CP CU1*.

The template contains the following test cards:

- **Instruction** (describes the usage of the template)
- **Return1** (measures the current of the 1st return path)
- **Version** (version check for Excel template)

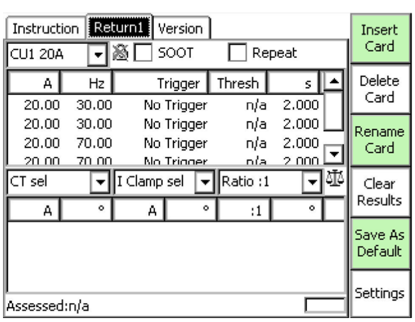
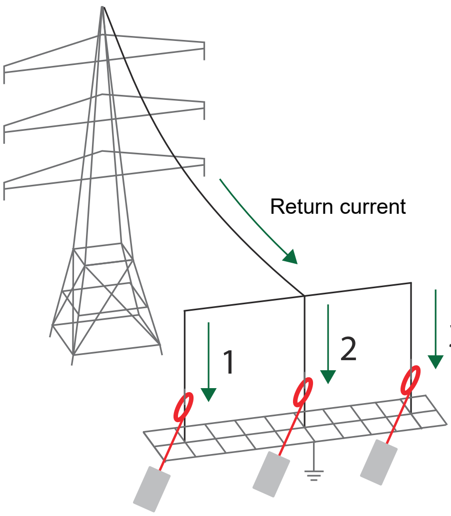


Figure 5-30: **Return1** test card of the **Reduction Factor** template on the *CPC 100*

Figure 5-30 above shows the settings of the sequencer test card in the **Reduction Factor** template. The test current, in this example 20 A, is injected twice at 30 Hz and twice at 70 Hz. The injected test current is displayed in column **CT sel**. The return current, which is measured by the Rogowski coil, is displayed in column **I clamp sel**.

Note: The number of measured return currents depends on the situation on site. In the example in Figure 5-31 below the current returns via the three poles of a portal.



Note: The arrow marking on the connecting mechanism of the Rogowski coil (for closing it) needs to point in the direction of the current flow.

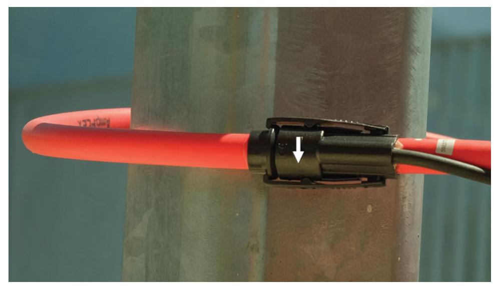


Figure 5-31: Example: Three return currents - three measurements

Depending on the number of measured return currents, additional sequencer test cards need to be added.

► In order to add a sequencer test card with the same settings, press "**Save as default**" in the **Return1** test card before adding another sequencer test card.

► Press **Insert Card** to add an additional sequencer test card.

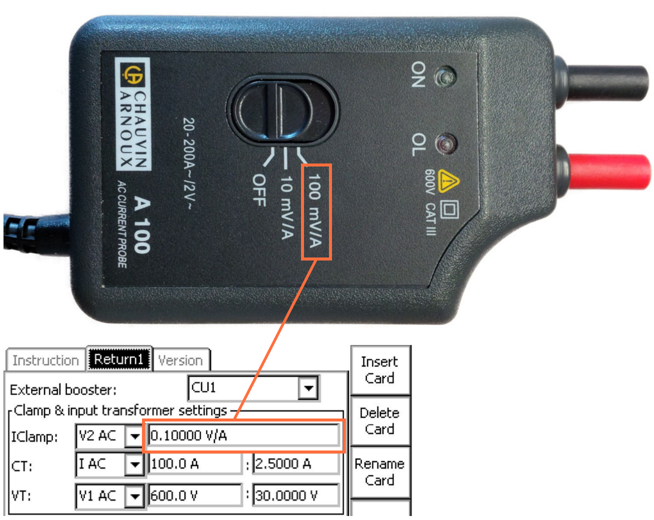


Figure 5-32: Setting for the Rogowski coil

Figure 5-32 above shows the range selector of a Rogowski coil and the corresponding settings in the sequencer test card.

9. Open the test card's settings by pressing **Settings**.

The selected input for **IClamp** is **V2 AC**, since the Rogowski coil is connected to this input, as can be seen in Figure 5-28: "Reduction factor measurement setup" on page 69. The ratio in the test card settings must be selected according to the range of the Rogowski coil as marked in Figure 5-32.

10. After all the setting and preparations are completed, press the **I/O** button on the front panel of the *CPC 100* to start a measurement loop.
11. Depending on the number of return currents, reposition the Rogowski coil accordingly and perform further measurements until all return currents are measured.

    Note: Position the Rogowski coil, so that the arrow marking on the connecting mechanism (for closing the Rogowski coil) is pointing in the direction of the current flow. Also see the example in Figure 5-31 on the previous page.
12. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Reduction Factor.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

Return Currents				
	Re / A	Im / A	Abs / A	φ / °
Return1	2,43	1,54	2,87	32,36
Return2	3,70	-1,45	3,97	-21,40
Return3	1,39	0,43	1,45	17,32
Return4	2,56	1,32	2,88	27,34
Current Split				
	Re / A	Im / A	Abs / A	φ / °
Total Current	20,00	0,00	20,00	0,00
I_Return_sum	10,07	1,84	10,24	10,37
I_Grid	9,93	-1,84	10,10	-10,51
Reduction Factor				
			Abs	φ / °
$\underline{r} = \frac{\underline{I}_G}{\underline{I}_{total}} = 1 - \frac{\sum_i \underline{I}_{return,i}}{\underline{I}_{total}}$			0,51	-10,51

Figure 5-33: Reduction factor Excel template

6 Measurement of coupling into signal cables

The measurement of the coupling impedance $\underline{Z}_k$ between power and signal lines is performed for two current loops of the power lines under test. One loop is shaped by two lines featuring the largest area, the other loop is shaped by three lines in parallel and the ground. For each loop, the measurement setup is calibrated by measuring the voltage with the measurement cable short-circuited.

6.1 Performing measurements

1. Follow the instructions in chapter 3 "Connecting the CP CU1 to a power line" on page 23 in order to connect the *CP CU1* to the power line under test.
2. When checking the fourth criterion, use the dedicated template on the *CPC 100* by following this path in the file operations view:

   Templates > Cables & Transmission Lines > **Coupling into Signal Cables**
3. Choose the template matching the current range selected on the *CP CU1*.

The template contains the following test cards:

- **L-L cal setup** (comment test card, showing the necessary connections)
- **L-L cal** (sequencer test card - line-to-line calibration)
- **L-L meas setup**
- **L-L meas** (sequencer test card - line-to-line measurement)
- **L-E meas setup**
- **L-E meas** (sequencer test card - line-to-ground measurement)
- **L-E cal setup**
- **L-E cal** (sequencer test card - line-to-ground calibration)
- **Version** (version check for Excel template)

The **setup** test cards are comment test cards, which show how to connect the cables. The measurement is then performed in the sequencer test card which is following the **setup** test card.

4. Use a voltmeter to measure the voltage at the signal cable.

WARNING

Death or severe injury caused by high voltage possible

- ► If the measured voltage is below 3 V, use the *CPC 100*'s V2 AC input.
- ► If the measured voltage is higher than 40 V, take safety precautions to avoid electrical hazard.
- ► If the measured voltage is between 3 V and 300 V, use the *CPC 100*'s V1 AC input.
- ► If the measured voltage is higher than 300 V, the measurement cannot be done, since this would exceed the limits of the *CPC 100*'s V1 AC input.

5. If the measurement is possible, establish the measurement setup as shown in Figure 6-1 below.

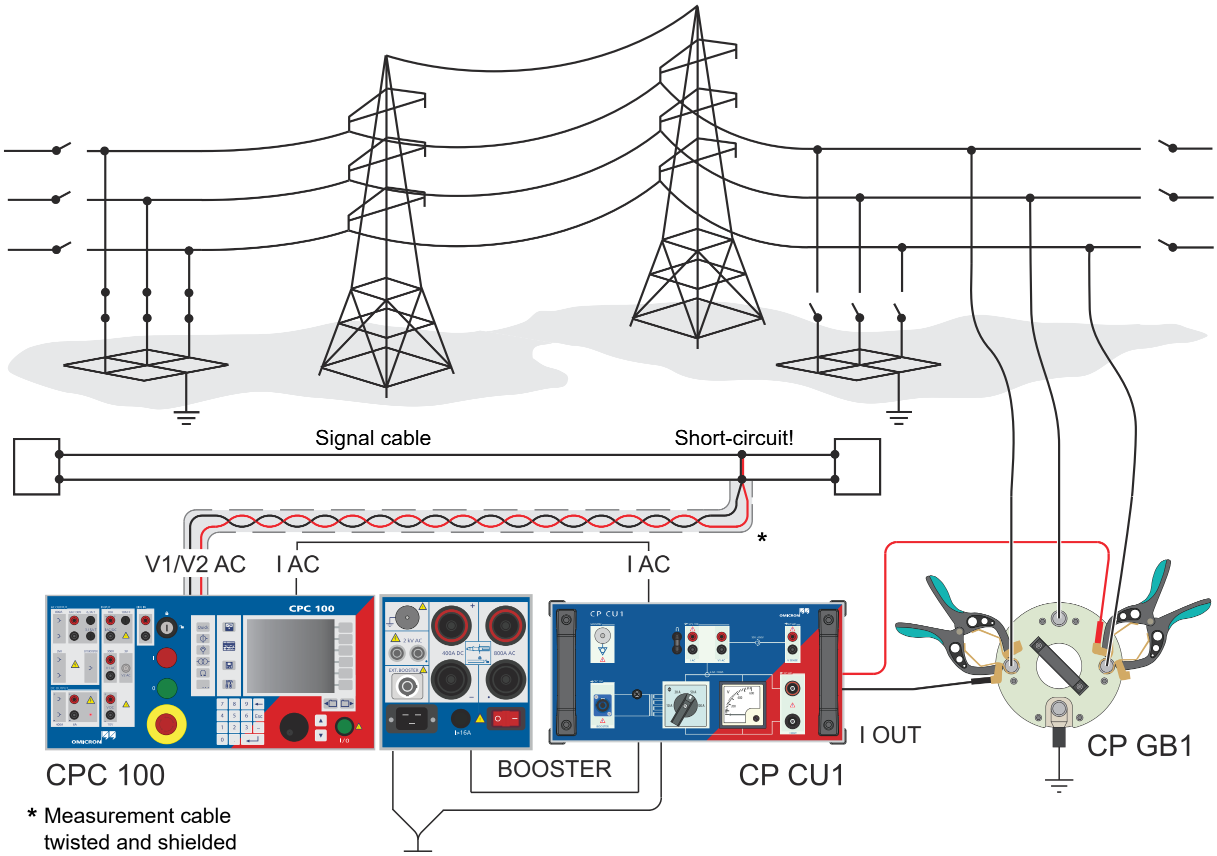


Figure 6-1: Coupling into signal cables measurement setup for the line-to-line calibration

6. Depending on the results of the before mentioned measurement with the voltmeter, connect the measurement cable either to the *CPC 100*'s V2 AC input (max. 3 V) or the V1 AC input (max.300 V).

   Note: The measurement cable needs to be twisted and shielded!

7. Short-circuit the measurement cable at the end and connect it to the signal cable as shown in Figure 6-1 above.
8. After the measurement setup is completed, start the **L-L cal** sequencer test card by pressing the **I/O Button** on the front panel of the *CPC 100*.

9. Reconnect the measurement cable according to Figure 6-2 below.

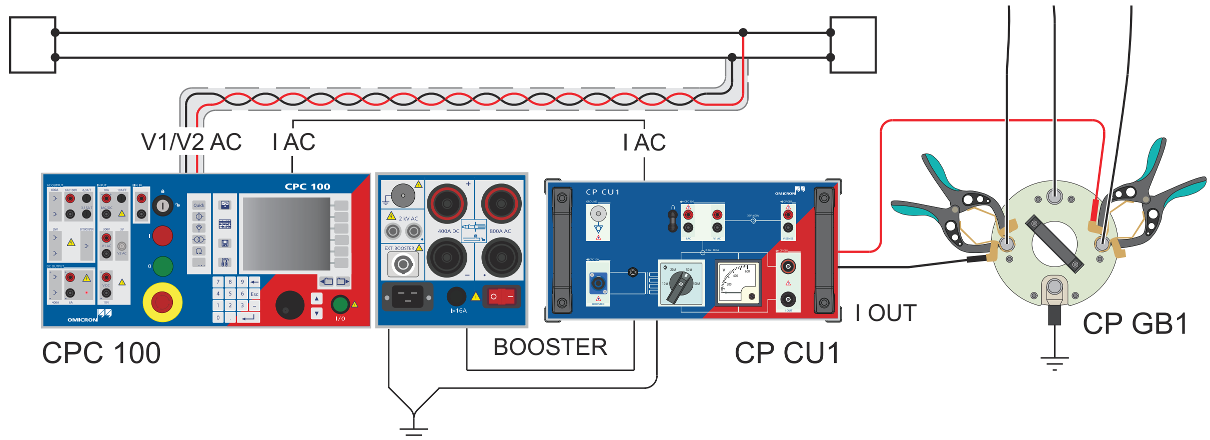


Figure 6-2: Coupling into signal cables measurement setup for the line-to-line measurement

10. Start the **L-L meas** sequencer test card by pressing the **I/O Button** on the front panel of the *CPC 100*.

    During calibration the voltage coupled into the measurement cable was measured. This voltage is now subtracted from the line-to-line measurement result by the template, to determine the voltage coupled into the signal cable only.

11. Reconnect the clamps at the *CP GB1* according to Figure 6-3 below.
12. Use the three-lead cable (see 2.4.2 "Shorting the phases" on page 16) to shorten the three phases for the line-to-ground measurement.

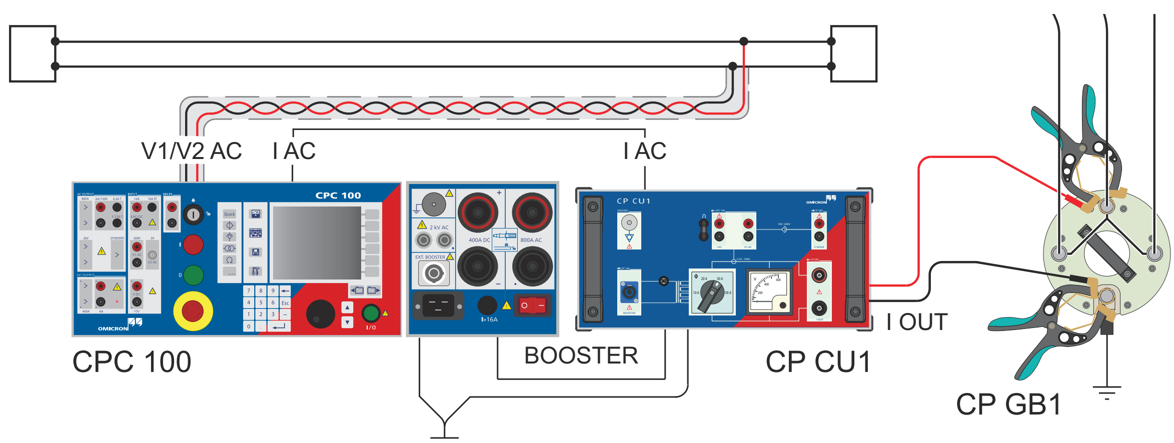


Figure 6-3: Coupling into signal cables measurement setup for the line-to-ground measurement

13. Start the **L-E meas** sequencer test card by pressing the **I/O Button** on the front panel of the *CPC 100*.
14. Disconnect the measurement cable from the signal cable.

15. Short-circuit the measurement cable at the end and connect it to the signal cable as shown in Figure 6-4 below.

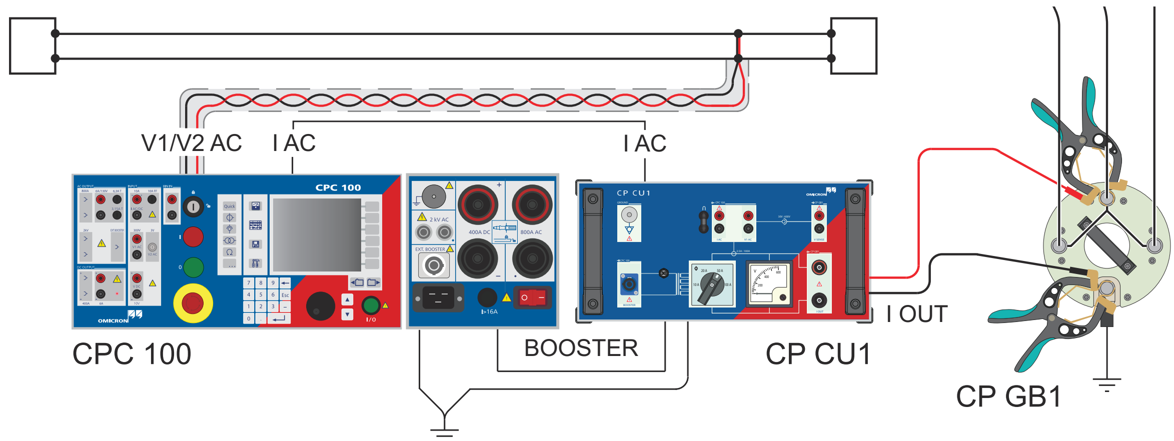


Figure 6-4: Coupling into signal cables measurement setup for the line-to-ground calibration

16. After all tests have been performed, open the *CPC 100* file (xml-file) with the corresponding Excel template (Coupling Into Signal Cables.xlt) from the *CPC 100* Start Page in the section **Test Templates**. Check the test results carefully. The cell comments in the test report sheet help you to assess the test results.

7 Technical data

7.1 *CP CU1* output ranges

Table 7-1: Output ranges of the *CP CU1*

Range	Current	Compliance Voltage at > 45 Hz
10 A	0…10 Arms	500 Vrms
20 A	0…20 Arms	250 Vrms
50 A	0…50 Arms	100 Vrms
100 A	0…100 Arms	50 Vrms

7.2 *CP CU1* measuring transformers

Table 7-2: Measuring transformers of the *CP CU1*

Transformer	Ratio	Accuracy at 50/60 Hz
VT	600 V : 30 V	Class 0.1
CT	100 A : 2.5 A	Class 0.1

7.3 *CP CU1* inputs

Table 7-3: Inputs of the *CP CU1*

	Characteristic	Rating
V SENSE	Overvoltage category	CAT III (IEC 61010-1)
	Voltage range	0…600 Vrms
BOOSTER[1]	Overvoltage category	CAT I
	Voltage range	0…200 Vrms
	Current range	0…30 Arms
	Frequency range	15…400 Hz
	Fuse	30 A fast acting, automatic circuit breaker

1. The BOOSTER input supplies power to the *CP CU1*. It must be connected only to the *CPC 100*.

7.4 *CP GB1* specifications

Table 7-4: *CP GB1* specifications

Characteristic	Rating
Nominal AC spark-over voltage	< 1000 Vrms
Impulse spark-over voltage	< 2000 Vpeak
Short-circuit proof with:	
16 mm cylindrical or 20 mm ball studs	26.5 kA (<100 ms)/67 kApeak
25 mm or 1 inch ball studs	30 kA (<100 ms)/75 kApeak
Torsional moment for changing arrestors	> 15 Nm

7.5 Output power

Table 7-5: Output power of the *CPC 100* and *CP CU1*

Characteristic	Rating[1]
Maximum power	5000 VA (45…70 Hz), cosφ < 1.0 for 8 s at 230 V AC mains voltage 5000 VA (45…70 Hz), cosφ < 0.4 for 8 s at 115 V AC mains voltage
Continuous power	0…1600 VA
Frequency	15…400 Hz (15…45 Hz with reduced voltage)

1. Ambient temperature 23 ºC ± 5 ºC/73 ºF ± 10 ºF

7.6 Accuracy

Table 7-6: Accuracy of the *CPC 100* and *CP CU1*

Impedance Range	Typ. Accuracy[1] of abs(Z) Value	Typ. Accuracy[1] of Phase Angle	V SENSE Voltage	I OUT Current	Current Range
0.05…0.2 Ω	1.0…0.5%	1.5…0.8º	5…20 V	100 A	100 A
0.2…2 Ω	0.5…0.3%	0.8…0.5º	20…50 V	100…25 A	100 A
2…5 Ω	0.3%	0.5º	100 V	50…20 A	50 A
5…25 Ω	0.3%	0.5º	100…250 V	20…10 A	20 A
25…300 Ω	0.3…1.0%	0.5…1.5º	250…500 V	10…1.5 A	10 A

1. Ambient temperature 23 ºC ± 5 ºC/73 ºF ± 10 ºF

7.7 Environmental conditions

Table 7-7: Environmental conditions for the *CP CU1* and *CP GB1*

Characteristic	Rating
Operating temperature	–10…+55 ºC/14…131 ºF
Transport & storage temperature	–20…+70 ºC/–4…158 ºF
Relative humidity	5…95%, non-condensing

7.8 Mechanical data

Table 7-8: Mechanical data of the *CP CU1* and *CP GB1*

	Characteristic	Rating
CP CU1	Dimensions (w × h × d)	450 × 220 × 220 mm/17.72 × 8.66 × 8.66 inch
	Weight	28.5 kg/62.78 lb
CP GB1	Dimensions (Φ × h)	200 × 190 mm/7.87 × 7.48 inch
	Weight	4.2 kg/8.81 lb (without grounding cable) approx. 6.8 kg/13.22 lb (with grounding cable)

7.9 Standards

Table 7-9: Standards conformity

Safety		
Safety	IEC / EN / UL 61010-1	CE
Other		
Humidity	IEC / EN 60068-2-78, 5…95 % relative humidity; no condensation Tested at 40 °C (104 °F) for 48 hours	
Protection class (housing)	IP20, according to EN 60529	

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