XI1-E/-E-R – Earth fault relay for isolated compensated systems

Manual XI1-E/-E-R (Revision A)
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1. Applications and features

The XI1-E of the PROFESSIONAL LINE is an all-purpose protection against earth faults, used for electrical machines, lines and isolated or compensated systems; it is mainly used in radial networks. Very often the XI1-E can be found as backup protection at the central earthing point of the system. It detects all earth faults occurring in the system. In this case the trip delay selected must exceed the longest time delay setting of any other earthing protection used in the system.

Relay variant XI1-E-R with directional current sensing is a selective earth-fault protection and is normally used in ring systems, networks with parallel feeders and in complex meshed systems.

When compared to the conventional protection equipment all relays of the PROFESSIONAL LINE reflect the superiority of digital protection techniques with the following features:

- High measuring accuracy by digital data processing
- Fault indication via LEDs
- Extremely wide operating ranges of the supply voltage by universal wide-range power supply
- Very fine graded wide setting ranges
- Data exchange with process management system by serial interface adapter XRS1 which can be retrofitted
- RMS measurement
- Extremely short response time
- Compact design by SMD-technology

Note:
The relay type XI1-S can be used if a not very sensitive earth current relay is needed for earth current measuring without directional feature.
2. Design

Analog inputs
The analog input signals are connected to the protection device via terminals IE1 and IE2. The residual voltage UE required for determining earth fault direction can be connected from the e-n winding to the terminals Ue and Un (XI1-E-R).

Auxiliary voltage supply
Unit XI1-E/-E-R needs a separate auxiliary voltage supply. Therefore a DC or AC voltage must be used. Unit XI1-E/-E-R has an integrated wide range power supply. Voltages in the range from 19 - 390 V DC or 36 - 275 V AC can be applied at connection terminals A1 and A2.

Figure 2.11: Connections XI1-E in holmgreen circuit

Figure 2.2: Connections XI1-E-R in holmgreen circuit
**Contact positions XI1-E**

![Diagram](image)

**Operation without fault or dead conditions**

**Earth fault low set tripping**

**Earth fault high set tripping**

*Figure 2.3: Contact positions XI1-E*

**Note:**
In case of both the tripping contacts of IE> and IE>> should cause the tripping coil of the C.B. to trip, they have to be interconnected.

**Contact positions XI1-E-R**

![Diagram](image)

**Operation without fault or dead conditions**

**Earth fault directiona warning (Residual voltage tripping)**

**Earth fault directional tripping**

*Figure 2.4: Contact positions XI1-E-R*

**Note:**
No earth fault directional tripping takes place without exceeding the residual voltage setting. A core balance C.T. can be connected to terminals IE1 and IE2 instead of holmgreen circuit.
3. Working principle

The incoming currents from the main current transformers on the protected object are converted to voltage signals in proportion to the currents via the input transformers and burden. The noise signals caused by inductive and capacitive coupling are suppressed by an analog R-C filter circuit. The analog voltage signals are fed to the A/D-converter of the microprocessor and transformed to digital signals through Sample- and Hold-circuits. The analog signals are sampled at 50 Hz (60 Hz) with a sampling frequency of 800 Hz (960 Hz), namely, a sampling rate of 1.25 ms (1.0 ms) for every measuring quantity.

A pickup of a supervision circuit is indicated by flashing of the corresponding LED. At tripping the flashing light changes to steady light.

3.1 Earth-fault directional feature (E-R-relay type)

For earth-fault direction detection it is mainly the question to evaluate the power flow direction in zero sequence system. Both the residual voltage and neutral (residual) current on the protected line are evaluated to ensure a correct direction decision.

The residual voltage UE required for determining earth fault direction can be measured at the e-n winding (Connection at terminals Ue and Un see fig. 2.2). Total current can be measured by connecting the unit either to a ring core C.T. or to current transformers in a Holmgreen circuit. However, maximum sensitivity is achieved if the XI1-E-R is connected to a ring core C.T.

In isolated or compensated systems, measurement of reactive or active power is decisive for earth-fault detection. It is therefore necessary to set the E-R-relay type to measure according to sin φ or cos φ methods, depending on the neutral-point connection method (see table. 4.1).

Figure 3.1: Phase position between the residual voltage and zero sequence current for faulted and non-faulted lines in case of isolated systems (sin φ)

- UE - residual voltage
- IE - zero sequence current
- IC - capacitive component of zero sequence current
- IW - resistive component of zero sequence current

\[
\begin{align*}
\text{(a) non-faulted lines} & \quad \text{(b) faulted lines} & \quad \text{(c) Trip / No-Trip region}
\end{align*}
\]
By calculating the reactive current component (sin $\phi$ adjustment) and then comparing the phase angle in relation to the residual voltage $U_E$, the E-R-relay type determines whether the line to be protected is earth-faulted.

On non-earth-faulted lines, the capacitive component $I_{C(a)}$ of the total current precedes the residual voltage by an angle of 90°. In case of a faulty line the capacity current $I_{C(b)}$ lags behind the residual voltage at 90°.

![Diagram showing phase position between residual voltage and zero sequence current for faulted and non-faulted lines in case of compensated systems (cos $\phi$)](image)

**Figure 3.2**: Phase position between the residual voltage and zero sequence current for faulted and non-faulted lines in case of compensated systems (cos $\phi$)

- $U_E$ - residual voltage
- $I_E$ - zero sequence current
- $I_L$ - inductive component of zero sequence current (caused by Petersen coil)
- $I_C$ - capacitive component of zero sequence current
- $I_W$ - resistive component of zero sequence current

In compensated mains the earth fault direction cannot be determined from the reactive current components because the reactive part of the earth current depends upon the compensation level of the mains. The ohmic component of the total current (calculated by cos $\phi$ adjustment) is used in order to determine the direction.

The resistive component in the non-faulted line is in phase with the residual voltage, while the resistive component in the faulted line is opposite in phase with the residual voltage.

By means of an efficient digital filter harmonics and fault transients in the fault current are suppressed. Thus, the uneven harmonics which, for instance, are caused by an electric arc fault, do not impair the protective function.

If the measured residual voltage is higher than the setting value $U_{E>}$, relay $U_{E>}$ trips after the adjusted trip delay $t_{U_{E>}}$ has expired. At this moment the instant relay $U_{E>}$ picks up and the earth fault direction is calculated by using the sin$\phi$ or cos $\phi$ algorithm.

If the ohmic component (cos $\phi$-measuring) or capacitive component (sin $\phi$-measuring) of the total current is above setting value $I_{E>}$, relay $I_{E>}$ trips after the adjusted trip delay $t_{I_{E>}}$ has expired.
3.2 Demand imposed on the main current transformers

The current transformers have to be rated in such a way, that the saturation should not occur within the following operating current ranges:

Independent time overcurrent function: $K_1 = 2$
High-set function: $K_1 = 1.2 - 1.5$

$K_1$ = Current factor related to that setting value where the current transformer does not yet work in its saturation range.

Moreover, the current transformers have to be rated according to the maximum expected short circuit current in the network or in the protected objects. The low power consumption in the current circuit of XI1-E/-E-R, namely <0.1 VA, has a positive effect on the selection of current transformers. It implies that, if an electromechanical relay is replaced by XI1-E/-E-R, a high accuracy limit factor is automatically obtained by using the same current transformer.
4. Operation and settings

All operating elements needed for setting parameters are located on the front plate of the XI1-E/-E-R as well as all display elements. Because of this all adjustments of the unit can be made or changed without disconnecting the unit off the DIN-rail.

![Figure 4.1: Front plate XI1-E](image1)

![Figure 4.2: Front plate XI1-E-R](image2)
For adjustment of the unit the transparent cover has to be opened as illustrated. Do not use force! The transparent cover has two inserts for labels.

![Figure 4.3: How to open the transparent cover](image)

**LEDs**
LED „ON“ is used for display of the readiness for service (at applied auxiliary voltage $U_v$). LED $IE>$ and $IE>>$ ($IE>$ and $UE>$ at XI1-E-R) indicate pickup (flashing) or tripping (steady light) of the corresponding function.

**Test push button**
This push button is used for test tripping of the unit and when pressed for 5 s a check-up of the hardware takes place. Both output relays are tripped and all tripping LEDs light up.
### 4.1 Setting of DIP-switches

The DIP-switch block on the front plate of the XI1-E/-E-R is used for adjustment of the nominal values and setting of function parameters:

**Type XI1-E:**

<table>
<thead>
<tr>
<th>DIP-switch</th>
<th>OFF</th>
<th>ON</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>5</td>
<td>not blocked</td>
<td>blocked</td>
<td>Blocking of the IE&gt;&gt; element</td>
</tr>
<tr>
<td>6</td>
<td>50 Hz</td>
<td>60 Hz</td>
<td>Rated frequency</td>
</tr>
<tr>
<td>7*</td>
<td>x1 s</td>
<td>x10 s</td>
<td>Time multiplier for tIE&gt;</td>
</tr>
<tr>
<td>8*</td>
<td>x1 s</td>
<td>x100 s</td>
<td>Time multiplier for tIE&gt;</td>
</tr>
</tbody>
</table>

*Table 4.1: Functions of XI1-E DIP-switches*

*Only one of the DIP-switches 7 - 8 shall be in „ON“-position at the same time.

**Type XI1-E-R:**

<table>
<thead>
<tr>
<th>DIP-switch</th>
<th>OFF</th>
<th>ON</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>No function</td>
</tr>
<tr>
<td>5</td>
<td>sin</td>
<td>cos</td>
<td>Calculation procedure for isolated / compensated systems</td>
</tr>
<tr>
<td>6</td>
<td>50 Hz</td>
<td>60 Hz</td>
<td>Rated frequency</td>
</tr>
<tr>
<td>7*</td>
<td>x1 s</td>
<td>x10 s</td>
<td>Time multiplier for tIE&gt;</td>
</tr>
<tr>
<td>8*</td>
<td>x1 s</td>
<td>x100 s</td>
<td>Time multiplier for tIE&gt;</td>
</tr>
</tbody>
</table>

*Table 4.2: Functions of XI1-E-R DIP-switches*

*Only one of the DIP-switches 7 - 8 shall be in „ON“-position at the same time.

**Blocking of the earth fault high set element of XI1-E-R (IE>>)***

When the DIP-switch 5 is in position „ON“, the earth fault high set element of the XI1-E is blocked.

**Calculation procedure for isolated/compensated systems**

Dependent on the earthing method used, the directional element of the XI1-E-R can be chosen by using DIP-switch 5 for isolated (sin Φ-measuring) or compensated (cos Φ-measuring) systems.

**Rated frequency**

With the aid of DIP-switch 6 the rated frequency can be set to 50 or 60 Hz, depending upon the given mains characteristics.

**Change-over of the time multiplier**

By using DIP-switch 7, the trip delay tIE> is multiplied by factor 10.

By using DIP switch 8, the trip delay tIE> can be multiplied by factor 100.
4.2 Setting of the tripping values

The PROFESSIONAL LINE units have the unique possibility of high accuracy fine adjustments. For this, two potentiometers are used. The coarse setting potentiometer can be set in discrete steps of 0.05 x In.

A second fine adjustment potentiometer is then used for continuously variable setting of the final 0.05 x In. Adding of the two values results in the precise tripping value.

**Earth fault low set element**
The tripping value IE> can be set in the range from 0 - 0.3 x In (min. limit value 0.001x In) with the aid of the potentiometer illustrated on the following diagram.

**Example:**
A tripping value IE> of 0.18 x In is to be set. The set value of the right potentiometer is just added to the value of the coarse setting potentiometer. (The arrow of the coarse setting potentiometer must be inside of the marked bar, otherwise no defined setting value).

![Figure 4.4: Adjustment example](image)

**Trip delay for the earth fault low set element**
The time delay for the low set element can be adjusted in the range from 0 - 100 s.

**Earth fault high set element (XI1-E)**
The high set element IE>> can be adjusted in the range from 0 - 1.5 x In (min. limit value 0.001x In). This adjustment is done similar to the low set element adjustment.

**Trip delay for earth fault high set element (XI1-E)**
The time delay for the high set element tIE>> is adjustable in the range from 0 - 1.25 s.

**Residual voltage element (XI1-E-R)**
The residual voltage element UE> can be adjusted in the range from 10 - 120 V. This adjustment is done similar to the adjustment of the earth fault low set element.

**Trip delay for the residual voltage element (XI1-E-R)**
The time delay for the residual voltage element tUE> can be adjusted in the range from 0 - 10 s.
4.3 Communication via serial interface adapter XRS1

For communication of the units among each other and with a superior management system, the interface adapter XRS1 is available for data transmission, including operating software for our relays. This adapter can easily be retrofitted at the side of relay. Screw terminals simplify its installation. Optical transmission of this adapter makes galvanic isolation of the relay possible. Aided by the software, actual measured values can be processed, relay parameters set and protection functions programmed at the output relays. Information about unit XRS1 in detail can be taken from the description of this unit.
5. Relay case and technical data

5.1 Relay case

Relay XI1-E/-E-R is designed to be fastened onto a DIN-rail acc. to DIN EN 50022, the same as all units of the PROFESSIONAL LINE. The front plate of the relay is protected with a sealable transparent cover (IP40).

**Figure 5.1: Dimensional drawing**

**Connection terminals**
The connection of up to a maximum 2 x 2.5 mm² cross-section conductors is possible. For this the transparent cover of the unit has to be removed (see para. 4).
5.2 Technical data

Measuring input circuits
Rated frequency fn: 50/60 Hz
Thermal withstand capability in current circuits:
- dynamic current withstand (half wave) 250 x In for 1 s
- 100 x In for 10 s
- 30 x In continuously
Thermal capacity of the voltage circuit: continuously 120 V AC
Power consumption:
- at In = 1 A: 0.1 VA
- at In = 5 A: 0.1 VA
- at Un = 100 V: 0.1 VA
Power consumption in voltage circuit: at Un = 100 V: 0.1 VA

Auxiliary voltage
Rated auxiliary voltage Uv:
- 19 - 390 V DC or 36 - 275 V AC (f = 40 - 70 Hz):
- 4 W (terminals A1 and A2)

Common data
Dropout to pickup ratio: > 97 %
Resetting time from pickup: < 50 ms
Returning time from trip: 200 ms
Minimum initialization time after supply voltage has applied: 100 ms
Minimum response time when supply voltage is available: < 50 ms

Output relay
Number of relays: 2
Contacts: 1 changeover contact for each trip relay
Maximum breaking capacity:
- ohmic 1250 VA / AC resp. 120 W / DC
- inductive 500 VA / AC resp. 75 W / DC
Max. rated voltage:
- 220 V DC: ohmic load Imax. = 0.2 A
- inductive load Imax. = 0.1 A at L/R ≤ 50 ms
- 24 V DC: inductive load Imax. = 5 A
Minimum load: 1 W / 1 VA at Umin ≥ 10 V
Maximum rated current: 5 A
Making current (16 ms): 20 A
Contact life span: 10⁶ operations at max. breaking capacity
Contact material: AgCdO

System data
Design standard: VDE 0435 T303; IEC 0801 part 1-4;
VDE 0160; IEC 255-4; BS142; VDE 0871
Temperature range at storage and operation: -25°C to +70°C
Constant climate class F acc. DIN 40040 and DIN IEC 68, part 2-3:
more than 56 days at 40°C and 95 % relative humidity

High voltage test acc. to VDE 0435, part 303
Voltage test: 2.5 kV (eff.) / 50 Hz; 1 min
Surge voltage test: 5 kV; 1.2/50 µs, 0.5 J
High frequency test: 2.5 kV / 1 MHz
Electrostatic discharge (ESD) acc. to IEC 0801, part 2: 8 kV
Radiated electromagnetic field test acc. to IEC 0801, part 3: 10 V/m
Electrical fast transient (burst) acc. to IEC 0801, part 4: 4 kV / 2.5kHz, 15 ms
Radio interference suppression test as per DIN 57871 and VDE 0871: limit value class A
Repeat accuracy: 1 %
Basic time delay accuracy: 0.5 % or ±25 ms
Basic accuracy of characteristic quantities:
- ±2 % of IE the setting value or ±0.002 x IN
- ±1 % of Ue or ±0.5 V
Transient overreach at instantaneous operation: ≤ 5 %
Frequency effect: 1 % per Hz deviation from rated value in the range from ±10 % of fn (50 Hz or 60 Hz)

Earth fault direction accuracy (XI1-E-R)
Real current component measuring in compensated systems: \( I_E \times \cos \varphi \)
Reactive current component measuring in isolated systems: \( I_E \times \sin \varphi \)
Accuracy of measured angle at Ue > 20 V:
- ± 6° at \( I_E = 0.002 \times I_N \)
- ± 3° at \( I_E = 0.005 \times I_N \)
- ± 2° at \( I_E = 0.010 \times I_N \)
- ± 1° at \( I_E \geq 0.015 \times I_N \)

Mechanical test:
Shock: class 1 acc. to DIN IEC 255-21-2
Vibration: class 1 acc. to DIN IEC 255-21-1

Degree of protection
Front plate: IP40 at closed front cover
Weight: approx. 0.7 kg
Mounting position: any
Relay case material: self-extinguishing
### 5.3 Setting ranges XI1-E

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting range</th>
<th>Graduation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE&gt;</td>
<td>0 - 0.3 x In (min. limit value 0.001 x In)</td>
<td>Continuously variable</td>
</tr>
<tr>
<td>IE&gt;&gt;</td>
<td>0 - 1.5 x In (min. limit value 0.001 x In)</td>
<td>Continuously variable</td>
</tr>
<tr>
<td>tIE&gt;</td>
<td>0 - 1 s / 0 - 10 s / 0 - 100 s</td>
<td>Continuously variable</td>
</tr>
<tr>
<td>tIE&gt;&gt;</td>
<td>0 - 1.25 s</td>
<td>Continuously variable</td>
</tr>
</tbody>
</table>

Table 5.1: Setting ranges and graduation

### 5.4 Setting ranges XI1-E-R

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting range</th>
<th>Graduation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE&gt;</td>
<td>0 - 0.3 x In (min. limit value 0.001 x In)</td>
<td>Continuously variable</td>
</tr>
<tr>
<td>tIE&gt;</td>
<td>0 - 1 s / 0 - 10 s / 0 - 100 s</td>
<td>Continuously variable</td>
</tr>
<tr>
<td>UE&gt;</td>
<td>10 - 120 V</td>
<td>Continuously variable</td>
</tr>
<tr>
<td>tUE&gt;</td>
<td>0 - 10 s</td>
<td>Continuously variable</td>
</tr>
</tbody>
</table>

Table 5.2: Setting ranges and graduation
6. Order form

<table>
<thead>
<tr>
<th>Earth fault current relay  X11-</th>
<th>E</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>for isolated / compensated systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with earth fault directional feature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal current: 1 A 5 A</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Technical data subject to change without notice!
Setting list XI1-E/-E-R

Project: ____________________ Woodward job-no.: ________________
Function group: = __________ Location: + Relay code: - ____________
Relay functions: ____________________ Date: ____________________

Setting of parameters

<table>
<thead>
<tr>
<th>Function</th>
<th>Unit</th>
<th>Default settings</th>
<th>Actual settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE&gt;</td>
<td>Earth fault low set element</td>
<td>x ln</td>
<td>0.001</td>
</tr>
<tr>
<td>IE&gt;&gt;</td>
<td>Earth fault high set element</td>
<td>x ln</td>
<td>0.001</td>
</tr>
<tr>
<td>tIE&gt;</td>
<td>Trip delay for earth fault low set element (XI1-E)</td>
<td>s</td>
<td>0</td>
</tr>
<tr>
<td>tIE&gt;&gt;</td>
<td>Trip delay for earth fault high set element (XI1-E)</td>
<td>s</td>
<td>0</td>
</tr>
<tr>
<td>UE&gt;</td>
<td>Residual voltage element (XI1-E-R)</td>
<td>V</td>
<td>1</td>
</tr>
<tr>
<td>tUE&gt;</td>
<td>Trip delay for residual voltage element (XI1-E-R)</td>
<td>s</td>
<td>0</td>
</tr>
</tbody>
</table>

DIP-switch settings

<table>
<thead>
<tr>
<th>DIP-switch</th>
<th>Function</th>
<th>Default settings</th>
<th>Actual settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>No function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>No function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>No function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Blocking of IE&gt;&gt; element (XI1-E) or calculation procedure isolated/compensated systems (XI1-E-R)</td>
<td>not blocked/sin</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Rated frequency</td>
<td>50 Hz</td>
<td></td>
</tr>
<tr>
<td>7*</td>
<td>Time multiplier for tIE&gt;</td>
<td>x1 s</td>
<td></td>
</tr>
<tr>
<td>8*</td>
<td>Time multiplier for tIE&gt;</td>
<td>x1 s</td>
<td></td>
</tr>
</tbody>
</table>

*Only one of the DIP-switches 7 - 8 shall be in „ON“-position at the same time.*
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