Doepke

RESIDUAL CURRENTS IN PHOTOVOLTAIC INSTALLATIONS

and appropriate protective measures

Doepke Schaltgeräte GmbH, Norden

Stefan Davids
Sales Promotion Manager

Günter Grünebast
Manager of Standardisation/Test Laboratory/Certification

Version 1.1






Brief Introduction

Doepke Schaltgeräte GmbH, Norden

- Proprietor- led, medium-sized company
- High in-house production rate
- Manufactured in Germany
- High flexibility in the production of individual solutions
- Extensive programme in the RCD sector

Overview

1. Definition RCD / RCM
2. Definition Type A /Type B
3. What is an RCMU?
4. Residual current protection at the DC side of a PV installation
5. Residual current protection at the AC side of a PV installation
6. Practical example: Faults at the DC side of a PV installation
7. Which residual currents may arise?
8. Using RCDs in PV installations

Definition: RCD / RCM

RCD
(Residual Current Device)

- **RCCB**
- **RCBO**
- **CBR**
- **MRCD**

RCM
(Residual Current Monitor)

» RCCB

- » **Residual Current Operated Circuit Breaker conforming to DIN EN 61008-1 / VDE 0664-10 and -100**
- » **Suitable as protective measure for safeguarding by means of automatic disconnection of the power supply (disconnection characteristic)**
- » **Example: DFS 4 B**

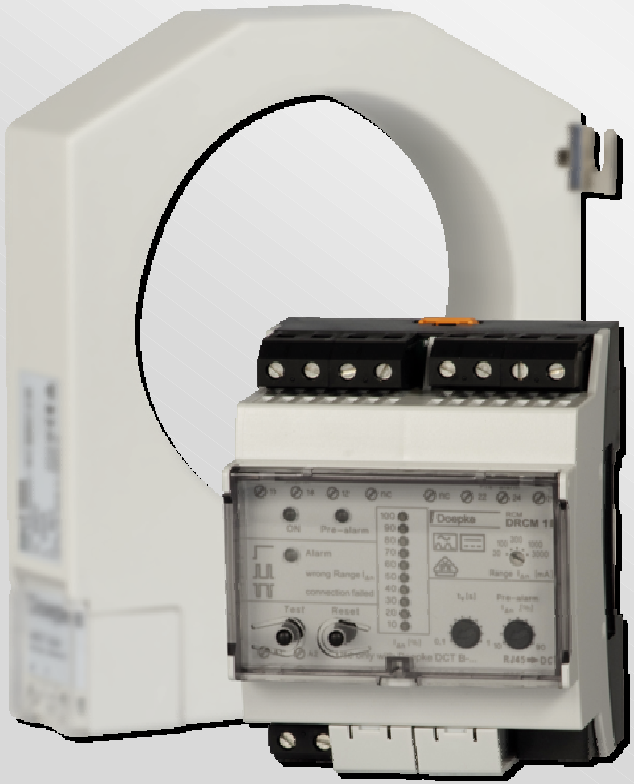
Definition: RCD / RCM

RCD
(Residual Current Device)

- RCCB
- RCBO
- CBR
- MRCD

RCM
(Residual Current Monitor)

- RCM



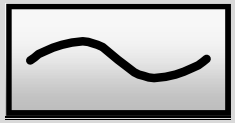
- **RCM**
  - **Residual Current Monitor conforming to DIN EN 62020 / VDE 0663**
  - **not suitable as protective measure for safeguarding by means of automatic disconnection of the power supply**
  - **Example: DRCM 1 A**

Definition: Type AC / Type A / Type B

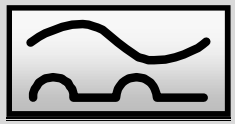
Type AC: Detecting AC residual currents of mains frequency
(not permissible in Germany)

Type A: Detecting AC residual currents and pulsating DC residual currents of mains frequency

Type B: Detecting AC residual currents and pulsating DC residual currents of mains frequency, as well as smooth DC residual currents and AC residual currents ≠ mains frequency



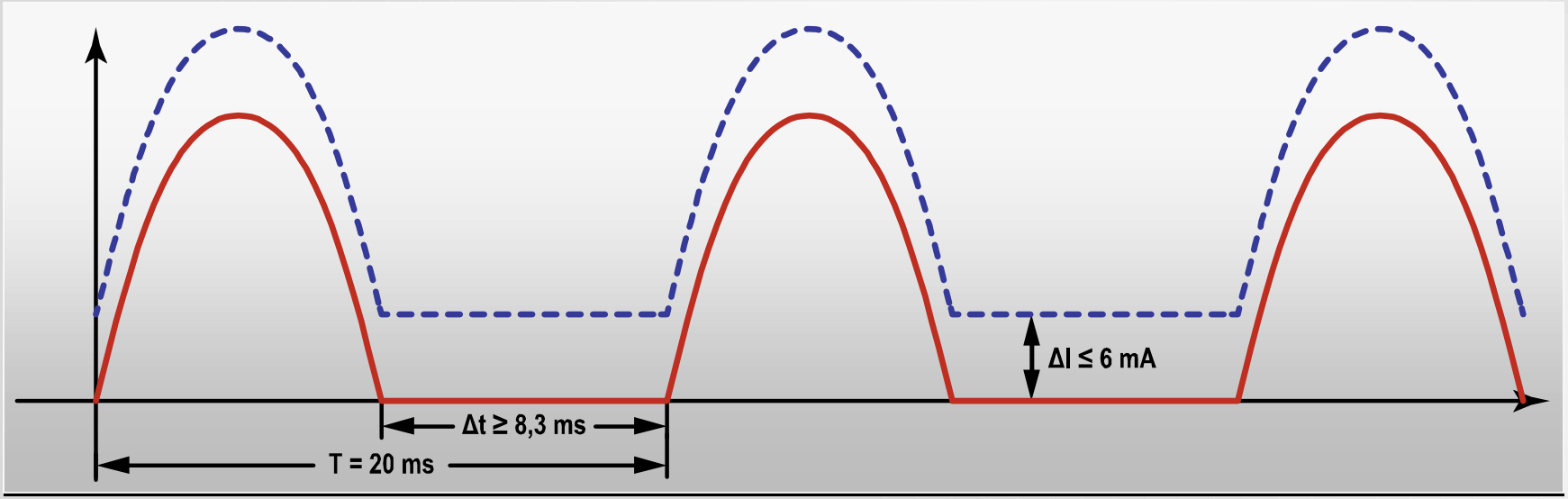
Type AC



Type A

Type B

Definition: “pulsating DC residual currents” (Type A)



IEC 60755:

Residual current must have at least 8.3 ms of zero contact (mains frequency f = 50 Hz)

Up to max. 6 mA superimposed smooth DC residual current is permissible (irrespective of the residual current rating)

DEUTSCHE NORM

DIN VDE 0100-530
(VDE 0100-530)

DIN

Diese Norm ist zugleich eine VDE-Bestimmung im Sinne von VDE 0022. Sie ist nach Durchführung des vom VDE-Präsidium beschlossenen Genehmigungsverfahrens unter der oben angeführten Nummer in das VDE-Vorschriftenwerk aufgenommen und in der „etz Elektrotechnik + Automation" bekannt gegeben worden.

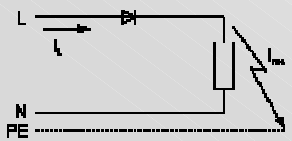
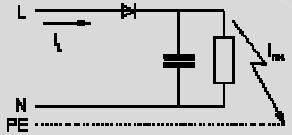
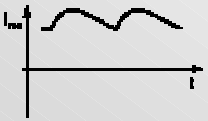
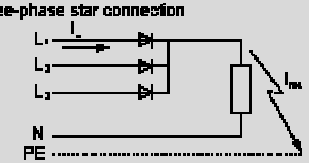
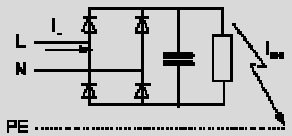
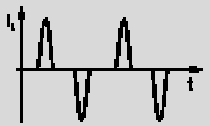
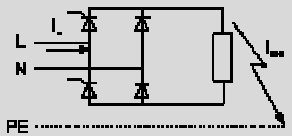
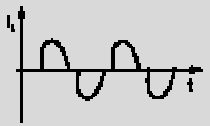
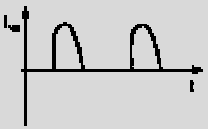
VDE

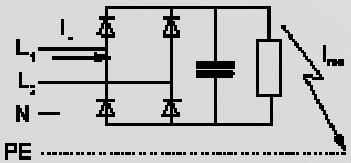
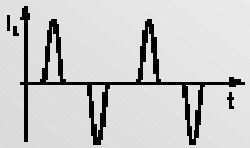
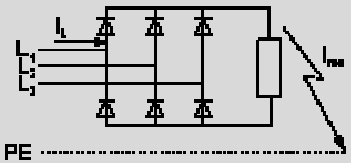
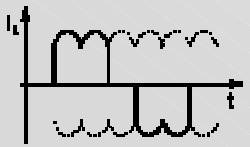
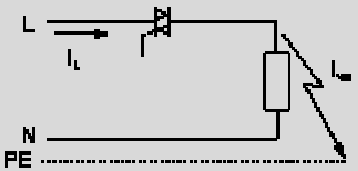
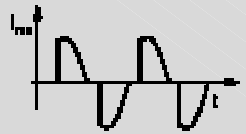
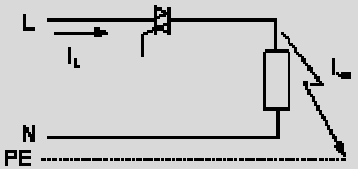
Errichten von Niederspannungsanlagen
Teil 530: Auswahl und Errichtung elektrischer Betriebsmittel –
Schalt- und Steuergeräte

Erection of low voltage installations –
Part 530: Selection and erection of electrical equipment –

VDE 0100-530: General conditions for the selection and installation of residual current devices (RCDs)

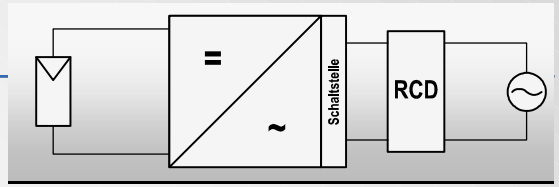
"If components of electrical equipment that are being installed as fixtures at the load side of a residual current device (RCD) could generate pure DC residual currents, then the residual current protective device (RCD) must be of Type B"

Line	basic circuit with fault location	Shape of the load current	Shape of the residual current	Fit Res. current		
				~	⩘	⩘
1	S ngle phase 				●	●
2	S ngle phase with smoothing 					●
3	Three-phase star connection 					●
4	Full briege circu t 				●	●
5	Full briege circu t, semi-controlled 				●	●

Line	Basic circuit with fault location	Shape of the load current	Shape of the residual current	Fit/Res. current		
				~	⩘	⩘
6	Full bridge between outer phases 					●
7	Three-phase full bridge circuit 					●
8	Phase-angle control 			●	●	●
9	Burst control 			●	●	●

Source: E DIN VDE 0100-530; Appendix B

Block diagram - PV installation



PV-Generator

Wechselrichter
Inverter

Überstrom-
schutzeinrichtung
Overload protective device

PV+

PV-

=

~

Schaltstelle

RCD

L

N

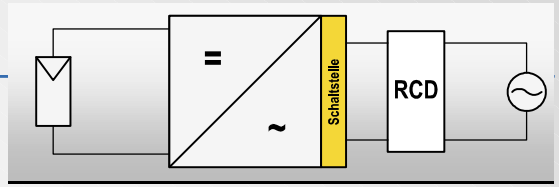
R_{Erde}

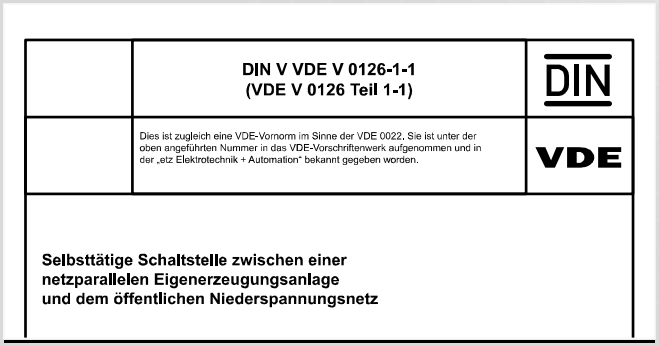
parasitäre Kapazitäten
des PV-Generators

Parasitic capacitances of
the PV generator

Doepke

Residual current protection at the DC side





DIN V VDE V 0126-1-1
(VDE V 0126 Teil 1-1)

DIN

Dies ist zugleich eine VDE-Vornorm im Sinne der VDE 0022. Sie ist unter der oben angeführten Nummer in das VDE-Vorschriftenwerk aufgenommen und in der „etz Elektrotechnik + Automation" bekannt gegeben worden.

VDE

Selbsttätige Schaltstelle zwischen einer netzparallelen Eigenerzeugungsanlage und dem öffentlichen Niederspannungsnetz

VDE V 0126-1-1:

»**Automatic switching point** between an own-energy generating installation and low-voltage net

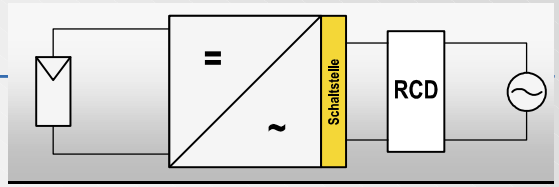
»Also known as **ENS** (facility for system monitoring with respective switching facility, in line)

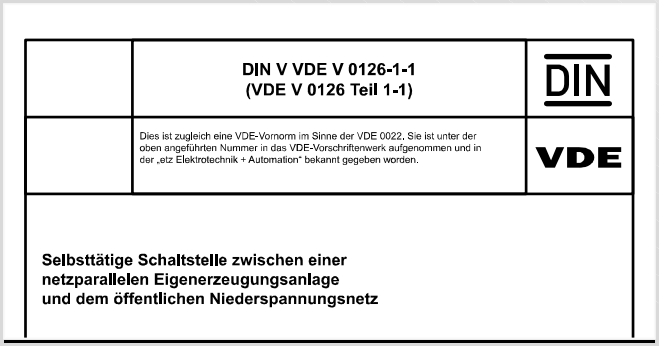
»It monitors mains voltage, mains frequency, DC input and prevents unwanted island net operation.

»Predominantly integrated in inverter

»Switching facilities for switching (relay) are integrated in the Inverter, but are not as a rule suitable for disconnection (no 4 mm creepage and air paths)

Residual current protection at the DC side





DIN V VDE V 0126-1-1
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VDE

Selbsttätige Schaltstelle zwischen einer netzparallelen Eigenerzeugungsanlage und dem öffentlichen Niederspannungsnetz

VDE V 0126-1-1:

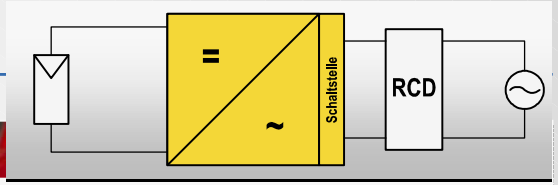
»Despite all the standards-based requirements in respect of basic protection and fault protection (double insulation of PV cables) there have been a number of accidents due to faults at the DC side (PV generator).

»Upon the recommendation of the professional body ETEM, in order to cover for faults at the DC side (protection of persons) a residual current monitoring unit has to be integrated when operating PV installations featuring an inverter without transformer:

RCMU (**R**esidual **C**urrent **M**onitoring **U**nit).

»The RCMU is a component of the automatic switching point (ENS)

»If no RCMU is integrated, then an external Type B RCD is required at the AC side of the PV inverter.



trafoloser Wechselrichter

Rectifier without transformer

DC input

Intermediate capacitors

RCMU board

PV+

PV-

Transistor full bridge

Chokes

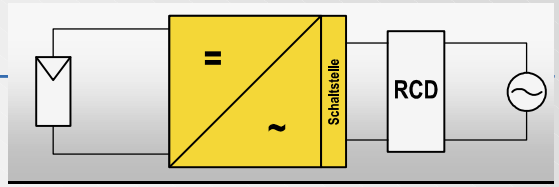
Steuerung

Control

Relays

Doepke

Residual current protection at the DC side



- Due to the parasitic capacitances of the PV modules (metal frames) to earth a high leakage current (capacitive AC residual current) is to be expected.
- Leakage current is not constant; it changes gradually, but markedly, during the day, as a result of e.g. dew precipitation.
- Due to high leakage currents it is therefore only possible under certain conditions to use a Type B RCD with IΔ = 30 mA only at the AC side of a non-transformer equipped inverter in order to provide the protection at the DC side as specified in VDE V 0126-1-1
- Hence integration of an RCMU in the automatic switching point.

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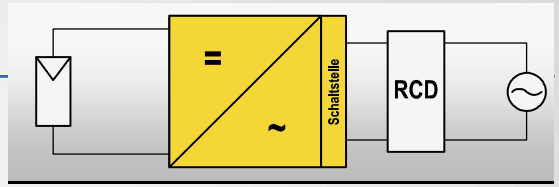
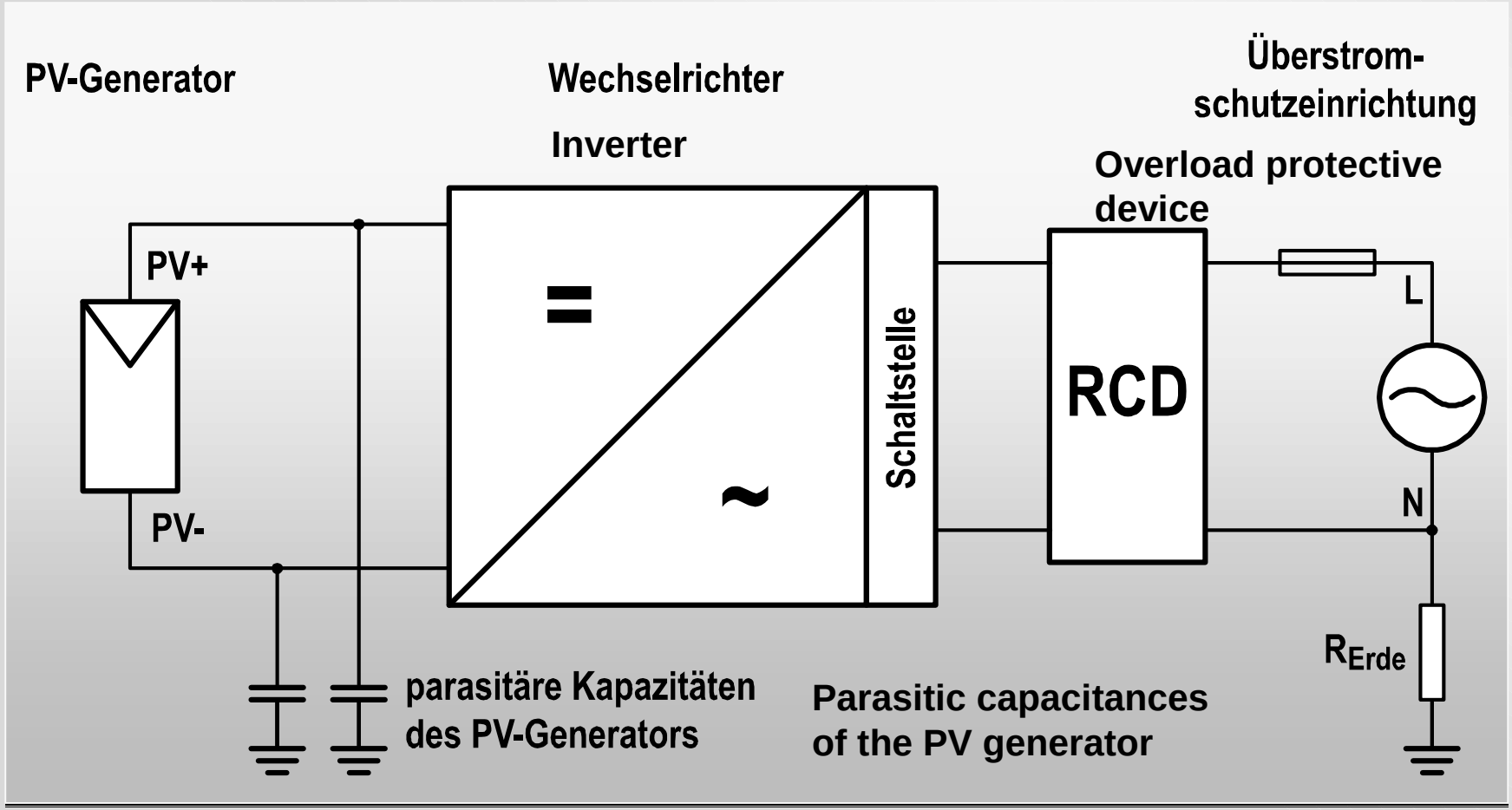
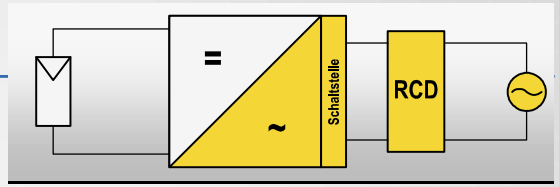
Residual current protection at the DC side

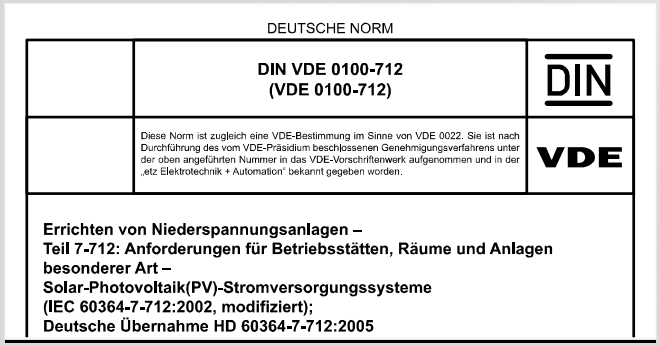


- RCMUs detect DC as well as AC residual currents and, in the event of a fault, trigger a disconnection with the aid of the inverter's output relays.
- The RCMU reacts to residual current "jumps" (ohmic) from 30 mA. Slowly changing residual currents, both AC as well as DC (!), result in disconnection only at max. 300 mA..
- An **RCMU is not a residual current protective device (RCD) and therefore also not an AC-DC sensitive residual current circuit-breaker**. Neither does it replace any RCDs to be fitted at the AC side of the inverter, if these are required as fault protection (or fire protection) according to the relevant erection specifications (e.g. VDE 0100-712).
- In the event of a fault an inverter with an integrated automatic switching point inc. RCMU thus offers a proven increase in the protection level at the DC side according to VDE V 0126-1-1.


PV-Generator
Wechselrichter
Inverter
Überstrom-
schutzeinrichtung
Overload protective
device
PV+
PV-
=
~
Schaltstelle
RCD
L
N
R_{Erde}
parasitäre Kapazitäten
des PV-Generators
Parasitic capacitances
of the PV generator

Residual Current Protection at the AC Side





DEUTSCHE NORM

DIN VDE 0100-712
(VDE 0100-712)

DIN

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VDE

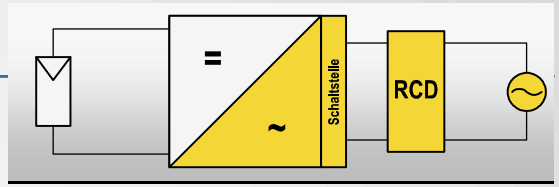
Errichten von Niederspannungsanlagen –
Teil 7-712: Anforderungen für Betriebsstätten, Räume und Anlagen besonderer Art –
Solar-Photovoltaik(PV)-Stromversorgungssysteme
(IEC 60364-7-712:2002, modifiziert);
Deutsche Übernahme HD 60364-7-712:2005

VDE 0100-712:

Requirements regarding fault protection (protection in the event of indirect contact) at the AC side of a PV installation:

»If, due to the design of the inverter, there is a simple disconnection between the AC and the DC voltage sides (electrical isolation, e.g. with the aid of an inverter with transformer) and if fault protection by means of automatic disconnection with overvoltage protective devices (miniature circuit breakers) cannot be realized due to inadequate earthing conditions (high loop resistances, e.g. TT system), then a Type A RCD must be employed.

Residual Current Protection at the AC Side



DEUTSCHE NORM

	DIN VDE 0100-712 **(VDE 0100-712)**	DIN
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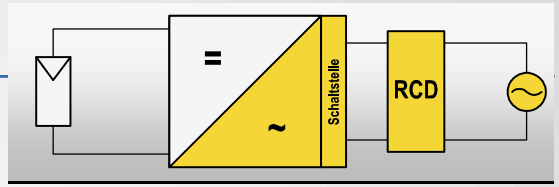
Errichten von Niederspannungsanlagen –
Teil 7-712: Anforderungen für Betriebsstätten, Räume und Anlagen besonderer Art –
Solar-Photovoltaik(PV)-Stromversorgungssysteme
(IEC 60364-7-712:2002, modifiziert);
Deutsche Übernahme HD 60364-7-712:2005

VDE 0100-712:

»If, due to the design of the inverter there is not at least a simple disconnection between the AC and DC voltage sides (e.g. inverter without transformer) and if fault protection by means of automatic disconnection with overload protective devices (miniature circuit breakers) cannot be realized due to inadequate earthing conditions (high loop resistances, e.g. TT system), then a Type B RCD must be employed.

»As high leakage currents are to be expected, the use of RCDs with higher rated residual operating currents is recommended (IΔn > 30 mA).

Residual Current Protection at the AC Side



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Errichten von Niederspannungsanlagen –
Teil 7-712: Anforderungen für Betriebsstätten, Räume und Anlagen besonderer Art –
Solar-Photovoltaik(PV)-Stromversorgungssysteme
(IEC 60364-7-712:2002, modifiziert);
Deutsche Übernahme HD 60364-7-712:2005

VDE 0100-712:

»If, in the event of a fault in the electrical installation, no smooth DC currents are to be expected, then the RCD intended as fault protection may also be a Type A device.

Note:
According to findings made to date, this requirement can presumably only be achieved if an inverter with transformer is used (electrical isolation between DC and AC sides).

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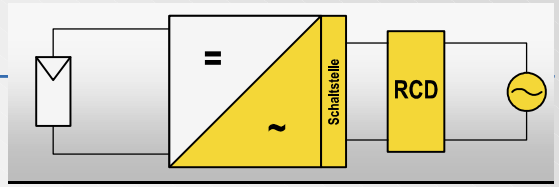
Residual Current Protection at the AC Side further standards-based Requirements



- **VDE 0100**-705 specifies that in agricultural establishments an RCD has always to be provided for fire protection (IΔn = 300 mA) (in final circuits with sockets: IΔn = 30 mA).
- According to the **VDE 0100-530** Erection Specifications, measures for preventative fire protection may be required in all areas of an electrical installation based on a risk assessment by the operator, the supervising authority or the fire insurance company.
- Some utility companies demand that an RCD be employed irrespective of the existing system (TN, TT).
- **VDE 0100-482** describes the requirements for fire protection in cases of special risks or dangers. See also **VdS 2033** (Fire-endangered work establishments).

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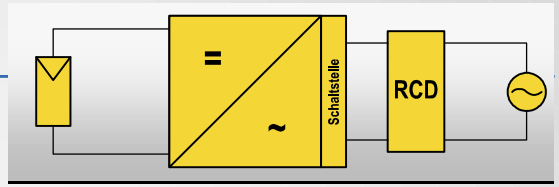
Example for Explaining the Residual Current Flow in a PV Installation with a Fault at the DC Side

- As a result of a rodent bite in a DC cable of the PV generator, a slowly rising residual current to earth develops during the input as contamination or moisture increases.
- The resulting residual current without zero contact consists of an AC and DC component (ignoring HF constituent).
- Due to the slow rise of the residual current, the integrated RCMU of the inverter will respond only to a current between 100 and 300 mA.
- The same residual current will flow through an RCD installed at the AC side.
- The response of Type A RCDs would be impaired by the existing DC constituent (magnetization of the inverter core).

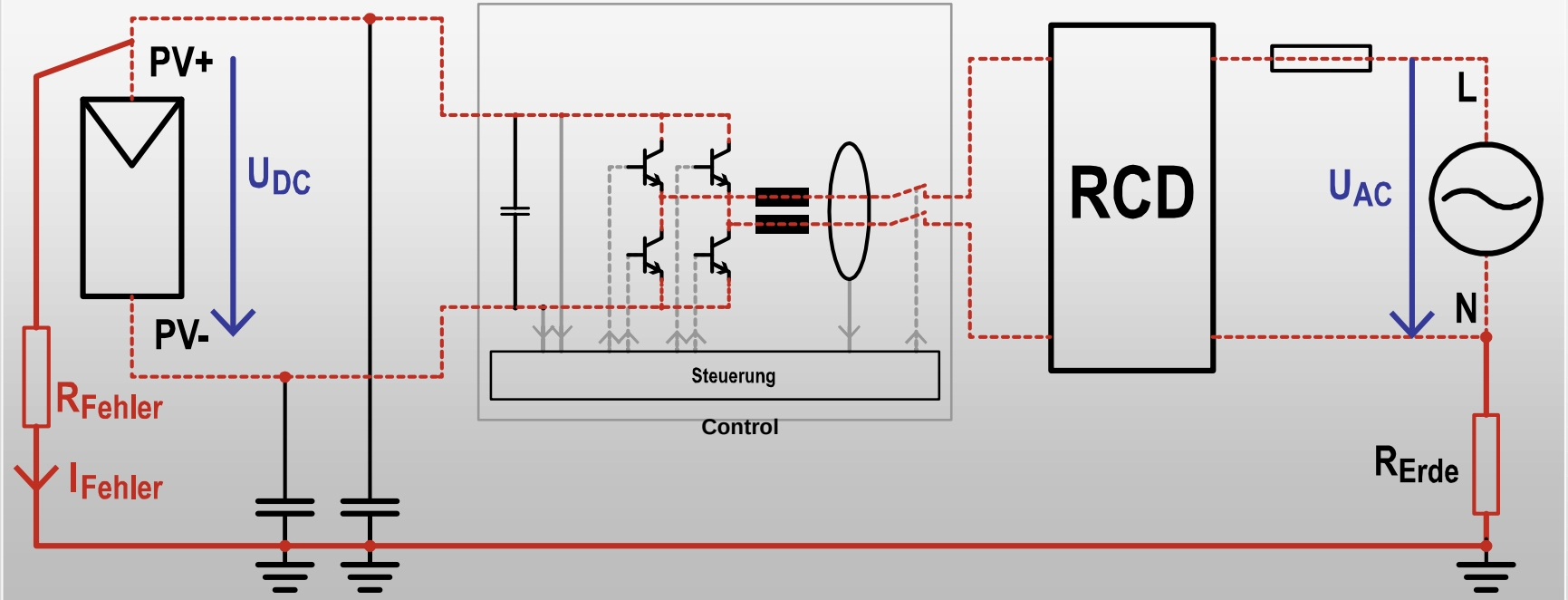


Fault: PV+ to earth

Fehler: PV+ gegen Erde

Inverter without transformer, all transistors pulsed

trafoloser Wechselrichter, alle Transistoren getaktet



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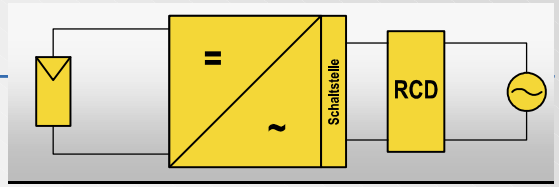
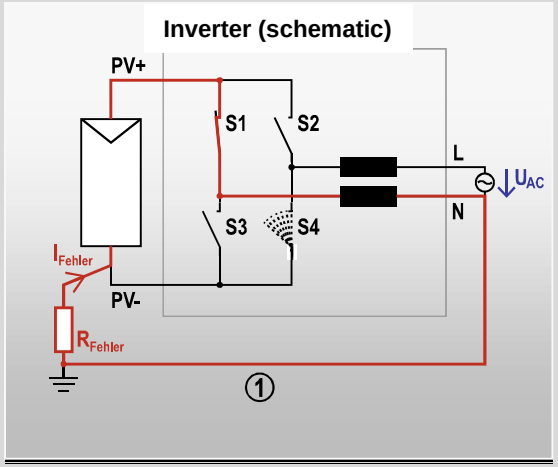
Representation of Residual Current Curves with Faults at the DC side

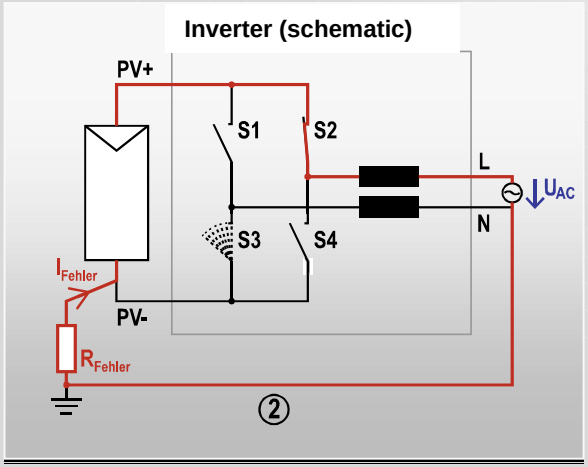


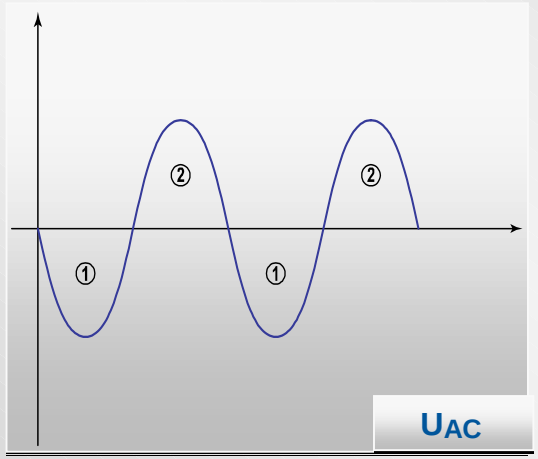
Further example: Fault PV- to earth; non-transformer equipped inverter: two transistors each switched and two transistors pulsed (transistors shown simplified as switches)

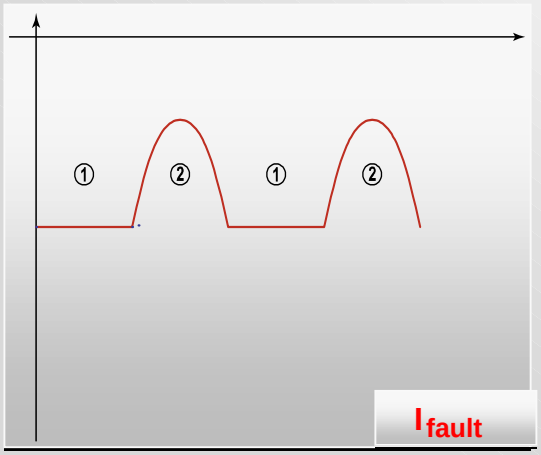
1. Mains voltage half-wave:
S1 closed, S4 pulsed (PWM)
S2 open, S3 open



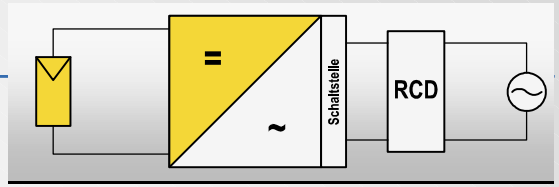
2. Mains voltage half-wave:
S1 open, S4 open
S2 closed , S3 pulsed (PWM)







Representation of Residual Current Curves with Faults at the DC side



In the event of faults to earth at the DC side, the DC and AC constituents of the residual current depend upon the design or topology of the inverter and the strength of the DC voltage of the PV generator.

The shape of the residual current's curve can thus vary considerably. The AC constituent can become so great that a Type A RCD will be markedly impaired in its function.

Composition of the residual currents:

»AC-constituent (normally 50 Hz)
»DC-constituent
»HF-constituent (determined by the inverter's switching frequency (typ. 16 – 22 kHz), size dependent upon HF filter provisions in the inverter)

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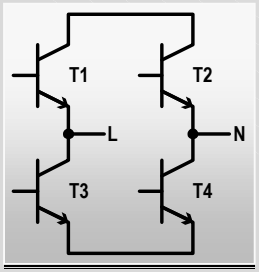
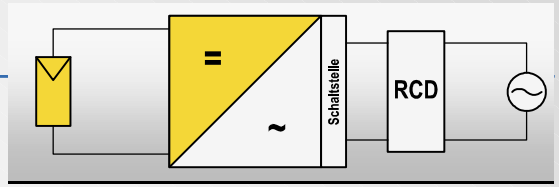
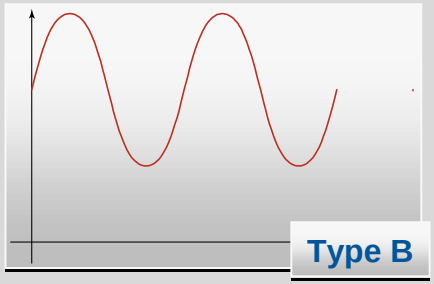


Representation of Residual Current Curves with Faults at the DC side with differing Inverter Topologies

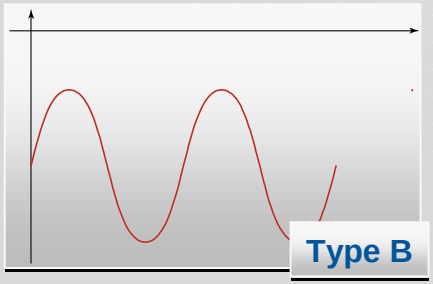


all transistors pulsed (PWM)

PV+ ▸ earth

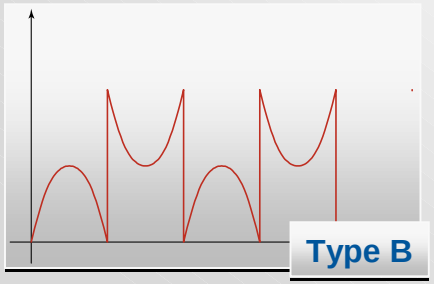


PV- ▸ earth

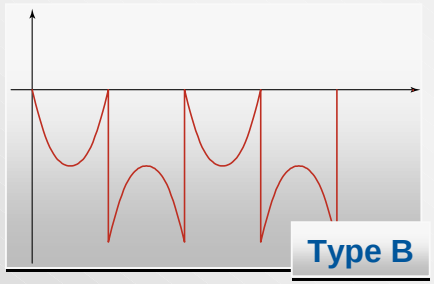


T1, T3 switched / T2, T4 pulsed (PWM)

PV+ ▸ earth

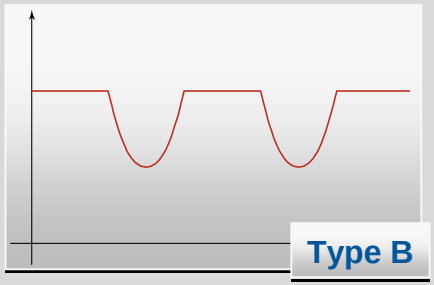


PV- ▸ earth

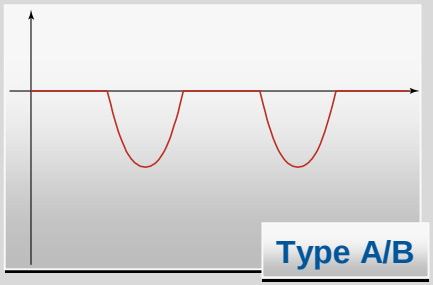


T3, T4 switched / T1, T2 pulsed (PWM)

PV+ ▸ earth

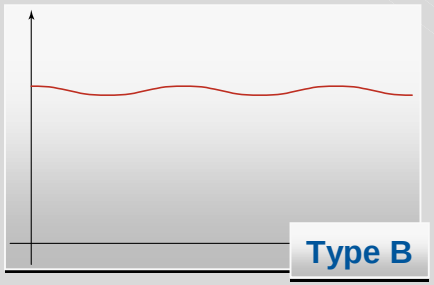


PV- ▸ earth

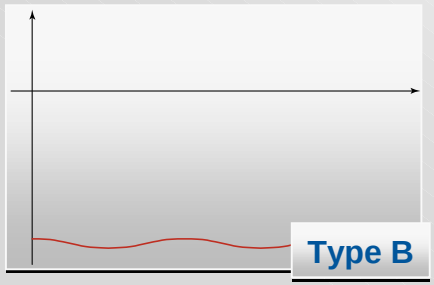


Inverter with separated DC link and step-up converter

PV+ ▸ earth



PV- ▸ earth



This illustration of possible residual currents is intended as an example and is not complete (schematic, without HF constituent).

Using RCDs in Photovoltaic (PV) Installations

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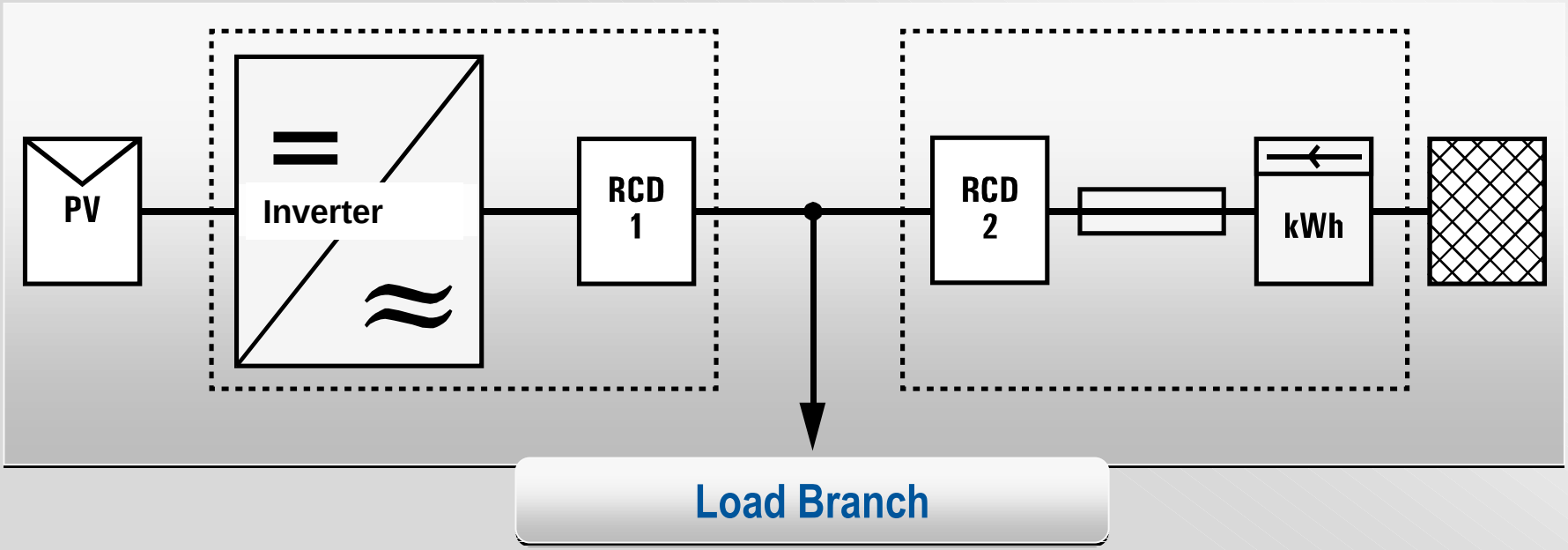
Using RCDs at the AC side of a PV inverter:

»RCDs for **fault protection** (AC side) with IΔn > 30 mA as per **VDE 0100-712**, when it is not possible to provide protection by means of automatic disconnection of the power supply using overload protective devices.

»RCDs for the **protection of persons** (DC side) with IΔn < 30 mA as per **VDE V 0126-1-1**, if there is no automatic switching point with RCMU.

Using RCDs in Photovoltaic Installations



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Aid for Selecting RCDs in Photovoltaic (PV) Installations

In systems where protection through automatic disconnection with overload protection devices is not possible:		RCD 1		RCD 2	
		without load branch	with load branch **	without load branch	with load branch **
Inverter Prot. Class I without switching point/RCMU	Inv. without transformer	-	Type B *	Type B *	Type B *
	Inv. with transformer	-	-	Type A	Type A
Inverter Prot. Class I with switching point/RCMU	Inv. without transformer	-	-	Type B	Type B
	Inv. with transformer	-	-	Type A	Type A
Inverter Prot. Class II without switching/RCMU	Inv. without transformer	-	-	Type B *	Type B *
	Inv. with transformer	-	-	-	Type A
Inverter Prot. Class II with switching/RCMU	Inv. without transformer	-	-	-	Type B
	Inv. With transformer	-	-	-	Type A

Irrespective of the supply system (TN, TT) of the low voltage net:

* For the protection of persons at the DC side according to VDE V 0126-1-1 the RCD must have a residual current rating of 30 mA (attention should however be paid to possible high leakage currents).

** In cases of load branches with plug-in sockets (non-professional, external areas): IΔn = 30 mA, or additional RCD in load branch with IΔn = 30 mA (see also VDE 0100-410).

Comments regarding the Table

Notes regarding Type B RCDs
Please refer to section “Residual Current Protection at the AC side” regarding a possible alternative use of Type A RCDs.

Additional Notes:
»Inverter Protection Class I without transformer: faults from the inverter must be taken into consideration. RCD1 required directly downstream of the inverter, if there is a load branch.
»Inverter without switching point: Input may also be possible if mains voltage fails (formation of island net). Furthermore, no protection for persons provided at the DC side, RCD with IΔn=30 mA required.
»Inverter with switching point: No input possible if mains voltage fails.

Protection Classes :
»Protection Class I: All electrically conductive enclosure parts of the equipment are linked to the protective earth system of the permanent electrical installation, which is located at earth potential.
»Protection Class II: Equipment has reinforced or double insulation between mains circuit and output circuits, or is provided with metal housing. It does not as a rule have a connection facility for a protective earth.