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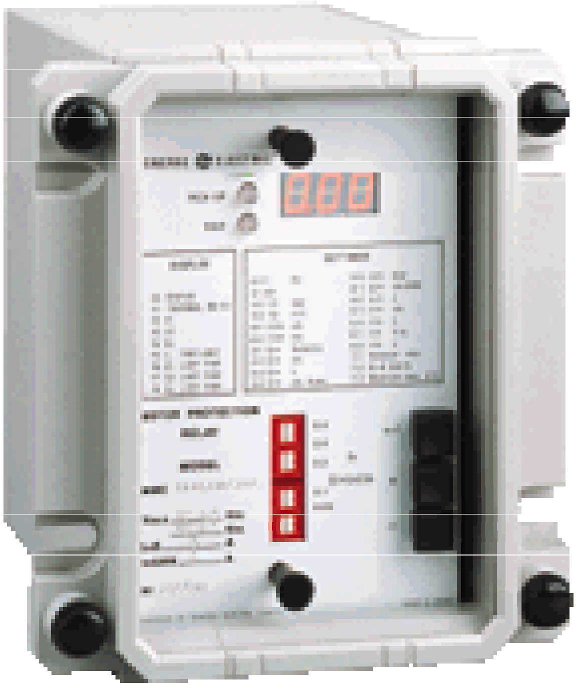
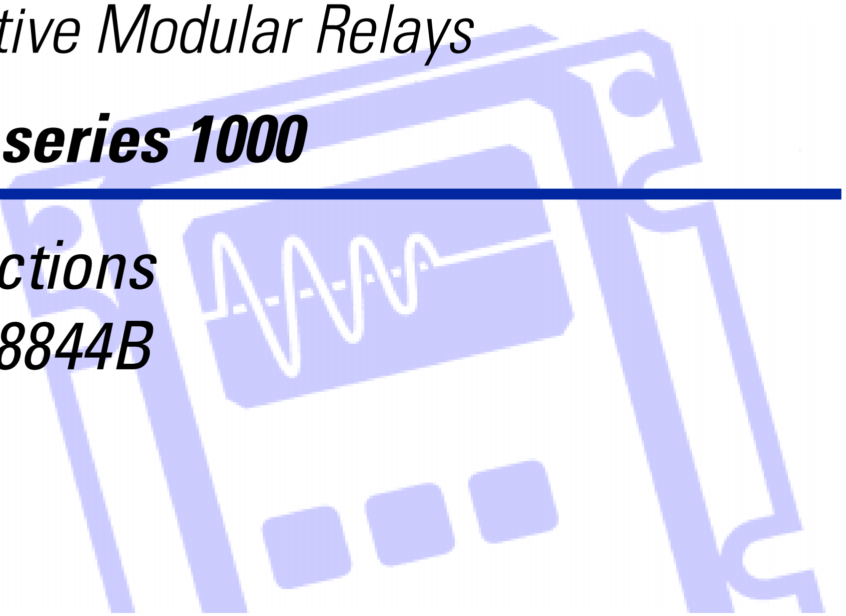


Microprocessor Based Motor Protective Modular Relays

MMC series 1000

Instructions
GEK 98844B



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1. DESCRIPTION

The 1000 series MMC provides a digital motor protection system that provides several protection functions such as: thermal protection by means of the thermal image from the line currents (49), phase-to-phase short-circuit (50), phase-to-ground short-circuits (51G), protection against locked rotor (51LR), protection against current unbalance or reversal (46), undercurrent protection (37) and monitoring of the number of starts (66).

The relay has been implemented using digital technology and is enclosed in a 19"-wide x 4-RU-high 1/3 module (non-drawout model) or ¼ module (drawout model).

The MMC has two tripping contacts, one of which is normally open and the other, electrically insulated, is a normally-closed contact. It is provided with two contacts (NO+NC) for a temperature pre-alarm, both are electrically insulated, and feature the same characteristics as the tripping ones. It also contains a NC contact for alarm of the device.

The information provided herein does not intend to cover all details of variations of the described equipment nor does it take into account the circumstances that may be present in your installation, operating or maintenance activities.

Should you wish to receive additional information, or for any particular problem which cannot be solved by referring to the information contained herein, please write to:

GENERAL ELECTRIC POWER MANAGEMENT S.A
Avda. Pinoa, 10
48170 Zamudio (SPAIN)

2. MODEL LIST

Data required for completely defining a type are indicated in the framed table. Please state clearly your characteristics together with the precise type identification.

MMC	1	0	*	0	D	0	1	0	*	00	*	DESCRIPTION
			0									5 A phase CT, 5 A ground CT
			1									5 A phase CT, 1 A ground CT
			2									5 A phase CT, 0.02 A ground CT (*)
			3									1 A phase CT, 1 A ground CT
												Auxiliary Voltage
									F			24/48 Vac/Vdc
									G			48/125 Vac/Vdc
									H			110/240 Vdc - 110/220 Vac
											C	Individual housing
											S	As part of a MID system

(*) This type must be used only with toroidal current transformers for the neutral current signal.

The possible models are:

MMC1000D010F00C
MMC1010D010F00C
MMC1020D010F00C
MMC1030D010F00C
MMC1000D010G00C
MMC1010D010G00C
MMC1020D010G00C
MMC1030D010G00C
MMC1000D010H00C
MMC1010D010H00C
MMC1020D010H00C
MMC1030D010H00C

MMC1000D010F00S
MMC1010D010F00S
MMC1020D010F00S
MMC1030D010F00S
MMC1000D010G00S
MMC1010D010G00S
MMC1020D010G00S
MMC1030D010G00S
MMC1000D010H00S
MMC1010D010H00S
MMC1020D010H00S
MMC1030D010H00S

3. OPERATING PRINCIPLES

3.1. MMC Setup

The MMC can operate at 50 or 60 Hz. The setup unit allows selection of the operating frequency.

Settings

The setup unit has been assigned the number 0. The settings are as follows:

0-1:	**Operating frequency**
Range:	50 OR 60 Hz

3.2. Thermal Protection

The MMC protection system, as mentioned earlier, provides thermal protection for three-phase AC motors by means of the thermal image obtained from the line current intensities. The MMC rated current (In) is multiplied by the factor that has been set by means of the front microswitches for finding the tap current (Is). The positive and negative sequence current intensities are given in times Is (please see section MMC FRONT ELEMENTS for details on the setting of Is).

Thermal image unit

The thermal image unit measures the current intensities from two phases of the motor. The protected circuit's current transformers supply the power for the relay input transformers, which reduce the current intensities to appropriate levels. These current intensities are digitized by means of an Analog-to-Digital converter; the subsequent processing is carried out based on digitized values.

An algorithm continuously calculates the positive and negative sequence component values I_1 and I_2. Subsequently, these values are combined producing an effect equivalent to:

$$Ieq = \sqrt{(I^2_1 + K_1 I^2_2)}$$

where K_1 is a constant that overvalues the effect of the negative sequence component I_2 and has been selected among the values 1-2-3-4-5-6.

In the previous formula, the negative sequence is included for protecting the motor against the effects produced by unbalanced currents, originated from the opening of one phase, unbalance of the phases or phase reversal. If line currents are not balanced, by using the symmetrical components, we can detect the appearance of a flux rotating at a synchronized speed but in the opposite direction. This flux produces in the rotor a supplementary heating that is transmitted to the stator, producing the effect of an overload. The MMC thermal image takes this effect into account and protects the motor against the overheating produced in the rotor and the stator due to the unbalanced currents. The thermal image unit protects the motor in a safe manner under short-term large-overload conditions.

The thermal image unit also protects the motor against excessively frequent starts, because once a trip has occurred, the tripping output remains active until the temperature drops below 80% of the tripping limit.

Operation mode

The above mentioned equivalent current intensity is processed by means of a thermal image algorithm to find an equivalent temperature at every moment. When the Thermal Image (θ) reaches a limit value of θ_{lim_x}, it causes the output to trip and the red TRIP LED lights.

The MMC F1 reading shows the percentage ratio between the temperature at a given moment and the limit value. This limit is the temperature at which the motor would be stabilized applying a symmetrical three-phase current system of the same modulus as the tap current. Please see section MMC OPERATION for the description of the reading details.

Figure 1 shows the operation time as a function of the equivalent thermal current of the thermal image curve for a time constant $\tau = 180$ s and with the motor starting from a cold state.

The time constants can be set to 3-60 minutes, with 3-minute steps. Operation times greater than the time constant $\tau = 3$ min are obtained by multiplying the matching times for 3 minutes by the appropriate factor. Thus, for example, the matching time for $\tau = 6$ will be twice the matching time for $\tau = 3$.

When cooling with the motor stopped takes place, the time constant that is used is different to the one that will be used for cooling the motor in service. This new time constant can be adjusted from 1 to 6 times the operation time constant with the motor in service. For the only purpose of selecting the time constant that is to be used, the MMC considers that the motor has come to a stop when the positive sequence component is smaller than 15% of the tap current

Settings

The thermal image unit has been assigned the number 1. Its settings are as follows:

1-1: **Negative sequence component overvaluing constant (K1).**
Range: 1 to 6 in 1-steps.
Units: Non dimensional.

1-2: **Time constant (τ_1)**
Range: From 3 to 60 in 3- steps.
Units: Minutes

1-3: **Time constant for cooling with the motor stopped (τ_2)**
Range From 1 to 6 in l-steps
Units: times τ_1.

This unit can be disabled if desired; this can be achieved by programming a 0 value in setting 1-2.

3.3. Positive Sequence Unit

The positive sequence component that has been calculated from the digitized data is compared to the programmed pick-up value. If it is greater than this value, the positive sequence unit timer is started. When the timer reaches the programmed time, the tripping output is set and the red TRIP LED lights.

The pick-up of the unit occurs at 100% the programmed pick-up value; its resetting takes place at 90% of the programmed pick-up value.

Settings

The positive sequence unit has been assigned the number 2. Its settings are as follows:

2-1 **Pickup current of the instantaneous trip**
Range: From 3 to 11 in steps of 1.
Units: Times Is.

2-2. **Timing.**
Range: From 50 to 100 in steps of 5
Units: milliseconds

This unit can be disabled if desired; this can be achieved by programming a 0 value in setting 2-1.

3.4. Negative Sequence Unit

The negative sequence unit features two operation modes: as an instantaneous tripping unit or as an inverse time tripping unit. In the latter mode, the unit matches the curve family shown in figure 2. The two modes cannot be active at the same time.

Instantaneous mode

The negative sequence component calculated from the digitized data is compared to the programmed pick-up value. If it is exceeded, the negative sequence unit timer is started. When the timer reaches the programmed time, the tripping output actuates and the red TRIP LED lights.

The pick-up of the unit occurs at 100% of the programmed pick-up value; its resetting takes place at 90% of the Programmed pick-up value.

Curve mode

The unit matches the curve family shown in figure 2. The pick-up value of the unit can be selected; this does not cause any variation of the curve form, but it is truncated, thus eliminating the current intensities to the left of the programmed values.

The pick-up of the unit occurs at 100% of the programmed truncated value; its resetting takes place at 90% of the programmed truncated value. The minimum tripping value is 105% of 0.2, that is, 0.21.

Settings

The negative sequence unit has been assigned the number 3. Its settings are as follows:

3-1: **Operation mode selection**
1: Instantaneous
2: Curve

3-2: **Pick-up value of the instantaneous trip.**
Range: From 0.5 to 8 in steps of 0.1.
Units: Times Is.

3-3: **Instantaneous trip delay.**
Range: From 0.05 to 10 in steps of 0.05
Units: seconds

3-4: Curve truncated value

Range:	From 0.2 to 1 in steps of 0.1
Units:	times Is.

3-5: Curve dial.

Range:	From 0.05 to 1 in steps of 0.05.
Units:	Non dimensional.

Each of the operation modes can be disabled independently if desired. For disabling the instantaneous mode, a 0 value is programmed in setting 3-2; for disabling the curve mode, a 0 value is programmed in setting 3-5. The purpose of the system is to prevent the unit from starting if in 3-1 a wrong mode is selected.

3.5. Zero Sequence Unit

The zero sequence current component can be applied to the relay either through a toroidal current transformer or a residual circuit of the three current transformers located in the system.

This current is digitized and compared to the programmed pick-up value. If it exceeds this value, the zero sequence unit timer is started. When the timer has reached the programmed time, the trip output actuates and the red **TRIP** LED lights.

The pick-up of the unit occurs at 100% of the programmed pick-up value; its resetting occurs at 90% of the programmed pick-up value.

Settings

The zero sequence unit has been assigned the number 4. Its settings are as follows:

4-1: Pick-up value of the instantaneous trip.

Range:	From 0.06 to 0.24 in steps of 0.01
Unit:	Times the neutral tap current (xIn GRN).

4-2: Timing.

Range:	From 0.05 to 10 in steps of 0.05.
Units:	Seconds.

This unit can be disabled if desired; this can be achieved by programming a 0 value in setting 4-1.

3.6. Locked Rotor and Excessively Long Start

When the fine current positive sequence component exceeds a programmed value, a timer is started. This timer must be set up at least to a time slightly higher than the motor starting time.

When starting the motor, if the rotor is locked or because of the load conditions the starting time is higher than the normal time, at the end of the starting time a current higher than the rated current will be sensed. This is an abnormal condition, and therefore a tripping signal is output and the red **TRIP** LED lights.

The pick-up of the unit occurs at 100% of the programmed pick-up value) its resetting occurs at 90% of the programmed pick-up value.

Settings

The locked rotor unit has been assigned the number 5. Its settings are as follows:

5-1: Pick-up value of the instantaneous trip.

Range:	From 1 to 4 in steps of 0.01
Unit:	Times Is

5-2: Timing.

Range:	From 1 to 60 in steps of 1
Units:	Seconds.

This unit can be disabled if desired; this can be achieved by programming a 0 value in setting 5-1.

3.7. Undercurrent Unit

When the positive sequence component drops below a programmed value, but is higher than 15% of the tap current value, this unit is started. When the timer reaches the programmed time, the tripping output operates and the red **TRIP** LED lights.

The pick-up occurs when the current is less than the programmed value and greater than 15% of the tap current value. The unit is reset if the current reaches a value higher than 110% of the programmed value or drops below 13.5% of the tap current value.

Settings

The undercurrent unit has been assigned the number 6. Its settings are as follows:

6-1: Pick-up value of the instantaneous trip.
Range: From 20 to 80 in steps of 10
Unit: Times Is as a percentage value

6-2: Timing.
Range: From 0.1 to 10 in steps of 0.1.
Units: Seconds.

This unit can be disabled if desired; this can be achieved by programming a 0 value in setting 6-1.

3.8. Control Unit for Monitoring the Number of Starts

This unit detects the number of motor starts and prevents that, within a given time, a number of starts greater than a programmed value is carried out. The detected starts are entered into a "Time window" of programmable duration. For example, if the window duration is programmed to 20 minutes, a start remains inside the window during the twenty minutes after the start is detected. When there is a number of starts equal to the programmed value in the window, the unit will trip if the motor comes to a stop, to prevent it from restarting. The unit will never trip with the motor in service. The tripping output is indicated by means of the red **TRIP** LED.

Once the trip has occurred, the tripping output remains active after a minimum user-programmable time span. Once this time has elapsed, it will remain active while there is in the time window a number of starts greater than, or equal to, the programmed value (the only way in which a number of starts greater than the programmed value can be carried out is when the tripping contact does not stop the motor; for example during test runs).

The maximum number of starts that can be stored in the time window is 10. If the number of starts exceeds this value, the "oldest" one in the window will be deleted and the last start will take its place. It is useful to take into account this behavior when running tests where the tripping output does not prevent further starts.

Settings

The control unit for monitoring the number of starts has been assigned the number 7. The settings are as follows:

7-1: **Time window span**

Range:	From 10 to 100 in steps of 1
Unit:	Minutes

7-2: **Number of permitted starts.**

Range:	From 1 to 10 in steps of 1.
Units:	Starts.

7-3: **Minimum tripping contact operating time**

Range:	From 10 to 100 in steps of 1
Unit:	Minutes

This unit can be disabled if desired; this can be achieved by programming a 0 value in setting 7-2.

For the purposes of detecting the number of starts, it is considered that the motor is stopped when the positive sequence current drops below 0.15 times the tap current value and remains at such a value for a continuous period of time of at least 0.1 seconds. A start is detected when, with a stopped motor (in accordance with the previous definition) the positive sequence current increases to a value of 0.15 and 0.70 times the tap current value for less than 0.1 seconds. If it increases to a value over 0.15 times the above mentioned value and remains for over 0.1 seconds, but does not fulfill the starting condition, it is considered that the motor is in operation, but no start operation is counted.

3.9. Auxiliary Power Supply

The auxiliary power supply provides the control auxiliary voltage of +5 VDC and +24 VDC for the internal circuitry.

There are three types (see Type List):

F Type:	24-48 V AC/DC
G Type:	48-125 V AC/DC
H Type:	110-240 V DC / 110-220 V AC

4. APPLICATION

Before a motor protection is selected, it is important to carefully bear in mind its main characteristics such as Power, Operation Voltage, Starting Current and Duration, Load characteristics, maximum time that a locked rotor condition can exist, as well as the current flowing under those conditions, etc.

4.1. Requirements for Protecting a Motor

Basically there are two conditions under which the motor is to be protected:

External conditions:

They depend basically on the conditions established by the power supply network the motor is connected to, and they can be itemized as follows:

- Unbalanced network voltages.
- Low operating voltages.
- Phase failure.
- Phase inversion.
- Loss of synchronization (synchronous motors).

Internal conditions

These are created by failures of the motor itself, such as:

- Bearing failures.
- Internal short-circuits.
- Overloads.

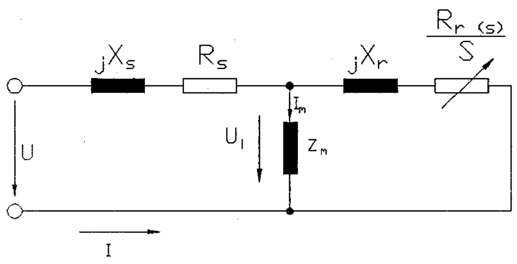
4.2. Induction Motor Characteristics

4.2.1. Starting Operation

During the start, the motor impedance is small because an induction motor equivalent circuit under those conditions is very similar to the one of a short-circuited-secondary-winding transformer (see diagram). This causes the starting current typically to be 4 to 8 times the motor rated current. Also, the motor starting time is approximately 10 to 15 seconds, and the starting current remains virtually constant during 90% of the starting time and then it rapidly decreases to the rated current or to the continuous load current

When connecting the motor, a very high asymmetrical current peak is produced, which can reach up to 2.5 times the pick-up current, but of very short duration (approximately one cycle).

INDUCTION MOTOR EQUIVALENT CIRCUIT DIAGRAM



$$I = \frac{U}{\sqrt{(X_s+X_r)^2 + \left(R_s + \frac{R_{r(s)}}{S}\right)^2}}$$

I = Motor stator current
Im = Magnetization current
U = Terminal voltage
Rs= Stator resistance
Rr(s) = Rotor resistance relative to the stator
S = Slip
Xr = Rotor dispersion reactance
Xs = Stator dispersion reactance
Zm = Magnetization impedance

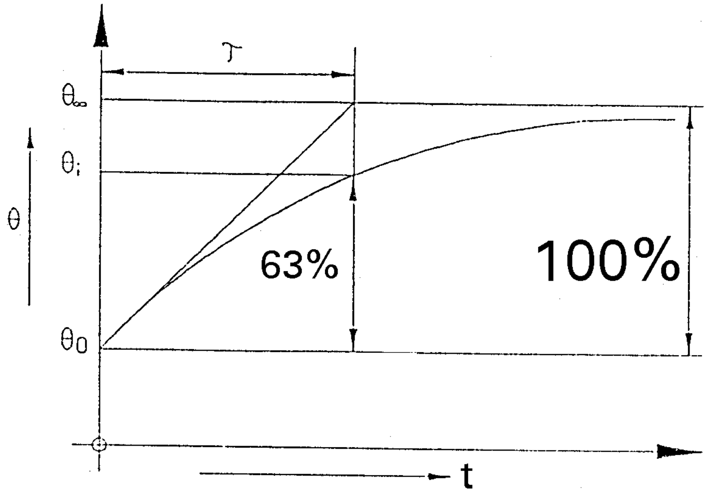
4.2.2. Motor in Service

According to the design and the optimization conditions, a motor working at continuous duty cycle operates within its heating limits, and therefore it is necessary to avoid thermal overloads that can damage the insulation, which is one of the weakest motor components.

In continuous duty, the motor heats up in accordance to an exponential relationship up to a final value, because heat is continuously delivered to the environment. Also, in normal operation the cooling time constants are similar to the heating time constants. On the other hand, if the motor is at a complete stop after having been in operation, the cooling time constants can be 4 to 6 times greater than the heating time constants. That is, a motor will take more time for cooling if it is stopped.

The "Time constant"" represented by τ is the time required for a body that is to be heated from an initial temperature θ_0 to a final temperature θ_∞ to reach 63% of the required temperature increase for reaching θ; that is, the time that it will take to reach the intermediate temperature θ_i from the temperature θ_0, where:

$$\theta_i = \theta_0 + (\theta_\infty - \theta_0) \times 0.63$$



If we make θ_0 as the origin of temperatures, at a given moment the temperature will be given by:

$$\theta = \theta_N \left(1 - e^{-(1/\tau)}\right) (I/I_N)^2$$

where:

θ: Temperature increase at a given time
θ_N. Rated temperature (temperature reached if $I = I_N$)
I_N Motor rated current
I: Current flowing through the motor (Motor current)
t: Time
τ: Time constant

4.2.3. Motor Overload

The overload condition in a motor occurs mainly under the following conditions:

- When the start is carried out over an excessively long period of time
- When mechanical problems make it difficult for the motor to start normally, originating a torque value greater than the rated value.
- Because of a phase voltage failure.

4.3. MMC Thermal Curves

The equation for the temperature given above was:

$$\theta = \theta_N \left(1 - e^{-(1/\tau)}\right) (I/I_N)^2$$

The MMC uses an equation, in which the tripping time is a function of the motor current, thus eliminating all references to the temperatures. The time constant τ in the MMC is designated as τ_1.

By means of microswitches located on the relay front plate, a tap current can be programmed. If the relay current is greater than the programmed tap current, the thermal protection will trip after a period of time which is given by the following equation:

$$t = \tau_1 \ln \frac{I^2}{I^2 - 1}$$

where:

t = Tripping time
τ_1 = Time constant
I = Im / Is
Im = Motor current
Is = Programmed tap current

This equation can be applied only if the relay starts from the thermal Zero Status, that is, from a condition at which a current I=0 was flowing through it. If, on the contrary, the relay had stabilized at a condition at which a given current was flowing through it, the value of which is smaller than the rated current, and at a given moment the current increases up to a value greater than the rated current, the tripping time from the moment at which the increase takes place is given by the equation:

$$t = \tau_1 \ln \frac{I^2 - I^2_e}{I^2 - 1}$$

where:

I_e = Ime / Is
Ime = Current at which the motor had stabilized
Is = Programmed tap current

and the rest of the symbols have the same meaning as in the previous equation.

In these equations, Im is defined as follows:

$$Im = \sqrt{(I^2_1 + K_1 I^2_2)}$$

where:

I_1: Positive sequence component
I_2: Negative sequence component

It has been found that this equation adequately represents the input current negative sequence component effects on the motor. The constant K1 is an integer value programmable from 1 to 6.

These equations show the theoretical curves on which the MMC is based. The thermal image unit works in accordance to the curve shown in figure 1, which very closely matches the theoretical values.

Im is called "Equivalent thermal current" and we represent it by Ieq

4.4. Digital Protection System Application Range

The MMC protects the motor against:

- Overload and temperature excess by means of the thermal image unit.
- Phase-to-phase faults, by means of the positive sequence instantaneous overcurrent trip.
- Locking of the rotor and an excessively long start, by means of a separate positive sequence overcurrent trip unit.
- Starting in single-phase, by means of a negative sequence overcurrent trip unit.
- Ground faults, by means of a zero sequence overcurrent trip unit.
- Pump no-load operation, by means of an undercurrent unit.

- Excessive frequency of starts, by means of a control unit for monitoring the number of starts.

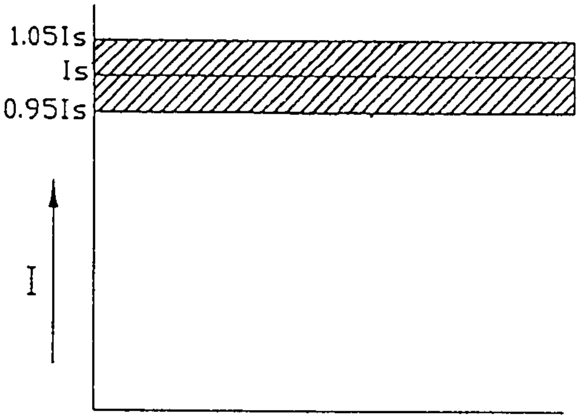
4.5. Application Criteria of the Overload Protection

For the correct regulation of the thermal element, we will have to act upon a selection of the input current (relay tap current, Is) as well as upon the thermal element time constant.

Every electric motor has a rated current (I_M), which can flow through it in such a way that it can work indefinitely without being damaged. It also has a maximum overload value (S) that is expressed in times I_M . With these two values we must delimit the relay input current setting.

The relay measurement error determines, for a given tap current, an area in which the tripping can occur. Since the MMC error is ±5%, the tripping range covers from 1/0.95 Is (≈1.05 Is) up to 1/1.05 Is (≈0.95 Is).

MMC TRIPPING RANGE



The main criterion that must be taken into account is as follows: **the tripping range must lie under the motor maximum overload range.** In this way it can be ensured that the relay will trip if the current exceeds the maximum overload value, thereby ensuring an adequate motor protection.

The second criterion that must be borne in mind is as follows: **the tripping range must lie above the nominal current intensity.** In this way we will utilize the motor operation range in an optimum manner.

If the motor characteristics are such that both criteria cannot be met at the same time, the main criterion has preference over the second one and we must trade off one part of the working range with the motor overload protection for overload levels that cannot be supported.

An application example of these criteria in two particular cases follows.

For the adjustment of the setting current, the following data are required:

S = Maximum permissible overload. For example, if a 10% overload is allowed, S = 1.1.

I_M = Motor rated current at full-load

R_{TI} = Transformation ratio of the line current transformers.

I_N = Relay rated current.

Example 1

Let us assume a motor with the following characteristics:

Power: 800 HP
Voltage: 6000 V
Efficiency: $\eta = 0.96$
Power factor: $\cos \varphi = 0.93$
Maximum permissible overload: 15%
Starting time: 25 sec.
Maximum time with locked rotor: 40 sec
Starting current: 5 times the rated current
Transformation ratio:75/5 (15)
MMC rated current: 5A

The motor rated current is computed as follows:

$\text{Pot (KW)} = \sqrt{3}\, V I_M\, \eta \cos \varnothing = \text{Pot (CV)} \times 0.736$

$$I_M = \frac{800 \times 0.736}{0.96 \times 0.93} \times \frac{1}{\sqrt{3}} \times \frac{1}{6\text{ kV}} \approx 63.5\text{ A}$$

Now this rated current is converted to relay reading values. For such a purpose, we must take into account the fine current transformer transformation ratio as well as the MMC rated current; we will designate Im the motor rated current seen by the MMC, expressed in times the MMC rated current:

$$I_m = \frac{I_M}{R_{TI} \times I_N}$$

in this case:

$$I_m = \frac{63.5}{(75/5) \times 5} = 0.8467$$

therefore, the maximum overload current has a value of:

$$1.15 \times 0.8467 = 0.9737$$

in order to comply with the main criterion, the current Is must be less than or equal to:

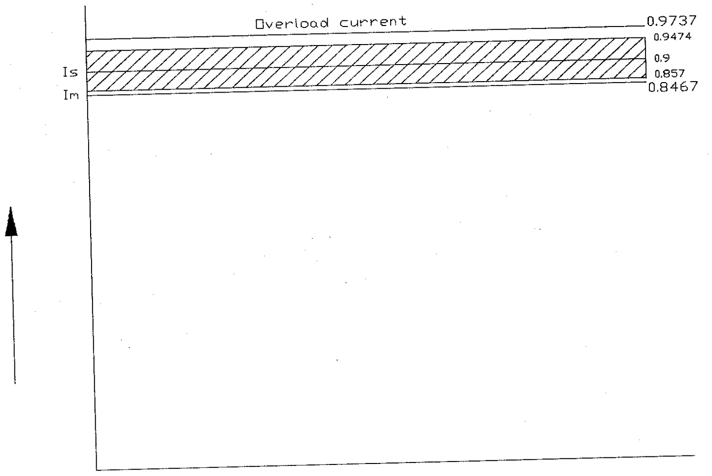
$$0.9737 / 1.05 = 0.9273$$

On the other hand, in order to comply with the second criteria, the current Is must be greater than or equal to:

$$0.8467 / 0.95 = 0.891$$

Thus, Is must be set to a value selected between 0.891 and 0.9273. We select 0.9, for which we move all front panel microswitches to the left except for the ones that are marked as 0.4 and the one marked as 0.1, which give us a sum of (0.4 + 0.4 + 0.1) = 0.9. In the figure, the tripping range for this setting is shown.

TRIPPING RANGE - EXAMPLE 1



Example 2

Let us assume a motor with the following characteristics:

Power: 400 HP
Voltage: 380 V
Efficiency: $\eta = 0.92$
Power factor: $\cos \phi = 0.89$
Maximum permissible overload: 10%
Transformation ratio: 600/5 (120)
MMC rated current: 5A

The motor rated current is computed as follows:

Pot (KW) $= \sqrt{3}\, V I_M\, \eta \cos \varphi$ = Pot (CV) x 0.736

$$I_M = \frac{400 \text{x}\ 0.736}{0.92 \times 0.89} \times \frac{1}{\sqrt{3}} \times \frac{1}{0.38\ \text{kV}} \approx 546\ \text{A}$$

$$I_m = \frac{546}{(600/5) \times 5} = 0.91$$

The maximum overload current is as follows:

$$1.1 \times 0.91 = 1.001$$

In order to comply with the main criterion, the current Is must be less than or equal to:

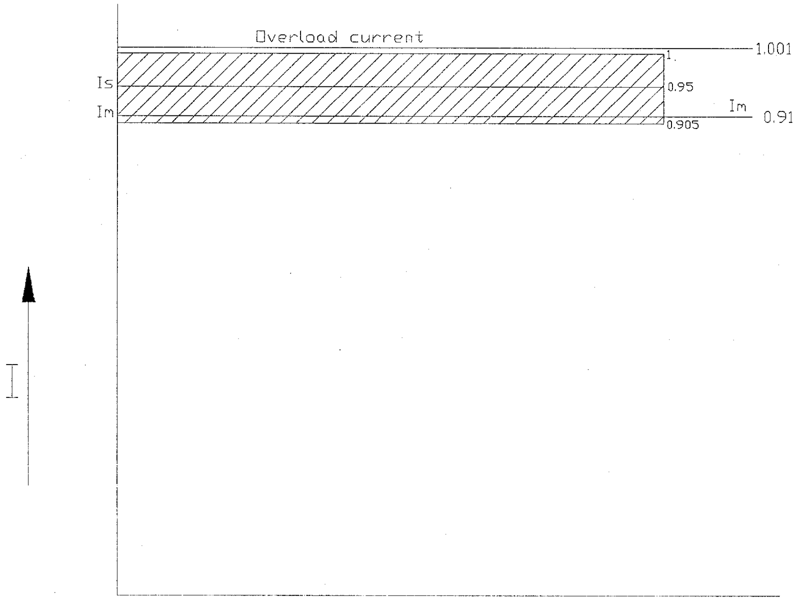
$$1.001 / 1.05 = 0.953$$

In order to comply with the second criterion, the current Is must be greater than or equal to:

$$0.91 / 0.95 = 0.9578$$

It is not possible to comply with both criteria at the same time, and therefore we will give priority to the first one and we will select Is = 0.95; for such a purpose we move to the left all microswitches on the front panel except for those marked as 0.4, the one marked as 0.1, and the one marked as 0.05, which gives us a sum of (0.4 + 0.4 + 0.1 + 0.05) = 0.95. In the figure below, it can be seen that the tripping range overlaps a part of the operation range.

TRIPPING RANGE - Example 2



For carrying out the time constant setting, the manufacturer must provide the time that the motor takes to reach a maximum permissible temperature at a given current, and by means of the formula $I^2t = K$ we will calculate the time constant that is to be used. Let us assume in the motor in example 1 this time to be 240 seconds at 150 A.

At the relay terminals we will have a current of:

$$150 \times (5 / 75) = 10 \text{ A}$$

Therefore

$$K = 10^2 \times (240) = 24000$$

At the curve corresponding to $\tau 1 = 180$ seconds we select the point matching 5 times the tap current, because in a worst case scenario (when starting) the current will be 5 times the rated value: an actuation time of 7.35 seconds matches this point.

$I = 5 I_M = 5 \times 0.95 \times 5 = 23.75$ A

$I^2t = 23.75 \times 7.35 = 4146$

So we can conclude that

$K/K_{180} = \tau_1/\tau_{180}$ = 24000 / 4146 = 5.7887

And the time constant to which the motor must be set is 5.7887 times greater than the minimum time constant.

τ_1 = 5.7887 x 180 = 1042 = 17.36 minutes

The closest one is clearly τ_1 = 18 minutes, which will be the selected one.

4.6. Phase-to-Phase Fault Protection

Should a short circuit between a motor's terminals occur, the fault current is generally greater than any normal current, including the starting current. In general, with a timing between 50 and 100 ms, such as the one that the MMC allows, the positive sequence protection actuating current must be selected to a value less than 50% of the three-phase short-circuit current, but greater than 160% of the starting peak current. For the motor in example 1, a value for $I_1>>$ = 8 (eight times the tap current) should be selected.

4.7. Ground Faults

As a general criterion, for the zero sequence unit setting a value of 20% the ground fault minimum current at the motor terminals must be taken as the protection operating value.

4.8. Locked Rotor Protection

A motor with its rotor locked is in a dangerous situation because of the enormous heat loss that cannot be dissipated at the necessary rate.

In general, it is not possible to make a distinction between this condition and the abnormal start only with the current as a criterion. It is also necessary to measure the time for which the current exists in order to see if it is greater than the motor normal starting time.

The motor starting time is about 10 sec and the maximum time that the motor (rotor) can remain locked is about 20 sec. It is very important that the manufacturer provides exact time values.

In the motor in case 1, a value between 25 and 40 sec should be programmed. A setting of 29 or 30 seconds will be appropriate.

4.9. Protection against Single-Phase Starting

The negative sequence instantaneous trip unit protects against input voltage unbalances. It can be selected between instantaneous operation or in accordance with the inverse time curves of figure 2.

4.10. Protection against Pump Priming Loss

For preventing damage to pumps in no-load operation, the MMC is provided with an undercurrent tripping unit. This unit constantly monitors the positive sequence component value. If it decreases below the programmed value a tripping signal is output, except if the current decreases below 15% the tap current setting limit. The tripping can be timed from 0.1 to 10 *sec*

4.11. Protection against Excessively Frequent Starts

In order to avoid the damage that may be caused by the accumulative effect of an excessive number of starts in a short period of time in the motor, the MMC is provided with a control unit for monitoring the number of starts. This unit prevents the occurrence of a number of starts greater than the programmed value for a given time, which is also programmable. If this unit trips, the tripping outputs remain active for a minimum programmable time in order to allow a recovery period for the motor.

5. TECHNICAL SPECIFICATIONS

5.1. Current Circuits

Rated currents

5 A or 1A for the phase elements; 5 A or 1 A for the ground element. Also 20 mA for a special ground unit.

Thermal capacities

Continuous:	4 x In
For 3 seconds:	50 x In
For 1 second:	100 x In

Loads

For unit types of:

In = 5A	0.3 VA.
In = 1A	0.3 VA.
In = 0. 02A:	0.08 VA

5.2. Setting Ranges

Thermal image unit

Tap currents (Is)
From 0.40 to 1.55 x In in 0.05xIn steps.

Time constant (τ_1)
From 3 to 60 minutes in 3-minute steps.

Cooling time constant" with the motor stopped (τ_2)
1, 2, 3, 4, 5 or 6 times τ_1

Negative sequence overvaluing constant" (K1)
Discrete values among 1, 2, 3, 4, 5 and 6.

Alarm temperature
80% of the tripping temperature.

Positive sequence unit

Range

From 3 to 11 times the selected tap current at the thermal image unit in 1-steps.

Operation time

Timed from 50 to 100 msec in 5 msec steps.

Instantaneous-mode negative sequence unit

Range

From 0.5 to 8 times the selected tap current at the thermal image unit in 0.1 steps.

Operation time

Timed from 0.05 to 10 sec in 0.05 sec steps.

Curve-mode negative sequence unit

The same curves as in figure 2, but truncated with a value which can be selected between 0.2 and 1.0 times the tap current in 0.1 steps.

Zero sequence unit

Range

From 0.06 to 0.24 times the zero sequence unit rated current (InGRN) in 0.01 steps.

Rated current

1 A or 5 A and 20 mA (optional).

Operation time

Timed from 0.05 to 10 sec in 0.05 sec steps.

Locked-rotor monitoring unit

Range

From 1 to 4 times the tap current selected at the thermal image unit in 0.1 steps.

Operation time

Timed from 1 to 60 sec in 1 sec steps.

Undercurrent unit

Range

From 20% to 80% of the tap current which has been selected at the thermal image unit, in 10% steps.

Operation time

Timed from 0.1 to 10 sec in 0.1 sec steps.

Unit for monitoring the number of starts

Range

From 1 to 10 starts in 1-steps.

Time window

From 10 to 100 minutes in 1-minute steps.

Minimum time with active tripping

From 10 to 100 minutes in 1-minute steps.

5.3. Frequency

50 and 60 Hz, user-programmable.

5.4. Tripping Contacts

Closing capacity:	3000 W, resistive, for 0.2 seconds, with a maximum of 30 A and 300 VDC.
Switching capacity	50 W, resistive, with a maximum of 2A and 300 VDC.
Continuous capacity	5A with a maximum of 300 VDC.

5.5. Alarm Contacts

Closing capacity: 5 A DC during 30 seconds and a maximum of 250 V DC.
Switching capacity: 25W, inductive, at a maximum of 250 V DC
Continuous capacity: 3 A.

5.6. Accuracy

Operation value: 5%
Operation time: 5 % or 0.025 sec, (whichever is greater)

Class E error rating to BS142 for current values and operation times: E-5 class.

5.7. Repeatability

Operation value: 1%
Operation time: 2% or 0.025 sec (whichever is the greater).

5.8. Temperature Ranges

Effective range	-5ºC to +40ºC
Operating range	-10ºC to +55ºC
Storage range	-40ºC to +65ºC

5.9. Ambient Humidity

Up to 95% without dew condensation

5.10. Insulation

Between each terminal and frame: 2000 V AC during 1 minute at industrial frequency.

Between independent circuits: 2000 V AC during 1 minute at industrial frequency.

Between each output circuit terminal:	1000 V AC during 1 minute at industrial frequency.

5.11. Type Tests

Interference tests

2,5 kV longitudinal mode, 1 kV transverse mode, III class according to IEC 255-4.

Impulse testing

5 kV peak value, 1.2/50 /sec, 0.5 J according to IEC 255-4

Electrostatic discharge

According to IEC 801-2, III class.

Radio interference

According to IEC 801-3, III class.

Fast transients

According to IEC 801-4, III class.

5.12. Power Supply

There are three types (see Type List):

F Type: 24-48 V AC/DC
G Type: 48-125 V AC/DC
H Type: 110-240 V DC / 110-220 V AC

Consumption: less than 1.5 W at all voltages.

5.13. Weights

Approximate weight:

- Net	4 kg
- Package	5 kg

6. CONSTRUCTION

6.1. Case

The MMC case is made of plated steel. The general outline is shown in figure 8.

The front cover is made of plastic, and can be fitted to the relay case by pressing on a rubber gasket located around the relay, which produces a dust-proof sealing.

6.2. Electrical and Internal Connections

Connection of the external wires is carried out at the two terminal blocks mounted in the outside of the case. Each terminal block contains 12 screw terminals, each of 4 mm screwed diameter.

All current inputs are located on a terminal block, which is located on the back, on the same back plate. This block has the capability of supporting the current transformer's secondary currents. The internal current input wires have a greater cross-section than the rest of the internal connection wires. They have been designed so that they have the minimum possible length to minimize the resistive load supported by the current transformers. The connections are produced through snap-on terminals. The input current wires run in their own harnesses, separated from the rest of the wire harnesses so that the magnetic field coupling effects associated with the input currents on the weak current internal wires can be minimized.

6.3. Identification

The complete relay type data is stated on the nameplate. Figure 3 shows the MMC front plate.

The terminal blocks are identified by characters located on the back plate, just over each block left edge (with the relay viewed from behind). There are two terminal blocks in each box and each has a single code (from A to B) to avoid confusion when connecting the external wires.

At each terminal block, the coupling screws (1 to 12) are marked with engraved numbers.

6.4. MMC Front Elements

On the MMC front as well as on its front plate, as shown in figure 3, the following setting and signaling elements are located:

Current tap select switch

This element selects the minimum relay operating current. It consists of 2 three-switch banks, five of which have a number marked on the right side. The switches are open when they are positioned to the left and closed when they are positioned to the right side. The tap current at which the relay is set (Is) will be the product of the rated phase current (In) times 0.4 plus the addition of the amounts written to the right side of each closed switch.

Example: setting a relay of In = 5A for an Is of 4.5A.

For this purpose, and since 5 x 0.9 = 4.5, we must close the necessary switches for obtaining an amount of 0.5, which, added to the fixed amount of 0.4, will give us 0.9; we will get this by closing the switches marked 0.4 and 0.1 and opening all the rest.

The current range is:

Is from 0.40 to 1.55 xIn in 0.05xIn steps.

Push buttons and display

The MMC is provided with three push buttons for controlling all relay operations. It is also provided with three luminous seven-segment displays for providing information to the user. A detailed description of the operation of those elements is given in section MMC OPERATION

6.5. External Signaling

The MMC is provided with three light-emitting diodes (LEDs) on the relay front plate for signaling the following conditions:

- **In service**. Green LED that indicates that the relay is in operation.
- **Protection pick-up**. Red LED that indicates that a protection unit has been operated.

- **Protection tripping**. Red LED that indicates that a protection unit has tripped. This LED remains lit until it is switched off by the user through a RESET (please see section MMC OPERATION); if the relay auxiliary voltage is switched-off, when it returns, the LED will change to the status it had before the voltage was switched-off

7. RECEPTION, HANDLING AND STORAGE

This relay is supplied to the customer in a special package, which adequately protects it during transportation, as long as this is performed in normal conditions.

Immediately after receiving the relay, the customer should check whether it shows any signs of transportation damage. If it is apparent that the relay has been damaged by inappropriate handling, it must be immediately advised in writing to the carrier, and the damage must be reported to the manufacturer.

For unpacking the relay, normal care should be taken in order not to lose the screws also supplied in the box.

If it is not intended to install the relay immediately, it is recommended to store it in its original package, and keep it in a dry and dust-free place.

7.1. Reception Test

Upon reception of the equipment, it is recommended to carry out an immediate visual check, as well as the tests that are described below, in order to make sure that the relay has not been damaged during transportation.

These tests can be carried out as installation or receipt tests, at the user's discretion. Since most users apply different procedures for installation and receipt tests, this section will indicate all tests that can be carried out with the MMC.

If the tests that have been carried out show that the relay does not function correctly, it must be reported to the manufacturer. Because of its digital design, the MMC does not require any calibration changes.

7.2. Visual Check

Make sure that the device type indicated on the front plate matches the order data.

Unpack the relay and make sure that there are no broken parts and there are no signs that the relay has been damaged during transportation.

7.3. General Considerations on the Power Supply Network

All devices that function with alternating current are influenced by frequency. Since a non-sinusoidal waveform results from a fundamental frequency wave plus a series of harmonics of this fundamental wave, it can be concluded that devices working with alternating current (relays) are influenced by the applied waveform.

In order to correctly test relays that operate under alternating current, it is fundamental to use a sinusoidal current and/or voltage wave. The purity of the sinusoidal wave (the lack of harmonics) cannot be expressed in a specific form for a given relay. Each relay that is provided with tuned circuits, R-L and R-C circuits or non-linear elements (such an inverse time overcurrent relays) will be affected by non-sinusoidal waveforms.

These relays respond to the current waveform in a different way from most AC amperemeters. If the power supply network that is used for the test contains a considerable amount of harmonics, the amperemeter and relay responses will be different.

The relays are calibrated by the manufacturer using a 50 or 60 Hz power supply network with minimum harmonic contents. When the receipt or installation tests are carried out, a power supply network with a harmonic-free waveform will have to be used.

Amperemeters and stop-watches that are used for carrying out the test must be calibrated and their accuracy must be better than that of the relay. The power supply network used for the tests must remain stable, mainly at levels close to the test pick-up current, as well as for the time for which the relay operates according to the curve under test.

It's important to stress that the test accuracy depends on the power supply network conditions as well as on the instruments used. Functional tests carried out under inappropriate power supply conditions or using inappropriate instruments can be used for making sure that the relay functions correctly and, therefore, for verifying its characteristics in an approximate manner.

7.4. Thermal Image Unit

This section describes the procedure for testing the MMC relay by means of the three-phase power supply network. The testing procedure by means of the single-phase power supply is described in Appendix 1.

1. Connect the relay as shown in figure 5. For supplying power to the relay, a 127 or 220 V - 50 Hz or 120 V - 60 Hz power supply with a variable series resistor must be used.

2. Disable the rest of the units in order to avoid any interference when testing. For that purpose, zero the settings 2-1, 3-2, 3-5, 4-1, 5-1, 6-1 and 7-2 following the procedure explained in the section MMC OPERATION.

3. Set the relay to the minimum tap value. For that purpose, by referring to figure 3 that shows the relay front panel:

   Position all tap current selection switches to the left.

   Set the time constant $\tau 1$ to 3 minutes (1-2 setting).

   Set the negative sequence component" overvaluing constant" to 3 (setting 1-1).

4. Apply successively currents of 2, 5 and 10 times the minimum tap value and make sure that the operating times are within the ranges shown in Table 1. Make sure that the output relay operates and the TRIP LED lights.

TABLE 1

Rated Current (A)	Applied Current (A)	Times minimum Is	Operation Time (sec)
5	4.0	2	48.5 - 53.6
	10.0	5	7.06 - 7.80
	20.0	10	1.77 - 1.95

5 Repeat point 4 test for selecting the constant" time T of 60 minutes. Check that the operation time lies within the ranges indicated in Table 2.

TABLE 2

Rated Current (A)	Applied Current (A)	Times minimum Is	Operation Time (sec)
5	4.0	2	960 - 1072
	10.0	5	141 - 156
	20.0	10	35.4 - 39

After each measurement the thermal image unit must be reset - please see "Zeroing the thermal image" in MMC OPERATION SECTION - so that the time obtained in the following test matches the values shown in figure 1 (Cold motor).

7.5. Positive Sequence Unit

1 Set up the relay to the minimum tab current. The positive sequence unit must be set to three times Is. Set the timing to 50 milliseconds

2 Disable the rest of the units so they don't interfere with the test, by zeroing the settings 1-2, 3-2, 3-5, 4-1, 5-1, 6-1 and 7-2 following the procedure explained in MMC OPERATION section.

3 Apply current to the relay and check that the PICK-UP LED lights, and then the tripping relay closes when the current lies between 95% and 105% of the set pick-up value.

4 With the tripping relay contact closed, decrease the applied current, making sure that the tripping relay is reset and the PICK-UP LED goes out for a current equal to, or greater than, 85.5% of the pick-up value.

Operation time checking

5 With the relay set up as shown in section 1, apply a current twice as large as the pick-up current (that is, 6xIs) and check the tripping time equals 50 milliseconds within the applicable error ranges for this relay. Repeat the test with this timer set to 100 milliseconds.

7.6. Negative Sequence Unit

Connect the relay as indicated in figure 6.

Instantaneous mode: pick-up checking

1 Set the relay to the minimum tap value. Select the instantaneous mode for the negative sequence unit. Set the pick-up value to 1 time Is. Adjust the timer to 50 milliseconds.

2 Disable the rest of the units so that they don't interfere with the testing, by zeroing the settings 1-2, 2-1, 3-5, 4-1, 5-1, 6-1 and 7-2 following the procedure explained in MMC OPERATION section.

3 Apply current to the relay and check that the PICK-UP LED lights and then the tripping relay closes when the current is between 95% and 105% of the set pick-up value.

4 With the tripping relay contact closed, increase the applied current making sure that the tripping relay resets and the PICK-UP LED goes out for a current equal to, or greater than, 85.5% of the pick-up value.

Instantaneous-mode: operation time checking

5 With the relay setup as shown in section 1, apply a current twice as large as the tap current (that is, 2xIs) and check that the tripping time equals 50 milliseconds within the applicable error ranges for this relay. Repeat the test with the timer set to 1n sec

Inverse-time mode: pick-up current calibration checking

6 Set the relay to the minimum tap current. Select the inverse time mode for the negative sequence unit. Adjust the truncated value to 0.2 times Is. Select the 0.1 dial curve.

7 Apply current to the relay and check that the relay front PICK-UP LED lights between 100 and 110% of the set truncated value and then the tripping relay closes.

8 With the output relay contact closed, decrease the applied current, making sure that with a current equal to, or greater than, 85.5% of the set truncated value, the output relay is reset and the PICK-UP LED goes out. Repeat the test for the truncated value of 1.

Inverse time mode: operating time checking

9 Adjust the relay to the minimum tap current. Select the inverse time mode for the negative sequence unit. Adjust the truncated value to 0.2 times Is. Select the 0.5 dial curve.

10 Disable the rest of the units so that they don't interfere with the testing, by zeroing the settings 1-2, 2-1, 3-2, 4-1, 5-1, 6-1 and 7-2 following the procedure explained in MMC OPERATION section.

11 Apply successively currents of 0.4, 1, 2 and 10 times the minimum tap current, making sure that the operation time is within the ranges indicated in Table 3.

TABLE 3. Inverse time curve
(I = 5A)

Times the minimum tap current	Applied current (A)	Curve operation times (IT = 0.5) in seconds
0.4	0.8	8.9 - 11.24
1.0	2.0	3.82 -4.43
2.0	4.0	2.3 -2.55
10.0	20.0	0.88 -0.973

7.7. Zero Sequence Unit

Connect the relay as shown in figure 7.

Pick-up checking

1 Set the relay to the minimum tap current. The zero sequence unit will be set to 0.06 times In GRN. Set the timing to 50 milliseconds.

2 Disable the rest of the units so that they don't interfere with the test, by zeroing settings 1-2, 2-1, 3-2, 3-5, 5-1, 6-1 and 7-2 following the procedure explained in MMC OPERATION section.

3 Apply current to the relay and check that the PICK-UP LED lights and then the tripping relay closes when the current lies between 95% and 105% of the set pick-up value.

4 With the tripping relay contact closed, decrease the applied current making sure that the tripping relay resets and the PICK-UP LED goes out for a current equal to, or greater than, 85.5% of the pick-up value.

Operation time checking

5 With the relay set up as shown in section 1, apply a current twice as large as the pick-up current (that is, 0.12 x In GRN) and check that the tripping time equals 50 milliseconds, within the applicable error ranges for this relay. Repeat the test with this timer set to 10 milliseconds

7.8. Locked Rotor and Excessively Long Start Unit

Connect the relay as indicated in figure 5.

Pick-up checking

1 Set up the relay to the minimum tap current. The locked rotor unit will be set to 1 time Is. Adjust the timing to 1 second.

2 Disable the rest of the units so they don't interfere with the test, by zeroing settings 1-2, 2-1, 3-2, 3-5, 4-1, 5-1, 6-1 and 7-2 following the procedure explained in MMC OPERATION section.

3 Apply current to the relay and check that the PICK-UP LED lights and then the tripping relay closes when the current lies between 95% and 105% of the set pick-up value.

4 With the tripping relay contact closed, decrease the applied current making sure that the tripping relay resets and the PICK-UP LED goes out for a current equal to, or greater than, 85.5% of the pick-up value.

Operation time checking

5 With the relay set up as shown in section 1, apply a current twice as large as the pick-up current (that is, 2xIs) and check that the tripping time equals 1 sec, within the applicable error ranges for this relay. Repeat the test with this timer set to 60 s.

7.9. Undercurrent Unit

Connect the relay as indicated in figure 5.

Pick-up checking

1 Set the relay to the minimum tap current. The undercurrent unit will be set to 80% Is. Adjust the timing to 0.1 seconds.

2 Disable the rest of the units so they don't interfere with the test, by resetting settings 12, 2-1, 3-2, 3-5, 4-1, 5-1, 6-1 and 7-2 following the procedure explained in MMC OPERATION section.

3 Apply current to the relay, starting from zero and slowly increase the applied current. Check that the PICK-UP LED lights and then the tripping relay closes when the current is within 14.25 and 15.75% of the value of Is.

4 With the tripping relay contact closed, decrease the applied current, making sure that the tripping relay resets and the PICK-UP LED goes out for a current equal to, or greater than, 12.8% of the value Is.

5 Apply current to the relay, from one time Is and slowly decreasing and check that the PICK-UP LED lights and then the tripping relay closes when the current is within 84 and 76% of the value of Is.

6 With the tripping relay contact closed, decrease the applied current, making sure that the tripping relay resets and the PICK-UP LED goes out for a current equal to, or less than, 92.4% of the value Is.

Operation time checking

7 With the relay set up as shown in section 1, apply a current of 50% x Is and make sure that the tripping time equals 100 ms within the applicable error ranges for this relay. Repeat the test with the timer set to 10 sec.

7.10. Control Unit for Monitoring the Number of Starts

Connect the relay as shown in figure 5.

1 Set the relay to the minimum tap current. Program the time window duration to a 10 minutes setting, the number of starts to 5 and the minimum time with active tripping output to 15 minutes.

2 Disable the rest of the units so that they don't interfere with the test, by resetting settings 12, 2-1, 3-2, 3-5, 4-1, 5-1 and 6-1 following the procedure explained in MMC OPERATION section.

3 Apply current to the relay, of 1 time the tap current (1 x Is), hold it for at least 100 milliseconds and switch it off. Repeat it four times in rapid succession. Apply current for a fifth time. Note that although a total of five starts have been counted, the relay does not trip. Switch off the current applied. At this moment the trip must occur and the timing starts.

4 With the tripping relay contact closed, make sure that it remains closed for 15 minutes, even if tripping signals have disappeared from the time window 10 minutes after occurring.

5 Set the relay to the minimum tap current. Program the time window duration to 15 minutes, the number of starts to 5 and the minimum time with active tripping output to 10 minutes. This setting change causes a resetting of the unit and all cumulated starts are deleted.

6 Produce five trips in the way explained in section 3. Start the timing when the tripping contact is closed.

7 With the tripping relay contact closed, make sure that it remains closed for 15 minutes, which is the time the trips take to come out of the time window. Since the time window has a half-minute resolution, the real time will be between 15' and 15'30".

8. MMC OPERATION

The MMC is controlled by means of the keyboard provided with three pushbuttons located on the relay front plate. These pushbuttons are vertically aligned and, starting from the upper one, are designated as "ENTER", "+" and "-". The first one is represented by an arrow (see figure 3), although throughout this manual we will refer to it as ENTER. The relay provides information by means of three seven-segment displays as well as three LEDs, all of them located on the relay front plate. The LEDs are aligned vertically and are marked, starting from the upper one, with "IN SERVICE", "PICK-UP" and "TRIP". With the cover installed only the push-button ENTER can be accessed from outside.

The MMC can be in one of two conditions:

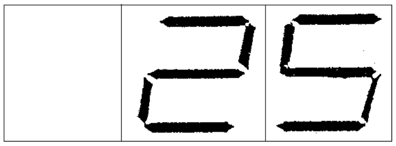
Reading sequence: it provides data on the relay status, symmetrical component values, last tripping recordings, etc. For its operation only the push-button ENTER is required.

Setting sequence: it enables to check and change the MMC operation settings, as well as to disable the units that allow it. It requires all three pushbuttons.

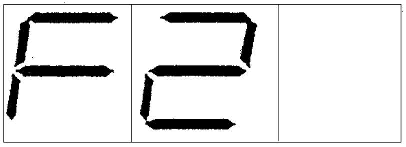
Apart from these sequences, two keyboard operations can be carried out: Thermal Image Unit Zeroing and RESET. A detailed explanation of these operations follows.

8.1. Readings Sequence

This is the MMC fundamental sequence and the MMC automatically sets itself to this sequence when starting. It is divided into a series of “functions”, each corresponding to different information. These functions are numbered from 0 to 8 and are identified by the letter “F” followed by a function number.



ENTER

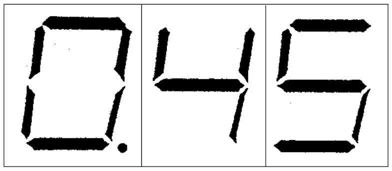


In normal operation, the MMC generally displays the value of one of these functions, which is selected in accordance with the active units. Generally, this reading will be the thermal image expressed as a percentage of the tripping limit; if, for example, we assume that the thermal image unit value is 25% of the tripping limit value, the number 25 will be shown on the display. If at this moment we press ENTER and maintain the push-button pressed, the letter "F" will appear followed by a number, in this case 2.

As long as the push-button is pressed, this code will remain on the display.

This indicated that we are in the readings sequence, and upon releasing the ENTER key the value for function 2 (Positive Sequence Current) will be displayed.

This is the general guideline for the Readings Sequence: the code that is shown while we press and hold ENTER corresponds to what appears on the display when it is released. Let us assume that we already have released ENTER. Then we will see the positive sequence current flowing through the motor expressed in times the tap current, constantly updated. So, if a current 0.45 times the tap current flows, the following is displayed:



If ENTER is pressed again, F3 will be shown, which is the code of the next reading, and upon releasing it the value of F3 corresponding to the Negative Sequence Current flowing through the motor will be displayed. If we keep pressing and releasing the ENTER key, all readings up to 8 will be successively shown. After this reading, it will cycle to 0.

The MMC readings are:

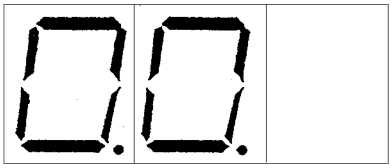
F0:	Relay status
F1:	Thermal image expressed as a percentage of the tripping value.
F2:	Positive sequence current
F3:	Negative sequence current.
F4:	Zero sequence current

F5: Code of the unit that has tripped
F6: Positive current that flowed when the trip occurred.
F7: Negative current that flowed when the trip occurred
F8: Zero sequence current that flowed when the trip occurred.

A detailed description of the readings follows:

F0: Relay status

The MMC status is given by a two-digit code which is shown on the left of the display. For distinguishing this code from other readings, the two corresponding decimal points are lit. So, at 00 (everything O.K.) status will be shown as:



The MMC status codes are as follows:

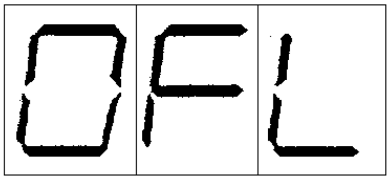
00: Everything O.K.
01: Settings failure. The stored settings are not operating properly.
02: Operation error. The measurement is not correct.
08: Overall failure.
80: ROM failure. The program memory has failed.
81: EEPROM write failure

Errors with a zero as the first figure can be corrected by the user. Errors with an eight as the first figure indicate relay electronic system failures and require the MMC unit to be repaired, The error resetting procedures will be discussed when explaining the RESET operation.

F1: Thermal Image

This reading will provide us the calculated value of the thermal image as a percentage relative to the trip value. When this value reaches 100 the relay will trip. As the display is capable of displaying three digits, it can display any value up to 999. If the thermal image calculation reaches 1000%, thus exceeding the display capacity, the message OFL (Overflow) will be displayed.

This message does not mean that the thermal image internal value does not keep increasing, it only means that the display is no longer able to show it.

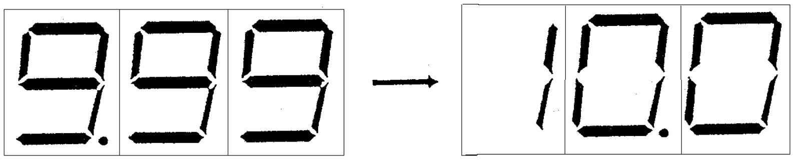


When current stops flowing across the line, the value will have to decrease again to 999 before the OFL message disappears.

When the thermal image internal representation is greater than the space for storing it, its value no longer increases, but it remains blocked until the current stops flowing and cooling begins. For every Time Constant of the thermal curve, this point represents a different percentage of the tripping limit, because each Time Constant has a different limit. In all cases, this value lies well over 100%, so that this blocking will not have any effect on normal operating conditions. Only when tests are carried out, where the tripping relay action does not interrupt the current, the Thermal Image may reach its internal limit. For a Time Constant of 60 minutes, the value at which the Thermal image will block is 182%. For the rest of the Time Constants the percentage is proportionally greater.

F2: Positive sequence unit

This reading shows the Positive Sequence Current that flows through the motor at every moment expressed in times the tap current (x Is). The representation is made with a variable accuracy, where the number of decimal figures that are shown depends on the reading value. For example, see the change from 9.99 to 10.00 times the tap current.



F3: Negative sequence current

This reading shows the Negative Sequence Current that flows through the motor at every moment in times the tap current (xIs). The representation is made with a variable accuracy, where the number of decimal figures that are shown depends on the reading value.

F4: Zero sequence current

This reading shows the Zero Sequence Current that flows through the motor at a given moment expressed in times the ground tap current (x InGRN). The representation is made with a constant precision of two decimal figures.

F5: Unit code of the last trip

This reading shows the code of the unit that has caused the last trip. When more than one unit has caused the trip the first one that caused it will be recorded.

For example, let us see how this reading will be shown by the tripping caused by unit 1 (Thermal image):

As shown in the figure above, the U (unit) character is shown, the central digit is blank and the right one shows the code of the unit that has caused the trip. Should there be no recorded trip, this code would be a zero. This information is preserved even if the relay auxiliary voltage is removed, and it can be deleted by the user.

F6: Positive sequence current of the last trip

This reading shows the Positive Sequence Current that was flowing through the motor when the last trip occurred, expressed in times the tap current (xIs). The representation is the same as F2. This information is preserved, even if the relay auxiliary voltage is removed, and it can be deleted by the user.

F7: Negative Sequence Current of the last trip

This reading shows the Negative Sequence Current that flows through the motor when the last trip occurred, expressed in times the tap current (xIs). The representation is the same as F3. This information is preserved even if the relay auxiliary voltage is removed, and it can be deleted by the user.

F8: Zero Sequence Current of the last trip

This reading shows the Zero Sequence Current that flowed through the motor when the last trip occurred, expressed in times the neutral tap current (xInGRN). The representation is the same as F4. This information is preserved even if the relay auxiliary voltage is removed and it can be deleted by the user.

The default reading is the one that the MMC normally shows on the display. This reading can lie anywhere between F0 and F4, inclusive. When voltage is applied to the relay, the default reading is shown on the display and the display returns automatically to this reading from any point in the Readings of Settings Sequences if two minutes elapse without pressing any key.

The default reading selection is automatically made by the MMC in accordance to the protection units active. Each protection unit has a related reading, which is the one that is useful for the functioning of such unit. For the reading related to a unit to be the default reading, all units with a lower identification number must be disabled.

The readings related to those units are:

Unit	Reading
1 (Thermal image)	F1 (% Thermal Current)
2 (Positive sequence)	F2 (Positive Seq. component)
3 (Negative sequence)	F3 (Negative Seq. component)
4 (Zero Sequence)	F4 (Zero seq. Component)
5 (Locked rotor)	F2 (Positive Seq. component)
6 (Undercurrent)	F2 (Positive Seq. component)
7 (Pickups)	F2 (Positive Seq. component)

For example, if unit 1 is active, the default reading will be F1, no matter what the status of the rest of the units may be.

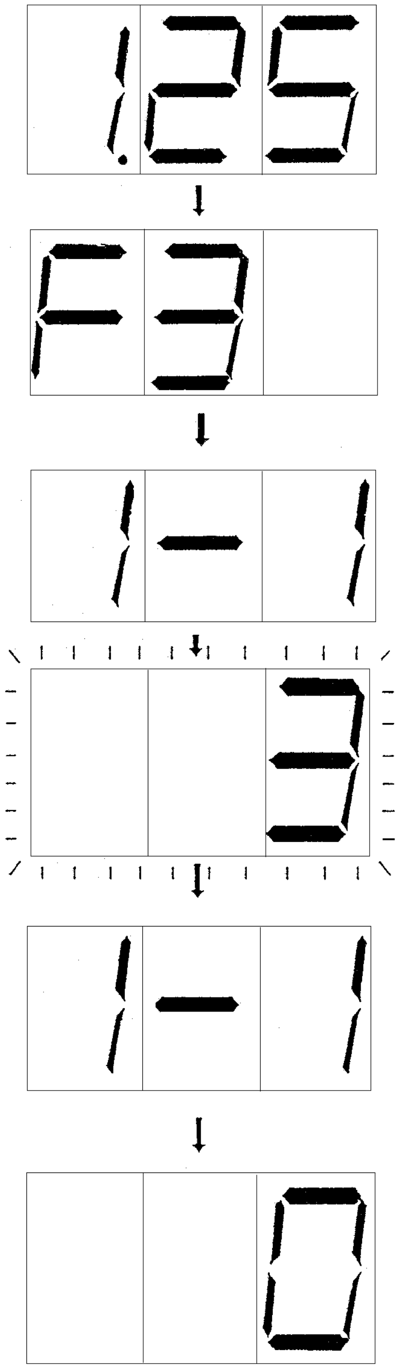
If we disable this unit (by setting a 0 value in setting 1-2) and unit 2 is active, the default reading will be F2. If units 1, 2 and 3 are not active and unit 4 is active, the default reading will be F4, etc. When all units are not active, the default reading will be F0, Relay Status.

8.2. Settings Sequence

The Settings Sequence is the relay state in which the settings of the different MMC units can be changed, as well as enable or disable those units which admit enabling and disabling. The Settings Sequence requires the use of all three MMC pushbuttons, and therefore it cannot be accessed with the cover mounted.

If, at any point in the Settings Sequence, two minutes elapse without pressing any key, the MMC will return to the Readings Sequence and within it to the default reading.

In order to enter the Settings Sequence, we must be in the Readings Sequence; it makes no difference at which point in the sequence we are .The input is carried out by pressing the "-" key while holding down the ENTER key. Let us see this operation in detail, assuming we are in F2 and the Positive Sequence Component Value, which is 0.25 times the tap current is being shown.



The display shows the positive sequence component value, 1.25 times the tap current. Now we press and hold ENTER. Then the code for the next function F3 will appear. The Settings sequence can be entered from any other function in exactly the same way.

While pressing and holding down ENTER, we press the "-" key. The display changes and the reading 1-1 appears. This is what we always see whenever we enter the Settings Sequence. The number on the left shows the unit and the number on the right the setting. Thus, 1-1 means Unit 1- Setting 1; unit 1 is the Thermal image and the setting 1 is the negative sequence component overvaluing constant. If we want to view or change this setting value, we press ENTER (without holding it down) and we see the current setting value which we assume to be 3. The setting value will blink. Whenever a setting value is shown on the display it will blink.

Before we go on, it is useful to give a complete list of MMC units and settings. So let us exit the Settings sequence.

For this purpose, first we press again (and release) ENTER. This causes the setting code (1-1) to be shown again on the display. For returning to the Reading Sequence the "+" and "-" are pressed simultaneously; the order in which they are pressed does not matter, as long as both are pressed at the same time. This takes us again to the Readings Sequence, but not to the same point where we entered. Whenever we exit the Setting Sequence we will return to the normal relay status, that is, the default reading.

In this case we have assumed that it is F1 and its value is zero.

The MMC consists of the setup unit and four protection units, namely:

Unit 0:Relay setup

0-1: Frequency Hz

Unit 1: Thermal image

1-1	K_1	Non dimensional
1-2	τ_1	Minutes
1-3	τ_2	Times τ_1

Unit 2: Positive Sequence Instantaneous Unit

2-1	Pick-up value	Times tap value (xIs)
2-2	Delay	Seconds

Unit 3: Negative Sequence

3-1	Inst. /curve-mode select switch	Inst=1, Curve=2
3-2	Inst. mode pick-up	Times tap value (xIs)
3-3	Inst. mode delay	Seconds
3-4	Curve truncating	Times tap value (xIs)
3-5	Curve dial	Non dimensional

Unit 4: Zero sequence instantaneous mode

4-1	Pick-up value	Times the neutral tap current (xInGRN)
4-2	Delay	Second

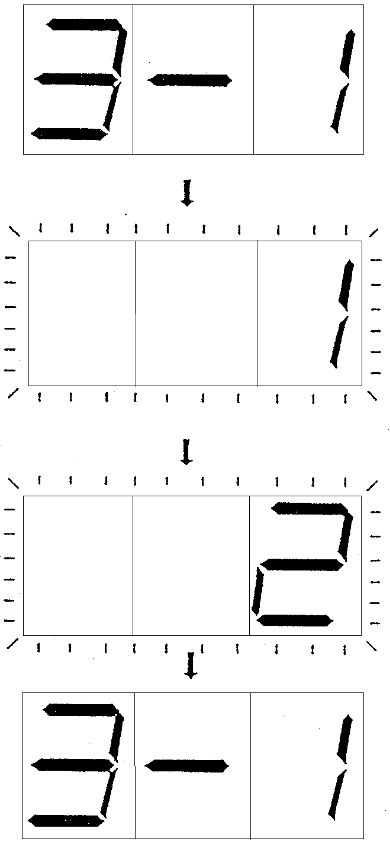
For a detailed description of the units' ranges and operation please see the OPERATING PRINCIPLES Section.

Once all of the units have been listed, it's time to carry out a real settings change. As an example we will program the negative sequence unit as an inverse time curve, with a truncating value of 0.3xIs and 0.75 dial.

We will enter the Settings Sequence using the procedure that has been explained, and then the code 1-1 will be shown. Our example requires that we change settings 3-1, 3-4, and 3-5. To access the setting, press repeatedly the "+" and "-" keys until the desired code is shown on the display, in this case 3-1. The settings selection is cycled, so that when "+" is pressed when the last setting is currently shown on the display, it is cycled to the first setting and viceversa, if "-" is pressed when the first setting is on the display, it is cycled back to the last one.

Once the 3-1 setting is on the display, press ENTER and the setting value will blink. Let us assume it is 1, that is, that the instantaneous mode is selected. For changing it to 2 (curve mode) press the "+" key. On the display the value 2 will be shown. For acknowledging this data, press ENTER and the code 3-1 will again be shown. In this way the 3-1 setting value has changed from 1 to 2. The flow diagram of this operation is shown on the next page.

This process is the same for any setting that is to be changed. Select the setting code that is to be changed. When the code appears on the display, press ENTER. Then the current setting value will be shown on the display. Using the "+" and "-" keys the setting value can be increased or decreased until the desired value appears on the display. At this moment press ENTER and the new setting value will be accepted.



If on the display the maximum permissible value for that setting is shown, pressing "+" will have no effect. The same will occur if the minimum permissible value for that setting is shown and the "-" key is pressed.

If the "+" or "-" key is pressed and held down, the setting value increases of decreases automatically five times per second. To avoid undesired repetitions of the pressed key, note that the first repetition occurs after half a second.

This mechanism only works when changing the setting value and not when selecting the setting code. For this operation, the "+" or "-" keys must be pressed and released for every code increase or decrease.

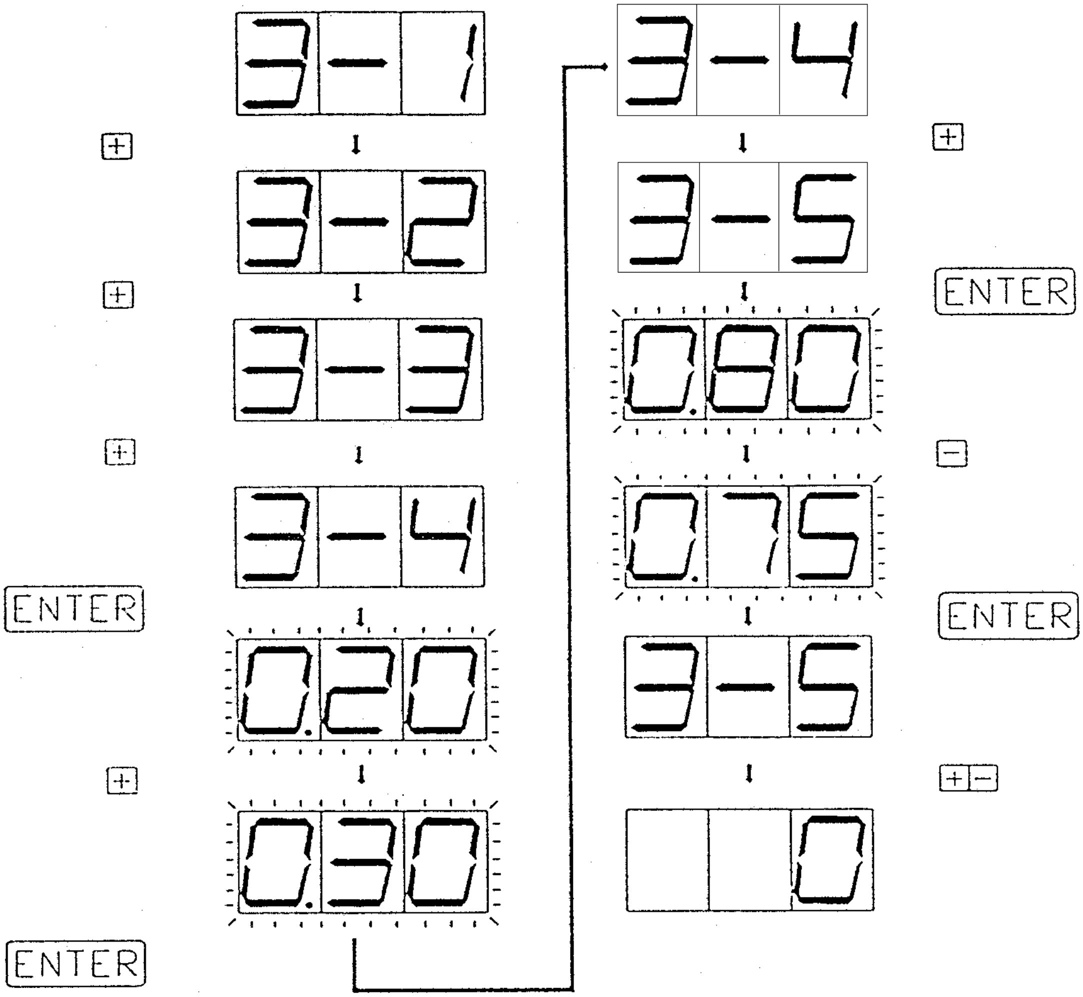
On the following page the change of the two other settings is shown in a summarized way, taking into account that the keys to be pressed would be the ones already mentioned.

We have assumed that the original value for setting 3-4 was 0.2xIs and the 3-5 setting value was 0.80. Had they been different, it would have been sufficient to press the "+" and "-" keys until selecting the desired values and then pressing ENTER.

After changing a setting value, it is updated when ENTER is pressed for accepting the change. When a setting is changed, the corresponding unit is completely reset. The rest of the units are not affected by the change and keep working normally. However, when ENTER is pressed, all protections are "frozen" in the status in which they are for the time it takes to process a new setting (between 0.08 and 0.1 seconds). Once the corresponding unit has been reset, all of them are restarted. The settings changes can be carried out at any moment, although it is recommended to do it with the motor stopped.

If the setting value has not been changed, the unit is not reset, even if the "+" and "-" keys have been pressed.

The resetting of the unit where the adjustments have been changed is completed, including the detection of a pick-up or trip should they have occurred.



8.3. Zeroing the Thermal Image

The MMC is provided with a system for zeroing the thermal image unit, thus allowing the tests to be carried out for cold curves. For zeroing the thermal image we must be in the Readings Sequence. At any point in this sequence, we press ENTER. The corresponding reading code will be shown on the display. While holding down ENTER we press the "+" key at the same time. The thermal image returns to 0 and the MMC goes back to the basic status, showing the default reading value on the display.

8.4. Reset

The reset operation is carried out, from the Readings sequence by pressing and holding ENTER for three seconds. The effects of these operations are different, depending on whether the MMC is operating normally or is in an error status.

MMC in normal operation:

The MMC returns to the default reading, the TRIP LED is switched off and the currents of the last trip are deleted, except if the trip output is active at that moment. In such a case, the only effect that RESET has in returning to the default reading.

MMC in error situation:

When the MMC detects a malfunction during its operation, the corresponding error code blinks on the display, the measurement is turned off, the READY LED is switched off and the DEVICE ALARM output is activated. If a RESET occurs under these conditions, the relay will completely reinitialize the software, thus allowing the operation to be restarted if the error causes have disappeared.

A detailed description of the error codes and their meanings follows:

01 - System Error

When starting the program, the MMC loads the EEPROM setting values. If the stored settings do not pass any of the controls to which they are subject, a setting error occurs. This error can be fixed by the user by reprogramming all of the relay settings.

The programming of settings after an error has occurred is identical to the procedures explained in this section, except for the fact that the settings values are random values. If one setting value is not valid, when pressing ENTER for accepting it, nothing will occur; the setting is not accepted until it is valid. For converting the setting to a valid value, press and hold "+" or "-" until the setting no longer changes. When this occurs, program the desired value using the normal procedure.

Once all settings have been reviewed, the MMC is restarted by pressing RESET.

02 - Operation error

If this error occurs, it is very likely that the relay has reinitialized by itself. In the event that it was not so, the problem would be solved by executing a RESET or, in a worst case situation, by switching off the MMC and switching it on again. If this does not fix the error, the whole relay unit must be repaired.

08 - Overall error

Overall software failure. The same criteria as code 02 apply, although the causes are different.

80 - ROM failure

The program memory contents have deteriorated. It must be replaced.

81 - EEPROM writing error

The non-volatile memory has deteriorated and it can no longer store the settings. It must be replaced.

APPENDIX 1: TESTING THE MMC WITH A SINGLE-PHASE POWER SOURCE

Based on the symmetrical components theory, it is known that a single-phase current applied to the relay current transformers as described in figure 9 produces positive and negative sequence currents given by the following expression:

$$I_1 = I_{2.} = \frac{I}{\sqrt{3}}$$

where:

I_1 = Positive sequence component detected by the relay.

I_2 = Negative sequence component detected by the relay

I = Applied single-phase current.

Therefore, when the MMC is tested with the single-phase power source, the negative sequence current (which is zero in a balanced three-phase system) must also be taken into account. For testing the thermal image, it must be considered that the equivalent current now is as follows:

$$I_{eq} = \sqrt{(I^2{}_1 + K_1 I^2{}_2)} = I \sqrt{(K_1 + 1)/3}$$

where I is the applied single-phase current. Based on this, the thermal image test can be carried out by applying the appropriate single-phase current.

For carrying out the positive and negative sequence units' test, the applied single-phase current must be 1.73 times greater than the current required in the acceptance test.

APPENDIX 2: SYMMETRICAL COMPONENTS

Introduction

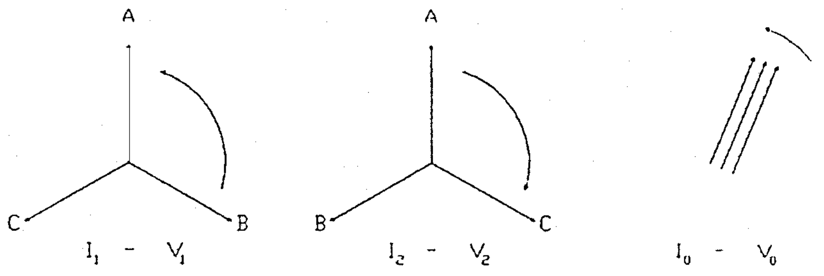
If the overlapping principle is applied, we can break down any three-phase phasor system into a set of three balanced phasor systems, two of them of three-phase type, but with opposite rotation directions to one another, and another one which consists of three balanced and parallel phasors, which rotate in the same direction as one of the previous ones.

The first three-phase system rotates counter-clockwise and is designated as "positive sequence system" or "forward component system", and will be represented by the subscript 1 added to the matching variable (V or I).

The second three-phase system rotates clockwise and is designated as "negative sequence system" or "inverse component system", and will be represented by the subscript 2 added to the matching variable (V or I).

The parallel phasor system rotates counter-clockwise, and is designated as "zero sequence", and will be represented by subscript 0.

SYMMETRICAL COMPONENTS



The positive sequence component is the one that generates the motor torque, which overcomes the mechanical load torque coupled to the motor and produces heat because of the Joule effect.

The negative sequence component acts as an additional load torque, originating greater heat loss in the rotor, because its apparent slip is very large.

The zero sequence component gives us an insight into the three-phase system ground fault, getting a large value when potential-free ground faults occur.

Calculation of a system's symmetrical components.

Let us consider operator a, which when applied to a phasor, rotates it 120º counter-clockwise without affecting the modulus. For a given current three-phase system, we could break it down in its symmetrical components as follows:

$$I_A = I_1 + I_2 + I_0$$

$$I_B = a^2 I_1 + a I_2 + I_0$$

$$I_C = a I_1 + a^2 I_2 + I_0$$

$$I_1 = 1/3\ (I_A + a I_B + a^2 I_C)$$

$$I_2 = 1/3\ (I_A + a^2 I_B + a I_C)$$

$$I_0 = 1/3\ (I_A + I_B + I_C)$$

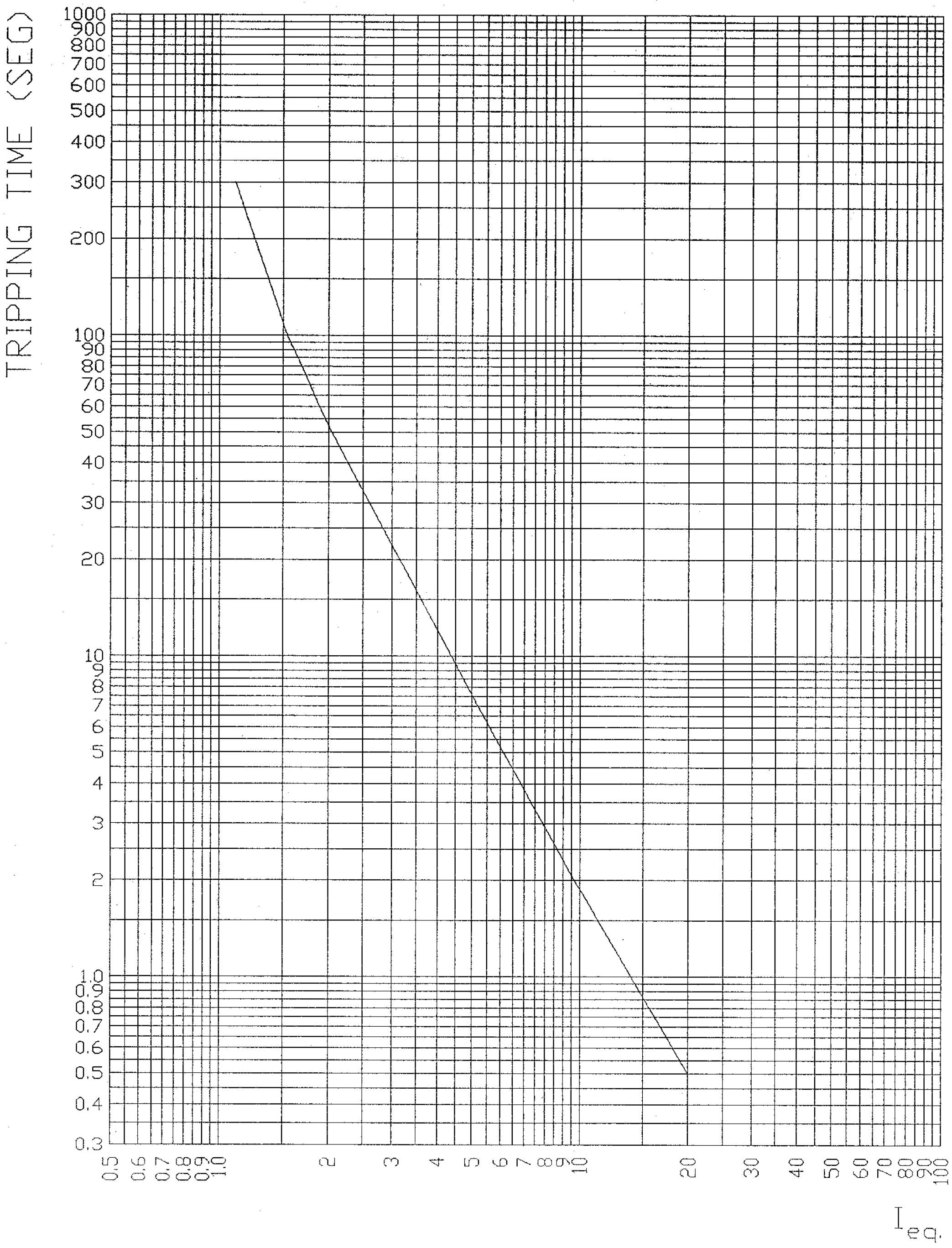


__Figure 1__. MMC thermal curve for $\tau1$ = 180 seconds.

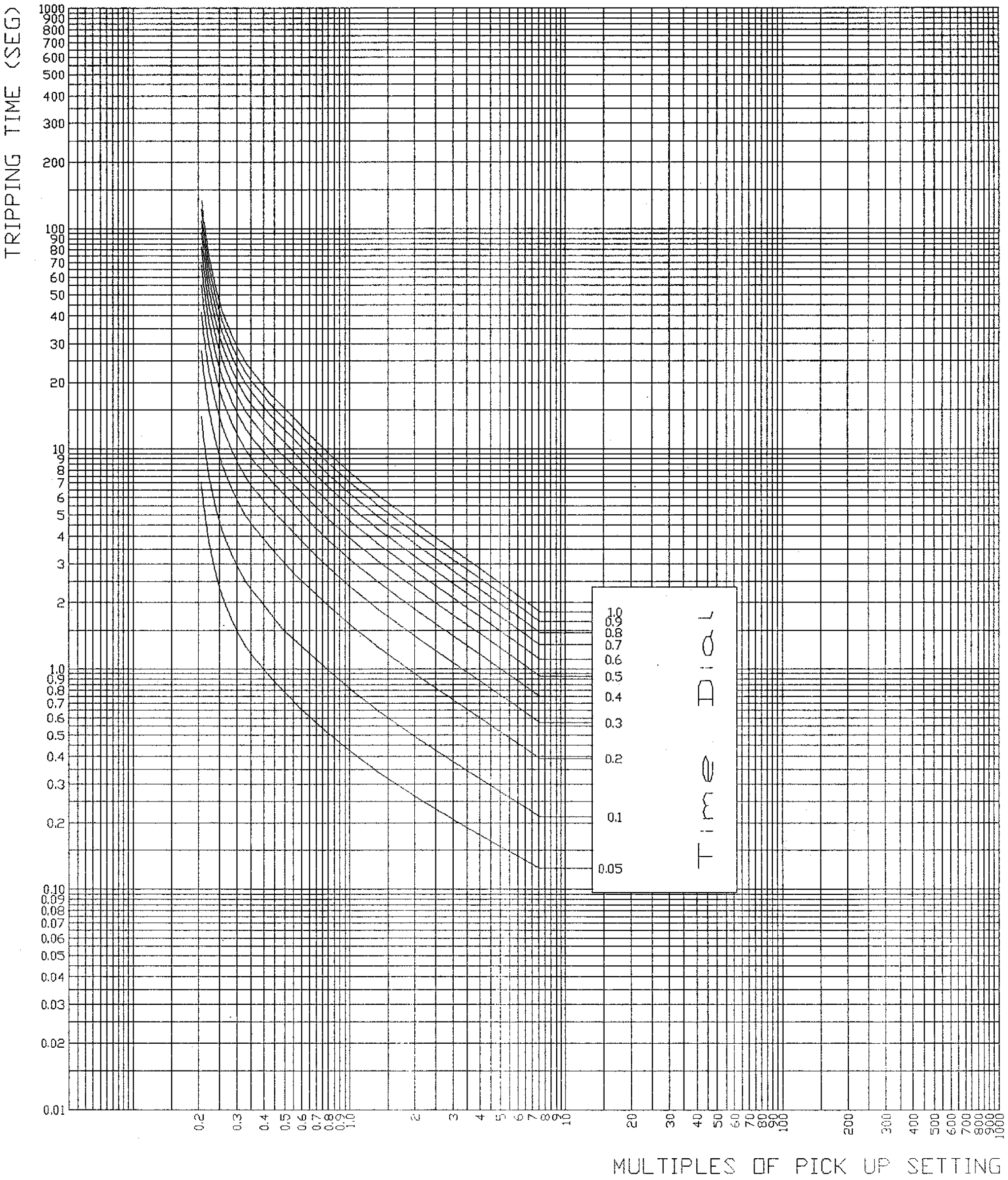


Figure 2. Inverse time curve family for the negative sequence unit.

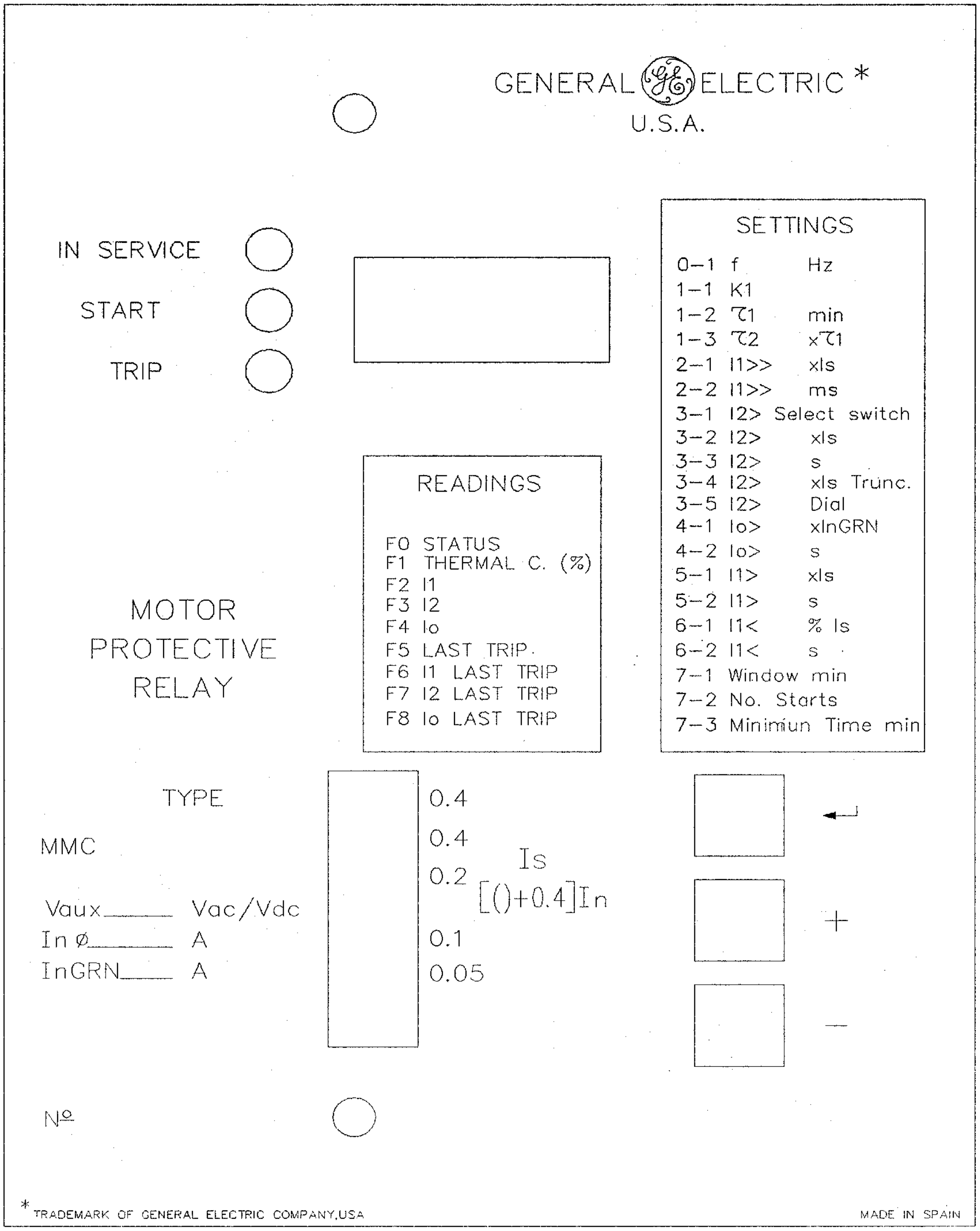


***Figure 3.** MMC front plate*

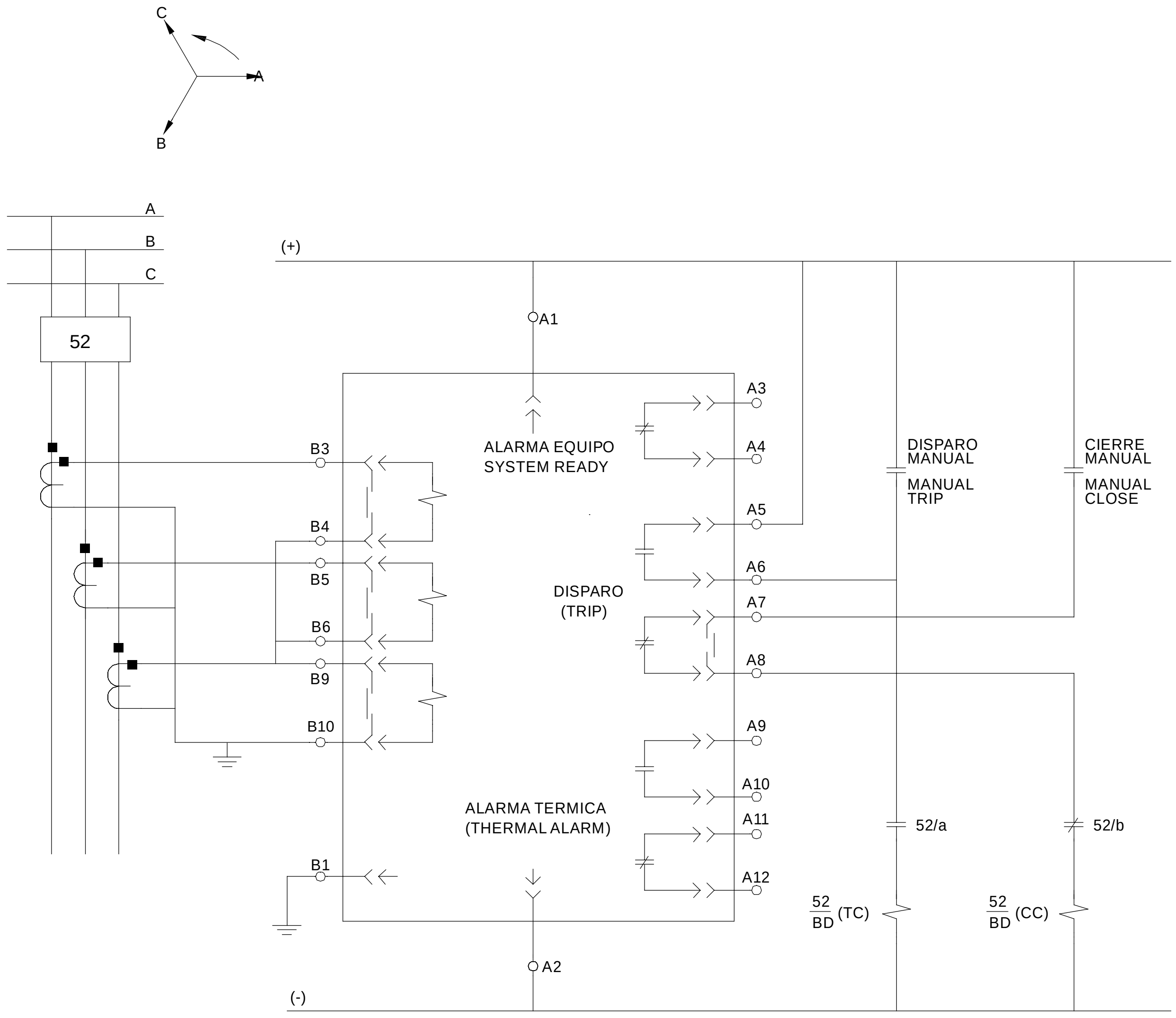


Figure 4*. MMC External connection diagram for drawout model*

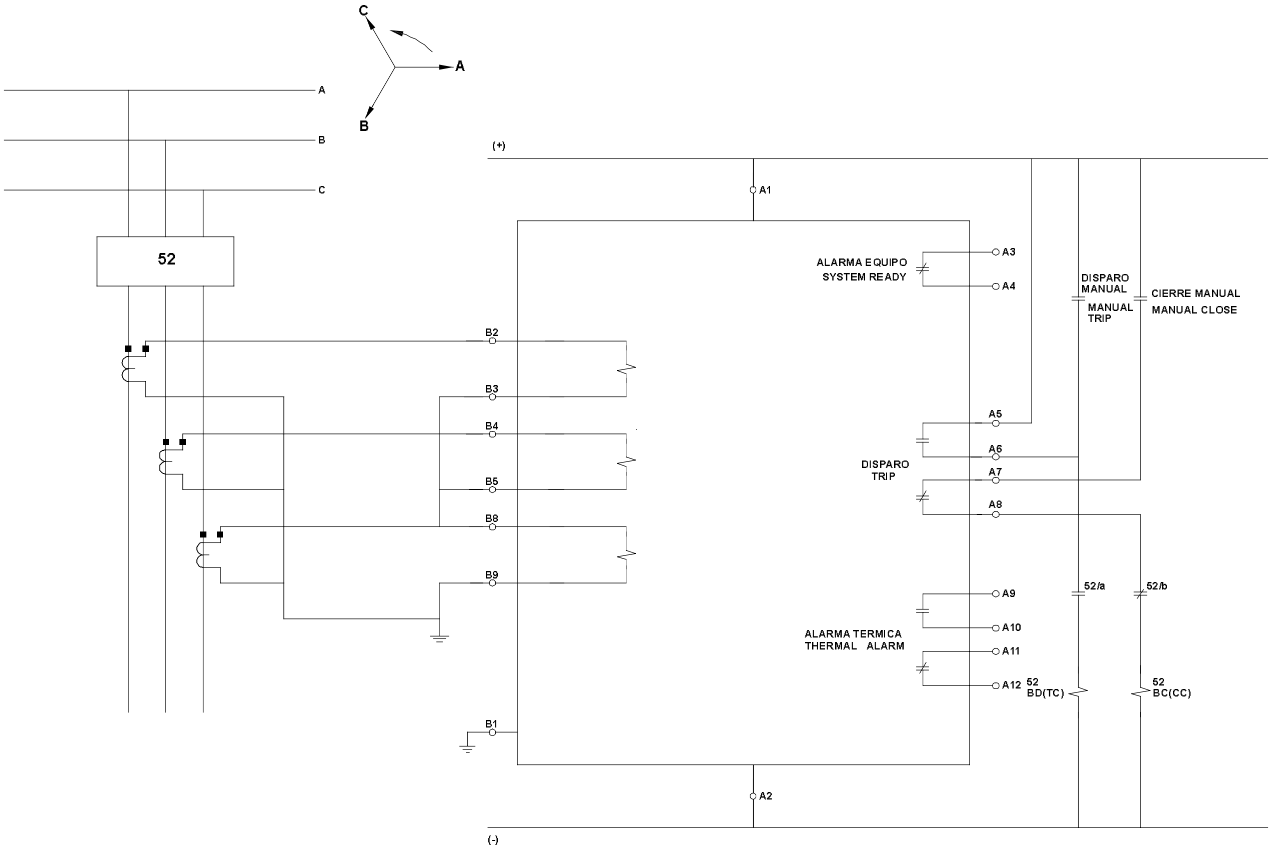
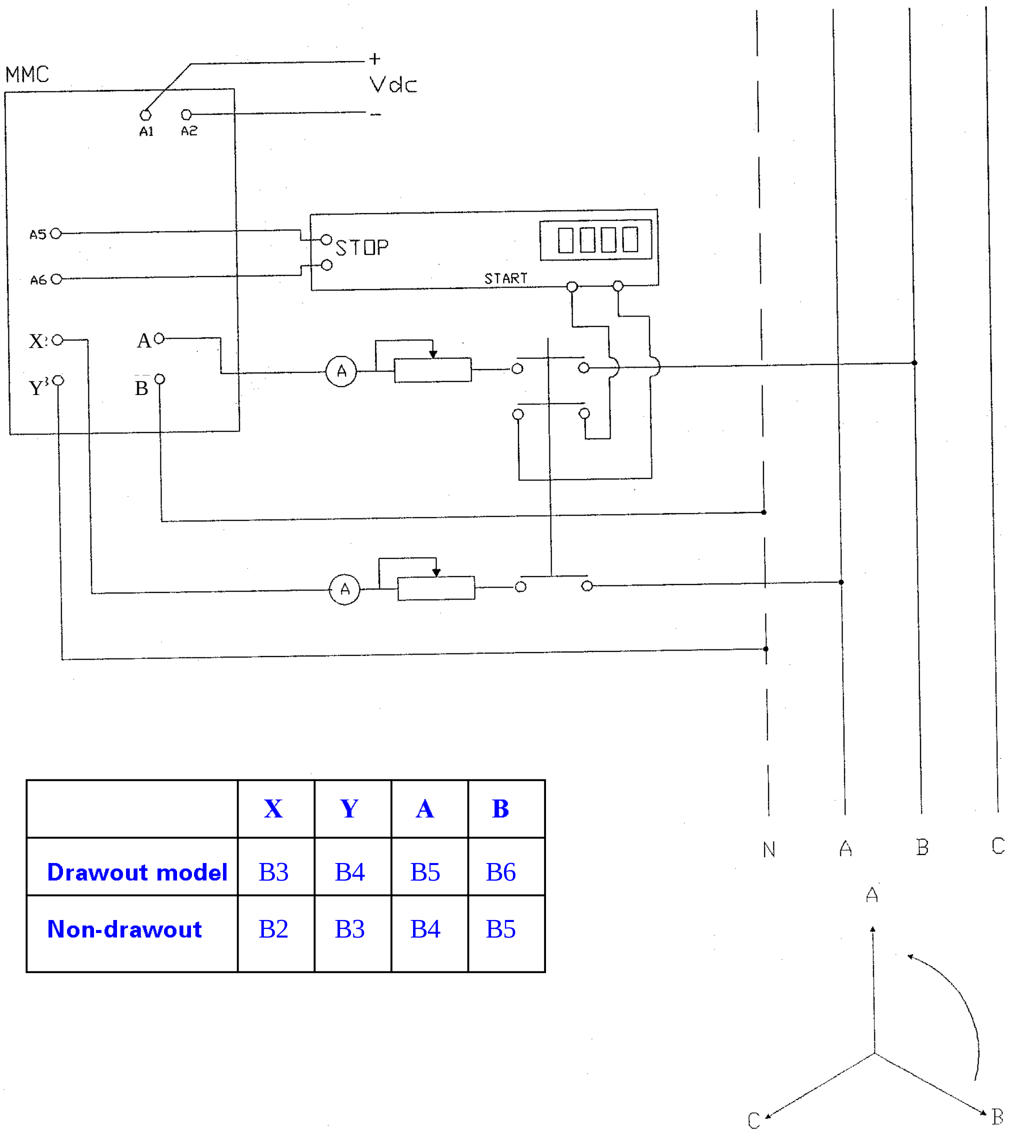
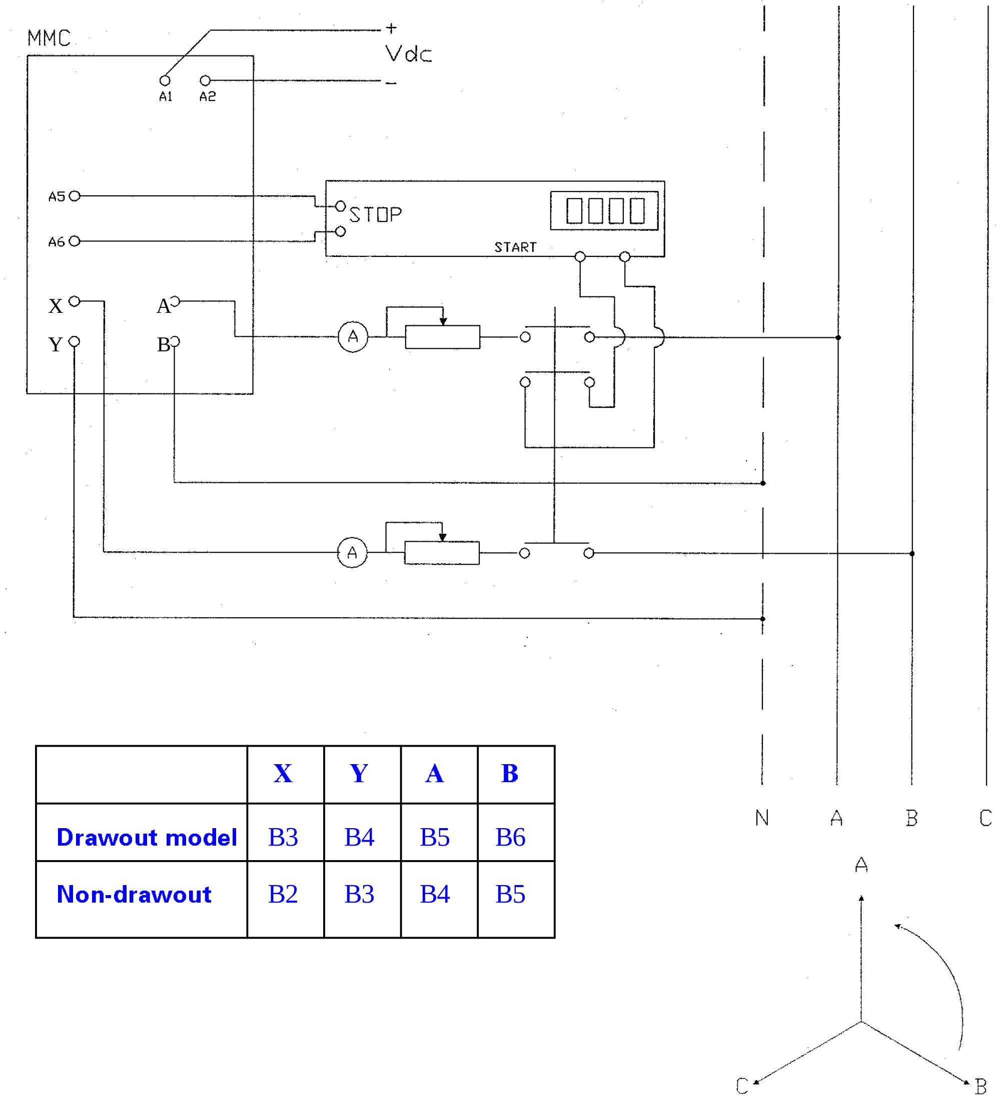


***Figure 5**. MMC External connection diagram for non-drawout model*



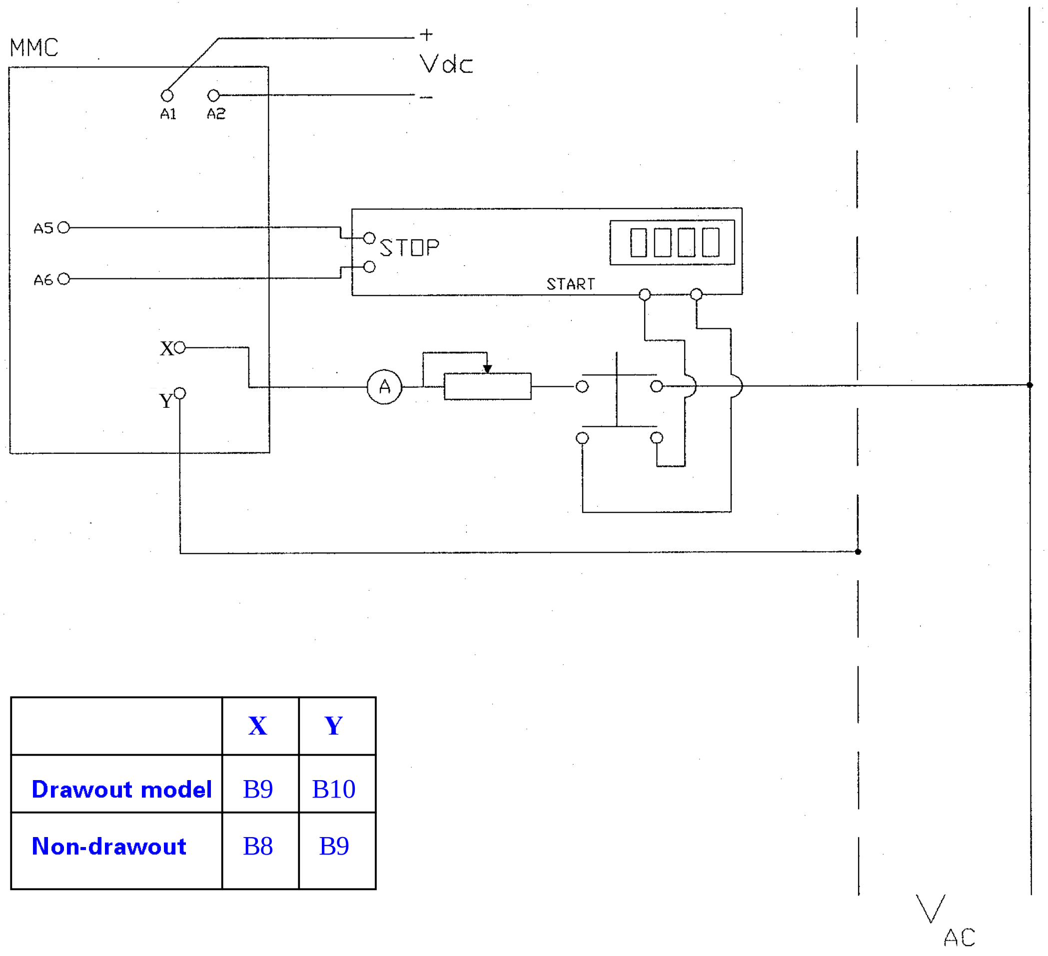
	X	Y	A	B
Drawout model	B3	B4	B5	B6
Non-drawout	B2	B3	B4	B5

Figure 6. *Connection for testing the thermal image, Positive sequence, Locked-rotor, Undercurrent units and the Control unit for monitoring the number of starts.*



	X	Y	A	B
Drawout model	B3	B4	B5	B6
Non-drawout	B2	B3	B4	B5

Figure 7. Connection for testing the negative sequence unit



	X	Y
Drawout model	B9	B10
Non-drawout	B8	B9

***Figure 8**. Connections for testing the Zero Sequence unit*

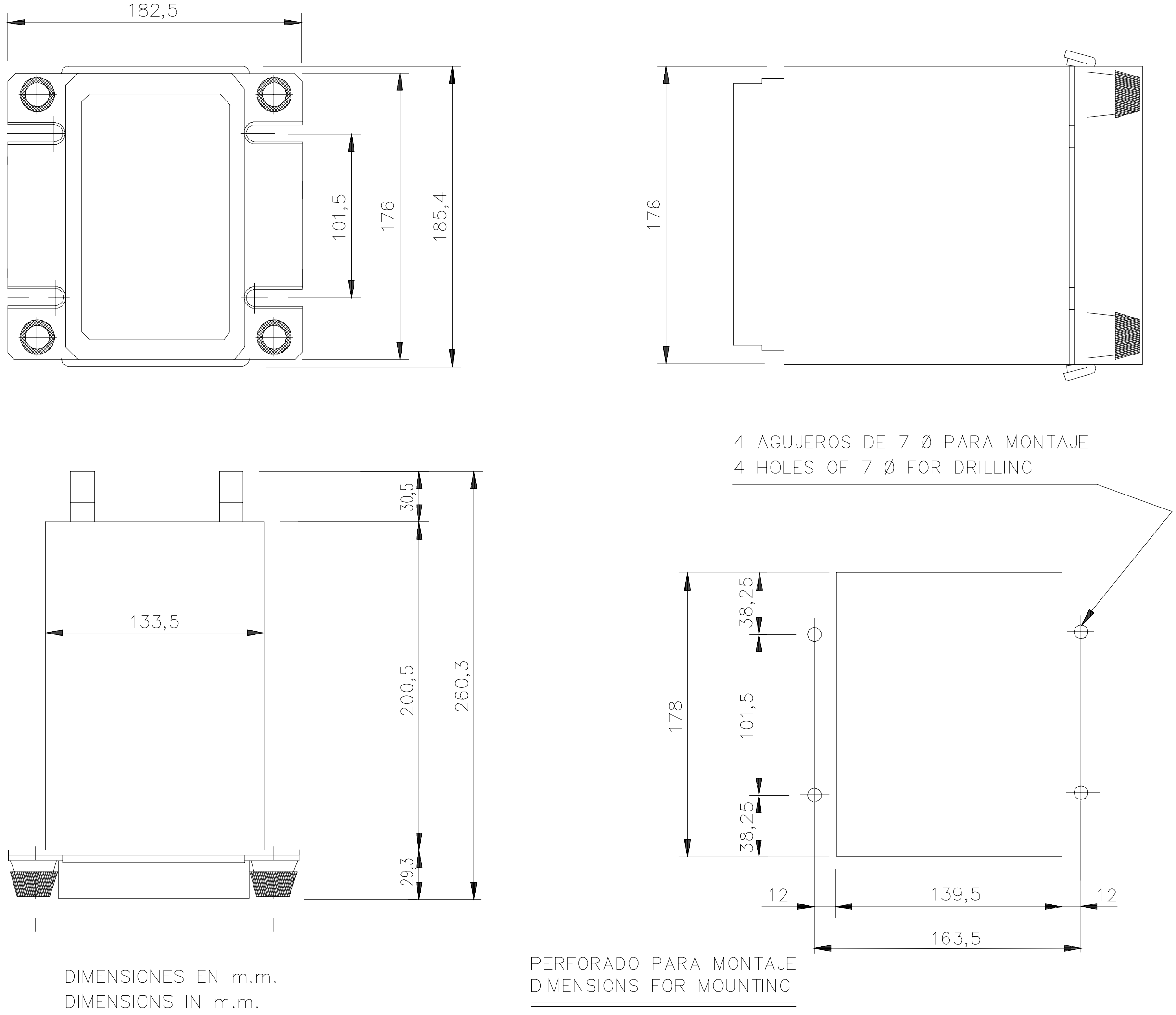


***Figure 9a**. Dimensions and mounting of the MMC (non-drawout type) 226B6086F4*

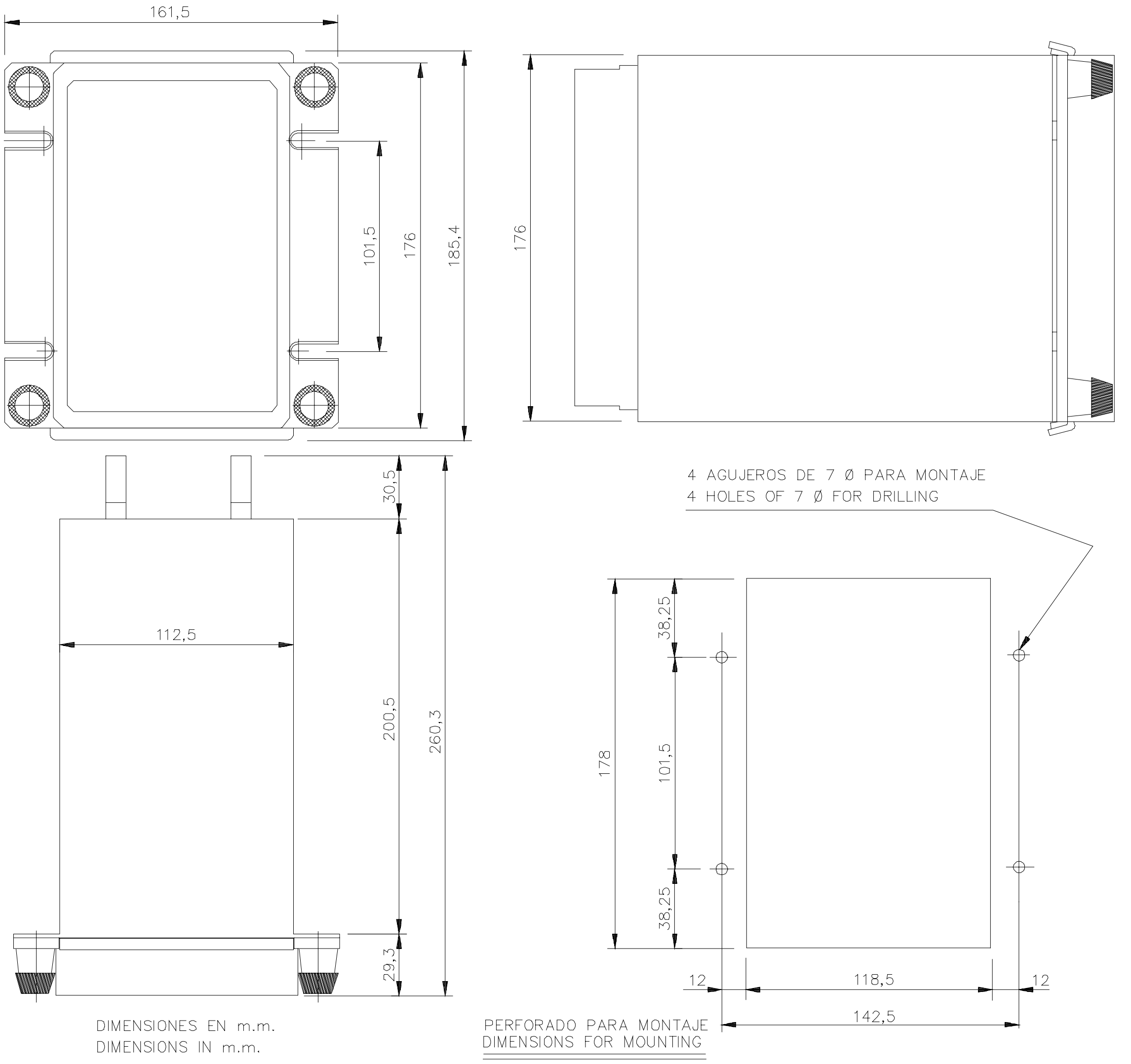
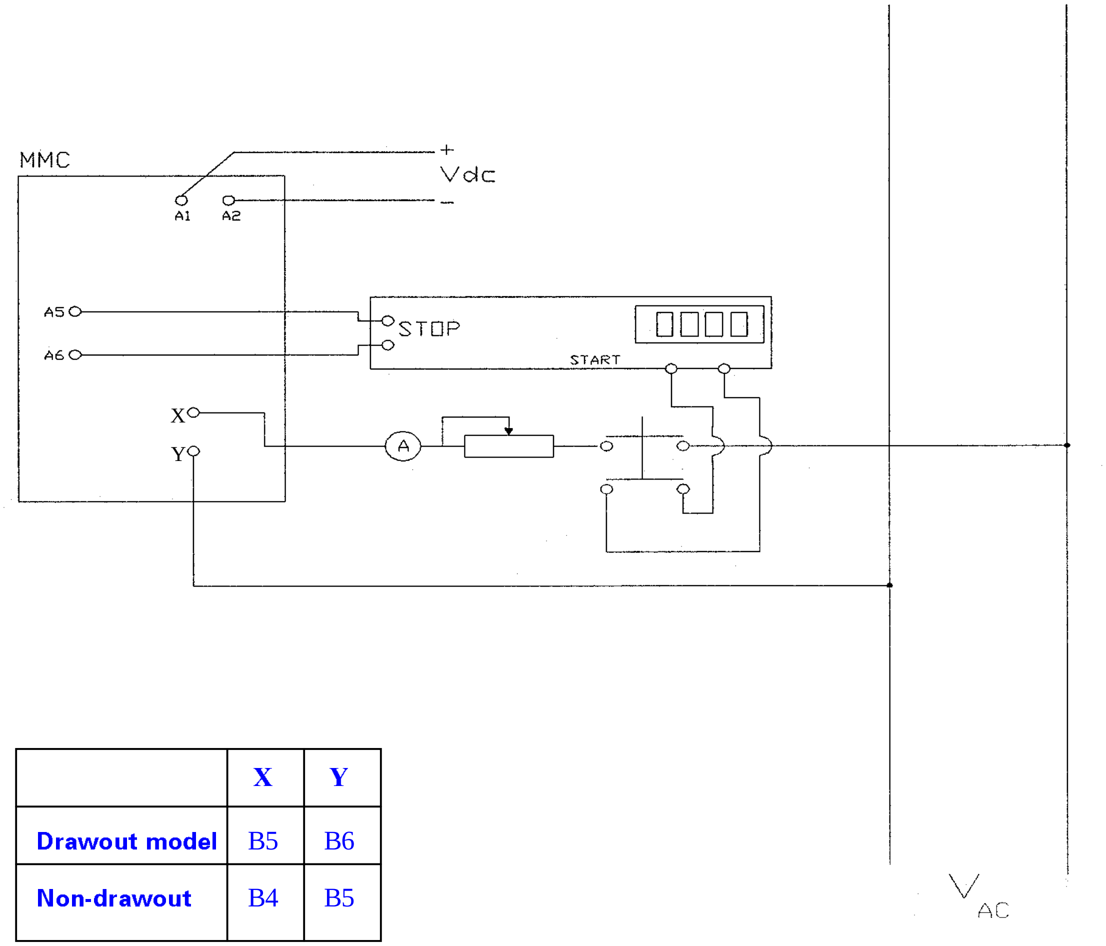
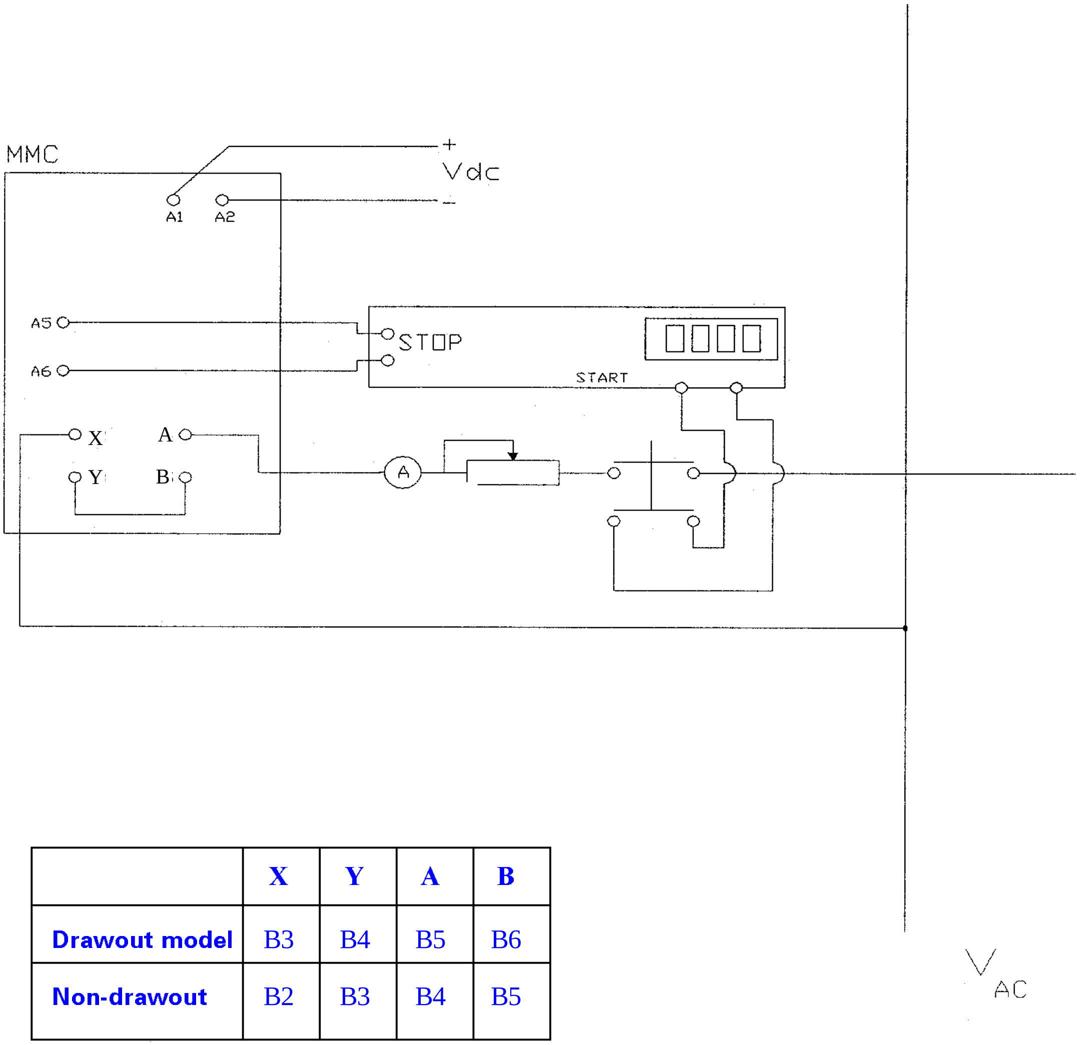


***Figure 9b**. Dimensions and mounting of the MMC (drawout type) 226B6086F2*



	X	Y
Drawout model	B5	B6
Non-drawout	B4	B5

***Figure 10**. Connections for testing the thermal image using single-phase power source (one circuit)*



	X	Y	A	B
Drawout model	B3	B4	B5	B6
Non-drawout	B2	B3	B4	B5

Figure 11*. Connections for testing the thermal image using a single-phase power source (two circuits)*

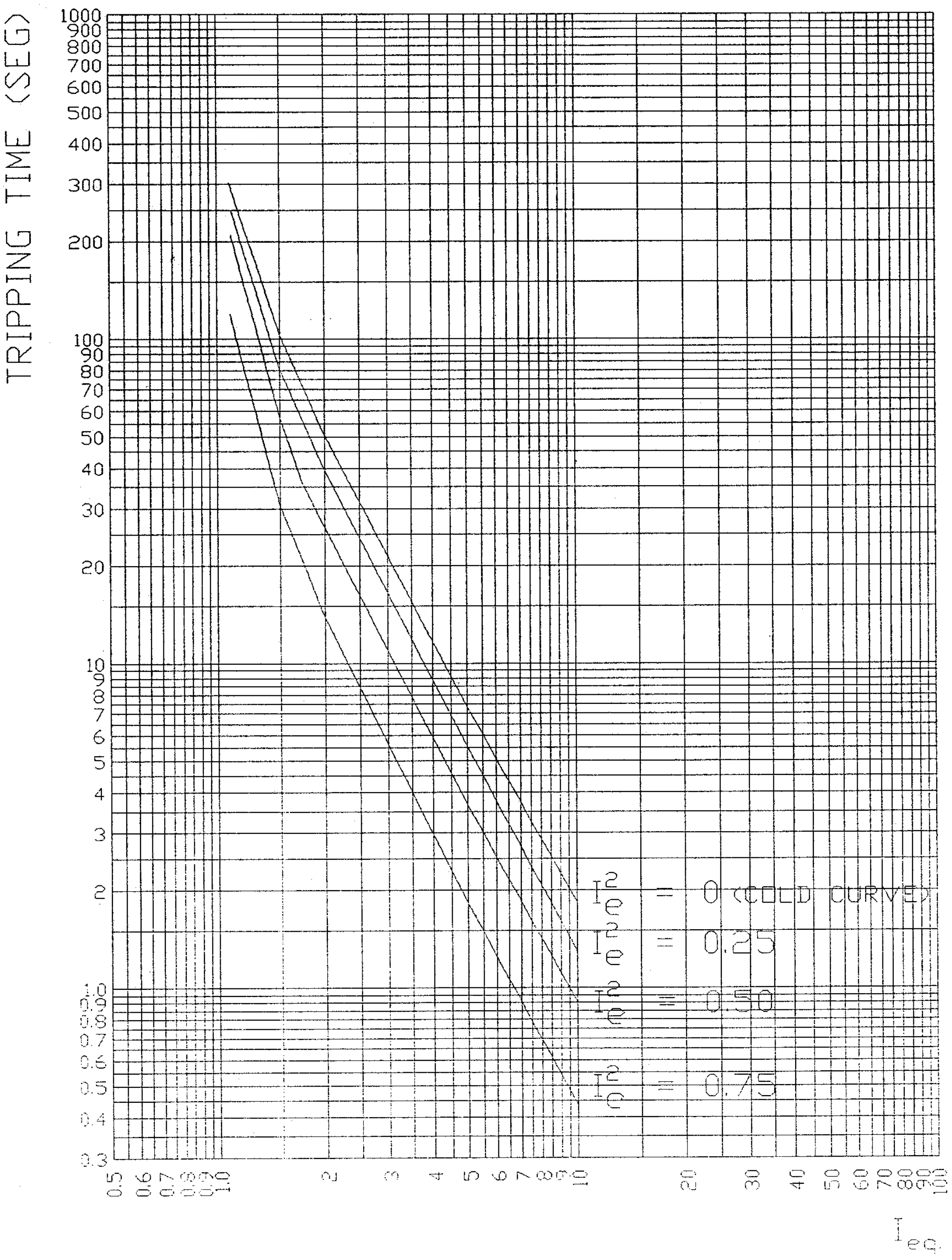


Figure 12. *MMC hot curves at τ1 = 180 sec.*