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Comprehensive Motor Protection with the Type MCX913 Relay

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The type MCX 913 relay—a member of the 900 series of solid-state protection relays from Asea Brown Boveri [1]—is designed for the protection of motors against faults and for the detection of inadmissible overcurrents or overloads. A microprocessor enables eight different protective functions to be concentrated in a single relay of small size.

The relay can protect rotating machines of all kinds, although its features make it particularly suitable for m.v. and h.v. motors. Since it affords protection against phase and earth faults as well as thermal overload, feeder protection is another field where the relay can be usefully applied.

Modern technology in protection facilitates more effective utilization of plant under a wide range of operating conditions, while also permitting faster intervention when faults occur.

A similar relay designed for insertion in 19-inch racks was presented in an earlier article [2].

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Characteristics of Motor Drives

In order to understand the protective functions provided by the MCX 913, it is worth reiterating the main characteristics of m.v. and h.v. motors.

Nature of the Torque

The behaviour of the torque varies with the type of motor drive. The counter-torque curves of two typical groups of drives are shown in *Fig. 1:*

- Curve 1
  Drives having a counter-torque which is independent of the speed (used for cranes, elevators, etc.)
- Curves 2-2′
  Drives having a counter-torque which increases as the square of the speed (used for pumps, fans, compressors, etc.)

The rotor losses arising when an asynchronous motor is started are proportional to the kinetic energy of the mass being accelerated. Thus, thermal stressing of the rotor is considerable when starting under heavy-load conditions, i.e. conditions involving the acceleration of a large mass.

- Curves 3-3′
  These curves show the torque characteristic of asynchronous motors. The typical torque curves of cage-induction motors, which depend upon the size of motor and the number of poles, lie in the hatched area.
- Curve 3
  This is valid for motors of a lower rating.
- Curve 3′
  Valid for motors of a higher rating.

The motor torque must always be greater than the counter-torque of the driven machine.

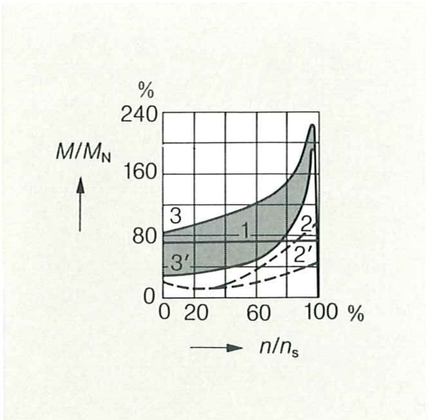


Fig. 1 - Torque characteristic at rated voltage

M/M_N = Relative torque
n/n_S = Relative speed
1-3 as in text

Motor Behaviour During Operation

The behaviour of asynchronous motors in operation has been discussed in [3].

Steady-State Temperature Rise

In the interest of maximum efficiency, electrical machines should be loaded as close as possible to their permitted operating temperature limit; however, excessive thermal stressing of any appreciable duration must be avoided if the life of the insulation is not to be shortened.

Under steady-state conditions, the temperature of a motor will rise exponentially, due to dissipation of the heat to the environment or cooling medium, towards its respective operating temperature. Since a motor is not a homogeneous mass, heat is dissipated in several stages. Temperature rise and fall thus take place according to a series of partial time constants.

In spite of this, it is sufficient for a thermal overload relay intended for protection under steady-state conditions to be set to the mean time constant of the motor. This means that proper account is taken only of the copper losses. Measurement of the voltage would be necessary in order to include the iron losses, but is not generally possible since the voltage transformers are usually located on the busbar and not adjacent to each motor. Most modern thermal overload relays only measure current, filtering out the highest of the three phase currents. The critical cases of starting, stalling and failure of a phase are taken care of by other protective functions.

Thermal Time Constant

The time constant τ is defined as the time in minutes required for the temperature of a body to change from an initial temperature ϑ_0 to 63% of the difference between ϑ_0 and the new steady-state temperature ϑ_∞ (*Fig. 2*).

The temperature rise ϑ is given by the exponential equation:

$$\vartheta = \vartheta_N \left(1 - e^{-\frac{t}{\tau}}\right) \left(\frac{I}{I_N}\right)^2 \qquad (1)$$

where

ϑ_N = Rated temperature rise
I_N = Rated current of motor
t = Duration of temperature rise

Unfortunately, the thermal time constant τ of the motor is frequently not known. *Table I* gives typical values in relation to motor ratings and mechanical design.

Table I is based on the mean time constants of asynchronous motors from Brown Boveri. As would be expected, the time constants of the metalclad versions are greater since their cooling is slower.

The cooling time constants during operation are approximately equal to those for temperature rises, while at standstill they are four to six times the values in the Table.

Motor Starting

Protection settings are particularly important during the starting period if discrimination is to be preserved on the one hand and maximum power to be obtained from the motor on the other.

Typical starting curves of cage-induction motors from Brown Boveri are given in *Fig. 3*

The difference in the temperature rise of stator and rotor windings is particularly notable during the starting phase. The reason for this can be seen from the equivalent circuit of an asynchronous motor (*Fig. 4*). Because of its high current the rotor features a much higher temperature rise than the stator. The rotor impedance depends on its design and on the slip frequency [4]. The temperature increases rapidly, virtually without any dissipation to the surroundings.

Rotor temperatures up to 200 °C are acceptable for short periods when starting under heavy-load conditions. The MCX 913's thermal replica, which follows an exponential function and has a relatively low setting, only affords protection under normal operating conditions and not during starting. MCX 913, however, derives the inte-

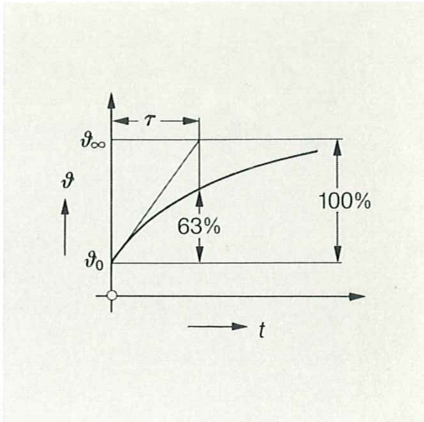


Fig. 2 - Definition of time constant

Symbols explained in text.

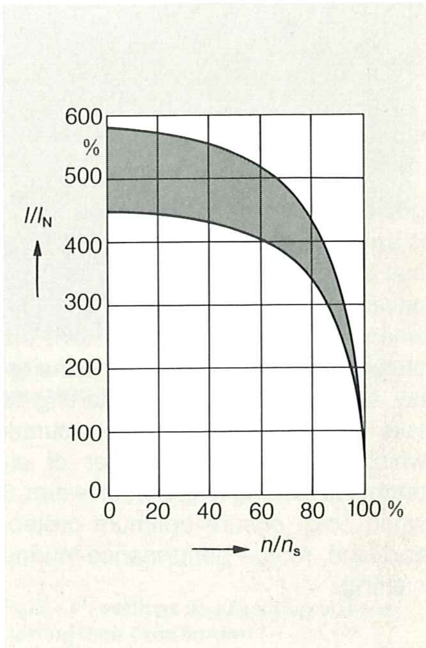


Fig. 3 - Typical starting currents

I/I_N = Starting to rated current ratio
n/n_S = Relative speed

Table I: Mean thermal time constants of asynchronous motors from Brown Boveri in relation to motor rating and type

Type \ A [mm]	355	400	450	500	560	630	710	800	900	1000	1120	1250
O	20	25	28	30	35	40	50	60	65	70		
R				45	50	55	60	70	80	90	100	110
U	30	35	40	45	50							

A = Shaft height (mm)
O = Open type (IP23)
R = Closed type with air/air heat-exchanger (IP54)
U = Fully clad with cooling fins (IP54)

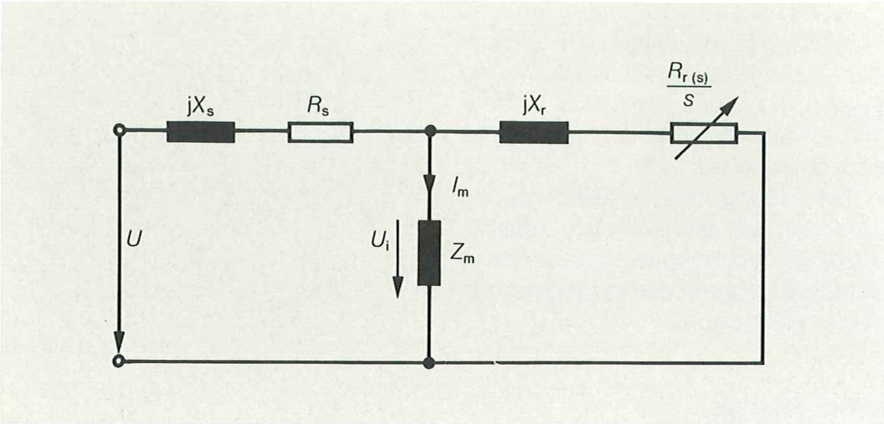


Fig. 4 - Equivalent circuit of a three-phase asynchronous motor

$$I = \frac{U}{\sqrt{\left(X_s + X'_r\right)^2 + \left(R_s + \frac{R'_{r(s)}}{s}\right)^2}}$$

P_{wr} = $I^2 . R'_{r(s)}$
I = Motor current (stator)
I_m = Magnetizing current
U = Terminal voltage
P_{wr} = Rotor losses

R_s = Stator resistance
R'_r = Rotor resistance, referred to stator
$R'_{r(s)}$ = Rotor resistance, referred to stator and slip
s = Slip
X_r = Rotor leakage reactance
X_s = Stator leakage reactance
Z_m = Magnetizing impedance

gral I^2t from the motor current I, which is a more accurate measure of the thermal stress during starting. The main advantage of the I^2t method is that when the supply voltage is low, the starting current is also low and the relay automatically permits starting to take longer. This and the counter which monitors the number of attempts at starting (e.g. 2 when warm, 3 when cold) ensure optimum protection and motor performance during starting.

Defects and their Causes

Defects in motor drives can have many causes; environmental conditions, application, design and load, to mention but a few of the possible factors, all play a part. However, they generally fall into one of the following categories:

- Starting problems
- Overvoltages
- Mechanical

To the *problems arising during starting* belong:

- Excessive loading
- Low supply voltage
- Interruption of a phase
- Low excitation in the case of synchronous motors

All these can lead to excessive heating of the winding insulation.

Overvoltages of atmospheric origin or arising from switching transients can cause flashovers and damage insulation.

Ingress of moisture or aggressive substances in the windings can also be a cause of insulation breakdown.

The direct consequences of insulation damage are:

- Phase faults
- Earth faults
- Interturn faults

Protection Scheme

To provide an m.v. or h.v. motor with adequate protection it is necessary to combine independent protective functions. Apart from any electrical faults (phase and earth faults), there are also abnormal operating conditions (starting time too long, too many attempts at starting, etc.) which must also be monitored and remedied.

The new microprocessor-based protection relays combine a multitude of protective functions in small compact units at reasonable prices, so much so that they are also an economic proposition for smaller motors rated below 0·5 MW.

Table II: Combination of protective functions for different items of primary plant

Relay function	Primary plant: Motor	Transformer	Generator (small units)	Cable/line
Short-circuit protection	●	●	●	●
Motor starting protection, protection against blocked rotor	●			
NPS	●		●	
Overload protection	●	●	●	●
Earth faults	●	(●)²	●	(●)³
Underload check	(●)¹			
Back-up protection, time-delayed overcurrent protection	●	●	●	●

(●) = depending on
1 = application
2 = phase group and system grounding
3 = whether system solidly earthed and radial

General Description of the MCX 913 Relay for Motor Protection and Detection of Overcurrents/Overloads

All functions of the MCX 913 protection relay (*Fig. 5*) are based on measurement of either the currents in three phases or the currents in two phases and the neutral current. Eight different protective functions are incorporated in the MCX 913. However, the total number of available protective functions is higher than this as several are present a number of times.

The inclusion of a microprocessor for performing integrated protective functions offers numerous advantages and new potential:

- Cost-effectiveness is greater than with conventional technology.
- Setting ranges can be extremely wide, and yet feature high resolution.
- The frontplate display signals the faults in the order in which they were detected.
- Both hardware and software are self-checking and self-monitoring.
- Primary system quantities can be displayed continuously during normal load operation.

Protective Functions

The MCX 913 protection relay detects the following conditions:

- Phase faults
- Overcurrents
- Earth faults (neutral current measurement)
- Negative phase-sequences (NPS)
- Thermal overloads
- Excessive temperature rises during starts
- Low loads
- Stalled motor (blocked rotor)

Combining the Protective Functions

The MCX 913 ingeniously resolves the problem of selecting the required combination of protective functions and their settings. Since the active and inactive functions may be chosen freely, the number of possible combinations is very high. The method of selection is so simple that the user can change and adapt his selection at any time.

Table II summarizes the recommended protection schemes for different items of primary system plant.

Thermal Overload Protection

The thermal overload protection features two independent stages for alarm ($\Delta\vartheta_1$) and tripping ($\Delta\vartheta_2$). For a motor current of $I \leqslant 2 I_E$, the steady-state temperature simulated in the relay is given by:

$$\Delta\vartheta = \left(\frac{I}{I_E}\right)^2 \left(1 - e^{-\frac{t}{\tau}}\right) \qquad (2)$$

where

I = Overload current

I_E = Base current setting, corresponding to the rated current of the motor

τ = Mean thermal time constant of the rotor

The temperature rise at currents greater than $2 I_E$ is assumed to be adiabatic:

$$\Delta\vartheta = \left(\frac{I}{I_E}\right)^2 \cdot \frac{t}{\tau} \qquad (3)$$

For higher currents, at which the temperature rises much more quickly, it is important for the thermal replica to respond according to a different, more suitably matched characteristic.

Motor Starting Protection (I_{start})

As has already been mentioned, one of the MCX 913 functions is to derive I^2t, and this current time measurement is activated as soon as the current exceeds the setting I_{start}. As a rule I_{start} is set higher than $2 I_E$. *Figure 6* shows how the I^2t setting is determined in relation to the starting time t and the starting current (expressed as a multiple of I_E).

All the overcurrent ($I>$) functions and the no-load ($I<$) function are disabled during the starting period and enabled again once it has been completed, thus ensuring discriminative operation of the relay during starting of the motor. This also applies when the relay is protecting a power transformer and is required to remain stable in the presence of the inrush current due to energization of the power transformer (see Table II).

Blocked-Rotor Protection ($I>_R$)

Providing the starting time is longer than the maximum permissible blocked-rotor time, an overcurrent function of the MCX 913 ensures blocked-rotor protection in combination with a tachogenerator or a centrifugal switch. A logic relating the two criteria decides whether the motor has stalled or not.

Underload Check

In certain applications a motor can overheat or be endangered if its load is removed, i.e. the current falls below a set value. In the case of pumps and fans, which depend upon a sufficient amount of air or water flowing for their cooling, overheating is possible if the flow rate diminishes in spite of the load having been reduced.

An underload check will also detect

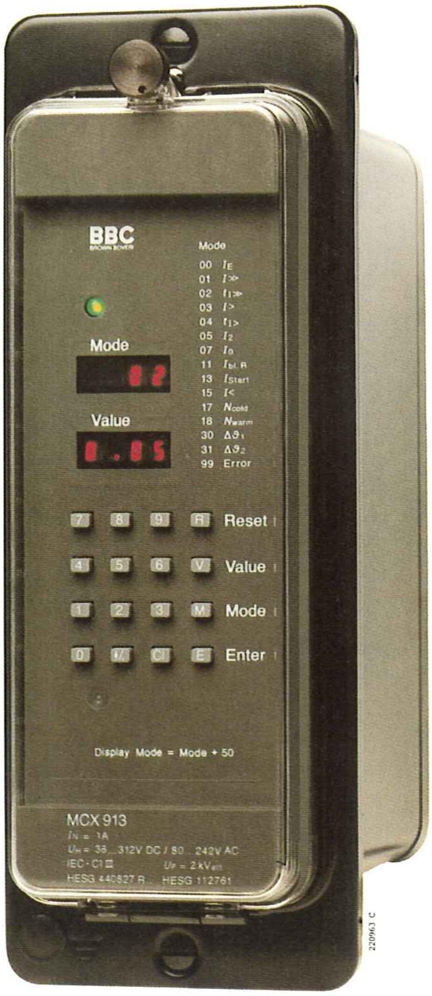
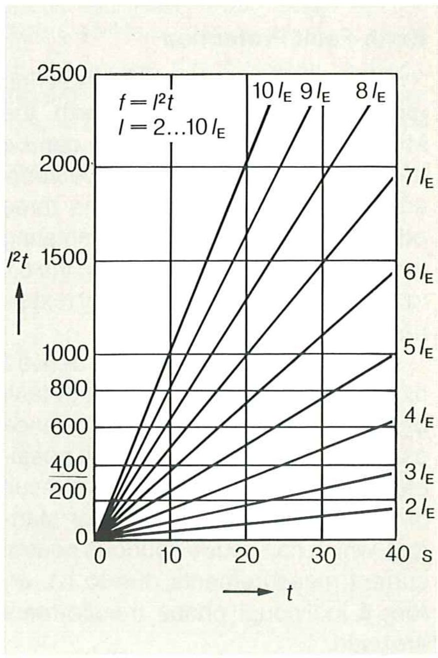


Fig. 5 – Multi-function motor protection relay MCX 913

Fig. 6 – I^2t settings as a function of motor starting time t and current I

I_E = Current setting



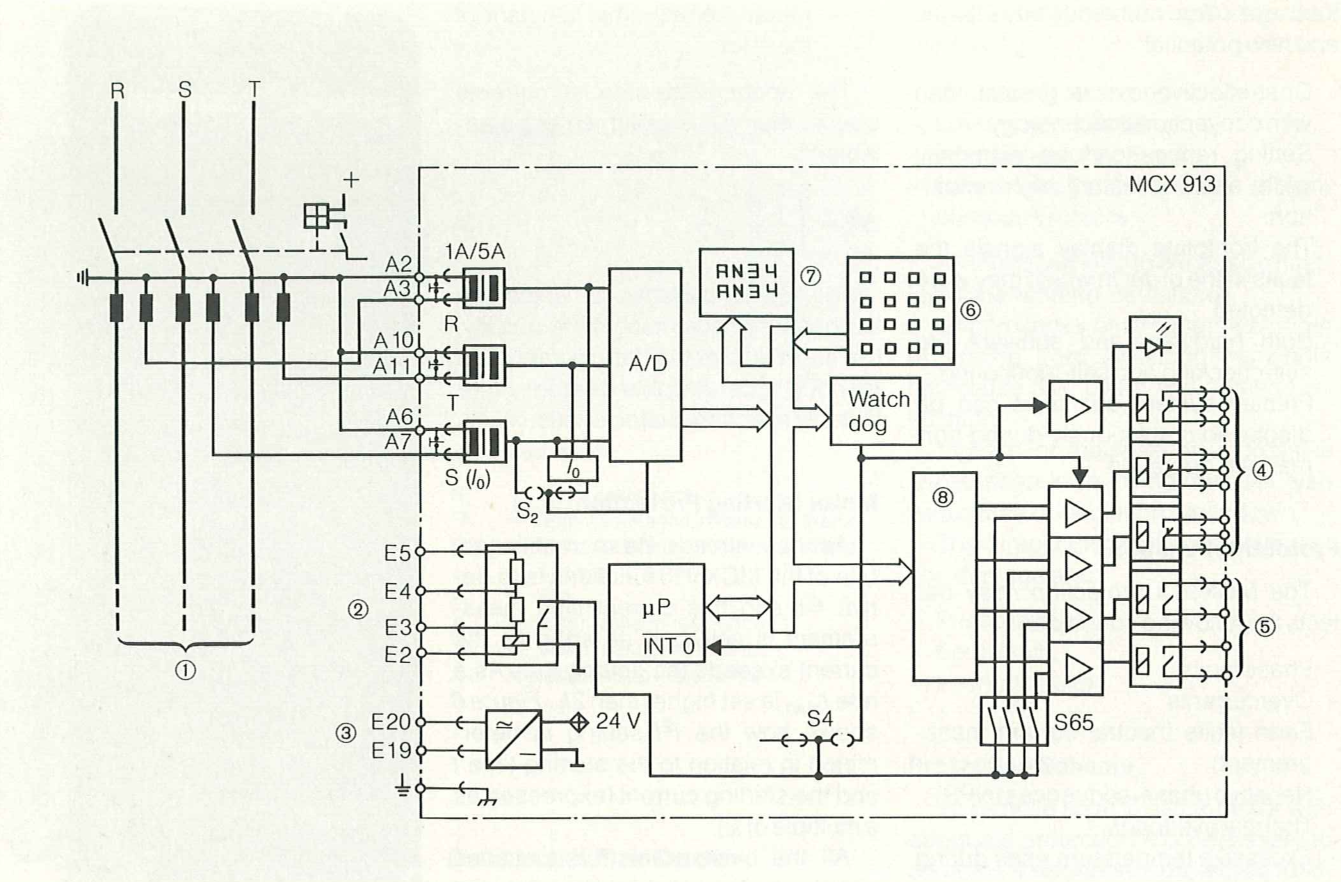


Fig. 7 - Block diagram of the MCX 913

① = Protected unit
② = Blocking input
③ = Aux. supply 36-312 Vdc or 80-242 Vac
④ = Aux. signalling relays
⑤ = Aux. tripping relays
⑥ = Keypad
⑦ = Display
⑧ = Software matrix

mechanical damage to the driving system, such as a broken shaft or a sheared flange.

Earth-Fault Protection

There are two ways of measuring motor earth-fault currents with the MCX 913. The neutral current can be derived either in the relay by vectorial addition of the currents in the three phases (internal I_0) or by summating them externally and connecting the c.t. to the S phase input of the relay (external I_0).

Where the neutral current is derived externally and sensitive earth-fault protection is required, a core-balance c.t. must be used. Only then is it possible to prevent maloperation as a result of transient phenomena (motor starting), which can cause spurious neutral current measurements due to c.t. errors if individual phase transformers are used.

Negative Phase-Sequence Protection

This protection will detect negative phase-sequence currents irrespective of whether the power system is ungrounded or not, and also of the method of grounding in the latter case. A negative phase-sequence component (I_2) is generated when the system voltages or the load are unbalanced or when a phase has been interrupted (single phasing). Since voltages which are only slightly unbalanced can cause appreciable unbalanced currents (in rotating machines), and these can heat the rotor beyond given limits, this is an extremely important protective function.

Operating Principle

The operating principle is explained with reference to the block diagram in *Fig. 7.*

The input current transformers R, T and S (I_0) of the relay are connected to the secondaries of the main current transformers. Initial signal conditioning is analog:

- Filtering out of the maximum of the three phase currents to be used for measurement (I)
- Vectorial addition of the three phase currents to obtain the neutral current (internal I_0), or use of a plug-in link for selection of the S phase input for the neutral current (external I_0)
- Derivation of the negative phase-sequence current (I_2)

After analog-to-digital conversion, the quantities I, I_0 and I_2 are transmitted to the microprocessor.

Tripping Value Memory

The value of the current being measured by a protective function at the in-

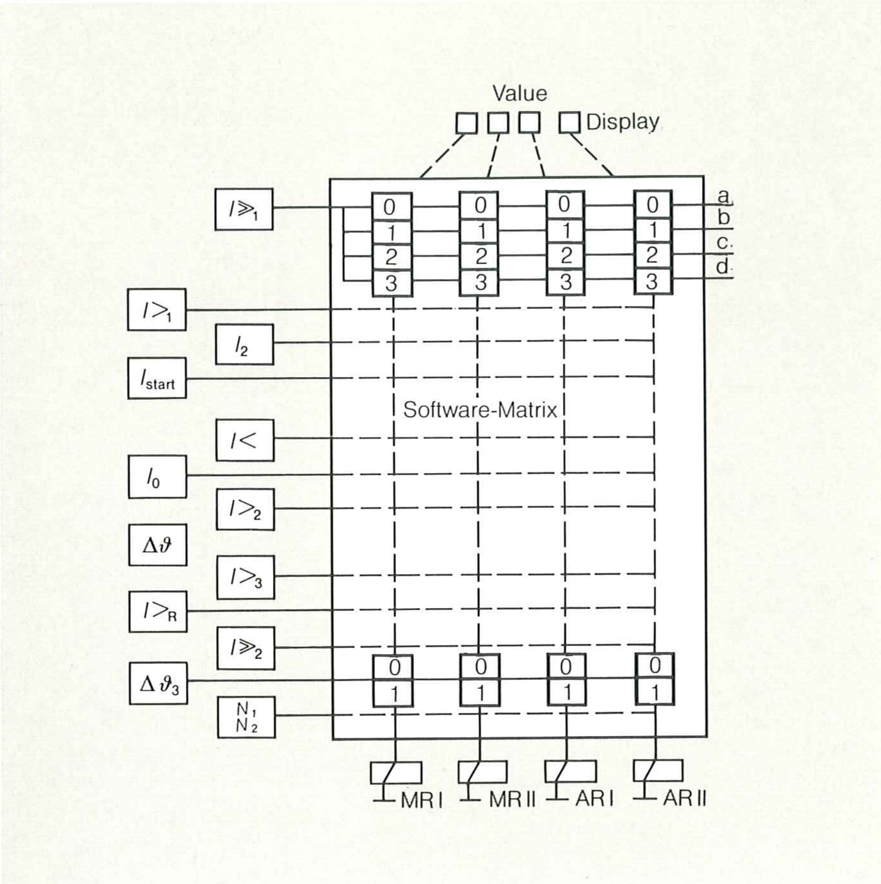


Fig. 8 – Operation of auxiliary signalling and tripping relays in relation to protective function

[0] = No operation	MR = Signalling relay
[1] = Start signal	AR = Tripping relay
[2] = Trip signal	Other symbols see text.
[3] = Trip signal with latching	

Selection is possible for all functions with the exception of $\Delta\vartheta_3$.

stant of the last trip (or last pick-up) is stored in the tripping value memory and can be displayed on the frontplate by operating the keypad.

Self-Monitoring

A comprehensive self-monitoring system for both hardware (watchdog) and software operates continuously to detect immediately any defects such as component failures. This system is so thorough that periodic testing can be virtually dispensed with without reducing availability.

Keypad and Display

Using the keypad and observing the two LED displays on the front of the relay, functions (Mode) can be selected and their settings (Value) or measured values checked. Pick-up and tripping of protective functions as well as relay defects are also signalled by the LEDs.

The relay settings are entered on the keypad. Comprehensive and user-friendly control software ensure easy setting of the values.

Software Matrix

The MCX 913 is equipped with two auxiliary relays for signalling and two for tripping. Their operation in relation to individual protective functions is selected using the software matrix *(Fig. 8)*. With each relay the following four events can be signalled for each protective function by means of a code:

- No operation (0)
- Pick-up signal (1)
- Trip signal (2)
- Trip signal with latching (3)

Users are therefore able to choose the signalling and tripping logic best suited to their application.

Mechanical Design and Power Supply

The mechanical design and the auxiliary supply arrangements for the connection of 36 to 312 Vdc or 80 to 242 Vac are the same as for the other relays of the 900 series [1].

Summary

When designing a protection scheme for an electric motor it is essential for its typical characteristics to be known and taken into account. Equally important are the operating conditions and application.

The information contained in this article will enable the user to choose appropriate protection for the given machine characteristics and behaviour. The new type MCX 913 microprocessor relay, with its special features for motor protection and the detection of inadmissible overcurrent or overload situations, its many protective functions and the flexibility it offers for settings, permits motor protection to be optimized and at the same time simplifies operation and the setting procedure.

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