APPLICATION NOTE

Auxiliary Devices for Generator Protection

SIPROTEC 5

APN-053, Edition 2, ENG; unrestricted

SIEMENS

SIPROTEC 5 - Application

Auxiliary Devices for Generator Protection

APN-053, Edition 2, ENG

Content

1 Auxiliary Devices for Generator Protection

1.1 INTRODUCTION

Looking into the primary part of a power plant, e.g. generator stator, generator rotor, grounding system we see that a direct connection of protection relays is not possible. Special coupling devices are necessary to connect e.g. rotor earth fault protection devices to the winding on the turning rotor.

This paper provides an overview of the most important auxiliary devices which are necessary to engineer a generator protection system.

To connect protection devices to the primary part of a power plant, several auxiliary devices need to be considered, especially for:

Stator Ground fault protection, Rotor Ground fault protection, under excitation protection, DC-Ground fault protection.

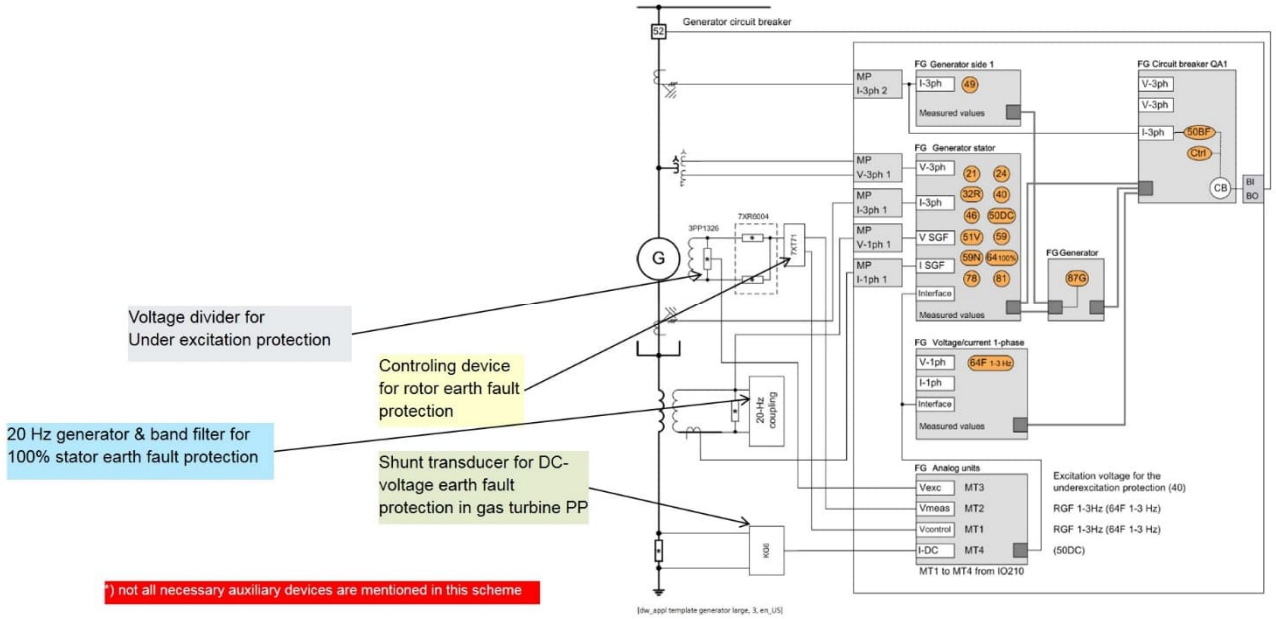


Figure 1: Basic Single Line Diagram

To understand why a certain coupling device is necessary for a specific protection function, and how it is connected between primary equipment and measuring input of the protection device is explained in this application note step by step.

It is structured according to the different protection functions.

1.2 90% Stator Ground Fault Protection

The easiest way to detect earth faults in a three-phase system is the supervision of the voltage symmetry; or simply spoken the measurement of the zero-sequence voltage e.g. at an open delta winding of a voltage transformer, at a grounding transformer or by summation of the 3 phase-ground voltages.

In a healthy situation the system voltages are balanced, and the zero-sequence voltage is 0.

In case of an earth fault in any phase there will be a zero-sequence voltage depending on how much of the faulty phase winding in the generator is involved. This method allows providing protection of the phase winding from the generator terminal 90% down to the starpoint.

Since the open delta winding of the earthing transformer very often has a relatively high voltage; e.g. typically 500V it doesn't fit to the nominal values of voltage measuring inputs of protection relays (typically 100V).

Together with electro mechanical relays from 1960th we'll find first coupling devices for stator earth fault protection.

Since these devices are almost passive elements not much has changed over the years. The adaptation is done with a voltage divider 5/1 for the 90% stator earth fault protection connecting to the 100V measuring input of the protection relay to the 500V open delta winding of the earthing transformer.

This is for example a 3PP13 device.

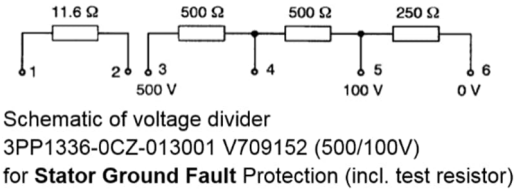


Figure 2: Schematic of voltage divider

Be sure to select the right order code and not forget the short code "K2Y" when placing the order.

Due to redesign according SIPROTEC 5 series the new coupling unit for the 90%-stator ground-fault protection now is the **7XR8600.** It can be used with 7UM85 machine protection relays but is also backward compatible with the 7UM62.

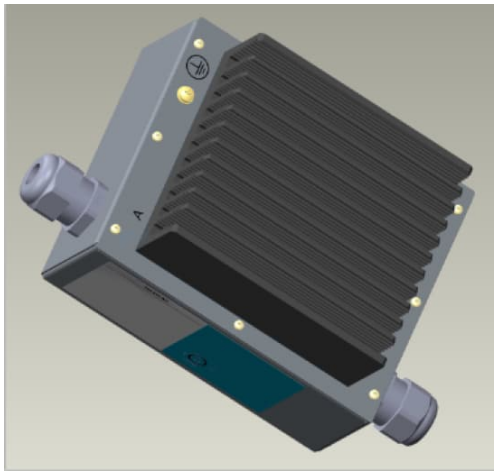


Figure 3: Mechanical Design of the 7XR86

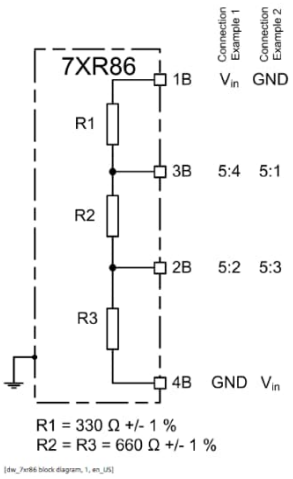


Figure 4: Connection diagram of the 7XR86

This device replaces the previous 3PP1336-1CZ-K2Y (5:1, 5:2 voltage divider) resistor unit.

The **7XR86** has the same construction as the resistor coupling unit 7XR8004 of 1-3 Hz Rotor Ground Fault protection.

1.3 100% Stator Ground Fault Protection

The 100% stator ground fault protection is one of the high sophisticated protection functions.

This function is used for larger generators (>80MW) which justifies a higher effort for a better protection principle.

In 1989 Siemens introduced the 100% Stator Ground Fault protection **7UE22**, in so called Subsystems with printed circuit boards technology.

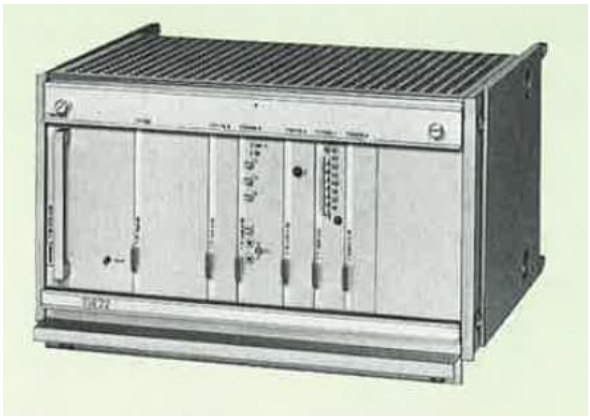


Figure 5: Mechanical Design and connection scheme of the 7UE22

Beside 20Hz generator **7XT3110-1** which generates a square-wave voltage of about 26V with maximum power consumption of <100VA**, a b**and pass filter **7XT3200-0** which filters the square-wave voltage of the 20-Hz generator (7XT33) and protects it in the event of ground faults at maximum residual voltage and voltage divider **3PP1336-1CZ/013001** to reduce the measured residual voltage (divider ratio is 5:2 or 5:1) to a grounding or neutral-point transformer an auxiliary relay was requested for testing purpose.

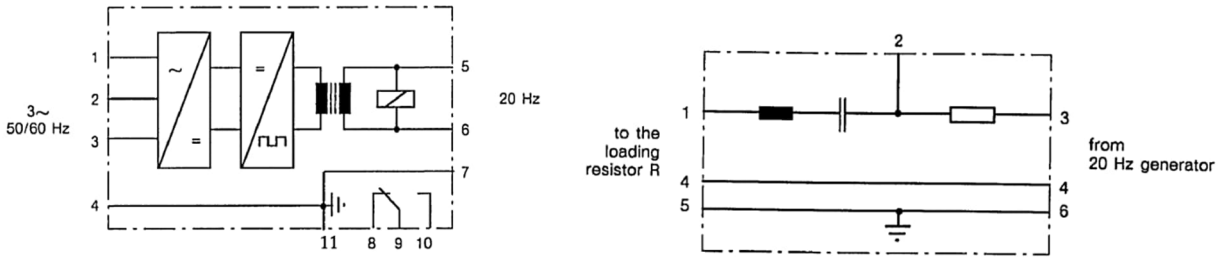


Figure 6: Schematic diagram of 7XT31 and 7XT32

At this time, there was no self-supervision function available. The picture shows the optional connection to Earthing Transformer (3phase) or Neutral Earthing Transformer.

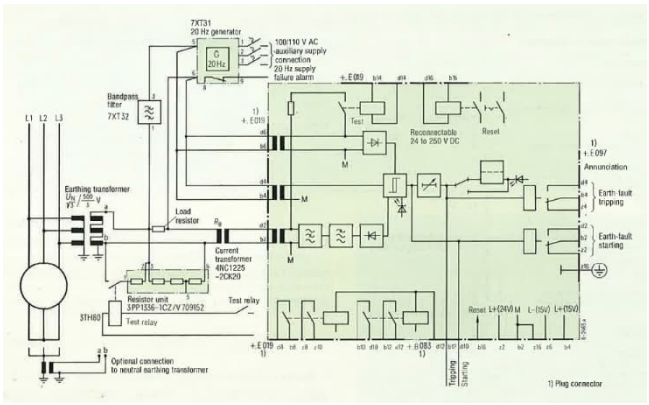


Figure 7: Connection scheme of the 7UE22

One important auxiliary device was - and is – the small current transducer which measures the current driven by the injected 20Hz voltage. For long time the **4NC5225-2CE20** (400 A/5 A), was used over short distances (burden > 5 VA).

Since this CT is no longer available, we are using nowadays the Low Voltage Current Transformer KSO 63 (400 A/5 A), 15 VA, class 0,5 of RITZ Company in Germany. The picture shows a mounting example of this CT.

Figure 8: Mechanical Design and Mounting example of Low Voltage Current Transformer KSO 63

Previous mentioned voltage divider 3PP1336-1CZ/013001 respectively 7XR86 is the same as the one used for 90% stator earth fault. In fact, SEF (stator earth fault) measuring inputs are connected to this divider. But this is explained in detail in a separate session.

Starting with the new millennium Siemens introduced the first numerical generator protection device with 100% SEF, 7UM515 (SIPROTEC V3). As you see in the connection diagram the auxiliary devices are the same. But due to the advantages of numerical technology external test equipment was no longer necessary.

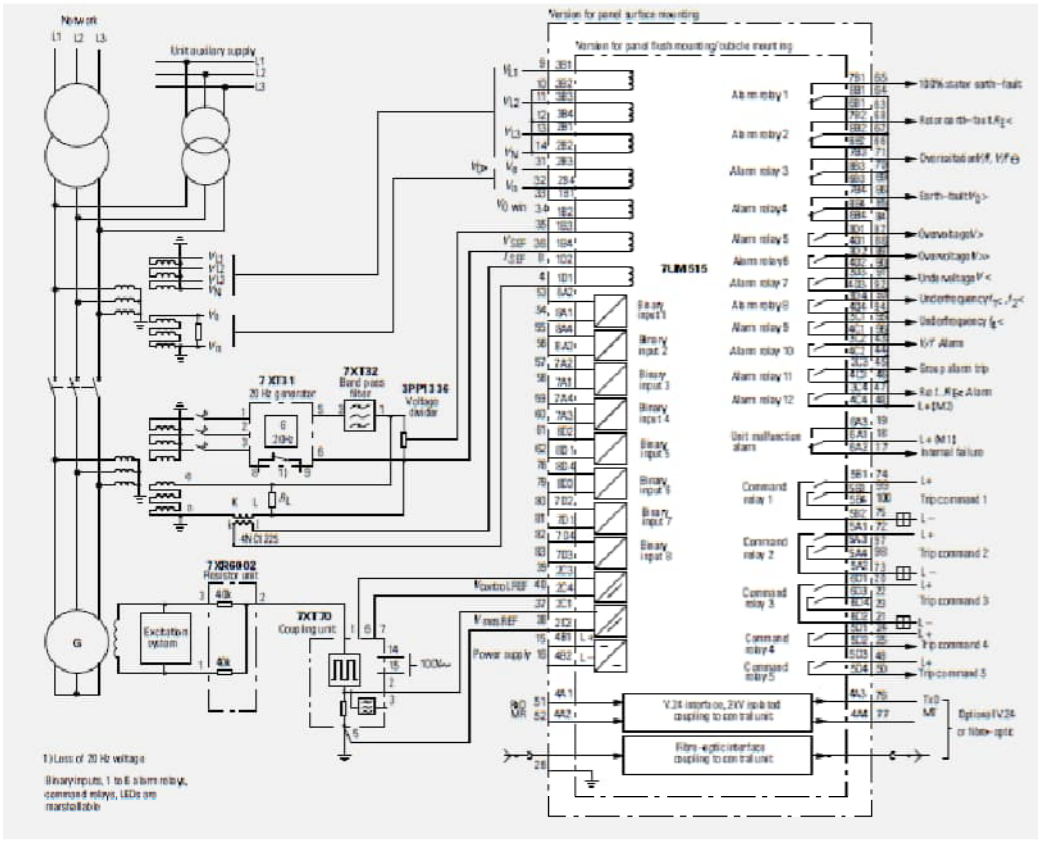


Figure 9: Schematic connection diagram SIPROTEC 3

With introduction of 7UM62 end of the 1990th – a device of SIPROTEC 4 – series there was a change in auxiliary devices. At this time, we redesigned the 20Hz generator 7XT31 to **7XT3300-0CA00** and the band pass filter 7XT32 to **7XT3400-0CA00**.

Figure 10: Mechanical Design of 7XT33

Figure 11: Mechanical Design of 7XT34

Due to change of production location the voltage divider got a new order code: 3PP1336-1CZ K2Y 013001.

Next changes came together with the SIPROTEC 5 device 7UM85.

Figure 12: Mechanical Design of 7UM85

The 20Hz generator 7XT3300-0CA00 was kept the same but the Band Pass filter 7XT3400-0CA00 was redesigned.

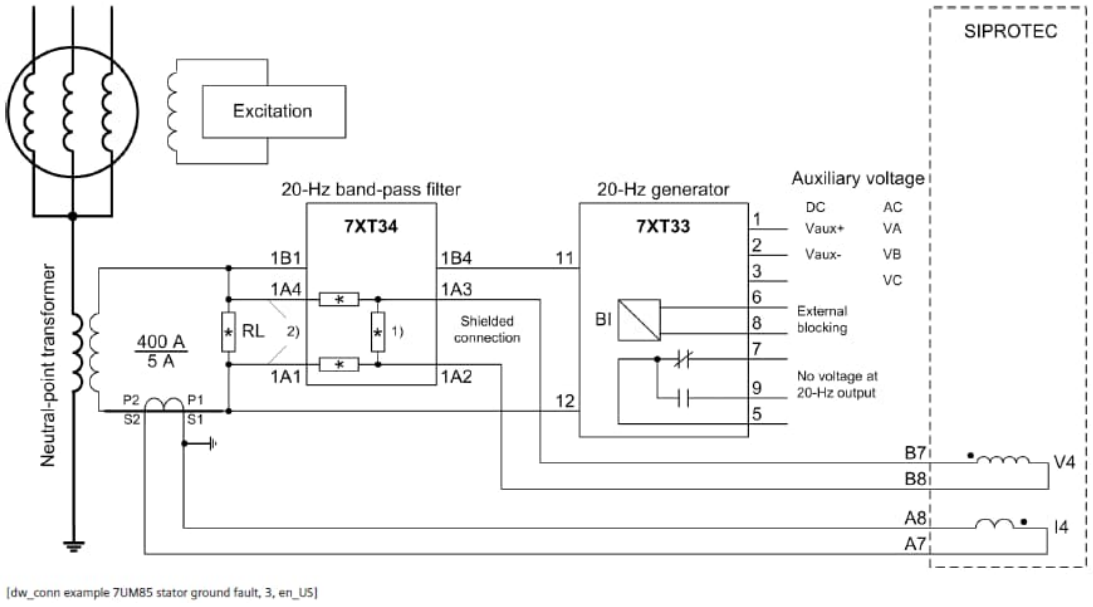


Figure 13: Schematic connection diagram of 7UM85

In addition, the new 7XT34 contains the voltage divider (divider ratio is 5:2 or 5:1) to a grounding or neutral-point transformer.

The external divider 3PP1336-1CZ is not used any more. The small CT was changed from 4NC1225 to **KSO 63** –– RITZ Co.

1.4 50Hz Rotor Ground Fault Protection

Now let us have a look to Rotor Ground Fault Protection with 50Hz voltage injection. Therefore, we're going back to 1974 where we used the RG60/RG60a, an electromechanical relay.

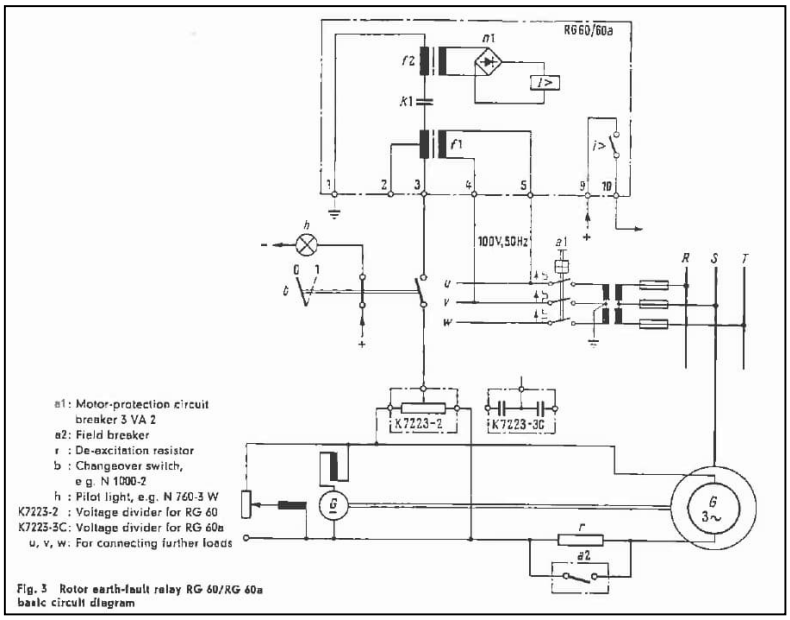


Figure 14: Schematic connection diagram of RG60/60a

At this time, we had coupling devices called: -K7223-2 resistor as voltage divider and –K7223-3C a capacitive coupling device.

In 1984 the successor of RG60 was 7UR90.

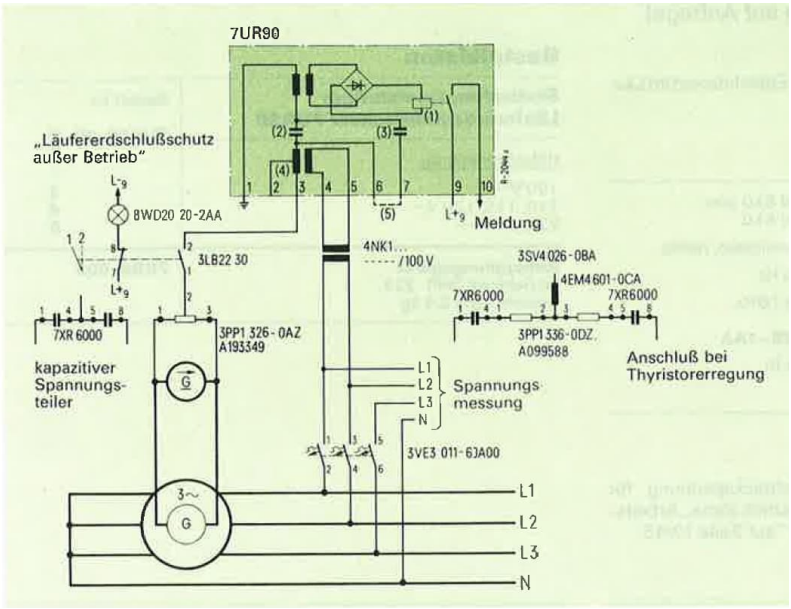


Figure 15: Schematic connection diagram of 7UR90

The related auxiliary devices were:

- 3PP1326-0AZ/A193349

- 7XR6000.

These devices replaced by 7XR8500-0 connection unit, which provided the 100V/40V transformer for the 50Hz voltage injection to the rotor winding, were also used with 7UM5112 (SIPROTEC 3) and later with 7UM62 (SIPROTEC 4).

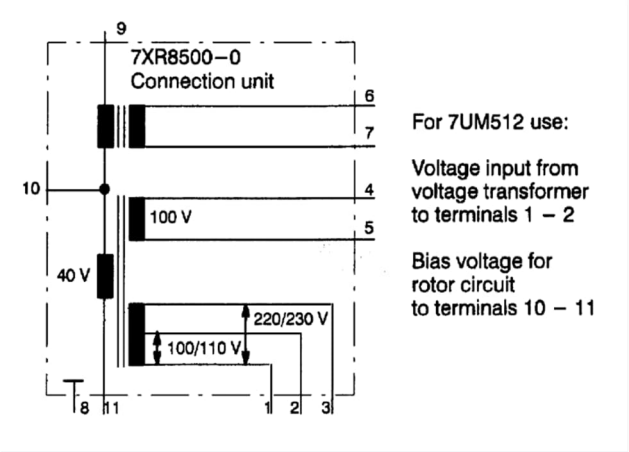


Figure 16: Schematic connection diagram of 7XR85

With 7XR6100-0*A00 we got a coupling device which includes the voltage transformer as mentioned before, 2 x 4µF capacitors and 2 x 99Ω resistors. Only for special cases the series resistor 3PP1336-0DZ-013002 is used as single auxiliary element (please check the max. current through the resistors by the AC ripples of the excitation voltage).

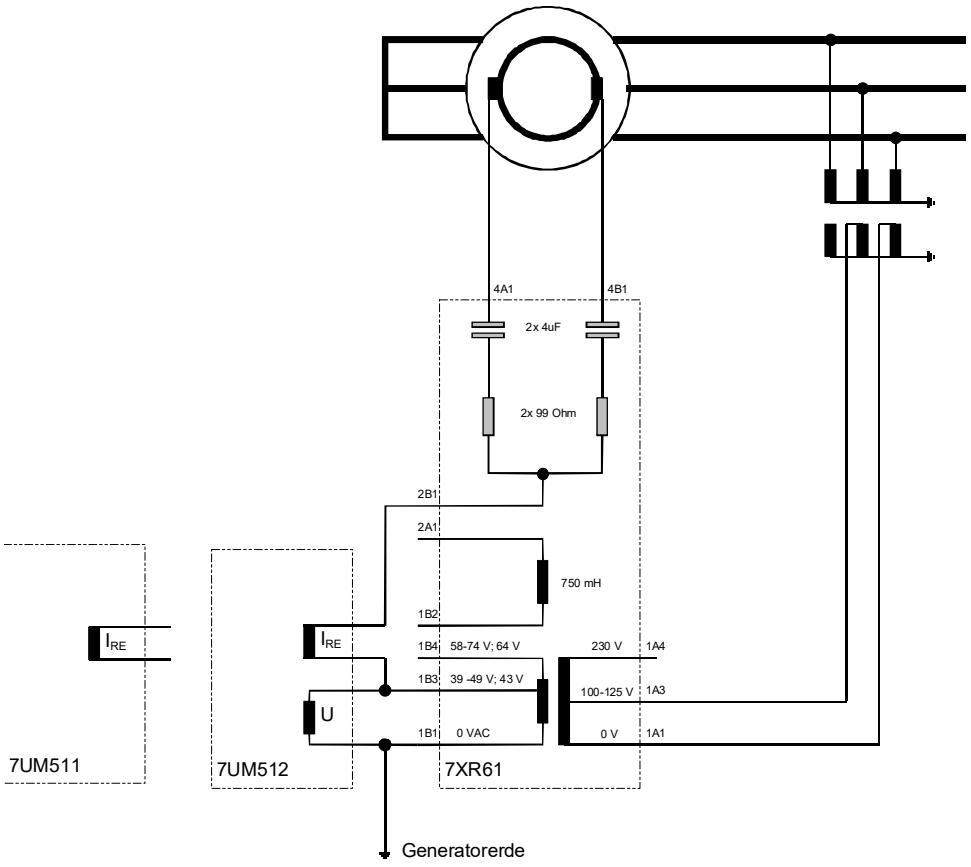


Figure 17: Schematic connection diagram of 7XR61

Only for special cases the series resistor 3PP1336-0DZ-013002 is used as single auxiliary element.

Below pictures shows two examples:

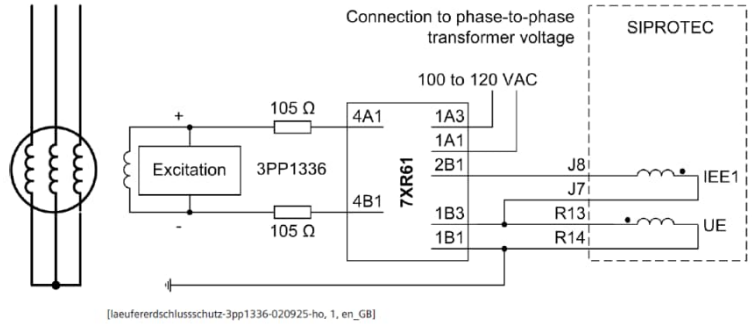


Figure 18: Schematic connection diagram of 7XR61 with 7UM62

The 7XR61 is used for injecting nominal-frequency voltage in the rotor circuit using series resistor 3PP1336. This resistor is only necessary if more than 0.2 Aeff are flowing permanently; (rule: Uexc load > 150 V). In this case the internal resistors of the 7XR61 the series device is to be shorted! The rotor earth fault protection calculates the complex earth impedance from the auxiliary AC voltage URE and the current IRE. The earth resistance RE of the excitation circuit is then calculated from the earth impedance.

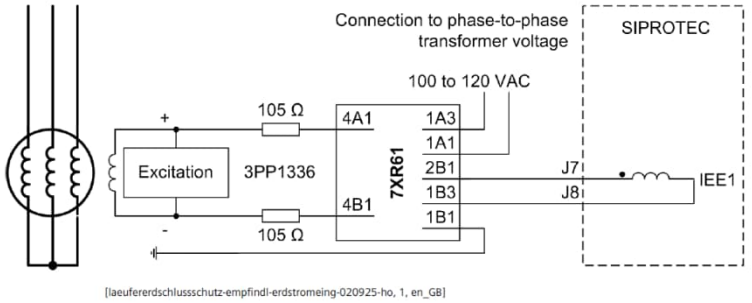


Figure 19: Schematic connection diagram of 7XR61 with sensitive ground current measurement with 7UM62

In this example series device 7XR61 is used for injection of a rated-frequency voltage into the rotor circuit if the sensitive earth current input is used. The 3PP13 is only necessary if more than 0.2 Aeff are flowing permanently; (rule: Uexc load > 150 V). In this case the internal resistors of the 7XR61 the series device are to be shorted!

The new 7XR81 coupling unit replaces the previous 7XR6100-0*A00 coupling unit and the 3PP1336-0DZ series resistor in one device.

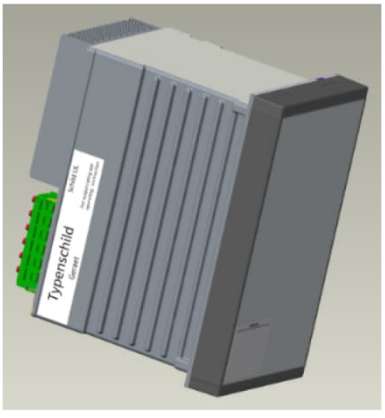


Figure 20: Mechanical design of 7XR81

It's the accessory for the rotor ground-fault protection with the 7UM62/7UM85 machine protection relays.

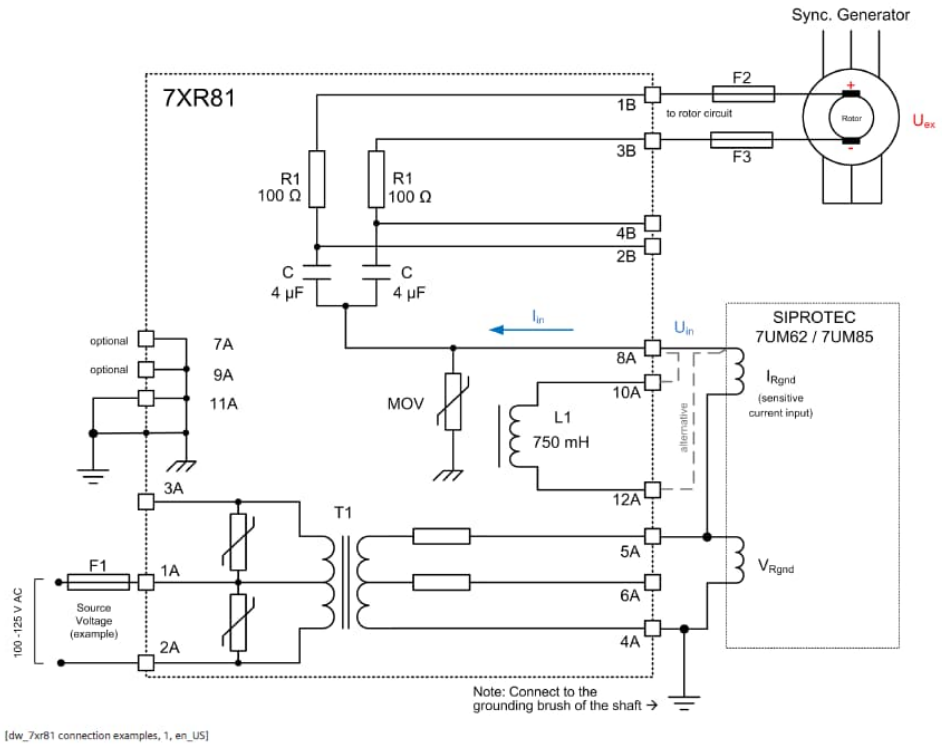


Figure 21: Connection diagram of 7XR81

The inductance L1 can be connected in series between the output 8A and the input current of the protection relay in order to reduce high ripple noise injected by some excitation regulators.

NOTE

- The fuse F1 must be rated for 250 V AC, 1 A T (time-lag).
- The fuses F2/F3 must have at least the rated voltage of excitation (e.g. 1000 V DC) and be rated for 0.6 A T (time

1.5 1 – 3 Hz Rotor Ground Fault Protection

This is the more complex Rotor Ground Fault Protection method.

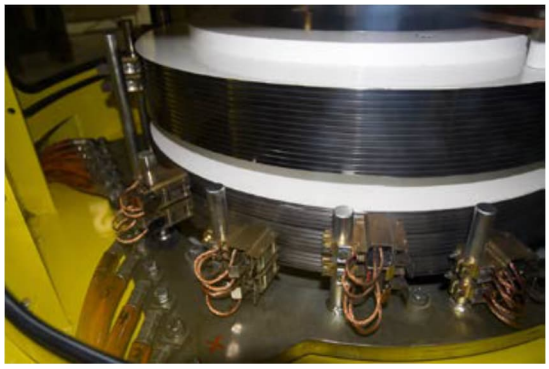


Fig. 22: Slip rings, carbon brushes

Fig. 23: Grounding brush

The function is available since we introduced 7UM515 (SIPROTEC 3).

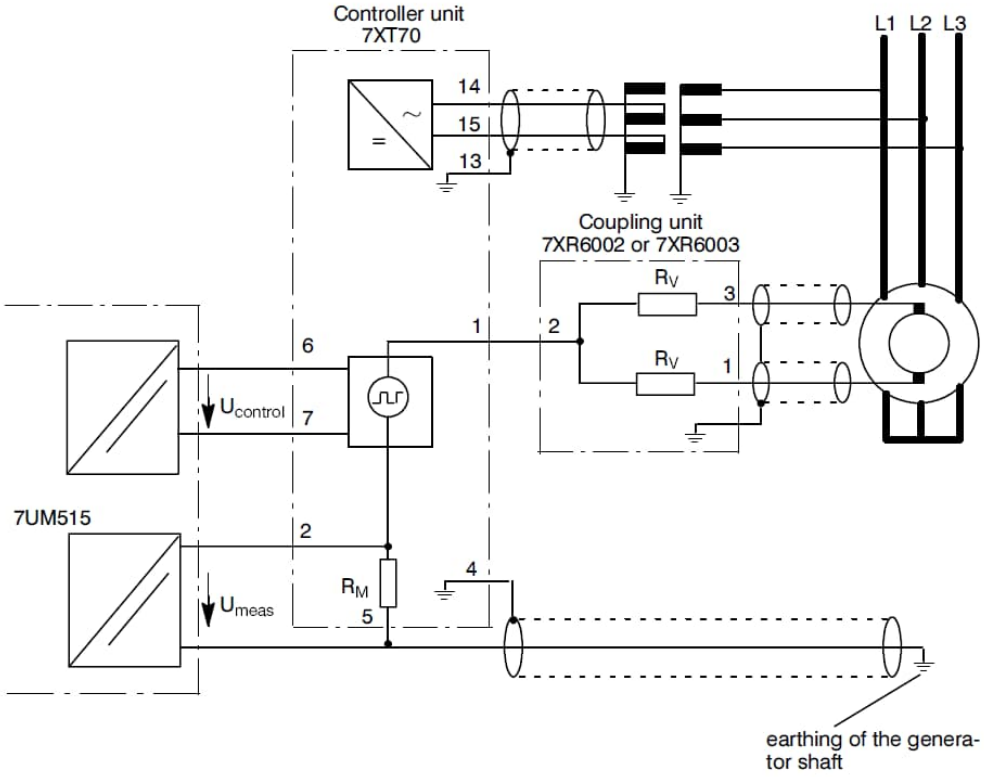


Fig.24: Connection diagram with controller unit 7XT70 and 7XR6002 or 7XR6003

Instead of rated frequency voltage we are using voltage pulses of 1 – 3 Hz.

In Figure 25 the measuring principle is briefly explained. For details, please have a look into the 7UM85 manual.

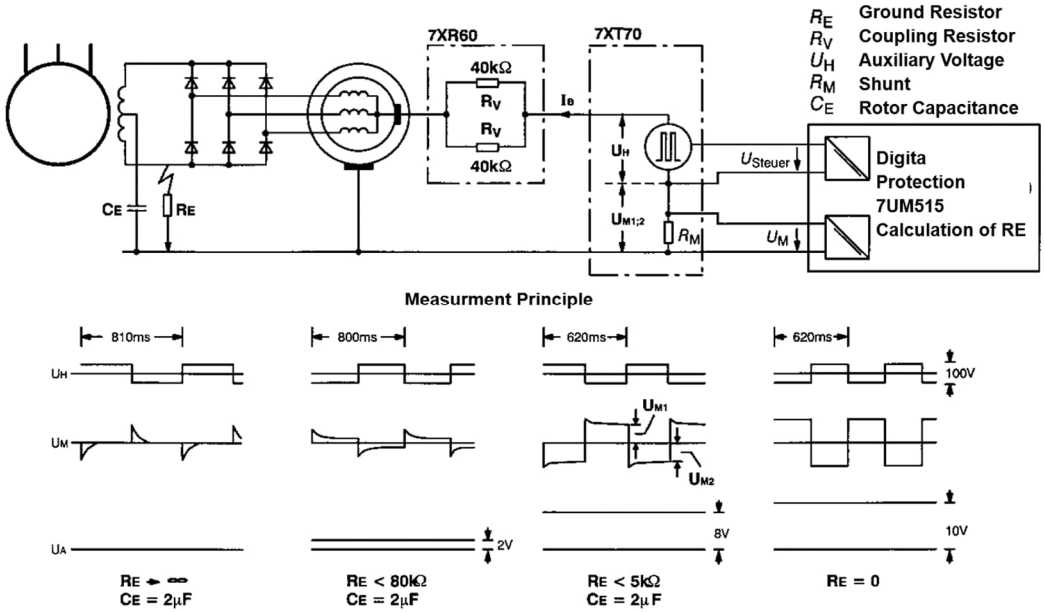


Fig.25: Connection diagram for machines with rotating rectifiers (RG-Excitation)

To connect rotor ground fault protection measuring to a machine with rotating diodes you have following possibilities:

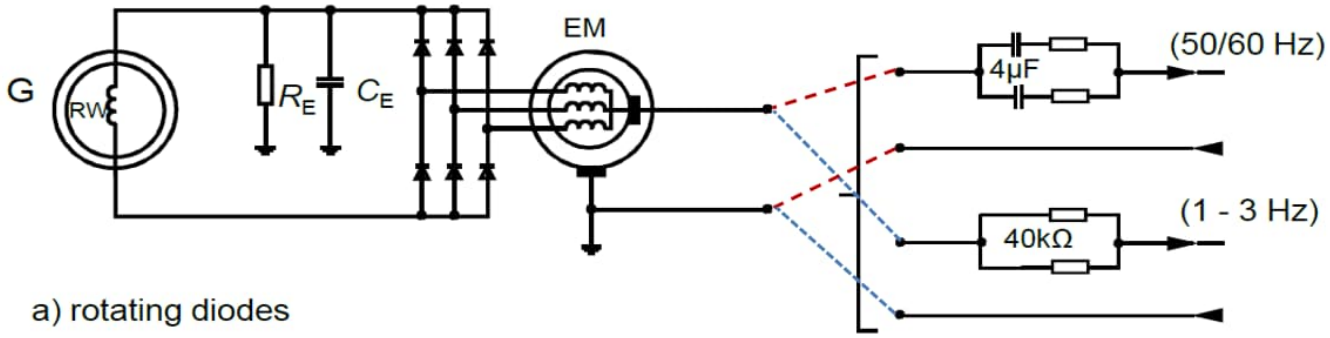


Fig. 26: Rotating Diodes

For machines with static excitation (separate exciter) you may use following connection:

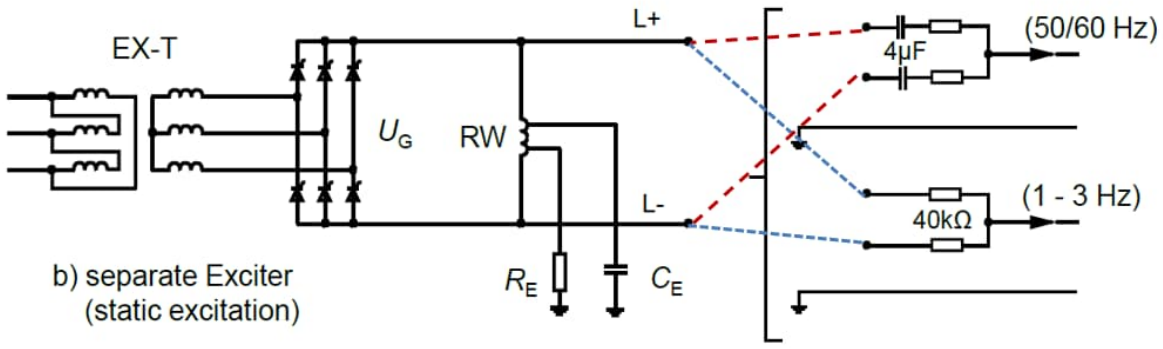


Fig. 27: Static Excitation

At the beginning the voltage was created by a controller unit 7XT7000-0B, connected to the rotor via a coupling unit 7XR6002 (7XR6003) as shown in Fig. 24.

The controller unit 7XT70 was later replaced by 7XT71 as well as the coupling devices 7XR6002 by 7XR6004 (see Fig. 28).

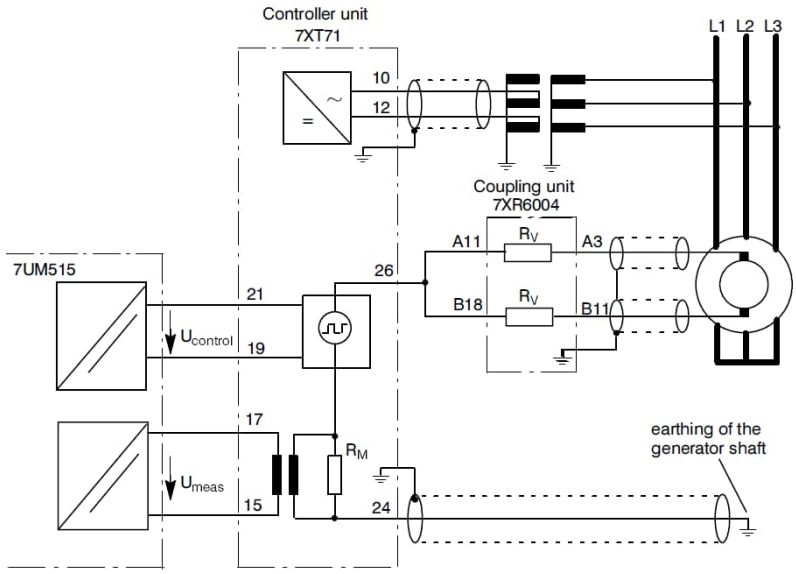
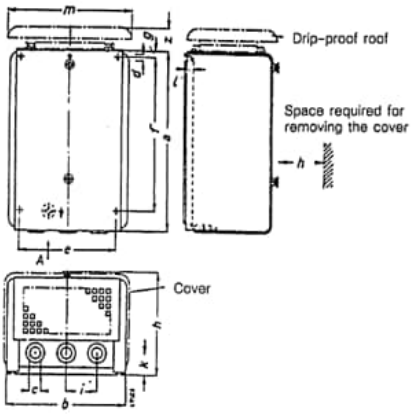


Fig.28: Connection diagram with controller unit 7XT71 and 7XR6004

Remark: Combination of **7UM515** and **7XT71** only for 7UM515 with **FW V3.11** and with 7XT71 until **HW-version /CC.**

The dimensional layout changed with the new devices.

The 7XR6002 contains 2 x 40kΩ resistors for connection to the excitation voltage circuit. It came in a 3PP133 housing with insulation voltage 4,5kV and 3PP1346 housing with insulation voltage 6kV as mentioned in the dimension drawing.



3PP1 with degree of protection IP 20 (IP 23 with drip-proof roof) Dimensions in mm

Type	a	b	c	d	e	f	g	h	i	k	l	m	z
3PP1 33	267	187	3 x 16	7	160	230	10	148	50	30	10	196	33
3PP1 34	267	237	4 x 20	7	180	230	12	198	50	32	10	--	--

Fig. 29: Dimension drawing of 3PP13 housing

Fig.30: Resistor Unit 7XR6004

Fig.:31: Controlling Unit 7XT71

Below diagram shows how the connection with these auxiliary devices looks like.

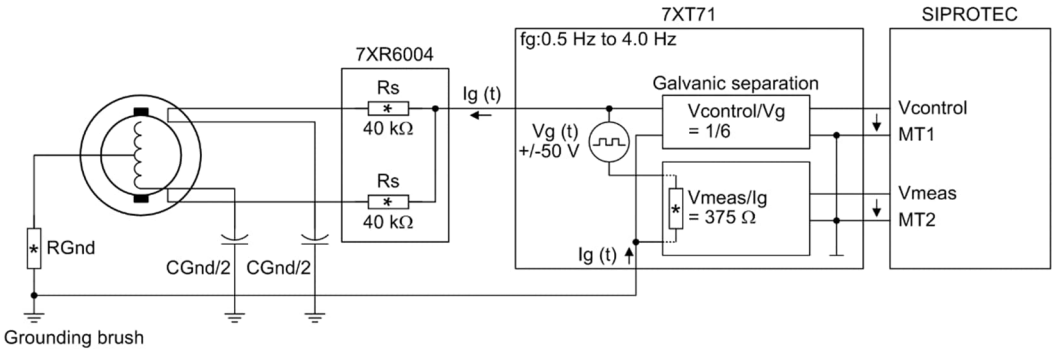


Fig. 32: Connection Diagram for 1 – 3 Hz Rotor Ground Fault

RGnd fault resistance

Vg square-wave voltage from the 7XT71

CGnd rotor ground capacitance

Ig current flowing from the 7XT71 to ground via the rotor

Today, after previous described redesign, we got a further change. The 7XR8004 resistor coupling unit replaces the previous 7XR6004-0*A00 resistor unit, allowing higher excitation voltages at a reduced size.

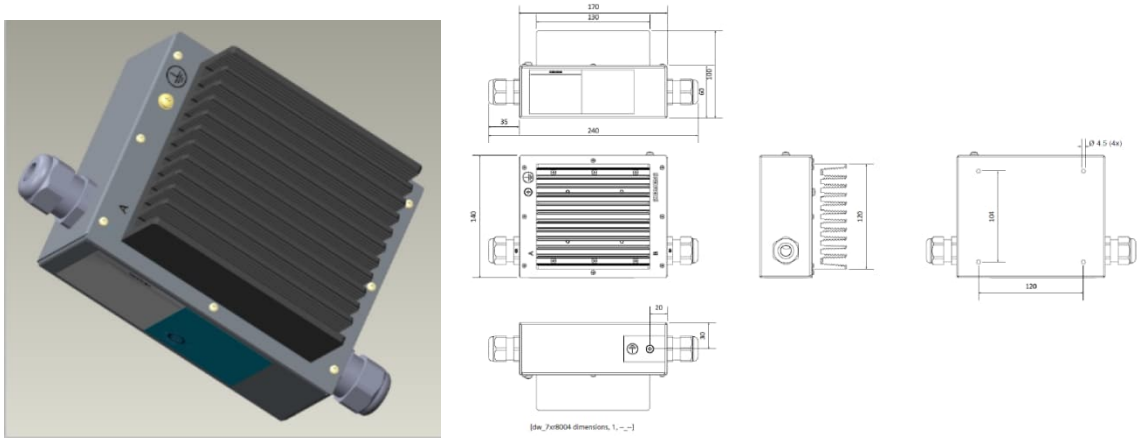


Fig. 33: Layout and Dimension of 7XR8004

It is the necessary accessory for the 1 to 3 Hz rotor ground-fault protection together with the 7XT71 (1 to 3 Hz) generator and the 7UM62/7UM85 machine protection relays.

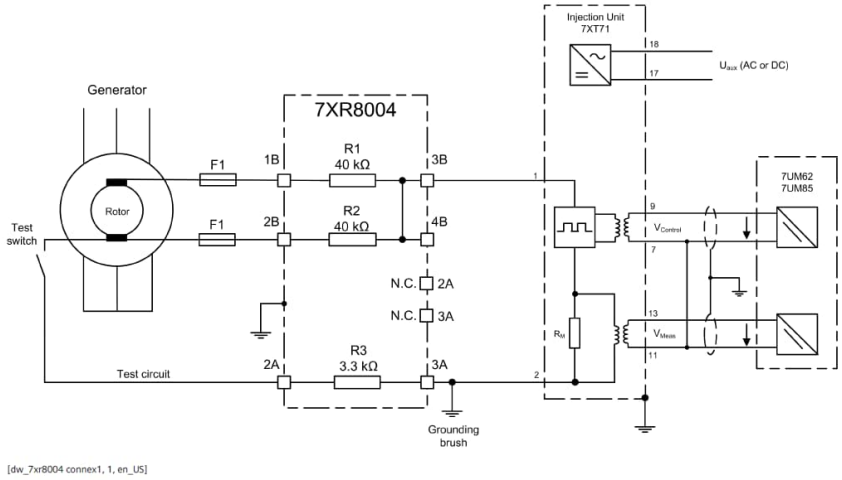


Fig. 34: Connection diagram with 7XR8004

For more details, please have a look into the catalog sheet.

1.6 Under excitation Protection

Starting with electromechanical relays from 1960th we find first coupling devices for rotor and stator earth fault protection as well as for under-excitation protection.

The 20/1 (10/1) voltage divider 3PP1326-0BZ-012009 (previously version 3PP1326-0BZ-012001-V708606) was used to connect the under-excitation protection relay input to the probably high excitation voltage in smaller housing.

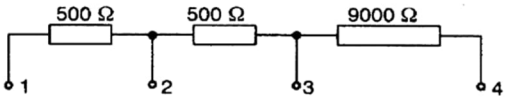
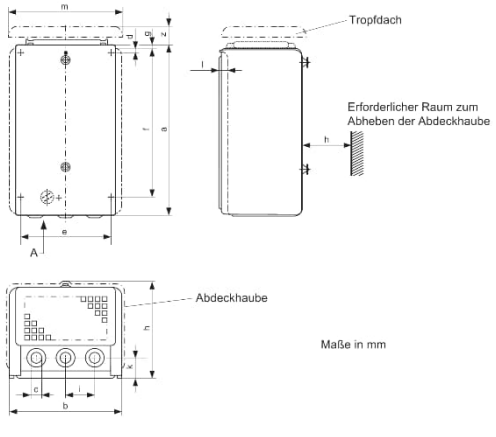


Fig. 35: Schematic of voltage divider 3PP1326-0BZ

It's part of the 3PP13-series.



3PP1 in Schutzart IP 20 (mit Tropfdach IP23)

Typ	a	b	c	d	e	f	g	h	i	k	l	m	z
3PP1 32	267	187	3 x 16	7	160	230	10	110	50	30	10	196	33
3PP1 33	267	187	3 x 16	7	160	230	10	146	50	30	10	196	33

Fig. 36: Layout and Dimension Drawing of 3PP132

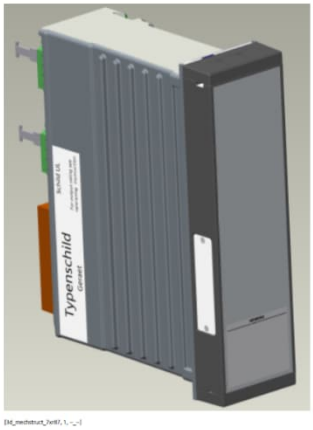
When looking to the dimensions drawings please take special attention to the different housing sizes and the required space for removing the cover and be sure not forget the short code "K2Y" when placing the order.

Since this device are almost passive elements they didn't change much over the years.

The **7XR87** replaces the 3PP1326-0BZ K2Y - 012009 voltage divider to provide additional divider ratios for higher excitation voltages.

The device provides 6 different voltage dividers ordered in 2 groups with 3 dividers each:

- Divider 1: 10:1, 20:1, and 30:1 for a maximum input voltage of 1000 V DC
- Divider 2: 40:1, 80:1, and 100:1 for a maximum input voltage of 2000 V DC.



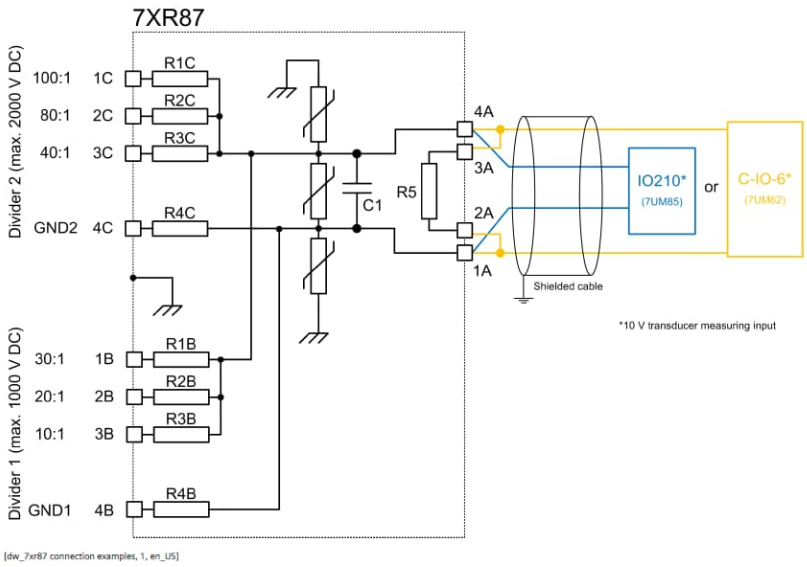


Fig. 37: Layout and Connection diagram of 7XR87

A capacitor (C1) provides, in combination with the input resistors, a low pass filter for attenuating the ripple of the excitation voltage.

The resistor R5 provides the necessary impedance adaptation for using the C-IO-6 of the SIPROTEC 4 7UM6x protection relay.

For the IO210 of the SIPROTEC 5 7UM85, do not connect the resistor R5.

7XR87 is available in panel surface and flush mounting version.

1.7 DC Ground Fault Protection

This very specific protection function will be found typically at generators driven by a gas turbine with Startup Frequency Converter.

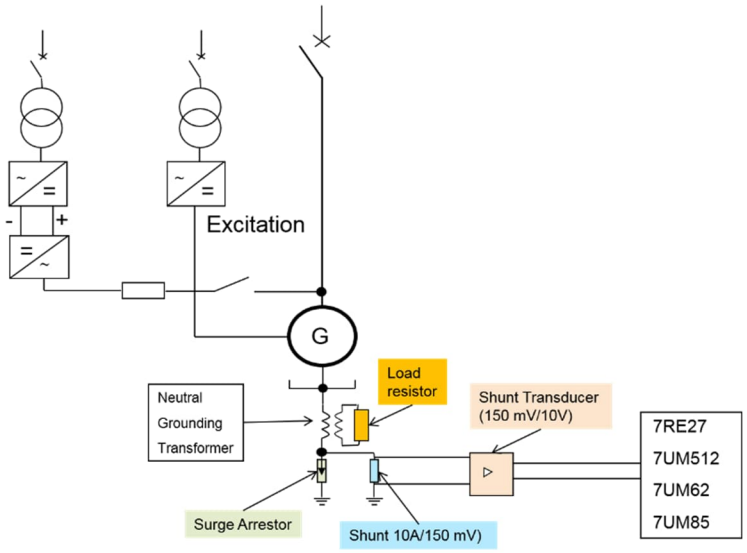


Fig. 38: Scheme of GT driven Generator with Start-up Converter

The generator/gas turbine set is run up from almost standstill by means of a starting frequency converter at appr. 10 % of rated generator voltage. At 70 % of the rated turbine speed the converter is shut off. Increasing up to 100% nominal speed and frequency is done by the turbine only.

If there is a ground fault on one pole (+ or -), a dc-current is flowing through the Vt's and the neutral grounding transformer (which are grounded). The consequences are:

- DC-magnetizing of Vt' s and NT
- Thermal stress (overheating)

An additional amplifier/transducer gains this voltage (linear characteristic: 20 mV/0.5V; 150 mV/8.7V). For protection against high voltages we need in parallel a surge arrestor. For details please have a look to the 7UM85 manual, chapter 6.33.

To connect protection measuring input to the grounding panel we are using following devices.

Auxiliary Device	Old	New
Shunt Transducer	7XR4001-4	7KG6131-1BM14
Shunt	N150	M01700-V4110 Gilgen, Müller & Weigert
Surge Arrestor	5SD7000/ 5SD7100	DEHN 961140

Fig. 39: Table of auxiliary devices for DC Ground Fault Protection

1.8 Temperatures Supervision

The Temperature supervision function checks the thermal state of:

- Motors
- Generators
- Transformers

In rotating machines, it also checks bearing temperatures for a limit violation. The temperatures are measured at various locations of the protected object using temperature sensors (RTD = Resistance Temperature Detector) and are sent to the device via one or more RTD units.

To connect temperature sensors to measuring inputs of SIPROTEC 4 protection devices like 7UM62 we used RTD box TR600 of Ziehl. The Siemens Order code was :

7XV5662-2AD10-0000 for (AC/DC 24-60V) version

or 7XV5662-5AD10-0000 for the (AC/DC 90-240V) version.

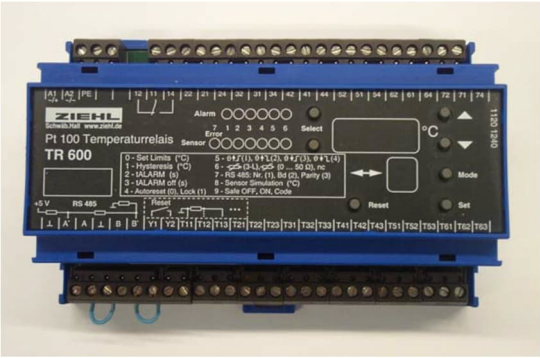


Fig. 40: RTD box 7XV5662-2AD10-0000

For connection we used cable: 7XV5103-0AA01 and 7XV5103-2AA00. And in case an auxiliary voltage for RTD box was necessary we used the Wide-range Power Supply 7XV5810-0BA00.

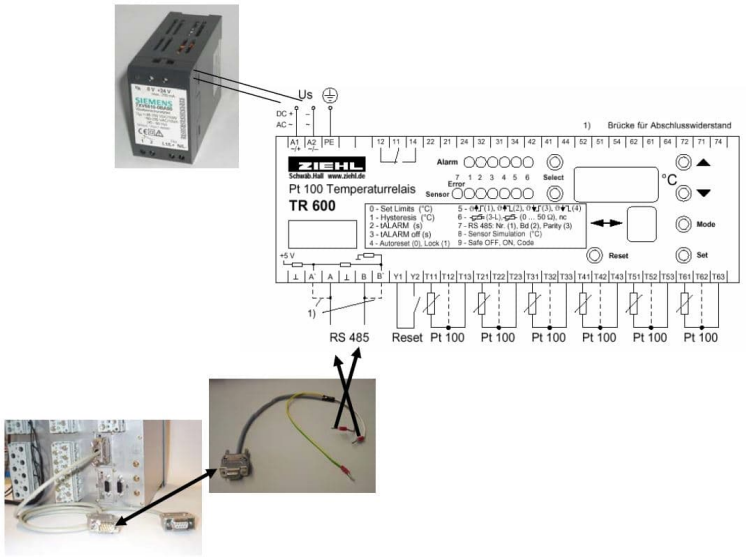


Fig. 41 Connection Example

Above mentioned RTD box Ziehl TR600 was **phased out** in the meantime.

In SIPROTEC 5 devices like 7UM85 the measured external (ambient or cold-gas) temperature can be transferred to the device via two ways:

SIPROTEC 5 has in its function group „Analog Units" communication-plug-in-modules for its „protection function groups". The function group provides RTD-Measurements by use of the Slave Unit Protocol (SUP), via Ethernet-, RS485 or FO connection of an external thermo box like the one of Ziehl. These Measurements can be used in any „ protection function groups", which have a temperature-monitoring function.

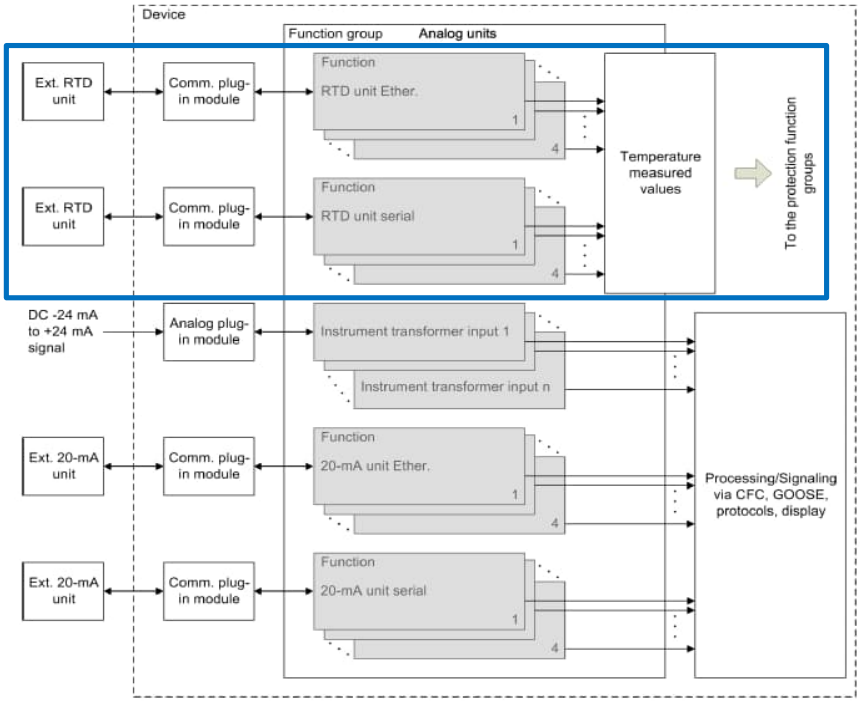


Fig. 42 Function Group Scheme

If we select serial communication with RS485-bus we are using: the thermo box 7XV5662-**6**AD10 equal to Ziehl TR1200 with 12 measurement inputs (e.g. of Pt100). This device replaces 7XV5662-2AD10/-5AD10 (Ziehl T600)

Fig. 43 RTD box Ziehl TR1200

One SIPROTEC 5-device can be connected up to 4 thermo boxes (max. 48 measurement Inputs) using RS485-Port.

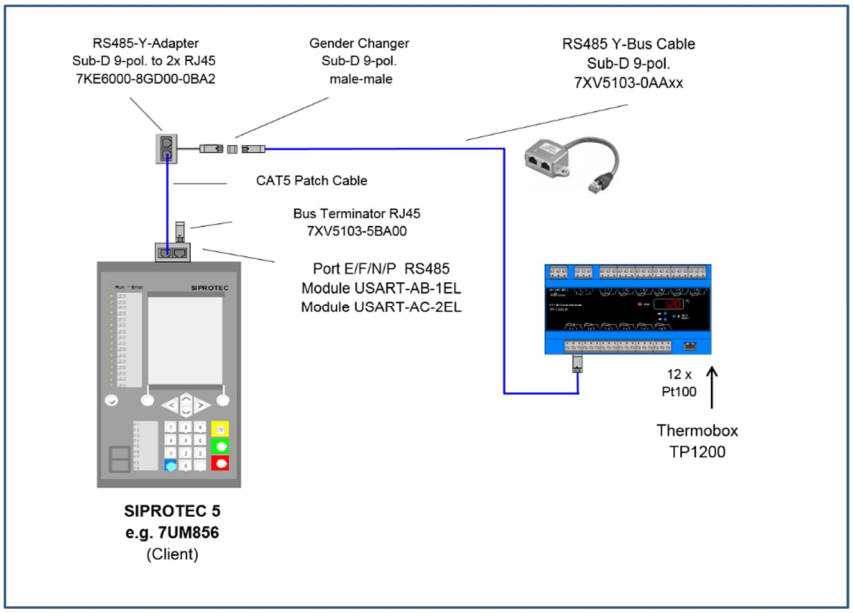
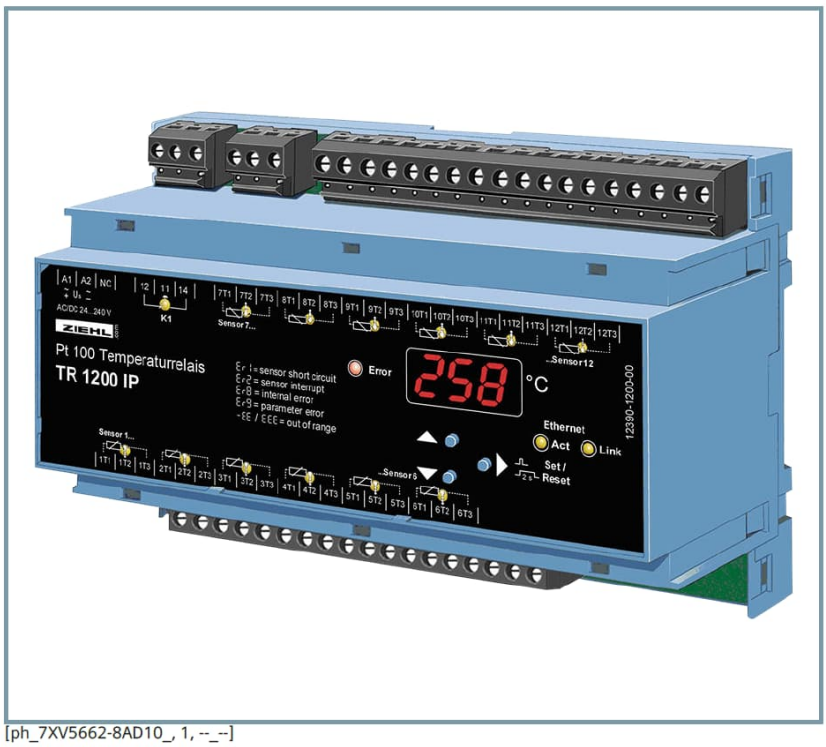


Fig. 44 Application Example (RS485, Modbus RTU / SUP)

The other way is the electrical Ethernet: For this way we are using the thermo box 7XV5662-**8**AD10 equal to Ziehl TR1200IP.



[ph_7XV5662-8AD10_, 1, --_--]

Fig. 45 RTD box Ziehl TR1200IP

This device replaces 7XV5662-2AD10/-5AD10 (Ziehl T600). One SIPROTEC 5-device can be connected to 4 thermo boxes (max. 48 measurement Inputs) using Ethernet-Port.

Please note: the 7XV5662-7AD10 with 6/8 temperature inputs cannot used together with SIPROTEC 5 relays.

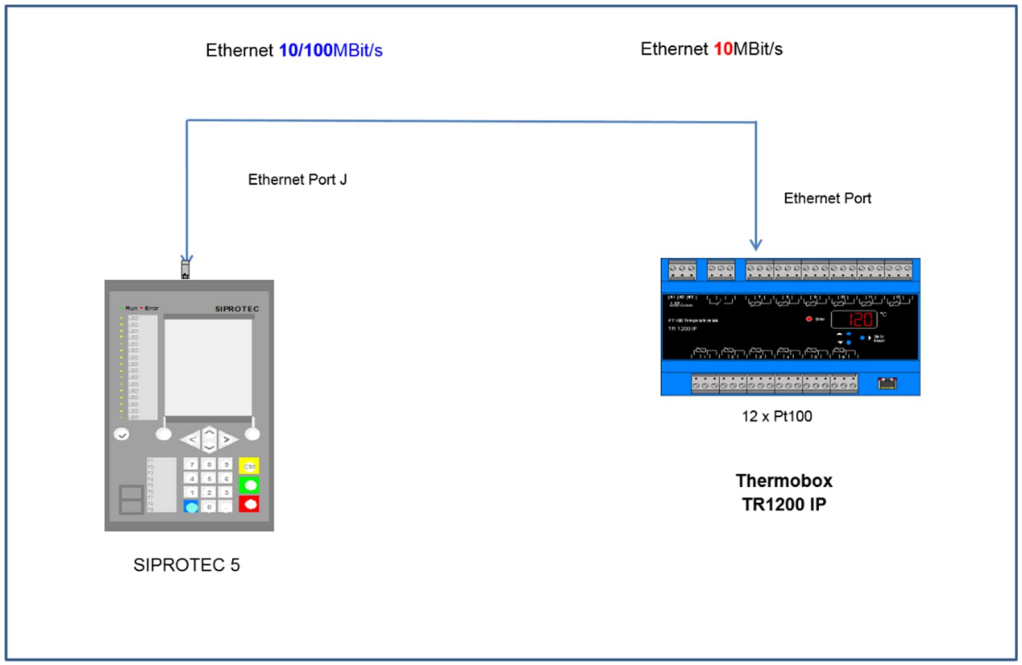


Fig. 46 Application Example via Ethernet an SIPROTEC 5 Port J

The RTD box Ziehl TR1200 IP supports Ethernet connection of 10 MBit/s. If you like to connect it to a 100-Mbit communication module you need a 10/100 MBit/s autosensing switch which automatically adapts the transmission rates.

Ethernet Port J of SIP5 is able to run 10 or 100 Mbit, all other Ethernet modules support only 100MBit.

For more details and back ground information, please use our intranet download area.

You will reach it with one of following links.

7XV5662-6AD10 (TR1200)

https://w3.siemens.com/smartgrid/global/en/products-systems-solutions/Protection/accessories/temperature-detection/Pages/7XV5662-6AD10.aspx

7XV5662-8AD10 (TR1200 IP)

https://w3.siemens.com/smartgrid/global/en/products-systems-solutions/Protection/accessories/temperature-detection/Pages/7XV5662-8AD10.aspx

SIPROTEC Accessories Communication and Test Equipment

https://wse06.siemens.com/content/P0009268/SitePages/SIPROTEC%20Accessories%20Communication%20and%20Test%20Equipment.aspx

SIPROTEC 5

https://w3.siemens.com/smartgrid/global/en/products-systems-solutions/Protection/siprotec5/Pages/overview.aspx

1.9 Shaft Current Protection

A special transformer detects the current entering the shaft. It is a window type transformer that is mounted around the shaft. Below figure shows the basic connection of the shaft-current protection function. The shaft-current transformer is then connected to a sensitive current transformer of the protection device. If the shaft current exceeds a certain value, the generator is shut down.

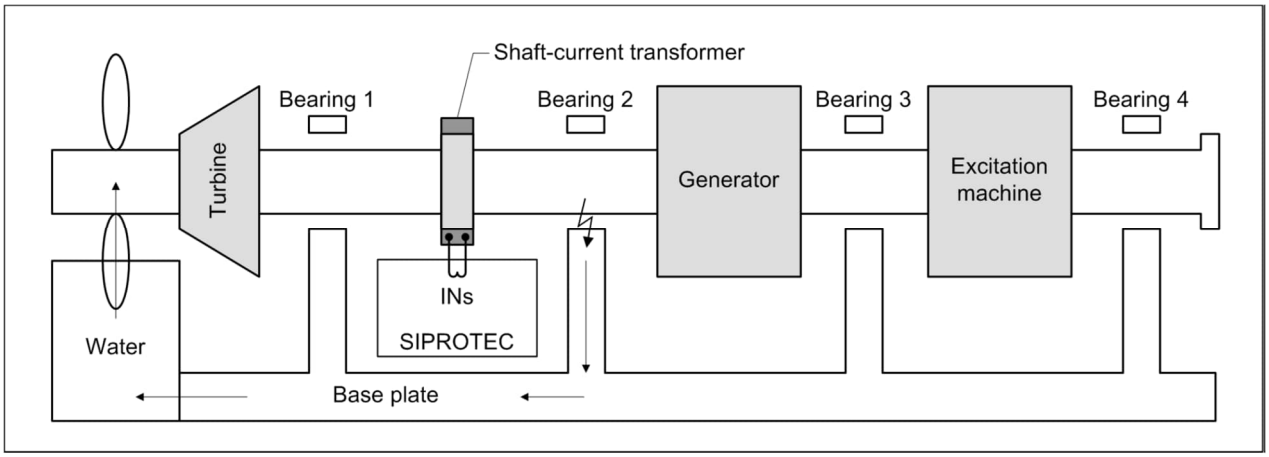


Fig. 41: Connection of the Shaft-Current Transformer (Possible Current Flow in the Event of a Fault)

Purchase the shaft-current transformer from a transformer manufacturer or use the existing shaft-current transformer when replacing the protection.

For more details, please have a look to the 7UM85 manual.

The diameter of the transformer depends on the shaft diameter and can be up to 2 m. The number of the secondary-winding turns varies slightly with the diameter. The transformer is available with turns from 400 to 1000. The transformers with fewer turns (for example, 600 turns) can be used to provide a sufficiently high measuring current. The shaft-current transformers also have a test winding with usually 4 turns. The test winding allows injecting a test current to check the entire circuit. Figure 6-452 shows an example of the terminals S1 - S2: measurement terminal (400 turns) and A - B: test terminal (4 turns).

To preserve the flexibility of the application, different methods of measurement are available for processing the shaft current.

The setting of the protection determines the value of the method of measurement.

1.10 Summary

In conjunction to all development steps of protection devices - from electro mechanical relays to the latest SIPROTEC 5 devices – also auxiliary devices have been subject to several changes.

Some of these auxiliary devices are still in place and operation even after a long-life time.

The following table gives you an overview of the compatibility of different generations of Generator Protection Devices and old and state of the art Auxiliary Equipment.

	Protection										
Protection Function	Auxiliary Device		7RE26/7RE66	7RE27	7UE22	7UM511	7UM512	7UM515	7UM61	7UM62	7UM85
	New	Old									
Rotor Earth Fault 50Hz		7XR8500-0				x	x				
		7XR6000				x	x				
		7XR6100-0BA00							x	x	
		7XR6100-0CA00							x	x	
	7XR8100-0BA00								x	x	x
	7XR8100-0CA00								x	x	x
	3PP1336-0DZ-K2Y-013002						x		x	x	x
Rotor Earth Fault 1-3Hz		7XT7000-0B						x		x	
	7XT7100-0BA00							(x)*		x	x
	7XT7100-0EA00							(x)*		x	x
		7XR6002						x			
		7XR6003						x			
		7XR6004-0BA00						x		x	x
		7XR6004-0CA00						x		x	x
	7XR8004-0BA00							x		x	x
Stator Earth Fault 80-100%		3PP1336-1CZ1V709152	x		x		x	x	x	x	x
		3PP1336-1CZ-K2Y-013001	x		x		x	x	x	x	x
	7XR8600-0BA00								x	x	x
Stator Earth Fault 100%		7XT3110-1			x			x			
	7XT3300-0BA00									x	x
	7XT3300-0CA00									x	x
		7XT3200-0			x			x			
	7XT3400-0BA00									x	x
	7XT3400-0CA00									x	x
		4NC1225-3CK20			x			x			
	KSO-63									x	x
Start up Earth Fault	3PP1356-0GZ K2Y 015028							x		x	x
	3PP1326-0BZ K2Y 012014							x		x	x
DC Earth Fault		5SD7000		x			x				
		5SD7001		x			x				
	DEHN 961140			x			x			x	x
	M01700-V4110, Gilgen, Müller & Weigert	M150		x			x			x	x
		7XR4000-3 7XR4000-4		x			x				
		7XR4500-3 7XR4500-4		x			x				
		7XR4001-3 (old)					x			x	x
		7XR4001-4 (old)					x			x	x
	7KG6131-1BM14						x			x	x
Under excitation		3PP1326-0BZ K2Y 012009				x				x	x
	7XR8700-0BA00									x	x
	7XR8700-0CA00										
Motor Thermal Overload	7XV5662-2AD10								x	x	
	7XV5662-5AD10										

Fig. 42: Compatibility Matrix of Auxiliary Devices for SIEMENS Generator Protection

*: combination of 7UM515 and 7XT71: 7UM515 only with FW version V3.11. 7XT71: only until HW version /CC

Published by Siemens AG

Smart Infrastructure
Electrification & Automation
Mozartstraße 31c
91052 Erlangen, Germany

For the U.S. published by

Siemens Industry Inc.
100 Technology Drive
Alpharetta, GA 30005
United States

www.siemens.com/siprotec

For more information, please contact our Customer Support Center.

Tel.: +49 911 2155 4466

Customer Support: www.siemens.com/csc