User's Manual

Control and Feeding Unit

Type RSE 400 / RSE 800

(Translation of the Original User's Manual)

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Dear customer,

We are especially pleased that you have decided to purchase our product.

HIGHVOLT Prüftechnik Dresden GmbH wishes you every success in your work.

Please read this User's Manual carefully before starting installation and commissioning of the product. Safe and reliable operation, optimum benefit and a long service life of the product are only possible if you have properly understood the contents of this User's Manual.

The contents of this document do not imply warranties or guaranties of any kind. Please observe all corresponding information in our General Terms and Conditions of Sale and Delivery.

Thank you very much.

Your

HIGHVOLT TEAM

Table of Contents

1. Product identification and specification

Product:	Control and feeding unit
Type:	RSE 400 and RSE 800
Manufacturer:	HIGHVOLT Prüftechnik Dresden GmbH
Use as intended:	Control and feeding unit for frequency-variable feeding of resonant test systems
Range of application:	Resonant test systems with adjustable frequency
Target group:	Operating personnel with qualifications as an electrical engineer

It is imperative to observe the occupational and safety regulations of the user.

2. Conventions in this User's Manual

Instructions

Instructions for actions / operations that are to be performed in a certain sequence are numbered.

The results of the actions / operations are highlighted by way of an arrow:

1. First step
2. Second step
   → Result of the operation / action

Instructions without a certain sequence are highlighted by way of a triangle.

▷ Step A
▷ Step B
  → Result of the operation / action

Screen controls

Screen controls, e. g. buttons, menu commands or simple text, to which reference is made in the text of this User's Manual are put in square brackets.

[Button]

Software command sequences

Software command sequences are put in square brackets. The individual commands are separated by way of dashes.

[Command 1 – Command 2 – Command 3]

Bilingual designations

Bilingual designations are placed next to each another and are separated by way of a slash.

Bezeichnung A / Designation A

References in the text

Internal references to a chapter / section in the same manual are printed in Italics.

See *Chapter 1*

External references to a different, enclosed document are represented using an arrow symbol in a black circle.

➲ See Document XY

3. General conditions

It is the customer's responsibility to select the product which is best suited for the intended application, and he is also responsible for correct installation, use and maintenance of the product.

Repairs or modifications to the design may only be performed by the service personnel of HIGHVOLT Prüftechnik Dresden GmbH or other specialists working for us on the basis of an appropriate contract or agreement. Exclusively genuine spare parts and accessories from HIGHVOLT Prüftechnik Dresden GmbH are to be used.

If any problems occur during installation and / or commissioning, do not hesitate to contact HIGHVOLT Prüftechnik Dresden GmbH.

No warranty claims will be accepted if you do not observe the conditions specified above.

4. Unpacking and checking the product

Check the consignment for transport damage and completeness against the enclosed list of parts.

If you discover any deviations from the scope of delivery specified above, contact HIGHVOLT Prüftechnik Dresden GmbH immediately.

5. Safety notes

5.1. Explanation of the degrees of hazards with their symbols

This User's Manual comprises notices which are to be observed for your personal safety and to avoid material damage. The notes are highlighted by way of a warning triangle and, depending on the degree of hazard, represented as shown below:

DANGER
Indicates an imminently hazardous situation which, if not avoided, will result in death or serious injury if the appropriate precautions are not taken.

WARNING
Indicates a potentially hazardous situation which, if not avoided, could result in death or serious injury if the appropriate precautions are not taken.

CAUTION
Indicates a hazardous situation which, if not avoided, could result in minor or moderate injury if the appropriate precautions are not taken.

NOTICE
Indicates that material damage may result if the appropriate precautions are not taken.

INFORMATION
Designates important information about the product or a specific part of the product documentation to which special attention must be drawn.

5.2. General safety notes

Standards

VDE 0104	Erection and operation of electrical test equipment
D0003 SB1	Safe operation of high-voltage test bays. Instructions for grounding, shielding and safety

INFORMATION

We expressly refer to D0003 (Chapter 5) *Specifications about safe and safety clearances in case of high voltage*.

Safety loop and EMERGENCY STOP

Some of the recommended safety devices are offered by us as an integral part of our test systems:

- EMERGENCY STOP pushbutton
- Safety loop

Our test system is also prepared for the following safety measures:

- Fencing by way of safety loop and door contacts;
- Green signal lamps to indicate readiness for operation;
- Red signal lamps to indicate readiness for switching on;
- Possibility of expansion for the EMERGENCY OFF circuit.
- Acoustic signaling via horn

Safety loop

The operator device is fitted with a closed-circuit control circuit for a door contact. Interruption of the control circuit switches the test system from the status READY TO SWITCH ON to the status READY FOR OPERATION; see also under *Signal lamps*.

This circuit can be extended to a safety loop securing all accesses to the hazardous area.

DANGER

Electric shock hazard

Manipulation of the safety system may result in the system not shutting down in critical situations.

► The functions of the safety loop must not be modified.

► The functioning of the safety loop must be checked at regular intervals.

EMERGENCY STOP

The EMERGENCY STOP pushbutton on the control system serves for shutting down of the system in case of problems. It turns off the control voltage of the test system and all subsequent switches.

After an EMERGENCY shutdown, the following vital control modules are still live.

Signal lamps

The switching status of the test system is indicated unambiguously by way of red and green signal lamps (warning lamps) that are also clearly visible from a distance. The mounting positions and number of the signal lamps can be adapted to the appropriate test bay.

The green lamps indicate the following state of operation:

READY TO SWITCH ON:

a) The power supplies for the signal and control circuits of the switchgear for voltage feeding are turned on.
b) All devices providing high voltage are turned off and secured against inadvertent re-energizing.
c) The hazardous zone is protected by way of safety devices and safety circuits.

The red lamps indicate the following states of operation of the test system:

READY TO SWITCH ON or IN OPERATION:

a) READY TO SWITCH ON:

    All devices providing high voltage are turned off.

    IN OPERATION:

    All devices providing high voltage are turned on.

b) All access roads to the hazardous zone are closed.
c) The safety measures in the hazardous zone can be canceled.

It is the customer's responsibility to select the unit which is best suited for the intended application, and he is also responsible for correct installation, use and maintenance of the product.

Provide for sufficient connection of the RSE 400 (800) to the earth potential. Connect the earthing connection to the earthing rod (rear side of the RSE). The minimum cross-section of the earthing connection is 50 mm^2 for an RSE 400 and 100 mm^2 for an RSE 800.

Make sure that the fuse switch-disconnector F1 is open when installing the mains connection.

WARNING

Danger of injuries from flying parts

The energy stored in the intermediate circuit can reach up to 1.3 kJ. In case of error in the intermediate circuit, mechanical damage may result. This can lead to injuries.

- ▶ Make sure that the cabinet doors are closed during operation.

The voltage in the inverter intermediate circuit only slowly falls even after total disconnection from the mains. Therefore, all parts are to be deemed live after a waiting time of 6 minutes after disconnection from the mains.

WARNING

Electric shock hazard

Electric shocks can cause fatal personal injury or even death.

- ▶ The connection, operation and maintenance of the RSE 400 (800) must only be performed by instructed and trained persons.
- ▶ Before connecting the device, always make sure that no power is connected.
- ▶ Before connecting the supply voltage, make sure that the RSE 400 (800) is earthed safely.
- ▶ Make sure that the cabinet doors are closed during operation.
- ▶ Before performing maintenance work in the RSE 400 (800) and replacing fuses, the RSE must be disconnected from the mains. Observe a waiting time of 6 minutes to ensure safe discharging of the intermediate circuit.

6. Electrical commissioning

6.1. Earth connection

To guarantee the electrical safety, the RSE 400 (800) must be connected to the earth potential by way of a line with sufficient cross-section. For RSE 400, a minimum cross-section of 50 mm^2 is required, and for RSE 800 a minimum cross-section of 100 mm^2. The earth connection is to be performed to the earthing rod on the RSE rear panel.

Connect the RSE additionally to the earth potential of the high-voltage test circuit by way of copper foil so as to avoid hazardous overvoltages in the earthing system in case of flashover on the test object. Connect the copper foil also to the earthing rod of the RSE to ensure that the neutral is also earthed when the RSE is supplied from a diesel generator.

For details on optimum design of the earthing system, refer to *Chapter 17*.

6.2. Connecting the exciter transformer

Connect the exciter transformer of the test system to the busbars X1.4 / X1.5 or the appropriate plug connectors (depending on the variant) on the rear side of the RSE.

NOTICE

Risk of damage to system components

Earthing of an inverter output will lead to severe damage of the inverter unit.

- ► The RSE output terminals must not be connected to earth potential.
- ► Make sure that the primary winding of the exciter transformer installed is not connected to earth potential.
- ► Before connecting the supply voltage, check by way of a multimeter that there is no connection between the inverter outputs and earth potential.

6.3. Connecting the voltage divider

The coaxial measuring cable to the voltage divider is to be connected to the N female connector X103 on the RSE rear panel.

6.4. Connecting safety loop, external emergency stop and warning lamps

RSE 400 (800) meets the requirements of Safety Integrity Level 3 (SIL 3) acc. to IEC 61508 and 61511. This means that the external EMERGENCY STOP loop and the safety loop are designed in two channels. This prevents that e.g. open safety contacts are not detected due to damage in the cabling (cross-circuits). Therefore, all external safety contacts (e.g. door contacts, EMERGENCY STOP pushbuttons) must possess at least two contacts which are looped in one channel each.

To support external safety devices possessing only one contact, the RSE 400 (800) may be switched to the single-channel mode. In this case, however, the safety system no longer meets the requirements of SIL3. For details, see the RSE 400 (800) circuit diagram.

6.5. Connection to the power grid

The RSE 400 (800) is connected to the three-phase power grid by way of the busbars X1.1, X1.2 and X1.3 on the rear side of the control cabinet. The neutral of the power grid must be connected to the earthing bar of the RSE 400 (800). For safety reasons, the fuse switch-disconnector F1 must be open during connection to the grid.

In the case of RSE 800, the feeding power has to be fed in both in one cabinet or in two cabinet parts, depending on the current project. In certain circumstances, the internal connection between the two parts of the cabinets is missing. In these cases, each cabinet must be connected to the supply network separately. If connection to only one cabinet is possible, the cable cross-section of the supply lines must be sufficient for the input current of both inverter units.

NOTICE

Risk of damage to system components

If the neutral conductor of the power grid is not connected to the RSE 400 (800), the internal arresters can be destroyed.

- ► The neutral conductor (star point) of the power grid must be connected to the earthing bar.
- ► Since the neutral of the earthing rod is connected to the earthing potential, no residual-current-operated circuit-breaker must be used in the power grid, or - if installed - it must be deactivated.

The input current of RSE 400 (800) is not sinusoidal, but contains a large content of harmonics. Due to the six-coil rectifier circuit in the mains input, very high current peaks can result. The ratio of the peak current to the r.m.s. value of the current is not constant, but dependent on the modulation, mains impedance and on the ratio of output and mains frequency. Ratios of 3 to 4 are quite common. An excessive mains impedance (including the mains connection lines) can result in impermissibly high voltage dips at the busbars. This may lead to malfunctions and impermissible heating of the intermediate circuit capacitors.

There are generally two types of supply mains: In most cases, a diesel generator is installed at the site; occasionally, connection to a 400 V mains in the station is also possible.

If an infinite power supply system is used (e.g. if the RSE is connected to a transformer), the mains must be protected from the feedback of the harmonic in the input current of the RSE. To this end, the RSE is to be fitted with a three-phase current-limiting reactor in the mains input (L1) in the vicinity of the busbars. Since in most cases generators are used for power supply, this reactor is bypassed by way of short busbars. If the RSE is operated at a stiff system, these shorting jumpers are to be removed.

Depending on the design, the impedance (short-circuit voltage) of a diesel generator is approximately 4 times higher than that of a transformer. The internal voltage regulation of these generators is too slow to be able to compensate the voltage dip caused by the current peaks in the RSE input current. Therefore, as experience over many years has shown, a generator with a nominal power should be selected which is at least three times as high as the power actually required for the test. The impedance of the generator is reduced due to the larger size required as a result of the higher nominal power and leads to lower voltage dips. In addition, it should be ensured that the current-limiting reactor L1 is bypassed with the short busbars in all three phases, since it increases the system impedance by approx. 90 µH per phase.

The mains power supply cables also have influence on the impedance of the supply mains. If they are very long, a larger cross-section should be used for the cables than necessary from the point of view of the r.m.s. value of the input current.

7. Design layout

All components of the RSE 400 are accommodated in a two-door steel cabinet. In the case of RSE 800, a second control cabinet is flanged on which comprises a second inverter unit, but no control system (operator panel, PLC, peak-voltage measuring instrument and controller module RSE-CTRL).

The following connections can be found recessed on the rear side of the device:

(1) Busbar for the earthing connection

(2) Busbars for connection of the exciter transformer (X1.4 / X1.5)

(3) Busbars for connection to the three-phase power grid (X1.1 / X1.2 / X1.3)

(4) Connection for the fan batteries (X111, X112)

(5) Temperature sensor Pt100 for measuring the ambient temperature

(6) Connection for the voltage divider (X103)

(7) Connection for safety loop, external EMERGENCY STOP and warning lamps (X80)

(8) Connection for the safety interface for connecting further RSE units (X81)

(9) DSUB9 connections for the CAN bus to further RSE units (XCAN1, XCAN2)

(10) DSUB15 connection for a Pt100 temperature sensor (X110)

(11) Contact interface for special applications (X22)

(12) DSUB25 connection for additional Pt100 temperature sensors (X8)

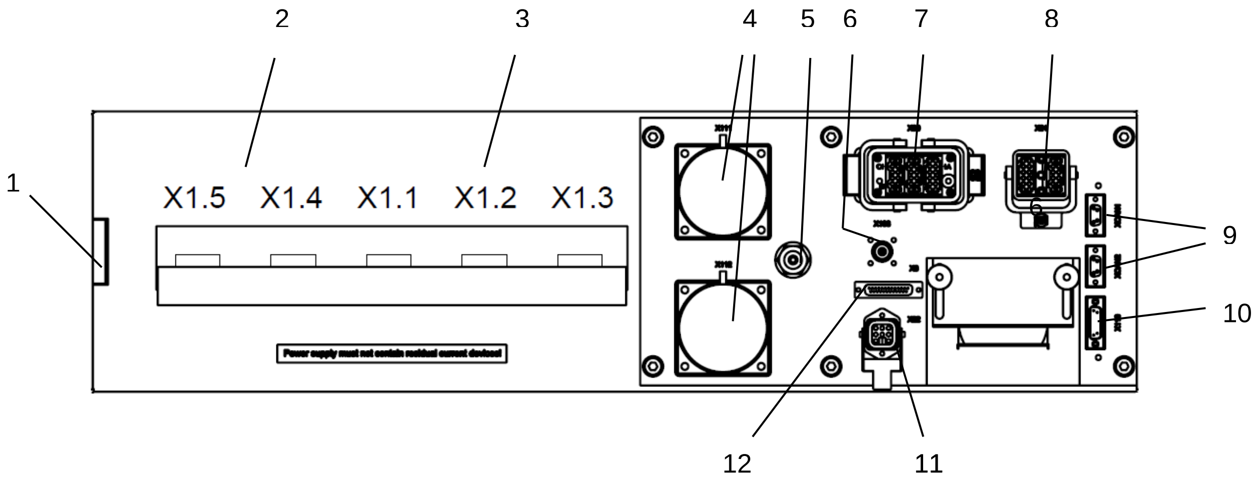


Fig. 1: Connections on the RSE 400 (800)

Deviating from the arrangement of the connections above, in the case of special variants, the exciter transformer(s) can also be connected via non-interchangeable plug connections, or the busbars for connection of the exciter transformers can be mounted in a side panel.

If the RSE 400 (800) is integrated into an operating container, the cooling air escapes via a special dome construction of the roof and a fan in the container wall. If the RSE is not intended for accommodation in an operating container, the cooling air escapes through slots in the roof. In this case, the size of the RSE increases by 100 mm.

NOTICE

Risk of damage to system components
When the RSE is lifted on the roof by way of a crane at an angle, the roof construction can be damaged.

► Use a crossbar for lifting.

Depending on the type of the overall test system (stationary or mobile), the operator controls of the RSE (operator panel, keys) can be installed recessed in the control cabinet door or in a separate operator panel.

8. Technical specifications

Power circuit

Nominal output voltage (peak value)	560 V
Nominal output current (r.m.s. value)	400 A (2x 400 A for RSE 800)
Output frequency	10 ... 300 Hz in two ranges
Resolution of the output frequency in steps of	400 ns
Output voltage range (r.m.s. value)	10 ... 520 V
Range of output current limiting	1 ... 400 A per inverter unit
Settable in steps of	1 A
Form of the output voltage	Square-wave voltage with adjustable pulse width (2 ... 85%)
Rise time of the output voltage	Approx. 200 ns

Connection parameters

Connection voltage	230 / 400 V +/- 10% , 50/60 Hz, 3-phase
Connected load	300 kVA (600 kVA for RSE 800)

Measurement and display of parameters

Test voltage	
Display	4-digit
Measuring error	≤ 0.5%
Nominal input voltage (r.m.s. value)	100 V
Input impedance	10 MΩ / 100 pF
Output current (r.m.s. value)	
Display	4-digit
Resolution	0.1 A
Measuring error	≤ 3%
Output frequency	
Display	5-digit
Resolution	0.01 Hz
Measuring error	≤ 0.1%

PC interface

Interface type	Ethernet (WLAN)
Baud rate	10 Mbit
IP address (Ethernet controller)	192.168.47.10
IP address (WLAN bridge)	192.168.47.5
Network name	RDA-XXXXXX (XXXXXX: HIGHVOLT order ID)

Safety interface

External EMERGENCY OFF circuit	230 VAC
Safety loop	230 VAC
Warning lamps (red / green)	230 VAC / 5 A

Dimensions, weight

Width	1000 mm (2000 mm for RSE 800)
Depth	600 mm
Height	1600 mm
Weight	350 kg (630 kg for RSE 800)

Ambient conditions

Temperature range during operation	0 … + 40°C
Temperature range during storage and transport	-20 … + 60°C

9. Range of application and function

9.1. General function

Resonant test systems are normally used for the AC testing of high-capacitance test objects. Thanks to the use of these test systems, in the ideal case, the electrical power required for the test can be reduced to the active power losses in the test circuit. Especially for on-site testing, it is imperative to keep the power required for the test, the weight of the required components and the installation expenditure as low as possible. The required resonant reactor is of great importance in this connection. Reactors with fixed inductivity can be designed considerably smaller and lighter than those with variable inductivity. To be able to achieve resonance, however, it is imperative that the frequency of the feeding voltage can be varied steplessly.

The high test voltage in a series resonant test system is generated by induction in the resonant reactor as a result of the capacitive current. The test voltage is approx. 100 … 200 times higher than the output voltage of the exciter transformer and is a pure sinusoidal oscillation. The resonant reactor and the load capacity form an oscillating circuit. Its natural frequency can be calculated using the following formula (Thomson formula):

$$f = \frac{1}{2\pi\sqrt{C \cdot L}}$$

The energy in the circuit oscillates at this frequency between reactor and load capacity. Due to the inevitable losses in the oscillating circuit (e.g. copper resistance of the reactor winding, losses in the magnetic circuit, …), this voltage would fade out without compensation of these losses. To obtain a constant voltage, these losses must be compensated by way of an external energy source (inverter). In the case of resonance, the output frequency of the inverter must correspond exactly to the natural frequency of the series oscillating circuit. In this case, pure active power is fed in from the inverter to cover the losses. The amount of the feeding power corresponds then exactly to the losses and lies commonly in a range of 0.5 … 1% of the apparent test power. The ratio of test apparent power and losses is called circuit quality or, in brief, Q factor.

In the case of HIGHVOLT resonant test systems, the supply voltage is provided by the inverter in the RSE 400 (800) in connection with the downstream exciter transformer. This transformer isolates the outputs of the inverter against earth and adapts the output voltage of the inverter (approx. 560 V peak value) to the supply voltage required for the series oscillating circuit.

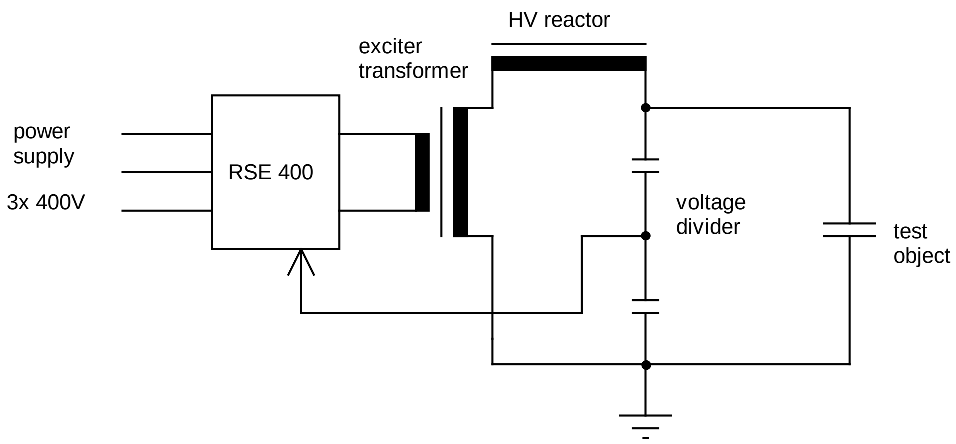


Fig. 2: Series resonant circuit with RSE 400

The control and feeding unit RSE 400 (800) comprises all modules required for power supply of a resonant circuit with adjustable frequency. These modules include an inverter with adjustable output frequency, a control system to control the test sequence, a calibrated peak voltmeter and the appropriate operator controls and display elements.

All test parameters and limit values for the test can be entered on the operator panel of the RSE 400 (800). Then the test process can be started and runs fully automatically. Connection of a PC via a WLAN connection allows controlling of the test sequence and saving of the test data on an external computer.

The dependency of the test voltage on the frequency entails the risk of overvoltages. Therefore, the RSE 400 (800) comprises numerous safety mechanisms to rule out this case reliably.

9.2. Design

Fig. 3 shows the block diagram of an RSE 800 control and feeding unit. Whereas an RSE 800 comprises two inverter units (inverter 0 and inverter 1), inverter unit 1 is missing in the RSE 400.

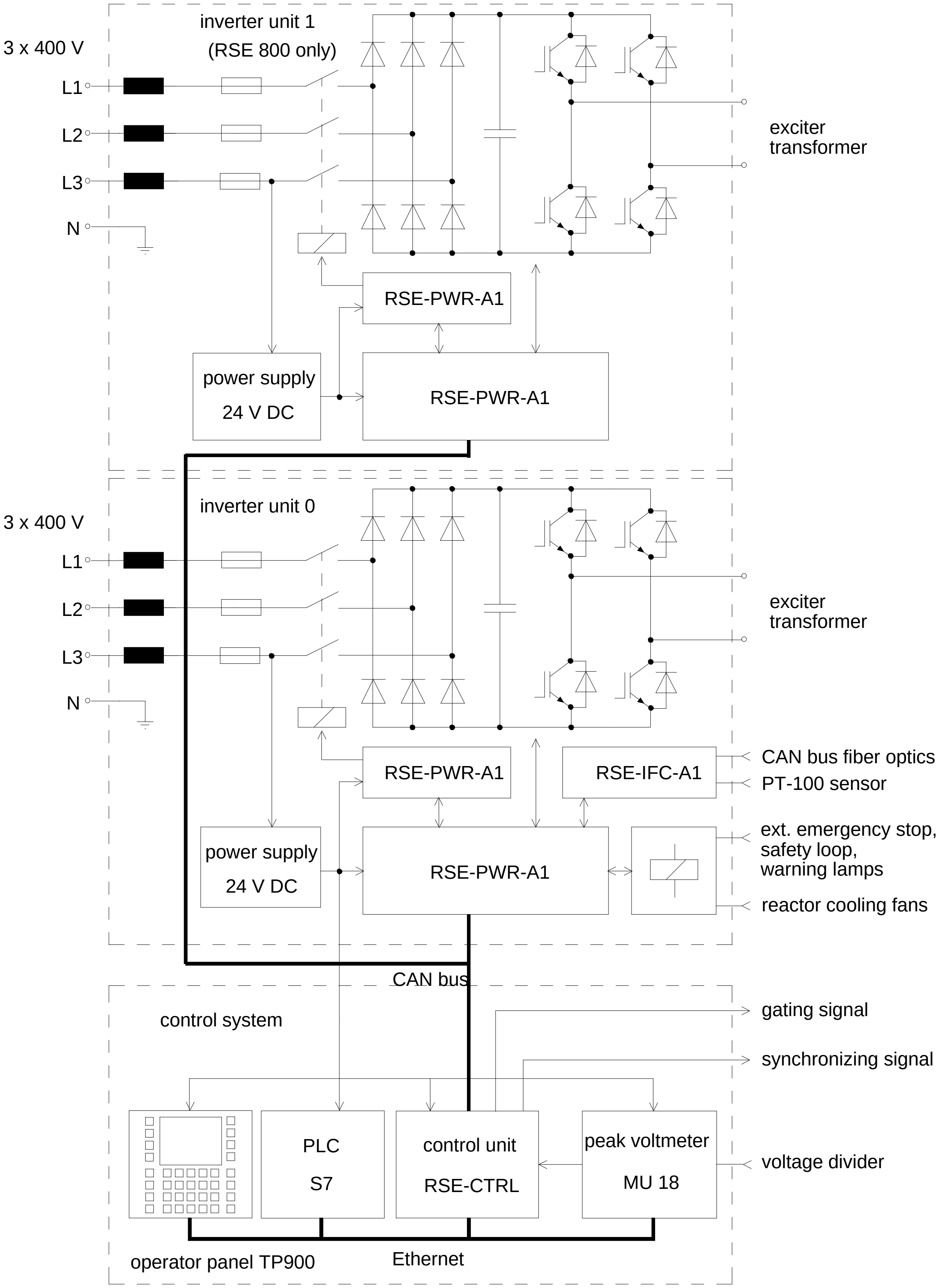


Fig. 3: Block diagram of RSE 800

9.3. Power circuit

The square-wave output voltage of an RSE is generated by way of a voltage-source inverter. A capacitor battery (C1...C3), the so-called intermediate circuit, is charged via a six-coil bridge connection consisting of the diode modules V1, V2 and V3 from the three-phase power grid to a DC voltage of approx. 560 V. To be able to limit the charging current in the case of fully discharged intermediate circuit, charging is performed via the series resistors on the p.c. board RSE-PWR-A2 (A14). Once the full intermediate circuit voltage is reached, the series resistors are bypassed with a contactor. During the precharging phase with a duration of 4 s, only a relatively low charging current may flow through the series resistors into the capacitor battery. The converter is only ready when the circuit breaker Q1 and the main contactor K2 are closed.

The intermediate circuit voltage generated in this way constitutes the supply voltage for a full-bridge inverter in a sample-and-hold circuit containing the two half-bridge IGBT modules V4 and V5. These modules comprise two IGBT transistors (**I**nsulated **G**ate **B**ipolar **T**ransistor) each.

Fig. 4 shows the general function of the inverter bridge for generation of a symmetrical square-wave voltage with variable duty. The transistors T1 and T4 constitute the IGBT module V4, and T2 and T3 the module V5.

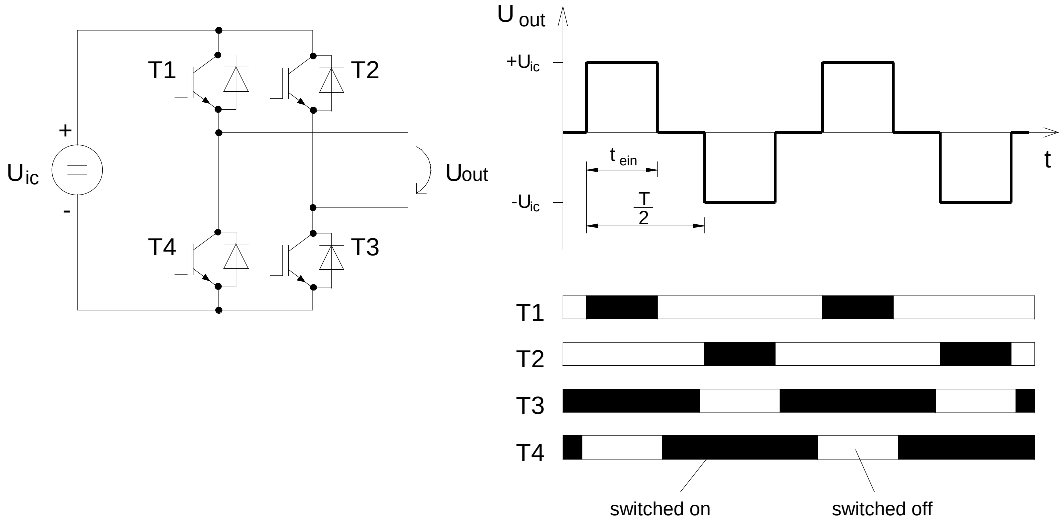


Fig. 4: Functioning principle of the inverter

As shown in the diagram above, the output voltage does not jump from one polarity directly to the opposite polarity, but assumes the value '0' for a certain time. The ON time t_{ON} may vary in the range $0 < t_{ON} < 0.5$ T. Thus, the r.m.s. value of the output voltage can be varied steplessly. The ratio of the ON time at the time of a half period is called duty which can assume values between 0 and 100% but is practically limited to 85%. The limiting to 85% prevents excessive overshot of the voltage on the exciter transformer secondary side. Since in the case of a connected resonant circuit only the fundamental wave contributes a share to the test voltage, the generated high voltage is not proportional to the r.m.s. value of the output voltage, but proportional to the component of the fundamental wave which occurs at a certain pulse duty factor. The practical meaning of this fact is that the generated test voltage scarcely increases if the duty is greater than 85%.

Due to the non-linear connection between duty and generated test voltage, displaying of the duty is inappropriate. Instead, the so-called modulation is displayed on the operator panel of the RSE. There is a linear correlation between modulation and generated test voltage, considerably facilitating the estimation of possible reserves when increasing the test voltage. The correlation between the duty as a percentage and the modulation as a percentage is described by means of the following equation:

$$\text{Modulation} = \cos\left(\frac{\pi}{2}\left(1 - \frac{\textit{Duty factor}}{100\%}\right)\right) \cdot 100\% \quad = \cos\left(\frac{\pi}{2}\left(1 - \frac{2\,t_{ON}}{T}\right)\right) \cdot 100\%$$

The control signals for the IGBT modules are provided by the p.c. board IGBT-CTRL-A1 (A4) whereas the level adjustment, electrical isolation, error, temperature and current acquisition are provided by the IGBT modules. In case of overcurrent, the modules gently shut down the transistors automatically. This shutdown - called IGBT desaturation - is reported to the higher-level control system and leads to immediate interruption of the test.

A critical case in operation occurs if the control system breaks down during the test with high test current, e.g. due to power failure on the supply side or due to an EMERGENCY OFF command. Since at this moment the current in the test circuit flows further until the current totally decays due to the natural attenuation, a current path must be maintained on the primary side of the exciter transformer, as otherwise high overvoltage can occur at the exciter transformer.

To avoid such damage, various protective measures are implemented in the RSE 400 (800):

- No switching elements (e.g. contactor) are installed between the inverter output and exciter transformer.
- The supply voltages of the p.c. boards are also not shut down in case of an EMERGENCY OFF command. Thus, it is possible for the inverter control system to turn on the two lower transistors in *Fig. 4* permanently. Thus, the decay current finds a low-ohmic path via one transistor and one freewheeling diode each.
- The two lower transistors are also always turned on when the system is turned off (prior to and after the test).
- A so-called crowbar switch connected parallel to the converter output short-circuits the latter if a voltage of more than 700 V occurs between the output terminals. This is a sure sign that all transistors of the inverter are turned off and cannot bear the current (e.g. in case of a power supply failure). In this case, the enforced current flowing through the freewheeling diodes charges the capacitor bank in the reverse direction to high voltages. The crowbar switch possesses its own power supply that can also turn on the switch for at least 6 s in case of mains power failure, thus preventing further increase of the intermediate circuit voltage.
- Additionally, arresters (R14, R15) are connected over the intermediate circuit which may also assume energy to a limited degree which is fed-in in the reverse direction, thus limiting the intermediate circuit voltage to 900 V.

9.4. Control principle

In the case of resonant test systems, the current trend towards higher and higher test powers results in a growing demand for feeding power. Thanks to the modular control concept of the control and feeding units RSE 400 (800), up to maximum 64 inverter units can be coupled to each other. Therefore, the individual inverter units (one in RSE 400 and two in RSE 800) are designed as closed units and only connected to the controller unit RSE-CTRL by way of a CAN bus connection. For details, see *Chapter 12*.

9.5. Inverter unit

Every converter unit comprises all components of a fully featured frequency inverter. The main components are the rectifier modules (V1, V2, V3) and the IGBT half-bridge modules (V4, V5). All these power modules are mounted on two forced-air-cooled heat sinks. The converter units additionally comprise a circuit breaker Q1, the main contactor K2, a fuse switch-disconnector (F1), a capacitor bank (C1…C3) forming the intermediate circuit, a discharging resistor (R1) and precharging resistors on the p.c. board RSE-PWR-A1 (A3).

The electronic components of a converter unit are distributed over three p.c. boards. A micro-controller on the p.c. board IGBT-CTRL-A1 (A4) communicates with the controller unit RSE-CTRL via the CAN bus and receives from the latter commands and parameters for controlling its main contactor K2, for precharging and controlling the IGBT modules. At the same time, it returns its measurement values and status information. The values for the converter output current and the chip temperatures of the IGBT modules are prepared in these modules and read in as analog values from the p.c. board IGBT-CTRL-A1. The measurement of the intermediate circuit voltage and the phase voltages of the supply mains, as well as controlling of the precharging relays are performed on the p.c. board RSE-PWR-A1 (A3).

All p.c. boards are operated with 24 VDC provided by a switched-mode power supply (A8). A 230V AC voltage to control various relays, for the warning lamps and for the internal fans is generated from the line-to-line input voltage by way of transformer T1.

The p.c. board RSE-IFC-A1 (A5) forms the interface for connection of an external temperature sensor (type Pt100, X110) for measuring the oil temperature of a resonant reactor and, in addition, possesses two DSUB9 plug connectors (XCAN1 and XCAN2) for connecting further RSE 400 (800) in the case of parallel operation for power extension.

In the case of RSE 800, only one of the two inverter units is fitted with connections for warning lamps, safety loop and external EMERGENCY STOP (X80, X81), as well as with a p.c. board RSE-IFC-A1.

All components of the inverter unit, except for the p.c. board RSE-IFC-A1, are installed on a mounting plate. For protection against accidental contact to live parts, a few of them are fitted with a transparent cover.

9.6. Higher-level control system

The control system consists of a programmable logic controller (PLC) from the Siemens S7 device family (A1), an operator panel with touch screen (A13), a peak voltmeter MU 18 (A7) and the controller module RSE-CTRL (A2). All devices communicate with each other via an Ethernet network.

The controller module RSE-CTRL possesses a CAN bus interface for data transfer to the individual inverter units. It transfers the command and limit values received from the PLC to the inverter units and collects its parameters and status information. They are handed over to the PLC via the Profibus DP interface. Furthermore, the RSE-CTRL controls the automatic frequency search and provides breakdown detection on test objects. It picks the information required for these tasks from the output signal of the voltage divider via a connection to the monitor output (X2) of the peak voltmeter MU 18.

In addition, the controller module RSE-CTRL provides signals for synchronization and gating for partial-discharge measurements (*see Chapter 16*).

The controller module RSE-CTRL and also the electronic components of the inverter units are active once the three-phase supply voltage is present at the RSE 400 (800), irrespective of whether the control system was turned on or the EMERGENCY STOP pushbutton was actuated. The EMERGENCY STOP command acts only on the circuit breaker Q1 and the main contactor K2. The shutting down of the control system additionally turns off the PLC, the operator panel and the peak voltmeter. This mode of operation is necessary so as to be able to de-excite the test circuit in case of unplanned shutdown (e.g. EMERGENCY STOP).

9.7. Measuring the test voltage

The generated test voltage is measured using a calibrated peak voltmeter MU 18 (A7). This device is designed for pure remote control and therefore does not possess any operator controls and display elements. It is controlled from the PLC via Ethernet network and sends its measurement values back to the PLC.

To measure the test voltage, an external capacitive voltage divider is required, which provides an output voltage of approx. 100 $V_{r.m.s.}$ at nominal voltage of the test system. The divider is to be connected by way of a coaxial cable (type-N connector) to the female connector X103 on the rear side of the device.

9.8. Monitoring of the reactor temperature

Depending on the type of resonant reactor installed, the RSE 400 (800) is configured for measurement of the oil temperature or calculation of the mean winding temperature of a gas-insulated reactor. The oil temperature is measured by way of an external Pt100 temperature sensor connected to X110. In both cases, the monitoring of the reactor temperature is intended to protect the reactor from thermal overload.

For design reasons, it is not possible to measure the mean winding temperature of a gas-insulated reactor by way of a sensor. Therefore, the PLC calculates the mean winding temperature on the basis of a thermal model in accordance with reactor current and ambient temperature. Each reactor type requires its own thermal model. They are stored in the memory of the PLC as temperature models 0 … 8. The model matching the system is activated during configuration of the RSE 400 (800). The models can only be changed with a special password.

To be able to calculate the winding temperature, the PLC requires the ambient temperature. It is measured at the rear side of the RSE 400 (800) by way of a Pt100 temperature sensor (R7). The temperature is calculated continuously, also for the time when the RSE was switched off. Thus, cooling e.g. over night is also considered. If the RSE has been turned off for three or more days, the mean winding temperature is set to the ambient temperature when the test system is turned back on.

NOTICE

Risk of damage to system components

Selection of the wrong temperature model can lead to thermal destruction of the resonant reactor!

- ► When changing the temperature model, observe that you select the temperature model matching the reactor type you are using.
- ► If you wish to perform the test using a gas-insulated reactor of a different type, the temperature model must also be adapted correspondingly.

Tab. 1: Temperature models for gas-insulated resonant reactors

Temperature model	U_{nom}	I_{nom}	L_{nom}	HIGHVOLT type	Manufacturer type
0	No temperature calculation, but temperature measurement with external Pt100 temperature sensor				
1	460 kV 680 kV	1.5 A	720 H	DEG 960/460-1.5 DEG 1020/680-1.5	STED 1/460 STED 1/680
2	400 kV	1.7 A	352 H	DEG 680/400-1.7	STED 1/400
3	740 kV	0.6 A	2800 H	DEG 450/740-0.6	STED 1/740
4	1000 kV	0.6 A	4000 H	DEG 600/1000-0.6	2x STED 1/500 (E)sp
5	750 kV	1.9 A	1390 H	DEG 1425/750-1.9-1	2x DSS375/1.9
6	750 kV	1.9 A	1390 H	DEG 1425/750-1.9-2	2x DSS375/1.9
7	140 kV	0.35 A	800 H	DEG 49/140-0.35	STED 1/140
8	750 kV	1.9 A	1500 H	DEG-1425/750-1.9-3	2x DSS375/1.9

The temperature models 4, 5, 6 and 8 are intended for reactor types comprising two gas-insulated reactors connected in series. The model is valid for operation of both a single reactor and of the two reactors connected in series. The values specified in Tab. 1 for nominal voltage and the inductivity refer to series connection of both reactors.

If temperature model 0 is selected, no temperature is calculated. If the installed resonant reactor is fitted with a Pt100 temperature sensor for measuring of the oil temperature, it can be connected to the DSUB15 connector X8 using the four-wire connection technology. In this case, the RSE 400 (800) will use the measured temperature value for temperature monitoring. If temperature model 0 is selected and no temperature sensor connected, the value 0°C is displayed for the reactor temperature.

If the measured or calculated reactor temperature reaches a value that lies 5 K below the temperature limit, the message [Warning: Reactor temperature] is displayed on the operator panel. If the maximum reactor temperature is reached or exceeded, the message [Reactor overtemperature] is displayed, and the test is switched off automatically.

10. Operation

10.1. Operator controls

The RSE 400 (800) is operated by way of an operator panel with touch screen and three keys. These elements are mounted recessed in one of the control cabinet doors or on a separate operator device. These operator controls are shown in Fig. 5 in detail.

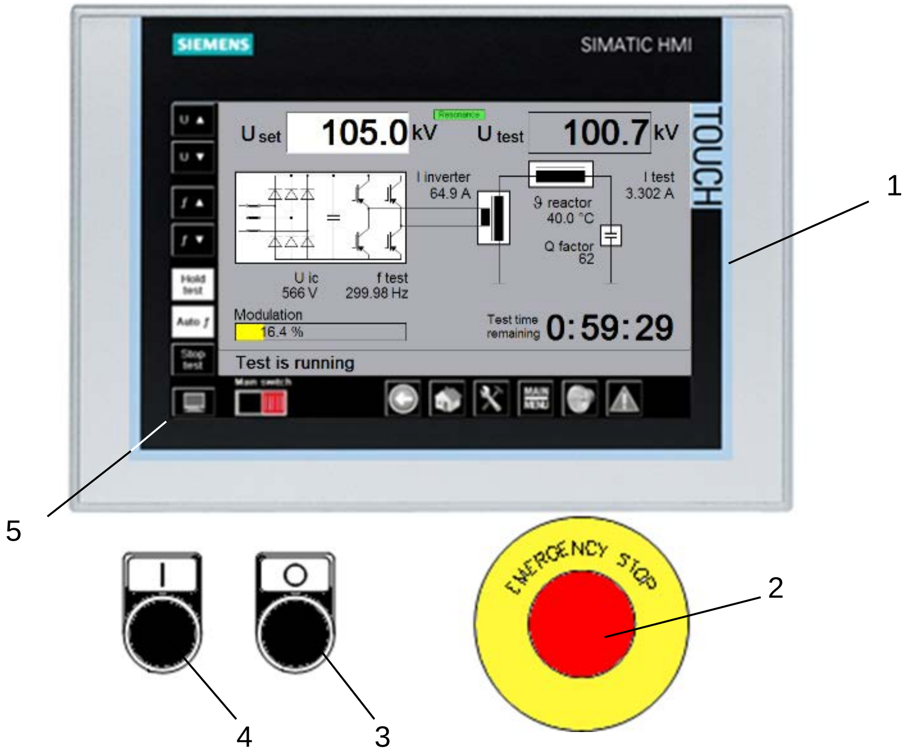
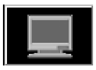


Fig. 5: Operator controls of the RSE 400 (800)

1	Operator panel	• The operator panel TP900 comprises a touch-sensitive color display with a resolution of 800x480 pixels. • The operator can enter all required limit values and setpoints and control functions by way of buttons. • The operator panel displays all important measurement values, as well as status and error messages.
2	EMERGENCY STOP pushbutton	• In an emergency case, the inverters can be turned off immediately using the EMERGENCY STOP pushbutton.
3	Pushbutton "Control OFF"	• Turns off the control system.
4	Pushbutton "Control ON"	• Turns on the control system.
5	Buttons	• Buttons with fixed functions can be found at the left and bottom margins of the screen. *Tab. 2* provides an overview of these buttons and their functions.

Tab. 2: Meanings and functions of the buttons on the operator panel

Button	Function, meaning	Status, remarks
	Opens the screen [Test]	
	Opens the screen [Test settings]	
MAIN MENU	Opens the main menu	
	Warning signal	Controls an external horn
	Acknowledges error messages	Is lit yellow when errors are present
	Jumps to the previous screen	
	Jumps to the next screen	Only visible if there is a next screen
	Main switch ON / OFF	Main switch is OFF (highlighted in green)
		Main switch is ON (highlighted in red)
	Enables / disables remote control from an external PC	RSE is not controlled by a PC
		RSE is controlled by a PC
U ▲	Increases the voltage	Only possible in holding mode
U ▼	Decreases the voltage	
f ▲	Increases the frequency	
f ▼	Decreases the frequency	
Start Test	Controls the automatic test frequency	Test is off or on hold; tap button for (re-)start
Pause Test		Test is running; tap button to suspend operation. The current actual value of the test voltage is accepted as the new setpoint.
Auto *f*	Enables / disables automatic frequency search	Automatic frequency search is active (default after turning on the main switches)
Auto *f*		No automatic frequency search
Stopp Test	Cancels a test sequence manually	

10.2. Inputs at the operator panel

Entering values

- ▷ Tap the appropriate input field to enter numerical values.
  - ➔ A virtual keyboard is displayed on the screen.
- ▷ Enter the desired numerical value using the virtual keyboard and press the ENTER [↵] key to confirm.
  - ➔ The virtual keyboard will then disappear automatically.

Faulty inputs can be discarded by pressing the [ESC] key. The old value is preserved. Illegal inputs are rejected or automatically set to permissible values.

Selecting predefined values

Predefined values (e.g. frequency range 10…150 Hz or 20….300 Hz) are highlighted by way of a circle. Your current selection is highlighted by way of a green point in the circle.

- ▷ To select a value, tap the appropriate circle.

10.3. Password protection

To prevent parameters to be changed by unauthorized persons, the following parameters are password-protected:

Voltage measurement scaling factor	(default password)
System nominal voltage	(default password)
Resonant reactor inductivity	(default password)
Temperature model	(special password)
Voltage regulator parameters	(special password)

The password is a three-digit number that is fixed by HIGHVOLT and cannot be changed by the operator.

- ▷ Enter the password when prompted and press OK to complete your input.
  - ➔ After you have entered the password, access to all password-protected parameters is possible for 10 minutes without re-entering the password.

- ➲ The default password is enclosed to the documentation on a separate sheet.

10.4. Screen brightness and dialog language

The brightness of the screen, the dialog language, the date and time can be changed or corrected. This is described in *Section 11.3.7* in detail.

11. Menu structure

After turning on the control system, both the PLC and the operator panel pass an initialization phase. As long as both devices have not yet completed this phase, the message [Please wait until system initialization passed…] is displayed on the screen. Once the initialization is completed, the screen [Test] is displayed.

The input of parameters and display of values are performed in different screens and menus. These screens are described in the following sections in detail.

Except for the screen [Test], the current test voltage in the top right corner of the screen is highlighted for safety reasons in red in all screens.

11.1. Screen "Test"

The screen [Test] displays the most important parameters of the test. It can be called at any time by tapping the button .

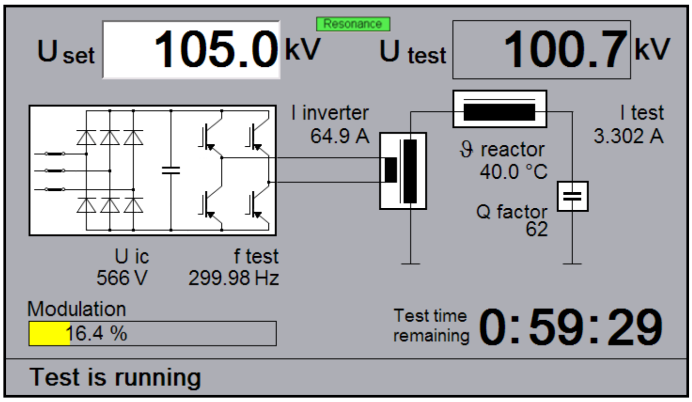


Fig. 6: The [Test] screen

[U set]	Test voltage setpoint; can be overwritten at any time
[U test]	Test voltage actual value; current test voltage (positive peak value / √2)
[Test time remaining]	Remaining test time in the format hours : minutes : seconds
[f test]	Current test frequency
[I inverter]	Total output current of all inverter units (sum)
[I test]	Calculated test current in the high-voltage circuit (load current)
[U ic]	Intermediate circuit voltage (mean value of all converters)
[ϑ reactor]	Oil or winding temperature of the hottest resonant reactor
[Modulation]	Inverter modulation (range utilization)
[Q factor]	Q factor of the resonant circuit calculated online
[Resonance]	A green rectangle with the text [Resonance] between the setpoint and actual voltages displays that the system is operating exactly at the resonance point of the test circuit.

11.2. Screen "Test settings"

The screen [Test settings] can be used to enter setpoints for a test. It can be called at any time by tapping the button . In addition, this menu can be called from the main menu using the button [Test settings].

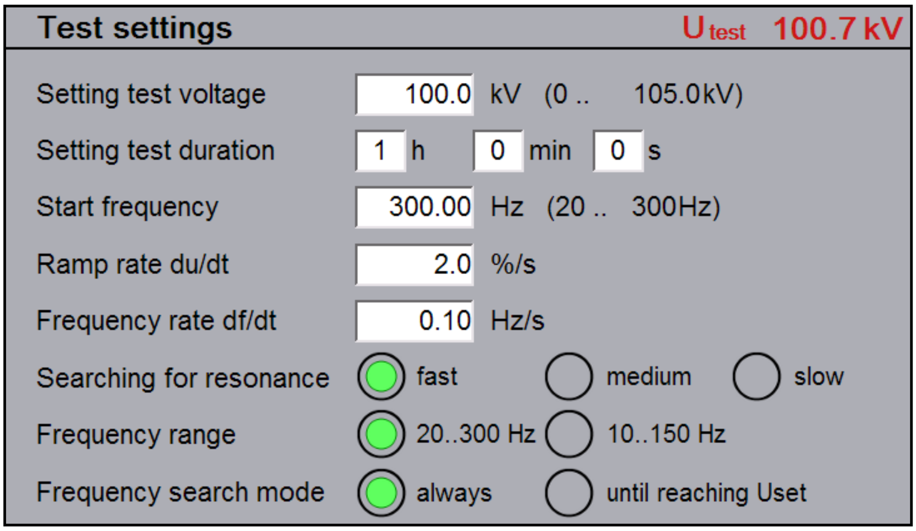


Fig. 7: Screen [Test settings]

[Setting test voltage]	Desired test voltage
[Setting test duration]	Desired test time (in the form hh:mm:ss)
[Start frequency]	Frequency at which the frequency search is to start. Since the search is performed towards lower frequencies, this value must be greater than the resonant frequency to be expected.
[Ramp rate du/dt]	Specification of the voltage ramp rate in %/s. 100% correspond to the system nominal voltage. Values between 1 and 3 %/s are recommended.
[Frequency change df/dt]	Specification of the frequency ramp rate in Hz/s. This value determines how fast the frequency is to change when tapping the key or . This value has no influence on the automatic frequency search.
[Searching for resonance]	Specifies the speed of automatic searching for the resonance point in three stages (fast / medium / slow). [fast] is used by default. If the resonance point is crossed, the search speed can be reduced to [medium] or [slow].
[Frequency range]	The RSE 400 (800) can operate in the frequency ranges 10…150 Hz or 20…300 Hz. If the test frequency to be expected lies between 10 and 20 Hz, the range 10 … 150 Hz must be selected, otherwise 20 … 300 Hz.

[Frequency search mode]	[always] or [until reaching Uset] The operating mode [Until Uset reached] disables the automatic frequency search once the test voltage has reached its setpoint.

In most cases, the operating mode [Always] is the better choice. In this mode, the frequency is always controlled during the entire test such that the system always operates at the resonance point. Thus, any changes in the natural frequency of the test circuit due to voltage or temperature-dependent changes of the reactor inductance or test object capacitance are compensated.

Merely for tests at a fixed test voltage and in case of danger of strong predischarges (e.g. tests at gas-insulated switchgear via a bushing), the operating mode [Until Uset reached] may be the better choice. Thus, it is ruled out that such predischarges lead to undesired, short-time frequency changes that influence the stability of the test voltage in a negative way.

Basically, the RSE 400 (800) searches for the resonance point starting from the start frequency towards lower frequencies. The time for frequency search can be reduced by appropriate selection of the start frequency. It must, however, be ensured that the start frequency is higher than the expected natural frequency of the test circuit; otherwise, the resonance point is not found.

For safety reasons, the setpoint of the test voltage is automatically set to 0 kV and the start frequency to the maximum possible value (150 or 300 Hz, depending on the frequency range) after turning on the control system of the RSE 400 (800).

11.3. Main menu

Whereas the screens [Test] and [Test settings] can be called directly by way of fixed buttons, all the other screens and menus must be called via the [main menu]. To this end, tap the button 
.

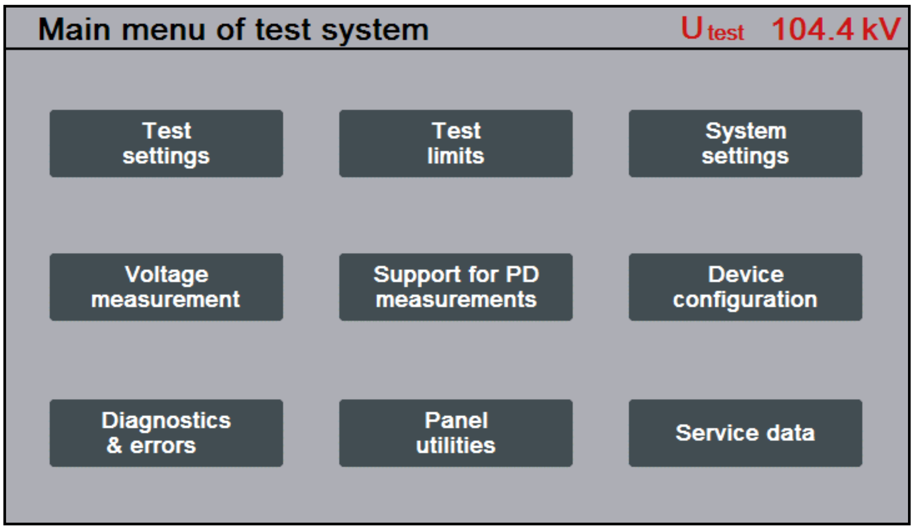


Fig. 8: The [main menu]

11.3.1. Screen "Test limits"

The screen [Test limits] can be used to enter limit values for a test; it can be called from the main menu using the button [Test limits].

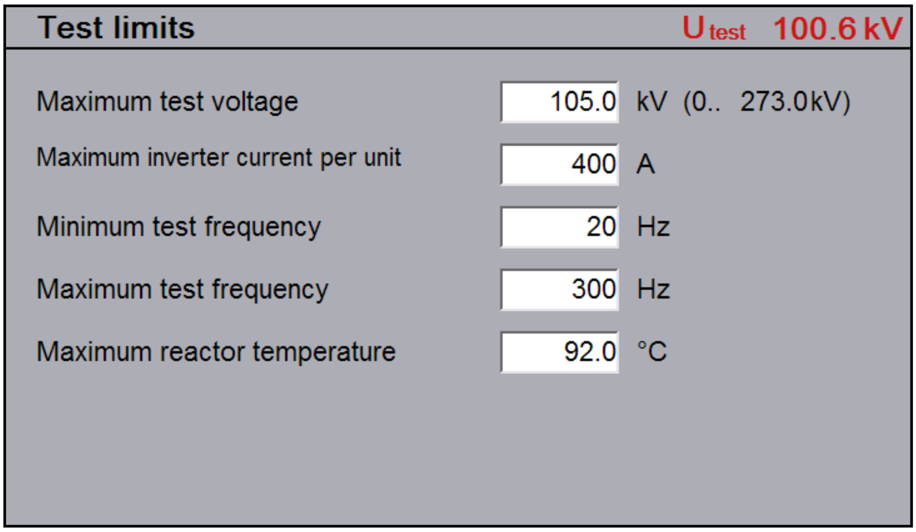


Fig. 9: Screen [Test limits]

[Maximum test voltage]	When the test voltage exceeds this value, the test is cancelled automatically. The limit value may lie up to 5% above the system nominal voltage to avoid shutting down by slight overshot during a test with system nominal voltage.
[Maximum inverter current per unit]	If the output current of an inverter unit exceeds this value, the test is automatically cancelled immediately with the message [Error: Overcurrent].
[Minimum test frequency]	Limit value for the lowest test frequency
[Maximum test frequency]	Limit value for the highest test frequency
[Maximum reactor temperature]	If the oil or winding temperature of a resonant reactor exceeds this value, the test is automatically cancelled immediately. Only values less than or equal to the maximum permissible reactor temperature in the system configuration are accepted.

11.3.2. Screen "System settings"

The screen [System settings] can be used to enter parameters describing the test system; it can be called from the main menu using the button [System settings].

The displayed parameters depend on the type of resonant reactors for which the RSE 400 (800) was configured by the manufacturer.

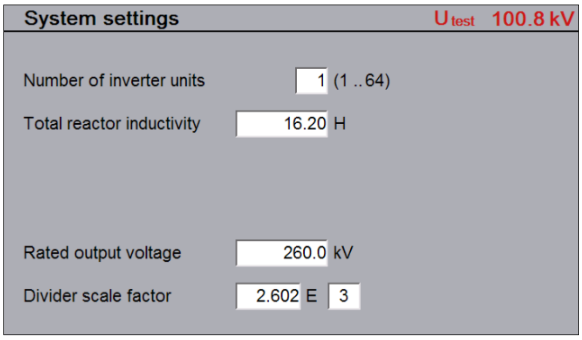


Fig. 10: Screen [System settings] if the RSE is configured for oil-insulated reactors

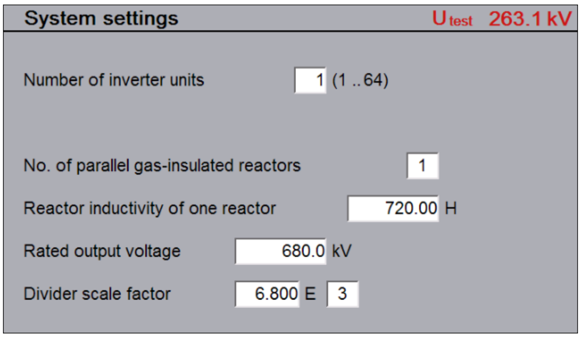


Fig. 11: Screen [System settings] if the RSE is configured for gas-insulated reactors

[Number of inverter units]	Specify the total number of inverter units to be controlled. In the case of one single RSE 400, "1" must be entered, and in the case of a RSE 800 the value "2".
[Rated output voltage]	The value to be entered is determined by the current system configuration. It corresponds to the nominal voltage of the high-voltage component in the test circuit (divider, reactor) with the lowest nominal voltage.
[Divider scale factor]	Corresponds to the scale factor for the entire voltage measuring system. For the exact value, refer to the calibration certificate. The value is to be entered in the exponential notation. A scale factor of "1200", for example, is to be entered in the form "1,200 E03" (corresponds to $1.2 * 10^3$).
[Total reactor inductivity]	This is the value to be entered for the effective total inductivity of all reactors used. For example, the series connection of two reactors of 16.2 H each would yield a value of 32.4 H. If they would be connected in parallel, a value of 8.1 H would result. If an incorrect value is entered, an incorrect test current and an incorrect Q factor are calculated.
[No. of parallel gas-insulated reactors]	Corresponds to the number of all identical parallel-connected gas-insulated resonant reactors in the test circuit. The RSE 400 (800) automatically calculates the resulting total inductivity and test current through a reactor, which is required for the temperature calculation, on the basis of this number and the inductivity of a reactor. An incorrect input value leads to an incorrect display of the test current, but has no influence on the temperature calculation.
[Inductivity of one reactor]	Corresponds to the inductivity of <u>one</u> gas-insulated resonant reactor. The input of an incorrect value leads to a faulty calculation of the test current and thus an incorrect calculation of the winding temperature.

NOTICE

Risk of damage to system components

Incorrect input of the number of gas-insulated reactors or their inductivity can also lead to thermal overload and irreversible damage.

- ► Before starting a test, ensure that the inputs for number and inductivity of the gas-insulated reactors correspond to the actual conditions in the test arrangement.

All input values are protected by way of the default password.

11.3.3. Screen "Voltage measurement"

The screen [Voltage measurement] can be used to enter a scaling factor for measuring of the test voltage; it displays different measurement values. This screen can be called from the main menu using the button [Voltage measurement].

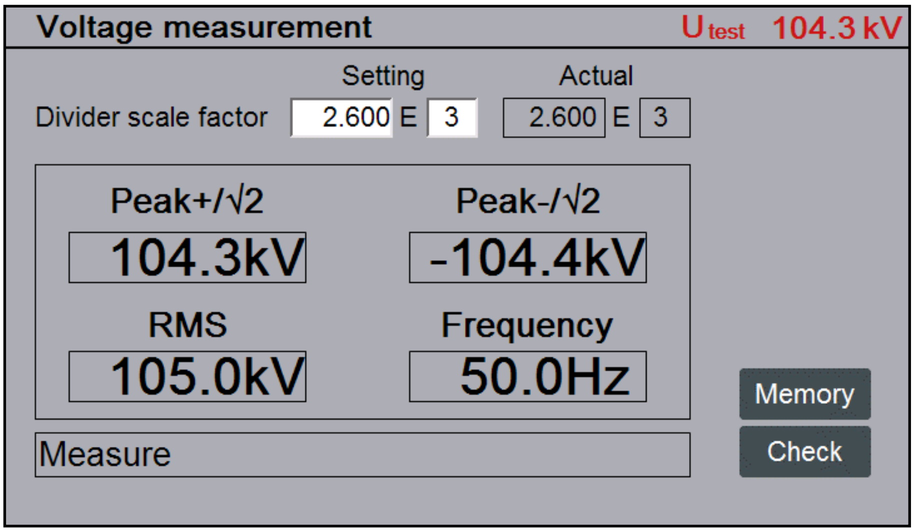


Fig. 12: The screen [Voltage measurement]

The only value that can be entered here is the divider ratio (scale factor) of the voltage divider used. This input is protected by way of the default password. For the exact value, refer to the calibration certificate. Enter the value in the exponential notation in the fields under [User preference]. A scaling factor of "1200", for example, is to be entered in the form "1.200 E03" (corresponds to $1.2 * 10^3$). After your input, the new value must appear under [Actual value] as the sign that the values were accepted.

Status information for the peak voltmeter are displayed at the lower margin. If no high-voltage is present, [No voltage] is displayed; otherwise, [Measurement].

The button [Check] activates an internal test of the peak voltmeter; it remains activated until the button is released. During this time, a DC voltage of +5.00 V is connected internally to the measuring circuit. An r.m.s. value of 5.00 V must be displayed, and a value of (-)3.536 V for "Peak+(-) /√2". The maximum permissible deviation is 0.2%.

11.3.4. Screen "Support for PD measurements"

The screen [Support for PD measurements] can be used to enter parameters supporting partial discharge measurements ("PD measurements"). This screen can be called from the main menu using the button [Support for PD measurements].

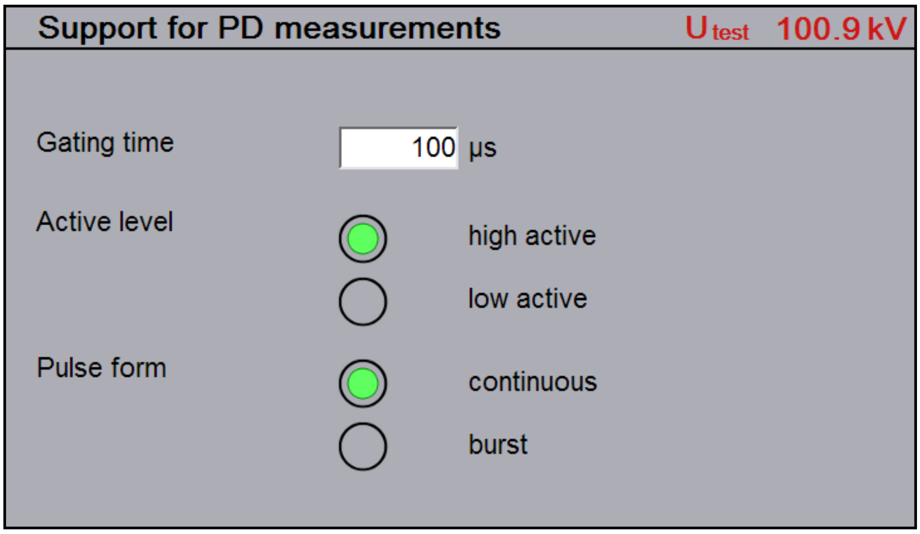


Fig. 13: Screen [Support for PD measurements]

[Gating time]	Duration of the gating signal for each of the inverter switching transients (four per period) in µs (0 … 1000)	
[Active level]	[high active]:	Output level >3.5 V during the gating
	[low active]:	Output level <0.8 V during the gating
[Pulse form]	[continuously]:	Simple square-wave signal
	[burst]:	Group of short gating pulses with a repetition frequency of approx. 300 kHz

11.3.5. Screen "Device configuration"

To request or modify the configuration data of the RSE 400 (800), tap the button [Device configuration] in the main menu to call the screen [Device configuration]. To be able to change the configuration data, a special password other than that of the default password is required. Changing the configuration data is reserved to the HIGHVOLT service personnel and is performed during the system factory test.

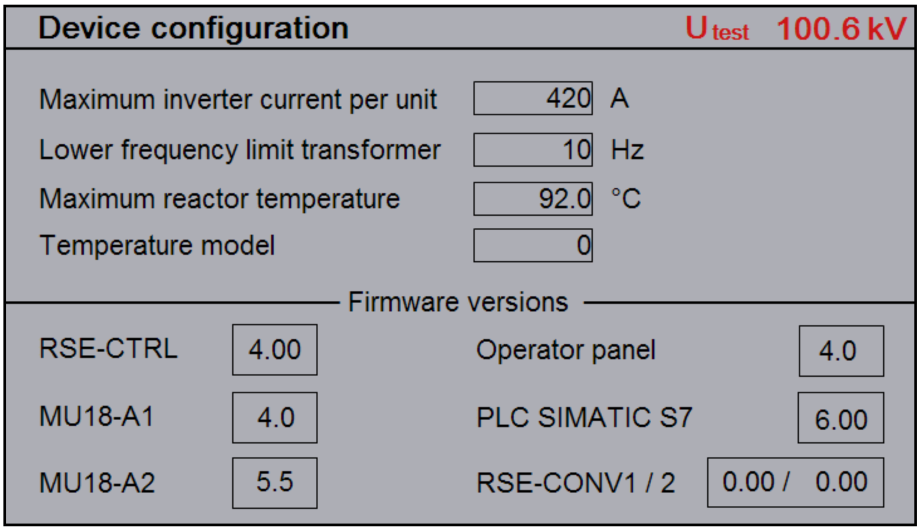


Fig. 14: Screen [Device configuration]

In special cases, it can occur that the operator must adapt the temperature model or minimum frequency of the exciter transformer. In this case, the customer is notified of the appropriate password separately. If a change is necessary and the RSE 400 (800) is configured accordingly, tap the button [Configuration] which is active in this case. Subsequently, the screen [RSE configuration] is displayed.

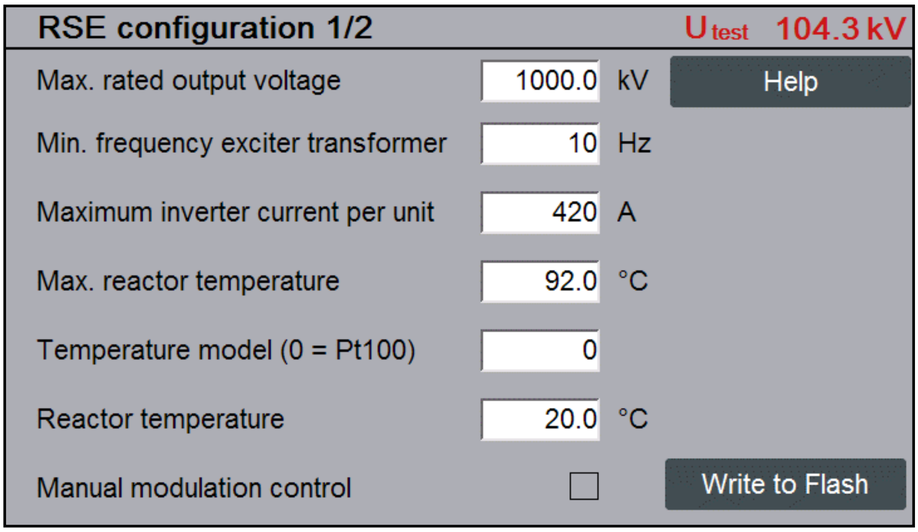


Fig. 15: Screen [RSE configuration]

The stored temperature models are numbered. Temperature model no. 0 means that the temperature calculation is deactivated and the temperature is measured by way of an external temperature sensor Pt100 (if connected). The temperature models applicable for the different gas-insulated resonant reactors are listed in *Section 9.8*.

If it is permissible to change the minimum frequency of the exciter transformer, the lower operating frequency must be specified for the parameter [Min. frequency of exciter transformer]. If the RSE 400 (800) is operated as master in an interconnected system comprising several test systems, the lower operating frequency of the exciter transformer with the highest lower operating frequency must be selected. If different exciter transformers with lower operating frequencies of 10 Hz, 20 Hz and 25 Hz are operated, the value 25 Hz must be set to be able to protect this exciter transformer reliably from overload.

All the other parameters may only be changed by the HIGHVOLT service personnel. After you have adapted the parameters, tap the button [Save] to save your changes permanently.

NOTICE

Risk of damage to system components
Selection of the wrong temperature model can lead to thermal destruction of the resonant reactor!

- When changing the temperature model, observe that you select the temperature model matching the reactor type you are using.
- If you wish to perform the test using a reactor of a different type, it is imperative to adapt the temperature model.

11.3.6. Menu "Diagnosis & errors"

In case of malfunctions at the RSE 400 (800), it is important to be able to request detailed status and error messages to determine the cause of faults. The menu [Diagnosis & errors] can be called from the main menu using the button [Diagnosis & errors].

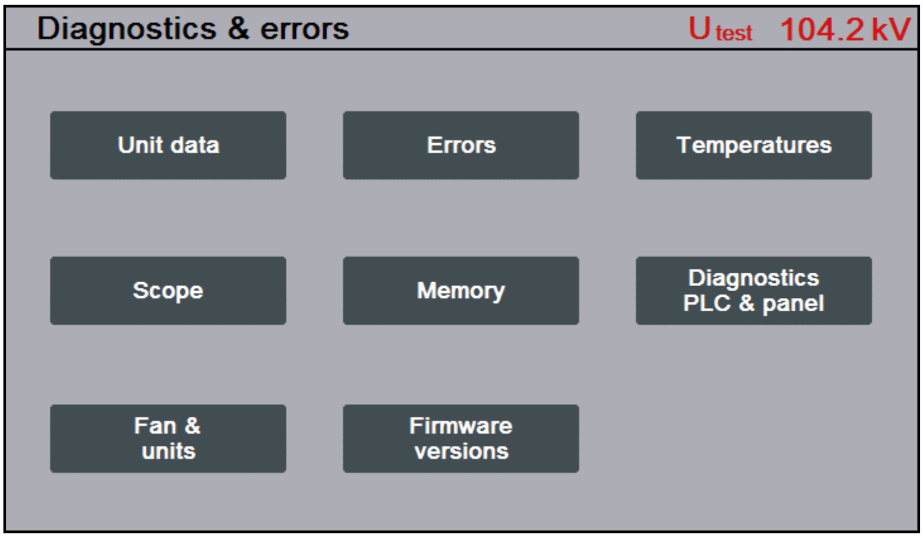


Fig. 16: Menu [Diagnosis & errors]

11.3.6.1. Screen "Data of inverter unit"

The screen [Data of inverter unit] displays various measurement values and status information of two inverter units. It can be called from the screen [Diagnosis & errors] using the button [Unit data].

Enter the addresses of the inverter units whose values you wish to be displayed in the appropriate input fields. Observe that the addresses must start with "0", not with "1". Therefore, only the value "0" is permissible for a single RSE 400.

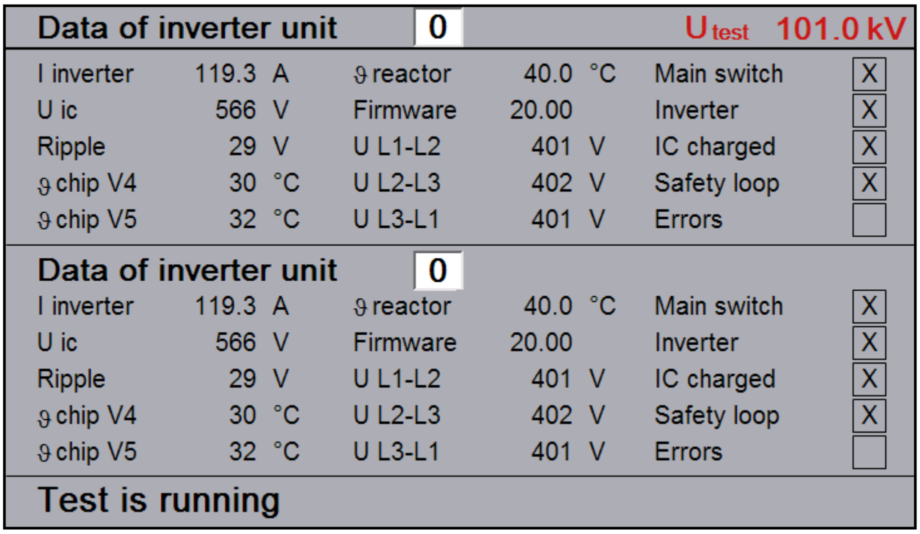


Fig. 17: Screen [Data of inverter unit]

[I inverter]	Output current of the inverter unit (r.m.s. value)
[U ic]	Intermediate circuit voltage
[Ripple]	Ripple factor of the intermediate circuit voltage (difference between the highest and the lowest values)
[U L1-L2] [U L2-L3] [U L3-L1]	Line-to-line voltages of the three-phase supply mains
[ϑ chip V4]	Chip temperature of the IGBT module V4 The measuring accuracy is strongly reduced at temperatures <30°C. Values up to 80°C are not critical.
[ϑ chip V5]	Chip temperature of the IGBT module V5
[ϑ reactor]	Oil temperature of a resonant reactor if its temperature sensor is connected to X110 of this inverter unit
[Firmware]	Firmware version of the controller on the p.c. board IGBT-CTRL-A1

The status of the operating switch, of the converter, the charging status, of the intermediate circuit and the safety loop are indicated by an [X] in the appropriate field. An [X] indicates the status "On", "Yes" or "Charged", depending on the appropriate parameter.

11.3.6.2. Oscilloscope

Various electrical signals can be represented on the screen in the same manner as on an oscilloscope. This facilitates troubleshooting in case of any malfunctions. The oscilloscope display can be activated from the menu [Oscilloscope] using the button [Output voltage], [Output current] or [DC link voltage]. The output voltage and the currents of the converters are represented for the appropriate period, independent of the frequency, and the intermediate circuit voltage is represented for a duration of 20 ms.

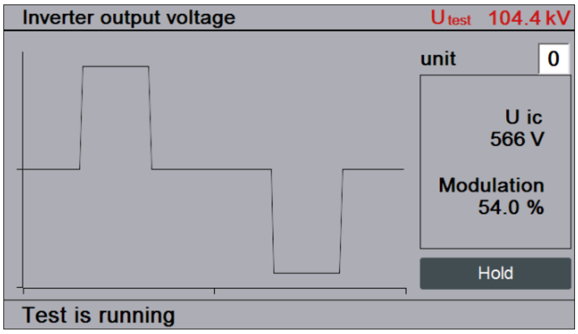


Fig. 18: Screen [Inverter output voltage]

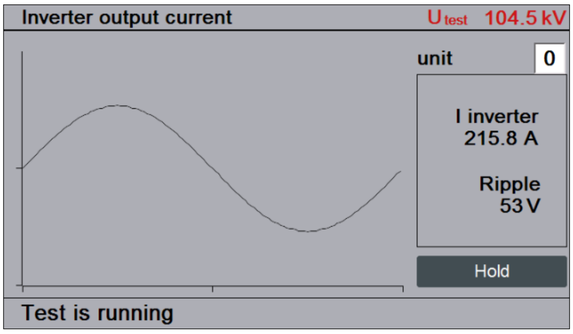


Fig. 19: Screen [Inverter output current]

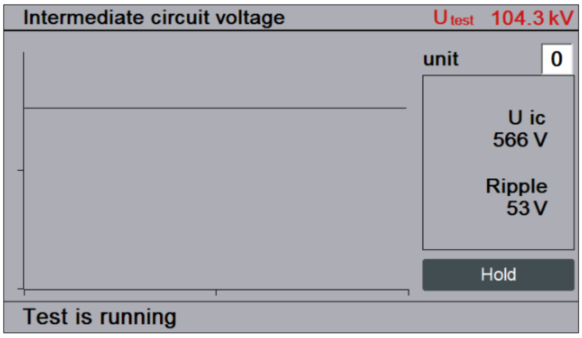


Fig. 20: Screen [Intermediate circuit voltage]

Type the address of the inverter unit whose signal you wish to be displayed in the appropriate input field. Observe that the addresses must start with "0", not with "1". Therefore, only the value "0" is permissible for a single RSE 400.

The form of the curve is continuously refreshed. To stop this permanent refreshing of the display, tap the button [Hold]. Tapping this button again restarts the refreshing.

NOTICE

Limited functionality
If more than 20 inverter units are used, the data exchanged via the CAN bus is reduced to limit the cycle time. The oscilloscope display is then not available.

11.3.6.3. Screen "Temperatures"

The screen [Temperatures] displays the measured ambient temperature, the temperature of the resonant reactor and, depending on the configuration of the RSE 400 (800), also the temperature in the control cabinet. The screen [Temperatures] can be called from the menu [Diagnosis & errors] using the button [Temperatures]. The source of the displayed reactor temperature depends on the selected temperature model. For gas-insulated resonant reactors (temperature model >0), the value is calculated by the PLC. If it is determined by way of a separate resistance measurement at the reactor winding that its temperature is higher than calculated, you may correct the value in the input field into higher values. For safety reasons, it is not possible to enter a value smaller than currently displayed.

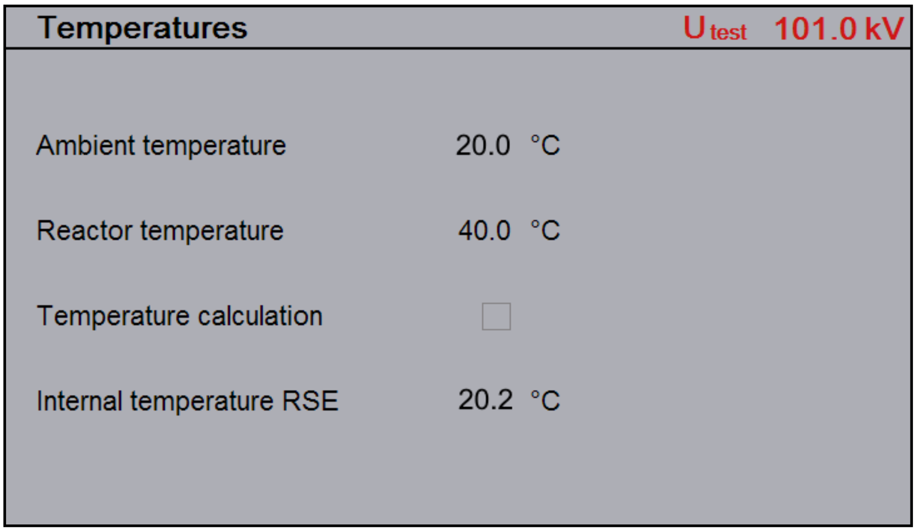


Fig. 21: Screen [Temperatures]

The checkbox [Temperature calculation] indicates whether the reactor temperature is calculated (Box checked) or measured (Box empty).

In special cases, the RSE 400 (800) can be fitted with an additional internal temperature sensor that measures the temperature in the interior of the control cabinet. It is displayed as the [Control cabinet temperature].

11.3.6.4. Screen "Measurement values memory"

The screen [Measurement values memory] displays the values of the breakdown voltage and of the resonant frequency in the form as they were saved during the last test. The breakdown voltage corresponds to the test voltage value at which the test was automatically aborted due to an error. This mostly occurs in case of a breakdown or flashover at the test object, but can sometimes also have other causes, e.g. an exceeding of the maximum permissible test voltage. The values are saved by the PLC until the main switch is turned back on again. The screen [Measurement values memory] can be called from the menu [Diagnosis & errors] using the screen [Measurement values memory] or from the screen [Voltage measurement] using the screen [Memory].

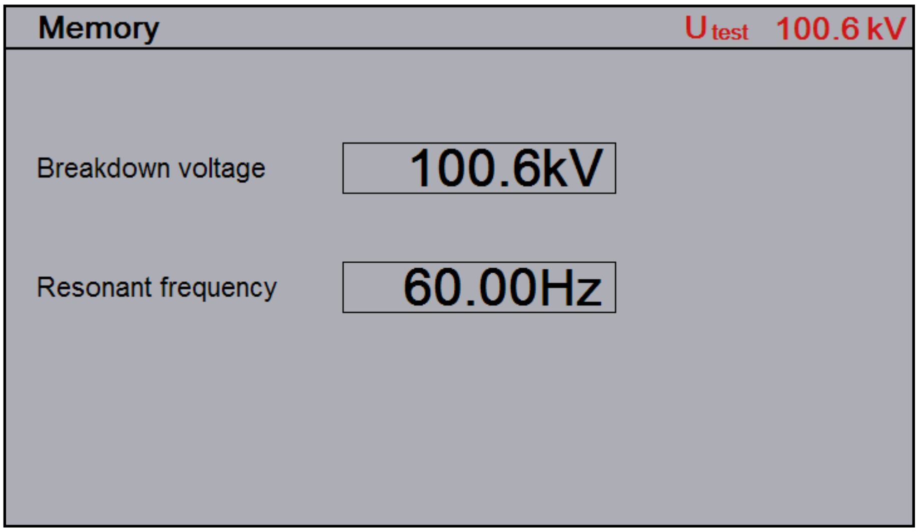


Fig. 22: Screen [Measurement values memory]

11.3.6.5. Screen "Errors"

The screen [Errors] provides a detailed overview of error information for the RSE 400 (800). It can be called from the menu [Diagnosis & errors] using the button [Errors].

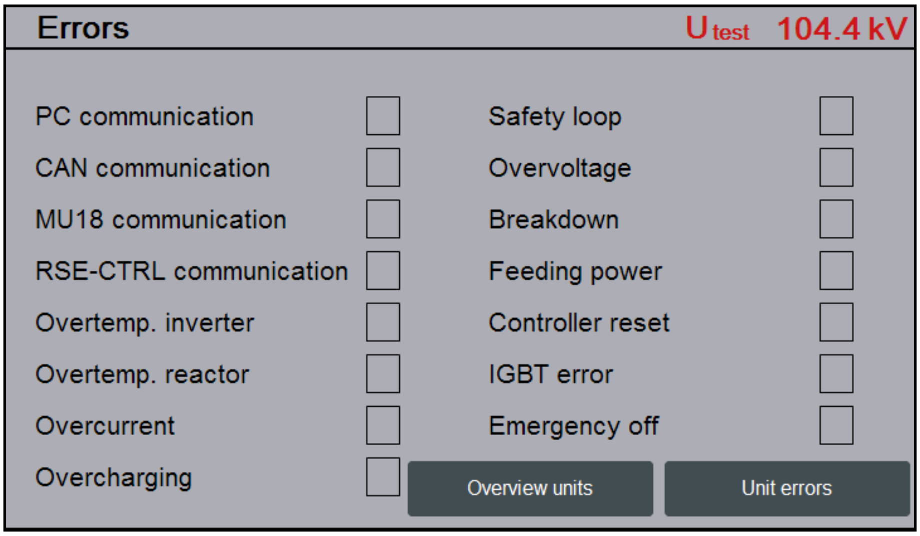


Fig. 23: Screen [Errors]

[PC communication]	Error in the communication between the PC and an RSE 400 (800) if remote control from the PC is active
[CAN communication]	Error in the communication with the CAN bus system
[MU18 communication]	No communication between the PLC and the peak voltmeter
[RSE-CTRL communication]	No communication between the PLC and the RSE-CTRL controller module
[Overtemp. inverter]	Overtemperature of the heat sinks of rectifiers and IGBTs
[Overtemp. reactor]	The temperature of the resonant reactor has exceeded its limit value.
[Overcurrent]	The output current of the inverter has exceeded its limit value.
[Overcharging]	The intermediate circuit voltage is (was) >635 V.
[Safety loop]	The safety loop was opened during the test.
[Overvoltage]	The test voltage has exceeded its limit value.
[Breakdown]	HV breakdown or HV flashover during the test
[Feeding power]	Mains undervoltage or missing phase (also for a short time)
[Controller reset]	A micro-controller on the RSE-CTRL or IGBT-CTRL-A1 module is reporting restart
[IGBT error]	At least one of the IGBT modules is reporting an error.
[Emergency off]	An internal or external EMERGENCY STOP pushbutton was actuated.

For detailed information about the errors in the individual inverter units, tap the button [Unit errors]. The button [Quit errors] can be used to acknowledge and thus clear stored errors. This is, however, only possible if the error cause does not exist any more.

Screen [Summary of unit errors]

This screen provides a summarized overview of error information for the RSE 400 (800) in respect of interconnected inverter units. It can be called from the screen [Errors] using the button [Overview units].

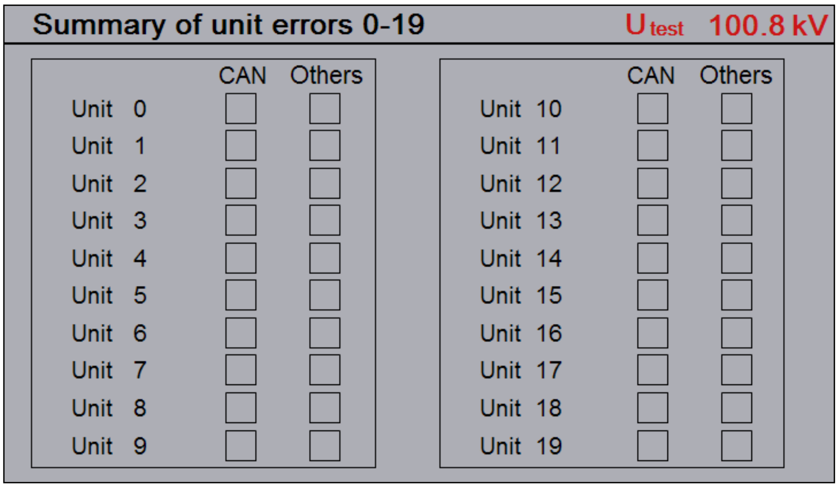


Fig. 24: Screen [Summary of unit errors]

An [X] in a box indicates that there is an error in the appropriate inverter unit. Errors are only displayed for inverter units which must be active in accordance with the system configuration (*see Chapter 12*). There are two error displays per inverter unit. An error in the CAN communication means that communication with this unit is no longer possible via the CAN bus. In this case, no other errors can be displayed, as they cannot be interrogated due to the missing connection.

If more than 20 inverter units are used, the button , which can be used to scroll to the overview of additional inverter units, appears at the bottom right of the display.

You may attempt to clear error messages by tapping the button [Quit]. This is, however, only possible if the error cause does not exist any more.

Screen [Errors of inverter units]

The screen [Errors of inverter units] provides detailed error information about an individual inverter unit. This screen can be called from the screen [Errors] using the button [Unit errors].

Some errors, e.g. overcurrent or overcharging, are only temporarily present and are stored by the PLC so as to be able to determine the error cause also after shutting down. They are only stored in the PLC until the main switch is actuated. In this moment, any errors are cleared automatically if the error cause no longer exists.

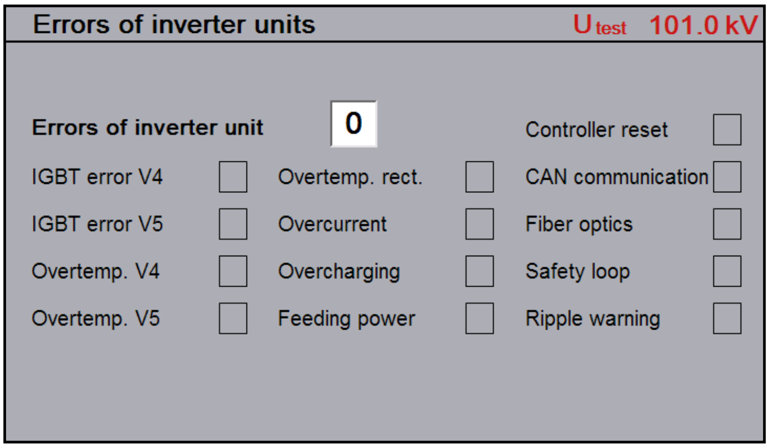


Fig. 25: Screen [Errors of inverter unit]

[IGBT error V4]	The internal control electronics of the IGBT module V4 detected an error and disables the module. Possible causes are overtemperature, desaturation due to excessive current, or a problem in the power supply. This error cannot be acknowledged as the other ones; it can only be cleared by disconnecting the RSE from the power supply completely (e.g. by opening the fuse switch-disconnector). Turning off the control system alone is not sufficient.
[IGBT error V5]	As the IGBT V4 error, but for V5.
[Overtemp. V4]	The internal control electronics of the IGBT module V4 disabled the module due to excessive chip temperature.
[Overtemp. V5]	The internal control electronics of the IGBT module V5 disabled the module due to excessive chip temperature.
[Overtemp. rect.]	Excessive heat sink temperature of the rectifier modules.
[Overcurrent]	The inverter output current has exceeded its limit value.
[Overcharging]	The intermediate circuit voltage has exceeded a value of 635 V.
[Feeding power]	Mains undervoltage or missing phase (also for a short time)
[Controller reset]	The micro-controller on the p.c. board IGBT-CTRL-A1 was restarted.
[CAN communication]	The micro-controller on the p.c. board IGBT-CTRL-A1 has detected a timeout in the CAN bus communication with the RSE-CTRL module.
[Fiber optics]	The fiber optic ("FO") connection to an old RSE (black plastic FO cables) does not operate correctly.
[Safety loop]	The monitoring system at the safety loop detected an open loop at this inverter unit.
[Ripple warning]	The ripple factor of the intermediate circuit voltage is too high. The message disappears once the value is back within the permissible range.

11.3.6.6. Screen "Firmware versions"

The screen [Firmware versions] displays the firmware versions of components that comprise micro-controllers. It can be called from the screen [Diagnosis & errors] using the button [Firmware versions].

The firmware versions of the optional inverter module RSE-CONV for connection of older RSE devices to the control system are only displayed if such an older device is connected and turned on.

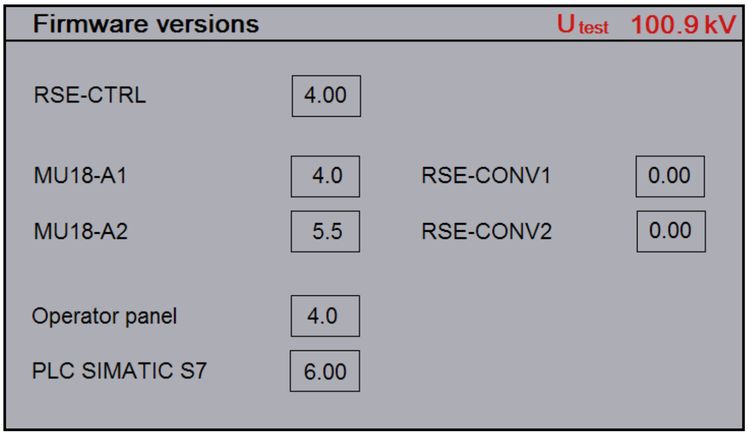


Fig. 26: Screen [Firmware versions]

11.3.6.7. Screen "Fan & units"

The screen [Fan & units] can be used to select the operating mode for the fans for cooling of the heat sinks of the rectifier and IGBT modules. It can be called from the screen [Diagnosis & errors] using the button [Fans].

Normally, the fans E1 and E2 operate whenever the inverter is turned on (setting "with inverter"). To allow cooling also in the test pauses, the operating mode can be set to "always". In this case, the fans operate whenever the control system of the RSE 400 (800) is turned on.

Furthermore, the number of inverter units currently coupled to each other is displayed under "Connected inverter units". In the case of one single RSE 400, a value of "1", and in the case of a RSE 800 the value "2".

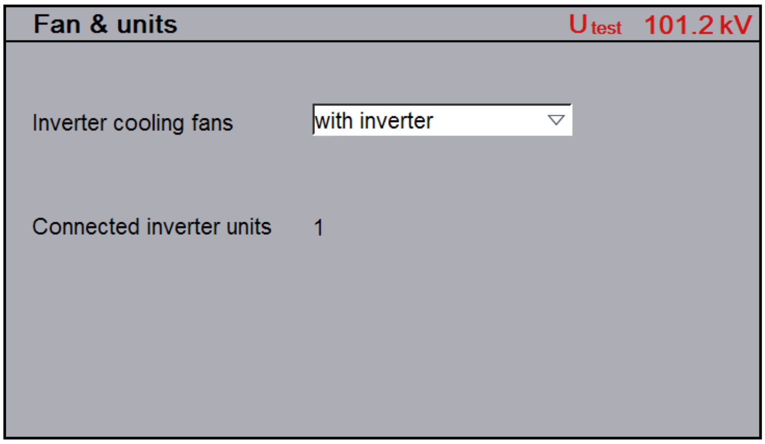


Fig. 27: Screen [Fan & units]

11.3.7. Menu "Panel utilities"

The menu [Panel utilities] provides access to settings and maintenance functions of the operator panel. It can be called from the main menu using the button [Panel utilities].

The function [Clean screen surface] can be used to clear the screen with the control system turned on, without touching the display surface resulting in any undesired actions.

If you tap the button [Password], you can enter a password that during the subsequent 10 minutes provides access to all password-protected values of the same password level without the need of re-entering the password.

If you tap the button [Calibrate touch screen], a system-internal screen can be called allowing the calibration of the touch-sensitive layer on the screen. Thus, it is possible to correct any geometrical deviations of the touch-sensitive surfaces of the buttons displayed on the screen beneath. Should you determine such a deviation, call the calibration function and follow the instructions displayed there.

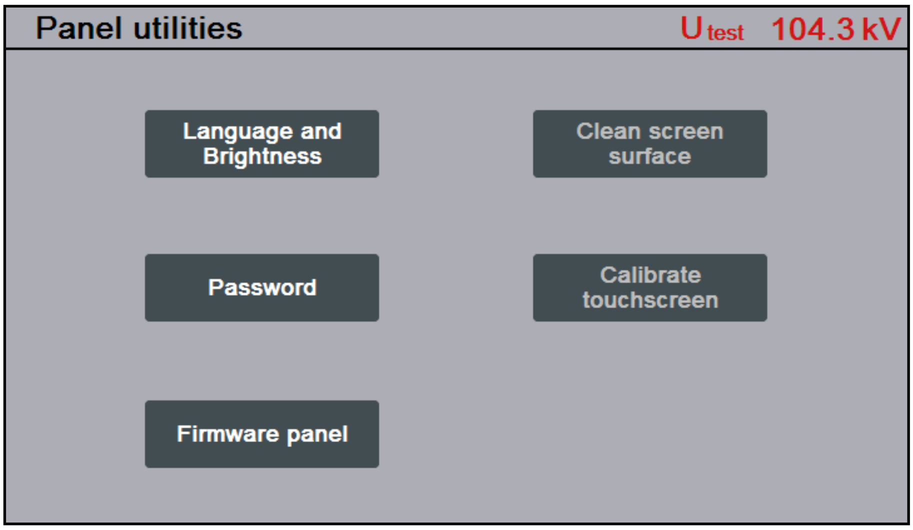


Fig. 28: Menu [Panel utilities]

Screen [Language and brightness]

This screen can be used to switch the dialog language, the settings for the brightness of the display, and to correct the date and time. It can be called from the menu [Panel utilities] using the button [Language and brightness].

The brightness of the display is adjusted by way of the slide controller on the right. The new settings are only maintained until the system is turned off. When the RSE is turned on, the brightness is always set to its maximum value.

The internal clock of the control system also continues to run for 60 days after disconnecting the RSE 400 (800) from the supply mains. If the unit is not used for a longer period, the current values for the date and time can be corrected in the appropriate input fields.

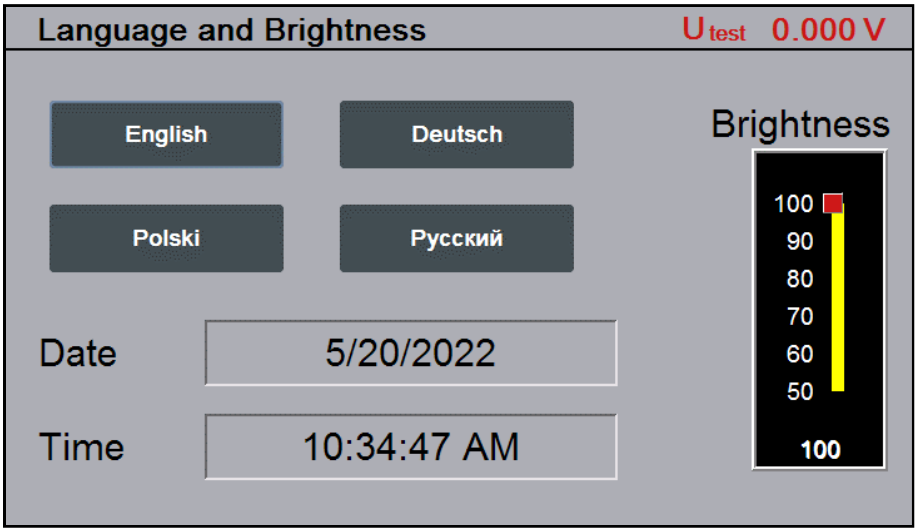


Fig. 29: Screen [Language and brightness]

11.3.8. Screen "Service data"

This screen displays the project information for the RSE 400 (800). It includes the exact product name, the year of manufacture, the HIGHVOLT order number and the contact details of the HIGHVOLT service team. This screen can be called from the main menu using the button [Service data].

Fig. 30: Screen [Project information]

12. Coupling several RSE 400 (800)

For the testing of large capacitances (e. g. long cables), the output power of one RSE 400 (800) may be not sufficient to be able to compensate the occurring losses. Therefore, it is possible to couple several RSE units with each other so as to generate an output power of up to 12 MVA by connecting up to 64 inverter units in parallel.

In this mode, one RSE unit operates as master, and all the other ones as slaves. All control functions are performed by the RSE 400 (800) operating as master. The slave units only operate as pure inverter units. Their peak-voltage measuring instrument, PLC and operating panels do not have any control functions. The control module RSE-CTRL in the master RSE controls all external inverter units in the same way as its internal inverter unit(s). The RSE-CRTL controller modules in the slave RSE are switched to "Slave" mode, meaning that they only receive data at the CAN bus as passive receivers, but can no longer send data. The PLC and the operator panel in the slave units also operate in a mode in which they can not influence the test. Fig. 31 shows the interconnection of two RSE 400 in master-slave mode.

12.1. Feeding

Each RSE unit must be connected to the three phases and the neutral conductor of the power grid separately. To avoid different intermediate circuit voltages in the individual inverter units, it is recommended to use one power supply source for all RSE units. If this is not possible, at least each RSE 800 must be connected to one common power source, since it internally provides a connection between the feeding busbars of both inverter units.

12.2. Power outputs

The outputs of the two inverter units must not be connected directly in parallel. This would result in excessive compensation currents between the inverters, since their intermediate circuit voltages are never absolutely equal due to the slightly different internal impedances and different mains impedances. The outputs of the individual inverter units must be connected to the primary windings of a separate exciter transformer. The primary windings of this exciter transformer are then to be connected to each other, as specified in the documentation for the test system.

NOTICE

Risk of damage to system components

Connecting the outputs of different inverter units leads to high compensation currents and is therefore impermissible.

- ► Each inverter unit must be connected to the primary winding of a separate exciter transformer.
- ► Connecting the secondary windings of different exciter transformers is impermissible due to any excessive output currents.

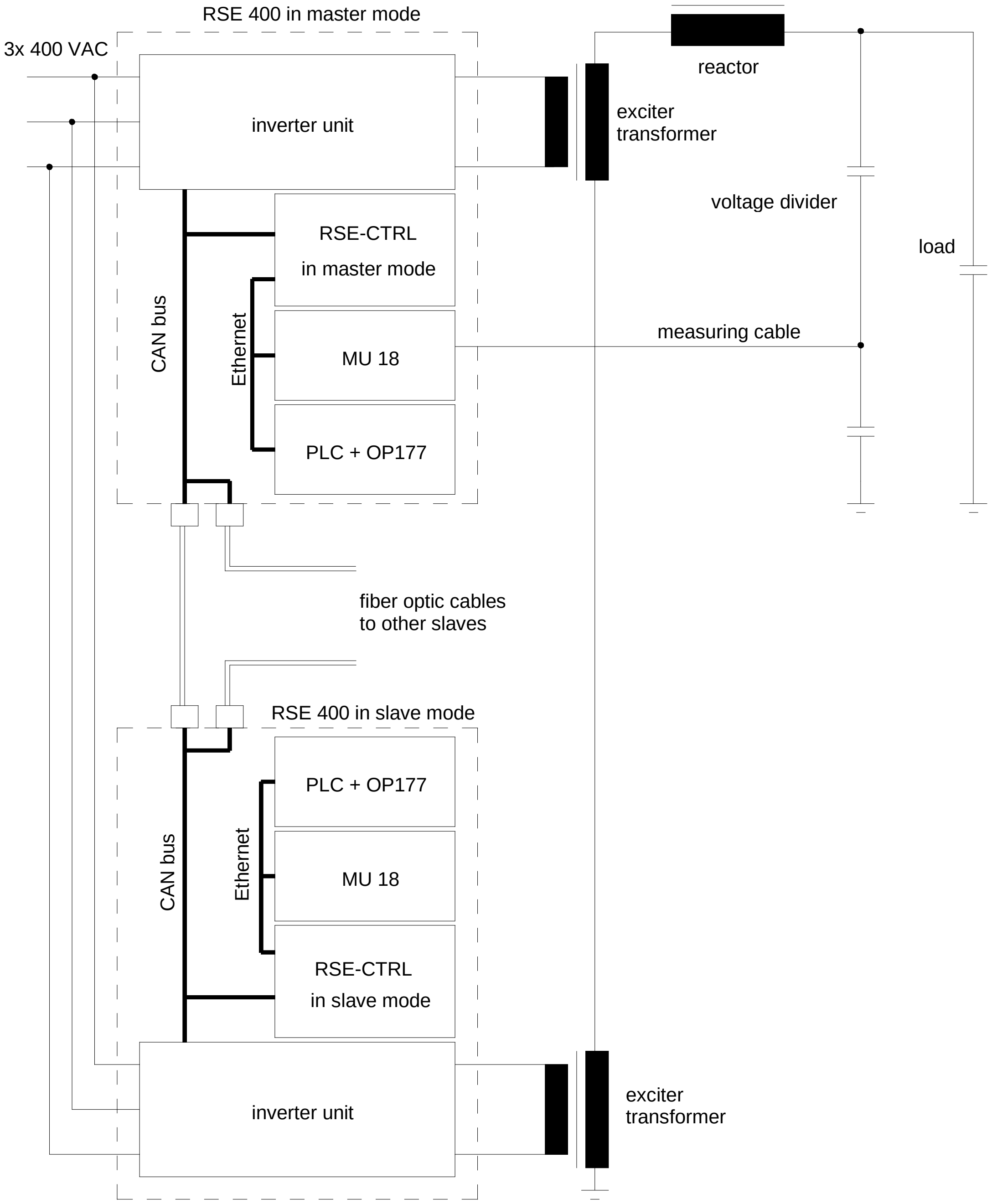


Fig. 31: Interconnected operation of two RSE 400 (representation without safety loops)

12.3. Coupling RSE units with SKIIP-IGBT modules

12.3.1. Hardware connections

To be able to connect the hardware of two RSE 400 (800) units to each other, merely a simple duplex optical fiber cable with CAN bus transceivers (electro-optical converter) is required. This cable connects the CAN bus systems installed in the RSE 400 (800) units to each other. Connect the transceivers to the DSUB socket connectors XCAN1 or XCAN2 on the rear panel of the unit. Since the XCAN1 and XCAN2 female connectors are internally connected in parallel, each of both can be used; furthermore, it is thus also possible to connect several RSE units to each other in a chain.

Due to its structure, the CAN bus only provides a limited delay time in the reaction of a receiver to a message. Due to the runtime in the fiber optic cables, their length is limited to max. 100 m.

NOTICE

Danger of malfunctions

Building up a CAN bus connection when a connection to the power grid exists (also when the control system is turned off) can result in connection problems.

- ► Make sure that the RSE units are disconnected from the power grid when connecting / disconnecting the CAN bus connections from the supply mains; turning off the control system alone is not sufficient.
- ► To disconnect the RSE from the supply mains, the fuse switch-disconnectors F1 in the RSE 400 (800) can be opened.

The connection of the fiber optic cables to the CAN transceiver modules must be performed diagonally, i.e. the signal output TX of the module on the one side must be connected to the signal input RX of the module on the other side and vice versa.

12.3.2. Settings in the control system

For proper functioning, it is imperative that the control system of the master unit knows how many inverter units operate in the interconnected system. In case of failure of a unit or if a unit reports an error, this is detected by the master immediately, ending the test immediately.

WARNING

Electric shock hazard

The configuration of the switches entails the risk of coming into contacts with live parts if the RSE 400 (800) was not disconnected from the power grid beforehand.

- ► Therefore, always disconnect all RSE 400 (800) units from the power grid before modifying the configuration; it is sufficient to open the fuse switch-disconnector F1 in all inverter units.

To be able to notify the RSE 400 (800) operating as master of the number of connected inverter units, adapt the parameter [Number of inverter units] in the screen [System settings] to the total number of inverter units involved. The appropriate value for one RSE 400 operated as a single unit is "1", and for a single RSE 800 "2".

To specify which RSE units are to operate in the interconnected system as master and which as slaves, proceed as follows:

- ▷ If you wish an RSE unit to operate as master, turn the slide switch S3 on the RSE-CTRL controller module to the position "Master mode" (see *Fig. 40*).
- ▷ If you wish an RSE to operate as a slave, turn the slide switch S3 to the position "Slave mode".

The operating mode selected is indicated by way of two LEDs. If the green LED is lit, this RSE operates as master. If it is lit red, the appropriate RSE operates as a slave. Observe that only one RSE 400 (800) may operate in the interconnected system.

Each inverter unit operating in the interconnected system must be assigned a separate, unambiguously used address under which the RSE unit communicates in the CAN bus system with the RSE-CTRL controller module operating as master.

This address is to be set using pushbutton S2 on the p.c. board IGBT-CTRL-A1 *(*see *Fig. 41).*The address range must start with "0" and must not contain gaps. It is not relevant how these addresses are distributed over the individual inverter units. The LED display alongside the key displays the currently valid address; the LEDs, however, must not flash.

If the address must be changed, press the pushbutton S2 briefly. The address is incremented by "1", and the display flashes. Each further, brief pressing of the pushbutton increments the address. If up to 20 inverter units are used, the display jumps back to 0 after the value 19. If more than 20 inverter units are used, the value jumps back to 0 after reaching the maximum possible address. If, for example, 25 inverter units are used, the value returns to 0 after the address 24 has been reached. When the desired address is displayed, hold down the pushbutton for at least 2 seconds. Thus, the new address is saved permanently. Successful saving is indicated by the transfer from flashing of the display to steady lighting.

NOTICE

Danger of malfunctions

When the LED display is still flashing, the new address has not yet been accepted and the inverter unit is still working with the previously set address.

- ► Hold down the pushbutton for at least 2 seconds to save the new address permanently. During saving, the flashing changes into steady lighting.

In the case of older devices, the address of the inverter unit is set not by way of a pushbutton, but by way of a rotary switch on the p.c. board IGBT-CTRL-A1. This board does not possess an LED display. Use a small screwdriver to set the appropriate address on the rotary switch. Please observe that only one address in the range 0 ... 15 can be set on these p.c. boards due to the 16 positions of the rotary switch.

NOTICE

Danger of malfunctions

Any changes to the rotary and slide switches in older devices are only accepted once when the power grid is connected. Any later changes to the switch positions remain without effect.

- ► Therefore, if you have changed the switch settings, disconnect the RSE 400 (800) from the power grid completely for a short time (e.g. by opening the switch-disconnector F1).

Tab. 3 shows how the appropriate switches are to be set, taking the example of an interconnected system of two RSE 800 and one RSE 400.

Tab. 3: Settings for the master-slave mode (example)

	RSE 800	**RSE 800**	**RSE 400**
Mode	Master	Slave	Slave
Operator panel Number of units	5	No influence	No influence
RSE-CTRL Rotary switch S1 Sliding switch S2 LED	 No influence Master Green	 No influence Slave Red	 No influence Slave Red
IGBT-CTRL-A1 no. 1 LED display or rotary switch S1	0	2	4
IGBT-CTRL-A1 no. 2 LED display or rotary switch S1	1	3	Not installed

12.4. Coupling older RSE units with discrete IGBT modules

It is also possible by way of a special inverter module to operate RSE units of the older design (produced until 2009 - they comprise 8 discrete IGBT transistors, instead of the two SKIIP modules) as slaves. This possibility is not limited to devices that already comprise a PLC of the S7 series. Devices with a PLC of the S7 series are not supported. The inverter group RSE-CONV is not included in the standard scope of supply and must be ordered separately. It can be upgraded at any time.

This module translates the current CAN bus protocol used for the older devices into the protocol used in the newer devices and adapts the baud rates. Furthermore, it generates the appropriate IGBT trigger signals for the older RSE devices which are transferred by way of two plastic FO cables in addition to the CAN bus connection. Up to three RSE 400 or RSE 800 of the older type can be connected to each inverter module.

12.4.1. Hardware connections

The older RSE devices must be fitted with an RESO-A3 interface board that allows connection of the FO cables with their electro-optical converters. This board has already become necessary to be able to connect these devices to each other.

In the case of the older devices, the coupling is performed via two separate paths. The data exchange (commands, measurement values, status information) is performed either via a CAN bus connection which operates at a higher baud rate, but only possesses a short range.

For triggering of the IGBTs in the slave units, the trigger signals "Period" and "Pulse width" are sent directly from the master to the appropriate slave units via additional plastic FO cables. To be able to guarantee the integrity of these signals, each signal is sent normally via an optical cable and, in addition, inverted via a second cable. In this way, errors in the connection can be detected reliably, and the inverter unit can be disabled separately in this case.

Tab. 4: Connection diagram for fiber optic cables

Signal	Master, RSE-CONV	Slave 1, RESO-A3	Slave 2, RESO-A3	Slave 3, RESO-A3
CAN (glass FO cable)	XCAN1	XCAN1		
	XCAN2		XCAN2	
	XCAN3			XCAN1
Period (plastic FO cable)	X1-P (TT)	XS-P (RR)		
	X2-P (TT)		XS-P (RR)	
	X3-P (TT)			XS-P (RR)
Width (plastic FO cable)	X1-W (TT)	XS-W (RR)		
	X2-W (TT)		XS-W (RR)	
	X3-W (TT)			XS-W (RR)

All FO cables in the older slave units must be connected there to the RESO-A3 p.c. board. This board is mounted above the large RESO-A1M controller board and only installed if the older RSE was already delivered with the option for interconnection. It is recommended to use the notch that is to be found on the rear side of the older RSE devices for guiding into the control cabinet. Make sure that these busbars are not under voltage during installation!

Tab. 4 shows how the individual fiber optic cables are to be connected to the converter module RSE-CONV and to the board RESO-A3 in older devices. Some older electro-optical converters are marked in different colors (receivers in blue and transmitters in red). Newer converters are not marked with color; in this case, the transmitters can be identified by way of the letters "TT" at the FO cable input and the receivers by way of the letters "RR".

For the positions of the connections for the electro-optical converters on the converter module RSE-CONV, refer to *Fig. 42*.

It is strongly recommended to leave the black FO cables in their appropriate electro-optical converters to rule out swapping. If the plastic cables must be replaced (e.g. due to mechanical damage), refer to *Fig. 32* to learn how the ends are to be connected to the electro-optical converters.

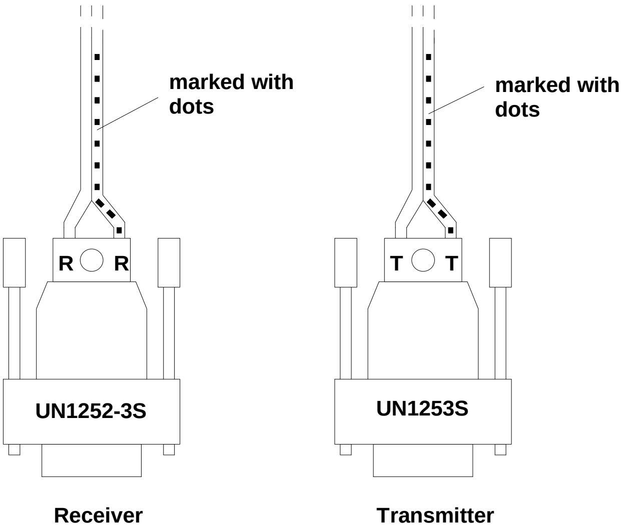


Fig. 32: Fiber optic cables for the IGBT signals

For connection to the CAN bus, an optic fiber cable with electro-optical converters (transceivers) is used. The connection of the fiber optic cables to the CAN transceivers must be performed diagonally, i.e. the signal output TX of the transceiver on the one side must be connected to the signal input RX of the transceiver on the other side and vice versa.

There is one specialty when using an older RSE 800 as a double-slave. To configure the RSE as double-slave, the internal cable connection between the plug connectors X3 on the RESO-A1M controller boards of the master and slave cabinet must be replaced by a special slave-to-slave cable. Only then the two inverter units can receive the IGBT trigger signals generated by the RSE-CONV.

Fig. 33 shows the connection of an RSE 400 (current model) as master to an older RSE 400 operating in slave mode.

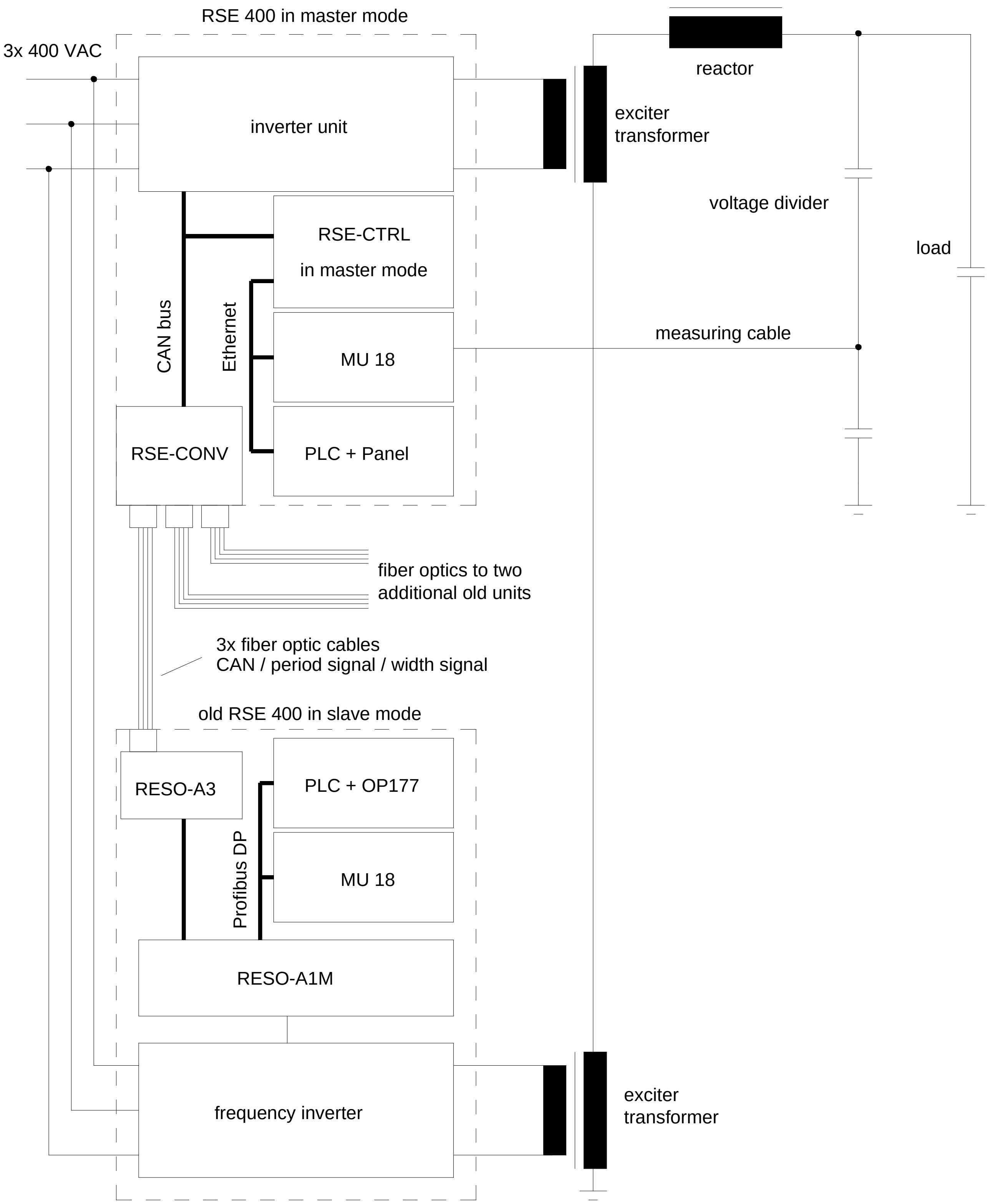


Fig. 33: Interconnected operation of two RSE 400 (old and new)

12.4.2. Settings in the control system

The settings in the master and slave units in the current design are performed as described in *Section 12.3.2*.

The settings for the RSE units of the older type as slaves are performed by way of two rotary switches installed on the controller board RESO-A1M (in the top left corner of the p.c. board). Rotary switch S3 ("Number Slaves") is always to be set to position "1". Rotary switch S2 ("Device ID") is used to specify the CAN bus address of the inverter unit and is to be set in the same way as rotary switch S1 on the boards IGBT-CTRL-A1 in the current devices.

Tab. 5: Settings for master-slave mode, new and old (example)

	RSE 800	**RSE 800**	**RSE 400, old**
Mode	Master	Slave	Slave
RSE-CTRL			Not installed
Rotary switch S1	4	0 (no influence)	-
Sliding switch S2	Master	Slave	-
LED	Green	Red	-
IGBT-CTRL-A1 no. 1			Not installed
LED display or rotary switch S1	0	2	-
IGBT-CTRL-A1 no. 2			Not installed
LED display or rotary switch S1	1	3	-
RESO-A1M	Not installed	Not installed	
Rotary switch S2	-	-	4
Rotary switch S3	-	-	1

12.5. Operation in parallel mode

There is no difference with reference to the operation between a single RSE 400 (800) and the interconnected system of several RSE units, as one RSE 800 already constitutes an interconnected system of two inverter units. Compared to the operation of one single RSE 400, the individual measurement values in the screen [Test] have only slightly different meanings:

- The value of the hottest reactor is displayed as the reactor temperature in the case that several oil-insulated reactors with their temperature sensors are connected.
- The value of the ripple factor is the average value of all inverter units.
- The value of the inverter output current is the total of all inverter output currents.

The measurement values and error messages of the individual inverter units may be interrogated via the screens [Data of inverter unit] (*see Fig. 17 in Section 11.3.6.1*) and [Errors of inverter unit] (*see Fig. 25 in Section 11.3.6.5*).

In case of errors, the inverter unit reporting the error can be determined quickly by way of the screen [Summary of unit errors] screen (*see Fig. 24 in Section 11.3.6.5*).

An error in transmission of the IGBT control signals to the older inverters via the black plastic FO cables can lead to fatal malfunctions. For this reason, the proper functioning of these transmission paths is checked automatically when the main switch is turned on. If during this check an error is found, the main switch is not turned on, and the error message [Error: FO error] is displayed on the operator panel.

If an RSE 400 (800) is operating in slave mode, the test cannot be influenced from the operator panel of this RSE. It is, however, possible to interrogate the inverter data and errors of all connected inverter units. The buttons [Errors] and [Unit data] can be used to switch between the following two possible screens:

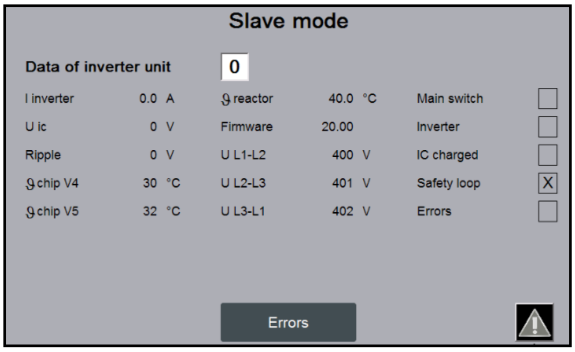


Fig. 34: Slave mode / Data of inverter unit

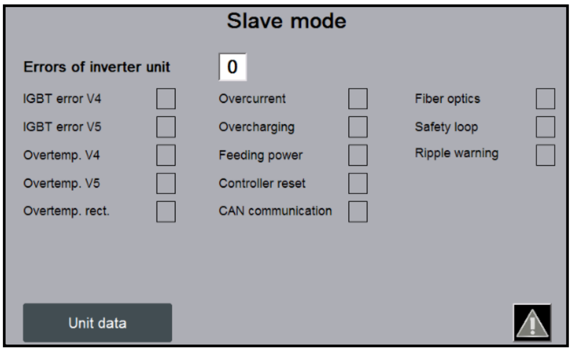


Fig. 35: Slave mode / Errors of inverter unit

13. Preparing a test

Any test should be prepared as follows:

1. Install all electrical connections starting from the copper foil of the earthing system (*see Section 6.1*).
2. Adjust an appropriate transmission ratio for the exciter transformer by selecting the relevant connections on the primary and / or secondary side (*see Adjusting the exciter transformer* in this Section)
3. Specify the CAN bus addresses in the inverter units, check the mode settings and adapt them accordingly when necessary using the rotary and slide switches on the p.c. boards (*see Section 12*).
4. Turn on the external power supply (diesel generator) with fuse switch-disconnector F1 in all inverter units turned on and check that the mains voltage at the input busbars of the inverter units is correct using a multimeter (conductor-conductor and conductor-earth voltages).
5. Turn on the fuse switch-disconnector F1 in all inverter units.
6. Turn on the control in all inverter units.
7. Enter the system configuration (system nominal voltage, total inductivity, divider ratio) at the master.
8. Enter the limit values (max. test voltage, lower frequency limit for GIS tests where applicable).
9. Enter the test parameters (test voltage, test time, start frequency).

All parameters with exception of the test voltage and start frequency are stored in the PLC and also remain stored after turning off. Nevertheless, we recommend to check these parameters after turning on before performing a test, in particular the divider ratio and the limit value for the test voltage.

Settings of the exciter transformer

In addition to the correct settings at the RSE 400 (800), it is also imperative to observe the selection of the optimum transmission ratio of the exciter transformer which has feedback to the RSE 400 (800). The transmission ratio should be selected as low as possible so as to ensure that the inverter modulation at test voltage is as high as possible. This reduces both the harmonics in the input current, the inverter output current, and leads to a smaller ripple of the intermediate circuit voltage of the inverter. A smaller ripple, in turn, reduces the thermal load on the intermediate circuit capacitors and extends their life time.

We recommend selecting of a transmission ratio which produces modulation within a range of 70 … 93% at test voltage. In the case of low test voltages, this is not always possible; then, however, the inverter output current and thus the danger of a thermal overload for the intermediate circuit capacitors is also low.

14. Test sequence

A test sequence can be controlled both fully automatically and manually. The operator may additionally enable or disable automatic frequency search.

14.1. Fully automatic testing

Step 1 – Input of all test parameters

Prepare the test system as described in *Section 13*.

Step 2 – Turning on the main switch

Tap the button [Main switch] to turn on the main switch.

This deletes all error messages stored at this time and all saved measurement values (breakdown voltage and resonant frequency).

If there are no any errors, precharging of the intermediate circuit is started via the resistors, and the message [Precharging] is displayed in the status line of the operator panel.

After one second of precharging time, it is checked that the intermediate circuit voltage is increased far enough. If no problem is detected, precharging is continued for another 3 seconds. Otherwise, the process is cancelled with the error message [Error: Mains].

The automatic frequency search is always activated when the main switch is turned on. If it is to be activated for the test, tap the button [Auto f].

Step 3 – Starting the test sequence

After the main switch has been turned on, the message [Ready] is displayed in the status bar. Tap the button [Start test] to start the test sequence. All further steps are performed automatically, and no further operating actions are required.

If frequency search is activated, the RSE 400 (800) searches for the resonant frequency of the test circuit by reducing the frequency at a fixed modulation of 3.9% slowly from the start frequency until the resonance point is reached. During this time, the status message [Searching for resonance...] is displayed. The speed of the resonance search cannot be changed. Once the resonance point has been found, the status message switches to [Test is running ...], and a green field with the text [Resonance] is displayed in the screen "Test".

Once the resonance point has been found, the RSE 400 (800) increases the modulation automatically until the desired test voltage is reached. If the automatic frequency search was activated, the process of searching is skipped, and the RSE 400 (800) increases the modulation at the specified start frequency immediately.

Once the tolerance band for the test voltage has been reached (setpoint test voltage – 3%), the test timer starts counting down the remaining test time until 00:00:00 is reached. At this moment, the RSE 400 (800) ends the test automatically and turns off the main switch.

If the warning message [Warning: Maximum modulation] is displayed, the RSE 400 (800) can no longer increase the test voltage. If the test voltage has not been reached by that time, either the Q factor is too low or the selected transmission ratio of the exciter transformer is too small. In this case, the test must be cancelled manually by tapping the button [Stop test].

14.2. Manual testing

It may be desirable to change the test parameters during the test, e.g. to increase the test voltage in steps. To this end, it is necessary to intervene into the automatic test sequence manually.

14.2.1. Changing the setpoint test voltage during the test

The setpoint test voltage can be changed in two different ways:

a) Overwrite the current setpoint in the "Test" screen. The test voltage will follow the new setpoint immediately, observing the specified voltage ramp rate du/dt. The test timer is not restarted, but continues to run provided that the test voltage lies in the tolerance range. A typical application of this procedure is the determination of inception and extinction voltages during an accompanying PD measurement.

b) Before changing the setpoint test voltage, tap the button [Suspend test]. Thus, the test timer is stopped, and the current actual value of the test voltage is accepted as the new setpoint. Now you may enter a new setpoint that, however, is not yet accepted. In this state, you may also assign other parameters (e.g. the test time) new values. Alternatively, you can change the voltage steplessly using the buttons [U ▲] and [U ▼]. In this case, the change is accepted immediately. The sensitivity of the two buttons is determined by the value of the parameter [Voltage ramp rate du/dt] (*see Section 11.2*.). In both cases, however, the test timer remains blocked until the button [Start test] is tapped. Then, the test time clock is restarted with the full specification value, and the automatic test is continued.

14.2.2. Changing the frequency manually during the test

In common tests, it is generally not necessary to change the inverter output frequency manually, since the RSE 400 (800) sets it to the optimum value automatically. Should this become necessary in special tests or should the automatic search not function, a manual change is possible.

To this end, tap the button [Suspend test] to suspend the automatic test sequence. Then you can deactivate the automatic frequency search using the button [Auto f]. Following, you can change the frequency manually using the buttons [**f** ▲] and [**f** ▼]. Its influence is determined by the parameter [Frequency change df/dt] (*see Section 11.2*).

If the set frequency is too far away from the resonance point, in most cases, the desired test voltage is not reached even if the voltage regulation increases the modulation up to the limit value of 97.3%.

If the resonance point is to be searched for manually using this procedure, the frequency should only be changed slowly and in small steps; otherwise, there is a risk of overshooting of the test voltage. In this case, the test is cancelled automatically with the error message [Error: Overvoltage]. To avoid this, a small value should be selected for the parameter [Frequency change df/dt] that lies in the vicinity of the resonance point (e.g. 0.05 Hz/s).

To restart the automatic test sequence once the frequency setting has been completed, tap the button [Start test]. The test timer will then restart with the full, previously entered time.

15. Connection to a personal computer (PC)

The RSE 400 (800) allows coupling to an external PC via an Ethernet network connection. To avoid problems especially in the case of fast transient processes with reference to the breakdown of the test object, the test object is connected not by way of a cable, but via WLAN. If several RSE devices of the current variant are interconnected, the WLAN adapters in the slave units are deactivated automatically. In the case of older-variant RSE devices, you must remove the network cable of the WLAN adapter from the socket-outlet located alongside.

To hand over the control from the operator panel to the external PC, you must start the appropriate remote control program on your PC beforehand. Once this program has established a connection to the RSE 400 (800), you may hand over the control to the PC by tapping the button . If you then tap this button once more, the remote control is ended, and you return the control back to the control panel. As long as the PC controls the RSE 400 (800) remotely, no inputs at the operator panel are possible, and the screen "Test" shown below is displayed permanently:

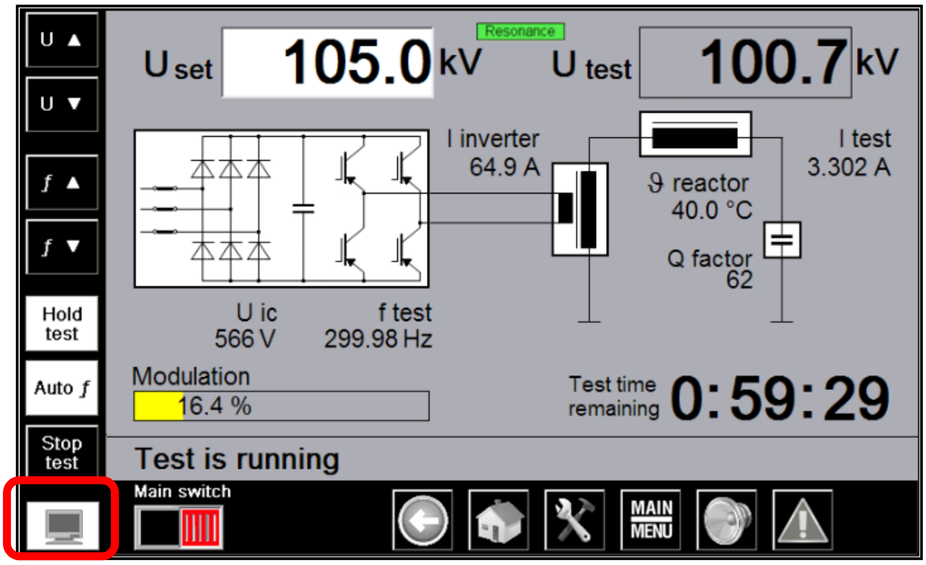


Fig. 36: Screen displayed on the operator panel when the RSE is remote-controlled from the PC

The PC used must possess a WLAN interface. Configure the WLAN connection to the PC as follows:

IP address: Fixed, 192.168.47.1

Subnet mask: 255.255.255.0

The network name (SSID) of the RSE 400 (800) is RDA-XXXXXX. The wildcard XXXXXX stands for the 6-digit HIGHVOLT order ID. The PC must be connected permanently to the WLAN; otherwise, no remote control is possible. Before you start the PC remote control program, check that the PC is connected to the network.

Due to the changes in the transfer log, it cannot be guaranteed that an older version of the remote control program than that of the program version delivered with the RSE 400 (800) is suited for remote control.

16. Support of partial discharge measurements

To support partial discharge measurements (PD measurements) in connection with an RSE 400 (800), the RSE provides three signals at the RSE-CTRL controller module.

For the phase-resolved representation of the PD activity, a PD measuring device requires a synchronization signal. To this end, the RSE-CTRL provides two different signals. One signal is sinusoidal and is a copy of the test voltage with an amplitude of 10 V at system nominal voltage. It possesses the same phasing as the test voltage. The second signal is a square-wave signal and possesses a constant amplitude (TTL level) that does not depend on the test voltage. During the positive half-period, the signal carries high level (>3.5 V), and during the negative half-period low level (<0.8 V).

In addition, the RSE-CTRL controller module issues a gating signal that can be used by an appropriate PD measuring device to disable the measurement during switching of the IGBT modules. Thus, the interference signals created by the switching process can be suppressed effectively. The gating signal has - like the square-wave synchronization signal, too - TTL level.

The diagram below shows the timely position of these signals with reference to the test voltage and the switching transients of the IGBT modules.

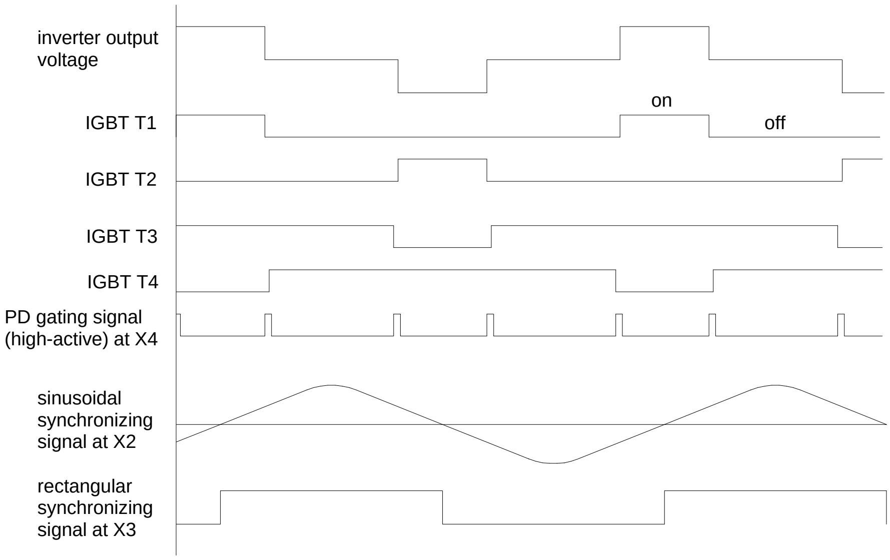


Fig. 37: Gating signal and synchronizing signals for support of PD measurements

The gating signal becomes active a few seconds before the switching process of the IGBT modules is started and has a settable duration in the range of 0 … 1000 µs with a resolution of 1 µs. The logic level for the active time can be selected.

A few PD measuring devices only evaluate the edge of a gating signal and operate with a fixed gating time of a few microseconds. Such devices require a burst to be able to reactivate the internal gating timer again and again until the desired total time is reached. For these cases, the shape of the impulse of the gating signal generated by the RSE 400 (800) can be set to [Burst]. Thus, a burst with the desired duration of the gating signal can be generated at a frequency of approx. 300 kHz.

The signal parameters and the gating time are set in the screen [Support for PD measurements] (*see Section 11.3.4, Fig. 13*).

The three signals are connected to the BNC jacks X2, X3 and X4 on the lower side of the controller module RSE-CTRL.

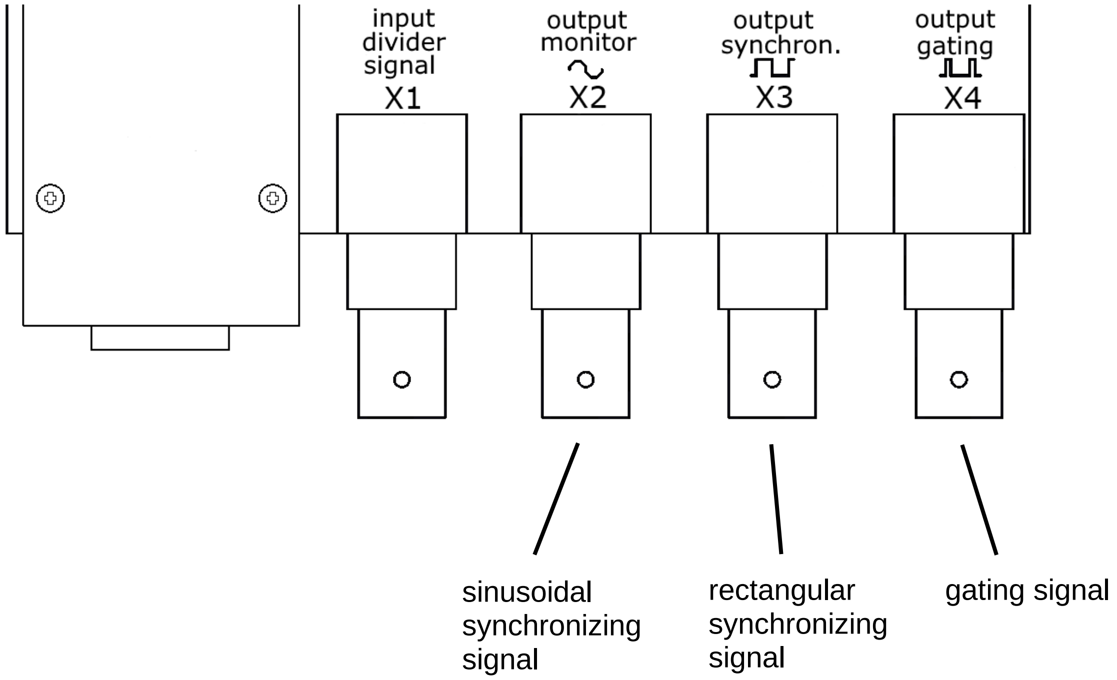


Fig. 38: Position of the outputs for the synchronizing signals and the gating signal

17. Notes regarding the earthing system

Proper earthing of the test system is a vital prerequisite for error-free operation. A bad earthing system can lead to malfunctions or destroy system components.

Especially in case of breakdown or flashover at the test object, very fast and high transients can occur. The best way to minimize such transients is to protect system components, mainly electronic modules, from damage. The recommended earthing principle is shown in the illustration below.

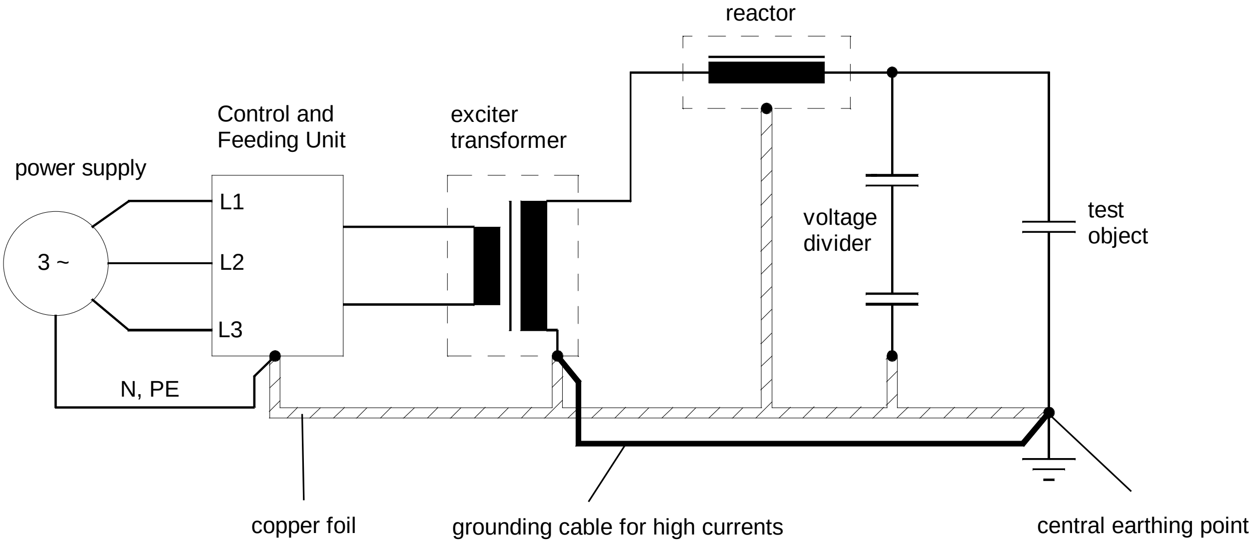


Fig. 39: Structure of the earthing system

All earthing points should be connected to each other in the form of a line, as shown in Fig. 39

Compared to the point-to-point earthing that is often practiced, the linear connection provides considerable advantages in this case. Compared to the very high and steep discharge current in the loop between the voltage divider and the test object, the currents in the other parts of the earthing system are relatively low in case of a breakdown of the test object. Therefore, the voltage drops in the earthing system are also low. In case of a breakdown, the potential of the complete test system is raised, without resulting in hazardous voltage differences between the RSE 400 (800), the exciter transformer and the voltage divider.

Using copper foil for the earth connections

A standard cable has a low impedance at line frequency. In this frequency range, the self-inductance only plays a minor part; the impedance is determined mainly by its ohmic resistance. The high transient currents in case of a breakdown at the test object, however, contain frequency components up to a few hundred MHz. For these frequency components, the cable represents a high impedance due to its inductivity; in addition, the skin effect becomes noticeable. As a result, high-frequency currents only flow on the surface of a conductor, and not in its interior. The consequence is a high impedance of a cable at high frequencies which results in very high voltage drops in the earthing system in case of a breakdown at the test object. Due to its geometry, a metal foil has a considerably lower impedance for high frequencies than a cable of the same cross-section and thus reduces the voltage drops in the earthing system.

Using the earthing system of the test object (station earth potential) as a central earthing point

As a rule, the earthing system of the test object (e.g. gas-insulated switchgear, cable termination, station earth potential) provides the best connection to the earth potential.

Using earthing cables parallel to copper foil in case of high test currents

For high test currents of several 10 A, the cross-section of standard copper foil is not sufficient. In this case, an additional earthing cable with a cross-section adapted to the test current must be laid for the earth connection from the exciter transformer to the test object. In this case, the stationary, high test current may be taken from the cable. The copper foil with its low impedance will then act as an efficient earthing connection for the very short, but high transients at the moment of the breakdown.

18. Status and error messages

During a test or its preparation, events or errors can occur that lead either to cancellation of the test or prevent its start. The error cause is displayed in the status bar of the screen [Test]. Errors occurring for a short time are saved until the main switch is turned on. Thus, it is possible to determine a cause for shutdown even if it is no longer present after shutting down (e.g. breakdown or overcurrent). *Table 6* below lists possible error messages and describes their causes.

Tab. 6: Error messages

Error message	Reason
[Error: Overvoltage]	The test voltage has exceeded its limit value.
[Error: Overcurrent]	An inverter output current has exceeded its limit value.
[Error: Feeding]	Faulty power grid (missing phase) or problems in the intermediate circuit when precharging (intermediate circuit voltage too low after 1s of charging).
[Error: IGBT desaturation]	Error in an IGBT module, probably due to excessive current; the RSE must be disconnected from the mains completely for a short time.
[Error: IGBT overtemperature]	Chip temperature of an IGBT module >85°C
[Error: Rectifier overtemperature]	Overtemperature of a heat sink for the rectifier modules
[Error: Safety loop]	The safety loop is not closed.
[Error: Comm. with peak voltmeter]	No communication with the peak voltmeter
[Error: Communication with RSE-CTRL]	No communication with the module RSE-CTRL
[Error: Breakdown]	Breakdown or flashover at the test object
[Error: CAN communication]	No data traffic possible at the CAN bus with at least one inverter unit
[Error: PC communication]	No data connection to the external control computer
[Error: Controller reset]	Restart of a microcontroller in the system after a program error
[Error: Reactor overtemperature]	The temperature of a resonant reactor exceeds the limit value.
[Error: Overcharged]	The intermediate circuit voltage has exceeded a voltage of 635 V.
[Error: Operator panel communication fault]	No communication between operator panel and PLC
[Error: [FO error]	An error occurred in the connection of the black plastic fiber optic cables to RSE units of the older model.

[Error: U ic difference too high]	The intermediate circuit voltage of a converter deviates from the mean value of all converters by more than 150 V.
[Error: PT100 sensor for ambient temperature defective]	The ambient temperature cannot be determined.
[Error: Buchholz relay]	Error message from the external Buchholz relay (gas in the oil).
[Error: Pressure monitor]	The external pressure monitor reports low pressure.
[Safety loops of channels 1 & 2 are different]	Illegal state in the dual-circuit safety system: One circuit is closed, and the other one is open.
[Unit error]	An active inverter unit reports an error.
[Error panel communication]	The PLC was temporarily unable to communicate with the operator panel. The test was canceled.
[Error: PLC in stop mode]	The PLC has stopped the program execution.
[Error: PLC not connected]	The operator panel cannot communicate with the PLC.
[Error: U test missing]	Despite starting the test, no test voltage could be detected. The test has been canceled.
[Error: Input voltage limit peak voltmeter (overflow)]	The maximum input voltage of the peak voltmeter was exceeded and the test was therefore aborted.
[Error: Circuit breaker power circuit]	The circuit breaker Q1 has a malfunction.

If an RSE 400 is operated in single mode, all error messages refer to the inverter unit in the control cabinet. If an RSE 800 is operated in single mode or several RSE are operated in interconnected mode, the error messages display with reference to the inverter units only that at least one inverter unit in the interconnected system reports an error. To determine this inverter unit, call the screens [Summary of unit errors] (*Fig. 24*) and [Errors of inverter unit] (*Fig. 25*) (*see Section 11.3.6.5*)

In addition to error messages, warnings and status information are also displayed at this point if no errors are present. These messages and their meanings are summarized in *Table 7*.

Tab. 7: Status messages

Message	**Meaning**
[Safety interlock]	The safety loop is not closed.
[Main switch is OFF]	The main switch is turned off; no errors.

[Precharging]	The intermediate circuit is precharged via the resistors.
[Ready]	The intermediate circuit is charged and ready to start the test.
[Searching for resonance]	The inverter searches for the resonance point at a modulation of 3.9%.
[Test running]	The standard test sequence is being executed.
[PC mode only if main switch OFF can be activated]	Passing the control to an external PC is only possible when the main switch is turned off.
[Pause mode; to continue, press the "Test" key.]	The test sequence was suspended (placed on hold).
[Warning: Reactor temperature]	Reactor temperature > (limit value – 5 K).
[Warning: [Maximum modulation]	The modulation has reached 97.3%; the test voltage cannot be increased further.
[Warning: [High ripple]	The ripple factor of the intermediate circuit voltage is greater than 230 V. This can be an indicator to excessive impedance of the power grid or of the feeding cables. Higher values can heat the capacitors of the intermediate circuit impermissibly. The warning can be ignored if it only occurs for a short time (a few minutes) in the case of a short-time test. For longer test times, it is expressly recommended to check the amount of the mains voltage at the busbars of the RSE 400 (800). They must lie within the permissible range (400 V +/- 10%). Furthermore, the ripple factor also strongly depends on the combination of output frequency and modulation. To minimize the ripple, it is recommended to use the maximum possible modulation (smallest possible transmission ratio of the exciter transformer) at which the desired test voltage is still reached.
[Warning: Buchholz relay]	A Buchholz relay connected to detect gas in the oil has issued a warning message.
[Water conditioning unit not ready]	Connected water conditioning unit for water terminations is not ready, high voltage must not be generated.
[EMERGENCY STOP actuated]	An EMERGENCY STOP pushbutton was actuated.
[Main switch restart delay time (6 s)]	After switching off the main switch, at least 6 s must have elapsed before it is switched on again.

19. Error rectification

Even if the RSE 400 (800) provides a large number of functions and messages to support the operator, it is possible that malfunctions can occur that lead to none or a misleading error description. The following notes are intended to help to identify the correct error causes and to take the appropriate measures.

The control system cannot be turned on.

- ▷ Check the fuses in fuse switch-disconnector F1.
- ▷ Check the miniature circuit-breakers.
- ▷ Check that all three phases of the power grid are present. To this end, measure all line-to-line voltages and the conductor-earth voltages on the input busbars using a multimeter.

The control system displays unusual effects when the main switch is turned on.

- ▷ Check that all three phases of the power grid are present. To this end, measure all line-to-line voltages and the conductor-earth voltages on the input busbars using a multimeter.
- ▷ Open the fuse switch-disconnector F1 for 10 seconds and then close it back again with a jerk.

  Especially multiple, unclear closing of F1 briefly in succession can disturb the initialization (Power-On reset) of the micro-controllers on various p.c. boards and cause malfunctions.

The test is cancelled with the error message [Error: Overvoltage].

There are several possible reasons for this behavior; in most cases, however, one of the following two reasons applies:

1. The voltage ramp rate du/dt is too high. An excessively fast increase, especially in the case of high Q factors, may lead to exceeding of the setpoint in case of brief overshooting of the test voltage. If the limit value for the test voltage is exceeded during this process, the system is shut down.
   - ▷ We recommend to use value in the range between 1 and 3 %/s for the voltage ramp rate.
2. The limit value for the test voltage is too close to the setpoint. Normally, the stability of the test voltage is better than 1%. If the voltage of the power grid, however, varies, these variations also lead to similar variations of the test voltage for a short time.
   - ▷ We recommend to select the limit value for the test voltage by approx. 3 … 5% higher than the setpoint.

The test voltage does not reach the setpoint, and the message [Warning: Maximum modulation] is displayed.

The compensation power supplied by the RSE 400 (800) to cover the losses in the HV circuit is not sufficient. Since the maximum modulation is already reached, the test voltage cannot be increased further.

- ▷ Increase the transmission ratio of the exciter transformer in steps until the desired voltage is reached.
- ▷ Possibly, corona losses reduce the Q factor in the case of higher voltages, especially in the case of small test capacitances. This problem could possibly be solved by an improved (corona-free) construction of the HV connection to the test object.

When performing the frequency search, the whole frequency range is passed, starting at the start frequency to the lower frequency limit, without finding the resonance point.

If the resonance point is not found, this has normally the following main reason: The RSE 400 (800) does not receive a clean signal from the voltage divider. Especially the zero crossings of this signal, however, are required to be able to find the resonance point.

The causes for a missing or blurred signal may be different:

1. The HV potential of the test circuit is still earthed at a point (e.g. remote cable end, earthing switch in GIS).
   - ▷ Disconnect the test object from the test system and measure the insulation resistance of the test object.
   - ▷ Alternatively, it is also possible to disconnect the connection between the exciter transformer and the resonant reactor and to measure the insulation resistance between the reactor input and the earth potential.
2. A connection in the test circuit is missing.
   - ▷ Measure the resistance between the high-voltage connection and earth at the test object with the earthing rod removed. You must measure the sum of the ohmic winding resistances of the resonant reactor and the secondary winding of the exciter transformer (a few 10 or 100 ohms, depending on the resonant reactor).
3. A problem occurred in the low-voltage branch of the voltage measuring system.
   - ▷ Measure the resistance between the input of the low-voltage measurement part (yellow cable) and earth potential. It must be approx. 10 MΩ (input resistance of the peak voltmeter MU 18). Due to the high capacity of the low-voltage measuring part, it may take a few seconds until a stable measurement value can be read. If a short-circuit is measured, there is probably an insulation error in the measuring cable. If the measurement value is significantly higher than 10 MΩ, there is a contact problem or the measuring cable is damaged (no passage).

During the automatic frequency search, the whole frequency range to the lower frequency limit is passed, but the RSE 400 (800) does not stop at the expected resonant frequency. In the vicinity of this frequency, however, the test voltage is increased for a short time.

This is an indication that the signal from the voltage divider is too small or disturbed. If the test system is earthed at two different points (station earth potential on the test object and mains neutral on the RSE 400 (800), this is occasionally attributable to compensation currents with mains frequency. A further explanation could be an insufficiently large signal from the voltage divider.

- ▷ Double earthing should be avoided if possible. If a diesel generator is used for power supply, it should be earthed on the test system. If an infinite power supply system of the station with **earthed (!)** neutral is used for power supply, the neutral conductor of the power grid may be disconnected from the RSE. In this case, however, the earth connection to the station earth potential on the high-voltage side must provide sufficient ampacity.
- ▷ Increase the output voltage of the exciter transformer to obtain a larger signal from the voltage divider during the frequency search.
- ▷ Limit the frequency range to a lower limit frequency of 1 ... 2 Hz below the frequency at which a voltage increase can be detected (probable resonance point).

If these measures do not lead to a solution of the problem, you may attempt to find the resonance point manually. To do so, proceed as follows:

1. Enter the resonance frequency to be expected as the start frequency.
2. Set the limit value for the test voltage to max. 50% of the future test voltage.
3. Set the setpoint test voltage to 10% of the future test voltage.
4. Set the frequency change speed to 0.05 Hz/s.
5. Turn on the main switch.
6. Deactivate the automatic frequency search (button [Auto f]).
7. Start the test.
   → The RSE will now increase the modulation at the start frequency.
8. Once the value set for the test voltage is reached or the message [Warning: Max. modulation] is displayed, tap the button [Hold test].
9. Now you can carefully change the frequency towards the resonance point using the buttons [f▲] and [f▼]. If you change the frequency in the correct direction, the test voltage is increased for a short time. If it exceeds the setpoint, a bit time must be given to the voltage regulator to reduce the modulation before you change the frequency further.
10. Once the resonance point has been found (display [Resonance] and lowest modulation), you may end the test.
11. Now enter the resonance frequency found as the start frequency.
12. Enter all parameters required for the actual test.
13. After turning on the main switch, tap the button [Auto f] to deactivate the automatic frequency search and to work only with the resonant frequency set as the start frequency.

Once the main switch has been turned on, the message [Precharging ...] is displayed for a short time, but after 1 … 2 s the main switch is turned off, and the error message [Error: Mains error] is displayed.

The charging of the intermediate circuit capacitors is monitored. If after approx. 1 s after starting the charging process a certain intermediate circuit voltage is not reached, an error is to be assumed, and the charging process is cancelled.

► Turn the main switch back on again and observe the intermediate circuit voltage. If it is not increased during precharging, check the miniature circuit-breaker F3.

20. Service and maintenance

No special maintenance is required. The RSE 400 (800) does not contain any batteries.

21. Faults

In case of faults, do not hesitate to contact:

HIGHVOLT Prüftechnik Dresden GmbH
Marie-Curie-Strasse 10
D-01139 Dresden
Telephone: +49 351 8425-800
Telefax: +49 351 8425-610
E-mail: **service@highvolt.com**

When reporting a fault, specify the type, serial number, year of manufacture (see rating plate on the rear side of the unit) and type of fault.

22. Abbreviations and symbols

RSE	Control and feeding unit
LED	Light-emitting diode
Inom	Nominal current
Unom	Nominal voltage
Lnom	Nominal inductivity
r.m.s. (RMS)	Root mean square value
PD	Partial discharge
PLC	Programmable logic controller
IGBT	Insulated gate bipolar transistor
FO	Fiber optical cable
WLAN	Wireless local area network
GIS	Gas-insulated switchgear
HV	High voltage
TTL	Transistor-transistor logic (class of digital circuits powered by +5V)

23. Layout diagram for the components on the p.c. boards

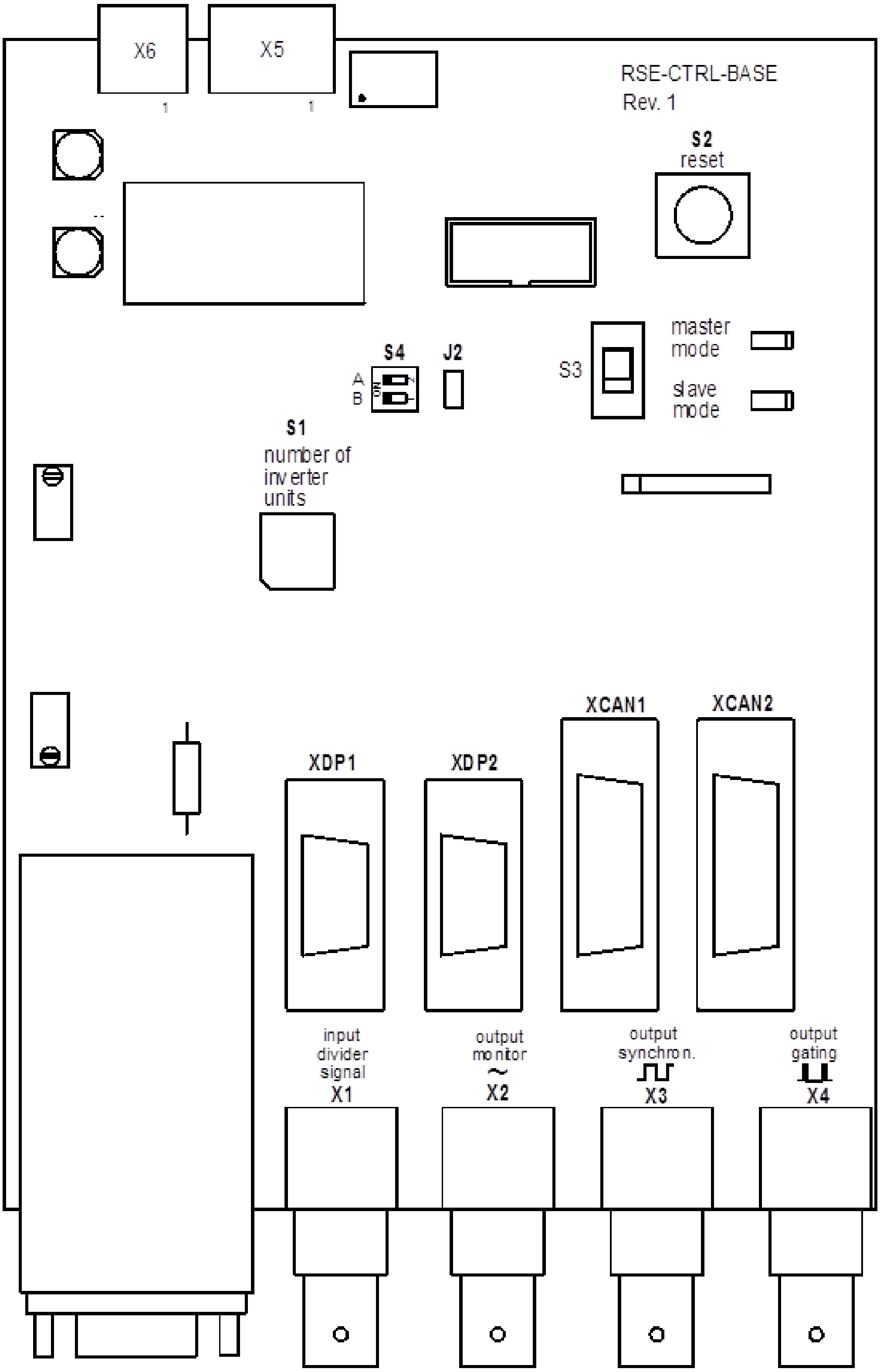


Fig. 40: Controller module RSE-CTRL

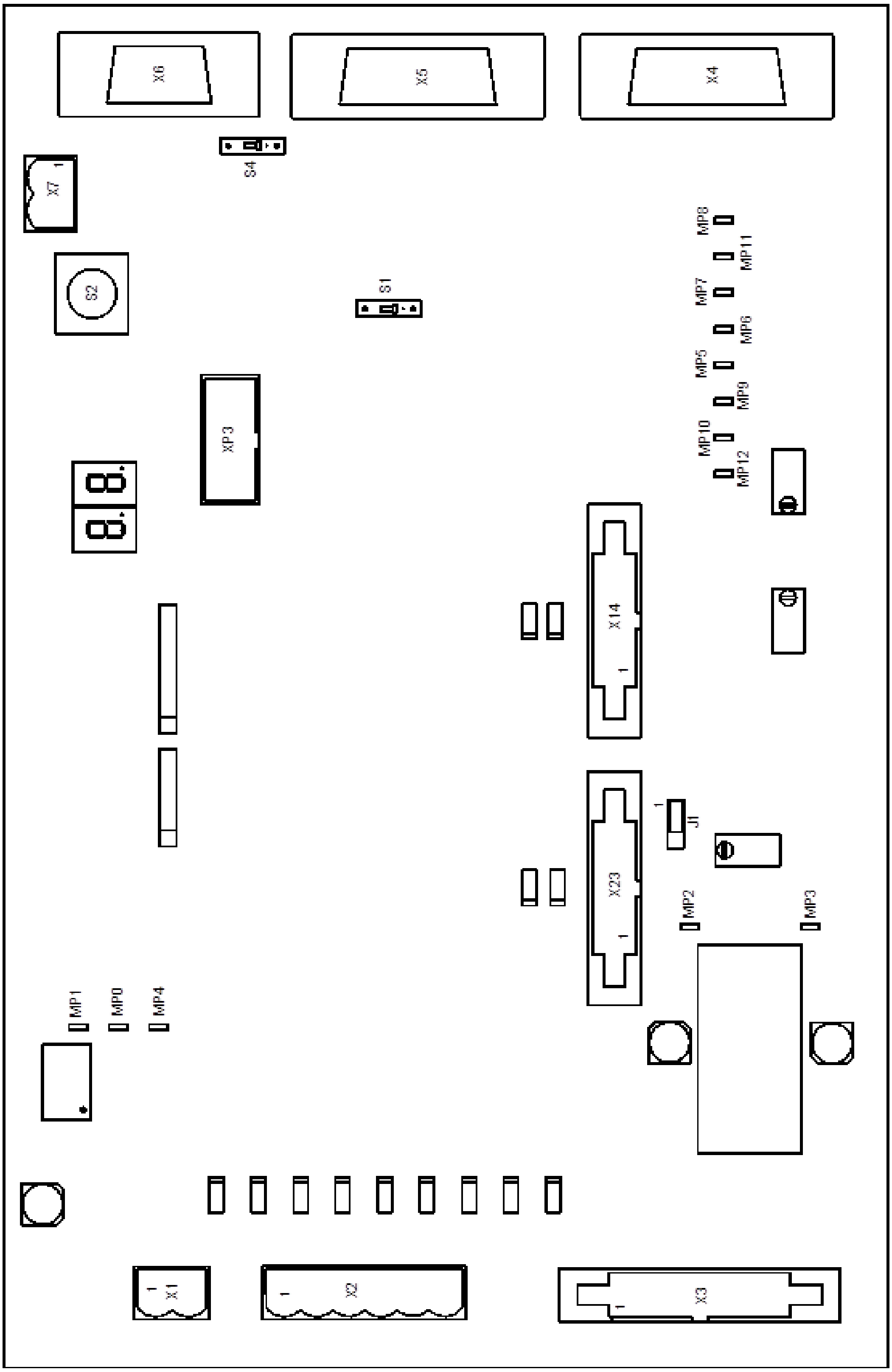


Fig. 41: PCB IGBT-CTRL-A1

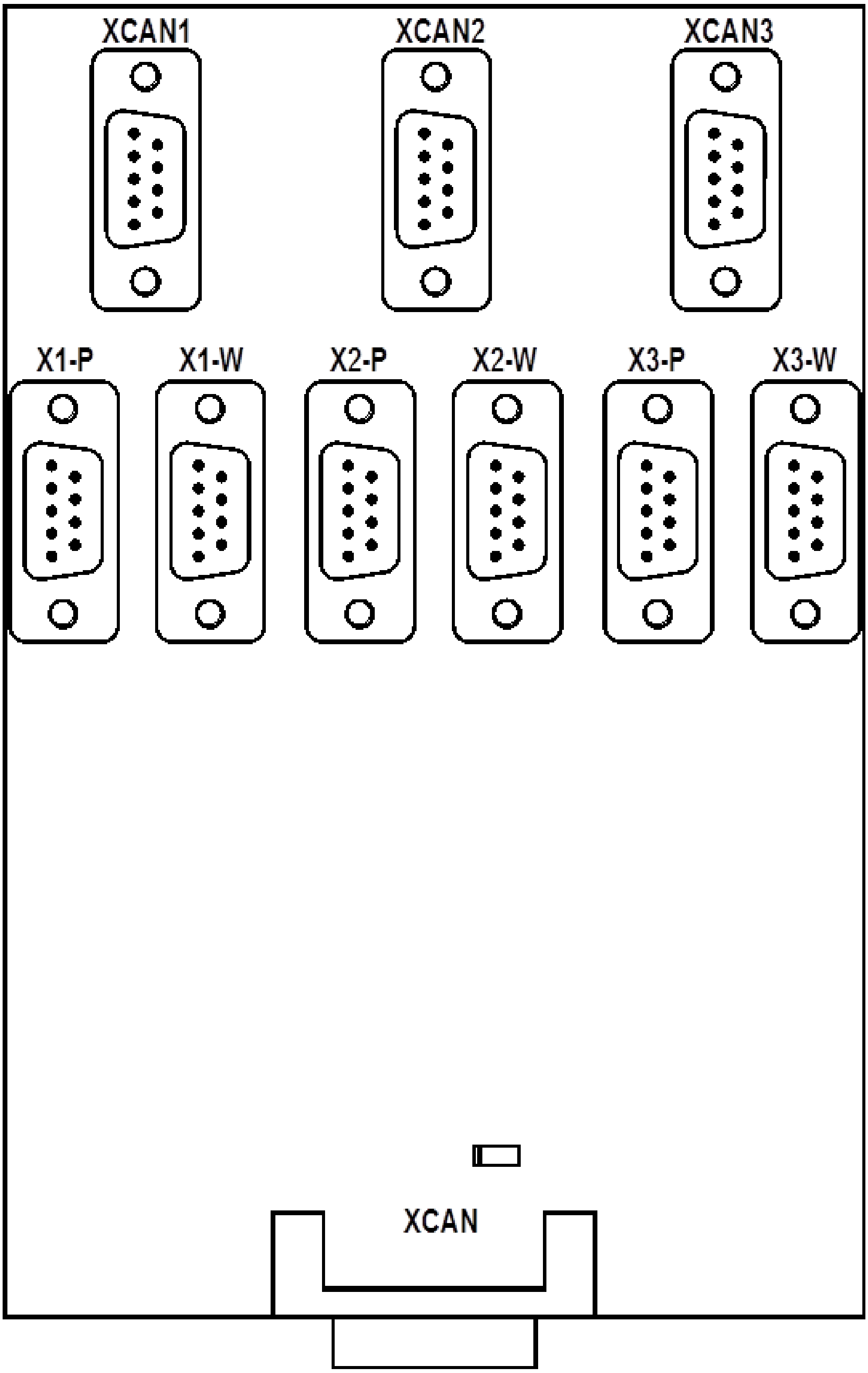


Fig. 42: Converter module RSE-CONV

24. List of Figures

25. List of Tables