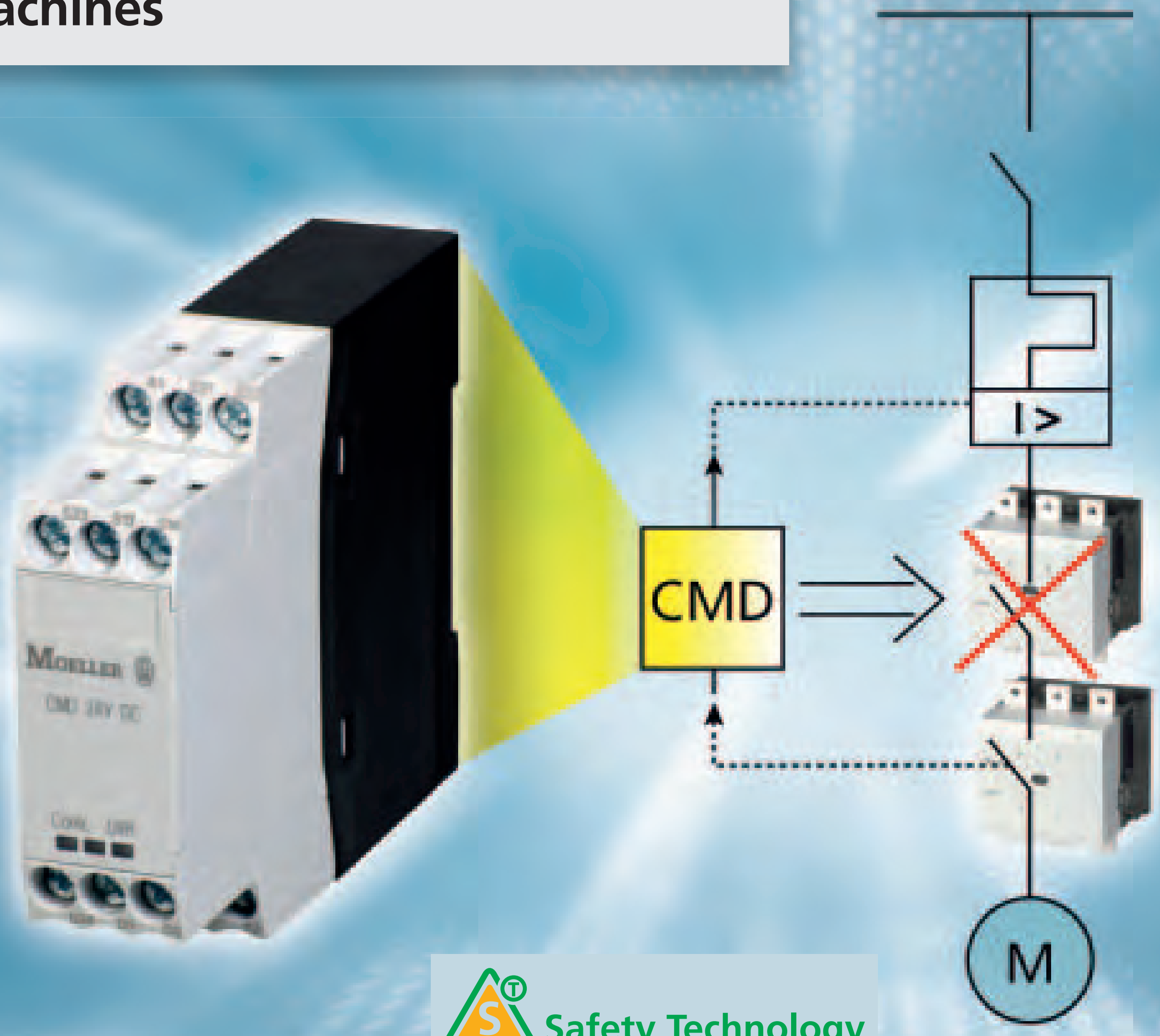
Contactor Monitoring Relay CMD – Cost-Effective Solution for Safe Machines



Safety Technology
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The complete range of contactors, efficient motor-starters and variable speed drives for the motor circuit. New simple to install solutions based on clever communication.

- **Contactors DIL**
- Motor-protective circuit-breakers PKZ
- Motor starters MSC
- Soft starters DS 4
- Frequency inverters DF, DV
- Rapid Link

Technical Paper
Dipl.-Ing. Wolfgang Nitschky

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We keep power under control.

The way to safe machines

During the engineering design phase of a machine, every design engineer – in addition to considering the functional aspects of the machine – is confronted eventually with the issue of safety features, and is posed with the following question: How dangerous is the machine that they are designing? The potential dangers posed by the machine can be identified by a risk assessment. A portion of the danger can be suppressed by mechanical modifications or extensions (no sharp edges, bulkheads in front of moving parts, etc.). If an electrical control is engineered, safety tasks are shifted to the control. Typical safety tasks are the Emergency-Stop or monitoring of safety doors, contact mats or photoelectric barriers. The question of the reliability of the control during a malfunction should be considered in order to delegate the control of safety-relevant tasks to the control.

The EN 954-1

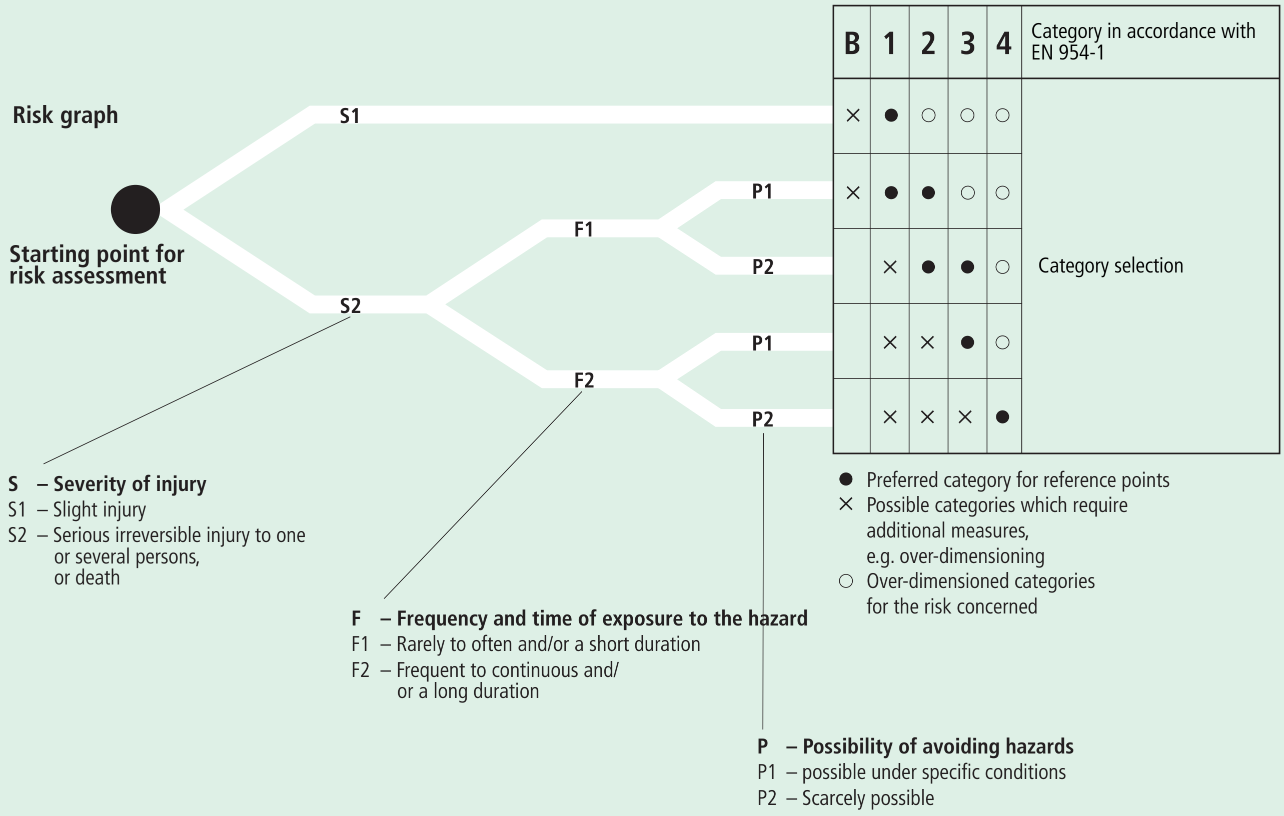
The European standard EN 954-1 can easily claim to be simple to apply. Based on the simplicity of its fundamental design, the standard can be easily integrated and applied in the field of mechanical engineering. The classification in specific cases is not always easy, but the basic steps to be applied remain transparent in all cases.

Using the tree structure (Figure 1) it is possible to appraise what can happen if the control fails. First of all the seriousness of the injury is assessed, followed by the time spent in the danger area and finally the perceptibility of the danger. The assessment results in the safety categories to which the control must comply. The safety categories are a measure of the reliability of the control during a malfunction. The fundamental difference between controls of safety category 1 or 2 to controls of categories 3 or 4 is that the controls in safety categories 1 and 2 may lose their safety function during a fault scenario. Controls of safety category 3 or 4 must maintain their safety function even in a fault scenario.

Contactor control circuits conform to EN 954-1

If the electrical circuits for control of motors are now examined, the motors are switched by contactors. A typical contactor fault is welding of the contactor contacts. If the control voltage on the contactor coil is removed by an Emergency-Stop and there is a fault involving "welded contactor contacts", further measures for maintaining the safety function in controls of safety category 3 or 4 must be provided. Generally, a connection of two contactors in series (Figure 2) is provided. With the rare exception that both contactors have not welded at the same time, the safety function is maintained as the second contactor will bring the drive which is the source of danger to a standstill.

This expensive solution, which requires significantly more space in the control panel and additional time and expense for manufacturing the main wiring harness, is not always acceptable in the engineering design. This is where Moeller uses the CMD **C**ontactor **M**onitoring **D**evice. Not a second, expensive and large contactor to maintain the safety function, but rather a small attractively priced relay. This continuously compares the specified state of the contactor based on the control voltage with the actual state which is signalled with the assistance of an auxiliary contact. In a fault scenario, the CMD switches the



B	1	2	3	4
×	●	○	○	○
×	●	●	○	○
	×	●	●	○
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	×	×	×	●

Figure 1: Risk assessment graph according to EN 954-1

Figure 2: Redundant power section

upstream contactor or switch-disconnector off using the undervoltage coil.

Enhancements of the EN 954-1 in the EN ISO 13849

The simple handling of the EN 954-1 described at the outset has the disadvantage that it fails to make any mention of the reliability of the control in the scheduled service life. This circumstance has lead to the EN 954-1 only being valid for a transitional period. The successor standard EN ISO 13849, has been expanded in some aspects and makes statements regarding the occurrence of malfunctions.

PL – Performance Level

The assessment of the consequences of a control failure using a tree structure no longer results directly in a safety category, but rather in a Performance Level in accordance with the EN ISO 13489. This can result in PLs ranging from "a" to "e" (Figure 3).

The PL reflects the level of danger that exists due to the failure of a control. On machines featuring a control of PL "a", there is only a low level of danger, whereas machines with a control categorised as PL "e" are categorised as very dangerous

The actual Performance Level that a control complies with no longer depends solely on the design of the control. Additionally, qualitative declarations regarding the service life and fault detection must also be considered.

MTTF – Mean time to failure

The MTBF time (mean time between failure) is a measure of the reliability of a component or a control which has been in use for a long time with electronic components. As the electromechanical components of an assembly no longer function after the first fault, the MTTF time (mean time to failure) is taken into consideration here. It is a measure of how long the component or control will function reliably. As only the faults, which can cause dangerous failures need to be examined from the safety technology perspective, the $MTTF_d$ (Mean time to failure dangerous) is considered for assessment of the Performance Level.

3 years $<= MTTF_d <$ 10 years → low
10 years $<= MTTF_d <$ 30 years → medium
30 years $<= MTTF_d <$ 100 years → high

DC – Diagnostic Coverage

The Diagnostic Coverage enables a quantitative statement with regard to detected faults. This involves the assumption principle that a control that detects a large number of faults is more reliable than a control that hardly detects any faults.

$DC < 60\%$ → no error detection
$60\% \leq DC < 90\%$ → low error detection
$90\% \leq DC < 99\%$ → medium error detection
$99\% \leq DC$ → high error detection

Common cause failure

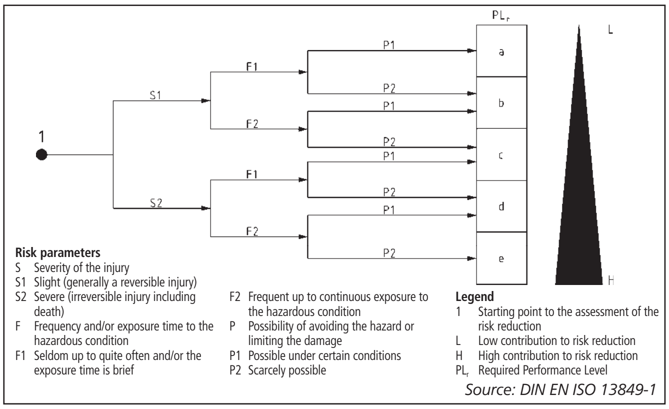
In order to avoid a "failure burst" measures must be undertaken to avoid common cause failures. For this purpose, a range of measures is provided by the standard to assist the users.

Interaction between PL, DC, $MTTF_d$

The Performance Level to which the control complies can be read off of a bar chart (Figure 4).

Operating principle of the CMD

The CMD relay has the task of monitoring the high-power contacts of the motor contactor for welding. For this purpose, the control voltage of the contactor coil is applied as the specified on the CMD. On the other side the actual state of the contactor is signalled via a reliable auxiliary N/C contact. The CMD compares the nominal and actual state. The undervoltage coil of the upstream circuit-breaker or switch-disconnector is supplied via a relay output. In the event of a fault the circuit-breaker / switch-disconnector is switched off via the

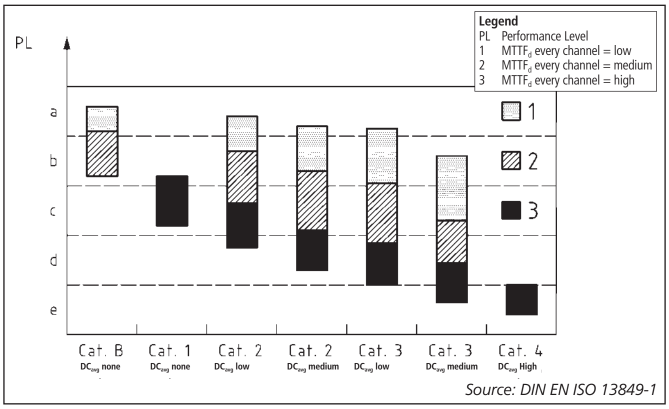


Risk parameters
S Severity of the injury
S1 Slight (generally a reversible injury)
S2 Severe (irreversible injury including death)
F Frequency and/or exposure time to the hazardous condition
F1 Seldom up to quite often and/or the exposure time is brief
F2 Frequent up to continuous exposure to the hazardous condition
P Possibility of avoiding the hazard or limiting the damage
P1 Possible under certain conditions
P2 Scarcely possible

Legend
1 Starting point to the assessment of the risk reduction
L Low contribution to risk reduction
H High contribution to risk reduction
PL_r Required Performance Level

Source: DIN EN ISO 13849-1

Figure 3: Risk assessment graph according to EN ISO 13489



Legend
PL Performance Level
1 $MTTF_d$ every channel = low
2 $MTTF_d$ every channel = medium
3 $MTTF_d$ every channel = high

Source: DIN EN ISO 13849-1

Figure 4: Performance Level

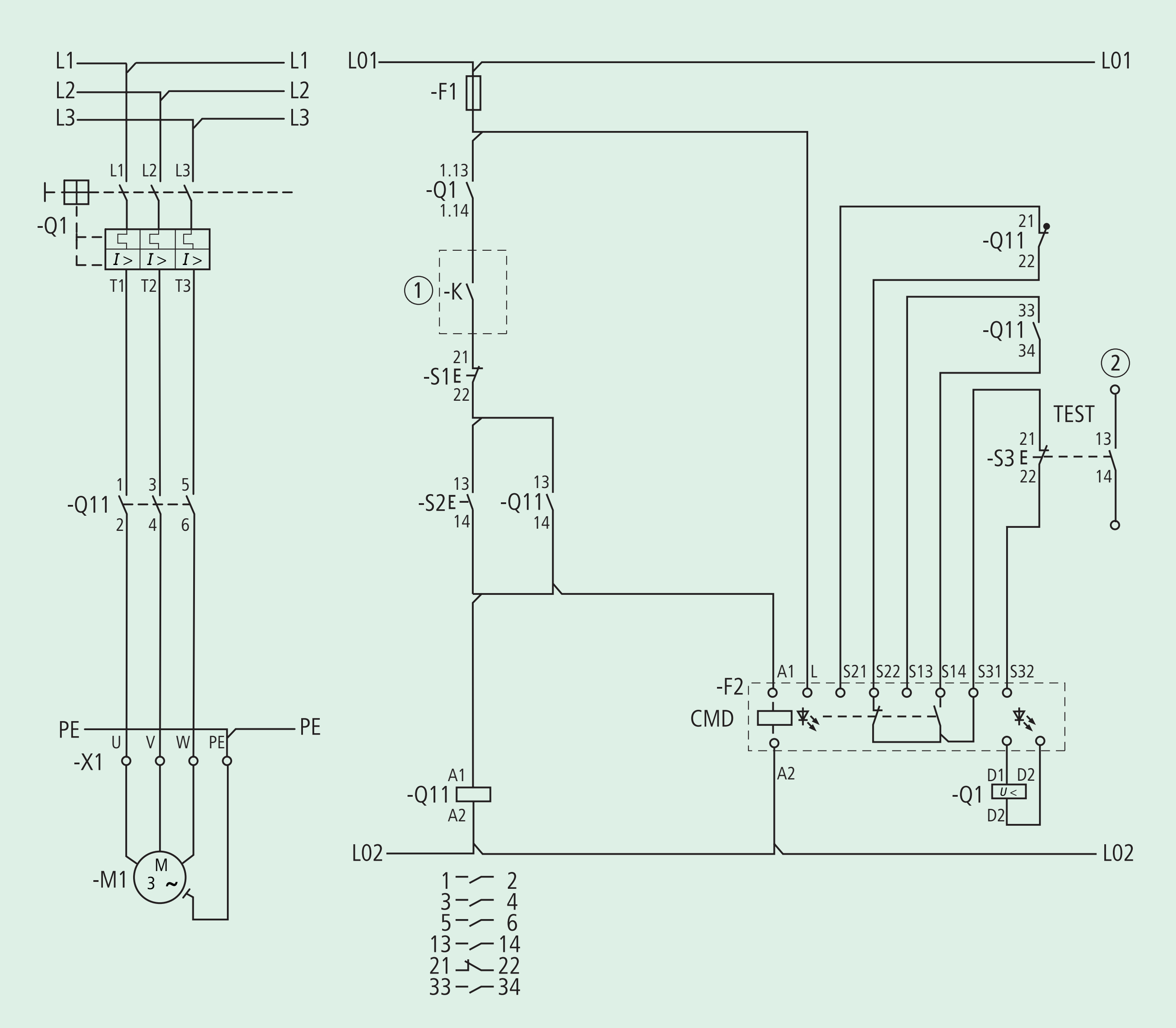


Figure 5: Circuit diagram of direct-on-line starter with redundant shutdown

Figure 6: High level of reliability of the contactor monitoring relay

undervoltage coil and the motor voltage source is switched off (Figure 5).

The CMD in combination with the circuit-breaker / switch-disconnector complies with the demand for a redundant shutdown. Irrespective of the “welded contactor” fault, the control continues to maintain its safety function (Figure 6).

Reliable signalling using auxiliary contacts

The quality of the signal relating to the state of the power contacts is decisive in the described application. Welding of the power contacts must be reliably detected. The IEC EN 60947 standard for electrical low-voltage switchgear has defined the term mirror contacts for this purpose. A mirror contact on a contactor

Figure 7: Contactor auxiliary contact with mirror contact

is an auxiliary N/C contact that can only close if all power contacts have opened.

All auxiliary N/C contacts on the three-pole contactors DILM 7 to DILM 1600 and DILH 1400 to DILH 2000 and the four-pole contactors DILM P comply with the demands of a mirror contact (Figure 7).

With the (high power) contact modules the side-mounted auxiliary contacts NHI2-11S-PKZ2 comply with the demands for a mirror contact.

As it is also possible that an auxiliary N/C contact can weld, monitoring is also necessary here. The IEC EN 60947 standard has also defined a solution for this situation. Mutual monitoring of auxiliary N/O contacts and auxiliary N/C contacts is possible with positively-driven contacts, as they may never by closed simultaneously. This is used for monitoring of mirror contacts. An additional auxiliary N/O contact which must be positively-driven to the mirror contact, is additionally monitored by the CMD. Welding of the auxiliary contact is thus detected which forces the drive to a standstill.

In the Moeller contactor series, all auxiliary contacts of an auxiliary contact module comply with the demands of positive operation. Auxiliary N/O contacts are positively driven against auxiliary N/C contacts on the same auxiliary contact module. Even in the standard auxiliary contact NHI2-11S-PKZ2, all the contact modules are positively-drive with respect to each other.

CMD variants

The supply voltage of the CMD must be identical to the control voltage of the contactor to be monitored. The CMD is available for different control voltage variants in order to cover the largest possible range of applications:

Control voltage	Type	Article number
24 V DC	CMD(24VDC)	106170
110V/50 Hz, 120V/60 Hz	CMD(110-120VAC)	106171
230V/50 Hz, 240V/60 Hz	CMD(220-240VAC)	106172

Most of the conventional safety-related control circuits operate at 24 VDC. However, with larger drive systems 230 V/50 Hz, 240 V/60 Hz are used and in American systems 110 V/50 Hz, 120 V/60 Hz are used. The variants thus cover the typical control voltages for contactor drives (Figure 8).

Permissible combinations

In order to guarantee a reliable functioning of the combinations of circuit-breaker/switch-disconnectors, contactors and CMD, only defined components are approved for use. Other contactors featuring other switching times or under-voltage releases with other voltage levels can cause a loss of the safety function.

Contactors

The following contactors are approved for establishing safety relevant control sections:

The contactor must feature an auxiliary N/C contact with mirror contact functions and a further auxiliary contact that

Figure 8: Contactor monitoring relay CMD

	Contactor type	Control voltage
CMD (24 VDC)	DILM 7 to DILM 15	24 VDC
	DILM 17 to DILM 500	RDC24
	SE1A-G-10-PKZ2, S-G-PKZ2	24 VDC
CMD (110-120 VAC)	DILM 7 to DILM 95	110 V 50 Hz, 120 V 60 Hz 110 V 50/60 Hz
	DILM 115 to DILM 170	RAC120
	DILM 185 to DILM 1600	RA110, RA250
	SE1A/..-PKZ2, S-PKZ2	110 V 50 Hz, 120 V 60 Hz 110 V 50/60 Hz
CMD (220-240 VAC)	DILM 7 to DILM 95	230 V 50 Hz, 240 V 60 Hz 220 V 50 Hz, 240 V 60 Hz 220 V 60 Hz 240 V 50 Hz 220 V 50/60 Hz 230 V 50/60 Hz
	DILM 115 to DILM 170	RAC240
	DILM 185-S to DILM 500-S	220-240 V 50/60 Hz
	DILM 185 to DILM 1600	RA250, RAW250
	DILH 1400 to DILH 2000	RAW250
	SE1A/..-PKZ2, S-PKZ2	230 V 50 Hz, 240 V 60 Hz 220 V 50 Hz, 240 V 60 Hz 220 V 60 Hz 240 V 50 Hz 230 V 50/60 Hz

is positively-driven to the mirror contact (Figure 9).

Circuit-breaker/switch-disconnector

The CMD is approved with the following circuit-breakers / switch-disconnectors (Figure 10):

Switch	Undervoltage release
PKZ2	U-PKZ2(18VDC)
NZM1, N1	NZM1-XUVL
NZM2, N2	NZM2-XUV
NZM3, N3	NZM3-XUV
NZM4, N4	NZM4-XUV

Safety-relevant observation of the CMD

From the safety technology perspective a circuit consists of two parallel paths:

- The contactor
- The series connection of CMD and undervoltage release

MTTF$_d$ of the circuit

Die MTTF$_d$ Zeit wird für beide Pfade getrennt berechnet.

For contactors the MTTF$_d$ time is dependent mainly on the switching conditions of the application. A contactor that switches once a day will achieve a significantly higher MTTF time than a contactor that must switch every 5 seconds (12 x 60 x 8 switching operations per day). Moeller cannot define fixed MTTF times for the observation as a result. Moeller provides the B10$_d$ values for calculation of the MTTF$_d$ time of the application in question. In combination with the application data the MTTF values of the contactors can be calculated using formula 1:

$$\mathrm{MTTF}_d = \frac{B_{10d}}{0{,}1 \cdot n_{op}}$$

where n_{op}: average count of annual switching operations

The following table provides the B10$_d$ values for calculation purposes with AC-3 applications at 400 V:

Figure 9: Contactor with fitted auxiliary contacts

Figure 10: Circuit-breaker with fitted undervoltage release

Contactor	B_{10d} value at 400 V AC-3
DILM 7 to DILM 12	1.3 million switching operations
DILM 15	0.75 million switching operations
DILM 17 to DILM 65	1.3 million switching operations
DILM 72	0.75 million switching operations
DILM 80 to DILM 150	1.3 million switching operations
DILM 170	0.75 million switching operations
DILM 185 to DILM 820	1.3 million switching operations
DILM 1000 to DILM 1600	0.3 million switching operations

The $MTTF_d$ time of the CMD relay is 125 years under the condition that a maximum switching frequency of n_{op} = 350,400 switching operations / year is not exceeded.

The B_{10d} values of the undervoltage release are:

Undervoltage release	B_{10d} value
PKZ 2	10,000 switching operations
NZM 1, NZM 2	10,000 switching operations
NZM 3	7,500 switching operations
NZM 4	5,000 switching operations

Diagnostic coverage of the circuit

The Diagnostic Coverage is also calculated separately for both branches. As the contactor is switched operationally and the state with each switch operation is checked by the auxiliary N/C contact with mirror contact, the error detection on the contactor is very high: DC contactor: = 99 %

In contrast to the contactor, the undervoltage release is a “dormant” component. The functional capability of the undervoltage release cannot be operationally tested. By additional testing of the circuit once a year a DC=90 % is achieved for the undervoltage release.

The Diagnostic Coverage of the CMD
DC = 90 %

Performance Level of the circuit

The parallel connection of the CMD and undervoltage release to a contactor complies with Performance Level PL=e. The calculation is subject to the following preconditions:

Maximum operations of the contactor: 350,400 switching operations / year

Maximum switching operations of the undervoltage release: 1095 switching operations / year

In the calculation of the overall Performance Level for the control the upstream safety components must be considered. Overall, controls that comply with Performance Level “d” can be established in this way.

Summary

The CMD is used in safety-relevant current circuits. It monitors if the main contacts of the contactor have welded. If welding is detected, it switches off the supply of power to the application using the upstream circuit-breaker.

Using the CMD, controls that comply with Performance Level “d” can be set up.

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